Censorship of Bachelor Thesis

Buskerud and Vestfold University College
Faculty of Technology and Maritime Science

Project number: **2015-16**
For school year: **2014/2015**
Course code: **SFHO3201**

Project name: 3D Ground Mapping

Executed in collaboration with: Cube AS

External supervisor: Stig Førrisdal

Summary:
Cube AS wants a system for 3D mapping of terrain using an UAV (unmanned aerial vehicle). We chose to equip the UAV with a camera to take aerial photos that are processed through image processing software to produce detailed, digital 3D maps.

Keywords:
- 3D
- UAV
- Aerial photography

Availability: Yes

Project members and grade:

Name	Grade
Therese Tokle Poverud	
Ole Petter Christensen	
Asadullah Jacop	
Giresse Kadima Mpoyi	
Harjit Laly Singh Mann	
Ngenzi Albert	
Bjørnar Dalset	

Date: 4. June 2015

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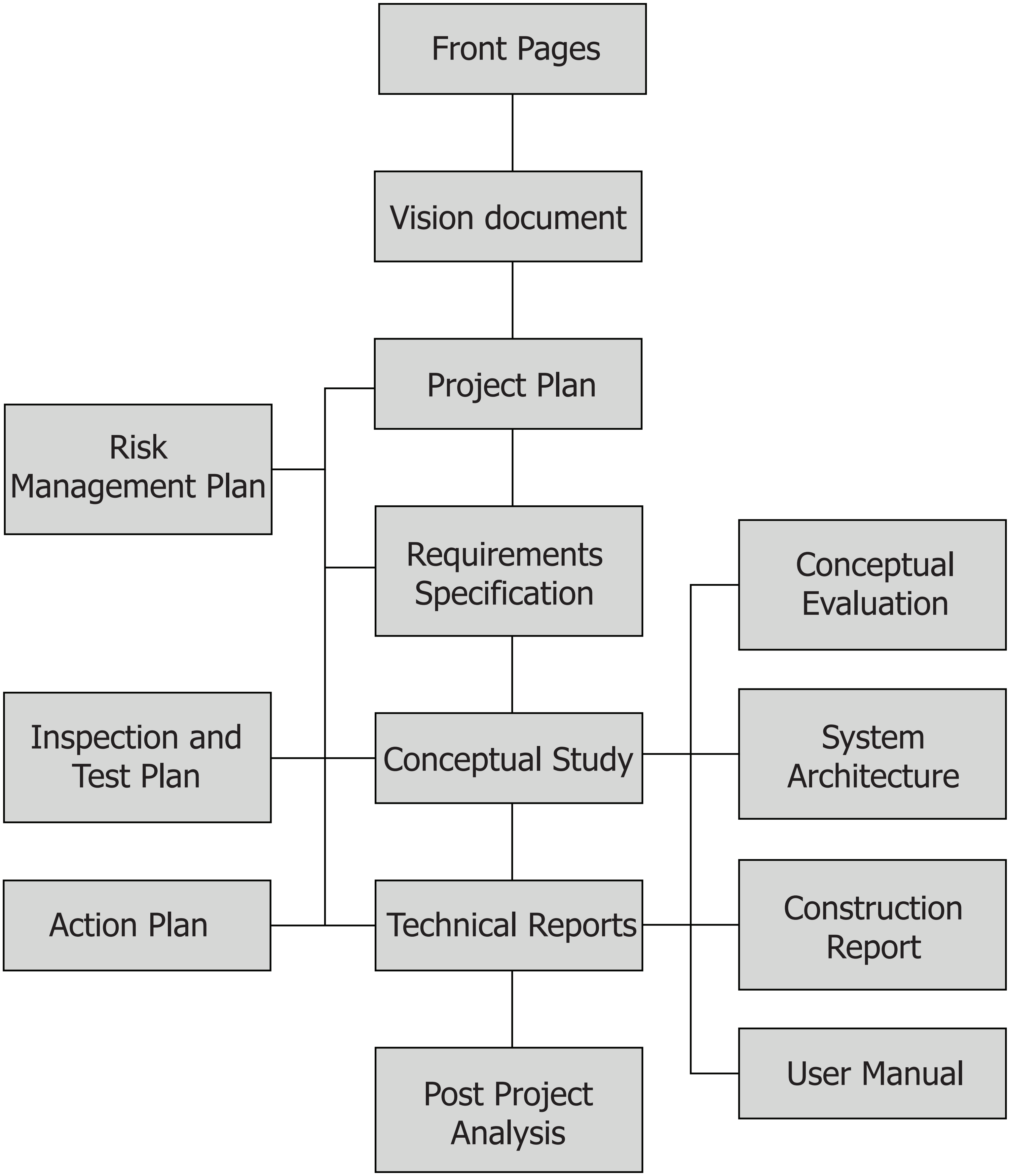
Øyvind Eek-Jensen Internal Supervisor	Karoline Moholth Internal Sensor	Stig Førrisdal External Sensor

Document List

Bachelor project: 3D Ground Mapping

Document ID	Document Name
000	Censorship sheet
001	Vision document
002	Project Plan
003	Requirements Specification
004	Inspection and Test Plan
005	Risk Management Plan
006	Conceptual Study
007	Conceptual Evaluation
008	System Architecture
009	Technical Reports
010	Construction Report
011	Action Plan
012	User Manual
013	Post Project Analysis

Project Document Hierarchy



Vision document

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
2.0	09.02.2015	OPC	STG	Released

Summary:

This document is intended to give an overall view of the system to be developed, key needs and features.

Owner: Bjørnar Dalset

Document Revision History

Rev	Date	Author	Description	Status
0.1	06.02.2015	BJD	Vision document, v0.1	Obsolete
0.2	07.02.2015	BJD	Vision document, v0.2	Obsolete
1.0	08.02.2015	BJD	Vision document V1.0	Obsolete
2.0	09.02.2015	BJD	Final Version V2.0	Released

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1.0 Introduction

1.1 Document purpose

The purpose of this document is to:

- Describe the overall vision for the 3D Ground Mapping system
- Document the primary needs of the project owner
- Outline the core requirements and constraints of the system

This vision document applies to the 3D Ground Mapping system, which will be developed for Cube AS. This project is a bachelor thesis for engineering students at HBV (Buskerud and Vestfold University College).

1.2 Project members

Project members: Therese Tokle Poverud, Ole Petter Christensen, Asadullah Jacop, Giresse Kadima Mpoyi, Harjit Laly Singh Mann, Albert Ngenzi, Bjørnar Dalset

Project leader: Therese Tokle Poverud
E:theresetoklepoverud@gmail.com **T:** 98494495

1.3 The project owner

Cube AS is the project owner. The finished system will be the property of Cube AS. The technology resulting from this student project can be hired through the services of Cube AS.

Contact: Stig Førrisdal
E:stig.forrisdal@cube.today **T:** 91575226

1.4 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
UAV	Unmanned aerial vehicle

Table 1 Abbreviations

2.0 Problem description

2.1 Background

Terrain analysis and land surveying is an important and time-consuming task for the construction industry. New technology is needed to improve efficiency, lower costs and create more advanced tools. This system will be of potentially great interest for anyone needing detailed 3D maps and models of areas of interest.

2.2 Problem statement

The problem of	• Time consuming land surveys • Poor visual representation of construction locations
affects	• Construction engineers • Architects
the impact of which is	• High costs • Longer acquisition times
a successful solution would provide	• High quality digital 3D maps • Less human resources • Lower associated costs

Table 2 Problem statement

3.0 System overview

3.1 System vision

Cube AS wants a system for 3D mapping of terrain using an UAV. The UAV will be built and equipped with a camera to take aerial photos, which will be processed to produce detailed, digital 3D maps.

Final 3D maps could either be viewed on a computer or used to print out physical models using a 3D printer.

3.2 System summary

The system must have:

- a fully controllable UAV, capable of carrying a payload such as a camera
- a camera, able to take images of sufficient quality
- a processing software for turning images into digital 3d models

3.3 Details

Things to consider:

- operation on preprogrammed waypoints
- stability for shooting accurate pictures while in air
- optimization with regards to flight routes/picture coverage
- gps tracking

3.4 Components to be considered

System components to consider:

- control system
- motors
- camera
- sensors
- battery
- mechanical parts
- 3D processing software

3.5 System constraints

The system must be designed using:

- Open-source software extensively when appropriate

If possible, the system will be designed:

- using parts and Software from the Cube AS inventory

Additional parts needed must be discussed with Cube AS.

Project Plan

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
3.0	15.05.2015	OPC	STG	Released

Summary:

This document is a guide to the project execution and the project lifecycle.

Owner: Bjørnar Dalset

Document Revision History

Rev	Date	Author	Description	Status
0.1	06.02.2015	BJD	Project Plan V0.1	Obsolete
0.2	09.02.2015	BJD	Project Plan V0.2	Obsolete
0.3	09.02.2015	BJD	Project Plan V0.3	Obsolete
0.4	10.02.2015	BJD	Project Plan V0.4	Obsolete
0.5	10.02.2015	BJD	Project Plan V0.5	Obsolete
0.6	10.02.2015	TTP	Project Plan V0.6	Obsolete
0.7	10.02.2015	BJD	Project Plan V0.7	Obsolete
1.0	10.02.2015	BJD	Project Plan V1.0	Obsolete
1.1	18.02.2015	BJD	Project Plan V1.1	Obsolete
1.2	11.03.2015	TTP	Update AUP and activities	Obsolete
2.0	15.03.2015	BJD	Released version	Obsolete
2.1	04.03.2015	TTP	Move and update content, add meetings and documents	Obsolete
3.0	15.05.2015	OPC	Final Version V3.0	Released

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Appendix List

1.0 Introduction

1.1 Purpose of the project plan

The purpose of this document is to describe the planned project execution and the project control of the 3D Ground Mapping system. This document is intended to give the stakeholders a clear view of:

- The project objectives
- How the projects objectives are to be achieved
- The schedule baseline
- Resource management

1.2 Abbreviations

List of abbreviations and acronyms with corresponding descriptions used in this document

Abbreviation	**Description**
3D	Three dimensional
UAV	Unmanned aerial vehicle
HBV	Buskerud and Vestfold University College
BAG16	Project team name. BAG16 = bachelor group 16
AUP	Agile Unified Process
TTP	Therese Tokle Poverud
OPC	Ole Petter Christensen
ADJ	Asadullah Jacop
HLM	Harjit Laly Singh Mann
NGA	Albert Ngenzi
BJD	Bjørnar Dalset
GKM	Giresse Kadima Mpoyi

Table 1 Abbreviation list

1.3 Related documents

Document number	Description
001	Vision Document
003	Requirements specification
004	Inspection and Test Plan
005	Risk Management Plan
006	Conceptual Study
007	Concept Evaluation
008	System Architecture
009	Technical Reports
010	Construction Report
011	Action Plan
012	User Guide
013	Post Project Analysis

Table 2 Related documents list

2.0 Identification

2.1 Project owner

The owner of this student project is Cube AS. Cube AS is an innovative company whose core areas are multimedia production and digital optimization of already existing solutions for communication systems. They have extensive experience with UAVs and UAV technology. They consider adding 3D ground mapping to their portfolio. This project is based on a request from a customer of Cube AS and the subsequent demands that Cube AS has put forward to the project team.

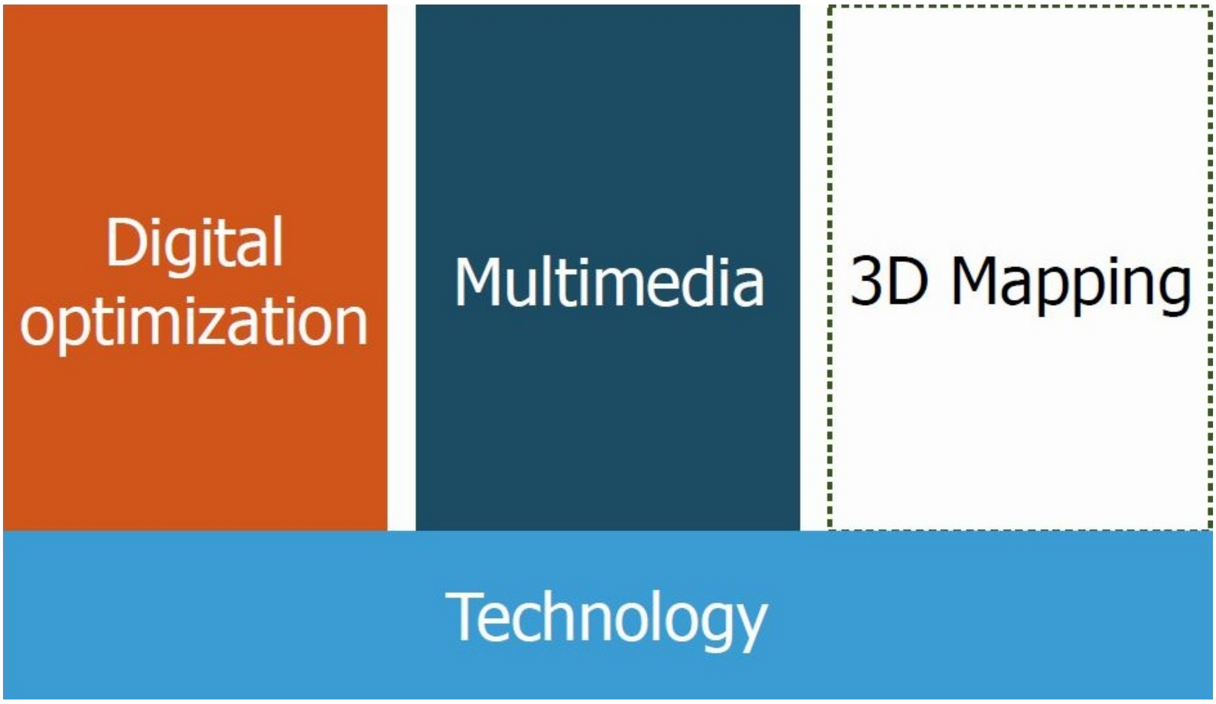

Figure 1 Cube AS portfolio

2.2 Project group

The 3D Ground Mapping system is a student project. It serves as the bachelor thesis for seven engineering students at HBV, Kongsberg. For communication purposes the project group has decided to use the name “BAG16”. “BAG16” refers to the project group – bachelor group 16.

2.3 Project name

The formal name of this project, in English and Norwegian, is:

- 3D Ground Mapping
- Kartlegging i 3D

3.0 Project overview

3.1 Background for the assignment

Terrain analysis and land surveying is an important task for many industries including:

- Construction industry
- Transport industry
- Communication industry
- Military
- Other specialized fields

Surveying often involves expensive laser equipment and long acquisition times. New technology allows for creation of 3D maps using low altitude aerial images. Standard camera equipment can be used and bypasses the need for high cost laser systems. 3D modelling is often associated with long processing times. However, new research and development in the field of orthorectified mosaicking of images, show that optimizing processes can significantly reduce software-processing times.[1]

The use of an UAV in acquiring aerial images creates an opportunity for a cheap and easy access system that will be of great interest for many of the industries listed above.

3.2 Project scope and limitations

In this project we will design, develop and construct a complete system for 3D mapping of ground, using a camera equipped UAV. The final system will be able to produce precise 3D maps and models of locations, which can be viewed on a computer screen or used to print out physical models using a 3D printer.

Requirement specification is based on demands from Cube AS and their shareholders, and the finished product will be the property of Cube AS.

This is a student project and as such, will have a limited timeframe. The project must be completed and delivered by May 19, 2015. External operational conditions like rain and snow – factors that could disqualify images from a 3D modelling process – will not be taken into consideration in this project.

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[1] Orthorectified Mosaicking of Images from Small-scale Unmanned Aerial Vehicles – Saeed Yahyanejad, Alpen-Adria Universitat, Klagenfurt, March 2013

3.3 Constraints

It is assumed that the 3D Ground Mapping system will be designed using primarily open-source software. If possible, the system will be designed using parts from the Cube AS inventory.

3.4 Change of scope

This project group was originally assigned a different project by HBV. However, after a meeting with Stig Førrisdal from Cube AS, it was decided on changing project owner and project scope. This decision was made as the team concluded that an external project would be beneficial for the overall project. This led to the team losing two weeks of research and documentation done on the former project scope.

3.5 Environment

Through the course of this project, the project team will have access to the Drone lab at HBV for testing and experimenting with existing UAV's and different parts. The group has reserved room F140 for meeting purposes and team efforts when at the University College.

The project team will have their base office at Cube AS headquarters, and have access to parts that are available in the Cube AS inventory.

3.6 Webpage

During this bachelor thesis we are assigned to create a website. This webpage will contain information about the project and will be continuously updated for the duration of the project. The project webpage will contain news and updates on the progress of this project.

The webpage can be found at:

- http://bag16.today
- https://home.hbv.no/web-gr16-2015/

4.0 Roles and responsibilities

4.1 Responsibilities

In this project, members of the project team have been assigned a role with their own area of responsibility. It is however expected that all members work on several different areas of the project.

Project Manager
The purpose of this role is to overall manage the entire project. It is the manager's responsibility to manage the team members and keep the team focused. The manager must make plans, shape priorities and manage resources. It is also the manager's responsibility to coordinate interactions with the supervisor and the stakeholders.

Document Manager
The purpose of this role is to keep track of documents. The document manager has to keep track of document versions and review documents. This also includes making sure all documents follow the standard document requirements set by the team and update templates.

Test Manager
The purpose of the test manager role is to be responsible for the success of the testing efforts. This includes planning, management and ensuring the quality of the tests. The test manager is responsible for supervising the tests and make sure that the results are according to the requirements specification.

UAV Manager
The purpose of this role is to be responsible for the overall UAV during the project. This includes developing architecture, build and test the system according to project requirements specification. It is the UAV manager's role to coordinate and overview all aspects of the UAV.

Control System Manager
The purpose of this role is to be responsible for the control system and other electrical engineering aspects of the project. It is the control system manager's responsibility to choose components, build and test the system according to project requirements specification.

Software Manager
The purpose of the software manager is to be responsible for selecting, acquiring and configuring the software needed to fulfil the project requirements specification.

3D Tool Manager

The purpose of the 3D tool manager is to ensure the visual quality of the images and 3D map are according to project requirements specification. This includes selecting and testing camera technology.

4.2 Roles

Therese Tokle Poverud (TTP) 18.04.1987
Role: Project Manager
Education: Mechanical Engineer with Specialization in Product Development
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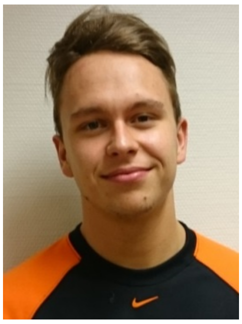
Phone: +47 984 94 405



Ole Petter Christensen (OPC) 07.11.1991
Role: UAV Manager
Education: Mechanical Engineer with Specialization in Product Development
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Phone: +47 454 75 989

Asadullah Jacop (ADJ) 01.08.1985
Role: Control System Manager
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Harjit Laly Singh Mann (HLM) 14.02.1984
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4.3 Other roles

Supervisor: Øyvind Eek-Jensen (HBV)
The supervisor is intended to help steer the project in the right direction by providing constructive feedback based on observations of the project team work. The supervisor also takes part in the evaluation process along with the internal examiner and the external examiner.

Internal examiner: Karoline Moholt (HBV)
The internal examiners main job is to evaluate the project work along with the supervisor and the external examiner.

External examiner: Stig Førrisdal (Cube AS)
The external examiners job is to evaluate the project work along with the internal examiner and the supervisor.

5.0 Project Execution Risk Analysis

5.1 Risk analysis

The purpose of this risk analysis is first to identify relevant risks in regards to the 3D Ground Mapping system. Risks will be identified as early as possible in the project to minimize their impact.

Further it was made to present possible strategies to achieve the main project goals even if some of these risks turn into incidents. This section will describe our main challenges for possible future risks and how we could either eliminate or minimalize them.

The risk occurrence and the consequence range from low to high:

- Low: Relatively little impact on schedule, performance or cost. These are not likely to occur.
- Medium: Potential to slightly impact project schedule, performance or cost. These risks might occur at a given time.
- High: Potential to greatly impact project schedule, performance or cost. These risks are likely to happen during the project lifecycle.

The options available for the management of risks are divided into four categories:

- Avoid: Eliminate the threat by eliminating the cause.
- Mitigate: Identify ways to reduce the impact of the risk or the likelihood of its occurrence.
- Accept: Nothing will be done.
- Transfer: Make another party responsible for the risk.

5.2 Risk list

The project execution risk analysis analyse general risks that might occur during the execution the 3D Ground Mapping project and finds a way to management these.

UAV pilot availability

No one in the team has the experience needed to fly an UAV. We are depending on Tommy Larsen from Cube AS fly the UAV. However, he might not be available when needed and this might result in delays.

Risk occurrence	Low	Medium	**High**
Risk consequence	Low	Medium	**High**
Risk management	**Accept:** Since no one on our team has any experience in flying UAVs we have to accept that we have to wait.		

Table 3 UAV pilot availability

Satisfying requirements

The high-level requirement specifications must be met in the finalized system.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** To make sure that the high-level requirement specifications are all met, the team must aim to deliver a system of higher quality or capacity than the high-level requirements. If all the high-level requirements can't be met, create an action plan. Keep the project manager and external supervisor informed of progress at all times.		

Table 4 Satisfying requirements

Acquisition

Necessary hardware parts that are ordered from another country may take long to ship or be defect upon delivery.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** Place purchase order in due time. Order from shops with good reputation. Upgrade to fast shipping.		

Table 5 Acquisition

Human failure

Sickness, injury, accident or other unforeseen issues may affect the project.

Risk occurrence	Low	Medium	**High**
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Eating healthy and getting enough sleep, as well some exercise, is recommended to avoid illness. Working as a team amongst the group so that if a team member is unable to deliver a part of the project because of illness, then another member of the team can step in. Work footprint free and with cloud saving so all information is accessible for everyone at all times.		

Table 6 Human failure

Defect components

Components from Cube AS's stockroom might be defect or not of good enough quality.

Risk occurrence	Low	Medium	**High**
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Make list over all components to fast ensure if they are good enough. Check for defects by running a Status test on the components. Order new at once if defect.		

Table 7 Defect components

Team failure

The project progress can be hindered if team members fail to play their active roles as agreed. This can be either due to lack of motivation, communication and other limitations or problems.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** Create positive team spirit by ensuring good communication. Show as much interest on the welfare of the team members as you show for the project. Helping and encouraging each other in areas that may be difficult.		

Table 8 Team failure

Technical issues

Hardware failure, software crash and human error are most common causes of data loss and loss of work already done.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Avoid:** Work from a cloud server (ex. Dropbox). **Mitigation:** Save the data from for the project and keep a backup on a hard drive. In case of failure of the hardware either in whole or in part, then the order for replacement parts must be made as soon as the necessary information is in. Keep the project manager and external supervisor informed of progress at all times.		

Table 9 Technical issues

Supervisor availability

The unavailability of our internal and/or external supervisors may result in hindering the project's progress if there is inadequate follow-up.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Use the supervisors as much as possible and at the same time the team must be responsible for the project and avoid depending upon supervisors in regards to the project progress. Have a contingency plan in place for who can be contacted in case a supervisor becomes unavailable.		

Table 10 Supervisor availability

6.0 Project model and phases

6.1 Agile Unified Process

For this project we chose to follow an iterative, agile process that will make it easier to develop the system. Agile Unified Process[2] is an easy to understand approach to project managing that is built on a few simple philosophies.

- Trust your staff; everyone doesn't have to know everything
- Focus on high-value activities; keep the focus on what actually counts
- Simplicity; keep documentation concise
- Agility; follow the principles and values of agile development
- Tool independence; use any toolset you want
- Tailor the process to meet your projects needs

The project is divided into four phases following the AUP making it easy to see where the project is in the project lifecycle. Each phase can have several iterations that are required to be short, around two weeks. Activities should be planned in detail no longer than two weeks into the future.

AUP has seven disciplines that will have a different amount of focus based on what phase the project is in. Disciplines are performed in an iterative manner, defining the activities needed to build, validate and deliver a working system which meets the needs of our stakeholders.

This project has several set milestones which the team has to reach in order to keep the project on track. Each phase has a primary goal we have to keep our focus on. Certain objectives have to be met before a phase can be closed and the project can move to the next stage. The iterative, agile nature of this process allows us to focus on the high-value activities so we can move to the next phase without every detail set first.

Agile Development

AUP is an agile process; this means that it follows the principles of agile development. The reason behind this is to make project team work more effective. While the agile manifesto was developed for software, it can also be applied to producing a product system.

The Agile Manifesto:

- Individuals and interactions over processes and tools

[2] http://www.ambysoft.com/unifiedprocess/agileUP.html

- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

That is, while there is value in the items on the right, we value the items on the left more.

The KISS principle:

- Keep it short and simple.

We try to implement this, especially in our project presentations. We do not wish to make it complicated and are therefore using simplicity as our key design goal.

Tailored AUP

This is a product development project that is also a bachelor thesis, and we have tailored the AUP after these criteria. We will be producing more through ought documentation than is normal for an agile process. We will try to keep it concise, but it is not a main priority as it is more important to show that the team has done during the process of the project.

We will start with the implementation and test disciplines later than what would happen in a software project as we need to make component decisions before we can start building the system. Because of this, the activities in both the Inception and Elaboration phases will be mostly in the model discipline.

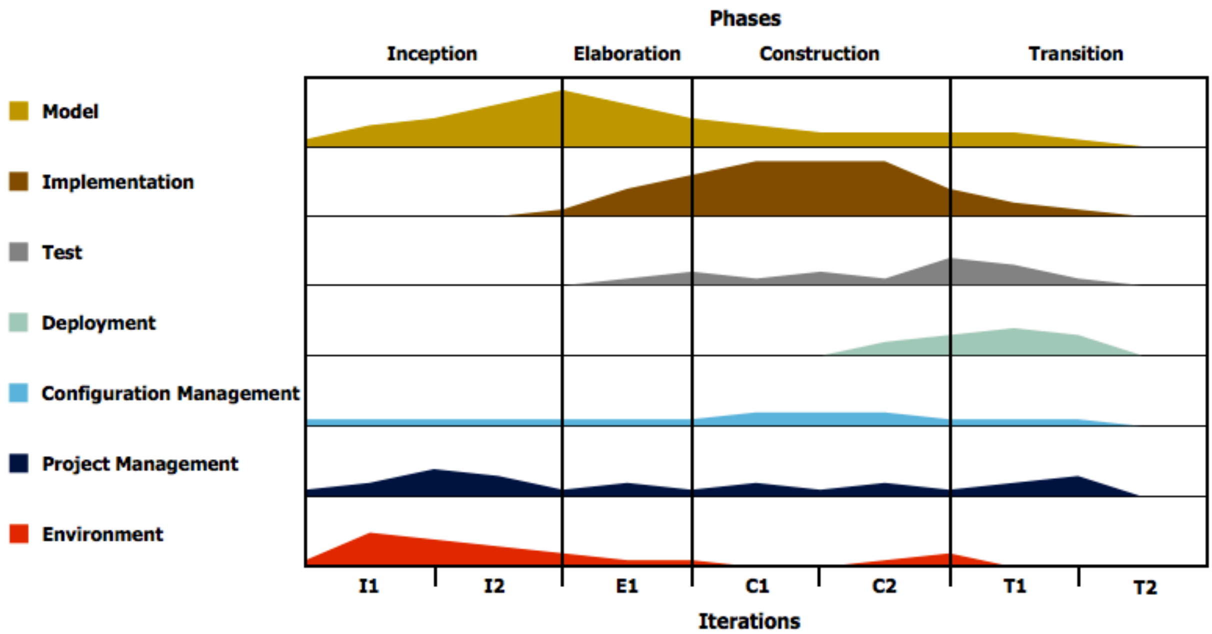


Figure 2 Overview of AUP project

6.2 Disciplines

Below is a table showing the seven disciplines of the AUP model. The first four is main disciplines and the last three are support disciplines. Each phase in AUP focuses on different disciplines, but all can be present.

Model	Understand the problem addressed by the project. Identify a viable solution addressing the problem.
Implementation	Implement the solution into a working product.
Test	Preform an objective evaluation of the product. Find defects, validate that requirements are met and the system work as designed.
Deployment	Plan for the release and finalize documentation.
Configuration Management	Tracks and ensures that documentation is accurate and consistent with the actual physical design of the product.
Project Management	Direct the people and activities within the project. Includes managing risks and coordinating with people and systems outside the scope of the project.
Environment	Ensuring support by providing working environment, tools and guidance to the team.

Table 11 Discipline list

6.3 Inception phase

The primary goals of the inception phase are to identify the initial scope and requirements of our project, and to obtain stakeholder acceptance regarding the objectives for the project. This phase will also be used to preform research and gain a better understanding of the 3D Ground Mapping project.

The milestones we have to reach within this phase are the delivery of initial project documentation and the 1st presentation. The discipline with the highest focus in this phase is model.

6.4 Elaboration phase

The primary goal of the elaboration phase is to prove the architecture for the product that is going to be developed. The point of building good baseline architecture is to ensure that our system satisfies the requirements. Architectural risks are identified and prioritized, and the high-level risks are addressed during this phase.

In the end of this phase we have to focus on the delivery of mid project documentation. The primary issue addressed by the end of this phase is whether we have a viable strategy to build the system. The discipline with the highest focus in this phase is model.

6.5 Construction phase

The primary goal in the construction phase is to build a working system which meets the highest-priority needs of our stakeholders. The focus of this phase is to develop the system to the point where it is ready for testing. The emphasis will be on prioritizing and understanding the requirements, and then building and testing the system. The primary issue here is whether the product is ready to move into the test environment and acceptance testing.

The milestones we have to reach within this phase are the delivery of the mid project documentation and the second presentation, both in the first week of this phase. The disciplines with the highest focus in this phase are implementation and test.

6.6 Transition phase

The primary goal of the transition phase is to validate and deploy our system. Extensive testing takes place during this phase. This is where the team fine-tune the system and to address significant defects. The primary issue here is whether the product can be safely and effectively deployed.

During this phase all documentation has to be finalized. A post project analysis will also be completed in the end of this phase. The disciplines with the highest focus in this phase are test and deployment.

6.7 Project delivery and evaluation

When the last phase of the project schedule is finished, we will deliver the final project report. The project wallpaper and website has to be completed here. This is also the time for the 3rd and last presentation to be held. The date is set to 26th May.

7.0 Schedule and time management

7.1 Iterations

Table 9 shows the iterations – with descriptions and durations – for this project.

Phase	Iteration name	Description	Start	End
Inception	I1	Drone initial requirements	15.01	29.01
Inception	I2	3D mapping requirements	30.01	15.02
Elaboration	E1	Plan architecture of system	16.02	01.03
Elaboration	E2	Build architecture of system	02.03	15.03
Construction	C1	Plan building working product	16.03	29.03
Construction	C2	Build working product	30.03	05.04
Transition	T1	System fine-tuning	13.04	26.04
Transition	T2	System and user testing, validate system	27.04	10.05
Transition	T3	Deployment and finalize documentation	11.05	18.05

Table 12 Iteration list

7.2 Milestones

Table 10 shows the milestones – with descriptions and dates – for each of this project's different iterations.

Iteration	Milestone	Description	Date
I1	Milestone 1	Start of project	15.01
I1	Milestone 2	Start of Inception phase	15.01
I2	Milestone 3	Deliver documents + CD for 1.presentation	11.02
I2	Milestone 4	1.presentation	13.02
I2	Milestone 5	End of Inception phase	15.02
E1	Milestone 6	Start of Elaboration phase	16.02
E2	Milestone 7	End of Elaboration phase	15.03
C1	Milestone 8	Start of Construction phase	16.03
C1	Milestone 9	Deliver documents + CD for 2.presentation	16.03
C1	Milestone 10	2.presentation	18.03
C2	Milestone 11	End of Construction phase	05.04
T1	Milestone 12	Start of Transition phase	13.04
T3	Milestone 13	End of Transition phase	18.05
-	Milestone 14	Deliver final project report	19.05
-	Milestone 15	Deliver physical wallpaper	21.05
-	Milestone 16	3.presentation	26.05
-	Milestone 17	End of project	26.05

Table 13 Milestone list

7.3 Project schedule

Appendix A[3] shows the project schedule for this project in the form of a Gantt chart. We made a Gantt diagram as part of our project plan to show the individual start and end dates for each activity. It also shows milestones and activity dependencies. This diagram shows the project's life cycle and makes it easier following our project's progress.

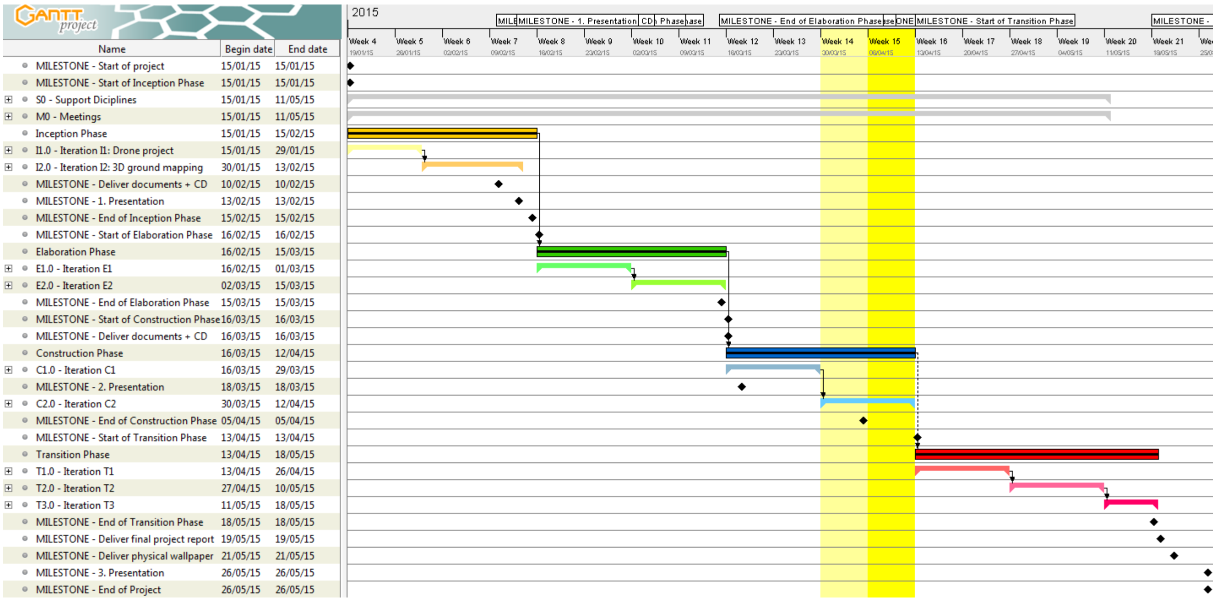


Figure 3 Overview of Gantt diagram

[3] Refers to the file located in the Appendix list/folder

8.0 Resource management

8.1 Activity list

Table 7 shows the set of activities we have defined in order to complete this project and deliver a working product that meets the needs of our stakeholders.

The activity number is constructed using the iteration name first to associate a particular activity with a particular iteration. This is followed by a number to differentiate the various activities within the iteration.

A few activity numbers are also detailed by the use of an upper case letter at the end. These are extra time-consuming activities related to the project plan, like documentation where we feel the need to differentiate further.

There are also three supporting activities, the supporting disciplines from AUP and four meeting activities. These activities will run for the whole duration of the project. These are listed in the beginning of the table and begin with either an "S" (supporting) or "M" (meeting).

Activity no.	Activity description
S0	**Support Disciplines**
S1	Project management
S2	Configuration management
S3	Environment
M0	**Meetings**
M1	Group-meeting
M2	Internal supervisor
M3	Other resources
M4	Cube AS
I1.0	**Iteration I1**
I1.1	Research
I1.2	Initial requirements
I1.3	Document writing
I2.0	**Iteration I2**
I2.1	Research
I2.2	Project scope
I2.3	Initial requirements
I2.4A	Vision document
I2.4B	Project plan
I2.4C	Requirements specification
I2.4D	Test plan
I2.5	1st presentation
E1.0	**Iteration E1**
E1.1	Research
E1.2A	Electrical System
E1.2B	Mechanical System
E1.2C	Camera System
E1.2D	Software

E1.5	Training
E1.6A	Project Plan
E1.6B	Requirements specification
E1.6C	Test Plan
E1.6D	Other documentation
E2.0	**Iteration E2**
E2.1	Research
E2.2	System Architecture
E2.3	Concept Study
E2.4	Technical risks
E2.5	Training
E2.6A	Project Plan
E2.6B	Requirements specification
E2.6C	Test Plan
E2.6D	Concept documentation
E2.6E	Other documentation
C1.0	**Iteration C1**
C1.1	Research
C1.2	2nd presentation
C1.3	CAD drawings
C1.4	Build system
C1.5	Component testing
C1.6A	Technical specification
C1.6B	Other documentation
C2.0	**Iteration C2**
C2.1	Research
C2.2	Build system
C2.3	CAD drawings
C2.4A	Component test
C2.4B	Software test
C2.5A	Project Plan
C2.5B	Technical specification
C2.5C	Other documentation
C2.6	Training
T1.0	**Iteration T1**
T1.1	Rework system
T1.2	CAD redrawing
T1.3	Testing
T1.4	Training
T1.5A	Project Plan
T1.5B	Requirements specification
T1.5C	Test Plan
T1.5D	Technical specification
T1.5E	Other documentation
T2.0	**Iteration T2**
T2.1A	System test
T2.1B	Simulation
T2.1C	Software test
T2.2	Update system
T2.3	Deploy system
T2.4A	Project Plan
T2.4B	Test Plan

T2.4C	Technical specification
T2.4D	Other documentation
T3.0	**Iteration T3**
T3.1	Finalize documentation
T3.2	Ready for print
T3.3	Testing
T3.4	3rd presentation

Table 14 Activity list

Meetings

Meetings are crucial to make sure that progress of the project is steady and that the project develops in the right direction. There are several different types of meetings that are important for the project.

Group-meeting, M1, are held when needed, at least once a week. We do status updates were we discuss what has been done since last meeting, what we are still doing, and plan and distribute work. The project plan and Gantt diagram gets updated if needed afterwards in accordance with information from these internal group-meetings.

Internal supervisor meetings, M2, are held every second week, if needed, to ensure that the project's development is kept steady, and so that the group can receive guidance and proper advice if needed. The internal supervisor acts as the school's representative during the project. Each meeting will require a head of meeting and a minute taker. Rotation of these roles is important to allow every group member to obtain the valuable experience this grants. Minutes will be written and delivered within 24 hours after each meeting.

Other resources meetings, M3, are information gathering meetings we have during our project lifecycle who are not with HBV or the stakeholders. These are held after need, and with different resources.

Cube AS meetings, M4, are meetings with our stakeholders in Cube AS. These are important for the requirement specification, to control the progress of the project is heading in the correct direction and allow the group to obtain important information or demands that is needed to complete the project.

8.2 Human resource plan

The following tables show how much time and resources we have estimated to spend on different activities in the different phases of the project. It also shows when we plan to start and be finished with each individual activity.

This plan was only an estimate and has been open to changes during the projects lifetime. This does not necessarily mean that the plan is wrong, but we have taken changes into consideration. This was one of the main reasons we chose an agile process. This resource plan shows the last revision of our project plan.

Table 12 shows activities that run for the whole duration of the project and is not pertinent to one particular project phase in our project model.

Support and meetings resource plan

Activity	Description	Duration	Resources	Hours
S1	Project management	15.01-18.05	2	120
S2	Configuration management	15.01-18.05	2	20
S3	Environment	15.01-18.05	1	20
M1	Group-meeting	15.01-18.05	7	120
M2	Internal supervisor	23.01-08.05	7	30
M3	Other resources	15.01-19.03	7	60
M4	Cube AS	22.01-18.05	7	80
			Total hours	450

Table 15 Support and meetings resource plan

Inception phase resource plan

Activity	Description	Duration	Discipline	Resources	Hours
I1.1	Research	15.01-29.01	Model	7	80
I1.2	Initial requirements	15.01-29.01	Model	7	60
I1.3	Documents writing	15.01-29.01	Model	7	5
I2.1	Research	30.01-10.02	Model	7	50
I2.2	Project scope	30.01-04.02	Model	7	20
I2.3	Initial requirements	05.02-08.02	Model	7	50
I2.4A	Vision document	02.02-10.02	Model	2	30
I2.4B	Project plan	02.02-10.02	Deployment	3	50
I2.4C	Requirements specification	02.02-10.02	Model	2	30
I2.4D	Test plan	02.02-10.02	Test	2	20
I2.5	1^{st} presentation	11.02-13.02	Deployment	7	140
				Total hours	535

Table 16 Inception phase resource plan

Elaboration phase resource plan

Activity	Description	Duration	Discipline	Resources	Hours
E1.1	Research	16.02-26.02	Model	7	70
E1.2A	Electrical System	17.02-25.02	Model	3	40
E1.2B	Mechanical System	23.02-01.03	Model	2	10
E1.2C	Camera System	18.02-27.02	Model	2	10
E1.2D	Software	19.02-25.02	Model	2	20
E1.5	Training	18.02-27.02	Deployment	7	30
E1.6A	Project Plan	16.02-19.02	Deployment	5	10
E1.6B	Requirements specification	18.02-01.03	Model	2	30
E1.6C	Test Plan	16.02-19.02	Test	2	20
E1.6D	Other documentation	16.02-28.02	Model	2	10
E2.1	Research	02.03-11.03	Model	7	10
E2.2	System Architecture	03.03-15.03	Model	7	130

E2.3	Concept Study	06.03-13.03	Model	7	70
E2.4	Technical risks	05.03-15.03	Model	3	20
E2.5	Training	12.03-15.03	Deployment	7	20
E2.6A	Project Plan	10.03-15.03	Deployment	2	15
E2.6B	Requirements specification	02.03-03.03	Model	2	5
E2.6C	Test Plan	11.03-15.03	Test	3	20
E2.6D	Concept documentation	07.03-14.03	Model	7	120
E2.6E	Other documentation	03.03-13.03	Model	2	20
				Total hours	680

Table 17 Elaboration phase resource plan

Construction phase resource plan

Activity	Description	Duration	Discipline	Resources	Hours
C1.1	Research	16.03-29.03	Model	7	40
C1.2	2nd presentation	16.03-18.03	Deployment	4	100
C1.3	CAD drawings	27.03-18.03	Model	1	40
C1.4	Build system	20.03-29.03	Implement	7	50
C1.5	Component testing	19.03-29.03	Test	3	20
C1.6A	Technical specification	19.03-29.03	Implement	2	60
C1.6B	Other documentation	19.03-29.03	Deployment	2	10
C2.1	Research	30.03-05.04	Model	3	5
C2.2	Build system	30.03-05.04	Implement	7	80
C2.3	CAD drawings	30.03-12.04	Model	1	20
C2.4A	Component test	30.03-05.04	Test	3	15
C2.4B	Software test	30.03-06.04	Test	2	5
C2.5A	Project Plan	30.03-05.04	Deployment	1	5
C2.5B	Technical specification	30.03-05.04	Implement	4	10
C2.5C	Other documentation	30.03-05.04	Deployment	2	5
C2.6	Training	30.03-05.04	Implement	7	15
				Total hours	480

Table 18 Construction phase resource plan

Transition phase resource plan

Activity	Description	Duration	Discipline	Resources	Hours
T1.1	Rework system	13.04-21.04	Implement	5	150
T1.2	CAD redrawing	13.04-26.04	Model	1	15
T1.3	Testing	13.04-26.04	Test	5	20
T1.4	Training	13.04-26.04	Deployment	7	10
T1.5A	Project Plan	13.04-26.04	Deployment	1	5
T1.5B	Requirements specification	24.04-26.04	Model	1	5
T1.5C	Test Plan	13.04-26.04	Test	1	5
T1.5D	Technical specification	13.04-26.04	Implement	5	60
T1.5E	Other documentation	20.04-26.04	Deployment	3	10
T2.1A	System test	27.04-06.05	Test	4	80
T2.1B	Simulation	27.04-10.05	Test	1	10
T2.2	Update system	27.04-03.05	Implement	7	30
T2.3	Deploy system	08.05-10.05	Deployment	7	10
T2.4A	Project Plan	27.04-10.05	Deployment	2	10
T2.4B	Test Plan	27.04-10.05	Test	2	10
T2.4C	Technical specification	27.04-10.05	Implement	6	100
T2.4D	Other documentation	27.04-10.05	Deployment	3	70

T3.1	Finalize documentation	11.05-15.05	Deployment	7	160
T3.2	Ready for print	14.05-18.05	Deployment	5	80
T3.3	Testing	11.05-13.05	Deployment	1	20
T3.4	3rd presentation	16.05-18.05	Deployment	7	175
				Total hours	1035

Table 19 Transition phase resource plan

Total hours estimated

Project phase	Hours
Support and meetings	450
Initiation phase	535
Elaboration phase	680
Construction phase	480
Transition phase	1035
Total hours	3180

Table 20 Total hours estimated

8.3 Working hours

We use a shared[4] excel sheet to registering our working hours. We do this by filling inn which activity we were working on, date, hours worked and a short description on what was done. Each row will only be allocated one activity in the spreadsheet, and if we are working on more than one activity each day we will utilize several rows. If everyone worked on the same activity at the same time we would use only one row to register it.

Week 9 **E1: UML** **23.02-01.03**

Complete	Activity	Description	Date	Houres	All	Name	Annotations
	E1.2B	Mechanical System	23.02.2015	4,0		Ole Petter	Work breakdown structure
	E1.1	Research	23.02.2015	7,0		Laly	Picture format, memory and storage
	E1.1	Research	24.02.2015	1,0		Therese	Architecture with UML, WBS and flowcharts
	E1.1	Research	24.02.2015	5,5		Laly	Communication with misson planer, Geotag and CHDK
	S1	Project Management	24.02.2015	0,5		Therese	Update code, now v5 timesheet
	E1.2C	Camera System	24.02.2015	3,0		Bjørnar	Camera system guide document
	E1.2D	Software	24.02.2015	4,0		Albert	Create software Architecture (flow chart)
	E1.6D	Other documentation	24.02.2015	3,5		Therese	Architecture with UML and WBS
	E1.6B	Requirements specification	24.02.2015	3,0		Ole Petter	Use Case Diagrams
	E1.2D	Software	24.02.2015	8,0		Albert	Architechture diagrams
	M1	Group-meeting	25.02.2015	0,5	x		Work status, info, prep M2 Friday, extend Elaboration
	S1	Project Management	25.02.2015	4,0		Therese	Review of work and process, follow-up doc, update activities
	E1.6B	Requirements specification	25.02.2015	3,5		Therese	Camera requirements and support requirements
	E1.5	Training	25.02.2015	2,5		Laly	Mission Planner
	E1.6B	Requirements specification	25.02.2015	3,5		Laly	Camera requirements and support requirements
	S1	Project Management	25.02.2015	0,5		Laly	Agenda M2 Friday
	E1.1	Research	25.02.2015	3,0		Giresse	Architechture diagrams

Figure 4 Example of Timesheet

4 Shared with Dropbox

9.0 Budget

There is no set budget plan for this project. It is assumed that the project will be realized using parts that are in the Cube AS inventory. If the project team finds it necessary to acquire extra resources, this will be discussed with the management at Cube AS. The software used in this thesis is tested with student license.

Resource budget list

All prices in this budget are the new value, even if they are from Cube AS's inventory or bought used. The list here shows the highest total sum of the system's cost[5].

Item name	Quantity	Price [NOK]
Tiger Motor MT2826-6 760kv	6	696
TURNIGY Plush 40amp Speed Controller	6	241
Tarot IRON MAN FY680 Hexacopter Kit TL68B01	1	931
Graupner E-Prop 30/15cm 12/6"	6	101
OrangeRx Open LRS 433MHz 9Ch Receiver	1	158
OrangeRx Open LRS 433MHz TX Module	1	236
Turnigy 9XR Transmitter Mode 2	1	396
3DR uBlox LEA-6H GPS with Compass Kit	1	704
DYS BLG3SN 3-Axis Brushless Gimbal Frame kit	1	1.430
FrSky DJT 2.4Ghz Combo Pack for JR w/ Telemetry Module & V8FR-II RX	1	302
Turnigy nano-tech 8000mAh 6S 25~50C Lipo Pack	1	888
KK Multi-Copter Power Distribution Board 5cm	1	63
APM2.5.2 APM2.6 Flight Control Board Pixhawk Power Module V1.0 Output BEC 3A XT60 Plug	1	176
APM 2.5 Flight Controller Ardupilot Mega	1	895
Tarot Gimbal Suspension Hook TL68A01	2	15
Sony NEX-5n	1	2.257
Silicone Wire 12 AWG 1M (Black + Red)	8	15
Agisoft PhotoScan Pro	1	26.234
	Total sum	35.738

[5] Excluding cost of shipping

10.0 Documents

During this project's lifecycle we will be documenting our project and the '3D Ground Mapping' system. Many of the documents we create will be delivered for evaluation. Each document that is to be released will follow the same template, ensuring that it contains the same layout and format.

On every document there will be one owner, one reviewer and one approver. If the document manager is not owner of a document scheduled to be released, he will in most cases function as the reviewer of the document, and sometimes as the approver. We will with this at least double-check the contents and ensure each document's proper quality. The project manager will also play an active part in every release process along with the document manager.

10.1 Project Report

This is the final delivery document and it shall contain all relevant project material. It shall be a complete composition of all documents that have influence on both the project's technical issues and execution. The documents that together compile the final report are further described here.

Vision document

This document contains a description and specifics about the project and the system that are to be developed. This information has been put together in collaboration with Cube AS, the project owner.

Document no.	Owner	Status	Revision
001	Bjørnar Dalset	Released	2.0

Project plan

This document is a guide to the project execution and the project lifecycle. It will be revised and updated if needed during the project lifecycle.

Document no.	Owner	Status	Revision
002	Bjørnar Dalset	Released	3.0

Requirement Specification

This document contains the project's requirements specification written in collaboration with Stig Førrisdal and the project group based upon demands from Cube AS. All requirements shall be listed and structured within this document. It may be several changes or updates in this document during the project lifecycle.

Document no.	Owner	Status	Revision
003	Ole Petter Christensen	Released	4.0

Inspection and Test Plan

This document is intended to give an overview on how the testing for this project will be executed, along with the results of all the tests the group has performed. The verification of each requirement is also stated in this document.

Document no.	Owner	Status	Revision
004	Giresse Kadima Mpoyi	Released	3.0

Risk Management Plan

This document is intended to identify, analyse, and manage all risks throughout the project. It will be changes and updates in this document during the project lifecycle.

Document no.	Owner	Status	Revision
005	Albert Ngenzi	Released	2.0

Conceptual Study

This document is intended to be a preliminary study in different concepts and design approaches for the 3D Ground Mapping system. It was created in the beginning of the Elaboration phase.

Document no.	Owner	Status	Revision
006	Bjørnar Dalset	Released	1.0

Conceptual Evaluation

This document is intended to analyse and evaluate the concepts and ideas presented in the conceptual studies. It was created during the Elaboration phase.

Document no.	Owner	Status	Revision
007	Bjørnar Dalset	Released	2.0

System Architecture

This document is intended to give an overview of the system architecture for the 3D Ground Mapping system. It was created and built up during the Elaboration phase.

Document no.	Owner	Status	Revision
008	Bjørnar Dalset	Released	2.0

Technical Reports

These documents are intended to give detailed, technical description of our system. They were created during the Construction and Transition phases and updated through the project lifecycle.

Document no.	Owner	Status	Revision
009	N/A	Released	1.0
009A	Ole Petter Christensen	Released	1.0
009B	Asadullah Jacop	Released	1.0
009C	Laly Mann	Released	1.0

009D	Bjørnar Dalset	Released	1.0
009E	Asadullah Jacop	Released	1.0

Construction Report

This document is intended to give detailed, technical description on the building process of our system. It was created during the Construction phase to be worked on during the rest of the project lifecycle.

Document no.	Owner	Status	Revision
010	Giresse Kadima Mpoyi	Released	1.0

Action Plan

This document is intended as mitigation to meet the project scope after the project UAV crashed.

Document no.	Owner	Status	Revision
011	Giresse Kadima Mpoyi	Released	1.0

User Manual

This document is intended as a guide to how our system works. It was created during the Transition phase.

Document no.	Owner	Status	Revision
012	Albert Ngenzi	Released	1.0

Post Project Analysis

This document is intended as a reflection on the entire project lifecycle. It was created at the end of the Transition phase.

Document no.	Owner	Status	Revision
013	Therese Tokle Poverud	Released	1.0

11.2 Appendix documents

This project has produced some documentation that is not a direct part of the main project report. These will be added as an appendix document and some will only be available internally[6].

[6] For supervisor and sensors

11.0 Credits

The project team would like to thank:

- Cube AS for giving us the opportunity to work on this project.
- Our supervisor Øyvind Eek-Jensen.
- Agisoft for licenses to use Photoscan during our project period.

CUBE AS

Project manager	
Project dates	15-Jan-2015 - 26-May-2015
Completion	96%
Tasks	117
Resources	7

Background:
Terrain analysis and land surveying is an important and time-consuming task for the construction industry. New technology is needed to improve efficiency, lower costs and create more advanced tools. This system will be of potentially great interest for anyone needing detailed 3D maps and models of areas of interest.

System Vision:
Cube AS wants a system for 3D mapping of terrain using an UAV. The UAV will be built and equipped with a camera to take aerial photos, which will be processed to produce detailed, digital 3D maps.
Final 3D maps could either be viewed on a computer or used to print out physical models using a 3D printer.

Tasks

Name	Begin date	End date
MILESTONE - Start of project	15/01/15	15/01/15
MILESTONE - Start of Inception Phase	15/01/15	15/01/15
S0 - Support Diciplines	15/01/15	11/05/15
S1 - Project Managment	15/01/15	11/05/15
S2 - Configuration Management	15/01/15	11/05/15
S3 - Environment	19/01/15	11/05/15
M0 - Meetings	15/01/15	11/05/15
M1 - Group-meeting	15/01/15	11/05/15
M2 - Internal supervisor	23/01/15	01/05/15
M3 - Other resources	15/01/15	19/03/15
M4 - Cube AS	22/01/15	11/05/15
Inception Phase	15/01/15	15/02/15
I1.0 - Iteration I1: Drone project	15/01/15	29/01/15
I1.1 - Research	15/01/15	29/01/15
I1.2 - Initial Requirements	20/01/15	29/01/15
I1.3 - Document writing	26/01/15	29/01/15
I2.0 - Iteration I2: 3D ground mapping	30/01/15	13/02/15
I2.1 - Research	30/01/15	10/02/15
I2.2 - Project scope	30/01/15	04/02/15
I2.3 - Initial Requirements	05/02/15	08/02/15
I2.4 - Document writing	02/02/15	10/02/15
I2.4A - Vision document	02/02/15	10/02/15
I2.4B - Project Plan	02/02/15	10/02/15
I2.4C - Requirements specification	02/02/15	10/02/15
I2.4D - Test Plan	02/02/15	10/02/15

Tasks

Name	Begin date	End date
I2.5 - 1.presentation	11/02/15	13/02/15
MILESTONE - Deliver documents + CD	10/02/15	10/02/15
MILESTONE - 1. Presentation	13/02/15	13/02/15
MILESTONE - End of Inception Phase	15/02/15	15/02/15
MILESTONE - Start of Elaboration Phase	16/02/15	16/02/15
Elaboration Phase	16/02/15	15/03/15
E1.0 - Iteration E1	16/02/15	01/03/15
E1.1 - Research	16/02/15	26/02/15
E1.2 - Create architecture	16/02/15	01/03/15
E1.2A - Electrical System	16/02/15	27/02/15
E1.2B - Mechanical System	23/02/15	01/03/15
E1.2C - Camera System	16/02/15	27/02/15
E1.2D - Software	16/02/15	27/02/15
E1.5 - Training	18/02/15	27/02/15
E1.6 - Document writing	16/02/15	01/03/15
E1.6A - Project Plan	16/02/15	19/02/15
E1.6B - Requirements specification	16/02/15	01/03/15
E1.6C - Test Plan	16/02/15	19/02/15
E1.6D - Other documentation	16/02/15	01/03/15
E2.0 - Iteration E2	02/03/15	15/03/15
E2.1 - Research	02/03/15	15/03/15
E2.2 - System Architecture	02/03/15	15/03/15
E2.3 - Concept Study	02/03/15	15/03/15
E2.4 - Technical risks	02/03/15	15/03/15
E2.5 - Training	11/03/15	15/03/15
E2.6 - Document writing	02/03/15	15/03/15

Tasks

Name	Begin date	End date
E2.6A - Project Plan	10/03/15	15/03/15
E2.6B - Requirements specification	02/03/15	03/03/15
E2.6C - Test Plan	10/03/15	15/03/15
E2.6D - Concept documentation	07/03/15	15/03/15
E2.6E - Other documentation	02/03/15	15/03/15
MILESTONE - End of Elaboration Phase	15/03/15	15/03/15
MILESTONE - Start of Construction Phase	16/03/15	16/03/15
MILESTONE - Deliver documents + CD	16/03/15	16/03/15
Construction Phase	16/03/15	12/04/15
C1.0 - Iteration C1	16/03/15	29/03/15
C1.1 - Research	16/03/15	29/03/15
C1.2 - 2.presentation	16/03/15	18/03/15
C1.3 - CAD drawings	27/03/15	29/03/15
C1.4 - Build System	20/03/15	29/03/15
C1.5 - Component testing	19/03/15	29/03/15
C1.6 - Document writing	19/03/15	29/03/15
C1.6A - Technical documentation	19/03/15	29/03/15
C1.6B - Other documentation	19/03/15	29/03/15
MILESTONE - 2. Presentation	18/03/15	18/03/15
C2.0 - Iteration C2	30/03/15	12/04/15
C2.1 - Research	30/03/15	05/04/15
C2.2 - Build system	30/03/15	05/04/15
C2.3 - CAD drawings	30/03/15	12/04/15
C2.4 - Testing	30/03/15	06/04/15
C2.4A - Component test	30/03/15	05/04/15
C2.4B - Software test	30/03/15	06/04/15

Tasks

Name	Begin date	End date
C2.5 - Document writing	30/03/15	05/04/15
C2.5A - Project Plan	30/03/15	05/04/15
C2.5B - Technical specification	30/03/15	05/04/15
C2.5C - Other documentation	30/03/15	05/04/15
C2.6 - Training	30/03/15	05/04/15
MILESTONE - End of Construction Phase	05/04/15	05/04/15
MILESTONE - Start of Transition Phase	13/04/15	13/04/15
Transition Phase	13/04/15	18/05/15
T1.0 - Iteration T1	13/04/15	26/04/15
T1.1 - Rework system	13/04/15	21/04/15
T1.2 - CAD redrawing	13/04/15	26/04/15
T1.3 - Testing	13/04/15	26/04/15
T1.4 - Training	13/04/15	26/04/15
T1.5 - Document writing	13/04/15	26/04/15
T1.5A - Project Plan	13/04/15	26/04/15
T1.5B - Requirements specification	24/04/15	26/04/15
T1.5C - Test Plan	13/04/15	26/04/15
T1.5D - Technical specification	13/04/15	26/04/15
T1.5E - Other documentation	13/04/15	26/04/15
T2.0 - Iteration T2	27/04/15	10/05/15
T2.1 - Testing	27/04/15	10/05/15
T2.1A - System test	27/04/15	06/05/15
T2.1B - Simulation	27/04/15	10/05/15
T2.2 - Update system	27/04/15	03/05/15
T2.3 - Deploy System	08/05/15	10/05/15
T2.4 - Document writing	27/04/15	10/05/15

Tasks

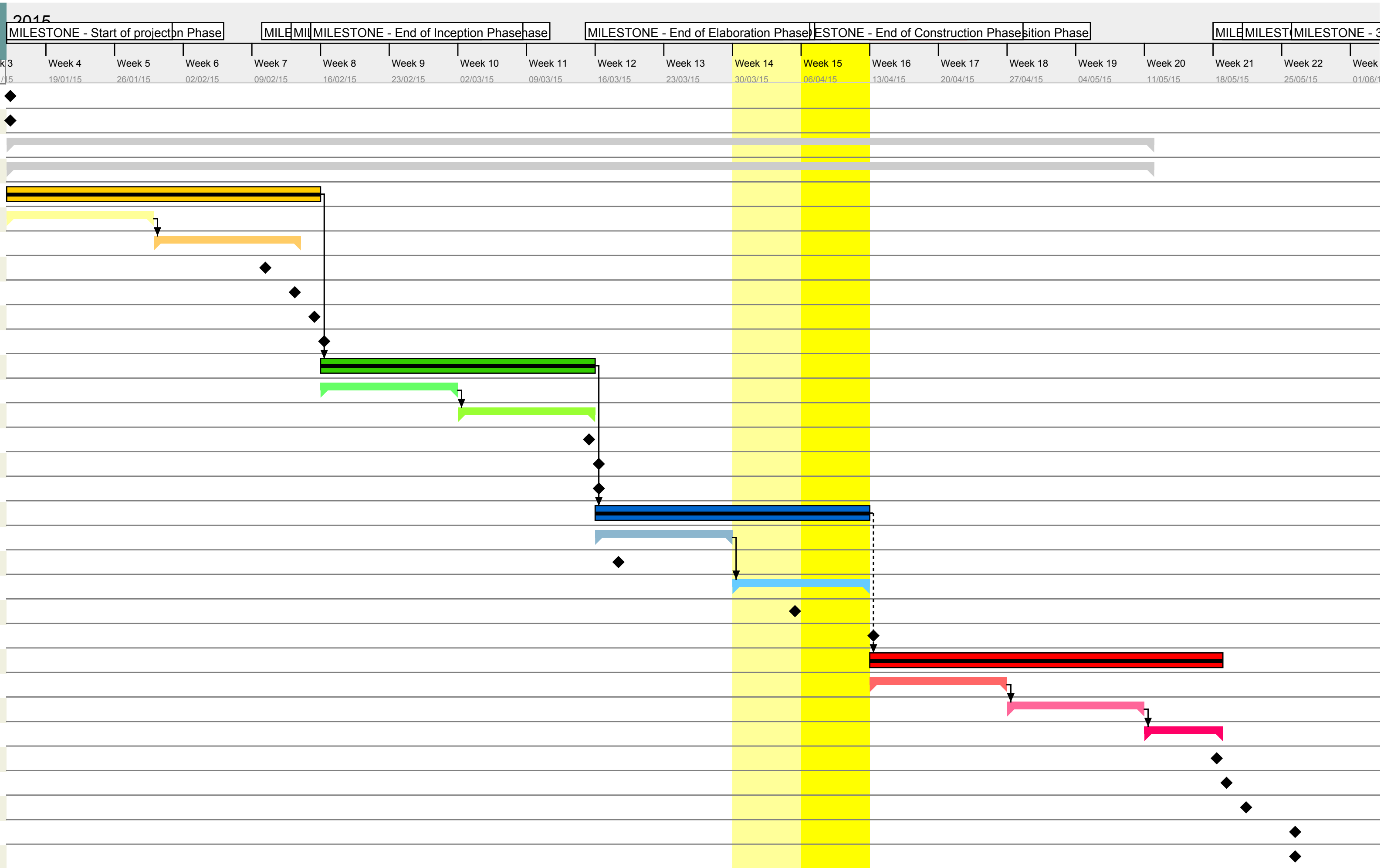
Name	Begin date	End date
T2.4A - Project Plan	27/04/15	10/05/15
T2.4B - Test Plan	27/04/15	10/05/15
T2.4C - Technical specification	27/04/15	10/05/15
T2.4D - Other documentation	27/04/15	10/05/15
T3.0 - Iteration T3	11/05/15	18/05/15
T3.1 - Finalize documentation	11/05/15	15/05/15
T3.2 - Ready for print	14/05/15	18/05/15
T3.3 - Testing	11/05/15	13/05/15
T3.4 - 3.presentation	16/05/15	18/05/15
MILESTONE - End of Transition Phase	18/05/15	18/05/15
MILESTONE - Deliver final project report	19/05/15	19/05/15
MILESTONE - Deliver physical wallpaper	21/05/15	21/05/15
MILESTONE - 3. Presentation	26/05/15	26/05/15
MILESTONE - End of Project	26/05/15	26/05/15

Resources

Name	Default role
Therese Tokle Poverud	Project Manager
Ole Petter Christensen	UAV Manager
Asadullah Jacop	Control System Manager
Harjit Laly Singh Mann	3D Tool Manager
Ngenzi Albert	Software Manager
Bjørnar Dalset	Document Manager
Giresse Kadima Mpoyi	Test Manager

Gantt Chart

Name	Begin date	End date
MILESTONE - Start of project	15/01/15	15/01/15
MILESTONE - Start of Inception Phase	15/01/15	15/01/15
S0 - Support Diciplines	15/01/15	11/05/15
M0 - Meetings	15/01/15	11/05/15
Inception Phase	15/01/15	15/02/15
I1.0 - Iteration I1: Drone project	15/01/15	29/01/15
I2.0 - Iteration I2: 3D ground mapping	30/01/15	13/02/15
MILESTONE - Deliver documents + CD	10/02/15	10/02/15
MILESTONE - 1. Presentation	13/02/15	13/02/15
MILESTONE - End of Inception Phase	15/02/15	15/02/15
MILESTONE - Start of Elaboration Phase	16/02/15	16/02/15
Elaboration Phase	16/02/15	15/03/15
E1.0 - Iteration E1	16/02/15	01/03/15
E2.0 - Iteration E2	02/03/15	15/03/15
MILESTONE - End of Elaboration Phase	15/03/15	15/03/15
MILESTONE - Start of Construction Phase	16/03/15	16/03/15
MILESTONE - Deliver documents + CD	16/03/15	16/03/15
Construction Phase	16/03/15	12/04/15
C1.0 - Iteration C1	16/03/15	29/03/15
MILESTONE - 2. Presentation	18/03/15	18/03/15
C2.0 - Iteration C2	30/03/15	12/04/15
MILESTONE - End of Construction Phase	05/04/15	05/04/15
MILESTONE - Start of Transition Phase	13/04/15	13/04/15
Transition Phase	13/04/15	18/05/15
T1.0 - Iteration T1	13/04/15	26/04/15
T2.0 - Iteration T2	27/04/15	10/05/15
T3.0 - Iteration T3	11/05/15	18/05/15
MILESTONE - End of Transition Phase	18/05/15	18/05/15
MILESTONE - Deliver final project report	19/05/15	19/05/15
MILESTONE - Deliver physical wallpaper	21/05/15	21/05/15
MILESTONE - 3. Presentation	26/05/15	26/05/15
MILESTONE - End of Project	26/05/15	26/05/15



Requirements Specification

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
4.0	14.05.2015	BJD	STG	Released

Summary:

This document is revision 4.0 of the requirements specification written in collaboration with Stig Førrisdal and the project group based upon demands from Cube AS.

Owner: Ole Petter Christensen

Document Revision History

Rev	Date	Author	Description	Status
0.1	16.01.2015	TTP	Project requirements V0.1	Obsolete
0.2	23.01.2015	TTP	Project requirements V1 Drone – old	Obsolete
0.3	04.02.2015	ASJ	Requirements V0.1	Obsolete
0.4	05.02.2015	ASJ	Requirements V0.2	Obsolete
0.5	06.02.2015	ASJ	Requirements V0.3	Obsolete
0.6	07.02.2015	OPC	Requirements Specification V0.4	Obsolete
0.7	08.02.2015	OPC	Requirements Specification v0.7	Obsolete
1.0	08.02.2015	OPC	Requirements Specification v1.0	Obsolete
1.1	09.02.2015	OPC	Requirements Specification v1.1	Obsolete
2.0	10.02.2015	OPC	Requirements Specification V2.0	Obsolete
2.1	18.02.2015	OPC	Requirements Specification V2.1	Obsolete
2.3	27.02.2015	BD	Requirements Specification V2.3	Obsolete
3.0	15.03.2015	TTP	Released version w. use cases	Obsolete
3.1	26.04.2015	BD	Removal of expired requirements	Obsolete
4.0	14.05.2015	OPC	Final Version V4.0	Released

Table 1 Document Revision History

Table of Contents

List of Tables

1.0 Documentation

1.1 Abbreviations

List of abbreviations and corresponding descriptions used in this document

Abbreviation	Description
BAG16	Project team name – Bachelor Group 16
CR	Constraining Requirements
ITP	Inspection and Test Plan
ITP ID	Inspection and Test Plan Identification
PRY	Priority
REQ	Requirement
REQ ID	Requirement Identification
SFR	Safety Requirements
SPR	Supporting Requirements
UAV	Unmanned aerial vehicle
URQ	User Requirement

Table 2 Abbreviations

1.2 References

This section provides a list of other documents referenced in this document:

Doc. number	Description
001	Vision document
004	Inspection and Test Plan

Table 3 Document references

1.3 Appendix A

2.0 Introduction

This document contains the requirements specification created by BAG16. The requirements presented in this document are the result of the demands from Cube A/S with attending Stig Førrisdal and written in collaboration with BAG16.

The requirements stated in this document are to ensure that the final system meets its intended purpose.

The background of this assignment is to establish a common understanding between Cube A/S and BAG16 regarding the result of the project based upon the vision document and the statement of need from Cube A/S.

This document contains the user requirements of the system and is arranged in the following categories:

- Supporting requirements, constraining requirements and safety requirements.

This document lays the foundation for the TIP document and is traceable through the REQ ID.

3.0 Requirements

The following requirements are organized in three categories:

1. Supporting Requirements SPR – These requirements supports the features presented in the Vision document. All of the supporting requirements shall be able to be transformed into use-cases and all of the use-cases should be able to describe the requirements.
2. Constraining Requirements CR – These requirements clarifies the boundary of the system and the development environment of the system.
3. Safety Requirements SFR – These requirements ensures the safety of personnel, environment and equipment

The requirement ID is unique and not trivial. It is based upon the requirement domain, the requirement category, requirement sub category and a two digit number. *Example:*

REQ ID	Description
URQ-SPR-01	User requirement – Supporting requirement – 01

Table 4 REQ ID

3.1 Requirement prioritization

Priority	Explanatory note
A	High Priority – Requirements that must be accomplished [1]
B	Medium Priority – Requirements that should accomplished [2]
C	Low Priority – Requirements that may be accomplished [3]

Table 5 Requirement prioritization

[1] Requirements that must be accomplished in order deliver the promised system or that concerns safety of personnel and environment

[2] Requirements that should be accomplished or that concerns safety of equipment, but not stated as necessary to deliver the promised system.

[3] Requirements that may be accomplished or partially fulfilled if the circumstances allow it, here: time overrun and budget overrun.

3.2 Supporting Requirements

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-01	TS-UAT-S01	A	The user shall be able to operate the UAV manually using a remote control	STG
URQ-SPR-02	TS-UAT-S02	A	The user shall be able to pre-program the UAV to operate on its own	STG
URQ-SPR-03	TS-UAT-S03	B	The user should be able to monitor the battery status, height, speed and position of the UAV	STG
URQ-SPR-04	TS-UAT-S04	A	The user shall be able to pre-program the picture shooting process	STG
URQ-SPR-05	TS-UAT-S05	C	The user should be able to print a physical model of the 3D map, using a 3D printer	STG

Table 6 Supporting Requirements

3.3 Constraining Requirements

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-01	TS-SIT-C01	A	The system shall be created using available resources	STG
URQ-CR-03	TS-SIT-C03	A	The system shall use extensively open-source software when available	STG
URQ-CR-04	TS-SIT-C04	A	The System shall be a battery driven UAV	STG
URQ-CR-05	TS-SIT-C05	A	The System shall be able to map an area of minimum 10 000 square meters	STG
URQ-CR-06	TS-SIT-C06	A	The system shall be able to operate with one single human resource	STG
URQ-CR-07	TS-SIT-C07	B	The system should not exceed a process time of 72 hours to create a digital 3D model	STG
URQ-CR-08	TS-SIT-C08	B	The UAV should be able to be transported fully assembled by the user with a Category B driver’s licence	STG
URQ-CR-09	TS-SIT-C09	A	The system must be able to geo-tag images	STG
URQ-CR-10	TS-SIT-C10	A	The system shall have enough battery capacity to do 500 exposures in one flight	STG
URQ-CR-11	TS-SIT-C11	A	The system shall be able to store at least 500 images	STG
URQ-CR-12	TS-SIT-C12	A	The system shall be able to maintain the same height over various terrain	STG
URQ-CR-14	TS-SIT-C14	A	If additional acquisitions are necessary, costs must be kept within budget.	STG
URQ-CR-15	TS-SIT-C15	A	The 3D map must be accurate enough to provide usable information for entrepreneurs and construction engineers.	STG
URQ-CR-16	TS-SIT-C16	A	The system must be able to adjust basic camera settings to achieve correct image exposure.	STG

Table 7 Constraining Requirements

3.4 Safety Requirements

REQ ID	ITP ID	PRY	Description	Origin
URQ-SFR-01	TS-SIT-SF01	A	The system shall in no operating condition be a lethal danger to human or animal life	STG
URQ-SFR-02	TS-SIT-SF02	C	The UAV should not crash in the event of battery loss	STG
URQ-SFR-03	TS-SIT-SF03	C	The UAV should not crash in the event of signal loss	STG
URQ-SFR-04	TS-SIT-SF04	A	The UAV should not crash due to mechanical failure	STG

Table 8 Safety Requirements

4.0 Use Case Diagram

With respect to AUP, the requirements specification is based on the supporting requirements and the corresponding use case diagrams. The use case diagram presented in this document is based on the concepts of UML 2.

Use case diagrams are interaction diagrams, which are commonly referred to as behaviour diagrams, which seek to clarify the flow of control and data among the things in the system being modelled.

The use case diagram presented is a simple representation of the user's interactions with the system. It is developed on the basis of the supporting requirements and is modelled to illustrate the relationship between the requirements and the users of the system, hereinafter known as actors. The system is the totality of the diagram and represents the border of the different use cases stated in the diagram.

4.1 Use Cases

Use Case Diagram – Supporting Requirements	
Name	Manual Operation
Identifier	UC01
Requirement ID	URQ-SPR-01, URQ-SPR-03
Description	Manuel operation of UAV includes: • Preparing UAV for flight. • Calibrating and monitoring sensors and equipment. • Controlling UAV with a hand-held remote control.
Preconditions	UAV is in operating condition: • Batteries are charged. • Sensors and equipment are wired correctly and working. • Weather is suitable for flying.
Assumptions	• User has knowledge to operate UAV in manual mode. • Operating UAV is not in violation of any regulation codes.
Basic Course	**1.** The use case begins with the drone pilot turning on the power for the UAV. **2.** The UAV sends information regarding battery levels, sensor values and GPS location to a computer. **3.** The drone pilot checks meters and sensor values to verify everything is showing expected values. **4.** The drone pilot proceeds to take off, using the controls on the remote control. **5.** The drone pilot steers the UAV in the wanted direction, using his/her vision to stay clear of any obstacles or boundaries. **6.** The drone pilot uses any meter or sensor values available to aid the steering of the UAV. **7.** The drone pilot checks the battery status to verify there is enough battery left to safely land the UAV. **8.** The drone pilot lands the UAV in due time, before battery is reaching critically low levels. **9.** The drone pilot turns off the power. **10.** The use case ends.
Alternate Course A	The battery is too low for operation: **A4.** The drone pilot decides there is not enough battery to fly the UAV.

	A5. The drone pilot starts charging the batteries. **A6.** The use case ends.
Alternate Course B	Switches to automated operation: **B5.** The drone pilot switches to automated operation after take-off. **B6.** The UAV operates on itself following pre-programmed routes; see use case UC02. **B7.** The use case ends.
Actors	Drone Pilot
Included Use cases	N/A

Table 9 Use case: Manual operation

Use Case Diagram – Supporting Requirements	
Name	Automated operation
Identifier	UC02
Requirement ID	URQ-SPR-02, URQ-SPR-03
Description	Automated operation of UAV includes: • Pre-planning of flight routes using software. • Calculating flight times. • Checking battery and sensor values. • Automated execution of pre-planned flight routes.
Preconditions	UAV is in operating condition: • Batteries are charged. • Sensors and equipment are wired correctly and working. • Weather is suitable for flying.
Assumptions	• User has knowledge about the software. • Operating UAV is not in violation of any regulation codes.
Basic Course	**1.** The flight planner opens the flight plan software. **2.** The flight planner plots the area the UAV will be covering in the software. **3.** The software suggests different routes and waypoints to cover the chosen area, and the corresponding time of flight. **4.** The flight planner decides the appropriate route and makes necessary adjustments. **5.** The flight planner turns on the power for the UAV. **6.** The UAV sends information to the software regarding battery levels, sensor values and GPS location. **7.** The flight planner initiates the automated flight by clicking a button in the software. **8.** The UAV takes off and starts flying the predetermined route using GPS and sensor values to determine its exact whereabouts. **9.** The UAV lands at a predetermined location after finishing the pre-programmed route. **10.** The use case ends.
Alternate Course A	Low battery before flight. **A7.** The flight planner deems the battery levels too low to execute the route and decides to not initiate the flight. **A8.** The flight planner charges the batteries. **A9.** The use case ends.
Alternate Course B	Low battery during flight. **B9.** The UAV reports low battery levels during flight to the software. **B10.** The flight planner deems the battery levels too low to continue the route. **B11.** The flight planner cancels the remaining route in the software.

	B12. The UAV aborts the route and returns to the predetermined landing location. **B13.** The use case ends.
Alternate Course C	Switches to manual operation. **C9.** The flight planner switches to manual operation while in air; see use case UC01. **C9.** The use case ends.
Actors	Flight planner
Included Use cases	N/A

Table 10 Use case: Automated operation

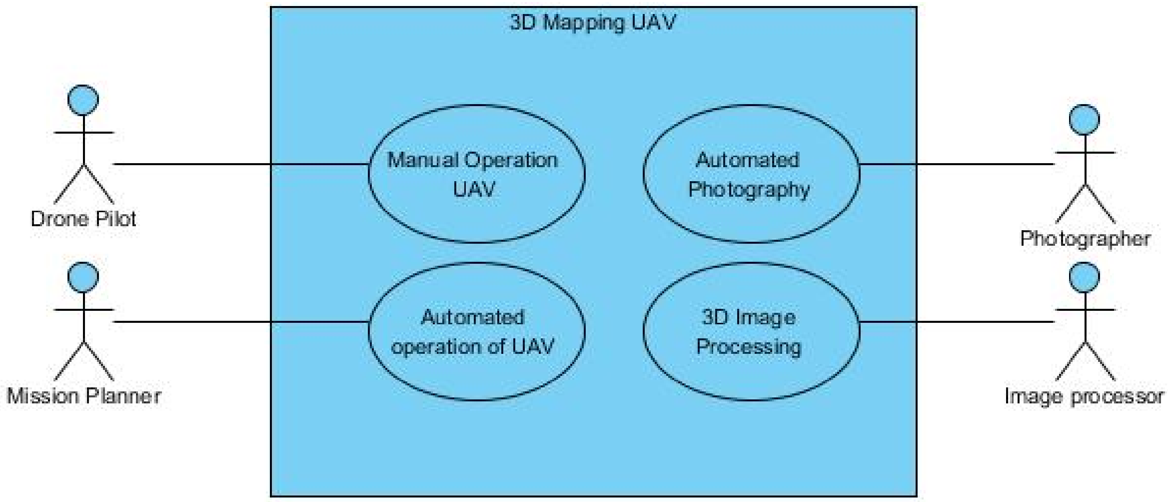
Use Case Diagram – Supporting Requirements	
Name	Automated photography
Identifier	UC03
Requirement ID	URQ-SPR-04
Description	Automated photography includes: • Pre-adjustment of exposure settings like ISO, aperture, shutter speed and other settings that affect the image quality. • Pre-planning the shooting with regards to the flight route. • Executing the automated picture shooting.
Preconditions	• UAV is in operational condition. • UAV is in automated operation mode. • Weather is suitable for aerial photography.
Assumptions	• User has knowledge about camera and software.
Basic Course	**1.** Photographer connects camera to the UAV, via a stabilization system. **2.** Photographer adjusts the angle of the camera. **3.** Photographer plots in the angle of the camera in the control software. **4.** Photographer plots in camera settings: ISO, aperture, shutter speed etc. into the software. **5.** Photographer plots in the wanted resolution. **6.** The software calculates the necessary height of flight based on camera specifications and the wanted resolution. **7.** Photographer plots in when and how many pictures to take. **8.** UAV takes off and executes the predetermined flight route in automated mode; see use case UC02. **9.** Pictures are taken at the predetermined locations set in the software. **10.** Images are stored on a memory card in the camera with the GPS coordinates for each image. **11.** UAV lands after finishing the pre-programmed route. **12.** The use case ends.
Alternate Course A	The flight route is aborted. **A11.** The flight route is cancelled before finishing. **A12.** The UAV returns to the landing location. **A13.** The use case ends.
Actors	Photographer
Included Use cases	UC02

Table 11 Use case: Automated photography

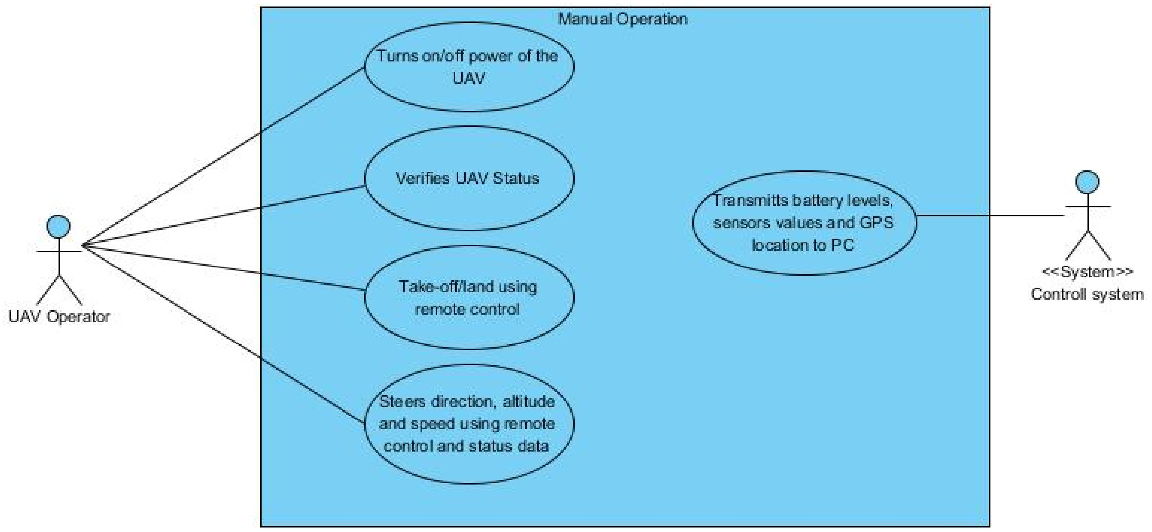
Use Case Diagram – Supporting Requirements	
Name	3D Image processing
Identifier	UC04
Requirement ID	URQ-SPR-05
Description	3D Image processing includes: • Managing files and formats. • Implementing images in 3D modelling software. • Examining the process and adjusting parameters for optimal results.
Preconditions	• Aerial images have been captured and stored with GPS coordinates for each image. • Images are of sufficient quality for 3D modelling process. • Computer is adequately powerful for 3D processing to take place.
Assumptions	• User has knowledge about the software being implemented.
Basic Course	**1.** The image processor imports aerial images taken from the flight. **2.** The software processes the images. **3.** The software creates a 3D map by mosaicking the geo-tagged images. **4.** The image processor examines the results and makes necessary adjustments. **5.** The software renders a digital 3D model. **6.** The use case ends.
Alternate Course A	**A5.** The image processor is not satisfied with the results. **A6.** No 3D model is rendered. **A7.** The image processor orders new images to be acquired; see use case UC03. **A8.** The use case ends.
Actors	Image processor
Included Use cases	N/A

Table 12 Use case: 3D Image processing

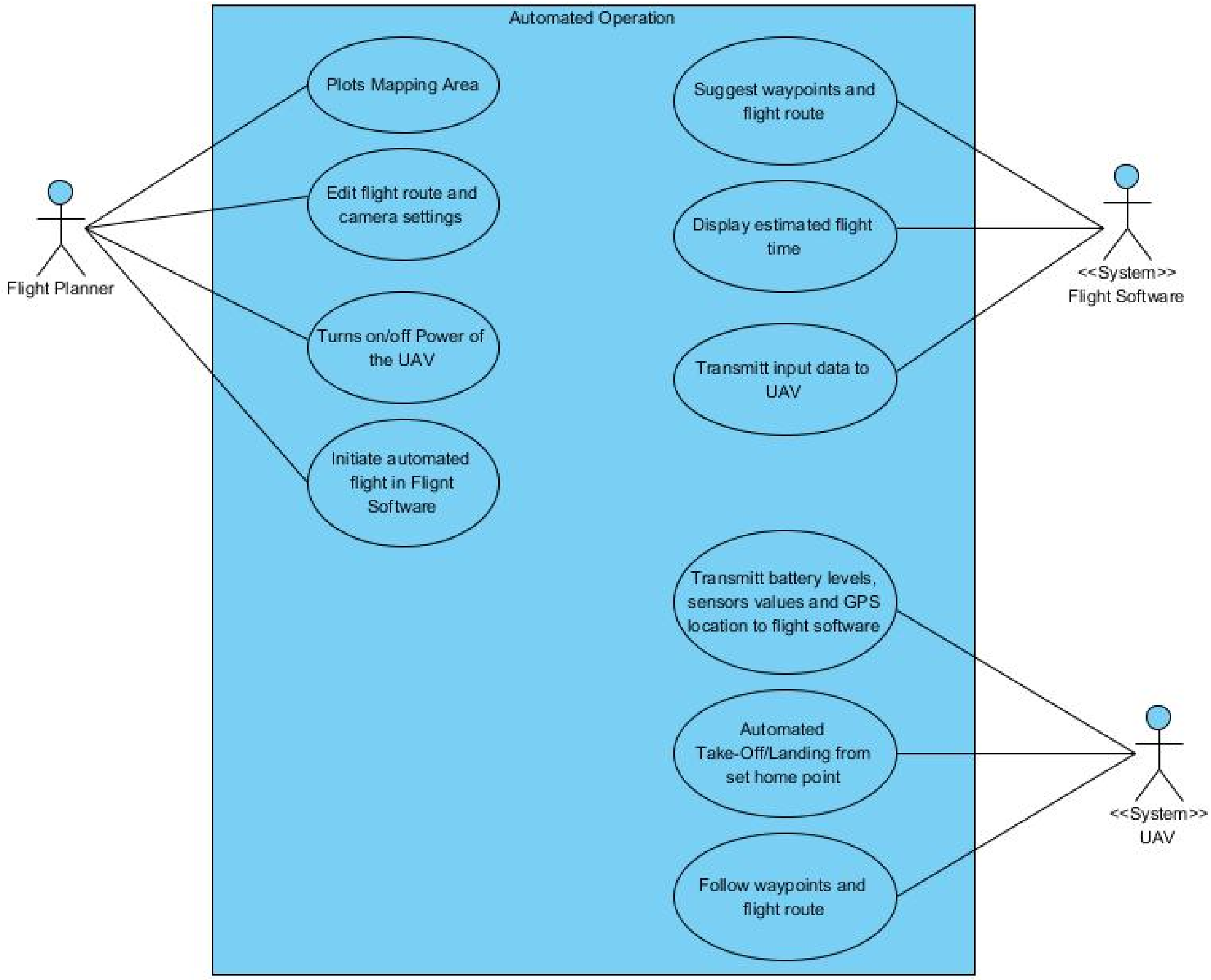
5.0 Appendix A – Use Case Diagrams



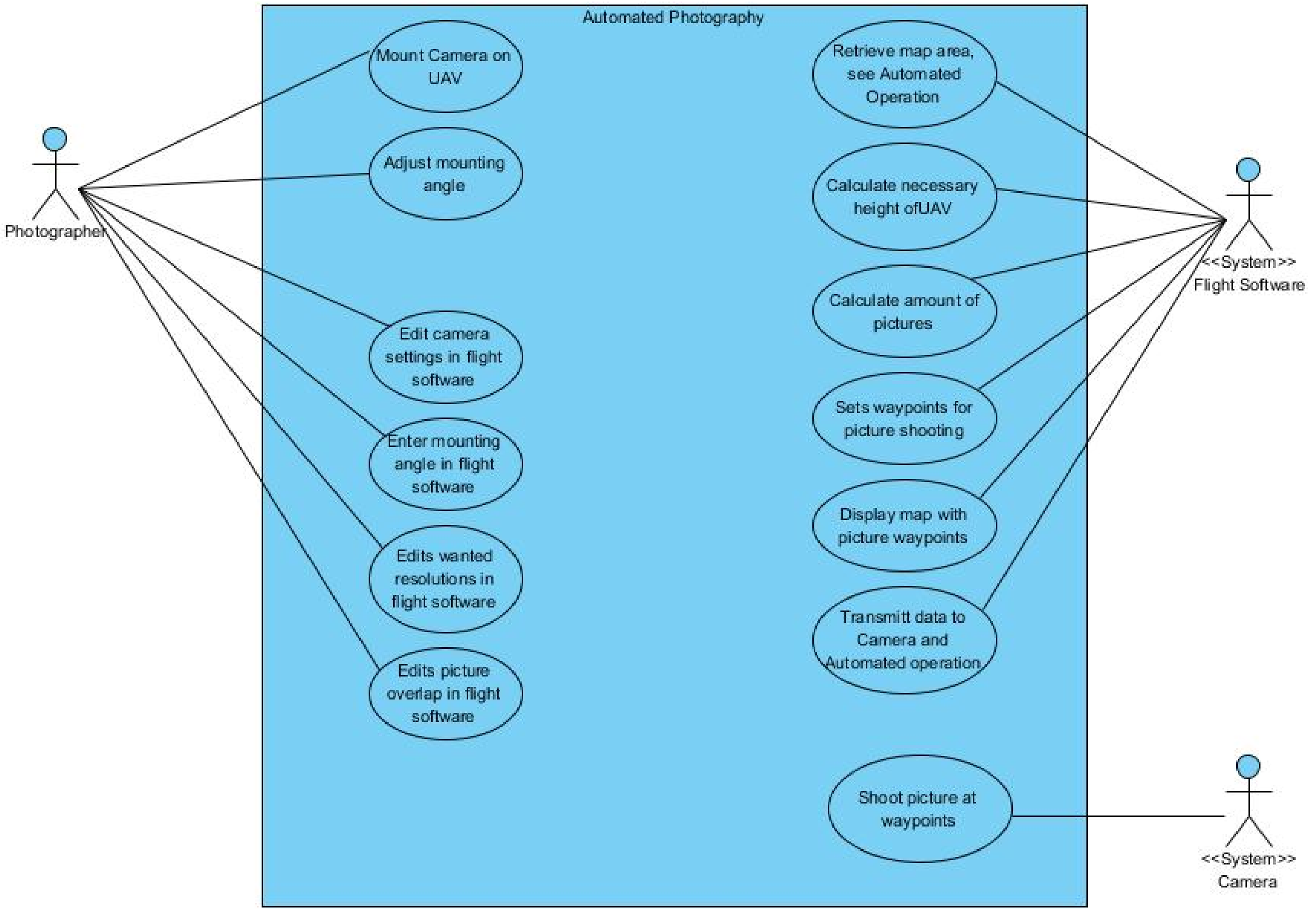
Use Case Diagram 1: 3D Mapping UAV



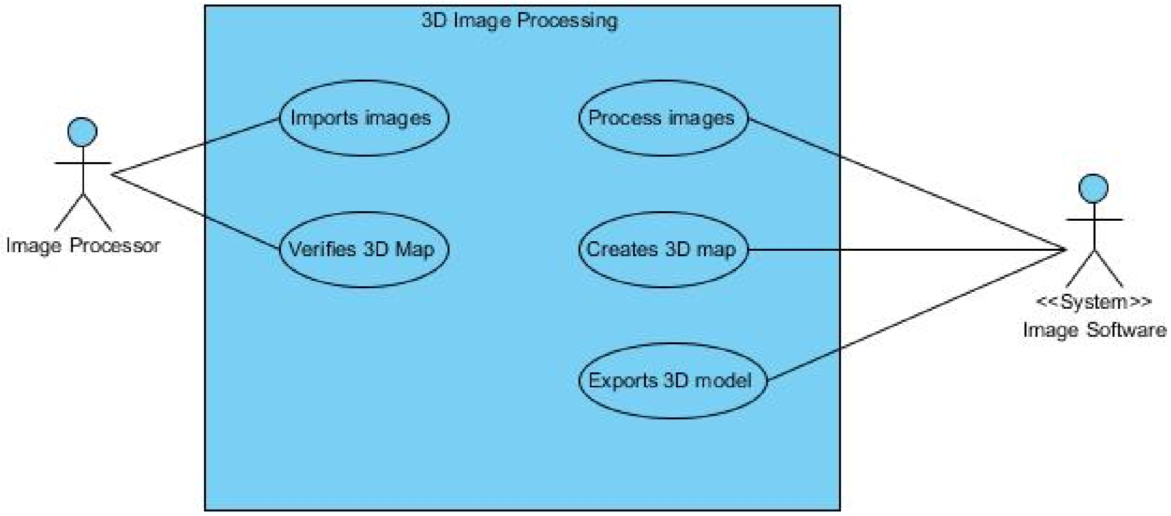
Use Case Diagram 2: Manual Operation



Use Case Diagram 3: Automated Operation



Use Case Diagram 4: Automated Photography



Use Case Diagram 5: 3D Image Processing

Inspection and Test Plan

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
3.0	12.05.15	BJD	STG	Released

Summary:

This document is intended to give an overview on how we are going to test our requirements.

Owner: Giresse Kadima Mpoyi

Document Revision History

Rev	Date	Author	Description	Status
0.1	08.02.15	GKM	Draft	Obsolete
1.0	08.02.15	GKM	Released version	Obsolete
1.1	19.02.15	GKM	Bottom-up testing	Obsolete
1.2	15.03.15	TTP	ITP update, ITP ID	Obsolete
2.0	15.04.15	OPC	Second Version	Obsolete
3.0	12.05.15	OPC	Final version, deleted unnecessary level descriptions, added test results	Released

Table of Contents

List of Tables

1.0 Introduction

1.1 Purpose of this document

The purpose of the Inspection and Test Plan is to put together a single document that records all inspection and testing requirements relevant to the 3D Ground Mapping project. ITP identifies the components and work to be inspected or tested, by whom and at what stage of the process or frequency. This document helps ensure that, and verify whether, work has been undertaken to the required standard and requirements.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
BAG16	Project team name – Bachelor Group 16
ITP	Inspection and Test Plan
UAV	Unmanned aerial vehicle
REQ	Requirement
REQ ID	Requirement Identification
URQ	User Requirement
SPR	Supporting Requirements
CR	Constraining Requirements
SFR	Safety Requirements
PRY	Priority
ITP ID	Inspection and Test Plan Identification
SW	Spot Witness
W	Witness
HP	Hold point
APM	Auto Pilot Modul

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents referenced in this document

Doc. number	Description
003	Requirements specification

Table 2 Related documents

2.0 Inspection and Testing

This process is to assist BAG16 in preparing Inspection and Test Plan for all work carried out on the 3D Ground Mapping project. Testing is important to verify the system that is being developed.

The scope of this testing plan is:

- To describe what is to be tested and how it will be tested.
- Detail if the plan is focused on a single system or on multiple systems. In this case there is one system with several subsystems.

The Project Manager is responsible for the implementation of this process. The Test Manager is responsible for managing the process. The entire team will be involved with planning the tests, testing and recording the results for the different subsystems and the final fully assembled system test.

2.1 Bottom-Up Test Strategy

A testing strategy is a general approach to the testing process rather than a method of devising particular system or component tests. There are different strategies that might be adopted depending on the type of system to be tested and development process used. In this project, we will be using a bottom-up approach.

In bottom-up testing the lowest level components are tested first, then used to facilitate the testing of higher level components. This process is repeated until the component at the top of hierarchy is tested.

All the lower level functions are integrated and then tested. After integration testing of lower level modules, the next level of modules will be formed and can be used for integration testing. This type of testing is helpful only when most of the modules of the same development level are ready.

2.2 Inspection level definitions

2.2.1 Witness (W)

Witness inspection is an activity during construction of the system where the inspection, or tests, must be done in place and documented.

2.2.2 Spot Witness (SW)

Spot witnessing inspection is an activity during construction of the system where inspection or test normally takes places. A SW provides the stakeholders with the opportunity to witness the inspection, or test, at their discretion.

2.2.3 Hold point (HP)

Hold point is an activity during construction beyond which work may not proceed without the approval of stakeholders or authority.

2.3 Test Level

Bottom-up testing follows the natural progression from component tests (QT and FAT) to subsystem test (EFAT) and complete system integration test (SIT). User acceptance test (UAT) is the last test in this process.

2.3.1 Qualification Testing (QT)

Qualification testing must be done on any unproven component to be used in the system. All testing should simulate expected working conditions or be more severe. This test takes place in the teams own workshop or at HBV's Drone lab.

QT tests:

- Maximum, and combined, load testing
- Function testing, determine operational limits
- Fatigue life testing
- Life cycle/endurance testing

2.3.2 Factory Acceptance Testing (FAT)

Components FAT's are always performed prior to the components being incorporated into a higher assembly. This test takes place in the team's own workshop or at HBV's Drone lab.

- Function test focuses on the output as per requirement and ignores the internal parts. It is performed to verify that a component performs and functions correctly according to design specification.
- Critical dimensions test checks for critical dimensions in the component being tested.
- Weight and centre of gravity test.

2.3.3 System Integration Testing (SIT)

SIT is a test where all components and subsystems are tested together as a full system. System, and subsystem, testing ensures that the interfaces is correct and the system works as required. This test takes place at HBV's Drone lab or the project owner's preferred location.

2.3.4 User acceptance testing (UAT)

UAT is the last phase of the testing process. During this test actual users test the system to make sure it can handle required tasks in real-world scenarios, according to requirements specifications. UAT is the final and most critical test that must occur before the system can be deployed. This test takes place at the project owner's location, or preferred location.

2.4 Inspection and Test Plan Identification

The inspection and test plan is unique. Table 4 below shows what every letter stands for.

ITP ID	Description
TS-UAT-S01	Test – User acceptance testing – Supporting requirement – 01
TS-SIT-SF01	Test – System integration testing – Safety requirement - 01

Table 3 ITP ID

2.5 Tools for testing

Tools to be used for testing:

- MATLAB/Simulink
- SolidWorks
- Physical model
- Multimeter

2.6 Testing procedures of requirements

REQ ID	ITP ID	Testing procedures	When	Approved
URQ-SPR-01	TS-UAT-S01	The UAV will be tested manually by using RC transmitter to fly the UAV.	When all components are integrated.	STG
URQ-SPR-02	TS-UAT-S02	The UAV will be tested automated by the use of software	When all components are integrated	STG
URQ-SPR-03	TS-UAT-S03	The test could be tested by having a telemetry which will display monitor the batter, height, speed and position of the UAV	When all the components are integrated	STG
URQ-SPR-04	TS-UAT-S04	It can be tested by preprogramed the camera with a software, to take a few pictures at different GPS locations. Without a UAV in the first place.	This can be tested when a mission planer software and the camera is available.	STG
URQ-SPR-05	TS-UAT-S05	The printing can be tested by the printer which can support this type file	In the end of project.	STG
URQ-CR-01	TS-SIT-C01	The system can be tested by inspection	The same time as we integrate and the other subsystems.	STG
URQ-CR-03	TS-SIT-C03	The system can be tested by inspection	The same time as we integrate and the other subsystems.	STG

URQ-CR-04	TS-SIT-C04	Inspecting test	Before integration of the UAV	STG
URQ-CR-05	TS-SIT-C05	Inspection test	Before and after the test flying.	STG
URQ-CR-06	TS-SIT-C06	Inspection test	After integration	STG
URQ-CR-07	TS-SIT-C07	Inspection test	After photographing an area	STG
URQ-CR-08	TS-SIT-C08	Can be tested by demonstration and inspection	After assembling the frame	STG
URQ-CR-09	TS-SIT-C09	Take pictures with Geo tagging of pictures. And try this on different locations to verify the result.	Can be tested after retrieving a camera system which have integrated GPS or supports an external GPS.	STG
URQ-CR-10	TS-SIT-C10	Inspection	When the camera is available	STG
URQ-CR-11	TS-SIT-C11	Inspection test and calculating the storing space per image	Before you buy the memory card	STG
URQ-CR-12	TS-SIT-C12	Can be tested by flying on automated mode and see the altitude of the UAV which is transmitted.	When both the UAV and software are available	STG
URQ-CR-14	TS-SIT-C14	Inspection	When project is finished	STG
URQ-CR-15	TS-SIT-C15	Inspection	After processing	STG
URQ-CR-16	TS-SIT-C16	Inspection	When the UAV is available	STG
URQ-SFR-01	TS-SIT-SF01	Test in uninhabited areas	When the UAV is available	STG
URQ-SFR-02	TS-SIT-SF02	This can be tested by flying in a low altitude, until the system run out of battery power.	When the UAV is available.	STG
URQ-SFR-03	TS-SIT-SF03	This can be tested by flying in a low altitude by turning off the controller	When the UAV is available	STG
URQ-SFR-04	TS-SIT-SF04	SOLIDWORKS simulation test on structural components and assemblies	During the designing process	STG

Table 4 Requirements and testing

However, not all the requirements will be tested. Our major tests will be done:

- UAV system
- Camera system
- Image processing system

3.0 Test activities

3.1 UAV system

This will be the testing of a system as a whole. The UAV will be tested to find out if it is able to fly. This could be both manual and automated. In order for the UAV to fly, components such us motor, speed control, receiver and transmitter need to be tested separated before they are connected to each other.

Another possible test which could be done is connecting a load (camera) on the UAV. and if the load will have any effect on the AUV in term of weight. This testing could be done after the whole system is completed. It could also be tested before the system is completed by the help of MATLAB and Simulink. SOLIDWORKS can be used for designing of almost every component.

This testing will make sure that that some of our requirements are testing. This Requirements ID and their ITP ID are shown on the table below.

REQ ID	ITP ID
URQ-SPR-01	TS-UAT-S01
URQ-SPR-02	TS-UAT-S02
URQ-CR-03	TS-SIT-S03
URQ-CR-04	TS-SIT-C04
URQ-CR-12	TS-SIT-C12
URQ-SFR-02	TS-SIT-SF02

Table 5 Requirements – UAV

3.1.1 Control System

This testing will be done to see the functionality of the combination of subcomponents to control the UAV such as sensors, autopilot (GPS), and micro-controller and speed controller. The testing of this part depends on UAV. Micro-controller and speed controller cannot be testing before the testing of UAV is complete tested. The system can be tested where the GPS signal is available. This testing will make sure that that some of our requirements are testing. This Requirements ID and their ITP ID are shown on the table below.

REQ ID	ITP ID
URQ-SPR-05	TS-UAT-SP05
URQ-CR-01	TS-SIT-C01
URQ-CR-03	TS-SIT-C03
URQ-CR-05	TS-SIT-C05
URQ-CR-07	TS-SIT-C07
URQ-CR-11	TS-SIT-C11
URQ-CR-15	TS-CR-C15

Table 6 Requirements – control system

3.2 Camera system

Below are the requirements affecting the camera system. Testing will be performed in order to verify that the Requirement Specification is fulfilled.

4.0 REQ ID	ITP ID
URQ-SPR-04	TS-UAT-SP05
URQ-CR-09	TS-SIT-C09
URQ-CR-10	TS-SIT-C10
URQ-CR-11	TS-SIT-C11
URQ-CR-16	TS-SIT-C16

Table 7 Requirements – image process

3.2.1 Geo Control Imaging

Photography is one of many critical parts in our project, and many factors should be taken into account in order for the photo camera to take the right image over the desired area. The percentage of image overlapping makes the quality of the 3D ground map. The image quantity should be calculated and programed with respect to required percentage of image overlapping, speed and attitude of the UAV. The testing process will be done after implementing the UAV with autopilot system (GPS), attitude, accelerometer gyroscope sensors in the end of this project. In the case of security, the testing would take place outside in different area to be sure that the system meets the requirement we sat.

3.2.2 Camera

- The camera will be tested to check if it can take a photo. This will be done manual by clicking on the camera or automated.
- We will look at the quality of the image.
- Linux programme will be used in order to communicate with the system.

3.2.3 Gyro

- We will test how well the gyro is able to stabilize the camera system mounted on an unmanned aerial vehicle. This test will be done both manual and automated.

4.1 Image processing system

The image processing system is a time consuming process, which is not dependent on the UAV. The testing of the processing system could be tested without necessarily having a UAV available. The photos can be taken manually. The test can be done by using processing software program to compute images which are taken by a camera to a 3D map. This testing will make sure that that some of our requirements are tested. This Requirements ID and their ITP ID are shown on the table below.

REQ ID	ITP ID
URQ-SPR-05	TS-UAT-SP05
URQ-CR-01	TS-SIT-C01
URQ-CR-03	TS-SIT-C03
URQ-CR-05	TS-SIT-C05
URQ-CR-07	TS-SIT-C07
URQ-CR-11	TS-SIT-C11
URQ-CR-15	TS-SIT-C15

Table 8 Requirements – image process

5.0 REQ ID with corresponding ITP ID

Requirements have unique REQ ID numbers and these have a corresponding inspection and test plan ID. The different tests have unique ITP ID number and several requirements can come under the same test.

5.1 Supporting Requirements

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-01	TS-UAT-SP01	A	The user shall be able to operate the UAV manually using a remote control	STG
URQ-SPR-02	TS-UAT-SP02	A	The user shall be able to pre-program the UAV to operate on its own	STG
URQ-SPR-03	TS-UAT-SP03	B	The user should be able to monitor the battery status, height, speed and position of the UAV	STG
URQ-SPR-04	TS-UAT-SP04	A	The user shall be able to pre-program the picture shooting process	STG
URQ-SPR-05	TS-UAT-SP05	C	The user should be able to print a physical model of the 3D map, using a 3D printer	STG

Table 9 Supporting Requirements

5.2 Constraining Requirements

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-01	TS-SIT-C01	A	The system shall be created using available resources	STG
URQ-CR-03	TS-SIT-C03	A	The system shall use extensively open-source software when available	STG
URQ-CR-04	TS-SIT-C04	A	The System shall be a battery driven UAV	STG
URQ-CR-05	TS-SIT-C05	A	The System shall be able to map an area of minimum 10 000 square meters	STG
URQ-CR-06	TS-SIT-C06	A	The system shall be able to operate with one single human resource	STG
URQ-CR-07	TS-SIT-C07	B	The system should not exceed a process time of 72 hours to create a digital 3D model	STG
URQ-CR-08	TS-SIT-C08	B	The UAV should be able to be transported fully assembled by the user with a Category B driver's licence	STG
URQ-CR-09	TS-SIT-C09	A	The system must be able to geo-tag images	STG
URQ-CR-10	TS-SIT-C10	A	The system shall have enough battery capacity to do 500 exposures in one flight	STG
URQ-CR-11	TS-SIT-C11	A	The system shall be able to store at least 500 images	STG
URQ-CR-12	TS-SIT-C12	A	The system shall be able to maintain the same height over various terrain	STG
URQ-CR-14	TS-SIT-C14	A	If additional acquisitions are necessary, costs must be kept within budget.	STG
URQ-CR-15	TS-SIT-C15	A	The 3D map must be accurate enough to provide usable information for entrepreneurs and construction engineers.	STG

Table 10 Constraining Requirements

5.3 Safety Requirements

REQ ID	ITP ID	PRY	Description	Origin
URQ-SFR-01	TS-SIT-SF01	A	The system shall in no operating condition be a lethal danger to human or animal life	STG
URQ-SFR-02	TS-SIT-SF02	C	The UAV should not crash in the event of battery loss	STG
URQ-SFR-03	TS-SIT-SF03	C	The UAV should not crash in the event of signal loss	STG

Table 11 Safety Requirements

6.0 Test Results – Qualification Tests

6.1 Qualification Test 1

Name: Power distribution board test

Test ID: TS-QT-01

Acceptance criteria: Power distribution board should be able to distribute power to electronics components.

Result: Failed

Date: 13/03/2015

Tested By: Giresse K Mpoyi, Assadullah Jacob and Ngezi Albert

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

Power distribution board not compatible with frame configuration. Breach in distribution circuit, tested with multimeter. New power distribution board ordered.

6.2 Qualification Test 2

Name: Power distribution board test

Test ID: TS-QT-02

Acceptance criteria: Power distribution board should be able to distribute power to electronics components.

Result: Passed

Date: 25/03/2015

Tested By: Giresse K Mpoyi, Assadullah Jacob and Ngezi Albert

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

We bought new power distribution board. Circuit was tested with multimeter and functioned as expected.

6.3 Qualification Test 3

Name: Motor test

Test ID: TS-QT-03

Acceptance criteria: Motor should be able to spin.

Result: Passed

Date: 25/03/2015

Tested By: Giresse K Mpoyi, Assadullah Jacob and Ngezi Albert

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

We connected all 6 motors and 6 ESC on the power distribution board. After applying voltage, we could see all motors spinning around.

6.4 Qualification Test 4

Name: GPS Receiver Test

Test ID: TS-QT-03

Acceptance criteria: Must be able to get satellite signal.

Result: Failed

Date: 19/03/2014

Tested By: Albert Ngenzi

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

For initial testing the GPS receiver was connected to the ArduPilot Mega 2.5 and tested on an Mission Planner ground station application software

We could see data was being transferred between the ArduPilot Mega 2.5 board and the GPS module, but this is where we encountered a problem. The GPS receiver was not able to get any satellite fixes and all the data that was being passed between the GPS receiver and the ArduPilot microcontroller was invalid GPS information.

We assumed that the GPS receiver was having problems getting a satellite signal indoors, so we moved the test outside. After testing outside, the GPS receiver still could not acquire a satellite reading.

6.5 Qualification Test 5

Name: GPS Receiver Test

Test ID: TS-QT-05

Acceptance criteria: Must be able to get satellite signal.

Result: Passed

Date: 26/03/2014

Tested By: Albert Ngenzi

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

We have purchased another GPS receiver with similar specifications and feature and the current GPS Receiver problem has been solved.

6.6 Qualification Test 6

Name: APM Test

Test ID: TS-QT-06

Acceptance criteria: Should calibrate with Mission Planner without any error reports.

Result: Failure

Date: 19/03/2014

Tested By: Albert Ngenzi

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

The APM 2.6 was connected to the computer and tested on mission planner ground station application software and the compass sensor was reporting that it is unhealthy which is a sign of a hardware failure.

6.7 Qualification Test 7

Name: APM Test

Test ID: TS-QT-07

Acceptance criteria: Should calibrate with Mission Planner without any error reports.

Result: Passed

Date: 26/04/2014

Tested By: Albert Ngenzi

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

We have purchased another APM 2.5 and the problem with the compass has been solved.

7.0 Test Results – Factory Acceptance Tests

7.1 Factory Acceptance Test 1

Name: ESC Test

Test ID: TS-FAT-01

Acceptance criteria: ESC must control the speed of Motor.

Result: Passed

Date: 25/03/2015

Tested By: Giresse K Mpoyi, Assadullah Jacob and Ngezi Albert

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

We tested our ESC by connected them to our motors on the power distribution board. The ESC controlled the speed and the direction of the motors after we played voltage.

7.2 Factory Acceptance Test 2

Name: RC Transmitter communication test

Test ID: TS-FAT-02

Acceptance criteria: RC Transmitter must communicate with Software to control the UAV.

Result: Passed

Date: 30/03/2015

Tested By: Giresse K Mpoyi, Assadullah Jacob and Ngezi Albert

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

We calibrated via Mission Planner and tested communication with UAV.

7.3 Factory Acceptance Test 3

Name: Calibrating and stationary system test.

Test ID: TS-FAT-03

Acceptance criteria: Signals from both RC Transmitter and GPS and correct direction rotation of each motor.

Result: All passed

Date: 28/04/2015

Tested By: All members of the group

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

By using open source software known as Mission Planner, we were able to calibrate our UAV in steps as shown below:

- Accelerometer calibration
- Compass calibration
- Battery monitor
- Radio control calibration

- ESCs calibration

After that we tested motor rotation. All motors span at the same rate. The problem which motor had was the direction of the rotation. Three motors had to rotate clockwise and other three had to rotate counterclockwise but only two motors were rotating counterclockwise and the rest were rotating clockwise.

We corrected this problem by switching two of the cobles connecting the motor to the ESC.

8.0 Test Results – System Integration Tests

8.1 System Integration Test 1

Name: Resource verification

Test ID: TS-SIT-C01

Acceptance criteria: The system shall be created using available resources

Result: Passed

Date: 15/05/2015

Tested By: All members of the group

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

The system was put together using the available parts from Cube AS inventory. Some parts were not available or not appropriate and needed to be acquired.

8.2 System Integration Test 2

Name: Open Source inspection

Test ID: TS-SIT-C03

Acceptance criteria: If possible, open source should be used.

Result: Passed

Date: 14/05/2015

Tested By: All members of the group

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

The control system is based around Mission Planner, which is an open-source software.

8.3 System Integration Test 3

Name: Open Source inspection

Test ID: TS-SIT-C04

Acceptance criteria: UAV must be battery driven

Result: Passed

Date: 30/01/2015

Tested By: All members of the group

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

The UAV is powered by a LIPO battery.

8.4 System Integration Test 4

Name: Processing time

Test ID: TS-SIT-C07

Acceptance criteria: Process time below 72 hours

Result: Passed

Date: 10/05/2015

Tested By: Bjørnar Dalset, Laly Mann

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

206 photos, covering an area of 70 000 square meters, were processed in six hours. Well below the specified limit. Refer to document 009D – Technical Report Image Processing.

8.5 System Integration Test 5

Name: Transportation Test

Test ID: TS-SIT-C08

Acceptance criteria: Transportation using a Category B drivers license

Result: Passed

Date: 29/04/2015

Tested By: Ole Petter Christensen

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

The UAV was transported using Category B vehicle.

8.6 System Integration Test 6

Name: Geotagging of images

Test ID: TS-SIT-C09

Acceptance criteria: System must be able to geotag images

Result: Passed

Date: 20/04/2015

Tested By: Laly Mann

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

The camera used in this system is compatible with the control software and images can be tagged via Mission Planner.

8.7 System Integration Test 7

Name: Battery capacity for Camera

Test ID: TS-SIT-C10

Acceptance criteria: System must be able to do 500 exposures without charging.

Result: Passed

Date: 20/04/2015

Tested By: Laly Mann

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

Camera was tested and was able to take at least 500 images without charging the battery.

8.8 System Integration Test 8

Name: Storage capacity for Camera

Test ID: TS-SIT-C11

Acceptance criteria: System must be able to store 500 images.

Result: Passed

Date: 20/04/2015

Tested By: Laly Mann

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

Camera was tested and was able to store at least 500 images.

8.9 System Integration Test 9

Name: Budget

Test ID: TS-SIT-C14

Acceptance criteria: Costs must be kept within budget

Result: Passed

Date: 15/05/2015

Tested By: Therese T. Poverud

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

All acquisitions have been discussed and approved by Stig Førrisdal (Cube AS).

8.10 System Integration Test 10

Name: Camera settings

Test ID: TS-SIT-C16

Acceptance criteria: Must be able to adjust basic camera settings

Result: Passed

Date: 20/04/2015

Tested By: Laly Mann

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

Camera settings are tested.

8.11 System Integration Test 11

Name: Mechanical Failure

Test ID: TS-SIT-SF04

Acceptance criteria: The UAV should not crash due to mechanical failure

Result: Passed

Date: 20/04/2015

Tested By: OPC

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

SolidWorks simulation linear static study. All components beneath yield strength of material. Refer to document 009A – Mechanical Properties of UAV.

9.0 Test Results – User Acceptance Tests

9.1 User Acceptance Test 1

Name: Automatic picture shooting

Test ID: TS-UAT-S04

Acceptance criteria: User must be able to pre-program the picture shooting process

Result: Passed

Date: 20/04/2015

Tested By: Laly Mann

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

Tested using Mission Planner to plan a route with commands for the camera at every waypoint.

9.2 User Acceptance Test 2

Name: Monitoring of UAV status

Test ID: TS-UAT-S03

Acceptance criteria: User should be able to monitor the battery, speed, height and positioning.

Result: Passed

Date: 03/05/2015

Tested By: Albert Ngenzi

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

UAV status was monitored through Mission Planner.

9.3 System Integration Test 3

Name: Remote control of UAV

Test ID: TS-UAT-S01

Acceptance criteria: The UAV should be able to fly and steer with the use of a remote control

Result: Failed/Crashed

Date: 29/04/2015

Tested By: All members of the group

Place: Lier Stadion

Description

First flight test failed. After doing all necessary setup calibration, there was bad communication between the UAV and RC transmitter. The UAV failed to respond correctly according to the instructions from the RC transmitter.

9.4 System Integration Test 4

Name: Remote control of UAV

Test ID: TS-UAT-S01

Acceptance criteria: The UAV should be able to fly and steer with the use of a remote control

Result: Failed/Crashed

Date: 03/05/2015

Tested By: All members of the group

Place: Svelvik Stadion

Description

Before flight testing calibration is needed. Calibration process is the same as the ones mentioned in the earlier tests.

This time around, the UAV was able to fly. However, it had no any balance as it was in air. It was shaking and in less than 2 min it crashed. There was no severe damaged made to the UAV. The parts which were damaged are two propellers and one CF tube.

We thought Battery was the course of the crash. However, after going through Mission planner flight log, there was nothing wrong with battery. But we have decided to investigate more on the battery and see if we will see anything wrong with it because we cannot see any other problem with our UAV.

9.5 System Integration Test 3

Name: Remote control of UAV

Test ID: TS-UAT-S01

Acceptance criteria: The UAV should be able to fly and steer with the use of a remote control

Result: Failed/Crashed

Date: 06/05/2015

Tested By: All members of the group

Place: Cube AS Dølasletta 7, 3408 Tranby

Description

After repaired the UAV from the crashed it had the previous testing, we decided to test again. Due the time we have. We decide this to be the last testing of our UAV. If it crashed then, we are done with it and we will find other option to get a new UAV. Unfortunately, the flight test failed. The UAV crashed once again.

10 Untested requirements

We were unable to test some of our requirements as planned. This was due to the crash of our UAV during flight testing time. Some of the requirements which were not testing due to the crash of the UAV are shown on the Table below

REQ ID	ITP ID	PRY	Description	Origin
URQ-SFR-01	TS-SIT-SF01	A	The system shall in no operating condition be a lethal danger to human or animal life	STG
URQ-SFR-02	TS-SIT-SF02	C	The UAV should not crash in the event of battery loss	STG
URQ-SFR-03	TS-SIT-SFO3	C	The UAV should not crash in the event of signal loss	STG
URQ-SPR-01	TS-UAT-S01	A	The user shall be able to operate the UAV manually using a remote control	STG
URQ-SPR-02	TS-UAT-S02	A	The user shall be able to pre-program the UAV to operate on its own	STIG
URQ-SPR-03	TS-UAT-S03	B	The user should be able to monitor the battery status, height, speed and position of the UAV	STG
URQ-CR-05	TS-SIT-C05	A	The System shall be able to map an area of minimum 10 000 square meters	STG
URQ-CR-06	TS-SIT-C06	A	The system shall be able to operate with one single human resource	STG
URQ-CR-12	TS-SIT-C12	A	The system shall be able to maintain the same height over various terrain	STG
URQ-CR-15	TS-SIT-C15	A	The 3D map must be accurate enough to provide usable information for entrepreneurs and construction engineers.	STG

Table 12 Requirements – untested

10.0Appendix A

Page 1 of 2	Inspection and Test Plan (ITP)								
Owner Name:	Stig Førrisdal		Test Level: UAT		H	Hold Point			
Project Title	3D Ground Mapping				W	Witness			
No	REQ ID	ITP ID	Control Documents	Acceptance Criteria	Date	**Inspection**		**Acceptance**	
						Project Team	Owner	Project Team	Owner
1	URQ-SPR-04	TS-UAT-S04	Doc No: 004	Doc No: 003	20.04.2015	W/H		Passed	Passed
2	URQ-SPR-03	TS-UAT-S03	Doc No: 004	Doc No: 003	03.05.2015	W/H	W/H	Passed	Passed
3	URQ-SPR-01	TS-UAT-S01	Doc No: 004	Doc No: 003	06.06.2015	W/H	W/H	Failed	Failed
4	URQ-SPR-02	TS-UAT-S02	Doc No: 004	Doc No: 003	-	-	-	Not tested	Not tested
5	URQ-SPR-05	TS-UAT-S05	Doc No: 004	Doc No: 003	-	-	-	Not tested	Not tested

Page 2 of 2	Inspection and Test Plan (ITP)									
Owner Name:		Stig Førrisdal		Test Level: SIT		H	Hold Point			
Project Title		3D Ground Mapping				W	Witness			
No	REQ ID	ITP ID	Control Documents	Acceptance Criteria	Date	Inspection		Acceptance		
						Project Team	Owner	Project Team	Owner	
1	URQ-CR-01	TS-SIT-C01	Doc No: 002	Doc No: 003	15.05.2015	W	W	Passed	Passed	
2	URQ-CR-03	TS-SIT-C03	Doc No: 009D	Doc No: 003	14.05.2015	W		Passed	Passed	
3	URQ-CR-04	TS-SIT-C04	Doc No: 004	Doc No: 003	30.01.2015	W	W	Passed		
4	URQ-CR-05	TS-SIT-C04	Doc No: 004	Doc No: 003	-	W	W	Not Tested	Not Tested	
5	URQ-CR-06	TS-SIT-C06	Doc No: 004	Doc No: 003	-	W	W	Not Tested	Not Tested	
6	URQ-CR-07	TS-SIT-C07	Doc No: 009D	Doc No: 003	10.05.2015	W	W	Passed	Passed	
7	URQ-CR-08	TS-SIT-C08	Doc No: 004	Doc No: 003	29.04.2015	W	W	Passed	Passed	
8	URQ-CR-09	TS-SIT-C09	Doc No: 012	Doc No: 003	20.04.2015	W		Passed		
9	URQ-CR-10	TS-SIT-C10	Doc No: 009C	Doc No: 003	20.04.2015	W		Passed		
10	URQ-CR-11	TS-SIT-C11	Doc No: 009C	Doc No: 003	20.04.2015	W		Passed		
11	URQ-CR-12	TS-SIT-C12	Doc No: 011	Doc No: 003	06.06.2015	W	W	Not Tested	Not Tested	
12	URQ-CR-14	TS-SIT-C14	Doc No: 002	Doc No: 003	15.05.2015	W	W	Passed	Passed	
13	URQ-CR-15	TS-SIT-C15	Doc No: 009D	Doc No: 003	-	W	W	Not Tested	Not Tested	
14	URQ-CR-16	TS-SIT-C16	Doc No: 009C	Doc No: 003	20.04.2015	W		Passed		
1	URQ-SFR-04	TS-SIT-SF04	Doc No: 009A	Doc No: 003	20.04.2015	W/H		Passed	Passed	
2	URQ-SFR-01	TS-SIT-SF01	Doc No: 004	Doc No: 003	-	W	W	Not Tested	Not Tested	
3	URQ-SFR-02	TS-SIT-SF02	Doc No: 004	Doc No: 003	-	W	W	Not Tested	Not Tested	
4	URQ-SFR-03	TS-SIT-SF03	Doc No: 004	Doc No: 003	-	W	W	Not Tested	Not Tested	

Risk Management Plan

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
2.0	14.05.2015	OPC	TTP	Released

Summary:

This document is intended to identify, analyse, and manage risks throughout the project.

Owner: Albert Ngenzi

Document Revision History

Rev	Date	Author	Description	Status
0.1	09.02.15	NGA	Risk analysis Initiation phase	Obsolete
0.2	11.03.15	TTP	Document layout, update on project risk, technical risk	Obsolete
0.3	13.03.15	TTP	Updated headings and add technical risks	Obsolete
1.0	15.03.15	TTP	Reviewed version	Obsolete
1.1	17.03.15	TTP	Update project execution risk and added technical risks	Obsolete
2.0	14.05.2015	OPC	Final Version V2.0	Released

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List of Tables

1.0 Introduction

1.1 Purpose of this document

A risk is an event or condition that, if it occurs, can have either positive or negative effect on our project. Risk Management is the process of identifying, assessing, monitoring and reporting risks.

This document defines how risks associated with the project will be identified, analysed, and managed. This plan is for recording and prioritizing risks. This helps us review the technical feasibility of the project and stabilize the architecture of the system.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
UAV	Unmanned aerial vehicle
3D	Three dimensional
GPS	Global Positioning System
RC	Radio control

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents referenced in this document

Doc. number	Description
002	Project Plan
003	Requirement Specification
010	System Architecture
011	Action Plan

Table 2 Related documents

2.0 Risk Management

2.1 Risk Monitoring and Controlling

The level of risk will be tracked and monitored throughout the project lifecycle. All project changes will be analysed for their possible impact to the project risks. A list of high-level risks will be maintained by the project team.

Top 5 Risk List

1. UAV pilot availability
2. Satisfying requirements
3. Acquisition
4. Team failure
5. Battery status

2.2 Risk Analysis

The purpose of this risk analysis is first to identify relevant risks in regards to the 3D Ground Mapping system. Risks will be identified as early as possible in the project to minimize their impact.

Further it was made to present possible strategies to achieve the main project goals even if some of these risks turn into incidents. This section will describe our main challenges for possible future risks and how we could either eliminate or minimalize them.

The risk occurrence and the consequence range from low to high:

- Low: Relatively little impact on schedule, performance or cost. These are not likely to occur.
- Medium: Potential to slightly impact project schedule, performance or cost. These risks might occur at a given time.
- High: Potential to greatly impact project schedule, performance or cost. These risks are likely to happen during the project lifecycle.

The options available for the management of risks are divided into four categories:

- Avoid: Eliminate the threat by eliminating the cause.
- Mitigate: Identify ways to reduce the impact of the risk or the likelihood of its occurrence.
- Accept: Nothing will be done.
- Transfer: Make another party responsible for the risk.

3.0 Project Execution Risk Analysis

The project execution risk analysis analyse general risks that might occur during the execution the 3D Ground Mapping project and finds a way to management these.

UAV pilot availability

No one in the team has the experience needed to fly an UAV. We are depending on Tommy Larsen from Cube AS fly the UAV. However, he might not be available when needed and this might result in delays.

Risk occurrence	Low	Medium	**High**
Risk consequence	Low	Medium	**High**
Risk management	**Accept:** Since no one on our team has any experience in flying UAVs we have to accept that we have to wait.		

Table 3 UAV pilot availability

Satisfying requirements

The high-level requirement specifications must be met in the finalized system.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** To make sure that the high-level requirement specifications are all met, the team must aim to deliver a system of higher quality or capacity than the high-level requirements. If all the high-level requirements can't be met, create an action plan. Keep the project manager and external supervisor informed of progress at all times.		

Table 4 Satisfying requirements

Acquisition

Necessary hardware parts that are ordered from another country may take long to ship or be defect upon delivery.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** Place purchase order in due time. Order from shops with good reputation. Upgrade to fast shipping.		

Table 5 Acquisition

Human failure

Sickness, injury, accident or other unforeseen issues may affect the project.

Risk occurrence	Low	Medium	**High**
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Eating healthy and getting enough sleep, as well some exercise, is recommended to avoid illness. Working as a team amongst the group so that if a team member is unable to deliver a part of the project because of illness, then another member of the team can step in. Work footprint free and with cloud saving so all information is accessible for everyone at all times.		

Table 6 Human failure

Defect components

Components from Cube AS's stockroom might be defect or not of good enough quality.

Risk occurrence	Low	Medium	**High**
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Make list over all components to fast ensure if they are good enough. Check for defects by running a Status test on the components. Order new at once if defect.		

Table 7 Defect components

Team failure

The project progress can be hindered if team members fail to play their active roles as agreed. This can be either due to lack of motivation, communication and other limitations or problems.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** Create positive team spirit by ensuring good communication. Show as much interest on the welfare of the team members as you show for the project. Helping and encouraging each other in areas that may be difficult.		

Table 8 Team failure

Technical issues

Hardware failure, software crash and human error are most common causes of data loss and loss of work already done.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Avoid:** Work from a cloud server (ex. Dropbox). **Mitigation:** Save the data from for the project and keep a backup on a hard drive. In case of failure of the hardware either in whole or in part, then the order for replacement parts must be made as soon as the necessary information is in. Keep the project manager and external supervisor informed of progress at all times.		

Table 9 Technical issues

Supervisor availability

The unavailability of our internal and/or external supervisors may result in hindering the project's progress if there is inadequate follow-up.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Use the supervisors as much as possible and at the same time the team must be responsible for the project and avoid depending upon supervisors in regards to the project progress. Have a contingency plan in place for who can be contacted in case a supervisor becomes unavailable.		

Table 10 Supervisor availability

4.0 Technical System Risk Analysis

Technical risks that might occur during creation and testing of the 3D Ground Mapping system.

4.1 UAV System

Battery status

Failure to monitor battery status may result in situations such as crash of the UAV if the battery status is too low and the battery becomes empty during flight.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** Make sure that it is easy to use the monitoring system and that it has no defects. Make sure to have enough battery to complete the whole mission. Have another warning system for low batteries, like sound.		

Table 11 Battery status

Transmit GPS location

Failure to transmit GPS location to flight software might results in loss of communication between UAV and ground station.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Use a GPS with good quality. If the GPS signal is lost, the failsafe system will land the UAV.		

Table 12 Transmit GPS location

Waypoints and flight route

Control of the UAV might be lost if the UAV fail to follow the waypoints or desired flight route. The mission might not have been completed. Loss of signals between the UAV and ground station may occur.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** It’s advisable to use GPS of good quality. The user must be able to take manual control over the UAV or the UAV should land.		

Table 13 Waypoints and flight route

4.2 UAV manual operator

RC transmitter

RC transmitter might fail to show the UAV's status. By having telemetry, the RC transmitter is able to show status of UAV such as, the location and monitory the battery. Failing to show the status might result in the UAV crashing, for example if the battery fails.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** If the user loses manual control over the UAV, then the automated operation takes over the control. If the UAV still has GPS signal, then it should return to the start point or else it should land.		

Table 14 RC transmitter

Power

To start the mapping process the power needs to be turned on. Failing to turn on the power of the UAV could be due to many reasons such as battery problems, that the subsystems of the UAV are not connected properly or error in communication between UAV and RC controller.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** If the user loses manual control over the UAV, then the automated operation takes over the control. If the UAV still has GPS signal, then it should return to the start point or else it should land.		

Table 15 Power

Remote control

Losing the ability to steer the direction and speed using the remote control can result in the UAV crashing.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** It's advisable to use a good quality GPS. If the user loses manual control, then the automated operation takes over the control of the UAV. If the UAV still have GPS signal, then it should return to start point or else it should land.		

Table 16 Remote control

4.3 Camera System

Internal GPS accuracy

If the internal camera GPS is inaccurate, it will lead to an inaccurate 3D model.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	**Medium**	High
Risk management	**Avoid:** Use a high quality standalone GPS, instead of the internal camera GPS. **Mitigation:** Use the pre-programmed waypoints as a reference for the internal camera GPS. Make adjustments if there are large variations.		

Table 17 Internal GPS accuracy

Motion Blur

Images might have an excessive amount of motion blur due to flight speed or small vibrations, rendering them useless in a 3D modelling process.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigation:** Increase the shutter speed to reduce most of the motion blur. Reduce the flight speed. Take new photos.		

Table 18 Motion Blur

Memory Card

A slow memory card might delay the camera triggering if the internal camera memory cannot be transmitted to the external memory card fast enough.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	**Medium**	High
Risk management	**Mitigate:** Make sure to use a fast memory card with enough storage.		

Table 19 Memory Card

Image Resolution

Poor image resolution results in poor accuracy for 3D Model.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Avoid:** Make sure the camera specification is more than adequate to achieve proper resolution for use in 3D modelling. **Mitigation:** Fly with a lower height over the terrain to improve the resolution.		

Table 20 Image Resolution

4.4 Image Processing

Image Quality

Images might for some reason not be of sufficient quality and therefore cannot be used for a 3D modelling process.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	**Medium**	High
Risk management	**Accept:** Nothing will be done. Images cannot be part of a 3D model. If a series of images are not of high enough quality, new pictures can be taken.		

Table 21 Image Quality

Processing Time

Large image sizes, poor computational power leads to very long software processing times.

Risk occurrence	**Low**	Medium	High
Risk consequence	**Low**	Medium	High
Risk management	**Mitigation:** Reduce the rendering quality to speed up the rendering process and reduce the overall processing time.		

Table 22 Processing Time

Rendering Quality

The rendered 3D model is not of high enough resolution.

Risk occurrence	**Low**	Medium	High
Risk consequence	**Low**	Medium	High
Risk management	**Avoid:** Use the best possible settings for render quality. May lead to longer process time.		

Table 23 Rendering Quality

4.5 Action Plan

General risks that might occur during the execution of our action plans.

Crash of borrowed UAV

UAV borrowed from Cube AS might crash.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Transfer:** Only Tommy Larsen from Cube AS can fly this UAV, the team can't do anything here. **Migration:** Use action plan 2.		

Table 24 Crash of borrowed UAV

Borrowed UAV might not work

The UAV borrowed from Cube AS might have problems that prevent it from working. This will leave the team without an UAV to take the necessary images.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Transfer:** Cube AS is responsible for this UAV. **Migration:** Use action plan 2.		

Table 25 Borrowed UAV might not work

Approval to buy image set

Buy an image set from Isachsen Gruppen AS for testing might not be approved by Cube AS.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** The team can pay for the image set or use action plan 1.		

Table 26 Approval to buy image set

Conceptual Study

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	28.02.2015	OPC	TTP	Released

Summary:

This document is intended to be a preliminary study in different concepts and design approaches for the 3D Ground Mapping system.

Owner: Bjørnar Dalset

Document Revision History

Rev	Date	Author	Description	Status
0.1	28.02.2015	BJD	Initial draft	Obsolete
1.0	15.03.2015	OPC	Final Version V1.0	Released

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Table of Figures

1.0 Introduction

1.1 Purpose of this document

This document is intended to be a preliminary study of various concepts for the 3D Ground Mapping system. The main focus will be to identify different design ideas and system elements that will need to be researched and analysed.

This document will serve as a guide in the development of the architecture and the final system design and is largely based on the requirements from the requirements specification document.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
DSLR	Digital Single Lens Reflex
GPS	Global positioning system
UAV	Unmanned aerial vehicle

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents referenced in this document:

Doc. number	Description
006	Concept Evaluation
007	System Architecture
003	Requirement Specification

Table 2 Related documents

2.0 Conceptual Study

2.1 System overview

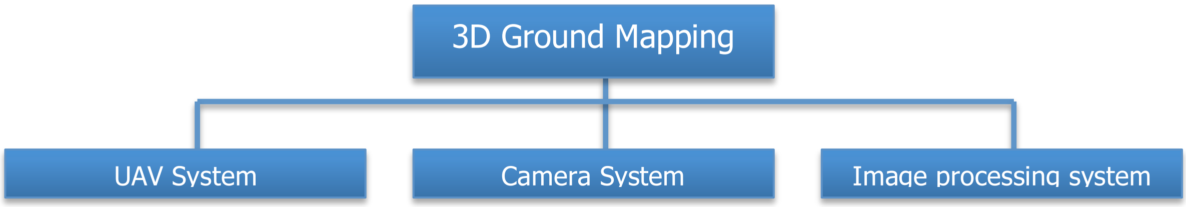

Figure 1 System overview

The 3D Ground Mapping system will comprise of several different subsystems. For simplification purposes, we have split the system into three main sections:

- UAV system
- Camera system
- Image processing system

These sections will be dealt with separately in this document and will contain specific design considerations that will need further investigation.

A big part of the project work will be evaluating if available parts and readymade hardware/software fulfils the requirements specification and whether there are other alternatives that would offer a better solution. If any available resources do not meet the specification needs, then additional parts acquisition will be discussed with CUBE AS.

2.2 UAV System

The UAV will be built from the ground up, but using available parts from the CUBE AS inventory whenever possible. The project team must do research on basic concepts and UAV structures, but also specific components related to this project and the requirement specification.

2.2.1 Fuel-based system vs. Battery driven UAV

The requirements specify a battery driven UAV. However, for comparison purposes the project team could look into major advantages and disadvantages of fuel-based systems. As this is outside of the constraining requirements; no thorough study will be performed.

2.2.2 Fixed wing vs. Multicopter

The project team will investigate major advantages and disadvantages of using a fixed wing UAV vs. a multicopter UAV. Performance areas to look into include:

- Aerial coverage
- Flexibility; maneuverability in hard to access areas.
- Image acquisition
- Cost

2.2.3 Motor configuration

The project team will look into several motor configurations to determine the optimal configuration for this project. Things to consider include:

- Power consumption
- Stability
- Payload capacity
- Cost

2.2.4 Frame configuration

The mechanical parts of the UAV will be evaluated to determine if the inventory parts are satisfying the requirements. Things to consider include:

- Aerodynamics
- Weight
- Strength

2.2.5 Sensor evaluation

The project team must evaluate which sensors the UAV must be equipped with in order to meet the requirements specification. Which sensors are absolutely necessary? Which sensors would benefit the system? Things to consider include:

- Locational sensors
- Monitoring sensors
- Cost

2.3 Camera System

The UAV will be equipped with a camera to take aerial pictures. The project team must do research to determine the important qualities needed to successfully reach the requirement specification.

Although a laser system is outside of the scope of this project, a comparison with such a system – often used for land surveying – could provide valuable information regarding the accuracy of a camera equipped system.

2.3.1 Compact camera vs. DSLR camera

The project team must decide if a compact camera could provide sufficient quality or if the extra cost and weight of a DSLR camera is worth it, with regards to the requirement specification. Things to consider:

- Image quality
- Weight
- Storing capacity
- Remote control functionality
- Cost

2.4 Image Processing System

The project team must investigate different 3D modelling software systems and determine the most suited solution for this project. According to the requirements specification, open source software is the preferred choice, however if the open source alternatives are not meeting the requirements, then proprietary solutions might be recommended.

2.4.1 Open source software vs. Proprietary software

The project team must compare open source alternatives to the proprietary alternatives. Things to consider:

- Processing time
- Functionality
- Render quality
- Intuitiveness
- Cost

Conceptual Evaluation

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
2.0	01.03.15	OPC	TTP	Released

Summary:

This document is intended to analyse and evaluate the concepts and ideas presented in the conceptual studies.

Owner: Bjørnar Dalset

Document Revision History

Rev	Date	Author	Description	Status
1.0	01.03.15	BJD	Final Version V1.0	Obsolete
1.1	01.05.15	BJD	Added ITP ID	Obsolete
2.0	15.05.15	OPC	Final Version V2.0	Released

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Table of Figures

1.0 Introduction

1.1 Purpose of document

This document presents the concept- and configuration selections of the UAV, presented in the conceptual study. The purpose is to analyse and evaluate these with respect to the requirement specification. The result of this document will present the recommended selection of concepts and configurations that will ultimately lead to the baseline architecture of the system.

1.2 Abbreviations

List of abbreviations and corresponding descriptions used in this document

Abbreviation	Description
BAG16	Project team name
CE	Concept Evaluation
CR	Constraining Requirements
PRY	Priority
QFD	Quality Function Deployment
REQ	Requirement
SFR	Safety Requirements
SPR	Supporting Requirements
UAV	Unmanned aerial vehicle
URQ	User Requirement

Table 1 Abbreviations

1.3 References

This section provides a list of other documents referenced in this document:

Doc. number	Description
003	Requirements specification
006	Conceptual Study

Table 2 References

2.0 UAV - Supplement of Concept Evaluation

2.1 Quality Function Deployment

The foundation of the evaluation and selection of different concepts and configuration is developed by interpreting both the vision document and the requirements specification. The constraining requirements from the requirements specification serve as the boundary for the evaluation, but the selection is ultimately governed by this requirement from Cube A/S:

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-01	TS-SIT-C01	A	The system shall be created using available resources	STG

Table 3 Extract of Requirements 1

Both the architecture and the design is limited by this constraint, hence the challenge of selecting concepts and configurations is to establish whether the available resources is sufficient enough to meet the overall requirements specification.

2.2 QFD matrix

The table shown below illustrates the transition between the customers' needs for the total system and the needs to consider in the QDF matrix. The output of this table is used to produce the input of the derived customer needs for the evaluation.

REQ ID	Customer needs (input)	Needs to consider in QFD (output)
URQ-CR-05	The System shall be able to map an area of minimum 10 000 square meters.	Arial coverage
URQ-CR-13	The camera shall be stable to take sharp pictures.	Quality of images
URQ-CR-08	The UAV should be able to be transported fully assembled by the user with a Category B driver's licence.	Portability
URQ-CR-14	If additional acquisitions are necessary, costs must be kept within budget.	Cheap

Table 4 Customer needs and QFD

When the "what's" of the QDF matrix is defined (demanded qualities), the focus shifts to the "how's" of the matrix (quality characteristics). These are the engineering characteristics that affect the demanded qualities. In this QDF matrix we will evaluate the following engineering characteristics:

Flight Time - Affects aerial coverage and cheap

Size – Affects aerial coverage and portability

Payload – Affects aerial coverage, quality of images and cheap

Manoeuvrability – Affects the safety aerial coverage and quality of images

Stability – Affects aerial coverage, quality of images and cheap

Cost of Production – Affects aerial coverage, quality of images, portability and cheap

The top of the quality matrix, hence the pyramid, displays the correlation between the quality characteristics and is founded on the direction of improvement. The direction of improvement is either to minimize, maximize or hit targets. The overall purpose of this section is to clarify the trade-offs between the engineering characteristics.

The strength of the relationships between the demanded quality and quality characteristics are the displayed in the legend table of matrix. The strength is given a numerical value ranging from 1 to 9 and is used along with the weight/importance of the demanded qualities to calculate the weight/importance of the quality characteristics.

House of Quality Matrix – Explanatory Table	
Weight/Importance (row)	Requirement Priority, A=5, B=3, C=1
Relative Weight (row) [%]	Sum of Weight/Importance divided by Requirement Priority
Weight/Importance (Column)	Relationship weight x Weight/Importance (row)
Relative Weight (Column) [%]	Sum of Weight/Importance (Column)/ Weight/Importance (Column)

Table 5 QFD Explanatory Table

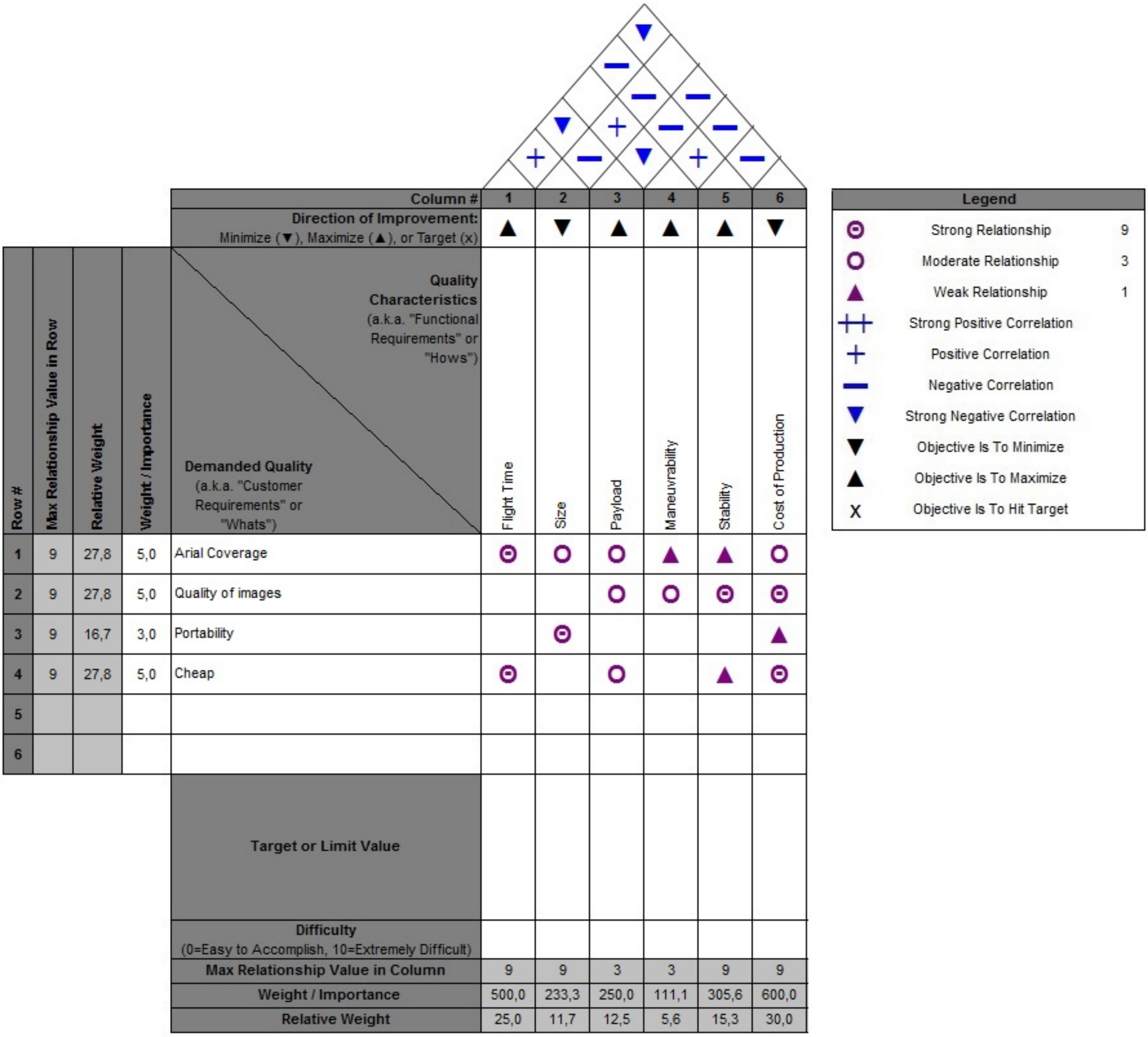


Figure 1 QFD - UAV

2.3 Output of QFD

The QDF matrix displays the calculated values in which of the quality characteristics that represent either the most weight or the highest importance in correlation with the demanded qualities. This weighting gives us the foundation for the decision-making matrices, hence the Pugh-Matrices, that will give us a similar weighting on which concept or configuration that is most suited in context with the requirements. However, it is important to express that the decision-making matrices do not govern the selections, but gives an objective view on which we will take in to account when presenting our recommendation.

2.3.1 Weight and Importance

The matrix gives the following results with importance from highest to lowest:

1. 600.0 – Cost of Production. Direction of improvement: **minimize**
2. 500.0 – Flight Time. Direction of improvement: **maximize**
3. 305.6 – Stability. Direction of improvement: **maximize**
4. 250.0 – Payload. Direction of improvement: **maximize**
5. 233.3 – Size. Direction of improvement: **minimize**
6. 111.1 – Manoeuvrability. Direction of improvement: **maximize**

2.3.2 Correlations

The trade-offs are decided upon the weighting of the characteristics. The characteristic with the lowest importance represents the trade-off selection. For instance, in the correlation between flight time and payload the payload represents the trade-off. It is more important with increased flight time than increased payload. If the correlation is positive, there will be no need for a trade-off.

The table below captures the trade-off of the characteristics in the UAV:

Correlation	Positive/Negative	Trade-off
Flight time and size	Positive	*None*
Flight time and payload	Strong Negative	**Payload**
Flight time and stability	Negative	**Stability**
Flight time and Cost of Production	Strong Negative	**Flight time**
Size and Payload	Negative	**Size**
Size and Manoeuvrability	Positive	*None*
Size and stability	Negative	**Size**
Payload and manoeuvrability	Strong Negative	**Manoeuvrability**
Payload and stability	Negative	**Payload**
Payload and Cost of Production	Negative	**Payload**
Manoeuvrability and stability	Positive	*None*
Manoeuvrability and Cost of Production	Negative	**Manoeuvrability**
Stability and Cost of Production	Negative	**Stability**

Table 6 Correlations

2.3.3 Conclusion

The QDF gives us the foundation for evaluating the most important characteristics for the concept selections in context with the needs of the customer. It will also serve as a guide for the architecture and design as it focuses on the high level requirements for the system. However, it is still the customer that governs the concept selection, but the recommendations are founded on the result from the QFD and the requirements specification.

The conclusion to the correlation section is that the negative correlation could result in trade-offs. The QDF matrix simplifies this selection by the weight/importance. The quality characteristic with the highest weight/importance value will govern the trade-off.

3.0 UAV - Concept Analysis and Evaluation

3.1 Fixed Wing and Multirotor

There are two units of unmanned aerial vehicle that can be used for mapping. These two units are fixed wing and multi-rotor.

Figure 2 Fixed wing and Multirotor

3.1.1 Fixed Wing

Fixed Wing is a conventional aircraft design. It has a vertical tail with horizontal stabilizers. Fixed-Wing UAV gives the opportunity to cover large areas with respect to its energy efficiency due to lift provided by buoyancy.

Pros	Cons
• The lift is provided by buoyancy, so it requires less energy to cover a greater area • Stability. It tends to be more forgiving in the air in the face of both piloting and technical errors. • Less complexity of solution, leads to lower cost of production. • In case of motor shutdown it can glide to land in emergency.	• Restricted minimum speed • Manoeuvrability is speed dependent • Cannot hover • Take-off/landing restrictions. • Size. The amount of payload is dependent of the buoyancy, which again is directly related to wing span and area.

Table 7 Pros/Cons Fixed Wing

3.1.2 Multirotor

A multi-rotor or multi-copter is a unique kind of aircraft that is equipped with two or more motors. A multi-rotor craft achieves its lifting power only by thrust provided from the propeller, requiring more energy to keep it airborne. Multi-copters often use fixed-pitch propellers, so the control of vehicle motion is achieved by varying the relative speed of each motor. Due to its hover and controlling capabilities, the multi-rotor craft is able to operate in most terrains with small clearances.

Pros	Cons
• By a plurality of sensors, it is possible to let the multi-rotor start automatically. • It has better payload capacity than a fixed wing of similar size • Manoeuvrability. It is able to fly in every direction, horizontally and vertically, as well as hover in a fixed position.	• Requires more energy to achieve longer duration of flight due to 100% mechanical lift. • Complexity of solutions derives higher cost of production.

Table 6 Pros/Cons Multirotor

3.1.3 Pugh concept selection

After conceptualizing the two above design possibilities for the UAV in our project, the whole group needed to select the most appropriate concept to be used. To aid in this selection, we utilized a tool called Pugh's method of concept selection. The goal of this process involves comparing the designs generated based on the requirements from the House of Quality developed for system requirement analysis.

			Column #	1	2	3	4
Row #	Relative Weight	Weight / Importance	Concepts / Quality Characteristics	Mulit-rotor	Fixed-Wing		
1	33,3	500	Flight time	3	5		
2	15,6	233,3	Size	4	3		
3	23,3	350	Payload	5	2		
4	7,41	111,1	Manoeuvrability	5	2		
5	20,4	305,6	Stability	5	3		
6	40	600	Cost of Production	2	4		
7	0						
8	0						
9	0						
10	0						
			Weight / Importance	7467	7439	0	0
			Relative Weight	50,1	49,9	0	0

Figure 3 Pugh Matrix Aircraft

- Scaling from 1 to 5, where 5 is the best and 1 is the worst.

From the matrix the fixed-wing scores higher in term off flight time and cost of production, which initially is considered the most important characteristics. Therefore, if we had only considered these criteria's, fixed-wing would be the best concept selection for our system.

In terms of size and payload, multi-rotor scores better than fixed wing. This is due to the fact that the multi-rotor achieves its lift by the thrust from the propellers, making it easier to design a more compact solution by varying the propeller and motor characteristics to achieve greater payload capabilities. The fixed-wing is dependent on the buoyancy from the wings, directly related to the wing span and area that will inflict a larger size of the aircraft to achieve greater payload capabilities.

When considering the stability and the manoeuvrability, the multi-rotor scores better than the fixed-wing. This is related to the operating speeds and the operating environment. The multi-rotor is not dependent on the forward motion to achieve lift, giving it greater flexibility in terms of manoeuvrability. The stability of the UAV is also related to the speed, and the multi-rotor will not be affected by it.

Fixed wing has higher score in the cost of production. We have assumed that it will cost more to design a multi-rotor than a fixed wing. This is because of the system complexity. The more components you need the more money you will have to spend unless you find very cheap ones. Cheap ones might not be the best one, which can result in higher maintenance costs.

In conclusion, the total score on Pugh Matrix shows that the multi-rotor design is the slightly better option in for our system. This is also the approved selection from our costumer and therefore, we will go for a multi-rotor design.

3.2 Motor Configuration

Based on our user requirements, the three type of multi-copter are considered to be analysed in this section in order to choose the right type for our project. These three types are quadcopter, hexacopter and octocopter. They are generally classified and named after how many motors they are equipped with. The number of motors and configuration of each type of these multi-copers bring some up and down sides of their performance

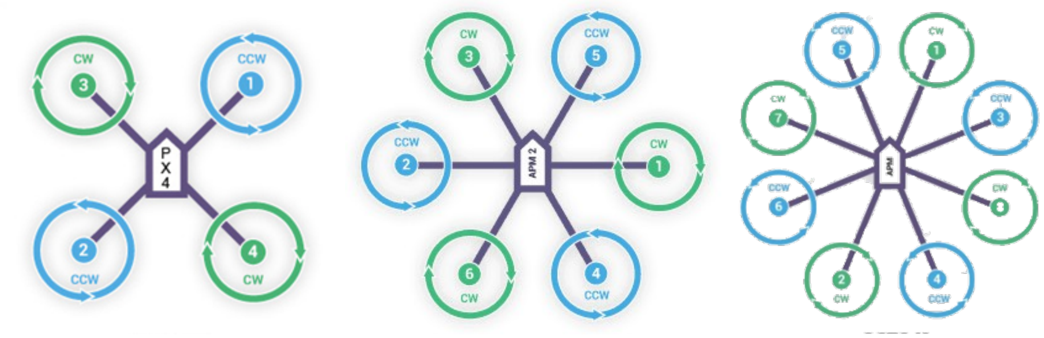


Figure 4 Motor Configuration

3.2.1 Quad-Configuration

Quadcopters typically have four motors mounted on the vertices of four arms with 90 degree apart on a symmetry frame with equidistant arms from the centre. In order to overcome the gravity to take off and stay stable, the quadcopter operates with two sets of clockwise (CW) 180 degree apart and counter clockwise (CCW) motors rotation with fixed pitch propellers mounted on the motors.

The quadcopter configuration is the most used type of UAV and mechanically one of the simplest to design and easiest to understand. The advantage with the design of quadcopter is to increase the stability and payload compared with tricopter, but this type copter will not manage in even one motor failure.

Pros	**Cons**
• Lower complexity of solution compared to hexa and octo, leads to lower cost of production • Size is smaller compared to hexa and octo.	• Less stability due to the amount of motor and motor control compare to hexa and octo • Less safe due to the amount of motors in case of motor failure • Lower payload capabilities compared to hexa and octo

Table 7 Pros/Cons Quad

3.2.2 Hexa-Configuration

The hexacopter has six motors mounted on six arms with 60 degree apart each arm, with three sets of CW and CCW rotation. It's very similar to quadcopter in operation, but with adding two extra motors make it possible for vehicle to manage one motor failure and increase the stability and payload. Increasing the motors to the system will automatically increase both the size, cost and energy consumer to the Vehicle and this is the downside of adding larger number of motor in some case.

Pros	Cons
• Able to lift heavier payload than the quad • Due to the lift capability, it allows for a battery configuration that increases the flight time compared to the quad • The stability is higher compared to the quad	• Larger in size compared to the quad • Increased cost of production compare to the quad

Table 8 Pros/Cons Hexa

3.2.3 Octo-Configuration

The octocopter has eight motors mounted on eight arms with 45 degree apart from each arm with four sets of CW and CCW propellers. It’s an upgrade version of the hexacopter with consideration to provide more stability and lifting capacity. The purpose of designing the octocopter is to lift heavy items and can be able to continue in some situation even after failure of one motor or two motors on opposite side. But eight motors draw more current from battery and because of some complicity between battery capacity and its discharge range, the weight and price of a battery increase.

Pros	Cons
• Able to lift heavier payload compared to the hexa • The stability is even higher for the octo compared to the hexa and quad	• Larger in size compared to the hexa and quad • Increased cost of production compared to the hexa and the quad • Since the battery configuration is the same as for the hexa, the increased weight and size will lower the flight time.

Table 9 Pros/Cons Octo

3.2.4 Pugh concept selection

After conceptualizing the three above motor configuration, we needed to decide the better option which we could use in our project. We are able to choose the better option by the help of Pugh method of concept selection. It helps in comparing the designs generated based on the requirements from the House of Quality developed for system requirement analysis.

			Column #	1	2	3	4
			Concepts				
Row #	Relative Weight	Weight / Importance	Quality Characteristics	Quadcopter	Hexacopter	Octocopter	
1	33,3	500	Flight time	3	4	3	
2	15,6	233,3	Size	4	3	2	
3	23,3	350	Payload	1	3	5	
4	7,41	111,1	Manoeuvrability	5	5	5	
5	20,4	305,6	Stability	3	4	5	
6	40	600	Cost of Production	5	4	3	
7	0						
8	0						
9	0						
10	0						
			Weight / Importance	7256	7928	7600	0
			Relative Weight	31,8	34,8	33,4	0

Figure 5 Pugh Matrix Motor Configurations

- Scaling from 1 to 5, where 5 is the best and 1 is the worst.

In the matrix the hexacopter scores the highest of the three configurations. The reason for this is dependent of a multiple of factors, but the main reason is the hexacopter able to lift a much heavier battery configuration, that allows for much better battery capacity. Even though the weight increases, the overall flight time increases with this type of configuration.

In terms of size, the quadcopter is the winner due to the amount of motors, the distance needed between the propellers and the battery configuration.

When considering the payload, the octo copter is the one with the highest capabilities. This is directly related to the amount of motors, but other factors such as propeller dimensions and design are important characteristics when it comes to the propulsion system.

For our system, the manoeuvrability is considered the same for all types of configurations. This is because the UAV will operate at a fixed speed. If you consider speed and agility the octocopter has the advantage over the hexa and the quad.

The cost of production is directly related to the complexity of solution, and the quad copter is considered the less complex of all three configurations.

In conclusion, the hexacopter is the configuration that scores the best in the Pugh matrix. In context with the requirements, this is also the configuration that fits best with the systems purpose presented in the vision document. This configuration is the one that we will base our architecture on, and is also the selection that the customer has agreed to.

4.0 UAV - Sensors

4.1 Sensor overview

In this section, we provide an overview of the different sensors that is absolutely necessary for proper control of UAV in order to meet the requirement specification.

The roles of sensors are to produce the connection between the physical world and the system. Through those sensors we obtain all the information needed to perform all the different tasks. These sensors are used for different purposes and they can provide different data.

4.2 Sensor Requirements

In this system, the UAV needs to know about its location, positioning, stabilization and other information. This information can be processed and used later according to the needs of the UAV. This section presents the reason why we need to have sensors for our system, from the extract of the requirements specification:

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-03	TS-UAT-SP03	B	The user should be able to monitor the battery status, height, speed and position of the UAV	STG
URQ-SPR-02	TS-UAT-SP02	A	The user shall be able to pre-program the UAV to operate on its own	STG
URQ-SPR-01	TS-UAT-SP01	A	The user shall be able to operate the UAV manually using a remote control	STG
URQ-SFR-02	TS-SIT-SF02	C	The UAV should not crash in the event of battery loss	STG
URQ-SFR-03	TS-SIT-SF03	C	The UAV should not crash in the event of signal loss	STG

Table 10 Extract of Requirements 2

In URQ-SPR-03, the requirement is directly related to the need for sensors. In the following four requirements, the sensors aid the system to accomplish these requirements.

When determining the sensors needed for the system the areas of interest are:

- Stability
- Determining Position and Speed
- Obstacle Avoidance

4.2.1 Accelerometer

An accelerometer is a device that measures acceleration on the x, y and z axes. Accelerometer can describes how fast something is speeding up or slowing down and is used to sense both static (e.g. gravity) as well as dynamic (e.g. start/stop) accelerations.

The advantages of the accelerometer sensor include a high accuracy in applications with noises.

The biggest disadvantage of this sensor is the limited high frequency where the sensor works.

4.2.2 Gyroscope

For measuring angular velocity we need to use a gyroscope sensor, to be able to know how fast something is spinning about an axis. For example if you want to control the orientation of an UAV in motion, an accelerometer may not give you enough information to know exactly how is oriented.

Gyroscopes are the most useful sensor for this task because of the following reasons:

- Its response is very fast compared to other sensors.
- It measures angular velocity fast and accurately.

4.2.3 Magnetometer

A magnetometer is an instrument for detecting and measuring magnetic fields. Depending on the setup they can measure strength of a magnetic field or both strength and direction of the field. By Using the accelerometer and gyroscope discussed earlier, a relative orientation can obtain for the UAV; it would however be good to have some type of absolute reference which both the gyroscope and accelerometer cannot provide. A good way to obtain an absolute reference is by using a magnetometer.

4.2.4 Barometer

A Barometer sensor is a device that measures the pressure and the temperature. For the unmanned aerial vehicles is used in two main aspects: one aspect is to be able to detect the weather for example if is windy, the other aspect is the ability to help the magnetometer and microcontroller to detect their height above the ground or sea level. The advantage of the barometer sensor is cheap and precise.

4.2.5 IMU

An inertial measurement unit (IMU) is an electronic device that measures and report a craft’s velocity, orientation and gravitational forces using a combination of accelerometers and gyroscopes, sometimes also magnetometer. An IMU works by detecting the current rate of acceleration as well as it changes in rotational attributes ,including pitch, roll and yaw .this data is then fed into a computer which calculates the current speed and position given a known initial speed and position.

IMU is extremely important for any autonomous UAV and can be used for stability control, velocity estimation and position estimation.

The advantages of IMU sensor is that hosts two or three types of sensor and those sensors are not affected by gravity so they make a great complement to each other.

The biggest disadvantage of an inertial measurement unit (IMU) is the error in measurement.

4.2.6 Ultrasonic sensor

To be able to maintain a certain height, a UAV should be able to measure its height above the ground. Its works by transmitting a short ultrasonic audio beam at a frequency that is inaudible to the human ear, this beam hits a solid object and bounces back to the ultrasonic sensor. The time between transmission and echo reception gives an indication of the distance between the Ultrasonic sensors and the object. These sensors can be used also for obstacle detection and collision avoidance.

Nevertheless, we do not really need this Ultrasonic sensor but it could have improved both safety and stability for the UAV

4.2.7 GPS

A global positioning system (GPS) devise is a helpful and commonly used sensor for a UAV.As most people know a GPS device can be used to help determine its own altitude, longitude, and latitude positions .A GPS device typically receives a signal from a satellite to calculate these positions.

5.0 Camera - Supplement of Concept Evaluation

5.1 Quality Function Deployment

The foundation of the evaluation and selection of different concepts and configuration is developed by interpreting both the vision document and the requirements specification. The constraining requirements from the requirements specification serve as the boundary for the evaluation, but the selection is ultimately governed by this requirement from Cube AS:

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-01	TS-SIT-C01	A	The system shall be created using available resources	STG

Table 11 User constraining requirement (QDF)

Both the architecture and the design is limited by this constraint, hence the challenge of selecting concepts and configurations is to establish whether the available resources is sufficient enough to meet the overall requirements specification.

5.2 QFD matrix

The table shown below illustrates the transition between the stakeholders' needs for the total system and the needs to consider in the QDF matrix. The output of this table is used to produce the input of the derived customer needs for the evaluation.

REQ ID	Customer needs (input)	Needs to consider in QFD (output)
URQ-CR-05	The System shall be able to map an area of minimum 10 000 square meters.	Arial coverage
URQ-CR-13	The camera shall be stable to take sharp pictures.	Quality of images
URQ-CR-14	If additional acquisitions are necessary, costs must be kept as low as possible.	Cheap

Table 12 User requirement and costumer needs

When the "what's" of the QDF matrix is defined (demanded qualities), the focus shifts to the "how's" of the matrix (quality characteristics). These are the engineering characteristics that affect the demanded qualities. In this QDF matrix we will evaluate the following engineering characteristics:

Weight - Affects the aerial coverage, portability and safety

Resolution - Affects the image quality and the accuracy of the model

Battery capacity – Affects the number of exposures

Storage capacity - Affects the maximum number of images saved

Expected life – Affects the cost

Cost of Production – Affects the quality of the images

The top of the quality matrix, hence the pyramid, displays the correlation between the quality characteristics and is founded on the direction of improvement. The direction of improvement is either to minimize, maximize or hit targets. The overall purpose of this section is to clarify the trade-offs between the engineering characteristics.

The strength of the relationships between the demanded quality and quality characteristics are the displayed in the legend table of matrix. The strength is given a numerical value ranging from 1 to 9 and is used along with the weight/importance of the demanded qualities to calculate the weight/importance of the quality characteristics.

House of Quality Matrix – Explanatory Table	
Weight/Importance (row)	Requirement Priority, A=5, B=3, C=1
Relative Weight (row) [%]	Sum of Weight/Importance divided by Requirement Priority
Weight/Importance (Column)	Relationship weight x Weight/Importance (row)
Relative Weight (Column) [%]	Sum of Weight/Importance (Column)/ Weight/Importance (Column)

Table 13 QDF Explanatory table

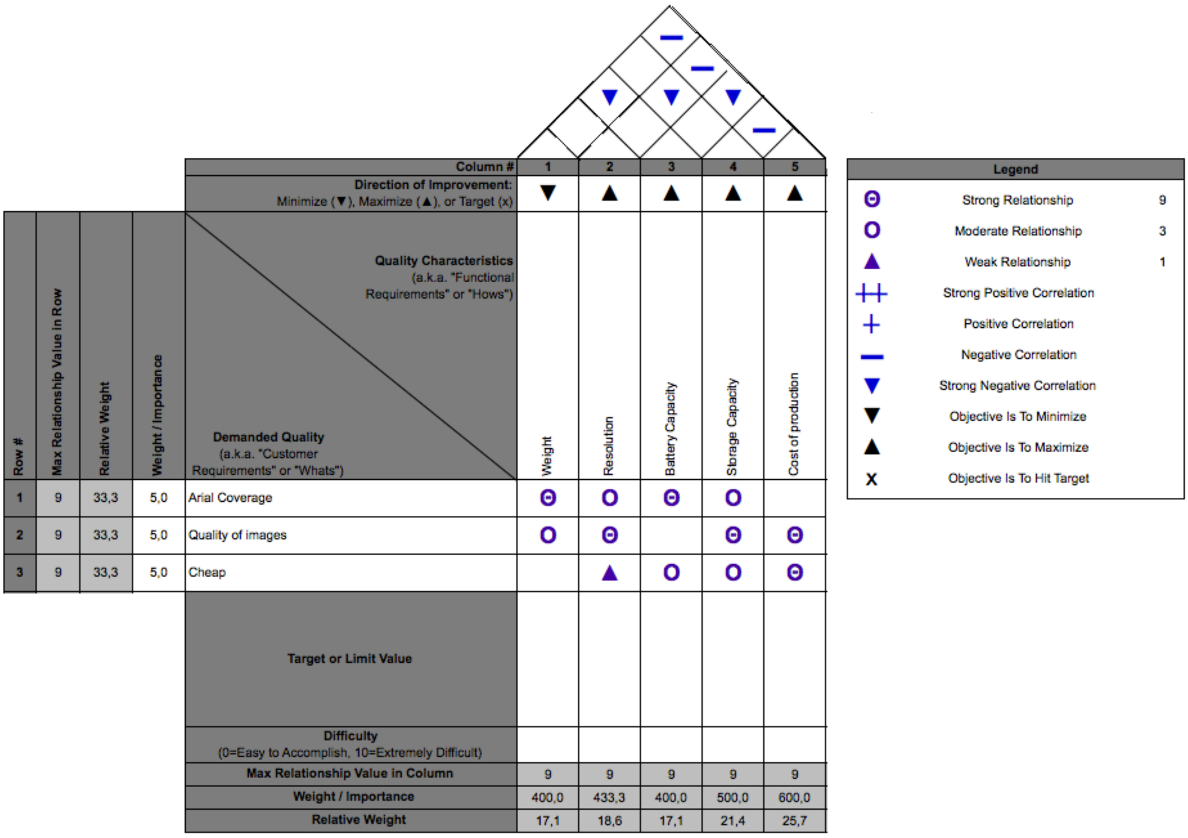


Figure 6 QDF

5.3 Output of QFD

The QFD matrix displays the calculated values in which of the quality characteristics that represent either the most weight or the highest importance in correlation with the demanded qualities. This weighting gives us the foundation for the decision-making matrices, hence the Pugh-Matrices, that will give us a similar weighting on which concept or configuration that is most suited in context with the requirements. However, it is important to express that the decision-making matrices do not govern the selections, but gives an objective view on which we will take in to account when presenting our recommendation.

5.3.1 Weight and Importance

The matrix gives the following results with importance from highest to lowest:

1. 600 – Cost of production. Direction of improvement: **minimize**
2. 500 – Storage capacity. Direction of improvement: **maximize**
3. 433.3 – Resolution. Direction of improvement: **maximize**
4. 400 – Weight. Direction of improvement: **minimize**
5. 400 – Battery capacity. Direction of improvement: **maximize**

6. 300 – Expected life. Direction of improvement: **maximize**

The trade-off table is based on the weight/importance score from the QDF. In the comparison stage the one with the lowest score will be in the trade-off section. If the score is equal there will not be any trade off.

Correlation	Positive/Negative	Trade-off
Weight and Battery	Strong Negative	**None**
Weight and Coast of production	Negative	**Weight**
Resolution and storage capacity	Strong Negative	**Resolution**
Resolution and cost of production	Negative	**Resolution**
Battery capacity and cost of production	Negative	**Battery capacity**
Storage capacity and cost of production	Negative	**Storage capacity**
Expected life and cost of production	Strong Negative	**Expected life**

Table 14 Trade-off table for QDF

5.3.2 Conclusion

The conclusion to the trade-off section is that negative correlation could result in trade-off's. The QDF matrix simplifies this selection by the weight/importance:

The quality characteristic with the highest weight/importance value will govern the trade-off.

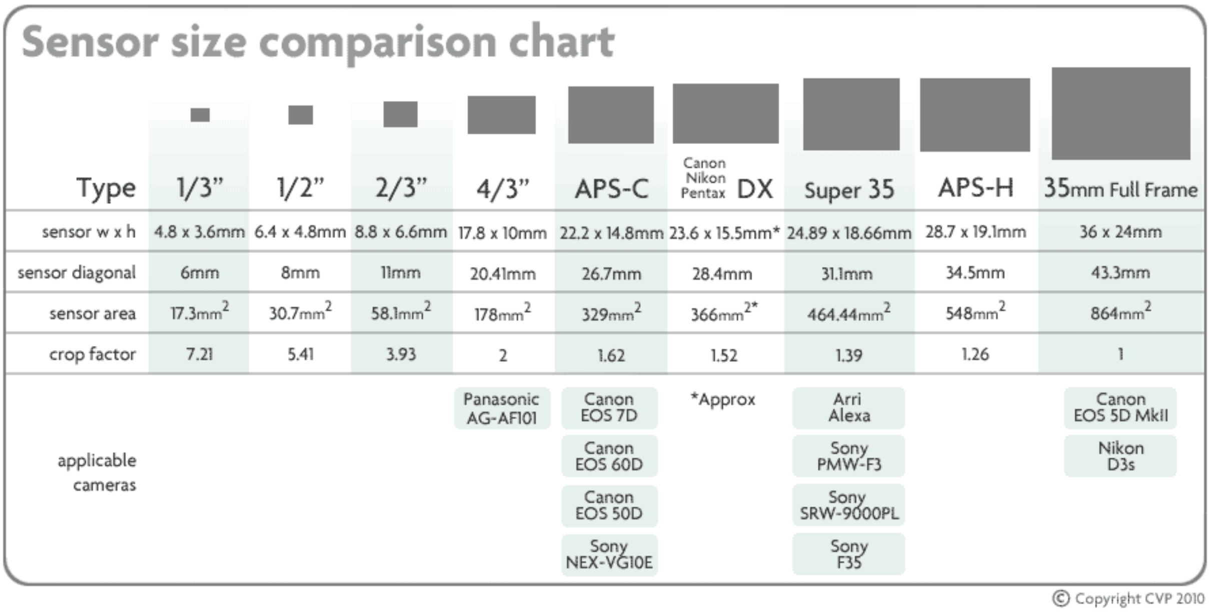
6.0 Camera - Concept Analysis and Design Evaluation

6.1 Basic camera functionality and characteristics

The quality of an image is dependent on a long list of settings. For this document we will not go into detail about all of the aspects that make up a photo, but we will describe a few important areas that must be considered for our project.

6.1.1 Sensor size and effective pixels

The sensor size and the effective pixel count of the camera will in combination with height of flight determine the final resolution of the image. Below is a comparison of different sensor sizes.



Sensor size comparison chart

Type	1/3”	1/2”	2/3”	4/3”	APS-C	Canon Nikon Pentax DX	Super 35	APS-H	35mm Full Frame
sensor w x h	4.8 x 3.6mm	6.4 x 4.8mm	8.8 x 6.6mm	17.8 x 10mm	22.2 x 14.8mm	23.6 x 15.5mm*	24.89 x 18.66mm	28.7 x 19.1mm	36 x 24mm
sensor diagonal	6mm	8mm	11mm	20.41mm	26.7mm	28.4mm	31.1mm	34.5mm	43.3mm
sensor area	17.3mm^2	30.7mm^2	58.1mm^2	178mm^2	329mm^2	366mm^{2*}	464.44mm^2	548mm^2	864mm^2
crop factor	7.21	5.41	3.93	2	1.62	1.52	1.39	1.26	1
applicable cameras				Panasonic AG-AF101	Canon EOS 7D Canon EOS 60D Canon EOS 50D Sony NEX-VG10E	*Approx	Arri Alexa Sony PMW-F3 Sony SRW-9000PL Sony F35		Canon EOS 5D MkII Nikon D3s

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Figure 7 Camera sensor chart

This is important because it will ultimately affect the accuracy of the final 3D map. A larger sensor will normally lead to a higher weight. This is a trade-off that must be taken into consideration when deciding what camera to use.

6.1.2 Shutter speed, Aperture, ISO

There are three main settings to adjust when taking an image:

- Shutter speed
- Aperture
- ISO

The primary function of these is to set the right exposure/light. The secondary function is different for all three and will affect qualities like depth of view, motion blur and noise. For our purpose the goal will be to take pictures with maximum sharpness at all lengths.

The speed of the UAV will affect which settings will be applicable in order to achieve sharp images and avoid motion blur.

6.1.3 Storage capacity

The storage capacity of the camera (memory card) must be of sufficient size in order to avoid flying several times over an area. The format of the images along with the sensor size, megapixels and other factors determines the overall size of the image file. The system should strike a balance between quality and quantity. Higher quality will result in fewer images and vice versa.

6.1.4 Geo-tagging

In order for the 3D modelling process to work, pictures must be geo referenced. Some cameras have a built in GPS that allow for automatic geo tagging of pictures (stored in the image file). If the camera doesn't have built in GPS, then a separate GPS must be implemented to geo-tag the images. This process should ideally be automated so that pictures are stored with the GPS coordinates automatically. If this is not possible, then a manual tagging of pictures are in order. This process can be time-consuming and should be avoided if possible.

6.1.5 Stability

In order for the pictures to be sharp and accurate, there is a need for a stabilization system to prevent vibrations being transferred to the camera (and thus the images). If an image suffers from a lot of motion blur, it may render it useless for the 3D modelling process.

6.1.6 Automate Image Acquisition

The camera system need an externally software that can automatically capture images on preprogramed waypoints and also GEO tag them. UAV speed, height, front/side overlap, resolution, area and waypoints. These are the most important parameters the software should let the user, to input. A system like this would give a optimized system for Automated Image Acquisition.

6.1.7 Camera delay

We have 2 types of delay regarding the camera system. There is a delay between the trigger and the shutter, depending on the camera brand and type. This occurs when picture target is moving. The delaying time varies between the camera types, and the interval is between 6ms - 1800ms. These times are from a user triggers the capture button, to picture are being taken.

The ways to eliminate or minimalize the delay are to preprogrammed Shutter speed, Aperture, ISO and waypoints for the system. The camera would also have a delay when the internal memory is full and have to offload the memory to the SD card. So there are very important to have a fast SD memory card, which can offload the camera memory fast enough to minimize the delay between the picture capturing.

6.2 DSLR

The DSLR is an advanced electronic camera where you got a numerous options to optimize the images. A DSLR camera will give very precisions images, about 95-100% from what was visible in the trough-the-lens (TTL), when the image is taken. With a DSLR it's possible to take picture in low light without flash, because of its many options like aperture, shutter speed and ISO. The DSLR have a startup time under 1 second that means that the camera is always ready to shoot a image. And it have not a noticeably delay in the image taking process. DSLR supports RAW formats, so it stores all the information about the image, so it is possible to customize or retrieve the image later on. The dimensions of a DSLR would be around 130 x 100 x 80mm and weight around 600g.

Pros	**Cons**
• Many options to adjust aperture, shutter speed and ISO • It has the opportunity to change the camera lens • Supports RAW and JEPG format • What you see trough camera lens, is what you get in the image • Covers more area per pictures(wider angle) • Able to use an external flash unit	• It's too heavy, around 600g • Do not have built in GPS • Poor battery, can take around 200 images in one charge when using flash

Table 15 Pros and cons for DSLR camera

6.3 Compact camera

Compact camera also called point-and-shoot cameras, is a simple camera and constraining camera in many ways. This camera is not designed for a professional photographer, because it has not the many options for changing aperture, shutter speed and ISO. And it not possible to change the lens to get better wide angle or zoom. Some of these cameras have now build inn GPS for GEO tagging of the pictures, but far from all of them.

Some of them from Canon can use something called CHDK(Canon Hack Development Kit), this is a hack that gives the camera a lot of same options that the DSLR cameras have, such as aperture, shutter speed, ISO and a controlled self-timer for the image taking. This is a hack who do not violet the manufacture warranty, so this is a legal and safe. But on the other hand these cameras are much lighter, compact and easy to use. The GEO tagging of the images with these cameras, are good enough to use to make a 3D map. This is only if the area that is going to be mapped, is a open area and the camera GPS have a good satellite signal.

Compact cameras have dimensions like 100 x 60 x 30 mm and weight around 230g.

Pros	Cons
• Light weight and compact • Easy to use and to carry around • Cheaper than DSLR cameras • Have built inn GPS for GEO tagging of the pictures	• Less options to adjust aperture, shutter speed and ISO • Compact cameras don't take interchangeable lenses • Poor battery, can take around 230 images in one charge when using flash

Table 16 Pros and cons compact cameras

6.4 Pugh concept selection

			Column #	1	2	3	4
Row #	Relative Weight	Weight / Importance	Concepts / Quality Characteristics	Digital single-lens reflex	Comact camera	Concept 3	Concept 4
1	16,4	400	Weight	2	5		
2	17,7	433,3	Resolution	5	3		
3	16,4	400	Battery capacity	4	3		
4	22,5	550	Storage capacity	4	3		
5	27	660	Cost of production	2	5		
6	0						
7	0						
8	0						
9	0						
10	0						
			Weight / Importance	8087	9450	0	0
			Relative Weight	46,1	53,9	0	0

Table 19 Camera - Pugh

Pugh matrix is a tool that can help too choose concept, based on quality characteristic, weight/importance and the relative weighting from the camera QFD. The scaling from 1 to 5, where 5 is best and 1 is worse.

The matrix indicates that compact camera (concept 2) is better than DSLR camera (concept 1) in this context. The Pugh matrix conclusion gives a recommendation based on the input parameter. This conclusion should be good enough to make a choice in the compact cameras favour. The scaling is based on a generalizing point of view, and there many cameras that is better than others.

The weight is an important parameter in this case, because this will impact on the whole system such as battery, motor and camera system choice. This parameter is not the most important due to the camera QDF.

Resolution is an important, but gets the 2nd not most important parameter. This is because the resolution will vary from the height, speed and clarity in the camera view of the UAV. Other thing that will have an impact on the resolution is stabilisation, camera type and the weather.

Camera battery capacity is also one of the least important parameters, because the camera can be powered by an own battery or the UAVs battery.

For storage capacity is possible to use a SD card, and this is the 2nd most important parameter. The crucial part is to have enough storage capacity to complete a whole mission.

Our most important parameter is the cost of production; this is supposed to as low as possible. So the main focus should be to find cheap camera that can perform the wanted actions and meet the needs for this system.

7.0 Image Processing - Supplement of Concept Evaluation

7.1 Quality Function Deployment

The foundation of the evaluation and selection of different concepts and configuration is developed by interpreting both the vision document and the requirements specification. The constraining requirements from the requirements specification serve as the boundary for the evaluation, but the selection is ultimately governed by this requirement from Cube AS:

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-01	TS-SIT-C01	A	The system shall be created using available resources	STG

Table 20 URQ-CR-01

Both the architecture and the design is limited by this constraint, hence the challenge of selecting concepts and configurations is to establish whether the available resources is sufficient enough to meet the overall requirements specification.

7.2 QFD matrix

The table shown below illustrates the transition between the customers' needs for the total system and the needs to consider in the QDF matrix. The output of this table is used to produce the input of the derived customer needs for the evaluation.

When the "what's" of the QDF matrix is defined (demanded qualities), the focus shifts to the "how's" of the matrix (quality characteristics). These are the engineering characteristics that affect the demanded qualities. In this QDF matrix we will evaluate the following engineering characteristics:

REQ ID	Customer needs (input)	Needs to consider in QFD (output)
URQ-CR-07	The system should not exceed a process time of 72 hours to create a digital 3D model	Fast
URQ-CR-15	The 3D map must be accurate enough to provide usable information for entrepreneurs and construction engineers.	Quality of 3D map
URQ-CR-14	If additional acquisitions are necessary, costs must be kept within budget.	Cheap
URQ-CR-06	The system shall be able to operate with one single human resource	Intuitive
URQ-CR-07	The system should not exceed a process time of 72 hours to create a digital 3D model	Intuitive

Table 21 Requirements needed for QFD matrix

Process time - Affects effectiveness of the system

Render quality - Affects the accuracy of the model

Cost of Production – Affects the quality of the 3D model

The top of the quality matrix, hence the pyramid, displays the correlation between the quality characteristics and is founded on the direction of improvement. The direction of improvement is either to minimize, maximize or hit targets. The overall purpose of this section is to clarify the trade-offs between the engineering characteristics.

The strength of the relationships between the demanded quality and quality characteristics are the displayed in the legend table of matrix. The strength is given a numerical value ranging from 1 to 9 and is used along with the weight/importance of the demanded qualities to calculate the weight/importance of the quality characteristics.

House of Quality Matrix – Explanatory Table	
Weight/Importance (row)	Requirement Priority, A=5, B=3, C=1
Relative Weight (row) [%]	Sum of Weight/Importance divided by Requirement Priority
Weight/Importance (Column)	Relationship weight x Weight/Importance (row)
Relative Weight (Column) [%]	Sum of Weight/Importance (Column)/ Weight/Importance (Column)

Table 22 House of Quality Matrix – Explanatory Table

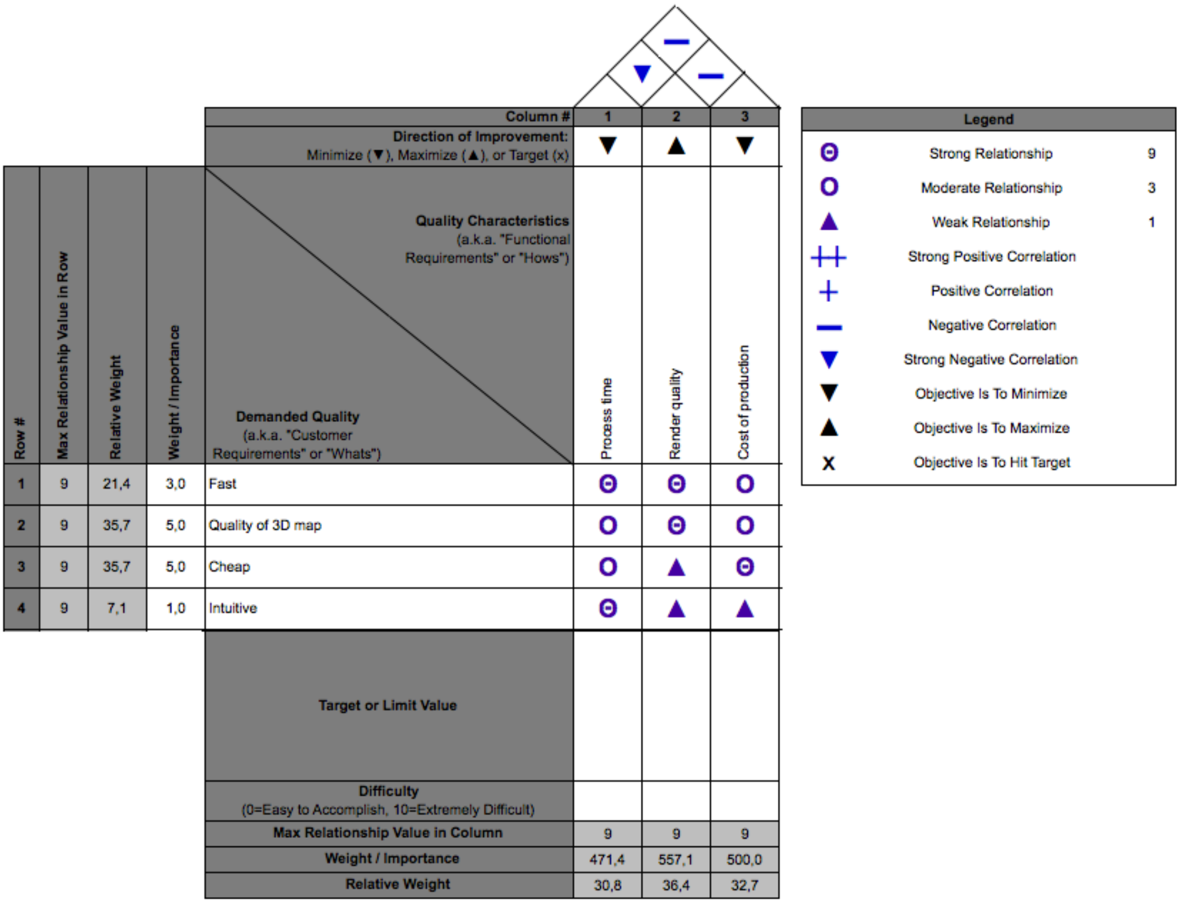

Figure 8 House of Quality Matrix

7.3 Output of QFD

The QFD matrix displays the calculated values in which of the quality characteristics that represent either the most weight or the highest importance in correlation with the demanded qualities. This weighting gives us the foundation for the decision-making matrices, hence the Pugh-Matrices, that will give us a similar weighting on which concept or configuration that is most suited in context with the requirements. However, it is important to express that the decision-making matrices do not govern the selections, but gives an objective view on which we will take in to account when presenting our recommendation.

7.3.1 Weight and Importance

The matrix gives the following results with importance from highest to lowest:

7. 557.1 – Render quality. Direction of improvement: **maximize**
8. 500 – Cost of production. Direction of improvement: **minimize**
9. 471.4 – Process time. Direction of improvement: **minimize**

7.3.2 Trade-Off's

Correlation:	**Positive/Negative:**
Process time and Render quality	**Strong Negative**
Direction of improvement is opposite of each characteristic: 1. Minimizing process time could lead to lower render quality. 2. Maximizing render quality could lead to higher process time.	

Table 17 Process time and Render quality

Correlation:	**Positive/Negative:**
Process time and Cost of production	**Negative**
Direction of improvement is opposite of each characteristics: 1. Lowering cost of production could affect the processing time.	

Table 18 Process time and Cost of production

Correlation:	**Positive/Negative:**
Render quality and Cost of production	**Negative**
Direction of improvement is opposite of each characteristics: 1. Maximizing render quality could increase the cost of production 2. Lowering the cost of production could lower the render quality.	

Table 19 Render quality and Cost of production

7.3.3 Conclusion

Improvement in one characteristic will result in a trade-off in another characteristic. All of the characteristics have similar weighting. The main goal will be to strike a balance between render quality, cost of production and process time.

8.0 Image Processing - Concept Analysis and Evaluation

8.1 3D Modelling

8.1.1 Important Preconditions

What is important for the software processing is that images are sharp and not blurry in order to extract key points from the images. Moreover, objects should appear in a similar way in consecutive images, in order to find common key points and match them.

This means that there should be a certain frontal overlap and side overlap. A general recommendation is:

- 75 % frontal overlap
- 60% side overlap

Rain and snow could be a problem and render images useless, but as long as images are captured in aerial nadir, light rain should not be a problem.

8.1.2 Processing speed

The processing time will depend on a lot of factors such as:

- Number of images
- Image size
- Render quality
- Computing power
- Software algorithms

Generally the larger the project, the longer the processing time will be. A properly optimized source code will have a big impact on the total processing time.

8.1.3 Resolution and accuracy

The final 3D Model accuracy will depend largely on the quality and resolution of the images acquired. The Ground Sampling Distance (GDS) is the distance between pixel centers measured on the ground. E.g. a GSD of 5 centimeters means that one pixel in the image represents 5 centimeters on the ground. The lower the number the higher the resolution will be with fewer errors. The GSD is related to the height of the flight. The lower the flight is, the higher the resolution will be.

8.2 Open Source

Open source software is a software whose source code is open for modification and altering by anyone. It is normally based on contributions from several contributors and is meant to be a collaborative effort to design something that is free and open to use by the general public.

Pros	Cons
• No licensing fee • Limitless installation • Anyone can fix bugs, update. No need to wait for the next official release • Code not dependent on a company or organisation • Everyone can access the source code and start modifying.	• No obligational support • Different versions may lead to compatibility issues • No guarantee that source code will be updated • Learning curve may be steep

Table 20 Open Source

8.3 Proprietary systems

A proprietary software is a software owned by a copyright holder, that can be licensed under exclusive rights for professional or private use. Normally the source code is not available for users to modify.

Pros	Cons
• High degree of support • Regular updates to keep up with technological advances • Well tested and optimized • User friendly, often with a well-documented user manual	• Costs • Little/No way to modify the source code and the functionality • Dependent on the copyright holder. If the copyright holder ceases to exist, the software might become obsolete

Table 21 Proprietary systems

8.4 Pugh Concept Selection

After conceptualizing the two above design possibilities for the UAV in our project, the whole group needed to select the most appropriate concept to be used. To aid in this selection, we utilized a tool called Pugh's method of concept selection. The goal of this process involves comparing the designs generated based on the requirements.

Row #	Relative Weight	Weight / Importance	Quality Characteristics \ Concepts	Open Source	Proprietary System	Concept 3	Concept 4
			Column #	1	2	3	4
1	30,8	471,4	Process time	2	4		
2	36,4	557,1	Render quality	3	5		
3	32,7	500	Cost of production	5	1		
4	0						
5	0						
6	0						
7	0						
8	0						
9	0						
10	0						
			Weight / Importance	5114	5171	0	0
			Relative Weight	49,7	50,3	0	0

Figure 9 Image Processing – Pugh Concept Selection

- Scaling from 1 to 5, where 5 is the best and 1 is the worst.

From the Pugh matrix above, we can see that the characteristics have a pretty similar weighting with render quality on top, cost of production second, and process time third.

8.5 Conclusion

The preliminary analysis in section 3.2 is a generalization and is not accurate enough to make any decision regarding which software to use for our project. This means that any particular open source software or proprietary software may score very differently than what we have generalized in the above analysis. A more thorough comparison should be performed at a later stage in order to verify the most adequate software for our use. This includes acquiring licenses to various software and test functionality and results, before settling on a particular recommendation.

System Architecture

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
2.0	15.05.15	OPC	TTP	Released

Summary:

This document is intended to give an overview of the system architecture for the 3D Ground Mapping system.

Owner: Bjørnar Dalset

Document Revision History

Rev	Date	Author	Description	Status
0.1	06.03.15	TTP	Initial draft	Obsolete
1.0	09.03.15	BJD	Final Version V1.0	Obsolete
1.1	01.05.15	BJD	Update ITP ID	Obsolete
2.0	15.05.15	TTP	Final Version V2.0	Released

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1.0 Introduction

1.1 Purpose of this document

This document is intended to give an overview of the system architecture for the 3D Ground Mapping system. The main focus will be to identify what components the system will consist of and how it will be build up. This document will prove that this system architecture is the one that will be used to build the system, based on the requirements.

This document is based on the conceptual study and the requirements specification document that will serve as guides in setting up the system architecture document. This document will serve as a guide to the overall system architecture of the 3D Ground Mapping project.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
AUP	Agile Unified Process
CCW	Counter clockwise
CW	Clockwise
DC	Direct Current
DLSR	Digital Single Lens Reflex
ESC	Electronic Speed Controller
GPS	Global Positioning System
GSD	Ground Sampling Distance
IMU	Initial Measurement Unit
QFD	Quality Function Deployment
RC	Radio Control
RF	Radio Frequency
UAV	Unmanned aerial vehicle
UML	Unified Modelling Language

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents referenced in this document

Doc. number	Description
007	Concept Evaluation
006	Conceptual Study
003	Requirement Specification

Table 2 Related documents

1.4 Appendix A

1.5 Appendix B

2.0 System Overview

2.1 Architectural overview

The 3D Ground Mapping system must have good baseline architecture to be used through ought the rest of the project in accordance with the AUP. The system must have good baseline architecture before the construction of the system can begin. It exists several ways to build system architecture and this project will be using QFD and UML for this.

For the purpose of making the architecture manageable the system has been split into three main subsystems that will be dealt with separately in this document:

- UAV system
- Camera system
- Image processing system

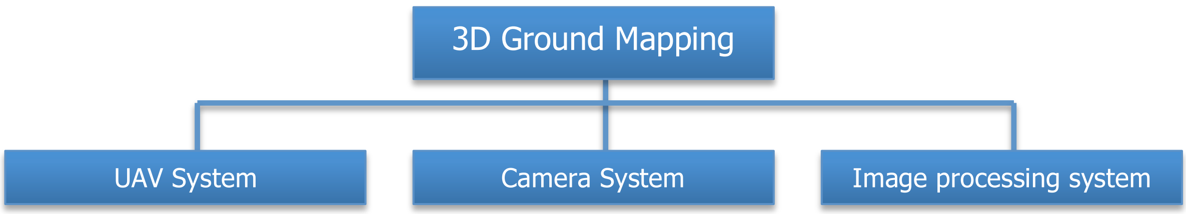


Figure 1 System overview

The point with creating the architecture is to ensure that the team can actually develop a system that satisfies the requirements. A good architecture gives the team a better understanding of the system to be built and its accompanying risks.

2.2 Product Breakdown Structure

The product breakdown structure in figure 2 is a decomposed view of the total system and the different subsystem parts. This is a high level diagram showing the most important parts of the total system. The diagram makes it easier to get an overall view of the system, and manage components according to the requirements specification. More detailed product breakdown structures can be found in the subsystem chapters.

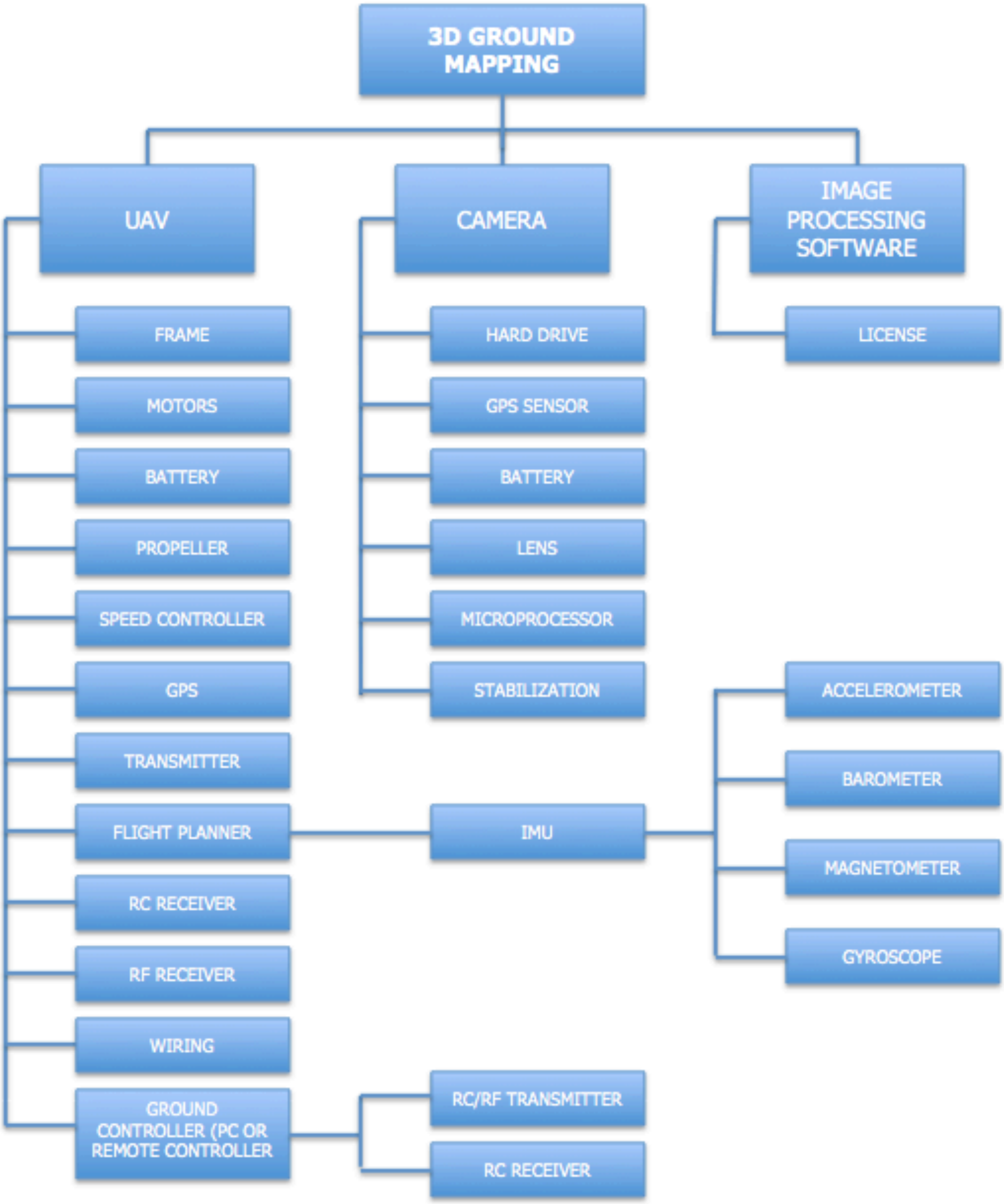


Figure 2 Product Breakdown Structure

2.3 High Level Activity Diagram

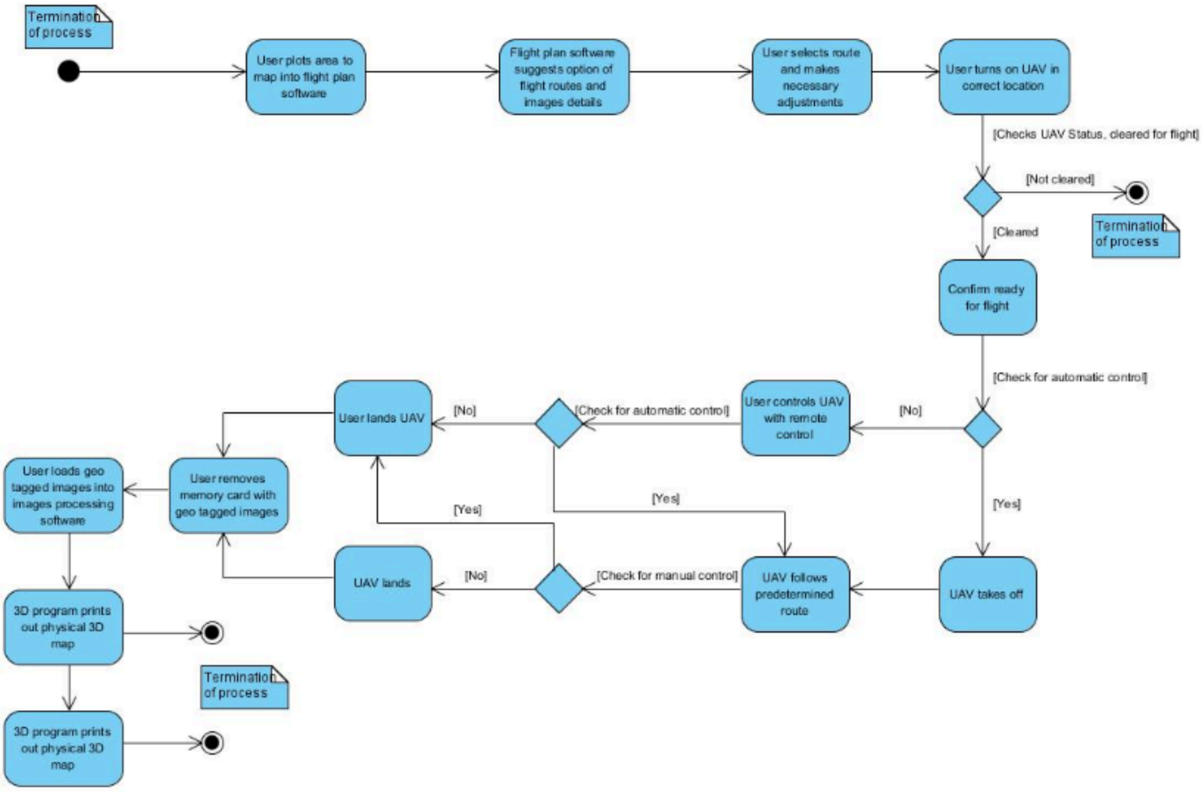


Figure 3 High Level Activity Diagram

Figure 3 shows the high level activities for the total system. This is a simplified overview of the system and is based on the use cases found in the requirements specification. More in depth activity diagrams for the specific subsystems can be found in later chapters.

3.0 UAV - Overview

3.1 Work Breakdown Structure

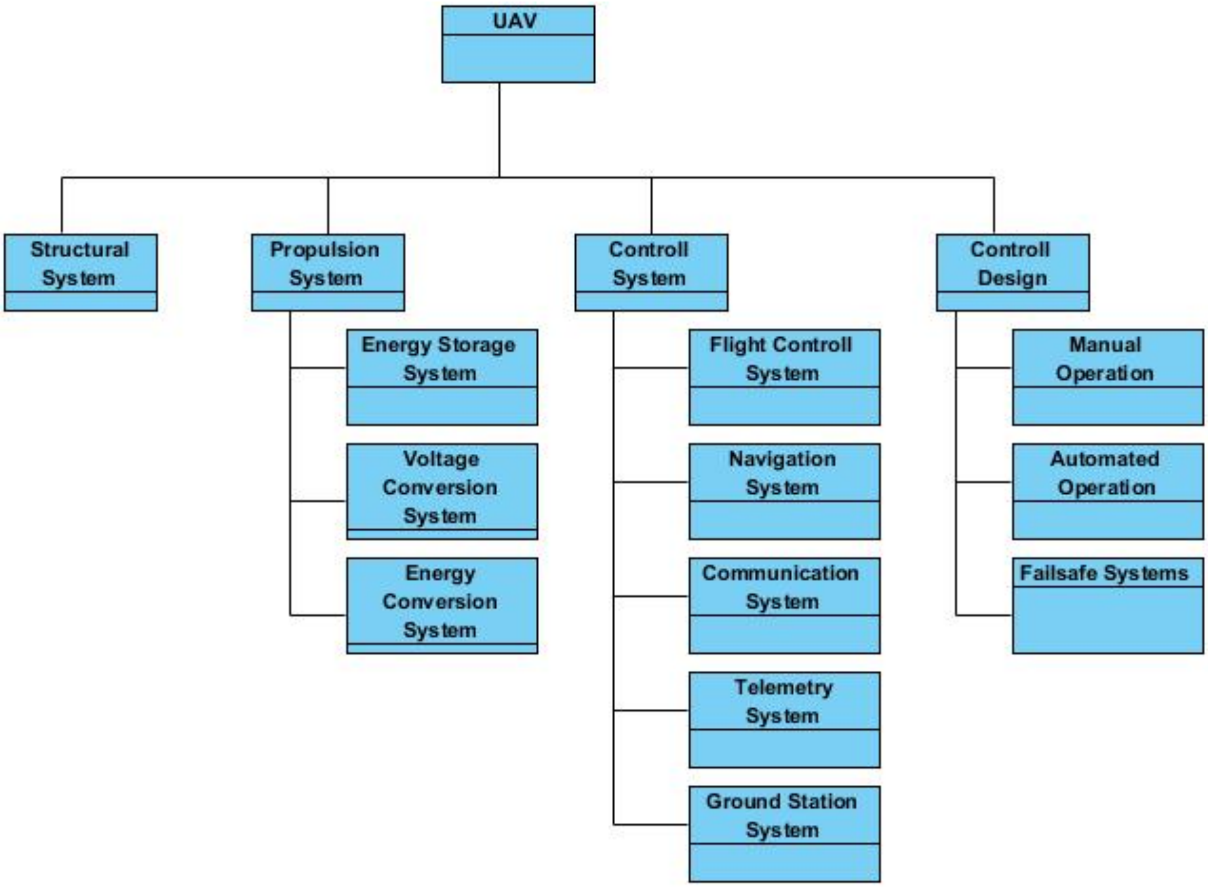


Figure 4: Work Breakdown Structure UAV

The work breakdown structure shows the work packages for the UAV that is absolutely necessary to accomplish in order to meet the requirements specification. The hierarchy is structured after the control design and the main systems; Structural, Propulsion and Control and their subsystem. It represents the deliverables for the elaboration and the construction phase for the UAV system.

This section of the work breakdown structure does not show the totality of the UAV system. The requirements section is captured in the inception phase and the test section is captured in the Inspection and Test Plan.

3.2 Product Breakdown Structure

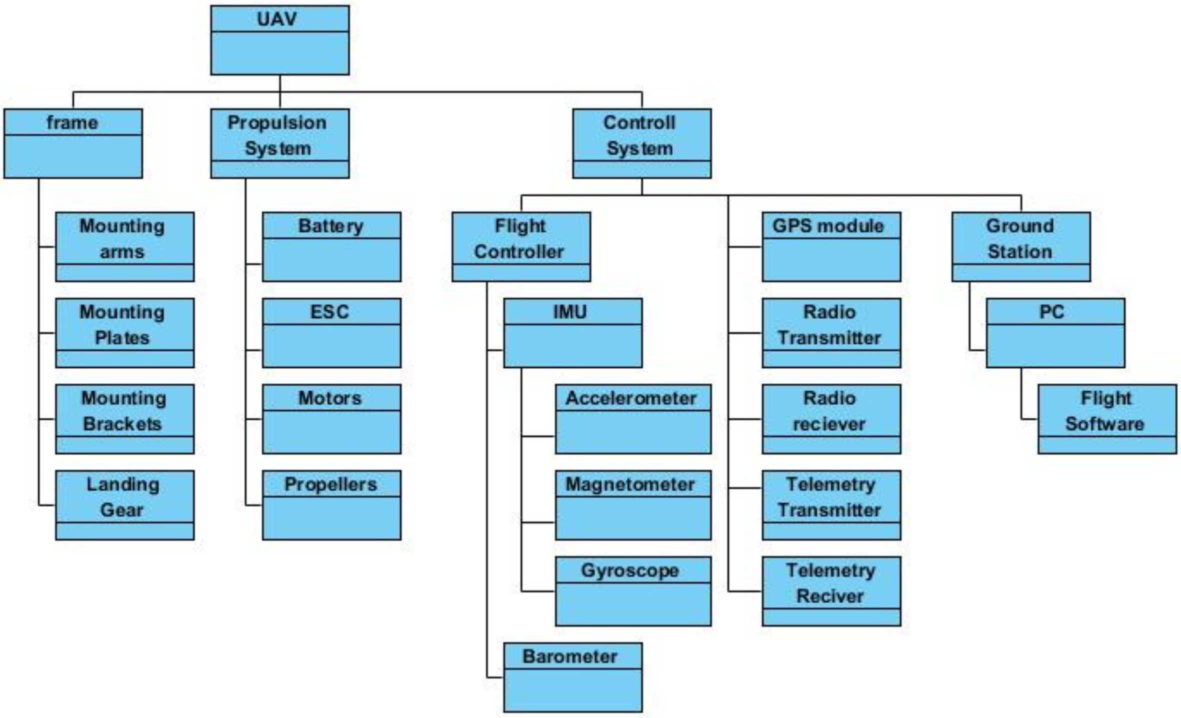


Figure 5: Product Breakdown Structure UAV

The product breakdown structure shows the systems, the subsystems and the components of the UAV. The first level represents the systems, and second level shows both subsystems and components and the third level shows the sub-subsystems. The components listed in this diagram are absolutely necessary in order to meet the requirements specification, and consists of both procured and designed items.

3.3 System Layout

In the conceptual evaluation document we used quality function deployment matrices and Pugh decision making matrices to select aircraft concept and motor configuration for the UAV. These evaluations lead to the following system layout:

- The UAV is a battery driven multirotor craft

- It has a hexa-X motor configuration with 6 motors and propellers

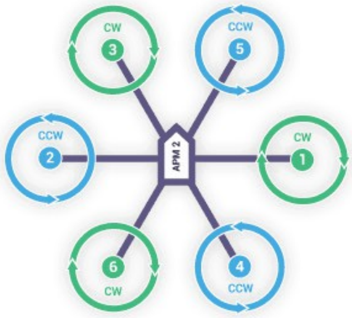


Figure 6: System layout UAV

The key focus in developing the architecture for the hexacopter is to develop a system that is in context with the requirements specification. The quality characteristics for the hexacopter are derived from the QFD matrix and are listed as following:

- Cost of production
- Flight time
- Stability
- Payload
- Size
- Manoeuvrability

Only when these characteristics are reflected in the architecture and the design the system can be validated to meet its intended purpose.

The hexacopter has six motors mounted on six mounting arms with a 60 degree mounting angle apart from each arm, with three sets of clock wise spinning propellers (CW) and three sets of counter-clock wise spinning propellers (CCW). Each motor is connected to an electronic speed controller (ESC) making a total of 6 ESCs.

The only way of operating it is to vary the speed of the different propellers, ultimately controlling the altitude, the yaw, the pitch and the roll of the hexacopter.

The hexacopter is a fly-by-wire solution and the user shall be able to control the hexacopter either manually with a remote control or by autopilot using a PC as a ground station. The user should be able to switch between the two operating modes prior and during operation.

The means of control are described in more detail in the section about control design.

4.0 UAV - Structural System

4.1 Frame

The frame is a structural system that supports other components of a physical construction. The layout for the design is the Hexa-X configuration as mentioned before and is the load bearing structure for the UAV. The frame of the UAV should be of low weight and of mechanical properties so it fulfils the quality characteristics as well as the requirement:

REQ ID	ITP ID	PRY	Description	Origin
URQ-SFR-04	TS-SIT-SF04	A	The UAV should not crash due to mechanical failure	STG

Table 3 Requirement - Frame

The frame is divided into the following components:

- Mounting arms for the motors and propellers
- Mounting plates for the control system components and battery
- Landing gear
- Mounting brackets for various components such as gimbal

5.0 UAV - Propulsion System

Propulsion is a means of creating force leading to movement. Propulsion system has a source of mechanical power such as engine or motor, and some means of using this power to generate force such as propellers or wheel axles. In recent years the electric propulsion system is prioritized over gas system in multi-copters for various reasons. One of the important reasons is that an electric system's thrust can be controlled more precisely and responds faster to throttle input. This is crucial to provide the differential thrust control required by the UAV. The other reasons are that electric system is easier to operate, produce less noise than gas system and minimalizing the possibility of crush due to motor failure.

5.1 Battery

This project has constraining requirements for the UAV electric system with a battery capacity that should be able to map an area of minimum 10 000 square meters, as shown in table 4. First step in designing the propulsion system is to choose a target battery life. The battery is one of the critical parts in the UAV, because the power of a battery is very limited and has a long charging time compared to gas. Given the limitations of the battery technology and high power requirements of a hexa-copter UAV, the battery life will be relatively low. We will choose to design for a minimum battery life that meets the requirements. In order to meet the requirement the type of motors, mission plan, type of propeller and altitude of the UAV have to be analysed before choosing the battery type, because the life of battery depends on those characteristics.

There are many different type of battery in the market which we can use, but the lithium based batteries is the appropriate choice for our UAV project due to high energy density compared to other battery types. Because the lithium is lightest metal lithium packs can have as low (20-25) % of the weight and volume of the other battery types with the same capacity.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-05	TS-SIT-C05	A	The System shall be able to map an area of minimum 10 000 square meters	STG
URQ-CR-04	TS-SIT-C04	A	The System shall be a battery driven UAV	STG

Table 4 Requirements - Battery

5.2 ESC

Brushless DC motors commutating electrically via an Electronic speed controller. A three phase current is delivered to the motor, creating a DC voltage across the motor terminal. The Brushless DC motor is explained next.

The Electronic Speed Controller (ESC) is a multirole and signal dependent electronic device uses pulse-width modulation (PWM) to control the effective voltage on the terminal of brushless DC motor. The change in the voltage controls the power output of the motor. The pulse-width modulation input in the speed controller is standardized for remote controlled transmitter/receiver. PWM is a type of electronic signal used to transmit information as squire wave and operate at constant frequency, but with different duty cycle. The duty cycle is the percentage of one period in which a signal is on. A period is the time it takes for a signal to complete a digital cycle (on and off). The percentage of on time of duty cycle sets the voltage level across the motor terminal. In other words the voltage of motor terminal will increase or decrease by in increasing or decreasing the on and off time of duty cycle.

The device is consisting of different electronic component arranged in the way to receive both the PWM signal from flight control or RC receiver with a certain rage of frequency to sets the speed of a motor according to the input signal. Multi-copters flight control are not able to use the same battery voltage level as the ESC and motor use, so the ESC has the functionality to step down the battery voltage to a certain voltage level that the flight control can tackle.

5.3 Motors

Brushless DC motors are the most common type of electric motor used in present-days multi-copters. The ways brushless motors work are different than traditionally brushed motors that have mechanical commutating system. This type of motors is commutating electrically without touching a mechanical part and requires sensors like hall-effect to sense the magnetic field to switch on the motors rotation. The hall-effect sensors in this type of motor operate by a magnetic field from permanent magnet, responding to North (release) and South (operate) poles. The sensor sense the poles in the motor and change the N and S poles as the poles with apposite polarity approach each other. With three phase power the brushless DC motors operates with two positive poles and a ground at a time.

The brushless DC motors speed constant (KV/V) is varying from couple of hundreds round per volt to over two thousands rounds per volt. The motors with low KV are usually used in systems that high thrusts are a factor. The middle KV rates are used in multi-copters that need both thrust and speed and the high KV rates are used just for high speed. Again the power efficiency of these motors is affected by the types of propellers dimensions.

To meet the requirement we sat for our project, we will choose the middle KV rates motors for our project, because it produce enough thrust to lift the UAV with planed payload and accelerate the UAV to an acceptable speed.

There are many reasons why this type of motor is most used in UAVs. The power system in UAVs is limited by using electric system and some important reasons are directly related to this system are their power efficiency, weight and speed. There are also easy to maintain and has long life time.

5.4 Propellers

Propeller is a mechanical device which is used to produce thrust in an UAV. The motor spin the propeller to generate a stream of air which in turn thrusts the propellers and UAV forward. The propeller dimension is specified by its twist and chord distribution. Different geometries provide varying performance characteristics such as maximum thrust, efficiency and maximum speed.

For the hexacopter there will be two kinds of propellers, the CW rotating, and the CCW rotating, making a total of 3 CW pairs and 3 CCW pairs.

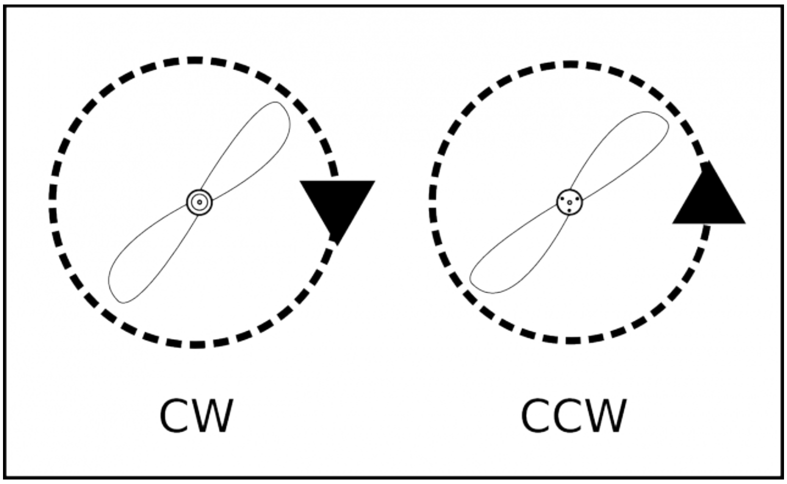


Figure 7: Propeller rotation

6.0 UAV - Control System

6.1 Flight Controller

When creating an autonomous multi-copter it should be able take in information from both ground station and GPS to determine the behaviour. Sensors make it possible for UAVs to communicate both with ground station and GPS system to operate as it should. UAVs can move in space in three dimensions and this makes controlling them more complicated than other robots. Many different sensors have to be used in combination to keep track of position and velocity of the UAV.

6.1.1 IMU

UAVs are inherently unstable machines and sensors must constantly make adjustment in order that UAVs can operate and stay stable. For this case the Integrated Measurement Unit is attached to the flight control that is meant to measure a physical quantity (for example temperature, or altitude) and convert it to a form easily readable and process able by the flight control. The IMU contains all the necessary sensors to determine the roll, pitch yaw of the UAVs and their rate of change. The microcontroller reads the output of these sensors and calculates the errors, and a correct value of their output will be made. The characteristics of these sensors are explained next.

Gyroscope

Gyroscopes are the sensors that measure angular velocity which is the rate at something is rotating. By rotating a vibrating mass produces a force perpendicular to the direction of oscillation.

Integrating the angular velocity of the UAV overtime gave its orientation relative to where it started. For measuring angular velocity we need to use a gyroscope sensor, to be able to know how fast something is spinning about an axis. For example if you want to control the orientation of an UAV in motion, an accelerometer may not give you enough information to know exactly how is oriented.

Accelerometer

An accelerometer is a device that measures acceleration on the x, y and z axes. Accelerometer can describes how fast something is spending up or slowing down and is used to sense both static (e.g. gravity) as well as dynamic (e.g. start/stop) accelerations

Barometer

A Barometer is a device that measures the atmospheric pressure and temperature. In the UAVs this sensor is used in two main aspects: one aspect is to be able to detect the weather for example if is windy, the other aspect is to measure the altitude of the vehicle.

Magnetometer/compass
A magnetometer is an instrument for detecting and measuring magnetic fields. Compasses are a single axis magnetometer. They give the angel they rotate from a calibration point, often magnetic north. For the UAVs, three magnetometers one for each axis can be used to measure the Earth's magnetic field vector.

6.2 GPS module

A global positioning system (GPS) devise is a helpful and commonly used sensor for a UAV and allows a flyer to find its exact location. The device measures the time it takes the signal to reach from four satellites in orbit and compute the distance it is from each, and find its exact location in space through geometry. In our project the GPS will be mostly used to coordinate the UAV positions and directions when we want to map an area. The mission plan over the target area will be send from ground station wirelessly to UAVs telemetry antenna and the flight controller connects the telemetry received and processed signal to the GPS system to fallow the planed waypoint. The UAV will be stable by the help of IMU and operate as normal in automated mode.

6.3 RC Receiver/Transmitter

The RC transmitter is a device that can be used to operate the UAV manually. The device transmits a radio signal with fixed frequency to the RF receiver. The RC transmitter with 2.4GHz is normal for the most UAVs and its signal range is about 1000 meter in open space. The purpose of RC transmitter is to control the operation and behaviour of the UAV. By using the different buttons of the device, the user will be able to control the UAVs behaviour as desired.

The RF receiver is a communication device attached to the UAVs. The device has several channels are connected to the flight control and can be used for different applications in the UAVs. It can be adjusted to receive a fixed signal which is transmitted from a radio control transmitter. The device converts the received radio signals which are analogue to a PWM signals and sends to the microprocessor in the flight control. The converted signal from receiver sends forward by flight control to the target ESC to regulate the speed of motors as required.

7.0 UAV - Control Design

7.1 Basic Movement

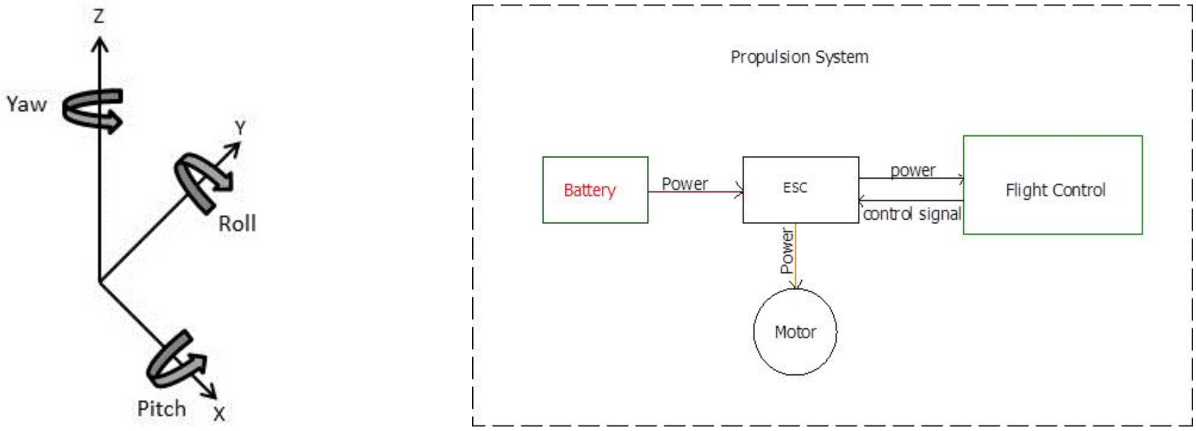


Figure 8: Basic Movement & Control

The basic movement of the hexacopter is executed through the propulsion system which consists of the batteries, the motors, the ESCs and the flight controller. The only way of controlling the movement is through the propeller rotation. On the hexacopter, there are three sets of clockwise rotating (CW) and three sets of counter clockwise rotating (CCW) propellers. The rotation of the propeller and motors exerts a reactional torque opposite of the direction of rotation, and the torque from the sets of CW and CCW propeller and motors cancel each other out when provided the equal amount of current and voltage through the ESCs.

The basic movements of the hexacopter are the throttle, the roll, the pitch and the yaw. These movements are performed by varying the speed of the propellers in a certain configuration.

7.1.1 Throttle

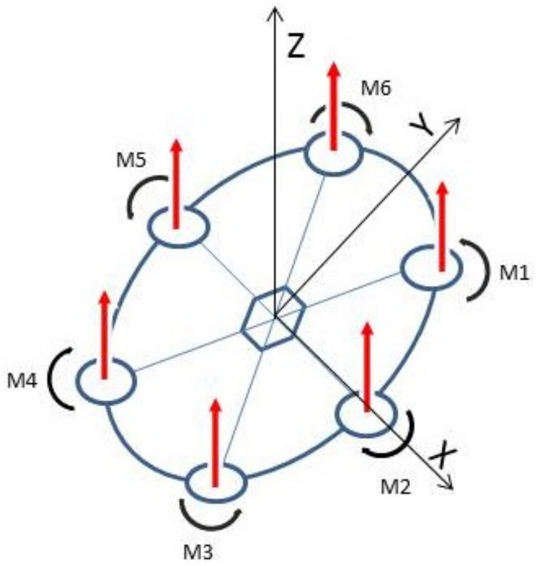


Figure 9: Throttle Control

The throttle of the UAV controls the amount of thrust that the hexacopter produces. It is governed by the gravitational force and must overcome this in order to move and accelerate in the vertical direction. If the hexacopter is pitched or rolled, the thrust will generate movement in the tilted direction.

7.1.2 Roll

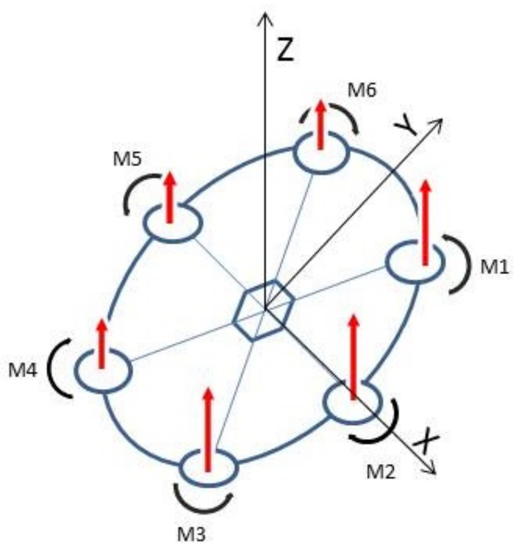


Figure 10: Roll Control

The control of roll is used to rotate the hexacopter around the y-axis. It works by increasing the speed of the rotors on one side of the y-axis while simultaneously decreasing the speed of the rotors on the opposite side. For instance, to tilt left, the

M1, M2 and M3 motors increase the rotational speed, while the M4, M5 and M6 rotors decrease theirs. A graphic illustration of this is shown in Figure 7.

7.1.3 Pitch

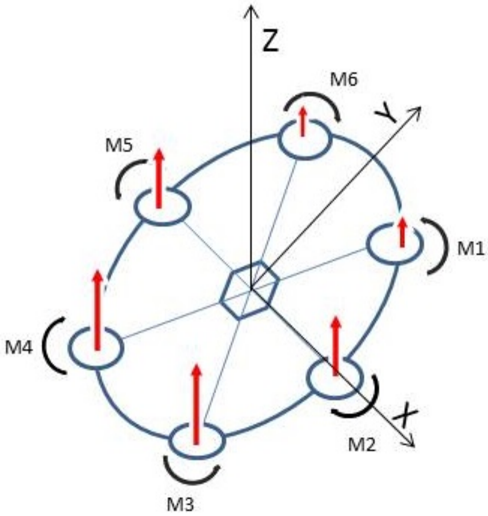


Figure 11: Pitch Control

The control of pitch is used to rotate the hexacopter around the x-axis. It works by increasing the speed of the either side of the x-axis while similarly decreasing the speed on the opposite side. The propellers located on the x-axis will rotate with the same speed, and range between the increased and the decreased propellers on each side of the axis. For instance, to pitch forwards the M4 and M3 rotors increase their speed, while the M2 and M5 propeller will maintain at the same speed, and the M6 and M1 decreases. A graphic illustration of this is shown in Figure 8.

7.1.4 Yaw

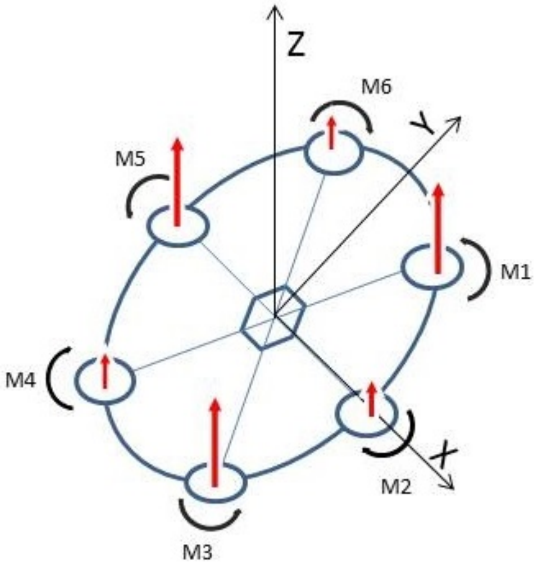


Figure 12: Yaw control

The control of yaw is used to rotate the hexacopter around the z-axis. It works by increasing or decreasing the speed of the CCW rotor while decreasing or increasing the speed of the CW rotors. With increasing speed of the CCW or CW rotors the reactional torque is no longer cancelled out and the hexacopter starts rotating. For instance, to rotate the hexacopter clockwise the CCW rotors increase their speed while the CW rotors decrease theirs. The CCW rotors now generate a larger reactional torque in the opposite direction of rotation, causing the hexacopter to rotate clockwise. A graphic illustration of this is shown in Figure 9.

7.2 Basic control and communication with the Hexacopter

The means of controlling the UAV is either through a hand-held remote controller or through a USB remote controller connected to the ground station. This method of communication is described more in section 5. The hexacopter is fitted with a radio receiver that filters the distorted signals and transforms the signal into an electric pulse. This signal is sent to the flight controller, which chooses the designated ESCs to execute the control. The ESCs varies the speed of the motor by turning on and off the current to the different poles in the motor, to either decrease or increase the speed depending on the requested control from the user or the ground station. This process is shown in the sequence diagram found in Appendix A – Sequence Diagram 1: Remote Control.

The two following section, gives an overview of the two modes of operating the hexacopter

7.3 Manual Operation

The manual operation of the hexacopter is executed through the hand-held radio controller. This operation is derived from the use case UC01 – Manual Operation and the requirements URQ-SPR-01, URQ-SPR-03;

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-01	TS-UAT-S01	A	The user shall be able to operate the UAV manually using a remote control	STG
URQ-SPR-03	TS-UAT-S03	B	The user should be able to monitor the battery status, height, speed and position of the UAV	STG

Table 5 Requirements – Manuel Operation

Manual operation is used to test the hexacopter when new functions or equipment is installed, or for take-off and landing in difficult operating environments, such as in hares weather conditions or when the GPS has no or low signals. The process of this operation is described in the activity diagram in Appendix B – Activity Diagram 1: Manual Operation.

7.4 Automated Operation

The automated operation of the hexacopter is executed through the USB radio controller connected to the ground station. This operation is derived from the use case UC02 – Automated operation and the requirements URQ-SPR-02, URQ-SPR-03:

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-02	TS-UAT-S02	A	The user shall be able to pre-program the UAV to operate on its own	STG
URQ-SPR-03	TS-UAT-SP03	B	The user should be able to monitor the battery status, height, speed and position of the UAV	STG

Table 6 Requirements – Automated Operation

Automated operation is essential for the total 3D mapping system, and is the operating mode that the hexacopter will execute when 3D mapping terrain. It is through the automated operation that the camera system and the hexacopter have their interactions. The process of the automated operation of the hexacopter is described in the activity diagram in Appendix B – Activity Diagram 2: Automated Operation. The process of the picture shooting process is described in the camera architecture.

7.5 Failsafe systems

The failsafe systems are needed as per requirements specification. The failsafe architecture of the failsafe systems is derived from the safety requirements:

REQ ID	ITP ID	PRY	Description	Origin
URQ-SFR-02	TS-SIT-SF02	C	The UAV should not crash in the event of battery loss	STG
URQ-SFR-03	TS-SIT-SF03	C	The UAV should not crash in the event of signal loss	STG

Table 7 Requirements – Failsafe Systems

These requirements states that the system should not crash in the event of battery or signal loss when operating the UAV.

The user configures the failsafe systems when connecting and installing the flight software and the ground station.

7.5.1 Radio Signal Loss

This failsafe system seeks to prevent that the system crashes in the event of Radio Signal Loss. This event can occur if:

- The pilot turns of the RC transmitter
- The hexacopter travels outside of the RC range
- The receiver loses power
- The wires connecting the receiver to the flight controller are broken

The architecture of the Radio Signal loss failsafe is described through the activity diagram in Appendix B – Activity Diagram 3: Failsafe Signal Loss.

7.5.2 GPS Signal Loss

This failsafe system seeks to prevent that the system crashes in the event of GPS signal loss. This event can occur if:

- The pilot disables the GPS mode in the ground station
- The GPS lock is lost
- The wires connecting the GPS to the flight controller are broken

The architecture of the GPS signal loss failsafe is described through the activity diagram in Appendix B – Activity Diagram 3: Failsafe Signal Loss.

7.5.3 Battery Warning System

The battery warning systems is aided to inform the pilot when the battery is at a critical low or at the decided level. The user configures this level prior to flight. The system seeks to prevent that the pilot lands the hexacopter before the battery voltage is too low to power the motors. The architecture of the battery warning system is described through the activity diagram in Appendix B – Activity Diagram 4: Battery Warning System.

8.0 Camera System

8.1 Camera Overview

This document does not aim to specify any explicit camera to use in this project. Any camera that satisfies the criteria's put forward in this document could potentially be used for this project. The main object is to illustrate high-level operation and how the system is going to meet the requirements in the requirements specification.

A more thorough analysis of different suitable cameras will be done in another document.

Note also that the control system discussed in this section is part of the same control system discussed in the UAV section. In this chapter, only the functionality related to the camera system will be presented.

8.2 Work Breakdown Structure

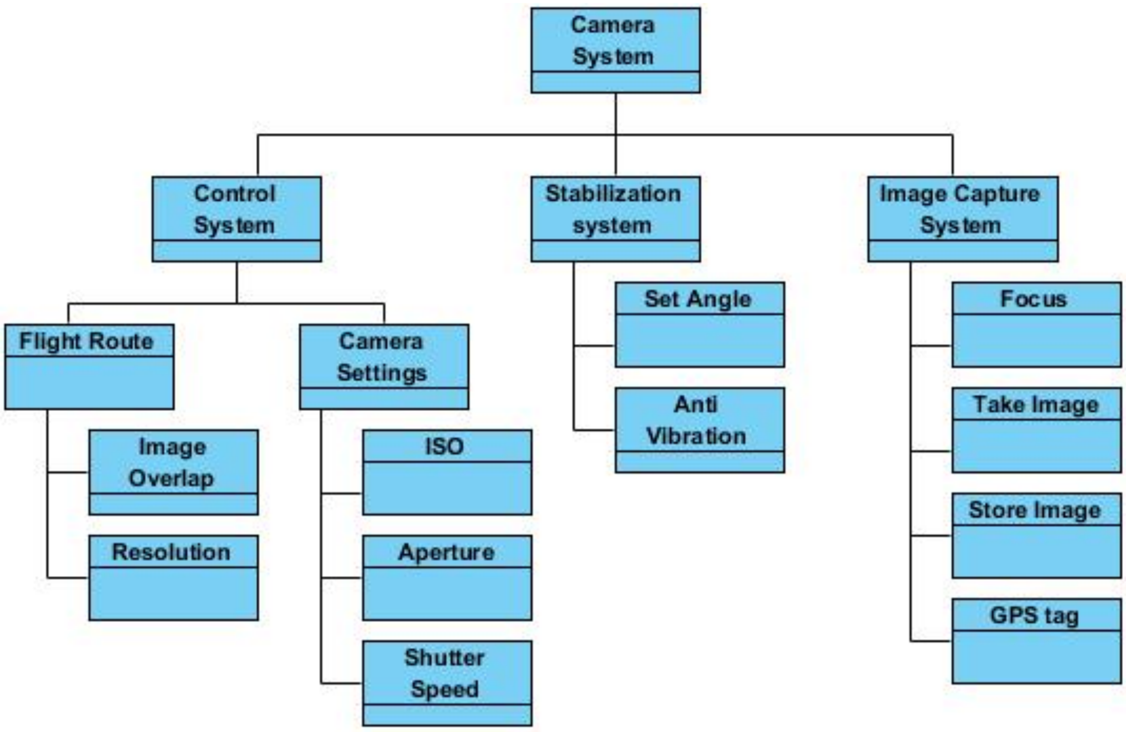


Figure 13: Work Breakdown Structure - Camera

Figure 13 shows the Work Breakdown structure of the camera system. This is a decomposition of the system into smaller, more manageable components. This breakdown structure makes it easy to get an overview of the system and to verify that requirements are covered by the system architecture. The camera system is divided into three subsystems:

- Control System
- Stabilization System
- Image Capture System

These subsystems are divided further for more detail.

8.2.1 Control System

The control system has two main subdivisions:

- Flight Route
- Camera Settings

The flight route is where the planning of the image acquisition takes place. In practice this is the same process as setting up the flight route for the UAV. This is where the user will be able to input when and where to take the pictures along with all the other parameters for the UAV flight. The advanced control system is a central part of the system and serves as the solution to the requirement listed below.

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-04	TS-UAT-S04	A	The user shall be able to pre-program the picture shooting process	STG

Table 8 Requirements – Automated photography

The other subdivision is the Camera Settings, where the user will be able to input basic camera parameters to get the correct image exposure. Achieving the correct exposure is vital in order to ensure that the images are usable in the 3D modelling process. Pre adjustment of camera settings also reduces the risk for any latency related problems.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-16	TS-SIT-C16	A	The system must be able to adjust basic camera settings to achieve correct image exposure.	STG

Table 9 Requirements – Camera Settings

8.2.2 Stabilization System

The stabilization system will have two main tasks:

- Set angle
- Reduce vibrations

Setting the angle involves physically adjusting the orientation of the camera. The ability to change the angle makes the system much more flexible in terms of capturing data in hard to reach locations.

The stabilization systems main job will be to prevent mechanical vibrations from manifesting themselves as motion blur in the images. Excessive motion blur will render images useless in a 3D modelling process.

8.2.3 Image Capture System

The image capture system is where the actual photography process will be executed and stored. The main tasks will be:

- Focus
- Take image
- Store image
- GPS tag image

The image capture system will receive instructions form the control system to take pictures at specific waypoints, with a specific set of camera settings. The images are then stored on a storage unit along with the unique GPS coordinates for each image. The camera must be equipped with an internal GPS to fulfil the requirement listed below. This geo-reference is vital for the 3D modelling process that will take place later on.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-09	TS-SIT-C09	A	The system must be able to geo-tag images	STG

Table 10 Requirements – Geo-tagging

8.3 Product Breakdown Structure

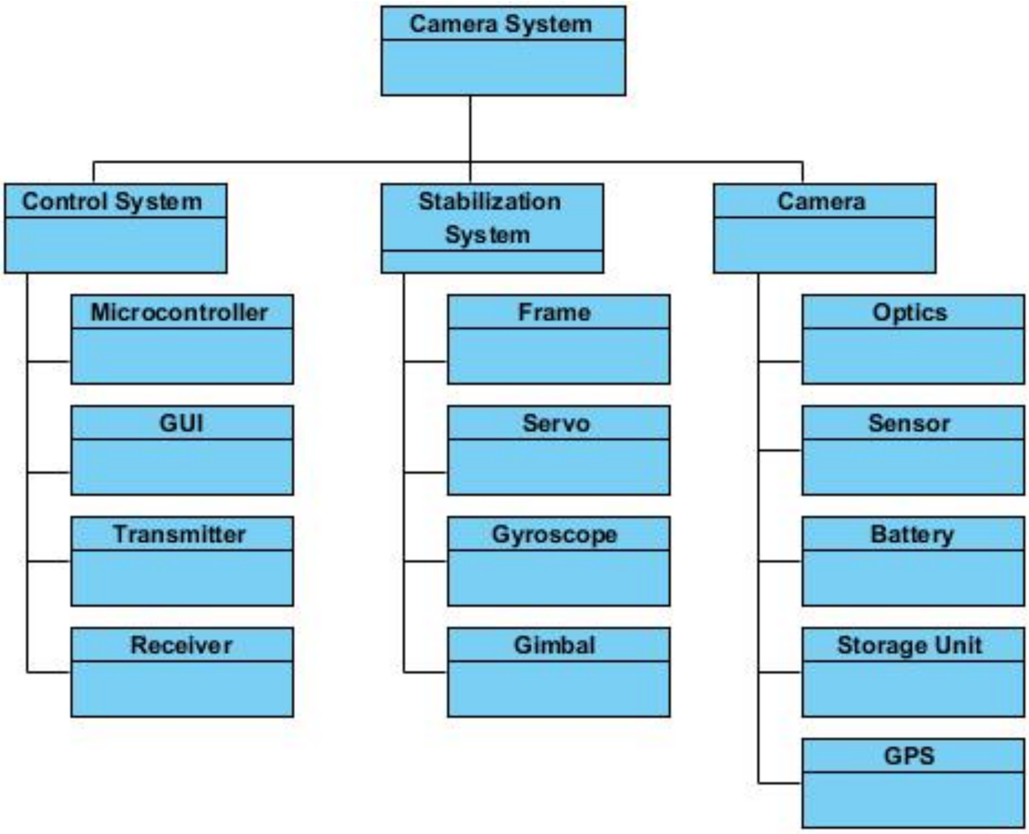


Figure 14: Product Breakdown Structure - Camera

The product breakdown structure is a decomposed view of the system and the different subsystem parts. Along with the work breakdown structure, this diagram makes it easier to get an overall view of the system, and manage components according to the requirements specification.

8.3.1 Control System

The control system is comprised of four main components:

- The Microcontroller (also called the flight controller)
- Software w/GUI
- Transmitter
- Receiver

The microcontroller (situated on the UAV) is the central brain of the system and is the main communication channel that links the different parts of the total system together. The microcontroller sends instructions regarding camera settings and when to take a picture, to the camera.

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-04	TS-UAT-S04	A	The user shall be able to pre-program the picture shooting process	STG
URQ-CR-16	N/A	A	The system must be able to adjust basic camera settings to achieve correct image exposure.	STG

Table 11 Requirements – Automatic photography & Camera settings

The microcontroller receives instructions from the software with a GUI, where the user inputs the wanted system parameters. Instructions and settings are communicated via a transmitter/receiver system.

8.3.2 Stabilization System

The stabilization system is comprised of three main components:

- Frame
- Servo Engine
- Gyroscope
- Gimbal

The camera will be connected to the rest of the UAV via the frame of the stabilization system. The system makes sure the cameras orientation in relation to a particular direction remains stable and that vibrations caused from motors or turbulence are minimized. This increases the likelihood of acquiring a usable photography.

8.3.3 Camera

The camera is comprised of four main components:

- Optics
- Storage Unit
- Battery
- GPS

The optics and the sensor of the camera will have a large impact on the quality of the images. This document will not specify a specific set of demands related to the camera specification, but some design considerations will be discussed in section 1.4. These design considerations will also be directly linked to some of the requirements in the requirements specification that have not yet been covered in this chapter, but have a significant impact on the system as a whole.

The storage unit is important as it must be of such a capacity that the requirement listed below can be fulfilled.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-11	TS-SIT-C11	A	The system shall be able to store at least 500 images.	STG

Table 12 Requirements – Storage Capacity

This is a somewhat inaccurate requirement as there are a lot of variables that will determine the actual size of an image and thus the total storage needed. The storage capacity should be selected such that the requirement holds true for the most common, standard image formats used in 3D modelling.

A typical image acquisition will often contain several hundred images. It is therefore important that the battery capacity is sufficient in order to satisfy the requirement listed below.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-10	TS-SIT-C10	A	The system shall have enough battery capacity to do 500 exposures in one flight.	STG

Table 13 Requirements – Camera Battery

To increase the battery time and avoid a situation with empty camera battery, the camera will be hooked up to the UAV battery. This will ensure that a minimum of 500 exposures in one flight is achievable.

8.4 Important Design Considerations

8.4.1 Sensor size and pixel count

The sensor size and the pixel count are important parameters for the overall resolution of images. In general, a higher resolution will increase the accuracy of the final 3D model. Increasing the sensor size and the pixel count could also affect requirements concerning areal coverage and processing time.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-05	TS-SIT-C05	A	The System shall be able to map an area of minimum 10 000 square meters.	STG
URQ-CR-07	TS-SIT-C07	B	The system should not exceed a process time of 72 hours to create a digital 3D model	STG

Table 14 Requirements – Areal Coverage & Process time

An increase in camera resolution could make a higher flight height possible while still maintaining an adequate GSD (Ground sampling distance). This in turn leads to shorter flight times and shorter image processing times.

8.4.2 Weight

The weight of the camera will impact the areal coverage. A higher payload will warrant bigger motors with more thrust, which in turn will impact the battery capacity. Weight is one of the most vital areas to consider when choosing a camera. Lower weight leads to more areal coverage.

8.4.3 Cost

Higher resolution and lower weight often means an increase in cost. The final selection must strike a balance between quality and cost and maintain within the budget limitations.

8.5 Sequence Diagram

The sequence diagram shows the interactions between objects in the sequential order that interactions occur. The sequence diagram is based on the workflow stated in use case: UC03, found in the requirement specification. Sequence Diagram 2: Camera and Image Processing can be found in Appendix A.

8.6 Activity Diagram

The activity diagram shows a stepwise workflow of the system. The activity diagram is based on the workflow stated in use case: UC03, found in the requirement specification. Activity Diagram 5: Automated Photography can be found in Appendix B.

9.0 Image Processing System

9.1 Image Processing Overview

This document does not aim to specify any explicit image processing software to use in this project. Any software that is capable of producing results within the constraints of the requirements and the criteria's put forward in this document, could potentially be used for this project. The main object is to illustrate high-level operation and how the system is going to meet the requirements in the requirements specification.

A more thorough analysis of different software alternatives with comparison of features and rendering results will be performed in another document.

9.2 Work Breakdown Structure

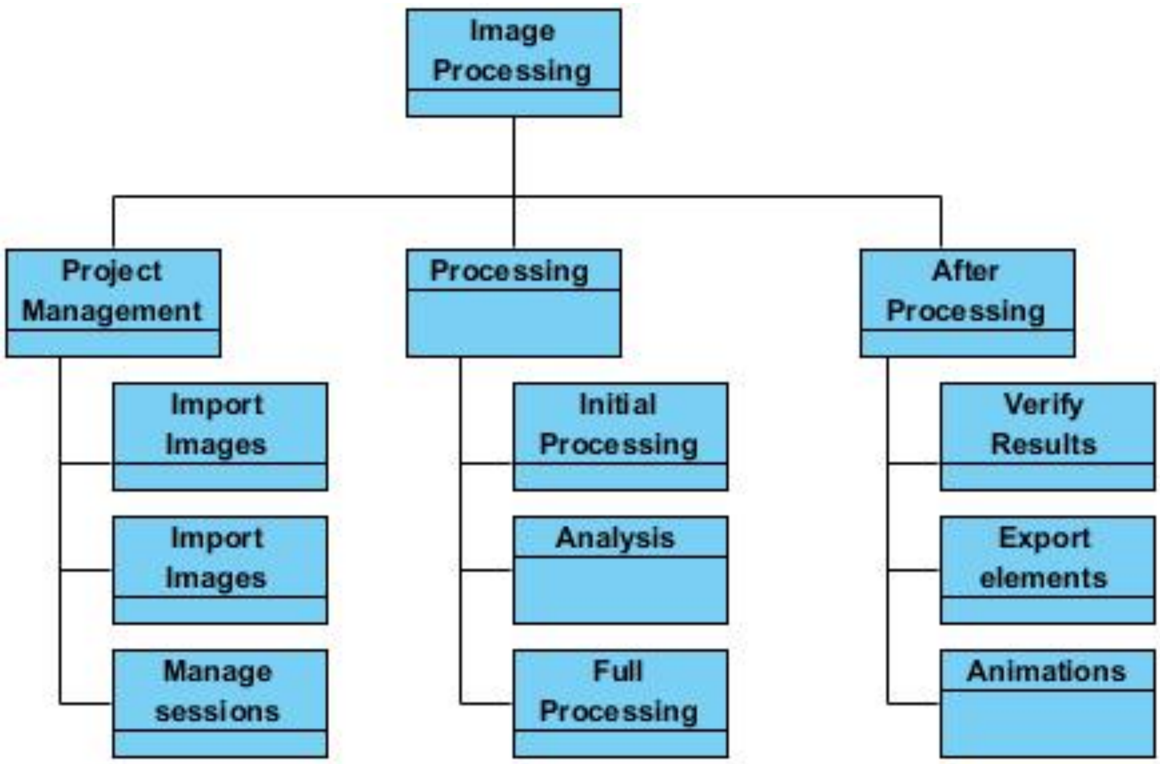


Figure 15: Work Breakdown Structure – Image Processing

Figure 15 shows the Work Breakdown structure of the image processing system. This is a decomposition of the system into smaller, more manageable components. This breakdown structure makes it easy to get an overview of the system and to verify that requirements are covered by the system architecture. The Image Processing system is divided into three parts:

- Project Management
- Processing
- After Processing

The project management section consists of importing images and configuring the project session details. The processing section contains the main processing and the after processing consists of verifying results and exporting the desired elements.

The size of the project – number of images, image filesize – will affect the total processing time. The total system process time (from image acquisition to 3D rendering) should not exceed the limit stated in the requirement below.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-07	TS-SIT-C07	B	The system should not exceed a process time of 72 hours to create a digital 3D model	STG

Table 15 Requirements –Process time

The after processing section contains the different export possibilities, which makes it possible to implement a 3D printer and make a physical model.

REQ ID	ITP ID	PRY	Description	Origin
URQ-SPR-05	TS-UAT-SP05	C	The user should be able to print a physical model of the 3D map, using a 3D printer	STG

Table 16 Requirements – Export format

9.3 Product Breakdown Structure

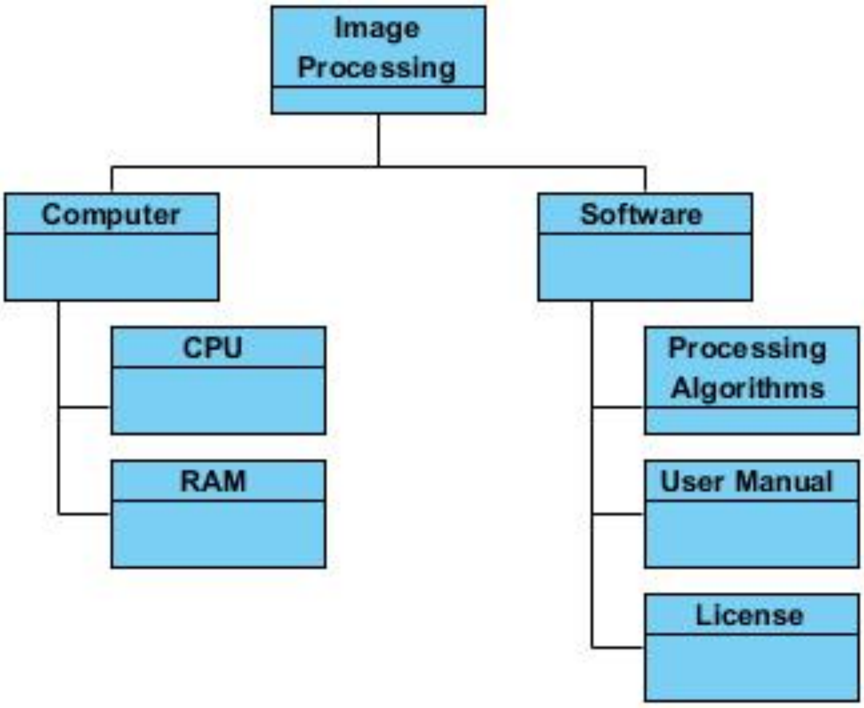


Figure 16: Product Breakdown Structure – Image Processing

The product breakdown structure shown above is a simple representation of the most basic elements in the image processing system. The computer used for processing will affect the processing time. The processing algorithms and the source code optimization will also affect the processing time.

Depending on the software – if it is open source or a proprietary system – the software might need some sort of license to enable use. A proprietary system might involve a pretty big investment and must be taken into account when deciding on the image processing software to use in this project.

The user must familiarize himself/herself with the user manual, in order to get the best results out of the software processing.

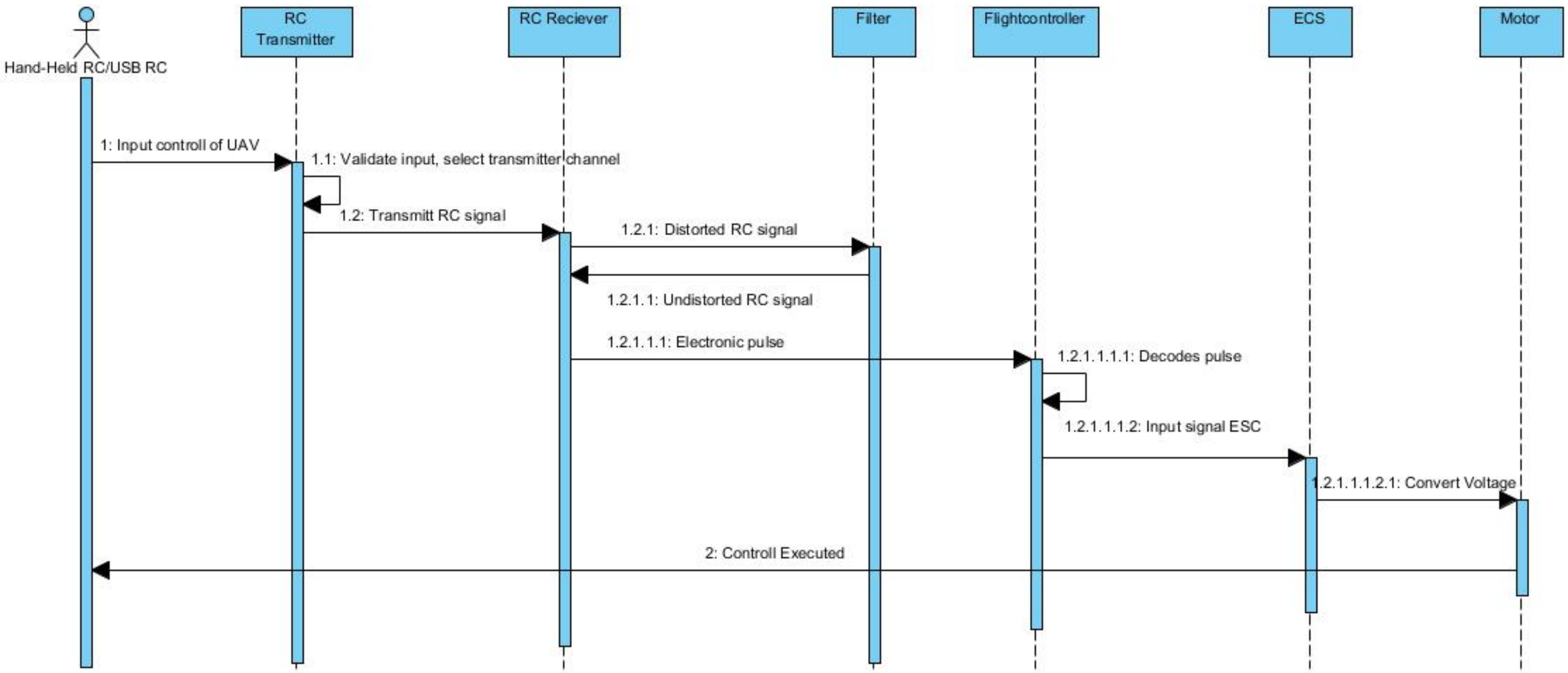
9.4 Sequence Diagram

The sequence diagram shows the interactions between objects in the sequential order that interactions occur. The sequence diagram is based on the workflow stated in use case: UC03 and UC04, found in the requirement specification. This is a sequence diagram for both the Camera system and the Image Processing. Sequence Diagram 2: Camera and Image Processing can be found in Appendix A.

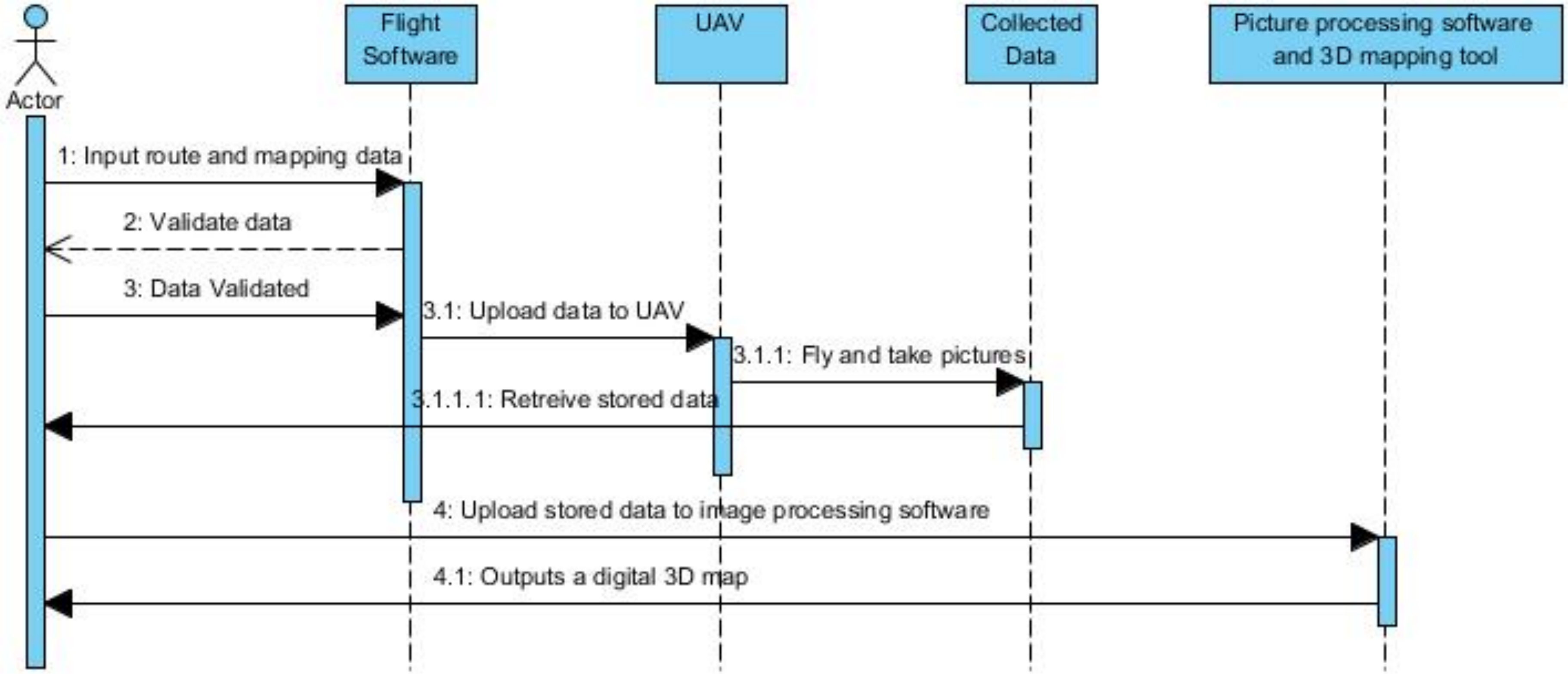
9.5 Activity Diagram

The activity diagram shows a stepwise workflow of the system. The activity diagram is based on the workflow stated in use case: UC04, found in the requirement specification. Activity Diagram 6 – 3D Image Processing can be found in Appendix B.

10 Appendix A

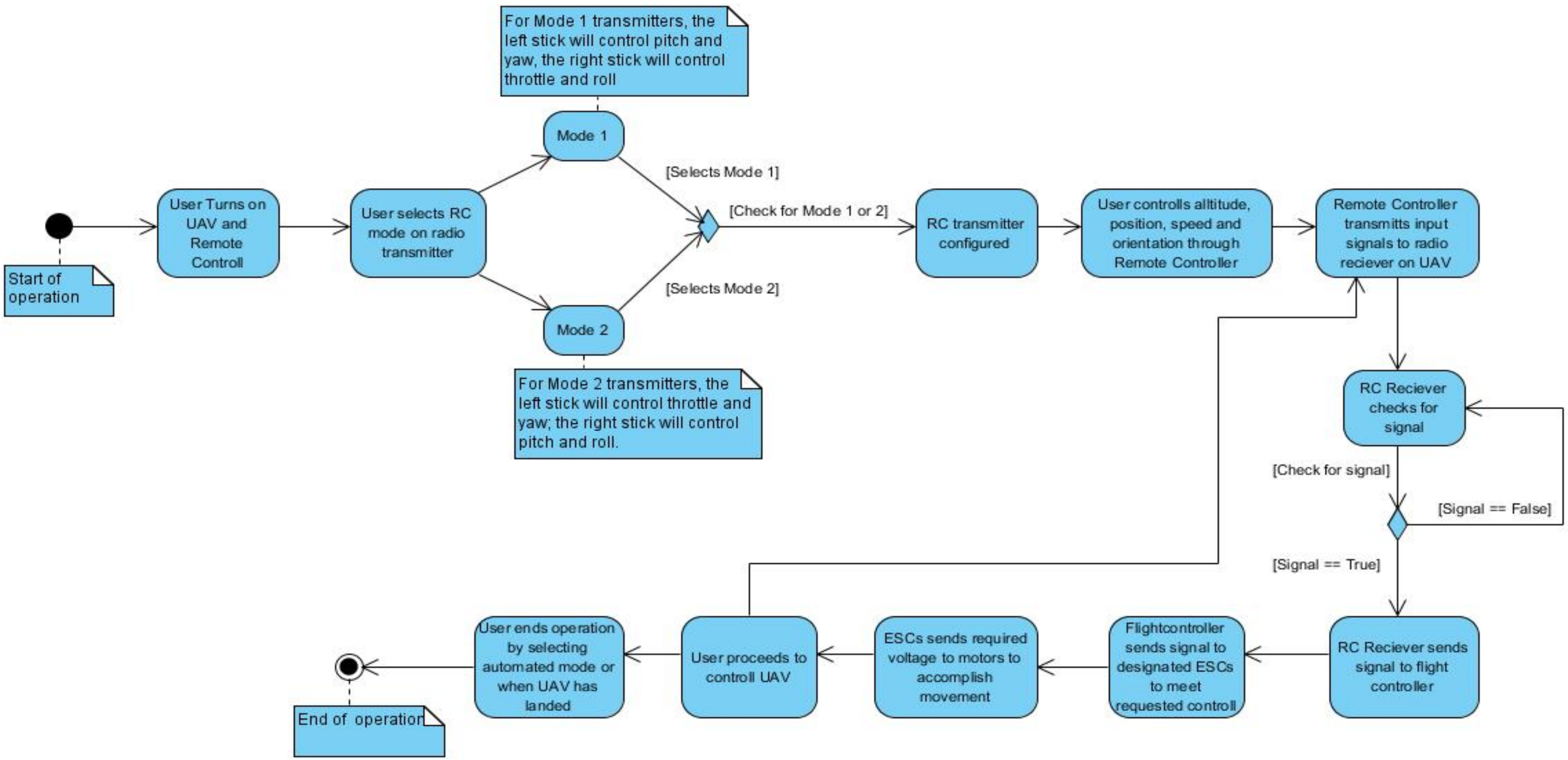


Sequence Diagram 1: Remote Controll

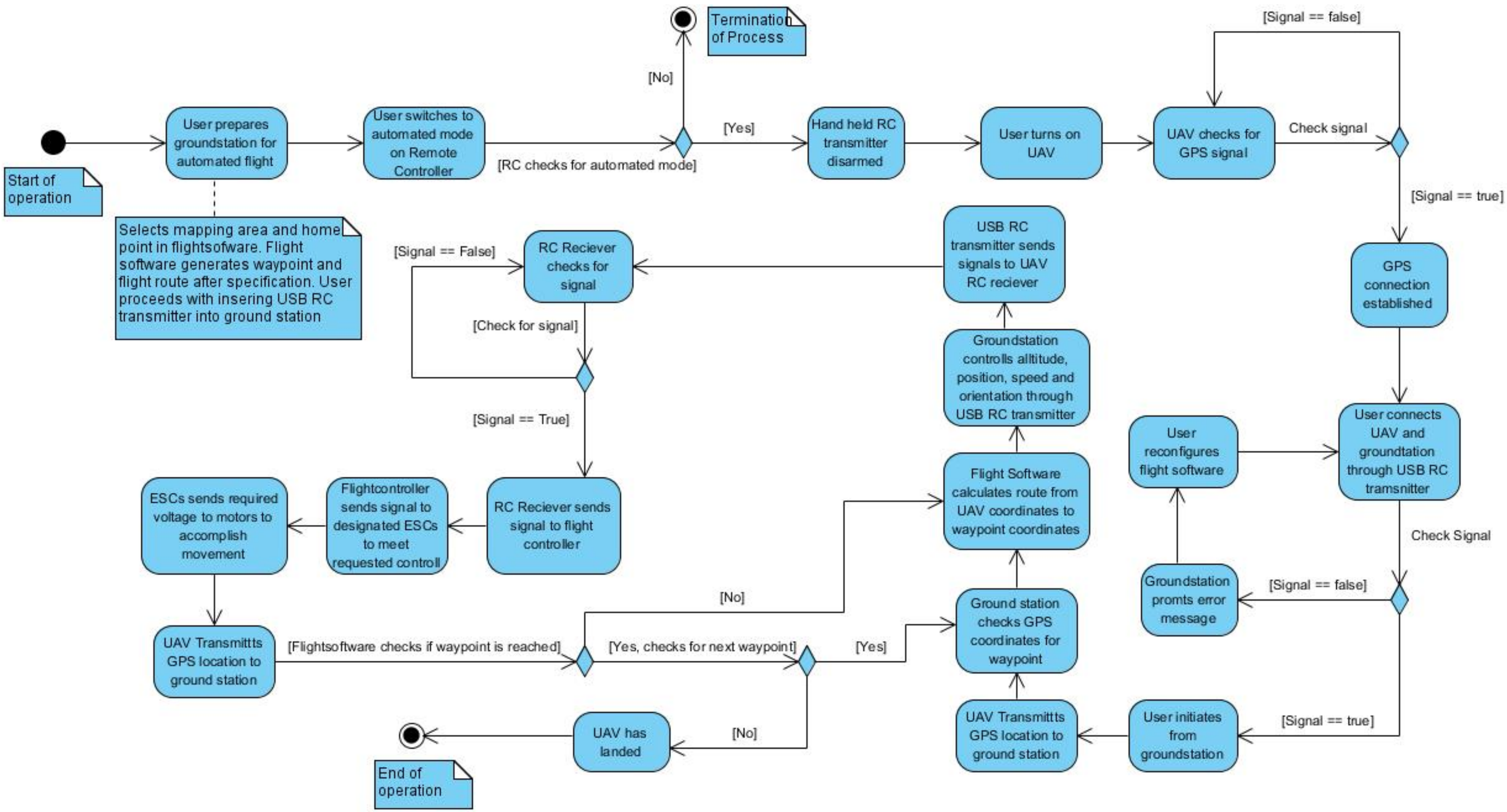


Sequence Diagram 2: Camera and Image Processing

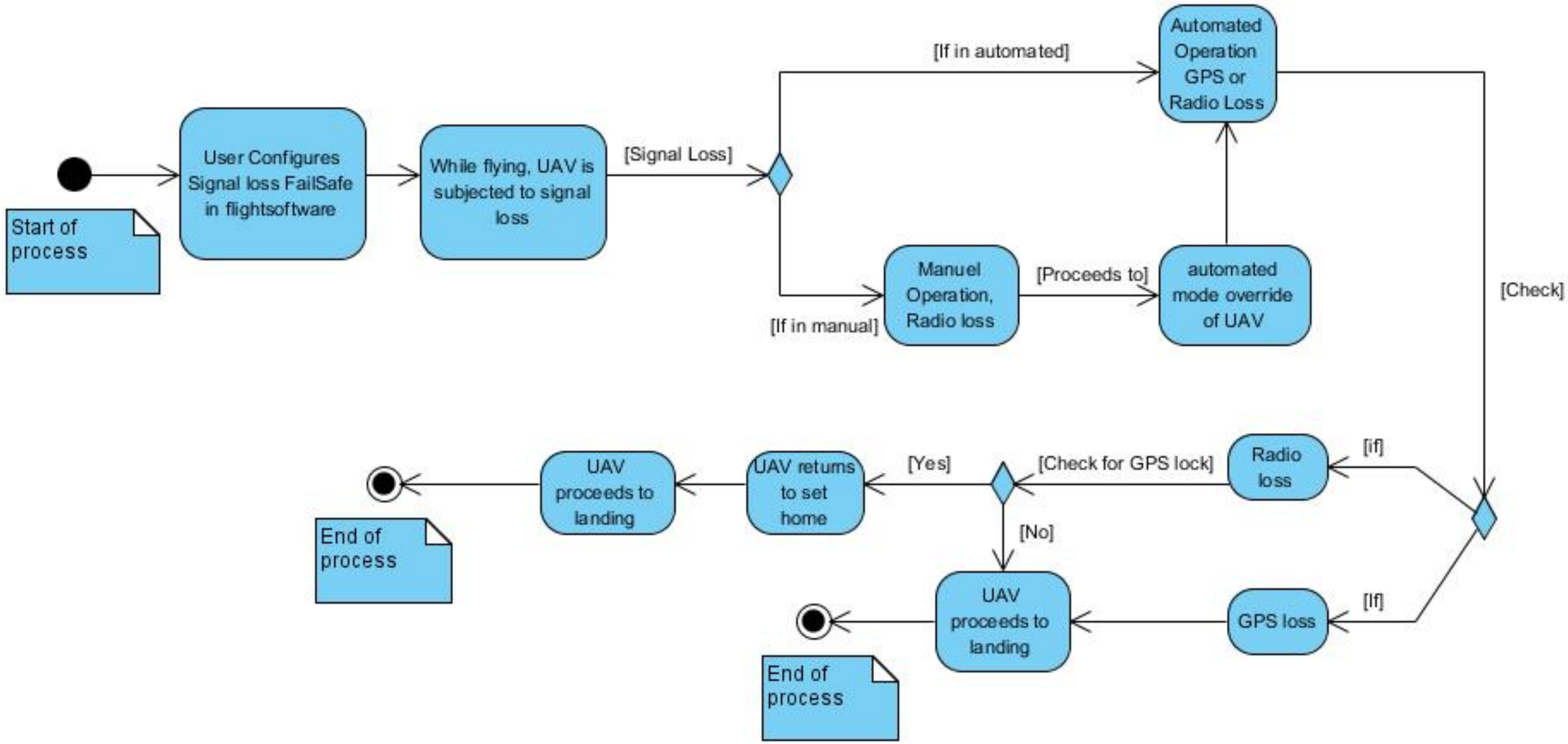
11 Appendix B



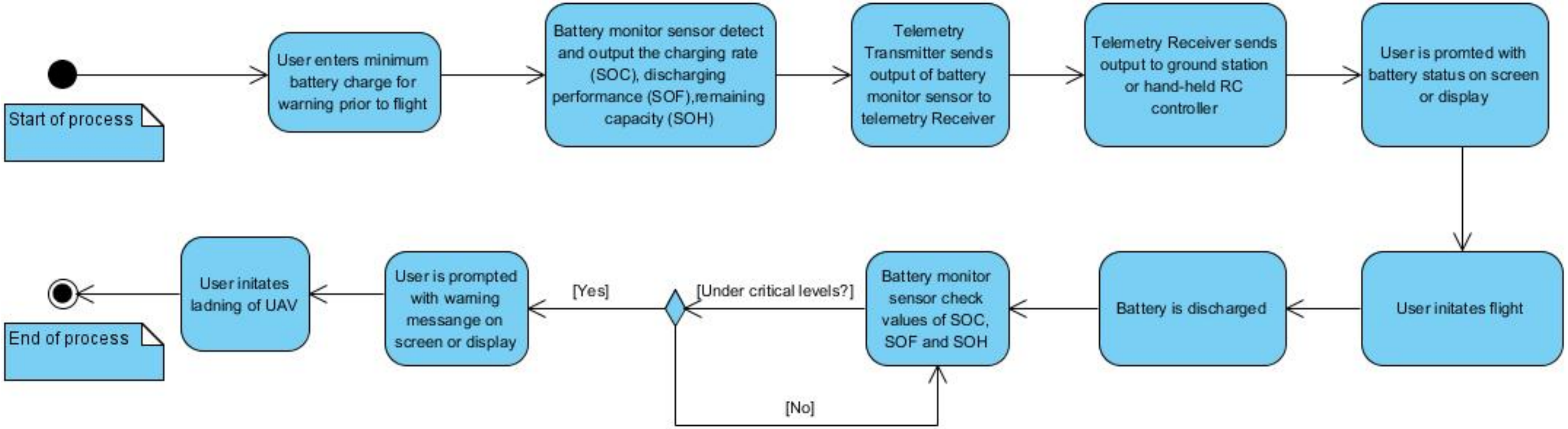
Activity Diagram 1: Manual Operation



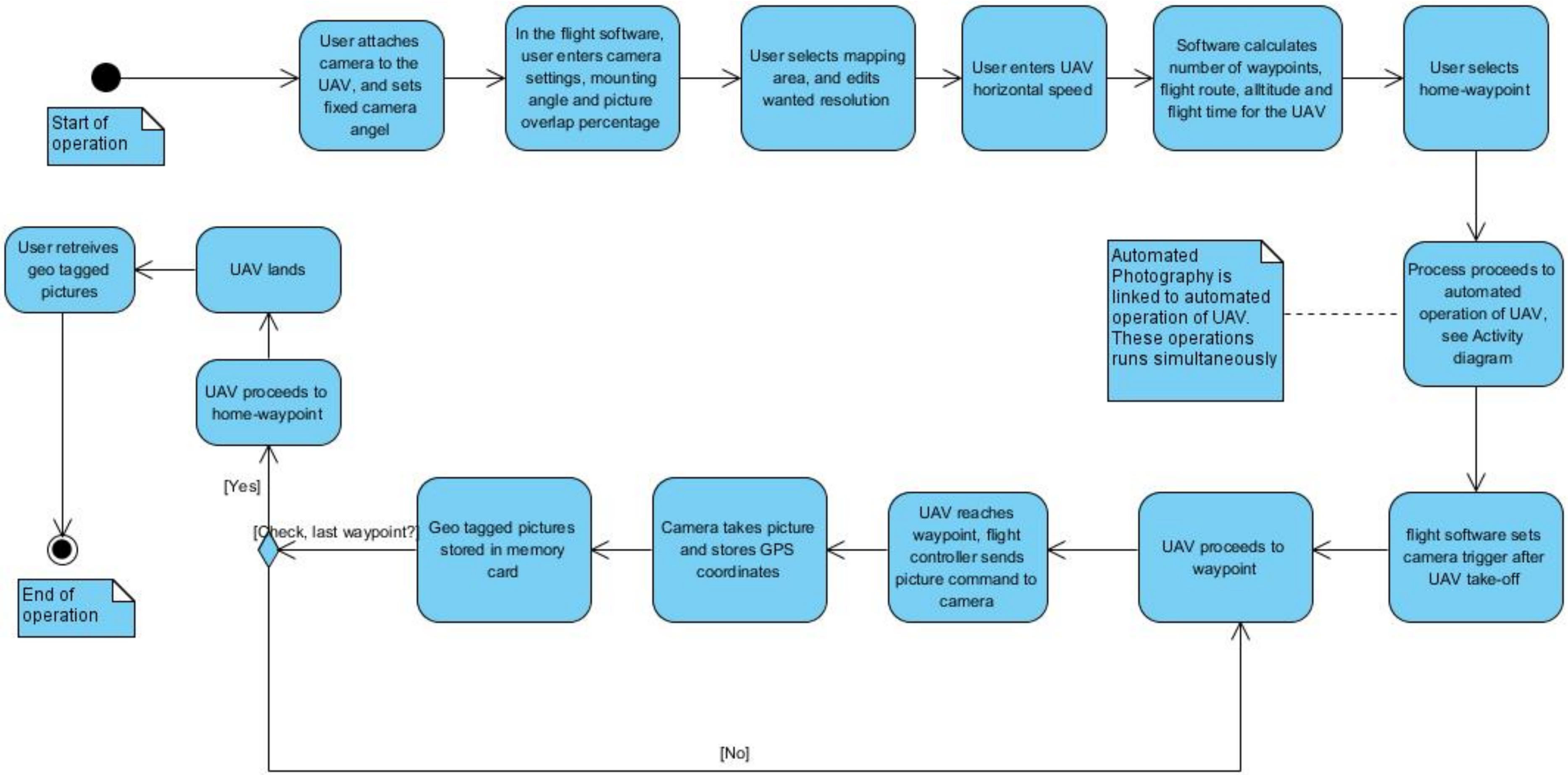
Activity Diagram 2: Automated Operation



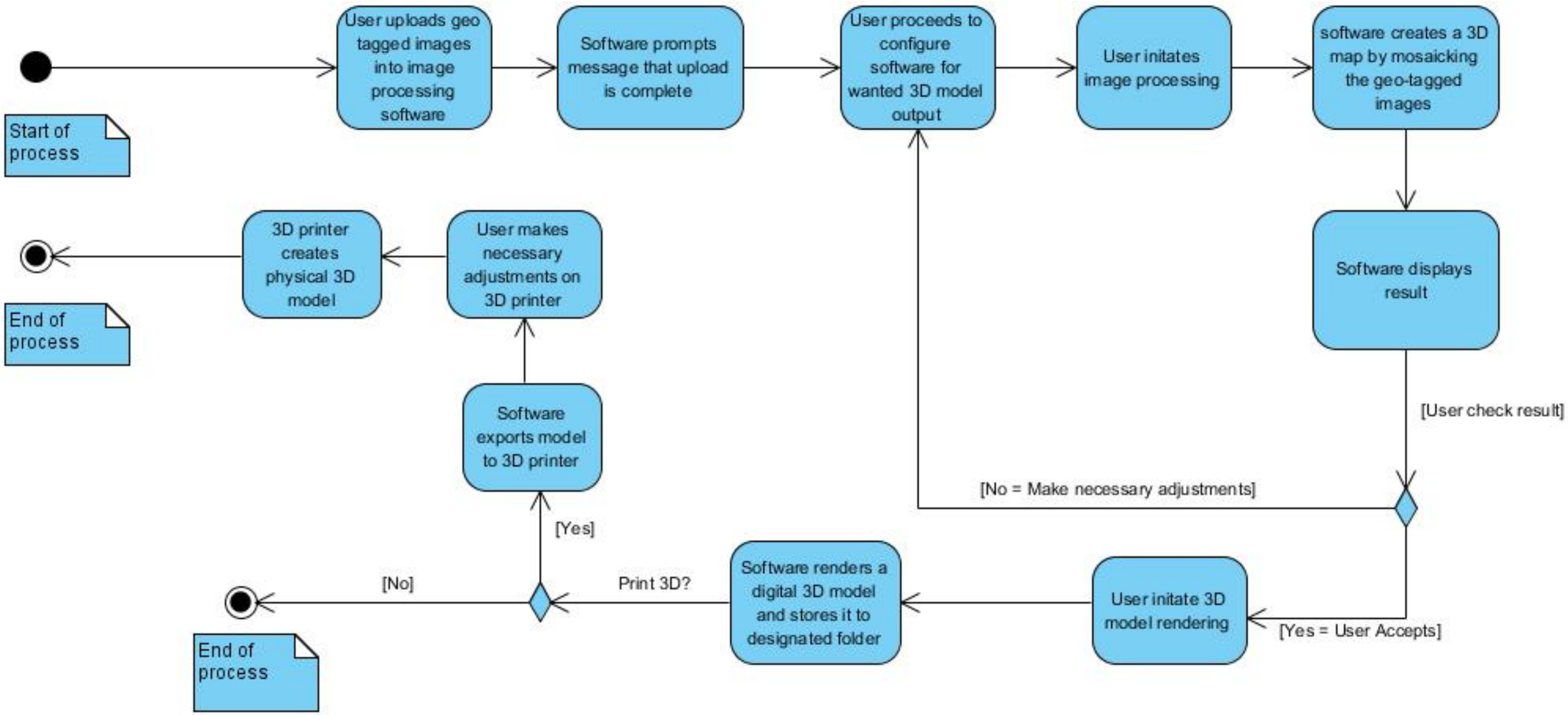
Activity Diagram 3: Failsafe Signal Loss



Activity Diagram 4: Battery Warning System



Activity Diagram 5: Automated Photography



Activity Diagram 6: 3D Image Processing

Technical Reports

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
V1.0	13.05.2015	N/A	N/A	Released

Summary:

This document gives an overview of the technical reports for the 3D Ground Mapping system.

Owner: N/A

Technical Reports Overview

Document ID	Document Name
009A	Technical Report – Mechanical properties of UAV
009B	Technical Report – Electrical and Software
009C	Technical Report – Camera
009D	Technical Report – Image Processing
009E	Technical Report – Analysing UAV Crash

Technical Report – Mechanical Properties of UAV

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	15.05.2015	BJD	TTP	Released

Summary:

This document is intended to describe, validate and verify the mechanical properties of the UAV in accordance with the requirements specification.

Owner: Ole Petter Christensen

Document Revision History

Rev	Date	Author	Description	Status
0.1	20.04.2015	OPC	Mechanical Properties of UAV	Obsolete
1.0	15.05.2015	BJD	Final Version V1.0	Released

Table of Contents

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1.0 Introduction

1.1 Purpose of this document

This document contains the verification of the mechanical aspect to the UAV in accordance to the requirements specification. The purpose is to describe the characteristics and overall requirements for an airframe, present our selection and verify it by using computer aided design and finite element analysis in SolidWorks.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
2D	Two dimensional
3D	Three dimensional
Al.	Aluminium
APM	Auto Pilot Module
CAD	Computer-Aided Design
CFRP	Carbon Fibre Reinforced Polymer
ESC	Electronic Speed Controller
ESTRN	Equivalent Strain
FEA	Finite Element Analysis
KV	Revolution per Volt
PAN	Polyacrylonitrile
PC	Polycarbonate
PMC	Polymer-Matrix Composite
RC	Radio Controlled
SW	SolidWorks
TDS	Technical Document Sheet
Tg	Glass Transition Temperature
Tβ	β-Transition Temperature
UAV	Unmanned Aerial Vehicle
URES	URES = SQRT $([Ux]^2 + [Uy]^2 + [Uz]^2)$. Resultant Displacement of vector U

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents referenced in this document

Doc. number	Description
002	Requirements Specification
004	Inspection and Test Plan

Table 2 Related Documents

2.0 Frame Selection

2.1 Mechanical Properties

The overall characteristic for any airframe is that is has to be light, strong and capable of operating in the required environment. The design, material selection and construction of any airframe are driven by consideration of a range of failure modes, which will be discussed in this document.

One of the most important things is to define the operating environment, such as determining loads, reliability requirements and climate conditions. This will contribute to design a product that meets the requirements and reduces the overall manufacturing and material costs.

For our system, we need a stable platform to take pictures, a structural framework that can handle the payload of a digital camera and that provides the structural framework for the powertrain and the control system of the UAV. To increase the flight time, but still have the capability of carrying payload, it is a need for lightweight high strength materials. As we have previously defined, the operating environment for our system is non-rain, non-snow, with winds that do not exceed 15 m/s. This, however, is not limited by the frame, but by the electronic components of the system and the camera.

Since we have to use parts that are found stock at Cube A/S we will not design or manufacture any physical frame. We will use computer aided design to model the frame that is available, and use finite element analysis to determine whether it meets the requirement specification. The teams concern is that the motors available are too powerful for the frame.

2.2 Tarot FY680 TL68B01

The Tarot FY680 is a Hexa-X frame, with a full folding six axis configuration with 60º apart each arm. It has a 680 mm wheelbase (the diameter of the periphery circle that runs through the centre of each motor), measures 265 mm in height and weighs approximately 600 grams. It is made of Toray T-300 K 3K carbon fibre reinforced polymer, high strength thermoset plastics and aluminium. Bolts and screws are designed with high grade steel, M 2.5 and M 3.0 with ISO metric thread.

In the configuration requirements from Tarot, it is stated that it is rated for 10-13 inch propellers, and 2212/2214/2814 Series brushless motors with a KV of 880-1000. It is rated for moderate payload capabilities, such as a small digital camera. (TL68B01 Product Desciption)

Tarot states that it is designed for users with high portability requirements, and is well suited for applications like surveillance, remote sensing aerial photography and mapping. (TL68B01 Product Desciption)

It is made by a Chinese company called Tarot, which has a wide selection of products within the aerial RC market segment. The company is recognized by professionals and hobbyists all over the world.

2.3 Requirements

The only requirement linked to the mechanical components of the UAV is the one listed below.

REQ ID	ITP ID	PRY	Description	Origin
URQ-SFR-04	TS-SIT-SF04	A	The UAV should not crash due to mechanical failure	STG

Table 3 Requirements

This requirement includes the propellers and the frame of the UAV, where the propellers are not included in the CAD or the FEA testing since these are dependent on the motors. However, the size and dimensions of the propellers needs to be verified and validated in compliance with the used motor in accordance to the rated operational requirements from the manufacturer.

Mechanical failure is described as surface fracture that may eventually lead to component failure. Cracking is the initial stage of this failure, and as cracks starts to grow, they eventually become interlinked and may cause a fracture. There are several types of failure modes that will lead to this scenario, such as excessive deflection, buckling, ductile fracture, brittle fracture, creep, thermal shock, corrosion and various types of fatigue.

Since the frame is bought stock for our system, we will not test every scenario listed in the previous paragraph. As mentioned in section 2.1 we will attempt to verify that the frame is compatible with larger motors than what is stated in the configuration requirements from the manufacturer.

3.0 Carbon Fibre Reinforced Polymers

Carbon-Fibre-Reinforced Polymer (CFRP) is an extremely strong fibre reinforced polymer which contains carbon fibres. CFRP is a polymer-matrix composite (PMC) where the fibre is the discontinuous face and the polymer is the continuous or binding face. The carbon fibres are strong, stiff, brittle and abrasive, and have low structural value alone, while the polymer has low strength and is very ductile. The composite gains its mechanical advantages with the combined properties of both fibre and polymer.

3.1 Toray T-300K 3K

The T-300K is a PAN (Polyacrylonitrile) based carbon fibre made in Japan by Toray. The T-300 is a commercial grade standard modulus carbon fibre available in 1K, 3K 6K and 12K tow sizes.

CFRP used by Tarot is the 3K cross ply twill woven cloth. The PAN is made by spinning the PAN into a 3K (3000) filament yarn and further carbonized to drive of non-carbon atoms. (TORAY CARBON FIBERS AMERICA)

Fibre Properties of Toray T-300 3K		
Tensile Strength	3 530	MPa
Tensile Modulus	230	GPa
Strain	1.5	%
Density	1.76	g/cm^3
Filament Diameter	7	µm
Yield 3K	198	g/1000m

Table 4 Fibre Properties T 300 3K

3.2 Epoxy Resin

Properties of EL2 Epoxy Laminating Resin			
Property	Resin	Hardener	Combined
Material	Epoxy Resin	Formulated Amine	Epoxy
Viscosity @20ºC [mPa.s.]	1200-1800	5-80	1000-1500
Density @20ºC [g/cm^3]	1.13-1.17	0.90-1.06	1.05-1.15

Table 5 Epoxy Properties EL2

Cured Properties of EL2 Epoxy		
Tensile Strength	70-80	MPa
Elongation at Break	6-10	%
Flexural Strength	103-117	MPa
Flexural Modulus	2600-3200	MPa
H.D.T	82-88	ºC

Table 6 Cured Properties EL2

(TDS EL2 EPOXY LAMINATING RESIN)

3.3 Laminate Orientation

Since the composite follows an orthotropic material model, we need to define both the thickness of the ply, the ply orientation and stacking order to obtain the mechanical properties. To describe this orientation we must define a 3D coordinate system, where the X-axis is the fibre direction, the Y-axis is normal to the direction, and the Z-axis is normal to the fibre.

Toray T300 3K is a cross-ply twill woven cloth, with an orientation of the fibres of ±45º and ply thickness of 0.20 mm. This gives us:

- For the tubes which has a thickness of 1.2 mm this will give an orientation to the X-axis of $[\pm 45º]_{3S}$, ultimately leading to a stacking order of [45º,-45º,-45º, 45º, 45,-45].
- For the plates and base boards which has a thickness of 1.6 mm this will give an orientation to the X-axis of $[\pm 45º]_{4S,}$ leading to a stacking order of [45º,-45º,-45º,45º,45,-45,-45,45].

3.4 Properties of Composite

The following properties are obtained from the tech-support at Easy Composites LTD and the International Journal of Engineering and Innovative Technology (IJEIT), Volume 2, Issue 8, February 2013. This is based upon EL2 and the T 300 K 2/2 Twill weave cloth, post-cured resin and a fibre to resin ratio of 60:40. (Corum, Battiste, & Liu, 2000) (Ing. Branislav & Ing. František, 2013)

Mechanical Properties of Composite		
Property	**Value**	**Units**
Elastic Modulus in X	135 000	N/mm^2
Elastic Modulus in Y	10 000	N/mm^2
Elastic Modulus in Z	10 300	N/mm^2
Poisson's Ratio in XY	0.27	N/A
Poisson's Ratio in YZ	0.54	N/A
Poisson's Ratio in XZ	0.27	N/A
Shear Modulus in	5 000	N/mm^2
Shear Modulus in	3 700	N/mm^2
Shear Modulus in	5 000	N/mm^2
Tensile Strength in X	1 860	N/mm^2
Tensile Strength in Y	57	N/mm^2
Compressive Strength in X	1570	N/mm^2
Compressive Strength in Y	228	N/mm^2
Shear Strength in XY	760	N/mm^2
Yield Strength	96	N/mm^2
Mass Density	1600	kg/m^3

Table 7 Properties of Composite

4.0 Computer Model of Frame

4.1 CAD model

For the design of the frame, we have used SolidWorks, which is solid modelling computer-aided design software. It runs on Microsoft Windows and is produced by Dassault Systèmes SOLIDWORKS Corp. The foundation for the model has been the included documentation from Tarot and the physical components of the frame.

It has been built with two configurations; Default and Surface CFRP. For the default configuration the model is constructed with solid bodies for every part with regards to the rendering and the dimensional drawings required for the documentation. For the surface CFRP the model has been constructed with solid bodies for aluminium, rubber and the thermoset plastics and surface bodies for the CFRP for the simulation of the model. This will be discussed more closely in section 5 of this document. Fasteners and washers are not included in the model as SolidWorks will include these parts in the simulation when configured as such.

4.2 Materials and Mass Properties

For the model, the following materials have been used:

SolidWorks Materials of CAD model						
Material	**E-Module [N/mm^2]**	**Poisson's Ratio [N/A]**	**Shear Modulus [N/mm^2]**	**Tensile Strength [N/mm^2]**	**Yield Strength [N/mm^2]**	**Mass Density [kg/m^3]**
Toray T-300K 3K	135 000	0.27	5000	18 60	96	1600
1060 Aluminium Alloy	69 000	0.33	27 000	68.94	27.57	2700
Natural Rubber	0.01	-	-	20	-	960

Table 8 Materials of CAD model

SolidWorks has calculated the following mass properties for the frame:

Mass Properties of Frame, Configuration: --Default--			
Mass [kg]	**Volume [cm^3]**	**Surface Area [cm^2]**	**Centre of mass [X,Y,Z] in [mm]**
510.26	271.54	5 457.10	[-0.03,-8.97,-0.20]

Table 9 Mass Properties of Frame

4.3 Rendered model, 2D drawings and Bill of Materials

Figure 1 Rendered 3D model of Frame

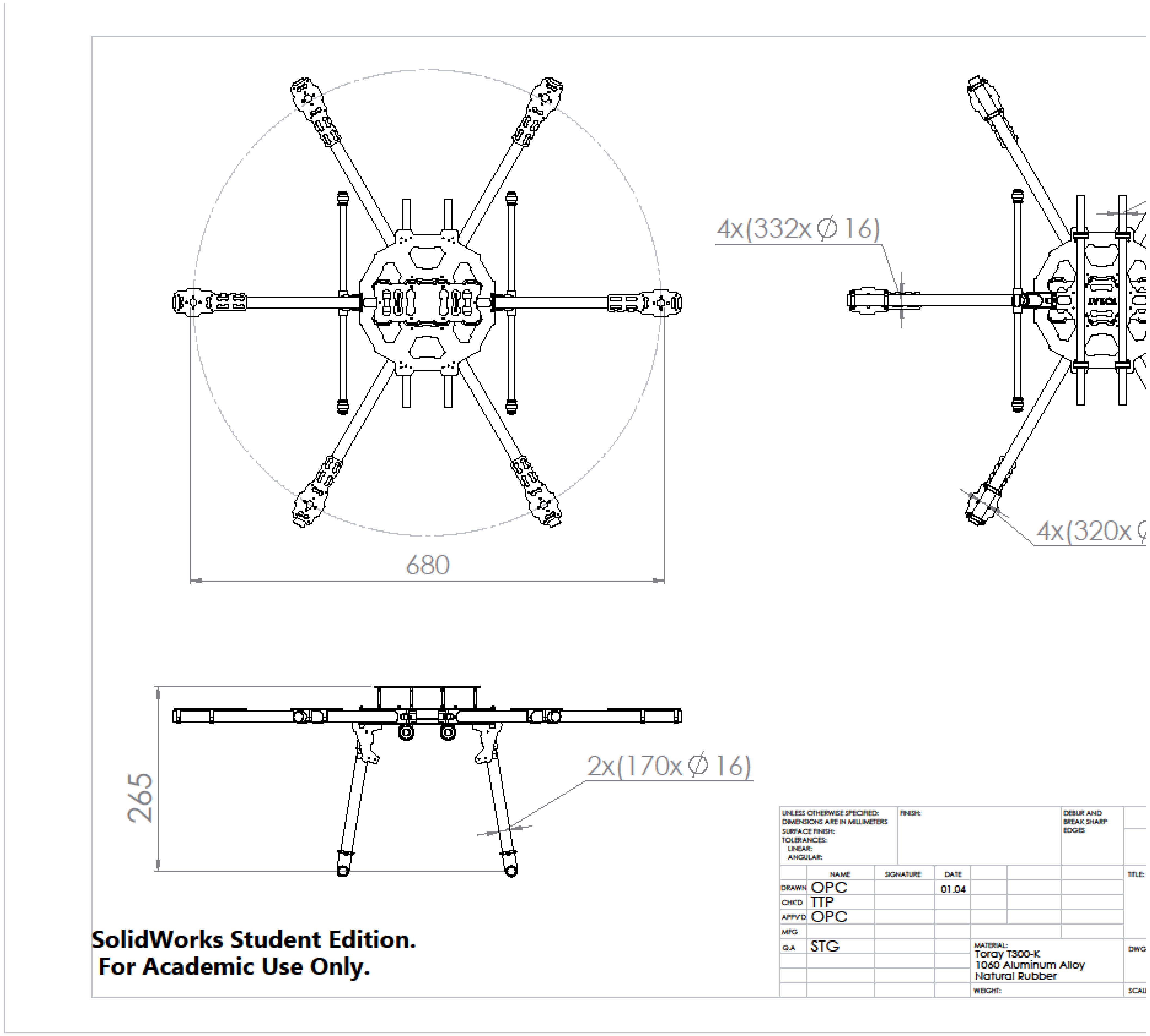


Figure 2 A3 Dimensional Drawing

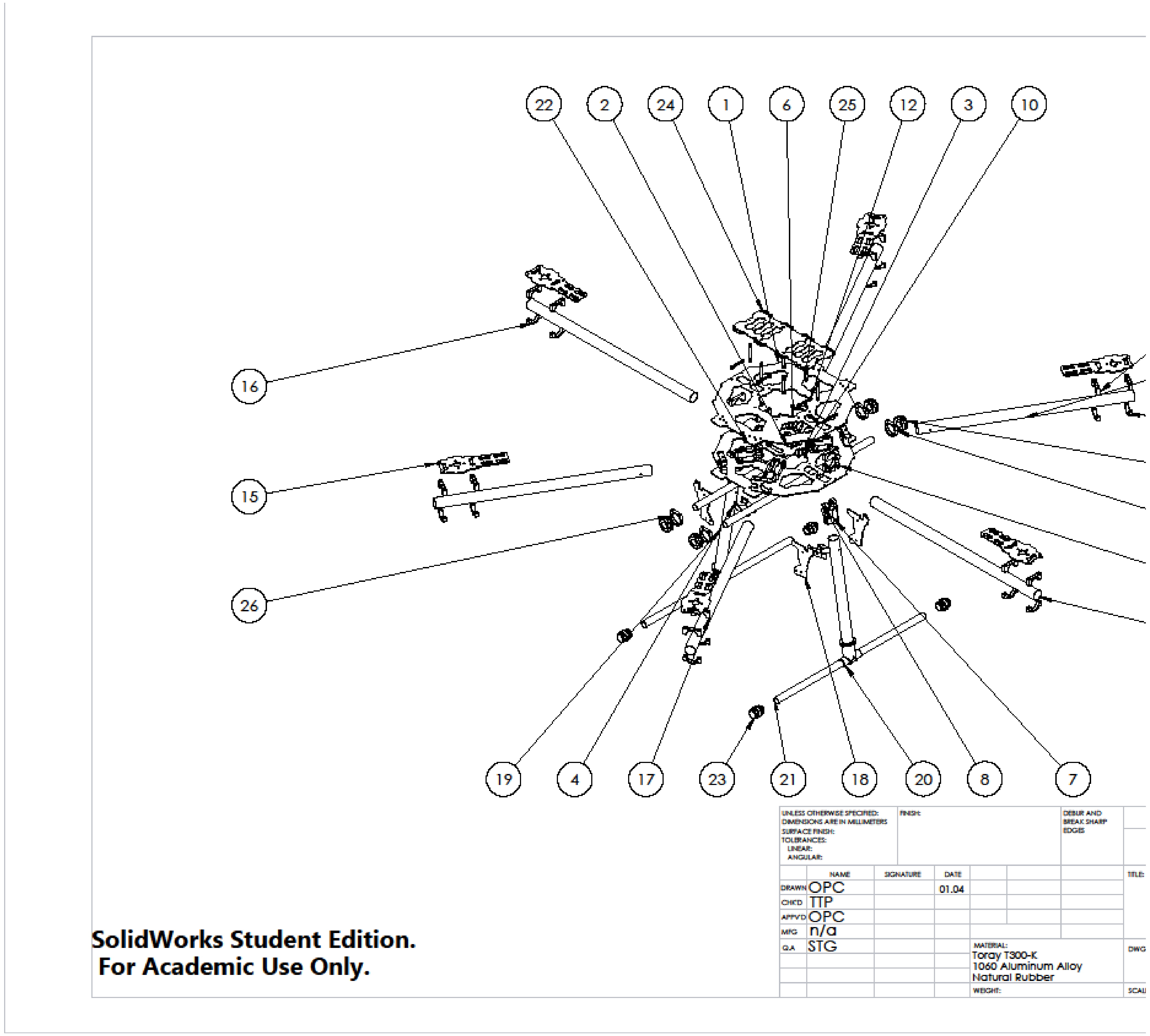


Figure 3 A3 Exploded View Frame

ITEM NO.	PART	MATERIALS	QTY.
1	Adapter Plate	Toray T-300K 3K	2 PCS
2	Mid-plate	Toray T-300K 3K	1 PCS
3	Shot Column	1060 Al. Alloy	4 PCS
4	Pipe Buckle	Polycarbonate	6 PCS
5	Tube 16x320	Toray T-300K 3K	4 PCS
6	PC Tube Connector	Polycarbonate	6 PCS
7	Brass Washer 4mm	Brass	12 PCS
8	Mirror Brass Washer 4mm	Brass	-
9	Tube 16x332	Toray T-300K 3K	2 PCS
10	Fixed Seat Top	1060 Al. Alloy	6 PCS
11	Fixed Seat Bottom	1060 Al. Alloy	2 PCS
12	Fixing Rod	Toray T-300K 3K	4 PCS
13	Motor Seat	1060 Al. Alloy	4 PCS
14	Motor Base	1060 Al. Alloy	4 PCS
15	Motor Base Board	Toray T-300K 3K	6 PCS
16	Motor Seat Blue	1060 Al. Alloy	8 PCS
17	Motor Base Blue	1060 Al. Alloy	8 PCS
18	Tripod Board	Toray T-300K 3K	4 PCS
19	Tube 16x170	Toray T-300K 3K	2 PCS
20	T-set	Polycarbonate	2 PCS
21	Tube 10x300	Toray T-300K 3K	2 PCS
22	Connector Landing Gear	1060 Al. Alloy	2 PCS
23	End Closure	Natural Rubber	4 PCS
24	Battery Base	Toray T-300K 3K	1 PCS
25	Long Column	1060 Al. Alloy	6 PCS
26	Tripod Fixing Seat Black	1060 Al. Alloy	2 PCS
27	Sleeve Fixed Seat	Natural Rubber	4 PCS
28	Tripod Fixing Seat	1060 Al. Alloy	2 PCS

Table 10 Bill of Materials Frame

5.0 Simulation of Airframe – SolidWorks

5.1 Test Introduction

This test is linked to the Test and Inspection plan for our project and is performed in SolidWorks Simulation. The overall goal is to verify that the frame of the UAV is compatible with large motors that produce more thrust than the ones that is recommended by Tarot. Normally, this frame is rated for motors with a KV value of 880-1000, that produce between 800-1300 grams of thrust at max power depending on the propeller dimensions.

The motors that is used for our system is the MT2826-6 KV760 with 12x6 inch propellers. These motors will produce approximately 2500 grams of thrust at max power.

This test will only cover a static linear study of the increased motor size in terms of increased load applied to the frame. Landing gear and payload connectors are not included as these will not be affected by the increase in thrust, but by the increase of payload. The payload for our system is a gimbal and a digital camera with a combined load of less than 1000 grams, which is well within the supported requirements by Tarots product description.

5.2 Description of test model

The test model, as mention in section 4.1, has the CFRP configuration. In this configuration the landing gear and payload connector-tubes are removed and we are left with the upper platform of the frame. The upper platform consists of:

ITEM NO.	PART	MATERIALS	QTY.
1	Adapter Plate	Toray T-300K 3K	2 PCS
2	Tube 16x320	Toray T-300K 3K	4 PCS
3	Tube 16x332	Toray T-300K 3K	2 PCS
4	Motor Base Board	Toray T-300K 3K	6 PCS
5	Pipe Buckle	Polycarbonate	4 PCS
6	PC Tube Connector	Polycarbonate	4 PCS
7	Motor Seat	1060 Al. Alloy	12 PCS
8	Motor Base	1060 Al. Alloy	12 PCS

Table 11 Bill of Materials Test Model

Items number 1 to 4 has been modelled with surface bodies, which in terms means that they are thin features. They have zero thickness until they are defined with the selected composite configuration mention in section 3.3, in the simulation. Item 5 to 8 are modelled as solid features. The test model is displayed in figure 4 on the following page.

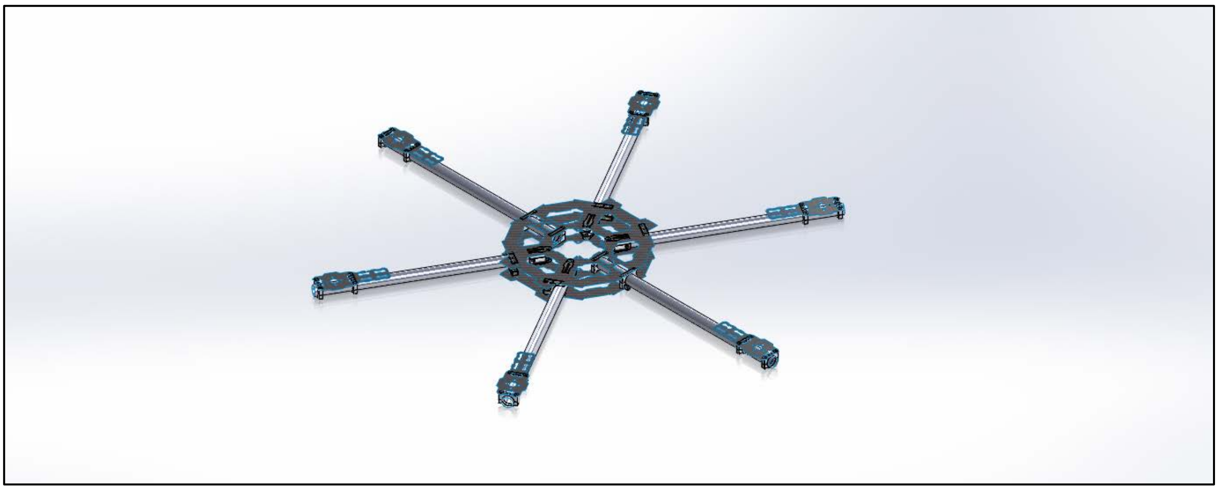


Figure 4 Test Model

5.3 Assumptions and Simplifications

This test is a static study, which neglects the dynamics of the UAV. This causes aerial resistance and forces that are exerted on the frame to be neglected. We assume that all motors have the same rotational speed and that the UAV is not operated with pitch-, roll- or yaw-motion. The torque due to weight force of motors and initial angular momentum due to motor rotation are not of significant proportions compared to the thrust and are therefore not included in this study.

Weight from other components such as battery, APM, ESC is not included as the frame is designed for this purpose by Tarot.

5.4 Loads

The goal is to simulate the event when the motors exert full trust as the frame is stationary. The frame is then subjected to the thrust force of the motors and by its own gravity. The test will simulate the thrust produced by the motors with a magnitude of 24.5 N from each motor, leading to a total of 147N of lifting force.

Current event for this scenario is when performing a motor-compass calibration. This calibration is done by strapping the UAV to solid ground while throttling the motors at full power.

5.5 Test Configurations

In section 5.5.2, 5.5.2 and 5.5.4 the test configurations are displayed for the static Simulation of the Frame. Global contact bonded is selected for every component.

5.5.1 Mesh

Mesh Information	
Mesh Type	Mixed Mesh
Mesher Type	Standard Mesh
Jacobian Points	4 Points
Jacobian Check for shell	On
Element Size	4.45072 mm
Tolerance	0.222437mm
Mesh Quality	High
Total Nodes	99232
Total Elements	48988

Table 12 Mesh Information

5.5.2 Fixtures

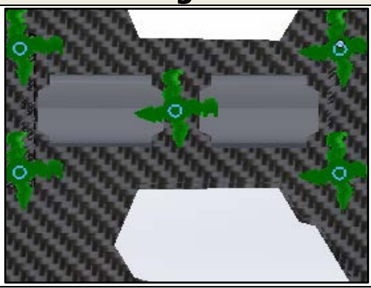
Fixture Name	Fixture Image	Fixture Details
Fixed1		**Entities:** 10 edge(s) **Type:** Fixed Geometry **Note:** The frame is fixed in the bolt holes where the landing gear is mounted.

Table 13 Fixture Information

5.5.3 Applied Loads

External Loads			
Load Type	**Value**	**Unit**	**Vector**
Gravity	9,81	m/s^2	[0,0,-9.81] [X,Y,Z] where Z is opposite direction of Gravity
Force M1	25,00	N	[0,0,25.50] [X,Y,Z] where Z is opposite direction of Gravity
Force M2	25,00	N	[0,0,25.50] [X,Y,Z] where Z is opposite direction of Gravity
Force M3	25,00	N	[0,0,25.50] [X,Y,Z] where Z is opposite direction of Gravity
Force M4	25,00	N	[0,0,25.50] [X,Y,Z] where Z is opposite direction of Gravity
Force M5	25,00	N	[0,0,25.50] [X,Y,Z] where Z is opposite direction of Gravity
Force M6	25,00	N	[0,0,25.50] [X,Y,Z] where Z is opposite direction of Gravity

Table 14 External Loads SW

For each motor base board, a total of 25 N is exerted through four motor bolt holes in the opposite direction of gravity, normal to the board. Force M1-to M6 represents motor 1 to motor 6.

In the applied loads, 24.5 N is rounded up to 25 N. This will give a greater reassurance that the frame can handle the increased motor power. The total lifting force produced by the 6 motors is then 150 N or 15300 grams of thrust.

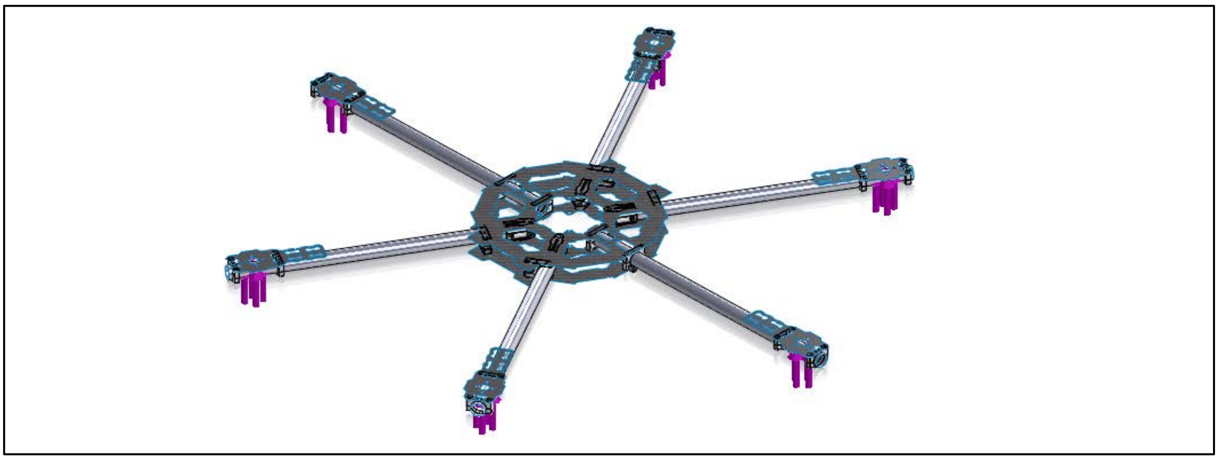


Figure 5 Applied Loads SW

5.5.4 SW Composite definition

Composite Parts: Adapter Plate, Motor Base board			
Ply	**Ply Thickness**	**Orientation**	**SW Material – Material Model**
1	0.20 mm	45º	Toray T-300K 3K – Linear Elastic Orthotropic
2	0.20 mm	-45º	Toray T-300K 3K – Linear Elastic Orthotropic
3	0.20 mm	-45º	Toray T-300K 3K – Linear Elastic Orthotropic
4	0.20 mm	45º	Toray T-300K 3K – Linear Elastic Orthotropic
5	0.20 mm	45º	Toray T-300K 3K – Linear Elastic Orthotropic
6	0.20 mm	-45º	Toray T-300K 3K – Linear Elastic Orthotropic
7	0.20 mm	-45º	Toray T-300K 3K – Linear Elastic Orthotropic
8	0.20 mm	45º	Toray T-300K 3K – Linear Elastic Orthotropic

Table 15 Composite Stack 1

Composite Parts: Tube 16x332mm, Tube 16x320mm			
Ply	**Ply Thickness**	**Orientation**	**SW Material – Material Model**
1	0.20 mm	45º	Toray T-300K 3K – Linear Elastic Orthotropic
2	0.20 mm	-45º	Toray T-300K 3K – Linear Elastic Orthotropic
3	0.20 mm	-45º	Toray T-300K 3K – Linear Elastic Orthotropic
4	0.20 mm	45º	Toray T-300K 3K – Linear Elastic Orthotropic
5	0.20 mm	45º	Toray T-300K 3K – Linear Elastic Orthotropic
6	0.20 mm	-45º	Toray T-300K 3K – Linear Elastic Orthotropic

Table 16 Composite Stack 2

5.6 Results

Simulation with a total load of 150N combined with the weight of the components show that maximum von Mises stress was calculated to value of 83 N/mm^2. The yield strength of selected composite, polycarbonate and 1060 Al. Alloy is shown in table below:

Material	Yield Strength
Toray T-300K 3K	96 MPa
1060 Al. Alloy	27.57 MPa
Polycarbonate High Viscosity	n/a

Table 17 Yield Strength of Test Materials

The plots of the test model are presented in Appendix A: Stress Plot, Appendix B: Displacement plot and Appendix C: Strain Plot, p. 23-25. Section 5.6.1 to 5.6.3 displays the results of the static study.

5.6.1 Stress

For the stress calculations maximum von Mises was selected. The maximum stress value was located at node 53344, which is the adapter plate. The highest concentration is through the tubes and the adapter plate. The selected composite as displayed in table 17 shows that this value is below the value of the yield strength. As for the 1060 Al. Alloy and the PC components, the stress never reached values above 6.92 MPa which is way below the limits of yield strength.

It is important to mention that the maximum stress displayed in appendix A is the maximum stress of all the plies of the composite. This ensures that there will be no yielding in each of the plies.

5.6.2 Strain

Equivalent strain ESTRN von Mises was calculated to 0.00235, shown in Appendix C.

5.6.3 Displacement

Maximum deflection URES, which is the resultant displacement, shows that the highest deflection occurs in the CFRP tubes. The maximum deflection was calculated to 2.28mm shown in appendix B. Since the deflection is of small proportions, it is safe to assume that the choice of using a static linear study is appropriate.

6.0 Summary

This document and the following FEA analysis performed in SolidWorks have shown that the increased motor size will not cause a mechanical failure as per requirement specification. However, the increased deflection may affect the stability of the UAV and could also disturb the sensors like gyroscope and accelerometer in the APM that governs this stability and the motion of the UAV

The test is performed with a thermal effect similar to the normal operating environment of 291 K or 25ºC. The PC is very ductile at ambient temperature (between Tβ= -80°C and Tg = 150°C) and has there for good resistance capabilities to shock within the operating temperature of the UAV and the test temperature which could be the effect of increasing the power. If the temperature increases above 130°C, which is way above the operating limit of the UAV, this test will no longer be applicable.

Frequency analysis and fatigue analysis has not been performed, and we are therefore not able to guarantee that the frame performs in a similar manner as with smaller motors.

The results of FEA analysis were also verified when we performed the motor-compass calibration, as shown in figure 6.

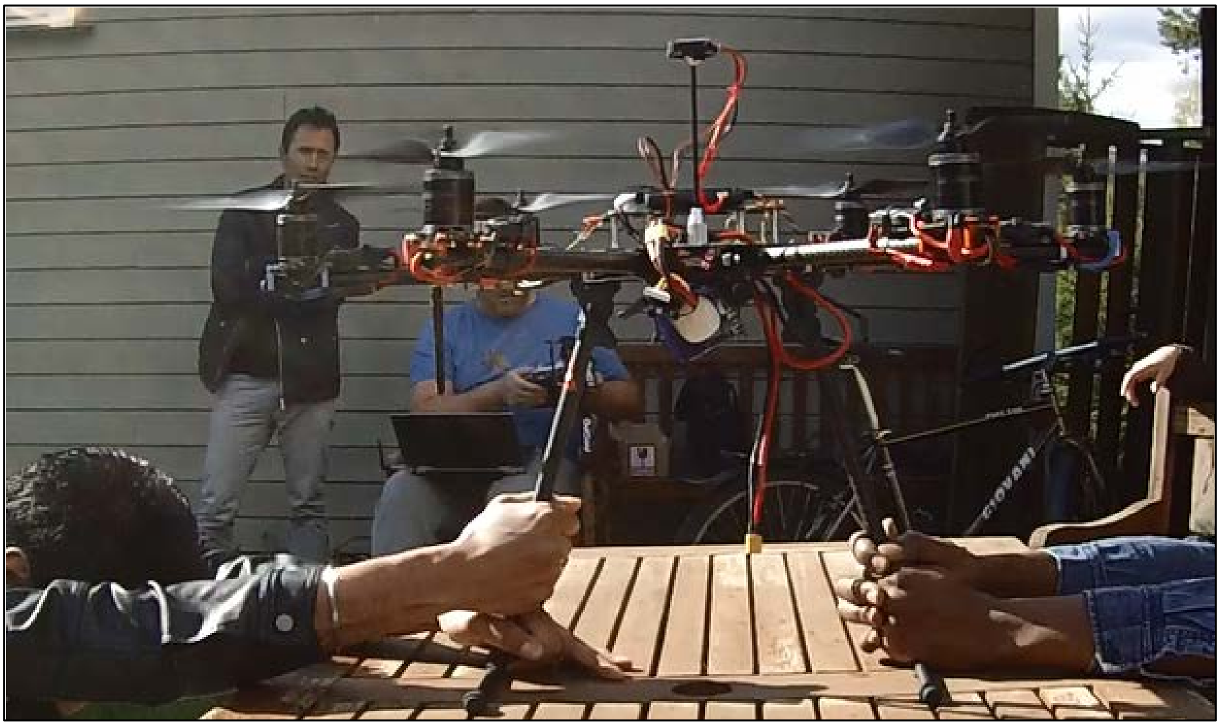


Figure 6 Motor to Compass Calibration

7.0 References

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APPENDIX A

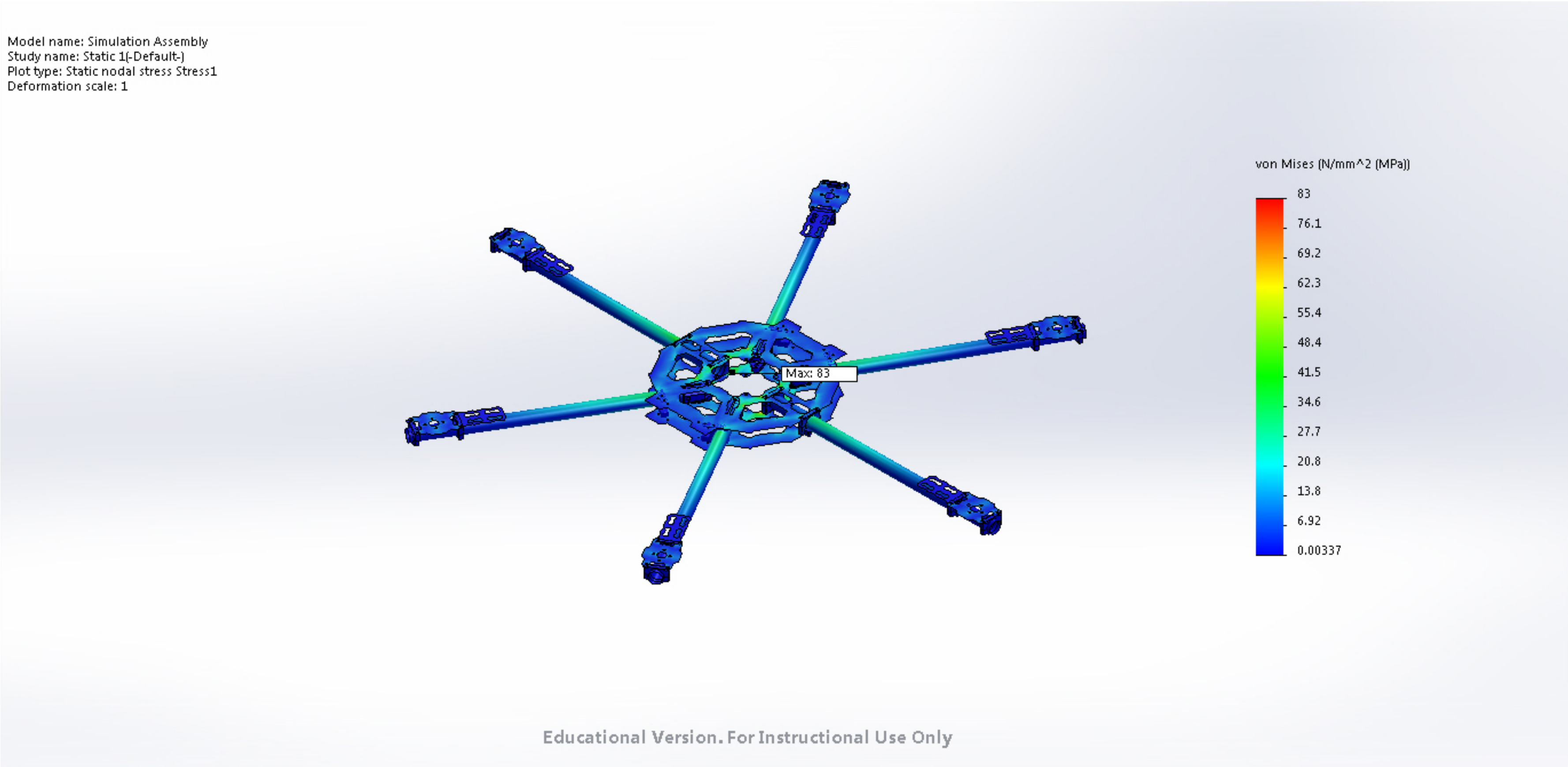


Figure 7 Stress Plot von Mises

APPENDIX B

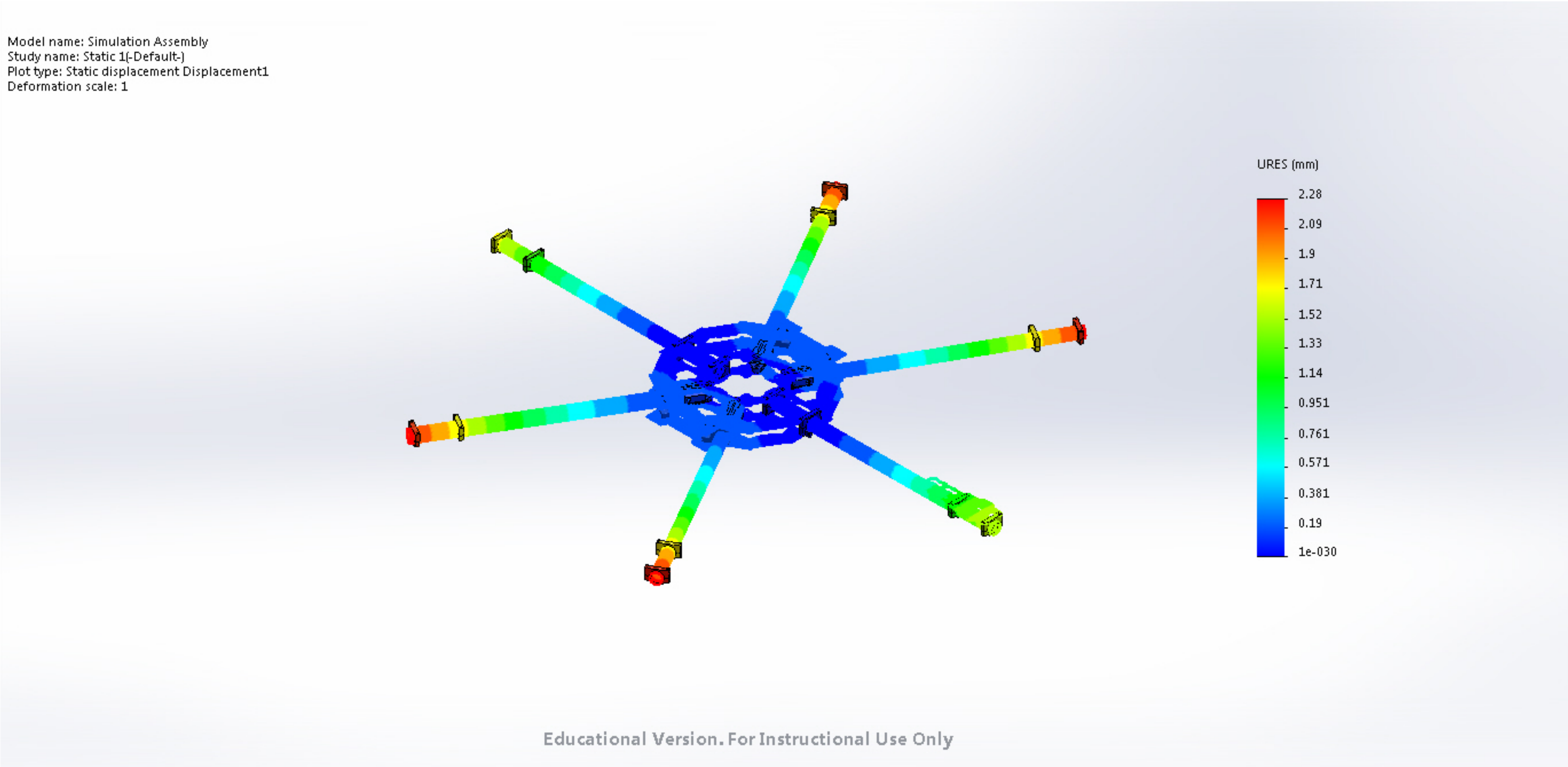


Figure 8 URES: Resultant Displacement

APPENDIX C

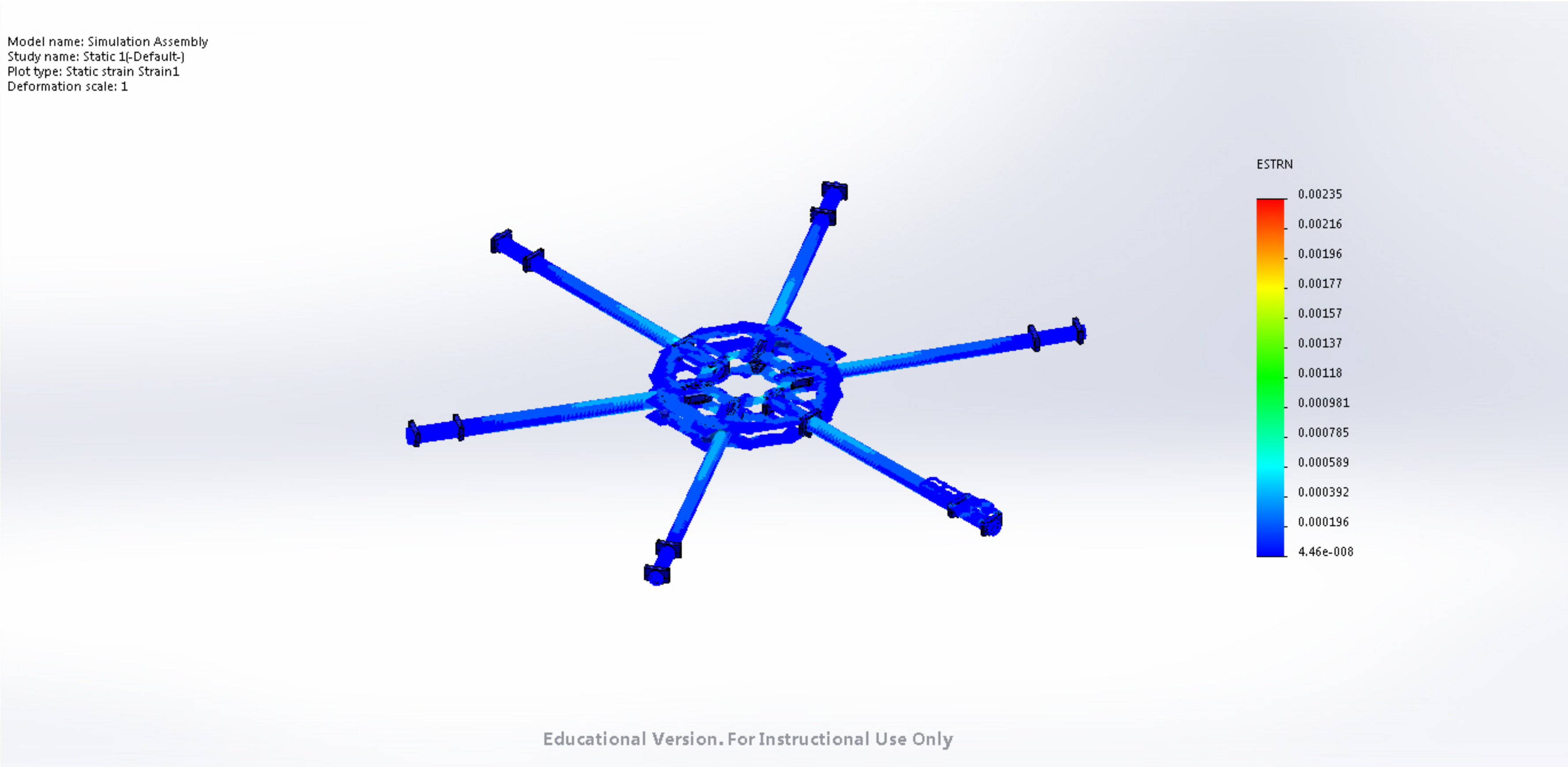


Figure 9 ESTRN: Equivalent Strain

Technical Report- Electrical and software

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	15.05.2015	OCP	TTP	Released

Summary:

This document is intended to explain more about the technical report for the UAV.

Owner: Asadullah Jacop

Document Revision History

Rev	Date	Author	Description	Status
0.1	20.04.2015	ADJ	Initial draft	Obsolete
1.0	15.05.2015	OCP	Final Version V1.0	Released

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Purpose of this document

The purpose of this document is to analyse more deeply about the hardware and software we have decided to use in our project in a specific manner.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
BLDCM	Brushless Direct Current Motor
C	Discharging rate
D	Derivative
DCM	Direct Current Motor
EKF	Extended Kalman filter
EMF	Electromotive force
GCS	Ground Control station Software
GSC	Ground Station Control
I	Integration
IMU	Inertial Measurement Unit
Li-ion	Lithium ion
LiPo Hybrid/LiPo	Lithium ion Polymer
P	Proportional
UAV	Unmanned aerial vehicle
UKL	Unscented Kalman filter
KV	rpm constant of a motor - revolutions per minute that the motor will turn when 1V

Table 1 Abbreviations

2.0 Motor

The electric motors can be broadly classified into Direct Current (DC) and Alternating Current (AC) motors. The motors can be further classified depending on the physical construction of the motor and how the motor is wired. Stator and rotor are the two main components of the motors. These two components are separated by an air gap. When you consider the rotary-type electric motors, you will find out that, the stator always take the form of a hollow cylinder that is attached to the housing, while the rotor has a shaft that is supported by bearings.

There are two types of DC motors which are Brush and Brushless configuration. We will use Brushless configuration in our project as said in earlier phases. The reason we choose it was just to make sure we meet some of the requirements.

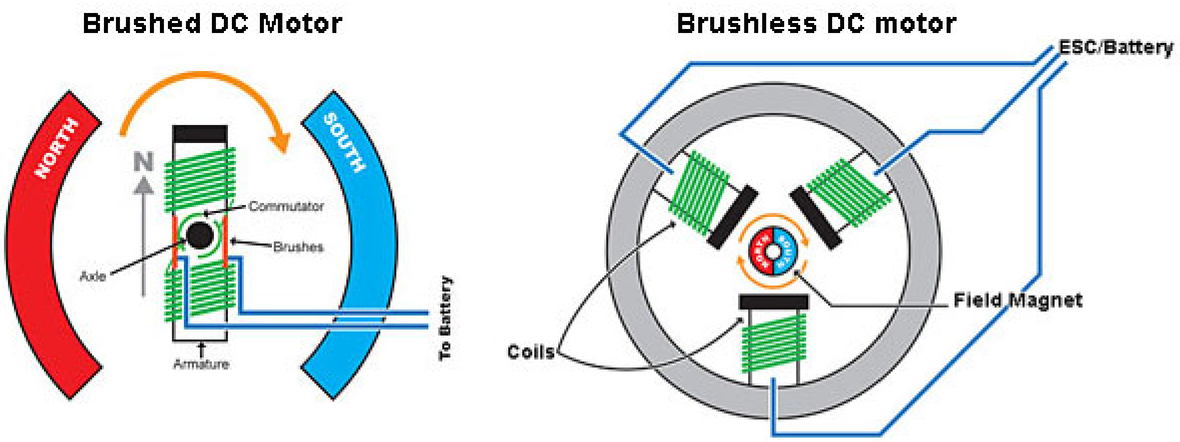


Figure 1 Brushed and brushless DC motor

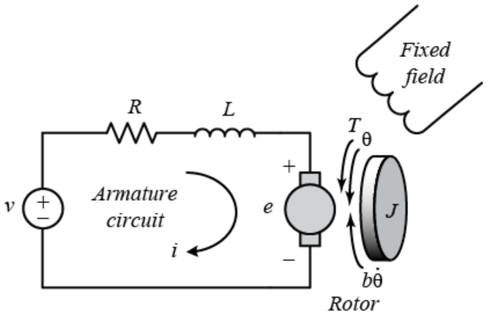
2.1 Brushed DC Motor

Brush type DC-motors are very common, and are used in many battery-powered devices such as electric toys, and in industrial applications such as conveyers, indexing tables, and material handling.

The Brushed DC motor consists of 5 components. These components are:

- Armature or rotor
- Commutator
- Axle
- Field magnet
- DC power supply of some sort

Electro-Mechanical Model of a PM DC Brush Motor



- Electrical model
  $V_{in} - L\frac{di}{dt} - iR - V_{bemf} = 0$ (1)
- Mechanical Model

  $I\frac{dw}{dt} = T_{in} - bw = Kt\ i - bw$ (2)

These two equations are the ones which form the model that relates the input voltage to rotor speed. A brushed DC motor has a rotating armature which acts as an electromagnet with two poles. A rotary switch called a commutator reverses the direction of the electric current twice every cycle, to flow through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor. As the poles of the armature electromagnet pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet. During the instant of switching polarity, inertia keeps the classical motor going in the proper direction. Brushes are the key to the switch. They maintain a set of a mechanical pressure against the rotating surface. This is most of the time accomplished by the spring loading the brushes. These brushes are subjected to wear and need to be replaced after extended use and therefore are the major contributor to the scheduled maintenance. (Tcheslavskis, 2008), (BRUSHLESS VS BRUSHED MOTORS)

Pros	Cons
• Two wire control • Replaceable brushes for extended life • Low cost of construction • Simple and inexpensive control • No controller is required for fixed speeds • Operates in extreme environments due to lack of electronics	• Periodic maintenance is required • Speed/torque is moderately flat. When speed is higher, the brush friction increases, thus reducing useful torque • Poor heat dissipation due to internal rotor construction • Higher rotor inertia which limits the dynamic characteristics • Lower speed range due to mechanical limitations on the brushes

Table 2 Pros and cons for DC brushed motor

2.2 Brushless DC Motor

DC-brushless has no brush as name suggested. In a DC-brushless motor, the rotor is made of permanent magnets, and the stator is constructed of coils. There is no wiring to the rotor.

In order for the motor to rotate, the stator fields are electronically commutated depending on the position of the rotor which is obtained from non-contact, hall-effect type, proximity sensors that are mounted on the stator. The commutating process in a sensor less brushless DC motor is done by the help of EMF or Kalman filters.

Brushed DC motors are available in 3 configurations. There are in single phase, two-phase, and three phase configuration. Three phase sensor less configuration is the one we are using in our project.

However, since a brushless DC Motor does not use brushes, it does use a permanent magnet and accomplishes the switching by electronically switching the polarity. In order to accomplish this in a controlled manner a position/speed feedback mechanism and an electronic controller are required. Feedback may be through a physical device mounted on the motor such as Hall Effect devices or a complex algorithm based on the motors own changing characteristics such as back EMF. The controller may be mounted on the motor or may be separate.

However, it might be seen as easy that without brushes the brushless DC motor has a much greater mean time between maintenance. Nevertheless, what is forgotten is the brushless motor design is more complex with the addition of the feedback and the controller and therefore has lower reliability. (How to choose the right motor for your multicopter, 2013)

2.3 Pugh concept selection

PUGH MATRIX	**Concepts**	**Brushed Motor**	**Brushless Motor**
Criteria	**Weight %**		
Production cost	40	3	5
Maintenance	10	4	2
Efficiency	15	2	4
Speed rage	15	4	5
Control system	20	5	2
SUM	**100**	**350**	**395**

Table 3 Pugh matrix motor type

- Scaling from 1 to 5, where 5 is the best and 1 is the worst.

Before deciding which type of DC motor we should use in our project, we use Pugh matrix methods to help us. With the help of the Pugh matrix as shown in Table 5, we could see that DC Brushless Motor had the highest scores compared to DC Brushed

Motor. Therefore we decided to use DC Brushless Motor instead of DC Brushed Motor. Note that the selected BLDCM is meant to be used in the UAV for middle speed and heavier payload. If the speed and heavier payload is not the purpose of the project, our recommendation is to use a less powerful motor with less KV per volt for the UAV. This is because the mentioned motor cost less money and pulls out less current from the battery.

2.4 Brushless DC Motor Specifications

Tiger Motor MT2626-6 is one example of Brushless DC Motor. Many of these motors are being used in UAVs. (T-MOTOR, 2013)

Tiger Motor MT2826-6	
KV	= 760
Configuration	= 12N14P
Stator Diameter	= 28mm
Stator Length	= 26mm
Shaft Diameter	= 5mm
Motor Dimension	= Q35x48mm
Weight	= 187g
Idle current (10) at 10v (A)	= 1A
No. of cells(LiPo)	= 3 – 6S
Max Continuous current(A) 180s	= 45A
Max Continuous Power (W) 180s	= 700W
Max efficiency current	= (10-28A) > 81%
Internal resistance	= 20m

Table 4 Tiger motor specification

The KV measures the RPM produced per volt of electricity supplied, assuming zero resistance or load.

Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (g)	RPM	Efficiency (g/W)	Operating temperature(℃)
MT2826 KV760	14.8	T-MOTOR 12*4CF	50%	7.5	111	860	6200	7.75	45
			65%	10.1	149.48	1040	6900	6.96	
			75%	12.6	186.48	1200	7500	6.44	
			85%	16.9	250.12	1500	8350	6.00	
			100%	20.3	300.44	1680	8800	5.59	
		T-MOTOR 13*4.4CF	50%	7.9	116.92	920	5750	7.87	46
			65%	11.2	165.76	1200	6500	7.24	
			75%	14.6	216.08	1380	7300	6.39	
			85%	19.6	290.08	1710	8000	5.89	
			100%	23.4	346.32	1900	8600	5.49	
		T-MOTOR 14*4.8CF	50%	9.1	134.68	1080	5200	8.02	57
			65%	14.9	220.52	1530	6200	6.94	
			75%	20.3	300.44	1890	6800	6.29	
			85%	26.3	389.24	2200	7400	5.65	
			100%	31.5	466.2	2470	7740	5.30	
Notes:The test condition of temperature is motor surface temperature in 100% throttle while the motor run 10 min.									

Table 5 Testing results of MT2826 KV760 for different sizes of propeller

Three different sizes of propeller used are T-motor 12 x 4 CF, T-motor 13 x 4.4CF and T-motor 14 x 4.8 CF. The voltage applied to the motor is the same for all propeller. For example if we look at the propeller size T-motor 12 x 4 CF, we can see that 50% of throttle gives a thrust of 860g, 6200 RPM and 7.75 of efficiency. Motor produces the current of 7.5 A and power of 111w. When the throttle is increased from 50% to 65%, all the parameters mentioned will all increase as we can see on the Table 5.

This process is the same with the rest of propeller. The more you increase the percentage of the throttle the more the rest of the parameters increase.

However, if we compare all these parameters to each of these different sizes of propeller, we can see that the bigger the size of propeller is the more the current motor will need to produce. More power will be needed. More thrust will be produced. The efficiency is high. The only parameter which is lower is RPM. The reason for this is that larger propeller rotates slowly compared to small propeller.

Nevertheless, thrust is one of the important parameter to consider when choosing the type of motor and size of propeller to be used in UAV. Things which are needed to be considered when trying to find out the amount of thrust needed are the total weight of all the components when went to carry.

However, since we are designing a hexacopter, we need 6 motors. We can find out the total amount of thrust by multiplying 6 with the values of thrust on Table 3. It is advisable that the total amount thrust should be at least double the total weight of our components.

On the Table 5, we can also the efficiency per motor for difference propeller size at difference throttle percentage.

However, these are the results after the test was taken at the specific temperature as it is mention on the Table 5. It is not sure these results will be the same in our project because of the size of propeller we have and the total weight of our hexacopter. The size of our propeller and the total weight of the hexacopter will have an effect on all if not some of the parameters mention on Table 5.

Pros	Cons
• Electronic communication based on Hall position sensors • Less required maintenance due to absence of brushes • Speed/Torque- flat, enables operation at all speeds with related to load • High efficiency, no voltage drop across brushes • High output power/frame size • Higher speed range • Low electric noise generation	• Higher cost of construction • Control is complex and expensive • Electric Controller is required to keep the motor running. It offers double the price of the motor

Table 6 Pros and cons of brushless motor

2.5 Mathematical model of a brushless dc motor

The characteristics of an actuator are usually unknown and should be analysed to understand the dynamic system of an actuator. This to make a compensator for an actuator to control the behaviour of a system as wished. Mathematic is an important tool to make a model of actuator. It is easy to analyse the systems dynamic behaviour from the model.

The selected three phase sensor less brushless dc motors have different commutation characteristics compared to brushed dc motor and brushless DC motor with sensors. The main different is that the BLDCM with sensor operates with three phase alternating current by receiving a feedback signal from the sensor which sense the magnetic field of rotor as shown in figure 2, and a brushed motor commutates using mechanical brush with DC current. The relation of sensors output to the electromotive force (EMF) is shown in table 7 and table 8. The sensor less BLCM use different methods depend on the accuracy and the order of the system. If the system is a higher order (with several pols and zeros) the unscented Kalman filter is the best option to use among the other alternatives. Unscented Kalman Filter is used for nonlinear state estimation which most flight controls provides. The benefit of sensor less BLDCM and this commutating method are less wiring, less mounting space, decrease the cost and increase the reliability of the system.

The mathematical equations of three phase motor which is nonlinear system are usually more complicated than a brush motor. A basic components represented in brushed and brushless DC motor are the armature resistance R, the armature inductance L and the back electromotive force (EMF) E also takes in to account when modelling these motors. The following mathematical equation and model are led from a three phase sensor less brushless DC motors and as shown in figure 3.

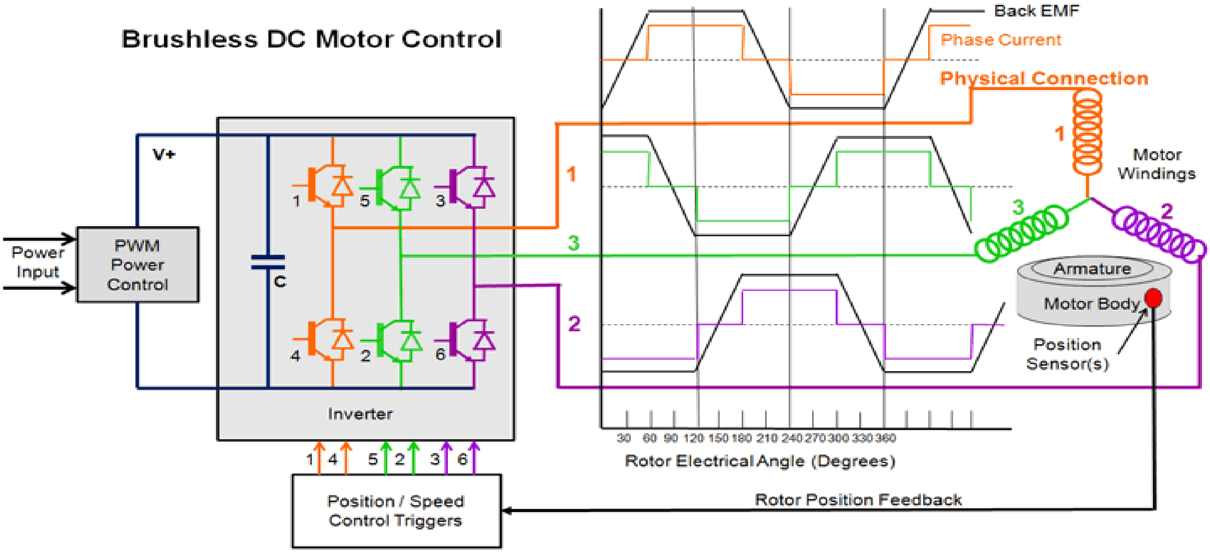


Figure 2 Schematic of brushless DC motor and six step switching

By using Hall Effect sensor as in figure 2 and current direction, the relation between sensors output and back EMF for three phases is calculated for clockwise rotation and counter clockwise rotation as shown in table 7, and table 8.

Hall A	Hall B	Hall C	EMF A	EMF B	EMF C
0	0	1	0	-1	1
0	1	0	-1	1	0
0	1	1	-1	0	1
1	0	0	1	0	-1
1	0	1	1	-1	0
1	1	0	0	1	-1

Table 7 Sensor output of commutation sequence for clockwise rotation

Hall A	Hall A	Hall A	EMF A	EMF A	EMF A
0	0	1	0	1	-1
0	1	0	1	-1	0
0	1	1	1	0	-1
1	0	0	-1	0	1
1	0	1	-1	1	0
1	1	0	0	-1	1

Table 8 Sensor output of commutation for counter clockwise rotation

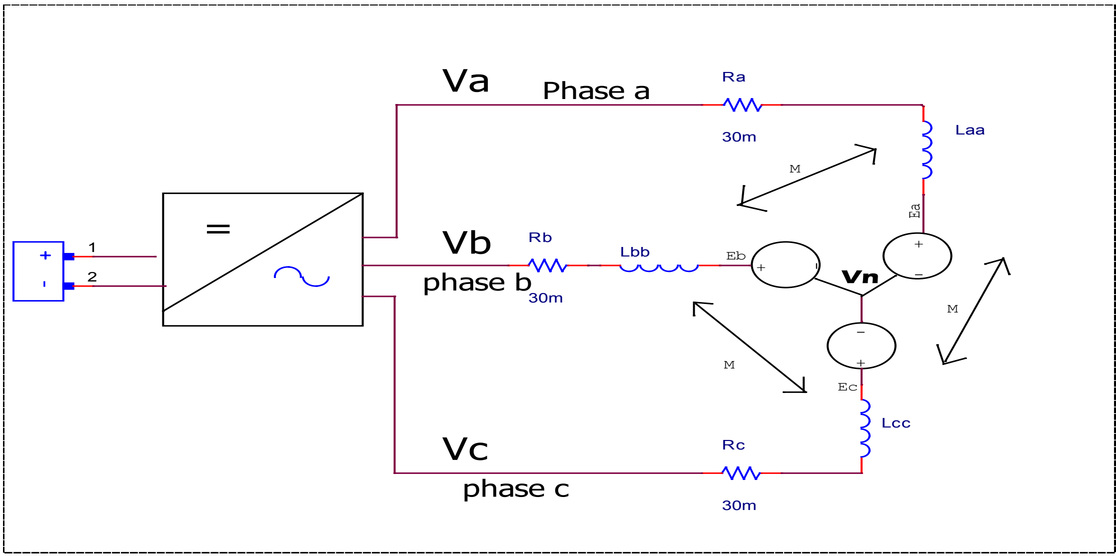


Figure 3 Equivalent circuit of sensor less BLDC drive with six step inverter

Using Kirchhoff's voltage law (KVL) to calculate the voltage across the motor winding by following equation;

$$V_a = R_a i_a + L_{aa}\frac{di_a}{dt} + L_{ab}\frac{di_a}{dt} + L_{ac}\frac{di_a}{dt} + E_a + V_n \quad (3)$$

$$V_b = R_b i_b + L_{bb}\frac{di_b}{dt} + L_{ba}\frac{di_b}{dt} + L_{bc}\frac{di_b}{dt} + E_b + V_n$$

$$V_c = R_c i_c + L_{ca}\frac{di_c}{dt} + L_{cb}\frac{di_c}{dt} + L_{cc}\frac{di_c}{dt} + E_c + V_n$$

Where, $V_a, V_b\, and\, V_c$ is the phase voltage, $i_a, i_b and\, i_c$ is the phase current and $E_a, E_b and\, E_c$ is the back EMF, V_n is neutral phase voltage.

The induced voltage is can be expressed by Faraday's law, that is

$$v_{ab} = \frac{d\lambda}{dt}, \lambda = N\phi = L_{ab}\frac{di_a}{dt} \quad (4)$$

$$v_{ac} = \frac{d\lambda}{dt}, \lambda = N\phi = L_{ac}\frac{di_a}{dt}$$

Where λ is referred to as the flux linkage and measured in weber-turns, ϕ is the magnetic field and **N** is number of line turns.

The induced voltage in phase **B** and **C** can be expressed the same as phase **A**.

All the phase resistances are the same in a balanced Y connection, so $R_a = R_b = R_c = R$

The equation (3, 1) can be defined in matrix as fallow;

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{di}{dt} \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} + V_n$$

Where, $L_{aa} \quad L_{bb} \quad L_{cc} = L$ are the self- inductance of phase **a, b** and **c**; $L_{ab} \quad L_{ac} \quad L_{ba} \; L_{bc} \; L_{ca} \; L_{cb} = M$ are mutual inductance between phase a, b and c.

The relating self-inductance and mutual inductance is given as

$$M = k\sqrt{L_{xx}L_{yy}},\; 0 \le k \le 1, L_{xx} = L_{yy} = L_{aa} = L_{bb} = L_{cc} \tag{5}$$

For Y connected stator winding; $i_a + i_b + i_c = 0$ and for synchronous inductance $L_m = L - M$

According to the BLDC motors operation principle which only two phases conduct in three phase stator winding at each time point. Thus, the neutral voltage point can be expressed as fallow:

$$V_n = \frac{1}{3}[(V_a + V_b + V_c) - (E_a + E_b + E_c)] \tag{6}$$

Substituting the equation (6) into a single phase **A** voltage in equation (3) as fallow:

$$\frac{di_a}{dt} = \frac{V_{ab} - V_{ca}}{3L_m} - \frac{R}{L_m} i_a + \frac{E_b + E_c - 2E_a}{3L_m} \tag{7}$$

Where $V_{ab} = V_a - V_b and\; V_{ca} = V_c - V_a$

The new voltage equation takes the form:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{di}{dt} \begin{bmatrix} L_m & 0 & 0 \\ 0 & L_m & 0 \\ 0 & 0 & L_m \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} + V_n$$

The electromotive force induced on the phase A winding is

$$E_a = K_E \omega_n f_a(\theta) \tag{8}$$

Where,

$$\omega_n = \frac{1}{P}\frac{d\theta}{dt} \quad (9)$$

P is the number of poles pair and θ is the electrical angel,

K_E is the magnetic flux, ω_n is the motor angular velocity, $f_a(\theta)$changing along with the rotor position by the wave function of the EMF of phase A and the maximum and minimum value are +1 and -1.

The $f_a(\theta)$ term is a nonlinear function and can be described as follows:

$$f_a(\theta) = \begin{cases} \frac{6}{\pi}.\theta, & 2k\pi \le \theta \le \pi/6 + 2k\pi \\ 1, & \pi\, 6 + 2k\pi \le \theta \le 5\pi/6 + 2k\pi \\ -\frac{6}{\pi}.(\theta - \pi), & 5\pi/6 + 2k\pi \le \theta \le 7\pi/6 + 2k\pi \\ -1, & 7\pi/6 + 2k\pi \le \theta \le 11\pi/6 + 2k\pi \\ \frac{6}{\pi}.(\theta - 2\pi), & 11\pi/6 + 2k\pi \le \theta \le 2\pi + 2k\pi \end{cases} \quad (10)$$

The BLDC motors have a symmetric structure with 120 degree phase angel between three phases. In this case we have

$$f_b(\theta) = f_b\left(\theta - \frac{2\pi}{3}\right)\ and\ f_c(\theta) = f_b(\theta) = f_a\left(\theta + \frac{2\pi}{3}\right)$$

Substituting the equations (8) into (7), it can be written as follows:

$$\frac{di_a}{dt} = \frac{V_{ab} - V_{ca}}{3L_m} - \frac{R}{L_m} i_a + \frac{K_E\omega_n[f_b(\theta) + f_c(\theta) - 2f_a(\theta)]}{3L_m} \quad (11)$$

This is an analogue expression of a single phase of motor, but for cost efficiency and extensive applications, the digital control system is widely used. The corresponding discrete time equation of (11) is:

$$i_a(k+1) = \frac{T[V_{ab}(k) - V_{ca}(k)}{3L_m} + (1 - \frac{TR}{L_m})i_a(k) + \frac{TK_E\omega_n(k)[f_b(\theta_k) + f_c(\theta_k) - 2f_a(\theta_k)]}{3L_m}$$

$$i_b(k+1) = \frac{T[V_{bc}(k) - V_{ab}(k)}{3L_m} + (1 - \frac{TR}{L_m})i_b(k) + \frac{TK_E\omega_n(k)[f_a(\theta_k) + f_c(\theta_k) - 2f_b(\theta_k)]}{3L_m}$$

$$i_c(k+1) = \frac{T[V_{ca}(k) - V_{bc}(k)}{3L_m} + (1 - \frac{TR}{L_m})i_c(k) + \frac{TK_E\omega_n(k)[f_a(\theta_k) + f_b(\theta_k) - 2f_c(\theta_k)]}{3L_m}$$

(12)

Where, T is the sampling time.

The torque equation of BLDS motor is substituted from equation (8) as follow:

$$T_{em} = \frac{E_a i_a + E_b i_b + E_c i_c}{\omega_m} = \frac{K_E \omega_n [f_a(\theta) i_a + f_b(\theta) i_b + f_c(\theta) i_c]}{\omega_n / p}$$
$$= K_E p [f_a(\theta) i_a + f_b(\theta) i_b + f_c(\theta) i_c]$$

(13)

Where T_{em} is the electromagnetic torque, $\omega_m$is the mechanical angular velocity and is the number of pole pairs of the motor.

The motion equation of BLDC motor is given as:

$$T_{em} - T_L = J \frac{d\omega_m}{dt} + B_v \omega_m \quad (14)$$

Where $T_L$the load torque of motor, J is is the inertia and $B_v$is the viscous friction coefficient.

Converting the mechanical angular velocity to the electrical angular velocity from equations (13) and (14), we have

$$\omega_n(k+1) = \frac{(p^2 T K_E)}{J} [f_a(\theta_k) i_a + f_b(\theta_k) i_b + f_c(\theta_k) i_c] - \frac{pT}{J} T_L + (1 - \frac{B_v T}{J}) \omega_n(k)$$

(15)

According to Newton's law motion, we have

$$\theta(k+1) = T\omega_n(k) + \theta(k) \quad (16)$$

To combine all of the above equation, we get a nonlinear multiple inputs and multiple outputs (MIMO) system and the state-space method in control system is easier to use for MIMO system and the state-space form is;

$$\boldsymbol{x_{k+1}} = (\boldsymbol{A}(\boldsymbol{x})\boldsymbol{x} + \boldsymbol{Bu})_k \quad (17)$$

$$y_k = (\boldsymbol{C}x + \boldsymbol{D}u)_k$$

$$[x_k] = [i_a \ i_b \ i_c \ \omega_n \ \theta]_k \hat{} T$$

$$[\dot{x}_k] = [i'_a \ \ i'_b \ i'_c \ \omega'_n \ \theta']_k \hat{} T$$

$$u_k = [V_{ab} - V_{ca} V_{ba} - V_{ab} V_{ca} - V_{bc} T_l]_k \hat{} T$$

$$e = [E_a \ E_b \ E_c \ ] \hat{} T$$

$$A = \begin{bmatrix} 1-\frac{R}{L_m} & 0 & 0 & F14 & 0 \\ 0 & 1-\frac{RT}{L_m} & 0 & F24 & 0 \\ 0 & 0 & -\frac{TR}{L_m} & F34 & 0 \\ F41 & F42 & F43 & 1-\frac{B_vT}{J} & 0 \\ 0 & 0 & 0 & T & 1 \end{bmatrix} \quad (18)$$

$$F14 = \frac{TK_E\omega_n(k)[f_b(\theta_k) + f_c(\theta_k) - 2f_a(\theta_k)]}{3L_m}$$

$$F24 = \frac{TK_E\omega_n(k)[f_a(\theta_k) + f_c(\theta_k) - 2f_b(\theta_k)]}{3L_m}$$

$$F24 = \frac{TK_E\omega_n(k)[f_a(\theta_k) + f_b(\theta_k) - 2f_c(\theta_k)]}{3L_m}$$

$$F41 = \frac{(p^2TK_E)}{J} f_a(\theta_k)$$

$$F42 = \frac{(p^2TK_E)}{J} f_b(\theta_k)$$

$$F43 = \frac{(p^2TK_E)}{J} f_c(\theta_k)$$

$$B_k = \begin{bmatrix} \frac{T}{3L_m} & 0 & 0 & 0 \\ 0 & \frac{T}{3L_m} & 0 & 0 \\ 0 & 0 & \frac{1}{3L_m} & 0 \\ 0 & 0 & 0 & \frac{Tp}{J} \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (18)$$

$$C_k = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \quad (19)$$

(Baldursson, 2005), (Modeling and Simulation of Cost Effective Sensorless Drive for Brushless DC Motor, 2013)

2.6 Kalman Filter

For the commutation of sensor less BLDC motor, the back electromotive force method is widely used. However, this method has a drawback that the back electromotive cannot be detected exactly under low speed condition. Considering this problem, some other methods are discussed such as estimation method using extended Kalman filter (EKF). The extended Kalman filter is an optimal recursive estimation algorithm for nonlinear system such as sensor less BLDC motor. However, there is some limitation for this algorithm, such as the complexity of computing the high order Jacobean matrices. To overcome the above drawbacks the unscented Kalman filter (UKF) developed.

2.7 UKF

The UKF algorithm uses a deterministic sampling approach to capture the mean and covariance estimate with a minimal sample set point. The UKF algorithm is shortly described by considering the state-space model of BLDC motor as follows

$$\boldsymbol{x_{k+1}} = (\boldsymbol{Ax} + \boldsymbol{Bu})_k + \boldsymbol{w_k} + \boldsymbol{v_k} \qquad (20)$$

$$y_k = (\boldsymbol{C}x + \boldsymbol{D}u)_k + \boldsymbol{v_k}$$

Where $\boldsymbol{w_k}$ and $\boldsymbol{v_k}$ is are the process noise and measurement noise, which can be assumed as Gaussian noise with covariance matrices $\boldsymbol{Q_k}$ and$\boldsymbol{R_k}$.

From equation (20) the UKF algorithm can be summed as follows

- Computing the order number of point x_{k-1}^i, based on the current optimal state estimation x_{k+1}^i and covariance estimation P_{k-1}^+ as follows

  $$\hat{x}_{k-1}^i = \hat{x}_{k-1}^+ + \tilde{x}^i,\ \ i = 1, 2, \dots 2n, x = n - dimensional\ variable$$

  $$\tilde{x}^i = (\sqrt{nP_{k-1}^+})_i^T = i = 1, \dots n$$

  $$\tilde{x}^{i-1} = -(\sqrt{nP_{k-1}^+})_i^T = i = 1, \dots n$$

- Propagating the order number points $x_{k-1}^i$to $\tilde{x}^i$ through the nonlinear system in state-space of BLDC motor
  $\tilde{x}^i = A_{k-1}(\hat{x}_{k-1}^i) + B_k u_k, i = 1, \dots ..2n$
- Acquiring the predicted mean $\hat{x}_k^-$

  $$\hat{x}_k^- = \frac{1}{2n}\sum_{i=1}^{2n}\hat{x}_k^i$$

- Computing the predicted covariance P_k^-
  $$P_k^- = \frac{1}{2n}\sum_{i=1}^{2n}(\hat{x}_k^i - (\hat{x}_k^-)(\hat{x}_k^i - (\hat{x}_k^-)^T + Q_{k-1}$$
- Selecting the sigma points $\hat{x}_k^i$ based on the predicted mean and covariance
  $\hat{x}_k^i = \hat{x}_{k-1}^+ + \tilde{x}^i, \;\; i = 1, 2, \dots 2n$
  $\tilde{x}^i = (\sqrt{nP_{k-1}^-})_i^T = i = 1, \dots n$
  $\tilde{x}^{i+1} = -(\sqrt{nP_{k-1}^-})_i^T = i = 1, \dots n$
- Transforming the new sigma points to the measurement model

  $\hat{y}_k^i = C\hat{x}_k^i, \;\; i = 1 \dots., 2n$
- Calculating the predicted mean of the observation $\hat{y}_k$
  $$\hat{y}_k = \frac{1}{2n}\sum_{i=1}^{2n}\hat{y}_k^i$$
- Computing the predicted covariance matrices of the observation P_y
  $$P_y = \frac{1}{2n}\sum_{i=1}^{2n}(\hat{y}_k^i - (\hat{y}_k^-)(\hat{y}_k^i - (\hat{y}_k^-)^T + R_k$$
- The cross covariance matrices can be computed as follow
  $$P_{xy} = \frac{1}{2n}\sum_{i=1}^{2n}(\hat{x}_k^i - (\hat{x}_k^-)(\hat{y}_k^i - (\hat{y}_k^-)^T$$
- Finally, update the estimation using the Kalman filter algorithm
  $K_k = P_{xy}.P_y^-$
  $\hat{x}_k^+ = \hat{x}_k^- - K_k(y_k - \hat{y}_k)$
  $P_k^+ = P_k^- - K_k P_y K_k^T$

(Patel, 2013), (E. Kallappan, 2012), (Haidong Lv, 2014)

If the parameters in the state-space matrixes are known, the computer software like Matlab/Simulink is used in control system to verify the MIMO systems stability and designing a controller. Using the parameters in matrix A and B, we have the opportunity to make different compensators, like a simple close loop with **K, nxm** matrix and a full order estimator or reduced-order estimator with **L, nxm** matrix when using state-space approach. We have also the opportunity to convert the state-space form to Laplace and Z form and make a three term PID controller for the system which is widely used.

The flight control which we have chosen to use for our project includes all of the four feedback measurement sensors for stability and a PID control function. The calibration of PID controller can be done manually by selecting the propositional gain

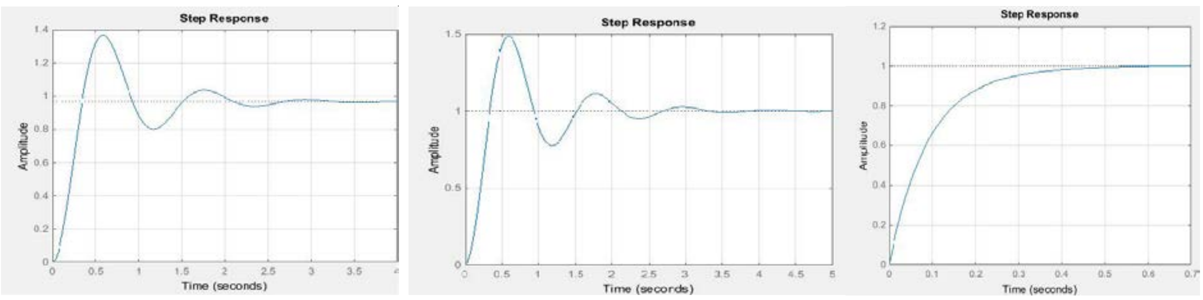
Kp from 0.20 to 0.80 during we test the UAV for first time. However, the auto tuning function in flight control is mostly used to adjust the coefficients of PID controller. The auto tuning function computes the controller's coefficients which gives the best response to the UAVs performance.

3.0 PID Controller

As previous mentioned, the movement of the UAV in any directions depends on the angular velocity of certain motors. To achieve the desired movement in the desired direction, a signal from a sensor or a signal combined from several sensors should be connected to the controller. In order to follow the reference input signal, a controller is needed. A PID controller is the most used and is very popular control, because of its simplicity, adaptability and performance in case where the system parameters are unknown. The goal of the PID control is to minimize the rise time, overshoot and steady state error defined as

$$e(t) = r(t) - y(t) \quad (21)$$

Where $r(t)$ the reference is input, and $y(t)$ is the measured output. In order to achieve a zero steady state error, the controller consists of three term controller, namely proportional (P), integration (I) and derivative (D). The proportional term multiplies the error with a proportional coefficient depends on the current error. The P controller will minimize the rise time, but it leads to an offset. The integration term integrates the area under the curve and adds up the previous error which leads to a zero offset, but in some case it will lead the system to oscillate and the settling time will increase as shown in figure 4. The integration term is included to P, because a system is usually affected by some external disturbances like gravity force and wind. In many cases the PI controller meets the requirement in less noisy environments. Anywhere, in noisy environments the D term should be added for a better control. The derivative term eliminate the oscillation which is produced by integration term and leads to shorter settling time, and improve the stability of the system. The effects of adding these terms are shown in figure 4.



(a) P controller **(b) pi controller** **(c) pid controller**

Figure 4 Effect of adding a P, I and D term in the controller

The PID controller is the sum of three terms P, I and D and can be described by equation

$$u(t) = K_p e(t) + K_i \int e\,(t)dt + K_d \dot{e}(t) \qquad (21)$$

Where K_p, K_i and K_d are designer defined gains if the motor parameters are known. But in our project where the parameters are unknown, the auto tuning function in flight control is used to adjust these coefficients. These gains are chosen by analysing the actuators pol placement in the Laplace and Z domain. The PID controller is described schematically in Figure 5.

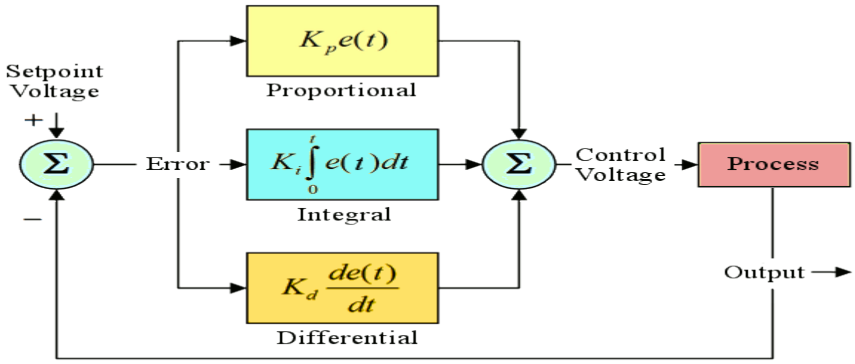


Figure 5 Block diagram of a PID controller

3.1 Roll

The Y-direction of the UAV is controlled by roll controller and the desired angel is calculated with the PD compensator where K_i is zero. The estimated angular velocity from the optical flow algorithm and the position derivative from the accelerometer sensor are submitted to the controller. The output of the controller is the signal which leads the UAV to a desired angel by increasing the angular velocity of motors on one side of Y-axes and decreasing the motors velocity on the other side. By considering the flipping issue and stability the roll controller is designed to saturate at the desired angel, if the UAV does not receive the desired roll value.

3.2 Pitch

The operation of the pitch controller is almost the same as roll controller, where the X-angel of the UAV is controlled by the pitch controller and the angel can be calculated with a PD controller. In many case where keeping the UAV with a desired distance to an object, the pitch controller is used. The pitch controller receives the signal from the sensor and then regulates the movement of the UAV in desired direction. The same as roll controller, the pitch controller saturate at the pitch value.

3.3 Yaw

The Z-axes is controlled by the yaw controller and a P controller will be good enough for this purpose. For more efficiency the ‘I’ term can be added to P term to reduce static deviation. The output of controller is the desired angel given in radians.

3.4 Attitude

To control the attitude of the UAV, a PID controller is used. Here the integral term is added because of constant force of gravity forcing the UAV down. The controller receives the desired signal from barometer which is initiated at take-off. The barometer measures the barometric pressure and calculates the attitude of the UAV. The attitude of the UAV is simply controlled by increasing or decreasing all the simultaneously. (Høglund, 2014), (Fogelberg, 2013), (ICUAS, 2013)

4.0 Powertrain

4.1 Lithium based battery technology

Lithium-ion based batteries are the lightest and have the highest energy density compared to other batteries. There are two types of lithium based batteries we can use to power up our hexacopter, namely lithium-ion and lithium polymer batteries. Lithium ion and polymer batteries have essentially the same chemical and both depend on lithium ion exchange between the lithium carbon cathode and anode. The main differences are how the cells are packaged and the type of electrolyte used. In our project we will choose a battery type which scores the highest among the two alternatives and that meet the user requirement.

4.2 Li-ion

In Li-ion batteries a flammable solvent based organic liquid uses as electrolyte. This electrolyte is for lithium-ion exchange between the anodes and cathodes. The li-ion batteries are normally encased in a hard material like other batteries. This makes the Li-ion type about 20% heavier than LiPo type.

4.3 LiPo Hybrid / LiPo

LiPo batteries use a dry electrolyte polymer separator for lithium ion exchange. LiPo hybrid is a proved version of simple LiPo batteries, and uses a galled organic solvent based electrolyte to saturate the polymer separator. The separator is laminated between anode and cathode of battery allowing for the lithium-ion exchange. This method allows the batteries to be very thin and wide range of sizes and shapes of cells. LiPo hybrid batteries are actually hybrid lithium polymer and the correct name for this types of batteries are lithium-ion polymer, but it is still known as lithium polymer. This method improves the charge and discharge range of battery, but hybrid one can still catch fire and burst in case of overcharging and shortage like Li-ion type.

4.4 LiPo battery rating

There are three main battery ratings which have to be considered before choosing the right one. These three rating are voltage, capacity and discharge.

- Voltage

Unlike the other batteries cells with that have a voltage rate about 1.2-2.1 per cells, the LiPo battery cells are rated at 3.7 volt. The benefit of higher voltage rate is fewer battery cells can be used to make up the desired battery pack. The brushless DC motors which we have chosen for our project operate with a voltage rate from 11.1V 3S (3 cells connected in series) up to 22.2V 6S.

- Capacity

The capacity indicates how much power the battery pack holds and indicated in mAh (milliamp hour). This means that a battery with 1000 mAh capacity can deliver 1000 milliamp of current to a system in one hour until the battery is fully discharged. If the system draws 2000mAh, the battery will be fully discharged in 30 minute. For a higher power consumer system, a higher capacity battery is normally used, but as the capacity increases the weight of a battery will also increases.

By calculating the average current needed for operating our hexacopter, a battery with a voltage of 22.2V, the capacity of 8000 mAh and a C rate of (25-50)C has been chosen. This will give an average flight time of approximately 9 minutes with 80% of discharging the battery.

$$\frac{capacity*60\ \mathrm{min}}{current\ flowing\ to\ the\ system} = 8 * \frac{60}{42} * 0.8 = 9\ min \qquad (22)$$

We can increase the flight time by increasing the battery capacity, but not proportionally, because the capacity and discharging rate make the battery bigger and heavier. This brings down the efficiency of the battery compared to the total load of UAV and flight time.

- Discharging

Discharging rate indicate simply how fast a battery can be discharged safely. As mentioned earlier, the ion exchange the rate of ions flowing from anode to cathode in a battery will indicate the discharging rate. In the LiPo batteries, it is called the "**C**" rating. A battery with a discharging rate of X**C** means theoretically and safely discharge it at a rate X times more than the battery pack capacity.

Using our chosen LiPo battery as an example; the battery capacity is 8000 mAh with (25-50)C. This means that a system can draw a maximum current up to

$$(25 - 50) * 8000 = (200000 - 400000)\ mAh\ or\ (200 - 400)\ Ah$$

This correspond to the current flow with the C rate of 25C

$$\frac{200}{60} * 1000 = \frac{10000}{3} mA/minute. \qquad (23)$$

And with the 50C the battery can deliver the maximum current for a few second which is absolutely not recommended to pull out. The maximum amount of current is given as

$$\frac{400}{60} * 1000 = \frac{20000}{3}\text{mA/minute}$$

The discharging time is given by

$$\frac{\text{capacity}}{\text{xmA/minute}} = \frac{8000*3}{10000} = 2.4\text{minutes} \quad (24)$$

So the 8000 mAh battery would be completely and safely discharged in 2.4 minutes and the minimum time is

$$\frac{\text{capacity}}{\text{xmA/minute}} = \frac{8000 * 3}{20000} = 1.2\text{minutes}$$

The batteries companies usually mark the continually discharge rates and burst rates on the battery pack. The burst rating indicates the battery discharge rating for a few seconds maximum.

The right discharging rate is very important for safety, battery life time and economically. As the C rating increase the more expensive and even slight heavier and bigger the battery gets. If a system overloud the battery, it would catch fire or explode and decrease the battery life time. To avoid these problems we have calculated the approximately maximum current that would flow to our UAV system before choosing the right C rate.

4.5 Pugh matrix

After conceptualizing the two above battery types, we needed to decide the better option which we could use in our project. We are able to choose the better option by the help of Pugh method. It helps in comparing the advantages and disadvantages of both batteries based on the system requirements.

Pugh Matrix	**Concepts:**	**LiPo**	**Li-ion**
Criteria	**Weighted %**		
Weight	20	**5**	**3**
Capacity	20	**5**	**5**
Price	15	**2**	**3**
Safety	20	**3**	**4**
Size	10	**5**	**3**
C rating	15	**3**	**4**
Sum	100	**385**	**375**

Table 9 Pugh matrix battery type

- Scaling from 2 to 5, where 5 is the best and 2 is the worst.

From the matrix the LiPo battery scores higher in term of weight and size, which initially is considered the most important characteristics. The way LiPo packaged making it easier to design a more compact solution by varying the battery cells quantity.

In terms of safety and C rating, Li-ion scores better than LiPo. Li-ion batteries are very sensitive to light and heat and they are actually not safer than LiPo types, but the way the li-ion cells are packaged make them safer. The better C rating is because the Li-ion electrolyte is solvent based organic liquid which has less resistance and leads the current faster than gelled organic which is used as electrolyte in LiPo battery.

The price of both types of batteries is high, but the li-ion battery is temporary cheaper than LiPo.

In conclusion, the total score on Pugh Matrix shows that the LiPo type is slightly better option in for our system. This is also the approved selection from our costumer and therefore, we will go for a LiPo battery. (BU-205: Types of Lithium-ion, 2015)

5.0 ESC

The Electronic Speed Controller (ESC) is a multirole and signal dependent electronic device uses pulse-with modulation (PWM) to control the effective voltage on the terminal of the motor. It converts battery voltage down to 5v. It also converts the DC power from the battery to an AC current which is required by the motor.

The ESCs are usually designed for a specified type of motor. For example, if an ESC is designed for a three phase brushless DC motor would not fit to a brushed DC motor.

All brushless motor and brushless motors ESC's have three wires, in which only two of the three wires are energized by the ESC at any given time. The pole that is not energized at any specific instant will actually generate a small amount of the voltage that is proportional to how fast the motor is turning. This small voltage is used by the ESC to determine how fast and in what direction the motor is turning at any given time. This information helps the ESC to know how to charge the electromagnets to keep the motor turning. (Brushed vs Brushless ESC, 2013), (TURNIGY Manual for Brushless Motor Speed Controller)

5.1 ESC Specifications

PLUSH Series	
Model	= PLUSH-40
Cont. Current	= 40 A
Burst Current	= 55 A
BEC Mode	= Linear
BEC Output	= 5V/3A
LiPo Cells	= 2-6
Weight	= 33g (x6)
Size	= 55 x 28 x 13 mm
Price	= 176 NOK (x6)
User Programmable	= Available
Balance Discharge Protection	= N/A

Table 10 ESC specification

6.0 Flight control board

The flight control board is a unit whose purpose is to stabilize the UAV while in flight .it provide the ability to connect a radio receiver for manual control, telemetry and also a possible attachment of an autopilot for autonomous navigation.

On-board inertial sensors (IMU) or gyroscopes and accelerometers are used to detect signal generated as a result of the several of movement of the vehicle on which the flight control board is mounted.

Most flight control boards are programmable or can be flashed with the firmware provided by the manufactured.

There are several types of flight controllers in the market such as APM, Mikrokopter, DJI Naza, ZeroUAV, Uthere (Ruby)

6.1 Flight controller board Requirement

The selection criteria for the flight controller board were based on following aspects in order to fulfil our own requirements specification.

- Full Autonomy
- Cost/price
- Wireless Configuration
- Open source Communication Protocol
- Fixed wing Aircraft
- Compatible to Hexacopter

Contents	APM 2.5	DJI Naza	Mikrokopter	ZeroUAV	Uthere (Ruby)
Full Autonomy	Yes	Yes	yes	yes	Yes
Wireless Configuration	Yes	Yes	No	No	No
Fixed-Wing Aircraft	Yes	No	No	No	No
Compatible Hexacopter	Yes	Yes	Yes	Yes	No
Waypoint Package	Yes	Yes	Yes	Yes	No
Telemetry	Yes	Yes	Yes	Yes	No
Autopilot/GPS	Yes	Yes	Yes	Yes	Yes
Open source	Yes	No	No	No	No
Cost/price	$149	$300	$639	$2500	$345

Table 11 Flight controller board comparison

6.2 Features of APM 2.5

- Arduino Compatible
- Side entry pins
- Includes 3-axis gyro, accelerometer and high-performance barometer
- On-board 4 Megabyte Data flash chip for automatic data logging

(APM 2.5 and 2.6 Overview)

- One of the first open-source autopilot systems to use Invensense's 6 DoF Accelerometer/Gyro MPU-6000.
- Barometric pressure sensor upgraded to MS5611-01BA03, from Measurement Specialties.
- Atmel's ATMEGA2560 and ATMEGA32U-2 chips for processing and USB functions respectively.

7.0 Power Module

The power module is an electronic component which measure battery voltage and current consumption through a 6-pos cable. It also proves AMP 2.5/2.6 with power from a LiPo battery.

Figure 6 Power module

Figure 3 shows Power Module. It has one side which is connected to the battery and another side is connected to either speed controller or PDB. The main function of the Power module is to supply a steady clean voltage and sufficient current to the APM as mentioned above. It does this process by receiving the battery voltage from the UAV and sending it to the APM.

However, the module does not only send the 5V and ground needed to power the AMP itself but it also sends information about the voltage of the battery and the current which have been pulled by the craft to the APM. (AMP 2.5 and 2.6 Overview)

Power Module Technical Specification

Variables	Values
Max current sensing	18V
Max input voltage	90A
Voltage and current measurement configured for	5V ADC
Switching regulator outputs	5.3 V and 2.25A max
6-pos DF13 cable plugs directly to:	AMP 2.5’s ‘PM’ connector
Connectors	XT-60

Table 12 Technical specification

8.0 Ground Station control

8.1 Software

The Ground control station system (GCS) is a practical application Software program for UAV running on ground based computer, or laptop able to configure the controller board , monitor and control the UAV during flight.

It displays the information that UAV sends includes the latitude, longitude, roll, pitch, and yaw, the level of the battery when it's reached at a critical level and shows information coming from the Inertial Measurement unit (IMU).

UAV and GCS can be communicated through wireless telemetry and visualize all data needed to localize the UAV at any point on the Earth, any time by using GPS.

There are several different ground stations software to be considered such as Q Ground control, APM Planner 2, MAVProxy, DroidPlanner3(Tower),AndroPilot , Mission Planner ,iDroneCtrl, AndroPilot that can be used to communicate with Ardupilot. (Jovanovic, 2009)

8.2 Ground Station control Software Requirements

The selection criteria for the GCS software were based on following aspects in order to match our own requirements specification:

- Flight Data
- Flight Plan
- Configuration and Tuning
- Initial Setup
- Open Source

Role	Task
Flight Data, GCS should:	• Have the capability to control and monitor the UAV's status while in operation. • Monitor payload and telemetry data in real-time and record all the data for future review and processing. • Provide the system functionality necessary for monitoring the UAV's location, heading and altitude. • Provide flight data such as air speed, vertical speed, Throttle and Pitch percentage and servo voltage at all times.
Flight Plan	• Provide Visual mission ,editing ,Plan, save and load autonomous missions into to autopilot with simple point-and-click way-point entry on Google or other maps
Configuration and Tuning	• Set up, configure and tune the UAV for optimum performance.
Initial Setup	• Permit ArduPilot firmware installation, UAV selection, Sensor calibration, Failsafe configuration, Battery monitoring, camera setup and keyboard/joystick mode.
Open source	• Be software that can be freely used, changed, and shared by anyone.

Table 13 Selection criteria for GSC software

8.3 GSC Comparison table

The table shown below illustrates the different open source ground control software are available to meet the overall requirements.

Name	Description	Platform	License
Tower (DroidPlanner3)	Android GCS for phones and tablets. Intended for end users and enthusiasts. Tower includes features like follow-me, "dronies" (i.e. "selfies" but taken with a drone) and special missions for 3D mapping.	Android Phones and Tablets	Open source
APM Planner 2	The best autopilot for use on MAC and Linux platforms. It has a smaller user base and reduced feature set when compared with Mission Planner. It's allows you to plan, control and analyse all aspects of a UAV from a Mac, PC or Linux-based operating system. Intended for developers and enthusiasts.	Windows, Mac OS X, Linux	Open source
MAVProxy	Linux GCS often used by Plane developers. Primarily a command line interface with graphical modules for map and mission editing. Written in Python, and extensible via python modules.	Linux	Open source
Mission Planner	Full featured and widely used GCS. Intended for both developers and enthusiasts. Highest number of functions. It's allows you to plan, control and analyse all aspects of a UAV from a PC laptop or desktop computer Runs best on Windows but can be made to run on MAC using Mono.	Windows, Mac OS X	Open source
iDroneCtrl	iDroneCtrl is a free iOS app from Fighting Walrus, LLC. It uses Fighting Walrus' iDroneLink radio (915 MHz or 433 MHz) along with an iPhone or iPad to talk to the APM-powered UAV.	iPhone, iPad	Open source
QGroundControl	QGroundControl can connect and display attitude information and parameter lists but is not customised to work with the ArduPilot firmware as much as the other ground stations listed above.	Windows, Mac OS X, Linux	Open source
MAV Pilot	ArduPilot compatible GCS that runs on iPhone/iPad. Also supports PX4 Flight Stack and ArDrone2.0 with Flight Recorder.	iPhone, iPad	Proprietary.
AndroPilot	Android GCS intended for enthusiasts	Android Phones and Tablets	Open source

Table 14 GSC software comparison

Based on the GCS comparison table above the three types of GCS are considered to be analysed in order to choose the right GCS for our project .These three types are APM Planner 2.0, QGroundControl and Mission planner that are open source software, available for Windows, Mac OS and Linux.

Mission planner is more advanced in term of his full-featured ground station application for the APM open source autopilot project comparing to APM Planner with a smaller user base , reduced feature set and QGroundcontrol that cannot customised to work with the ArduPilot firmware as much as the mission planner ground station.

8.4 Features of Mission Planner

- Autopilot control by point and click way point entry using google maps.
- Full ground station for monitoring missions and sending in flight commands.
- See sensor output and test autopilot performance
- Download mission log files and analyse them
- Configure APM setting depends on the kind of frame configuration you're using
- User friendly interface with loads of useful functions
- Loads firmware onto APM, configures how you want to use your APM chip from different aerial and ground vehicles

In conclusion, the Mission planner fulfils all required specification to achieve our main goal. This is also the approved selection from our costumer; therefore Mission planner is the best selection for our project. (Choosing a Ground Station)

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Technical Report - Camera

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	15.05.2015	OPC	BJD	Released

Summary:

This document is intended to give an introduction to the camera and stabilization section of the 3D ground mapping system.

Owner: Laly Mann

Document Revision History

Rev	Date	Author	Description	Status
0.1	05.05.2015	HLM	Technical Documentation Camera	Obsolete
1.0	15.05.2015	OPC	Final Version V1.0	Released

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Purpose of this document

This document is intended to give an introduction to the Sony NEX-5N camera and stabilization system that is going to be used for the 3D ground mapping system. The main focus will be on the 5 most important criteria's for the camera system, and proving that our camera choice meets the system requirements. These criteria's are based on our conceptual study, concept evaluation and system architecture, which have been done in an earlier stage of this project. These 5 criteria's is low weight, high resolution, enough battery capacity, enough storage capacity and a low cost of production is a result of an analysis of our systems requirement.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
APM	Auto Pilot Module
APS-C	Advanced photo system type-C
AVCHD	Advanced Video Coding High Definition
CIPA	Camera & Imaging Products Association
CMOS	Complementary Metal-oxide Semiconductor
DSLR	Digital single- lens reflex camera
FPS	Frame per second
f-stop	Focal stop
IR	Infrared
ISO	International Organization of standardization
LCD	Liquid crystal display
mm	Millimetre
SD	Secure Digital
SDHC	High Capacity Secure Digital
SDXD	Extended Capacity Secure Digital
s-number	Focal number

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents referenced in this document

Doc. number	Description
003	Requirements specification
006	Conceptual Study
007	Concept Evaluation
008	System Architecture

Table 2 Related documents

2.0 Sony NEX-5N

2.1 Specifications

The Sony NEX-5 is a mirror less interchangeable APS-C lens camera. It also has a 16.1MP CMOS sensor. And it has also many features like LCD touch-screen, max shooting rate 10FPS, Video at 1080 60i/p (AVCHD). The body can be compared with a point and shoot camera, and the lens and performance can be compared with a DSLR camera. This camera has the best from bought camera types, small and lightweight body and the choice to change lens after need. (Digital Photography Review, 2011)

2.2 Lens and focal length

The NEX-5N has a standard lens kit with a Sony E-mount type lens, where the lens has a focal length 18-55mm. This lens has also an image zoom stabilization system built in, and auto pre focus function. Focal length is the distance between the centre of the camera lens and the camera sensor as shown in figure 1. The length is stated in mm and is often written on the camera lens, in this case its 18-55mm.

Focal length on 18mm will give a wide angle view (76°) and smaller object view than on the 55mm. The 55mm will give a smaller angle (29°) at maximum zoom and larger object view than the 18mm. To find out the optic zoom number for the lens, we have to divide the maximum focal number with the minimum. So 55mm/18mm=**3**, this state that with this lens it possible to zoom a object 3 times with this lens.

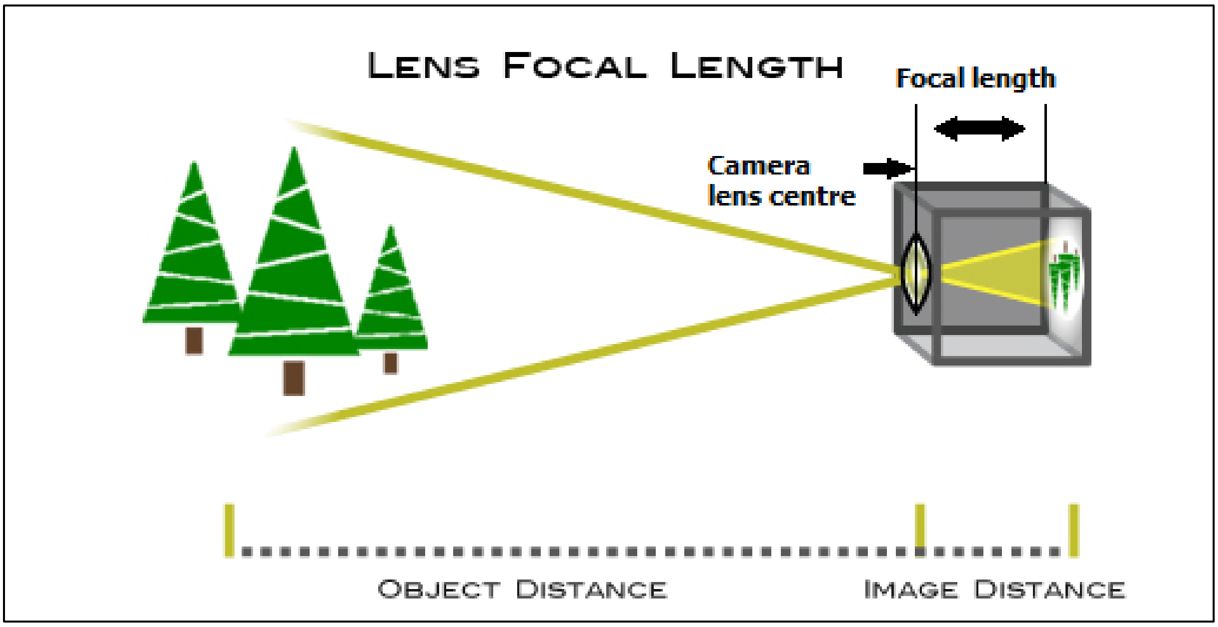

Figure 1 Lens Focal length (Nikon Inc.)

2.3 Aperture, ISO and Shutter

The aperture main task is to regulate the amount to light through the lens to the camera sensor. Figure 2 shows an aperture scale. The scale shows that if there is a large aperture then the lens lets more light to strike the image sensor and the result will be a shallow depth of field (focus). And smaller aperture let less light to strike the image sensor, and the result will be a deep depth of field (focus). With shallow depth of field means that the object closest to the camera lens is in focus and the background is out of focus (blurry), and this is when the aperture is large. And this will change as the aperture get smaller and it goes over to deep depth of field (focus), the blur in the background will move further in the background as the aperture get smaller. The aperture is stated with f-number and f-stops if there is an individual setting. The max aperture for the Sony NEX-5 is f/3.5 at its widest angle and can vary to 5.6 when the lens zooms in. And the angle gets smaller as the aperture reach minimum its f/22 – 32.

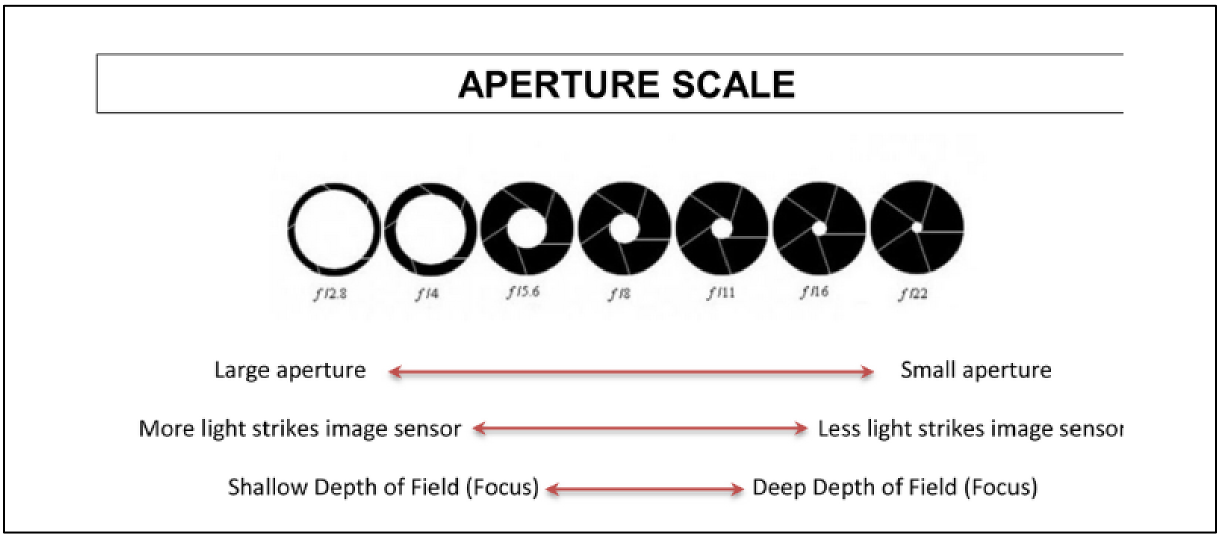

Figure 2 Aperture Scale (Style Honestly, 2012) (Pixgood)

2.4 ISO

ISO (International Standard Organization) values tell us how sensitive the camera sensor is to light. A low ISO value will give a less sensitivity and will require more light to the sensor. And higher ISO values give higher sensitivity and will require less light to the sensor. Low ISO give less image noise and high ISO give more image noise. These statements are shown in figure 3. The NEX-5N camera has an auto and a manual ISO setting, at the auto setting the values are from 100 to 3200. And from 100 to 25600 on the manual setting

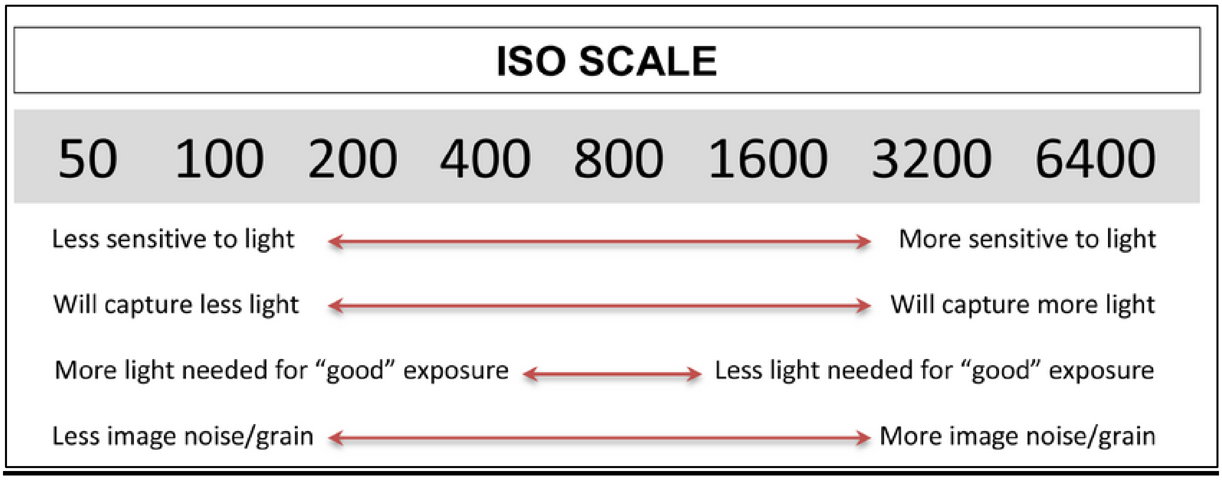

Figure 3 ISO Scale (Style Honestly, 2012)

2.5 Shutter and shutter speed

A shutter is like a curtain that opens to expose the sensor for light, and then closes when the expose is finished. The NEX-5 has an option to use electronic shutter to reduce a shutter lag between the trigger and the exposing and it also reduces noise in the image. There are also the options to not use the electronic shutter, and then the curtain is closed before the trigger button is pressed and this will take a little more time then with the electronic shutter. The NEX-5N has an optionally electronic curtain and one standard curtain that is the rear curtain. The electronic front curtain shutters lens is always open when the camera is in live mode, and when shutter button is triggered the curtain closes and then opens to expose the camera sensor for light. When the exposer time is done the rear curtain closes. Shutter speed is the amount of time that the camera shutter is open. Fast shutting speed will give a short opening time for the shutter, so the sensor will get less amount of light. A fast shutting speed will also be able to freeze the motion and reduce image noise. Slow shutting speed will give a long opening time for the shutter, so the sensor will get more amount of light. A slow shutting speed will also be able to get the motion in the image and create more image noise. The NEX-5N has as shutting speed from 30-1/4000sec. Figure 4 shows a shutter speed scale. (Wikipedia, 2015)

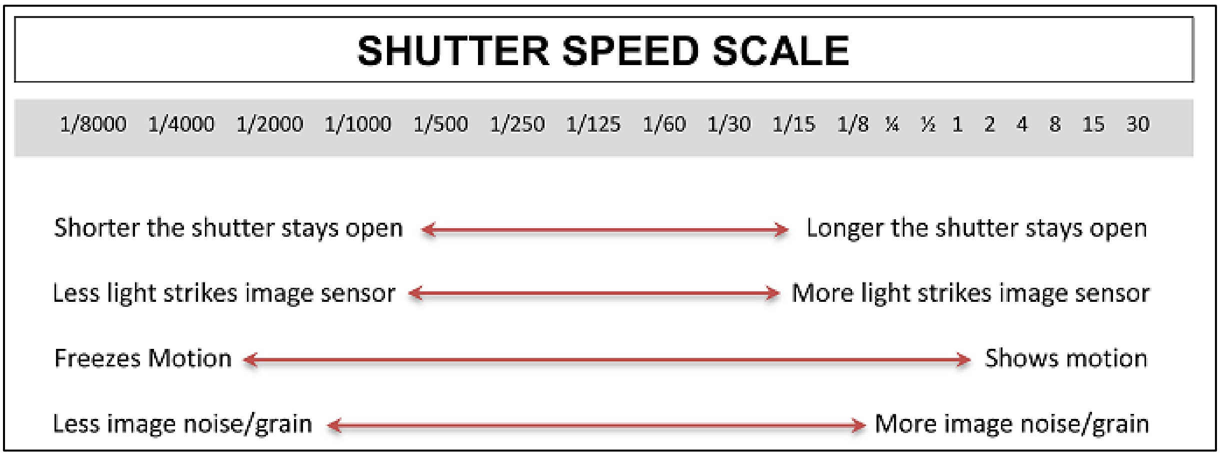

Figure 4 Shutter Speed Scale (Style Honestly, 2012)

2.6 Battery

This battery for our camera system is made after the Camera and Imaging Product Association (CIPA) standards. These standards apply to all digital cameras made after 2002. Sony states on their website that the battery should last 430 shots when half of the images are taken with flash and other half is without flash (CIPA standards). The nex-5 is equipped with a lithium-ion rechargeable battery, with part number NP-FW50. Battery capacity is 1080mAh. 7.7Wh is the physical work that is being done over time by the battery and is measured I Watt per hour. Battery voltage output is 7.2V. There is a possibility to power the camera from the UAV power supply, but in this case the camera system should have its own battery supply. (Sony Electronics Inc., 2015)

2.7 Memory

There are several types of storage options for the Nex-5N. Memory Stick PRO Duo, Memory Stick PRO-HG Duo is high-speed flash memory card/sticks with large storage capacity. The Secure Digital cards (SD), SDHC and SDXC are all memory card with low memory capacity to extra high memory. There are also Eye-fi SD cards that stream the images direct from the camera trough WI-FI. There is a need for enough storage capacity to meet the requirement URQ-CR-05, so the system is going to consist off a 35GB memory card also because its CUBE AS inventory.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-05	TS-SIT-C05	A	The System shall be able to map an area of minimum 10 000 square meters.	STG

Table 3 REQ ID - URQ-CR-05

2.8 Weight

Table 2 shows the weight distribution for the complete camera system, without any additional equipment that is available for this type of system. This weight parameter will vary after what kind of lens, battery pack and other extra equipment that are going to be used.

Body	Lens	Battery	SD Card	Sum Weight
210g	194g	42g	10g	456g

Table 4 Weight Distribution

2.9 Cost

The coast of the camera system is a bit difficult, because the NEX-5N is a outgoing product and therefor the electronic stores in Norway do not have access to this camera type anymore. But it can be order on EBay for 550$, this includes camera body, lens and battery without memory card. This system is also available on Finn.no for around 2000-3000Kr used. But our project assigner CUBE AS had a requirement (URQ-CR-01) regarding the cost of the product, that we should use the CUBE AS parts inventory. So the camera system has to be from their inventory, or have to be bought second handed to get the cost as low as possible.

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-01	TS-SIT-C01	A	The system shall be created using available resources	STG
URQ-CR-14	TS-SIT-C14	A	If additional acquisitions are necessary, costs must be kept as low as possible.	STG

Table 5 URQ-CR-01 and URQ-CR-14

3.0 Mission planer

In the mission planning phase there are some parameter/options that are needed so the software can calculate the image resolution for the mission that are being planned. These parameters/Options are:

- Exactly witch camera type that is going to be used for the mission.
- Wanted/possible flying altitude, flying speed and camera angle.
- The picture overlap and side lap percentage.

In the next step the software are going to calculate and recommend some parameters for the Focal Length, Image Width (Pixels), Image height (Pixels), Sensor Width (mm) and Sensor Height (mm). All these parameters can be changed, but they will only affect the resolution (cm/pixel).

3.1 Mission planer image capturing

There are many ways to take pictures with Mission Planer at assigned waypoints. For this system we did choose an IR solution. So we are using an Infrared Remote control shutter cable from the APM to the NEX-5 IR sensor in the front of the camera. This will work when flying route and waypoint for the image taking is planned. Then the waypoints list with a command list appear, the command on the next waypoint after "DO_SET_CAM_TRIGG_DIST" have to be changed to "DO_DIGICAM_CONTROL", this have to be done for all the waypoints, so this is for the command for IR trigging function. The Mission planner will know automatically take images at all the waypoints.

Figure 5 IR Trigger (AltiGator)

4.0 Stabilization

We are using a 3-axis gimbal for the Sony NEX series. The camera system needs a stable and independent platform to avoid vibrations and to be able to keep the predetermined angle under all circumstances. We are using a preprogramed Alexmos gimbal controller, so no programming will be needed. (DroneTrest, 2013)

The gimbal consists of a metal body with some kind of carbon fibre on the top plate. The camera that the gimbal is carrying is kept in angle by 3 brushless step motors. 1 is YAW motor, 1 is ROLL motor and the last is PITCH motor. (Explain That Stuff!, 2014)

5.0 References

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Technical Report - Image Processing

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	14.05.2015	OPC	TTP	Released

Summary:

This document is intended to showcase the image processing part in the 3D Ground Mapping system, identify some of the software alternatives and highlight different parameters that are vital for a good result.

Owner: Bjørnar Dalset

Document Revision History

Rev	Date	Author	Description	Status
0.1	30.04.2015	BJD	Initial draft	Obsolete
1.0	14.05.2015	OPC	Final Version V1.0	Released

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Purpose of this document

The purpose of this document is to identify different software alternatives for the image processing in the 3D Ground Mapping system, test the basic operation using Agisoft Photoscan and look at important parameters and requirements for the 3D processing results to be optimum.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
GSD	Ground sampling distance
GCP	Ground control points
ISO	International standards organization

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents relevant to this document

Doc. number	Description
003	Requirement Specification
004	Inspection and Test Plan
007	Conceptual Evaluation
008	System Architecture

Table 2 Related documents

2.0 Software

Currently there are several different 3D modelling programs – aimed specifically at rendering models from aerial photography – to choose from. Functionality, ease of use, and cost will vary greatly, however the basic operation will be the same for most programs. In this document we will be focusing on processing with Agisoft Photoscan, however any of the alternatives listed below could be used to produce sufficient results.

No software has been bought for this project. The software being tested is running on a student licence. This document will show the processing of a set of pictures as an example of how a 3D model can be acquired from aerial photography and verify that results can be obtained according to the needs specified in the Requirements Specification.

2.1 Alternatives

Manufacturer	Name	Cost
Agisoft	Photoscan (Professional Edition)	3499USD
PIX4D	PIX4DMapper (Pro)	7900CHF
Autodesk	Recap 360	500USD/year
MosaicMill	EnsoMOSAIC 3D	2900€

Table 3 Software alternatives

Agisoft Photoscan

Photoscan is a stand-alone software for photogrammetric processing of digital images, made by Agisoft. Photoscan can generate 3D models, point clouds and DSM's from digital photos. Collect spatial data, distances, areas, volumes and texturize in high definition for very detailed results. (Agisoft, 2015)

PIX4DMapper (Pro)

Pix4D is an image processing software aimed at converting terrestrial and aerial images into 2D mosaics and 3D models. Pix4DMapper Pro has an extensive feature set and can output results in a variety of formats and make fly-through animations. (PIX4D, 2015)

Autodesk Recap 360

Recap 360 is a 3D scanning software made by Autodesk. Recap 360 turns laser scans and digital photos into high-fidelity 3D models. (Autodesk, 2015)

MosaicMill EnsoMOSAIC 3D

EnsoMOSAIC 3D is a photogrammetry software made by MosaicMill. EnsoMOSAIC 3D is used for mapping of spatial objects like buildings, roads and terrain from digital aerial imagery. (MosaicMill, 2015)

3.0 Image processing with Agisoft Photoscan

3.1 Important prerequisites

For the 3D modeling process to work properly and results to be of required quality certain criteria's must be met. Below you will find a list of important considerations before starting the 3D modeling process. For further references: (Agisoft, 2015)

Sharp images

Objects of interest must be sharp and in focus, i.e. the aperture value must be high enough to result in sufficient image depth. A small aperture value will result in very shallow depth of field, thus possibly rendering important information blurry and obscure, and render the image useless.

Figure 1 Small aperture value – shallow depth of field

Figure 2 Medium/large aperture value – medium/large depth of field

Low noise

The amount of noise in the images will greatly depend on the camera being used. The lowest possible ISO value should be used in order to induce the least amount of additional noise to the image. This implies that images should be captured in reasonably bright conditions to avoid high ISO settings.

Figure 3 High ISO value – grainy and noisy image

Motion blur

Motion blur may occur if the shutter speed is set to slow. This could render the image useless in a 3D modeling process. The speed of the UAV must be taken into account when setting the shutter speed.

Figure 4 Slow shutter speed results in motion blur

Resolution

For the highest degree of accuracy, maximum resolution should always be used. The resolution will depend on the camera. In combination with the sensor size and the flight height, a certain GSD can be obtained.

Lens distortion

Although Photoscan can compensate for some lens distortion it is best to avoid very wide angle and fish-eye lenses. For best results a 50mm focal length is preferred. Fixed lenses are considered to give better results than zoom lenses.

Weather conditions

Light rain should not be a problem, especially if images are captured in aerial nadir. However, heavy rain, snow or fog may obscure the visual content of the images and render pictures useless. Strong wind may also affect the quality of the images, even if a gimbal is properly implemented.

Image overlap

In general, a lot of photos is better than a few photos. However, for a given project one must consider the amount of detail needed and the processing time. A huge photoset will increase processing time considerably.

For aerial photography a certain overlap is needed to avoid "blind zones" and find common key points. Agisoft recommends a 60% side overlap and a +80% front overlap. This ensures a high degree of common key points and minimizes potential blind spots.

GCP's and markers

Photoscan can complete reconstruction and geo-referencing without ground control points. However, in order to achieve the most accurate geo-referencing it is recommended to use ground control points – at least ten points – spread out evenly. This ensures a high degree of accuracy for geometrical and geo-referencing tasks.

If the user is planning to carry out measurements based on the reconstructed model, it is also recommended to locate at least two markers in the terrain, with a known distance between them.

GSD

The GSD refers to the distance between pixels measured on the ground. A lower GSD value results in more detail, while a higher GSD value results in less detail. The GSD is directly related to the height of the flight and must be considered when trying to achieve the highest degree of accuracy.

Sometimes a very low flight height is not practical or possible and a compromise must be made. A low GSD also leads to more images for a given area, and thus longer processing times. For the 3D Ground Mapping system the required GSD can be obtained by entering information regarding the camera being used in Mission Planner and setting the desired GSD. Mission planner will automatically calculate the appropriate flight height.

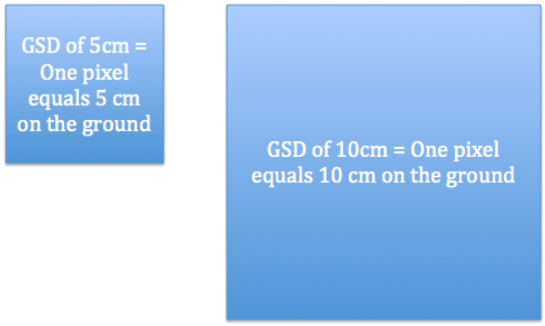

Figure 5 GSD of 5cm and 10cm

3.2 3D Modelling Example

Area of interest

For this test a 70 000 square meter area was to be scanned. The area is a typical construction site, with woods, rough terrain and some settlement. Below is four of the 206 images acquired showing the overlap.

Figure 6 Aerial Photos

Camera and Overlap

Images were captured with a Panasonic Lumix GH4. Pictures were shot in automatic mode. The side-overlap was 65% and the front-overlap was 85%.

Computer specifications

Processing of images was carried out on a PC with:

- Intel Core i7-2600 3.4GHz processor
- 8GB memory
- SSD Ultra Speed hard drive
- Windows 7 Ultimate 64bit

Adding images

The picture below shows the workspace of Photoscan. Pictures are added in chunks. These chunks can consist of the whole picture set, or can be divided into several chunks to lessen the processing burden. Chunks can then be processed separately and combined in the end to produce the same result as processing everything together at once. For this test only one chunk of images (206 images) was used.

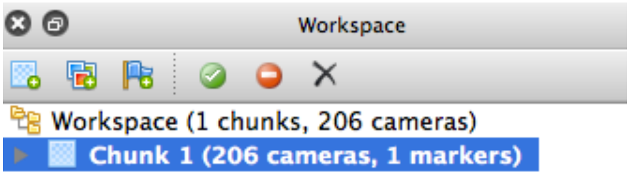

Figure 7 Adding Images

Below is a screenshot of the list of the images used in the processing. Photoscan has a function that evaluates the quality of the images in the chunk. This lets you remove any images that might not be of sufficient quality.

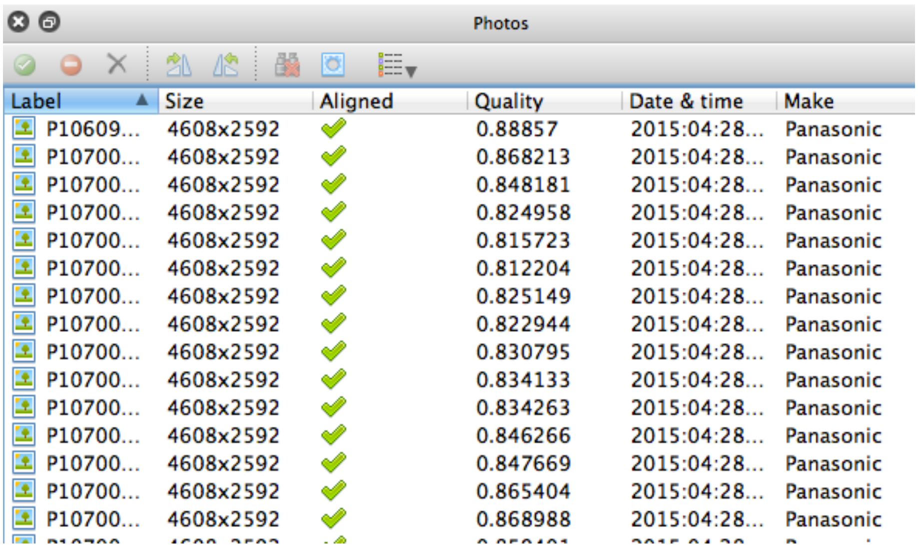

Figure 8 Quality Evaluation

Aligning images

After importing images into Photoscan, images need to be aligned. Photoscan automatically finds the camera position and orientation for each photo and builds a sparse point cloud model.

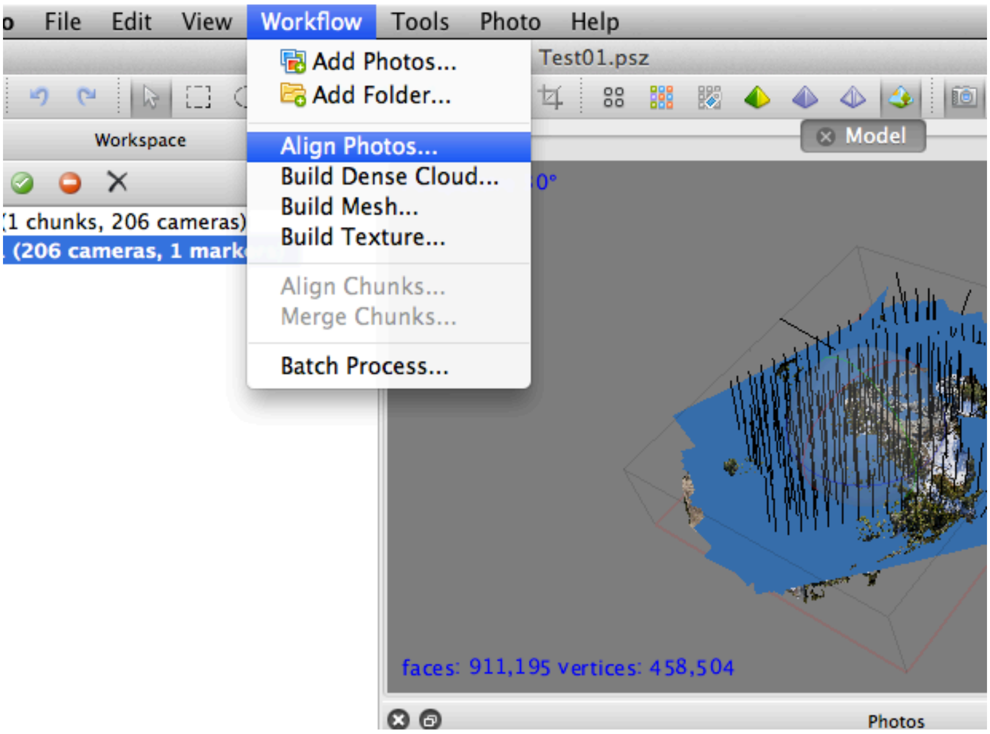

Figure 9 Aligning Images

Building dense point cloud

After aligning images, a dense point cloud is generated from the Workflow menu. For this test, a dense cloud of 13 590 063 points were generated.

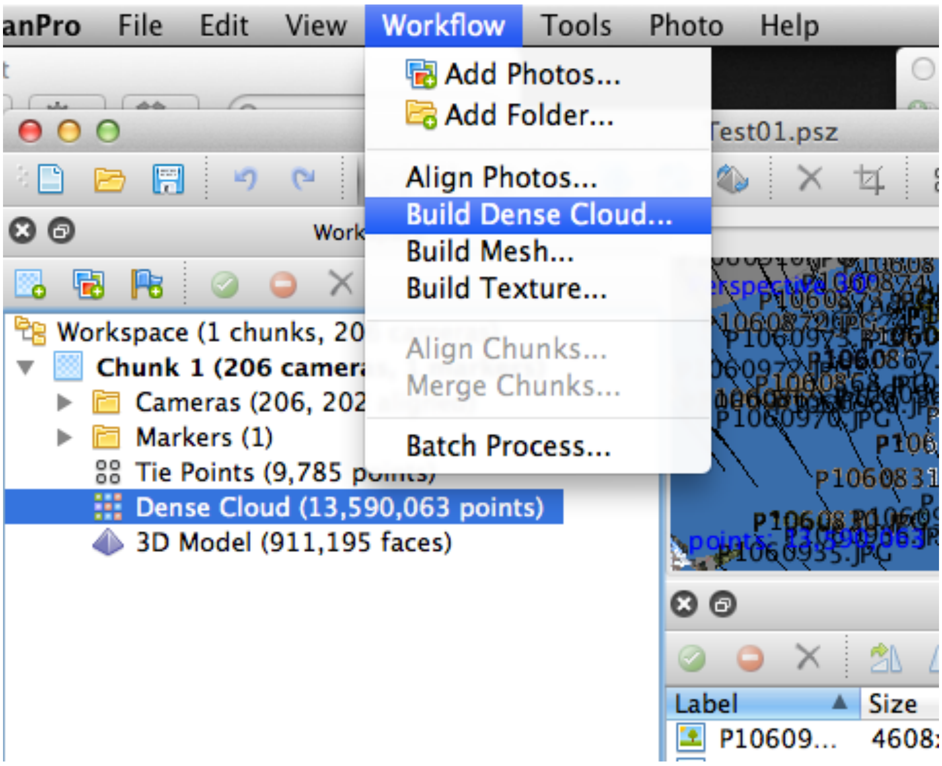

Figure 10 Building Dense Point Cloud

Building mesh and texture

After the dense point cloud is generated, the mesh and texture can be built from the same Workflow menu.

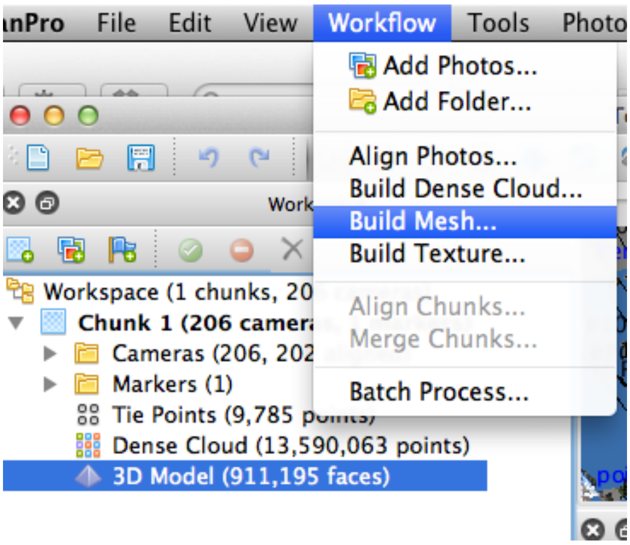

Figure 11 Building Mesh and Texture

Final 3D model

Figure 12 shows a few screenshots of the final 3D model. Photoscan offers a variety of settings to be adjusted during processing that affects the final 3D model. For this test default settings were used during the whole process. Changing these settings may affect the processing time and the quality of the final 3D model.

After processing the model may need to be reviewed to see if any anomalies have occurred. Photoscan offers a lot of possibilities to readjust the model to achieve the desired results.

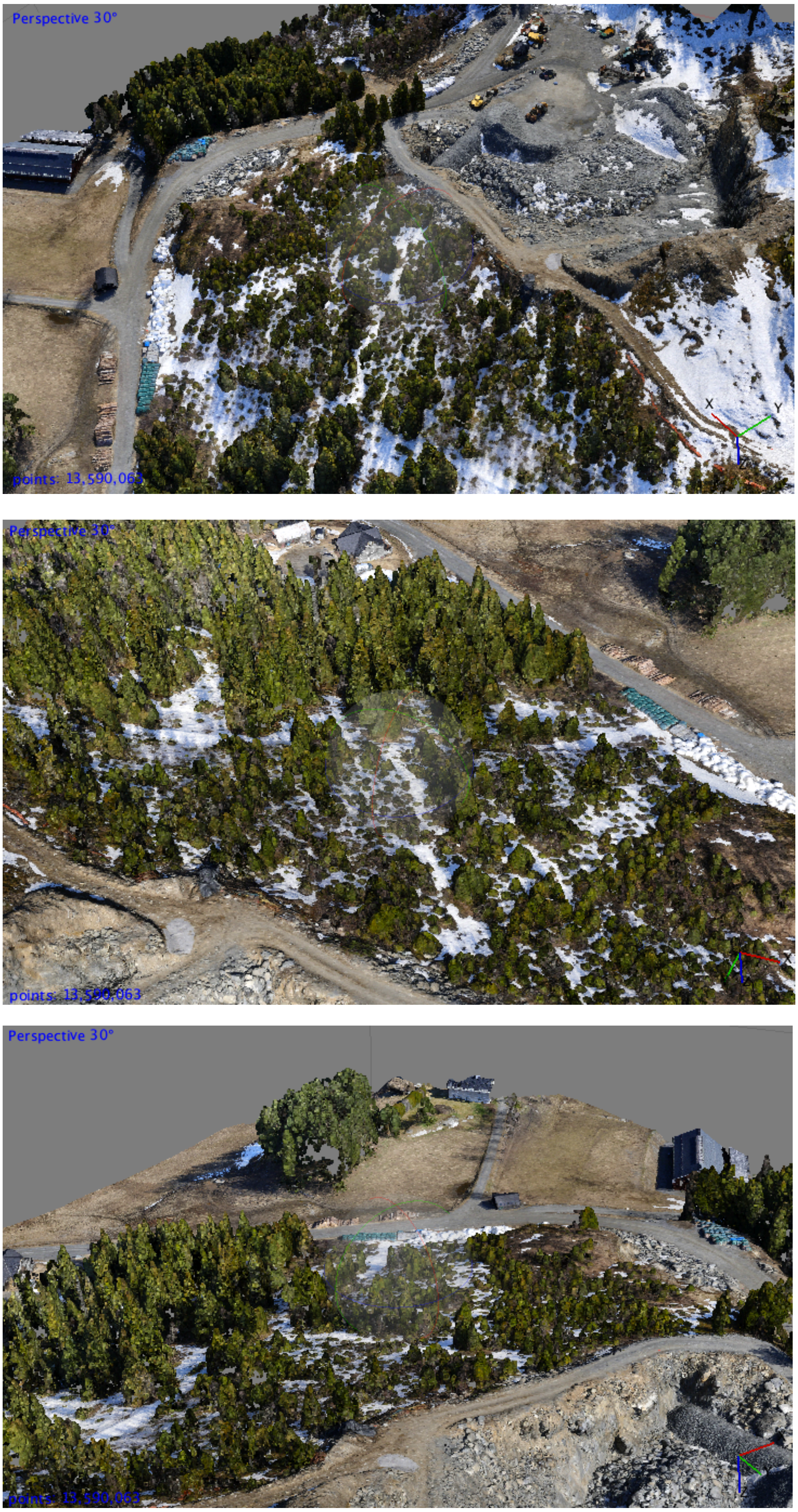

Figure 12 Final Map

Processing time

The final processing time for this test was six hours. For each step in the process (aligning photos, building dense cloud, etc.) the user manually started the next process. Photoscan does however have a feature that lets you do batch processing. This means that the software performs general workflow operations automatically without having to interfere until every chosen step in the process is completed.

Export options

Photoscan can export results in a wide variety of formats to be further processed and analysed. Export options can be found under the File and Tools menu.

3.3 Conclusion

Agisoft Photoscan is capable of delivering results that are well within the required specifications for this project. The coverage in this test (70000 square meters) far exceeded the needs specified in the Requirements Specification

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-05	TS-SIT-C05	A	The System shall be able to map an area of minimum 10 000 square meters.	STG

Table 4 Requirement – coverage

with a process-time well below the upper limit of 72 hours

REQ ID	ITP ID	PRY	Description	Origin
URQ-CR-07	TS-SIT-C07	B	The system should not exceed a process time of 72 hours to create a digital 3D model	STG

Table 5 Requirement – process time

Only default settings were used in this test. Tweaking parameters and raising quality settings could have yielded more detailed and accurate results at the cost of higher processing times.

Due to time constraints and licencing issues, it was not possible to compare the results from this test with any of the other major 3D modelling programs.

4.0 References

Agisoft. Retrieved April 20, 2015 from Agisoft: www.agisoft.com

Agisoft. Agisoft Photoscan User Manual Professional Edition Version 1.0.0. Retrieved April 20, 2015 from Agisoft Downloads: http://www.agisoft.com/downloads/user-manuals/

Autodesk. Retrieved May 10, 2015 from Autodesk Recap: http://www.autodesk.com/products/recap/overview

MosaicMill. Retrieved May 10, 2015 from Mosaicmill EnsoMOSAIC 3D: http://www.mosaicmill.com/products/software/ensomosaic_3d.html

PIX4D. Retrieved May 10, 2015 from PIX4D: www.pix4d.com

Technical Report – Analysing UAV Crash

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	14.05.2015	BJD	TTP	Released

Summary:

This document is intended to look at the reason for the UAV crash.

Owner: Asadullah Jacop

Document Revision History

Rev	Date	Author	Description	Status
0.1	06.05.2015	ADJ	Initial draft	Obsolete
1.0	14.05.2015	ADJ	Final version	Released

Table of Contents

List of Tables

1.0 Introduction

1.1 Purpose of this document

Purpose of this document is to analyse and look at potential reasons for the UAV crash.

1.2 Abbreviations

List of abbreviations and corresponding descriptions used in this document

Abbreviation	Description
UAV	Unmanned aerial vehicle
BLDCM	Brushless Direct Current Motor
PID	Proportional Integration Derivative

Table 1 Abbreviations

2.0 Troubleshooting of UAV crash.

We have discussed the possibly issues in our UAV system which caused the UAV to crash before we could use the auto tuning function for PID control to stabilize the UAV. Based on our observation of the behavior of the UAV under testing and the data from mission planner, the motors power compared to the total load of the UAV and the calibrations of the IMU, barometer and magnetizer are taken to be analyzed.

2.1 Motor

When we tested the UAV, it seemed to be very sensitive to the throttle. The UAV moved upward very quickly and crashed after a few seconds. The mission planner shows the rate of current flows to the system at the moment when the UAV takes off and when it crashes as shown in table 2. These information will help us to analyze the possibly reason of the UAV crash. In this case we analyze the rate of power and thrust produced by all of the six motors under take off and the rate of power is needed to take off the UAV smoothly and operate normally.

	The rate of current flow to da system	
Supply voltage	Take off	Crashed
24.8	28A	58A

Table 2 The rate of current flow under different conditions

The UAVs generally needs at list twice as much thrust (measured in force and gram) then its total load to overcome the force of gravity and operate normally. But if the maximum amount of thrust produced by all the motors is much more than twice of the systems total load, the auto adjusting control of the UAV will be very difficult. This is because the UAV will be very sensitive to throttle and behaves aggressively. These quick reactions will cause the control sensors to be less effective to follow the desired signal from the user and keep the UAV at desired angel.

The power each motor produced under take off and crash is as follows

$$P = VI = 24.8 * \frac{28}{6} = 112W \qquad (2, 0)$$

$$P = VI = 24.8 * \frac{58}{6} = 240W$$

The relation between the motors power and thrust is nonlinear and it's very difficult and even impassible to calculate it hundred percent correctly in the real world. Therefore, we use the data from tested table which is done by the motor company to find the approximately amount of thrust produced by the motors. To find the target percentage of the throttle, we use the mathematic formula from **Bob Boucher's Electric Motor Handbook** as shown in equation (2, 2) to find the required power at a specific angular velocity of the motor. The RPM is given as follows

$$RPM = K_v * V \quad (2, 1)$$

Where $RPM is$ the motor rotation specified in radian per minute, K_v is the motor constant and V is the rate of battery voltage.

$$P = K_p D^4 * P_i * RPM^3 \quad (2, 2)$$

Where K_p $is$the propeller constant depends on the material of the propeller, P is the motor power given in watts, D is the diameter of the propeller, $P_i$is the pitch of propeller and RPM is angular velocity of the motor given in thousand. The D and $P_i$specified in feet.

The equation (2, 2) gives us important information about the power observation which can be define as follows.

- Doubling the diameter of the propeller requires 16 times the power to spin the propeller at the specified RPM.
- Doubling the pitch requires twice as much power to spin the motor at given RPM.
- Doubling the RPM requires 8 times the power to spin the motor at a given RPM.

We refer these characteristics to the motor and propeller which have used in our UAV. We have used six motors in our hexacopter from T-Motor Company with data sheet shown in table 2. The diminution of the propeller and the cells of battery pack we have used are different than the tested one which tested by the company shown in table 4. The dimension of our selected propeller is 12x6 inch and the battery pack is 6s Lipo with a voltage of 22.2. Note that in the **kv** per volte given by the company will be always some error and the error increase when the angular velocity of the motor increase.

Tiger Motor MT2826-6	
KV	= 760
Configuration	= 12N14P
Stator Diameter	= 28mm
Stator Length	= 26mm

Shaft Diameter	= 5mm
Motor Dimension	= Q35x48mm
Weight	= 187g
Idle current (10) at 10v (A)	= 1A
No. of cells(Lipo)	= 3 – 6S
Max Continuous current(A) 180s	= 45A
Max Continuous Power (W) 180s	= 700W
Max efficiency current	= (10-28A) > 81%
Internal resistance	= 20m

Table 3 Tiger Motor Specifications

The table 4 is the tested result of the same motor a we chosen for our UAV.

Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (g)	RPM	Efficiency (g/W)	Operating temperature(℃)
MT2826 KV760	14.8	T-MOTOR 12*4CF	50%	7.5	111	860	6200	7.75	45
			65%	10.1	149.48	1040	6900	6.96	
			75%	12.6	186.48	1200	7500	6.44	
			85%	16.9	250.12	1500	8350	6.00	
			100%	20.3	300.44	1680	8800	5.59	
		T-MOTOR 13*4.4CF	50%	7.9	116.92	920	5750	7.87	46
			65%	11.2	165.76	1200	6500	7.24	
			75%	14.6	216.08	1380	7300	6.39	
			85%	19.6	290.08	1710	8000	5.89	
			100%	23.4	346.32	1900	8600	5.49	
		T-MOTOR 14*4.8CF	50%	9.1	134.68	1080	5200	8.02	57
			65%	14.9	220.52	1530	6200	6.94	
			75%	20.3	300.44	1890	6800	6.29	
			85%	26.3	389.24	2200	7400	5.65	
			100%	31.5	466.2	2470	7740	5.30	

Notes:The test condition of temperature is motor surface temperature in 100% throttle while the motor run 10 min.

Table 4 Testing results of MT2826 KV760 for different sizes of propeller

The approximately calculated power, thrust and RPM for our motor with maximum 97% efficiency at 25 percent throttle and minimum 71% efficiency at 100% throttle in table 5.

K_p	Motor	Voltage	Prop D&P_i	Throttle (%)	Current A	Power Watts	Thrust G	RPM	Efficiency g/w
1,20	MT2826 Kv 760	22.2 (24.8)	12x5	25	2.16	48	379	4600	7,9
				40	8.0	180	1368	7200	7.6
				50	14.41	320	2368	8800	7.4
				65	24.32	540	3672	10400	6.8
				75	32.88	730	4453	11500	6.10
				85	40.0	890	4717	12500	5.30
				100	48.65	1080	4860	13400	4.5

Table 5 Approximation of power/thrust and percentage of throttle for 12x6 propeller

We use the power calculated in equation (2, 0) and table 5 to find the percentage of the throttle and thrust produced by the motors at the moment when the UAV toke off. The single motor produced about 885 grams of thrust at about 30% of throttle and the total thrust produced by the six motors was about 5300 grams. This amount of force will be enough to overcome the force of gravity and take off the UAV with the total load of about 4.5 kilos. Compared to the total load of our UAV which is about 2800-2900 grams, this amount of force is too much at 30% throttle. This can be the reason why the UAV seemed to be very sensitive to the throttle and possibly caused the UAV to flip off and crash.

From the table 5 we find out the maximum thrust can be produced by the six motors and then finding the amount of net load for our UAV. Note that the maximum power should be just taken in account which is given in table 2, not from table 5. The table 5 shows a significant over powering the motor which not desirable and we can decrease this undesired power by decreasing the pitch of the propeller as given in equation (2, 2).

The limit of power in the selected motor is given to be 700 watts and the current is 45 amps. With the six cells pack battery and higher pitch of propeller the power of the motor is not saturating at 700 watts and it goes above the limited power, but the current remains below the limited one, because of the high voltage of 6 cells battery as shown in equation (2, 0) and in table 5. To calculate the suitable total payload, we have to take in account about 20-30 percent error with the calculated thrust to be sure that the UAV's performance meets the requirement. With the component which we have selected, our Hexacopter is able to take off and operate with a net load of 6000 grams to 7500 grams.

2.2 PID Rate Tuning and ESC Calibration

Calibration error can cause the crash of UAV during flight; in this section ESC and PID calibration are taken to be analyzed in order to know the reason why we crashed our UAV.

The PID tuning is a necessary parameter to be considered, the design objectives of PID controller are to choose the reasonable parameters which can make the system meet the design requirements.

In our system we have used Manual tune to calibrate the PID via mission planner. The Higher value will make the UAV more responsive to roll/pitch inputs, the UAV will oscillate on the roll and /or pitch axis and with lower value will make the UAV smoother and the UAV will become sluggish to inputs.

Rate Roll/Pitch PID are generally related to the power and weight ratio of the UAV .for example a UAV with high thrust might have Rate Roll/pitch P number of 0.08 while a lower thrust UAV copter might use 0,18 or even higher. In our case when we tested the UAV, it seemed that the UAV had a very high thrust and we supposed to start with a lower Rate Roll/Pitch PID value in order to control the UAV during the Test and can be a reason that the UAV flips immediately upon and take-off.

Electronic speed controllers (ESC) Calibration is also taken to be analyzed since it's responsible for spinning the motors at the speed requested by the autopilot and need to be calibrated correctly so that they know the minimum and maximum PWM values that the flight controller will send.

The calibration was done manually; the all at once ESC calibration mode can be the right way to calibrate the speed controllers.

2.3 Conclusion

Based on our analyzing the chosen motor for our UAV is much more powerful than required to lift up our UAV and operate as normal and the propellers diminutions which is a bit over size makes the motor even more powerful. To minimize the stability issues that caused the UAV crash, we have to increase the net load of the UAV up to about 5500 grams. It’s also possible to decrease the pitch of propeller from 12x6 to 12x4. This will decrease the requirement of the power which is a critical part in the UAVs.

The Assembly of UAV

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	15.05.2015	OCH	TTP	Released

Summary:

This document is intended to show how the UAV was built.

Owner: Giresse Kadima

Document Revision History

Rev	Date	Author	Description	Status
0.1	04.05.2015	GKM	Initial Draft	Obsolete
1.0	15.05.2015	OCH	Final Version	Released

Table of Contents

List of Tables

List of Figures

1.0 Introduction

This document is intended to explain the way the UAV was built.

1.1 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
UAV	Unmanned aerial vehicle
PM	Power Module
APM	Auto Pilot Module
ESC	Electronic Speed Control
PDB	Power Distribution Board

Table 1 Abbreviations

2.0 UAV

2.1 Components

Before we started with the building of the UAV, we need all components to be available. Each components and the quantity needed are shown in the table below.

Components	Quantity
Motor	6
ESC	1
APM 2.5 (2.6) flight control Ardupilot	1
Power Module	1
Battery	1
ESC	6
PDB	1
Propeller	6
Silicone wire 12 AWG 1M (Black + Red)	8
Telemetry	1

Table 2 Components & Quantity

2.2 Tools

Table below shows which tool we used in building our UAV

Tools	Quantity
Soldering Station	1
Heat Gun	1
Multi-meter	1
Soldering Tin Wire	1
Wire Cutters	5
Allen Wrench	3
Heat Shrink Tubing	2 (red + black)
Spanner	4
Screwdrivers	8
Ruler	1
Tape	2
Thread locker	1

Table 3 Tools used for construction

3.0 Procedures

3.1 Soldering of components

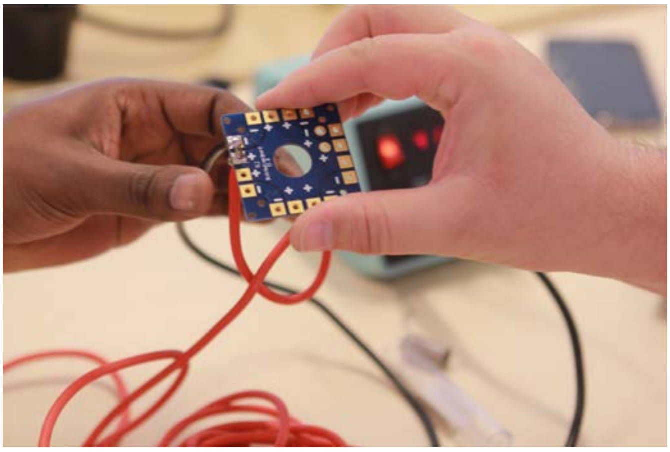

Figure 1 Soldering

We have a power distribution board which did not fit into the frame. Therefore we bought a new and started soldering it with a soldering station as we can see on Figure 1.

3.2 Placing of PDB

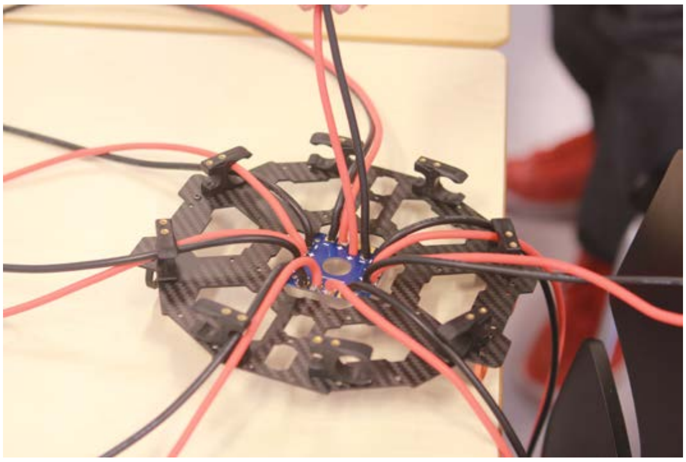

Figure 2 Placing of PDB

After soldering of PDB, we placed under the frame plate of the UAV as it is shown on Figure 2.

3.3 Putting upper and lower frame together

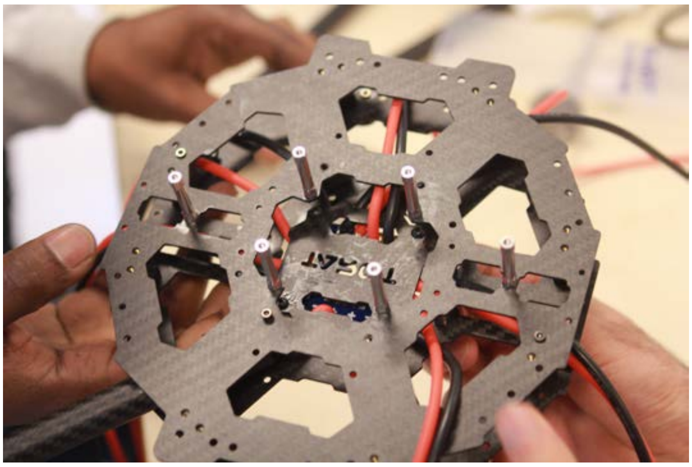

Figure 3 Putting the top and button together

Figure 3 shows how we put upper and lower frame together while the power distribution board laid between them.

3.4 Attach the arms and legs

Figure 4 attached the arms and legs

Figure 4 shows how we attached arms to between bottom and upper plates.

3.5 Soldering

Figure 5 soldering and attaching the ESC and motor to the arms

Figure 5 shows where we solder the power wires and control signal wires to the ESC and attach it with the motor to the UAV arms.

3.6 Shirked tube around the ESC

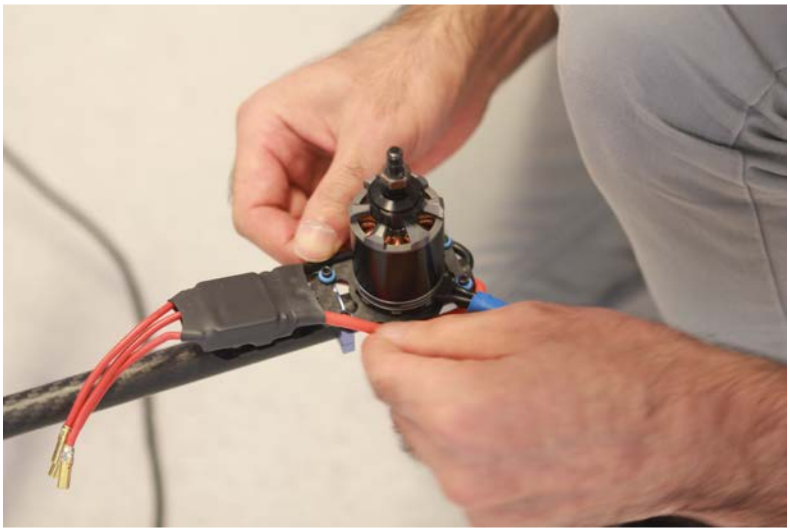

Figure 6 Shirked tube around the ESC

Figure 6 shows the shrunk tube around the ESC to avoid shorting the wire.

4.0 Completed product

Figure 7 Hexacopter

After integrating the entire component to gather in the UAV frame and the UAV building process is ended. The UAV is ready to be tested as shown in Figure 7.

Action Plan

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	15.05.2015	BJD	TTP	Released

Summary:

This document is intended as mitigation to meet the project scope after the project UAV crashed.

Owner: Giresse Kadima Mpoyi

Document Revision History

Rev	Date	Author	Description	Status
0.1	07.05.2015	GKM	Action Plan draft	Obsolete
1.0	15.05.2015	BJD	Action Plan final version V1.0	Released

Table of Contents

List of Tables

1.0 Introduction

1.1 Purpose of this document

The purpose of this document is to analyse the actions that will be considered in order to complete our project after the last UAV crash. Without the UAV we will not be able to complete our project scope to its full extent and we therefore we need an action plan to ensure the completion of the other part of the project scope. This document will also show risks that might occur during this process.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
UAV	Unmanned aerial vehicle
AP	Action Plan

Table 1 Abbreviations list

1.3 Related documents

This section provides a list of other documents referenced in this document

Doc. number	Description
001	Vision Document
003	Requirements Specification
004	Inspection and Test Plan

Table 2 Related documents

2.0 Background

As we have already stated in our project plan, in our project we will design, develop and construct a complete system for 3D mapping of ground, using a camera equipped UAV. And the final system will be able to produce precise 3D maps and models of locations, which can be viewed on a computer screen or used to print out physical models using 3D printer.

UAV is one of the important systems in our project. Therefore, by having a UAV, we will be able to take pictures of a desired terrain which will then be processed in software to produce our final product.

However, we have already built our own UAV to do the work of taking pictures. Unfortunately, the UAV has crashed twice. The first crash happened on our first flight test but it was not severe and we were able to repair those small damages. The second crash happened on the second flight test. Big damages occurred to the UAV.

Nevertheless, with the little time we have to complete our UAV, we will not be able to repair our UAV for this time around. In order to repair it, we need to order new components to replace the damaged ones. This will take time to receive the ordered components and it will be late for us to complete our project accounting to our plan.

Therefore, in this document, we will be discussing which actions the group will do in order to solve the problem we are facing now in order to complete the project on the time according to the project plan.

3.0 Action Plan

3.1 Using a borrowed UAV

In order to continue the project work, it is a possibility to borrow one of Cube AS's other UAV's. By borrowing an already working UAV we can modify it to suit our needs and continue the work with getting aerial photos to process.

Using an already flight-ready UAV will save us a lot of time with regards to testing. We can focus on preparing the UAV for taking pictures and fulfilling the requirement specification.

By borrowing a UAV with similar specifications we can continue the work without changing the requirements stated in our Requirements specification.

3.2 Buying pictures from Isachsen

Another possibility is buying a finished set of aerial photos, in order to test the processing and have more time to finish up the documentation. By buying photos we can verify that the 3D modelling process can be executed according to the Requirements Specification and we will not have to worry about another UAV failure this late in the project.

We can continue with the work immediately and will not have to wait for parts.

4.0 Risk list

General risks that might occur during the execution of our action plans.

Crash of borrowed UAV

UAV borrowed from Cube AS might crash.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Transfer:** Only Tommy Larsen from Cube AS can fly this UAV, the team can't do anything here. **Migration:** Use action plan 2.		

Table 3 Crash of borrowed UAV

UAV pilot availability

No one in the team is able to fly an UAV. We are depending on Tommy Larsen from Cube AS to fly the UAV. However, he might not be available when needed and this might result in delays.

Risk occurrence	Low	Medium	**High**
Risk consequence	Low	Medium	**High**
Risk management	**Accept:** Since no one on our team has any experience in flying UAVs we have to accept that we have to wait. **Migration:** Use action plan 2.		

Table 4 UAV pilot availability

Borrowed UAV might not work

The UAV borrowed from Cube AS might have problems that prevent it from working in the way we need it to work. This will leave the team without an UAV to take the necessary images.

Risk occurrence	**Low**	Medium	High
Risk consequence	Low	Medium	**High**
Risk management	**Accept:** Cube AS is responsible for this UAV. **Migration:** Use action plan 2.		

Table 5 Borrowed UAV might not work

Approval to buy image set

Buy an image set from Isachsen Gruppen AS for testing might not be approved by Cube AS.

Risk occurrence	Low	**Medium**	High
Risk consequence	Low	Medium	**High**
Risk management	**Mitigation:** The team can pay for the image set or use action plan 1.		

Table 6 Approval to buy image set

5.0 Conclusion

Ideally, we would like to borrow another UAV and continue the work as planned. However, at this point there is very little time to actually execute the necessary modifications to the UAV in order to meet our specifications and continue the testing and verification. The group has therefore come to the conclusion that buying a set of pictures is the most sensible alternative. Cube AS will decide wither or not to go through with this.

User Manual

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	14.05.2015	BJD	TTP	Released

Summary:

This document is an user guide for the 3D Ground Mapping system.

Owner: Albert Ngenzi

Document Revision History

Rev	Date	Author	Description	Status
0.1	04.05.2015	NGA	Initial draft	Obsolete
1.0	14.05.2015	BJD	Final Version V1.0	Released

Table of Contents

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1.0 Introduction

1.1 Purpose of this document

This document is intended to provide essential information for the UAV, includes a description of the UAV system functions and capabilities, alternate modes of operation, and step-by-step procedures for system access and use.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
APM	Auto Pilot Modul
GPS	Global Positioning System
WP	Waypoint
UAV	Unmanned Aerial Vehicles
ESC	Electronic Speed Controller
IR	Infrared
USB	Universal Serial Bus
CH	Channel
PID	Proportional-Integral-Derivative
WP	Way Point
RTL	Return To Launch

Table 1 Abbreviations

2.0 UAV Remote Control

2.1 Pre-Flight Checklist

At this point, all connections on the UAV should be made (except for the battery). Start with fully charged batteries in the remote control, and a charged battery on the receiver. The following steps will help you to prepare for the first flight.

2.2 Arming the motors

Before arming the motors, make sure all people and objects are clear of the propellers. Then do the following:

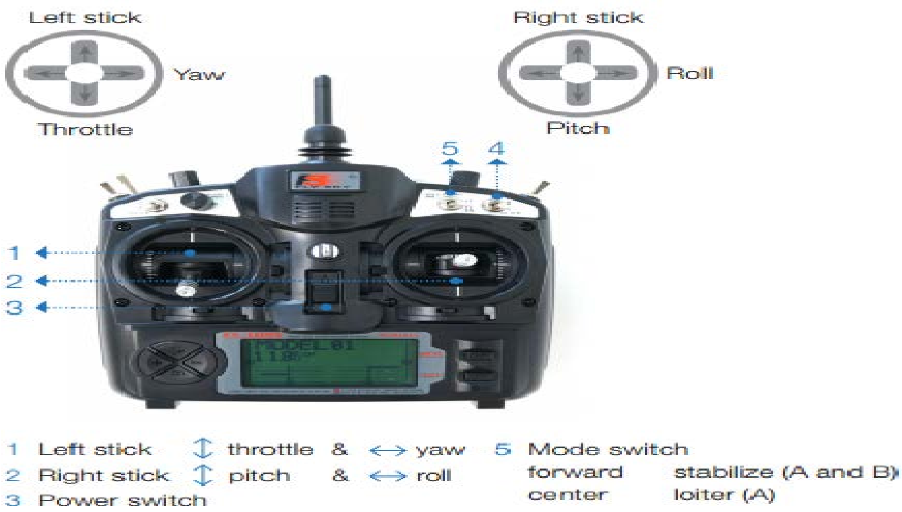


Figure 1 Transmitter

1. Turn on your transmitter

For Mode 1 transmitters, the left stick will control pitch and yaw, the right stick will control throttle and roll.

For Mode 2 transmitters, the left stick will control throttle and yaw; the right stick will control pitch and roll.

For either type of transmitter, the transmitter's three-position switch should be attached to channel 5 and will control flight modes. Channel 7 and Channel 8 switches can be used for controlling auxiliary functions.

2. Move the joysticks to neutral (centered) position.

3. Place the UAV on as level a surface as possible (if the surface is not level, the UAV may not want to arm).

4. Plug in the UAV's battery and step back.
Place the UAV at a distance with the front facing away from you.

5. Arm the motors by holding the throttle down, and pitch right for 5 seconds.It takes approximately 5 seconds the first time the UAV is armed as it re-initialises the gyros and barometer. Do not hold the rudder right for too long (>15 seconds) or you will begin the AutoTrim feature.

6. Once armed, the red arming light should go solid hold and will start the motors and set them to the idle speed.

7. Now the UAV is ready to fly, but do not take off.

2.3 Disarming the motors:

To disarm the motors do the following:

1. Check that your flight mode switch is set to Stabilize, ACRO, AltHold or Loiter.

2. Hold throttle at minimum and pitch to the left for 2 seconds.

3. The red arming light should start flashing on the APM.

4. Disconnect the battery.

5. Turn off your transmitter.

3.0 Mission Planner

3.1 Download and Installing Mission Planner software

Go to the Mission Planner download page and click on the "Mission Planner – MSI – Permanent link to latest" and then on the next page push the Download button.

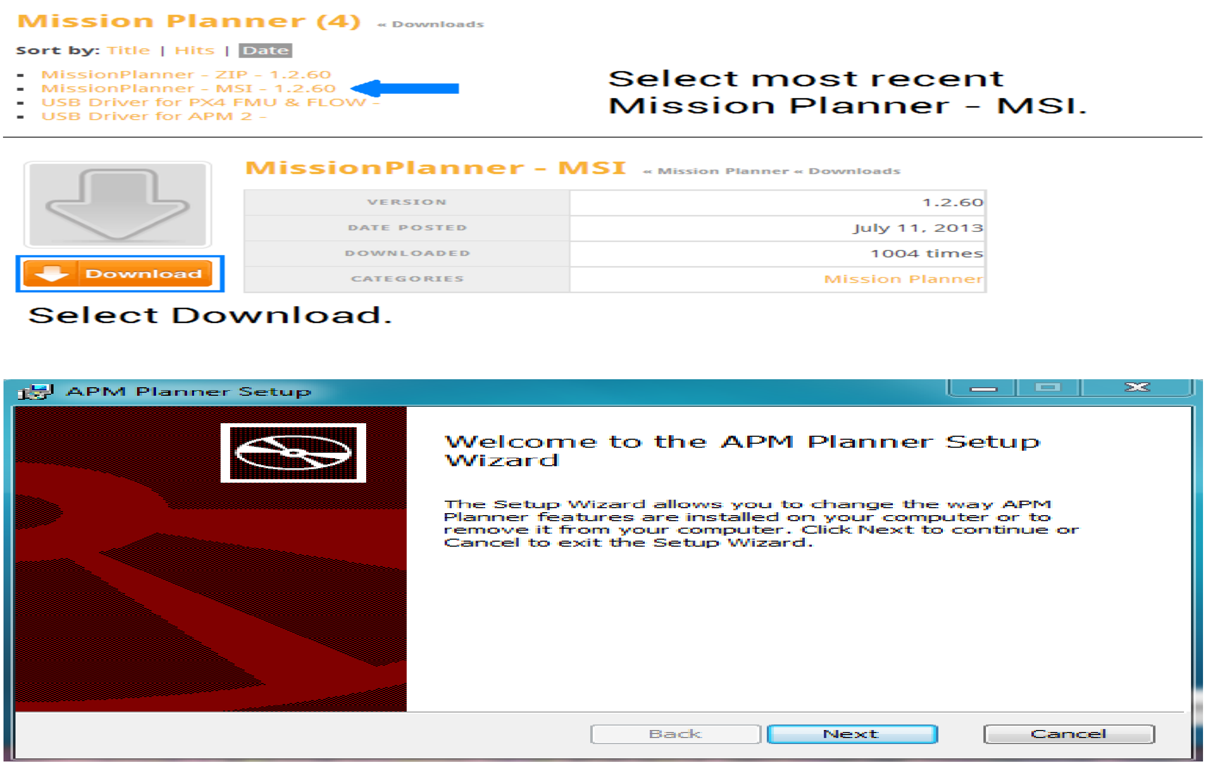


Figure 2 Mission Planner download

Follow the instructions to complete the setup process. The installation utility will automatically install any necessary software drivers.

If you receive the warning pictured here, select install this driver software anyway to continue

3.2 Connect APM to computer

Once you've downloaded Mission Planner onto your ground station computer, connect APM to your computer using the micro USB connector and APM's micro USB port.

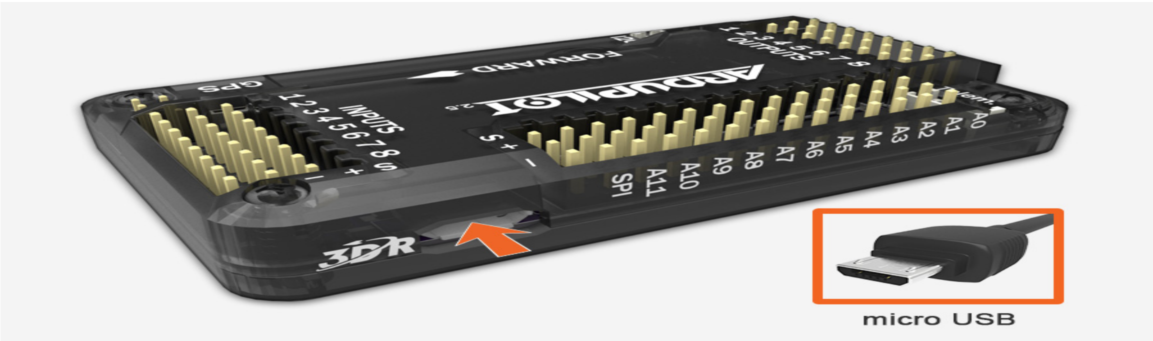


Figure 3 Connect APM 2.6 micro to computer

Windows will automatically detect APM and install the correct driver software.

3.3 Connect APM to Mission Planner

Next we'll let Mission Planner know which port we're using to connect to APM. In Mission Planner, use the drop-down menus in the upper-right corner of the screen (near the Connect button) to connect to APM. Select Arduino Mega 2560 and set the Baud rate to 115200 as shown. Don't hit Connect just yet.

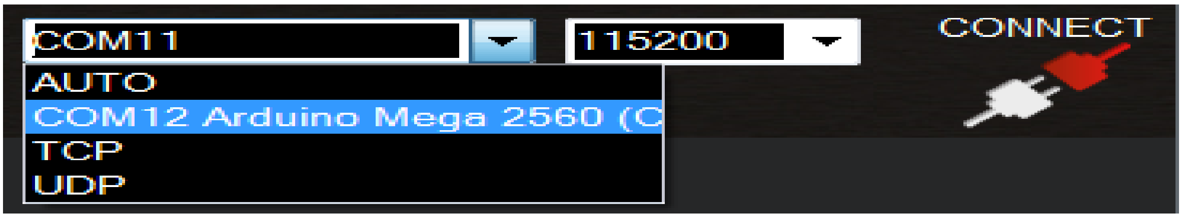


Figure 4 Connect APM to mission planner

3.4 Select firmware

Now we'll select which firmware to download to APM; this depends on the configuration of your craft. Select the Hardware screen from the icons at the top of the display. Choose your copter's frame by clicking the corresponding icon: Quad, Hexa, Y6, plane, rover, or other. (We'll specify + or x configuration later.) The firmware screen will not appear if you have already selected Connect, so ensure that Mission Planner shows a disconnected icon in the upper-right corner to access the firmware.

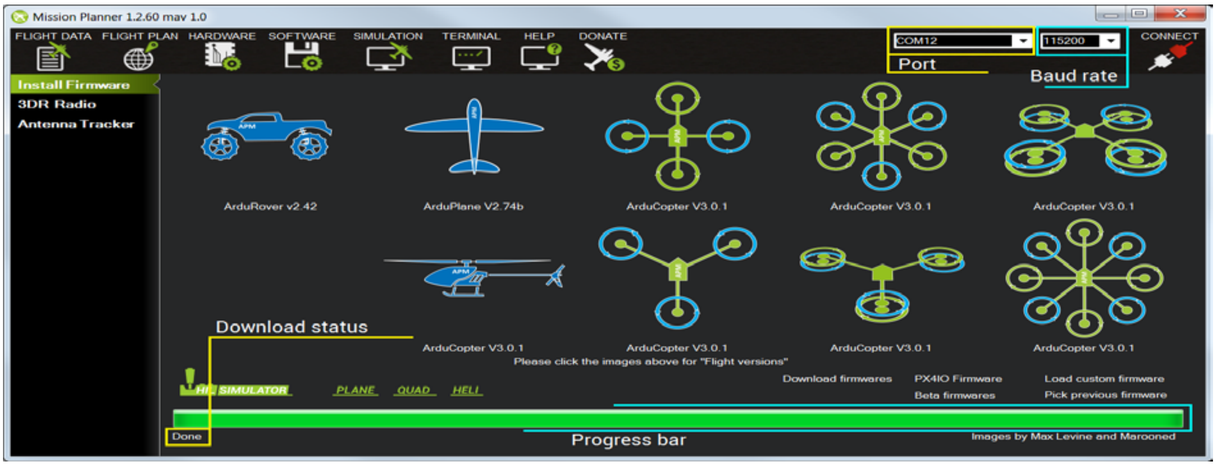


Figure 5 Selecting appropriate firmware

Once you select your frame, Mission Planner will automatically detect the latest firmware version for your craft and prompt you to confirm the download. Select yes to download the firmware onto APM. When the download status reads done, your firmware download is complete.

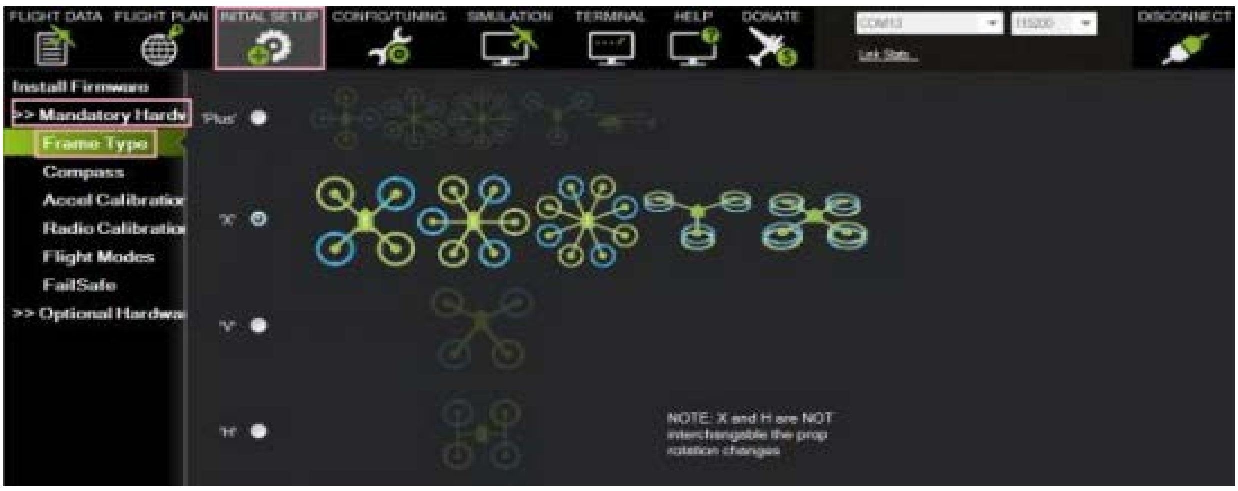


Figure 6 Select desired fram type

3.5.Connect to MavLink

Select Connect (upper-right corner of the screen) to load MavLink parameters to APM. Mission Planner will display a window showing the progress of the MavLink download.

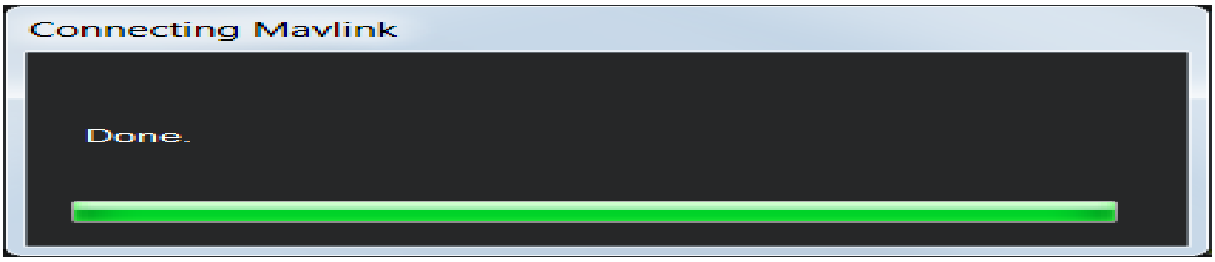


Figure 7 Connect to MavLink

When the window displays Done and Mission Planner shows the Disconnect option in place of Connect, your APM firmware has been downloaded successfully.

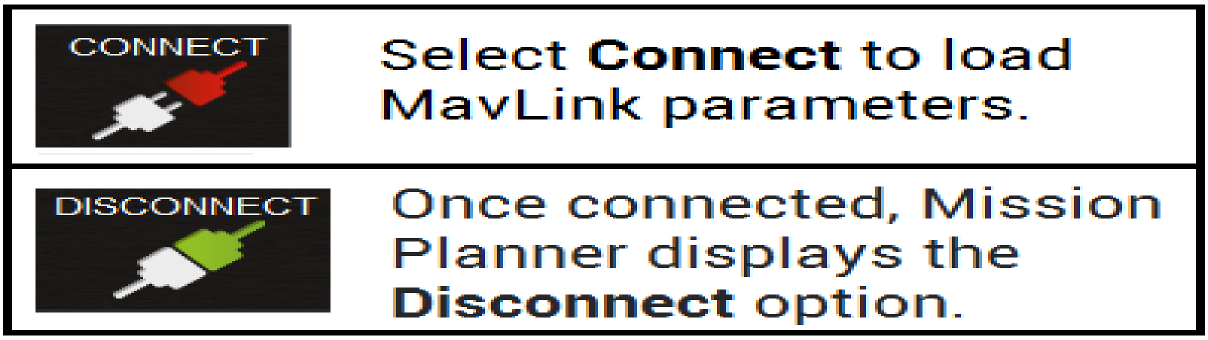


Figure 8 Connect/Disconnect to Mavlink

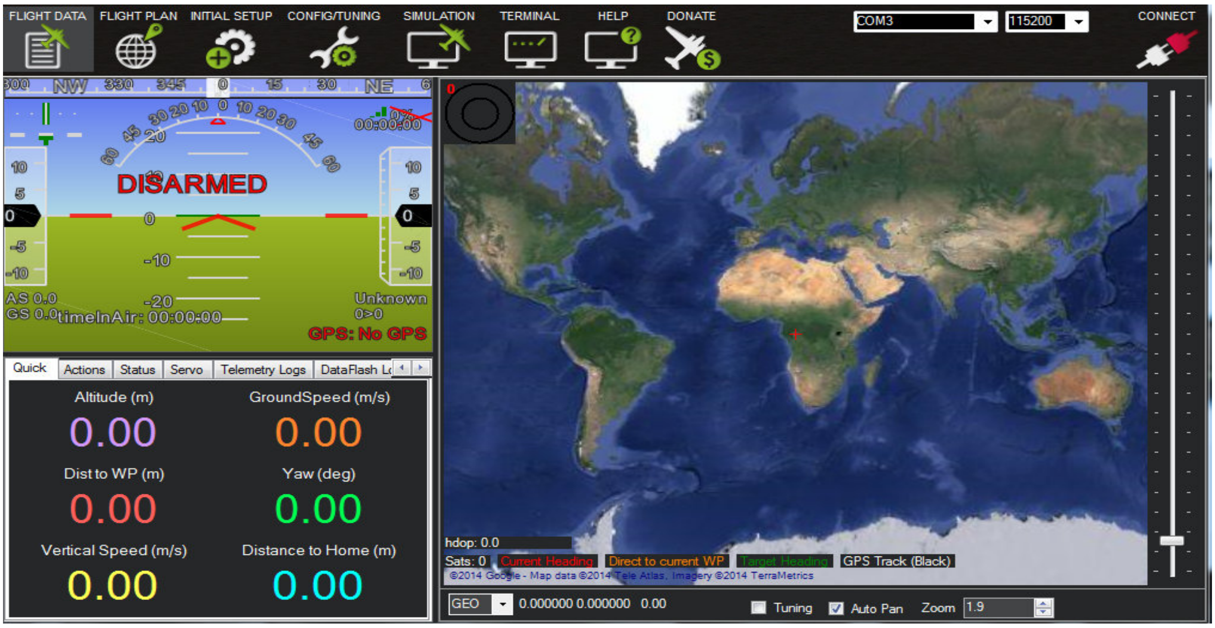


Figure 9 Mission Planner window displays

3.6.Connecting the GPS / Magnetometer Module

3DR uBlox GPS with Onboard Compass is compatible with APM 2.6 and includes two cables: the compass I2C cable is 4-position and the GPS cable is 6-position-to-5-position cable or can 6 to 6 positions. If it 6 to 5, connect it to the upper GPS port (new GPS style port. If it is 6 to 6, connect it to the side GPSport (old style GPS port).

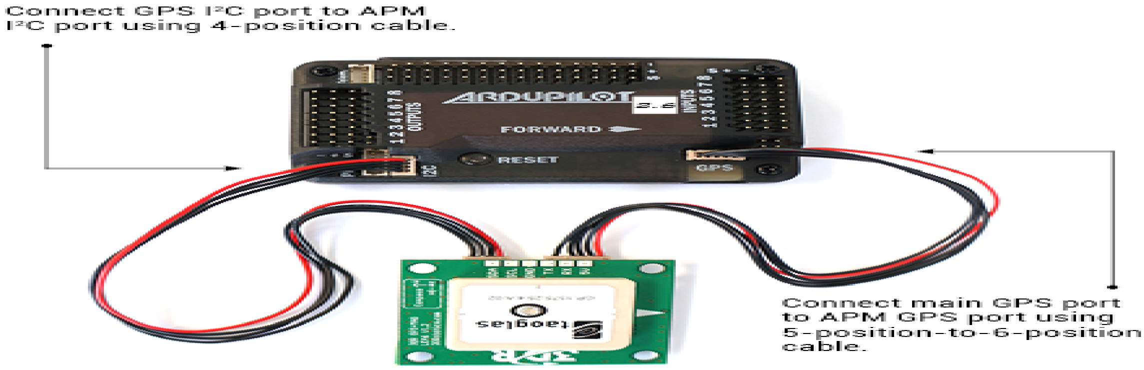


Figure 10 Connect main GPS port to APM GPS Port

Once GPS is connected, you will see, the "No GPS" message on the upper left corner (the green box in pic below) will change to "GPS not FIX". Wait for less than one minute for GPS to collect data from satellites and it will change to "GPS FIX", the GPS is working now. Please note that the GPS antenna better be directed to sky (outdoor) for easy GPS start

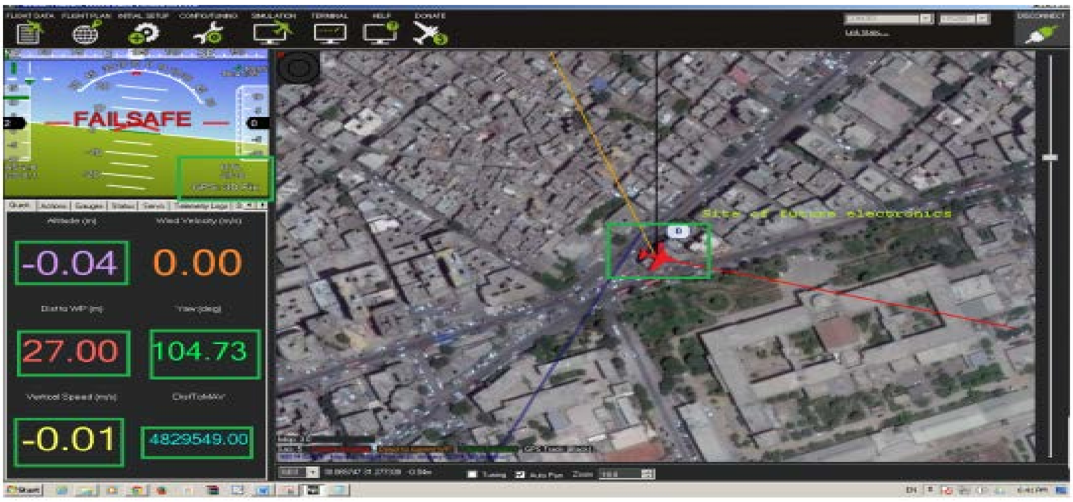


Figure 11 GPS connected on Mission Planner

3.7 Setup the Compass in Mission Planner

To perform the basic compass calibration you should:

- Under Initial Setup > Mandatory Hardware select Compass. Select the correct orientation for your setup.
- Ensure the Enable and AutoDec check boxes are checked
- Click the "Live Calibration" button
- Next select your autopilot configuration, for Pixhawk and PX4, select the option Pixhawk/PX4 with the image of the Pixhawk. For APM 2.6, select APM with External Compass with the image of the GPS with Compass module. These options will automatically enter the correct orientation for the board. Ensure that you have mounted the GPS with Compass with the arrow facing toward the front of the vehicle and in the same direction as the arrow on the autopilot.

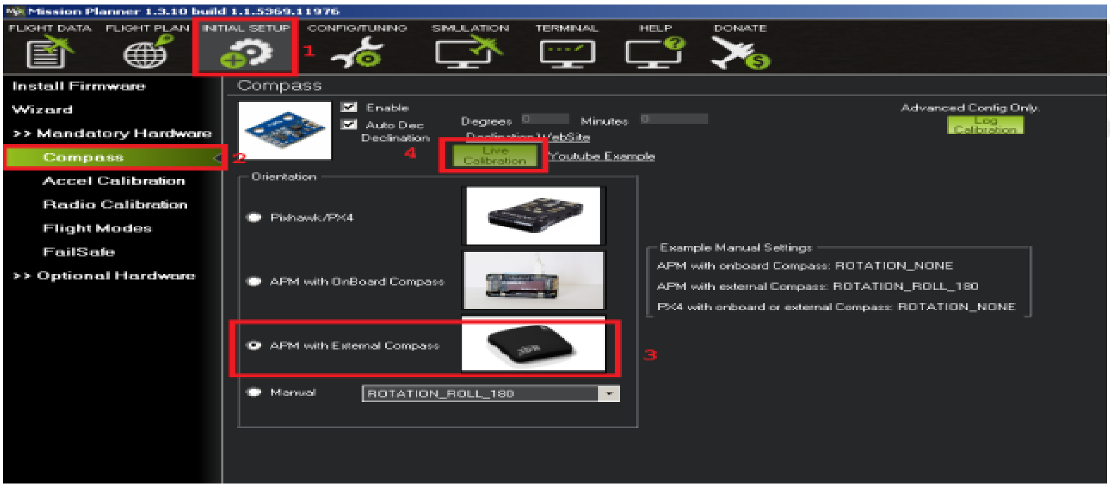


Figure 12 Compass setup

- A window should pop-up informing you that you have 60 seconds in which to rotate the APM/PX4 around all axis, press "OK"
- A countdown window should appear to show that the mission planner is collecting compass data
- During these next 60 seconds you should hold the copter in the air and rotate it slowly so that each side (front, back, left, right, top and bottom) points down towards the earth for a few seconds in turn

Figure 13 Compass calibration positions

- Upon completion, another window will pop up showing you the new offsets that it calculated.
- For APM, as long as all three values are between -150 and 150 the offsets are good. Press "OK".

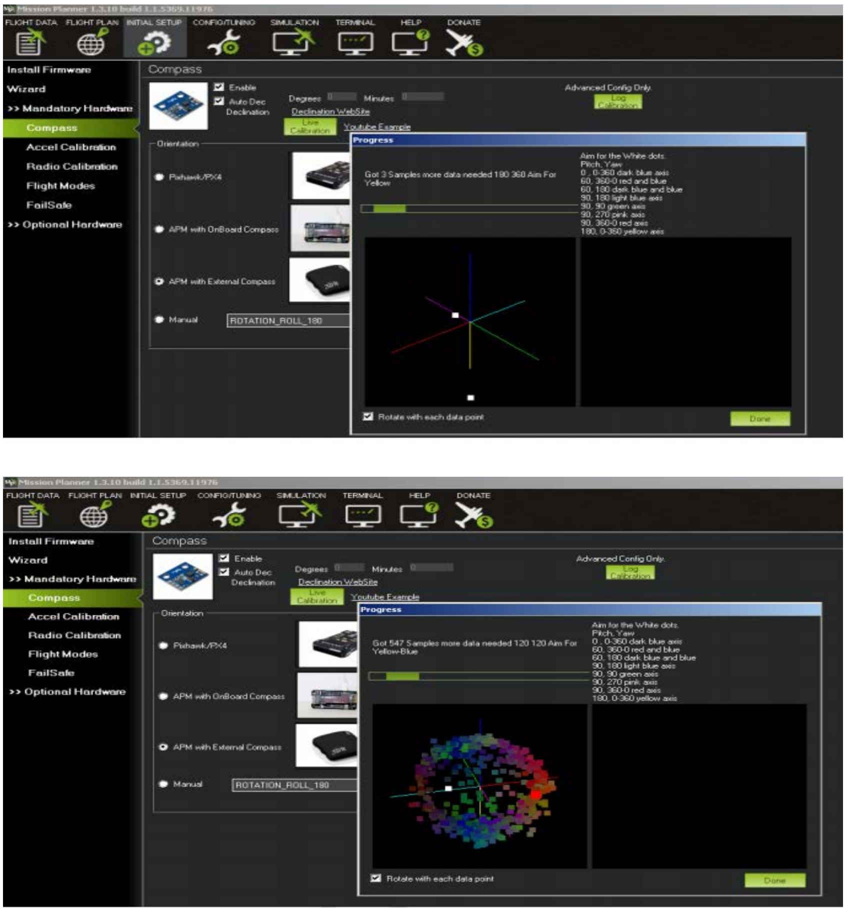


Figure 14 Compass calibration in Mission Planner

- For APM, as long as all three values are between -150 and 150 the offsets are good. Press "OK".
- Then it asks you to calibrate accelerometer by placing the Hexa on one of its 6 faces at a time, as shown in figure...
  Under Initial Setup, select Accelerometer
- Calibration from the left-side menu.

Figure 15 Accelerometer Calibration Positions

- When you're ready to perform the calibration, select Calibrate Accel.

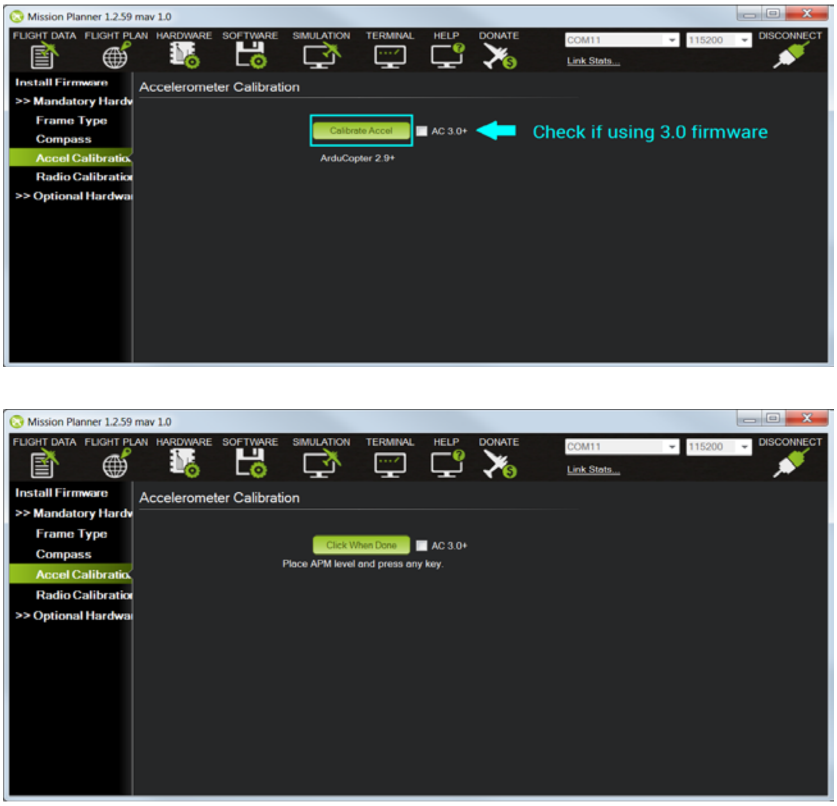


Figure 16 Accelerometer calibration positions in Mission Planner

Mission Planner will prompt you to place the copter in each calibration position and press any key. Proceed through the required positions.

When you've completed the calibration process, Mission Planner will display "Calibration Successful!".

3.8 Calibrate radio control

Turn on transmitter. Verify that the transmitter is in Airplane mode (APM needs airplane mode regardless of the platform type being piloted) and all trims are centered.

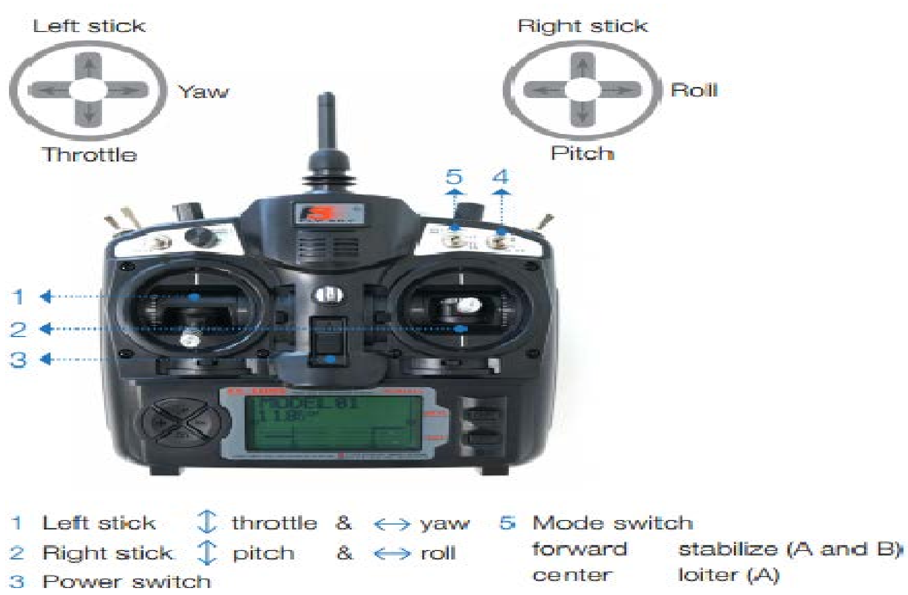


Figure 17 Radio control setup

- For Mode 1 transmitters, the left stick will control pitch and yaw, the right stick will control throttle and roll.

- For Mode 2 transmitters, the left stick will control throttle and yaw; the right stick will control pitch and roll.

- For either type of transmitter, the transmitter's three-position switch should be attached to channel 5 and will control flight modes.

- Optionally the transmitter's tuning knob should control channel 6 for inflight tuning. Channel 7 and Channel 8 switches can be used for controlling auxiliary functions.
  In Mission Planner, click on the green "Calibrate Radio" button in the lower right of the window. Mission Planner will call a dialog window to ensure radio control equipment is on, battery is not connected, and propellers are not attached. Select OK.

Figure 18 Radio calibration in Mission Planner

Select OK; move the control sticks and toggle switches on your transmitter to their limits of travel and observe the results on the radio calibration bars. Red lines will appear across the calibration bars to indicate maximum and minimum values. Move the Ch 5 and 6 toggle switches through their range of positions (Ch 7 and 8 are not used for basic operations).
Your transmitter should cause the following control changes:

- Channel 1: low = roll left, high = roll right.
  Channel 2: low = pitch forward, high=pitch back.
  Channel 3: low = throttle down (off), high = throttle up.
  Channel 4: low = yaw left, high = yaw right.

Figure 19 Radio calibration settings

When the red bars for roll, pitch, throttle, yaw, and radio 5 (and optionally radio 6, 7 and 8) are set at the minimum and maximum positions, select click when done**.** Mission Planner will show a summary of the calibration data. Normal values are around 1100 for minimums and 1900 for maximums**.** If the bars go in the opposite direction of the direction you're moving the stick which means that the channel is reversed on your RC transmitter side**.** Use your RC transmitter's channel-reverse function to reverse it at the transmitter Sid. (See your RC gear's manual for that, if you're not familiar with the process).

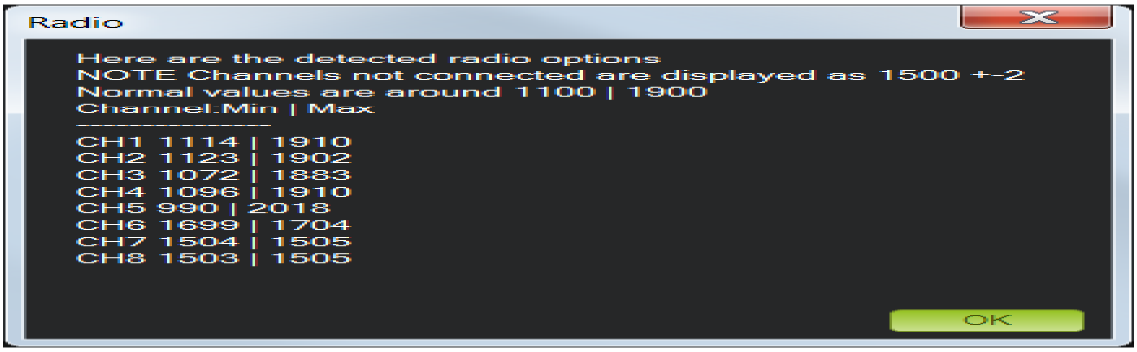


Figure 20 Summary of Mission Planner calibration

3.9 Inflight tuning of Roll and Pitch

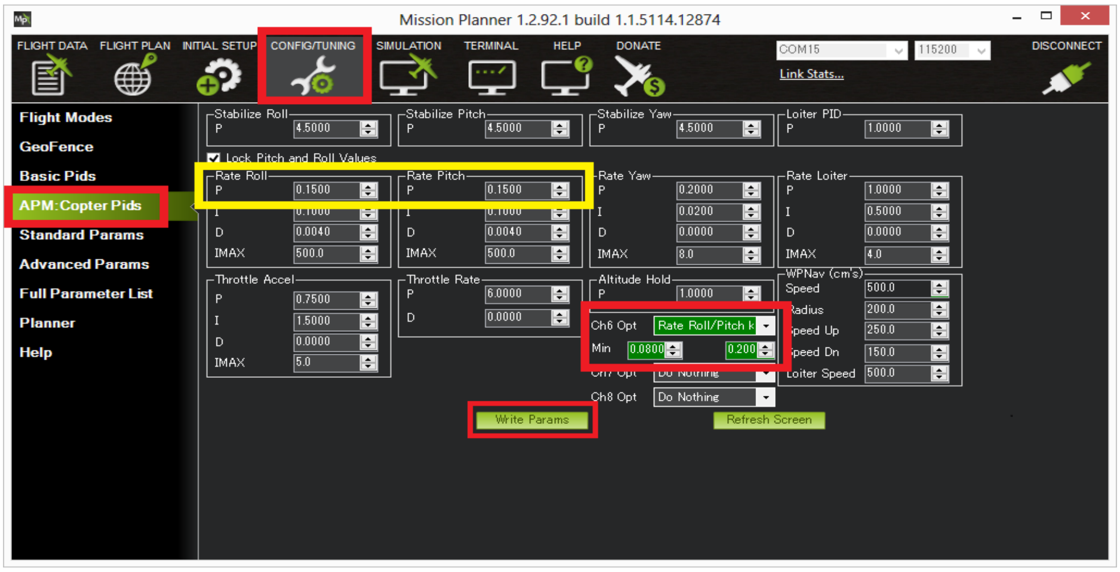


Figure 21 Inflight tuning of Roll and Pitch

1. Connect your APM/Pixhawk/PX4 to the Mission Planner.
2. In mission planner, select Config/Tuning >> Copter Pids.
3. Set the CH6 Opt to "Rate Roll/Pitch kP".
4. Set Min to 0.08, Max to 0.20 (most copters ideal gain is within this range although from a small number of copter the Max can be as high as 0.25).
5. Push the "Write Params" button.
6. Turn your transmitter's CH6 tuning knob to the minimum position, press the "Refresh Params" button and ensure that the Rate Roll P and Rate Pitch P values become 0.08 (or something very close).
7. Turn the CH6 knob to it's maximum position, press "Refresh Params" and ensure the Rate Roll P moves to 0.20.
8. Move the CH6 knob back to the middle.
9. Arm and fly your copter in Stabilize mode adjusting the ch6 knob until you get a copter that is responsive but not wobbly.

10. After the flight, disconnect your lipo battery and reconnect the APM to the mission planner

11. With the CH6 knob in the position that gave the best performance, return to the Copter Pids screen and push the "Refresh Params" button.

12. In the Rate Roll P and Rate Pitch P fields re-type the value that you see but just slightly modified so that the mission planner recognizes that it's changed and resends to the APM/PX4 (Note: if you re-type exactly the same number as what appears in Rate Roll P it won't be updated). So for example if the Rate Roll P appears as "0.1213" make it "0.1200".

13. Set Ch6 Opt back to "None" and push "Write Params".

14. Push the Disconnect button on the top right, and the Connect.

15. Ensure that the Rate Roll P value is the value that you retyped in step #12.

16. While you are moving the tuning knob the values update at 3 times per second. The need to press the Refresh button in the mission planner in steps #6 and #7 above is just because the Copter is not sending the updates to the mission planner in real-time.

3.10 Auto Tune

1. Set up one flight mode switch position to be AltHold.

2. Set the Ch7 Opt or Ch8 Opt to Autotune to allow you to turn the auto tuning on/off with the ch7 or ch8 switch.

3. Ensure the ch7 or ch8 switch is in the LOW position.

4. Wait for a calm day and go to a large open area.

5. Take off and put the copter into AltHold mode at a comfortable altitude.

Figure 22 Auto tune in Mission Planner

6. Set the ch7/ch8 switch to the HIGH position to engage auto tuning:

You will see it twitch about 20 degrees left and right for a few minutes, then it will repeat forward and back.

Use the roll and pitch stick at any time to reposition the copter if it drifts away (it will use the original PID gains during repositioning and between tests). When you release the sticks it will continue auto tuning where it left off.

Move the ch7/ch8 switch into the LOW position at any time to abandon the auto tuning and return to the origin PIDs.

Make sure that you do not have any trim set on your transmitter or the auto tune may not get the signal that the sticks are centered.

7. When the tune completes the copter will change back to the original PID gains.

8. Put the ch7/ch8 switch into the LOW position then back to the HIGH position to test the tuned PID gains.

9. Put the ch7/ch8 switch into the LOW position to fly using the original PID gains.

10. If you are happy with the auto tuned PID gains, leave the ch7/ch8 switch in the HIGH position, land and disarm to save the PIDs permanently.

If you DO NOT like the new PIDS, switch ch7/ch8 LOW to return to the original PIDs. The gains will not be saved when you disarm.

3.11 Planning a Mission with Waypoints and Events Take off

Make normal waypoints by clicking on mission planner, Flight plan then change type to TAKEOFF (or use "add below" button) as first waypoints.

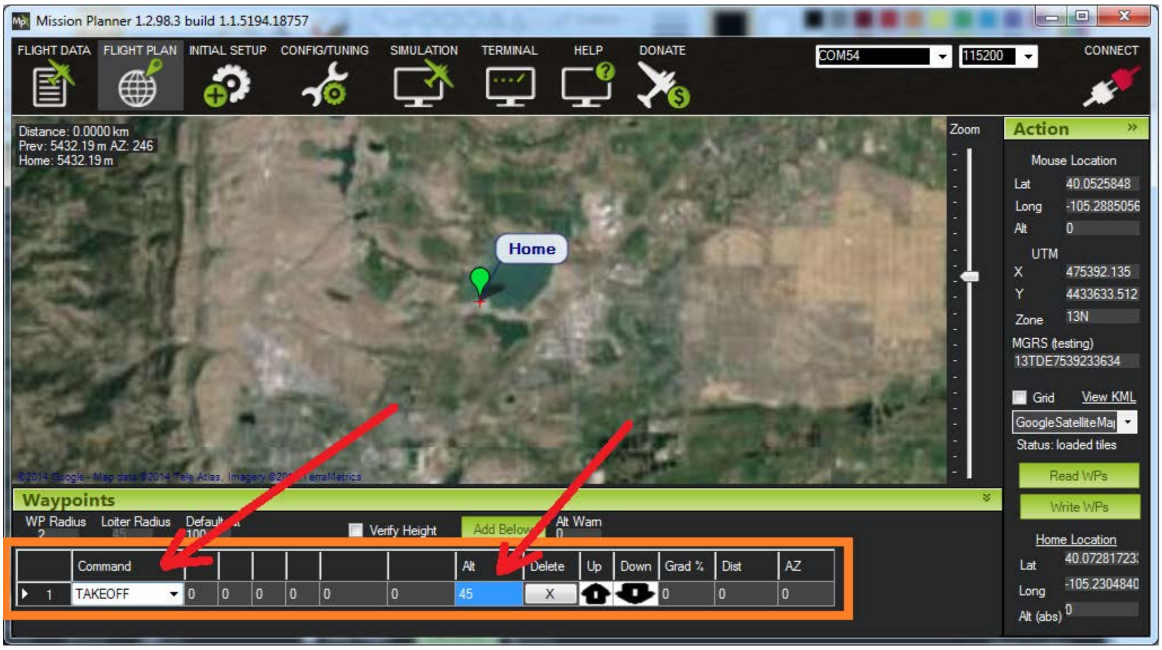


Figure 23 Planning with waypoints and events

The UAV will climb straight up from it's current location to the altitude specified (in meters). This should be the first command of nearly all missions. If the mission is begun while the copter is already flying, the vehicle will climb straight up to the specified altitude, if the vehicle is already above the specified altitude the takeoff command will be ignored and the mission will move onto the next command immediately.

1. Click On «FLIGHT PLAN" button

2. Change waypoint parameters, simply click on the waypoint you want to change on the waypoint table, then you can change things such as the Alt. The table column headings dynamically change depending on what type of waypoint you are using.

3. The vehicle will fly a straight line to the location specified as a lat, long and altitude (in meters).

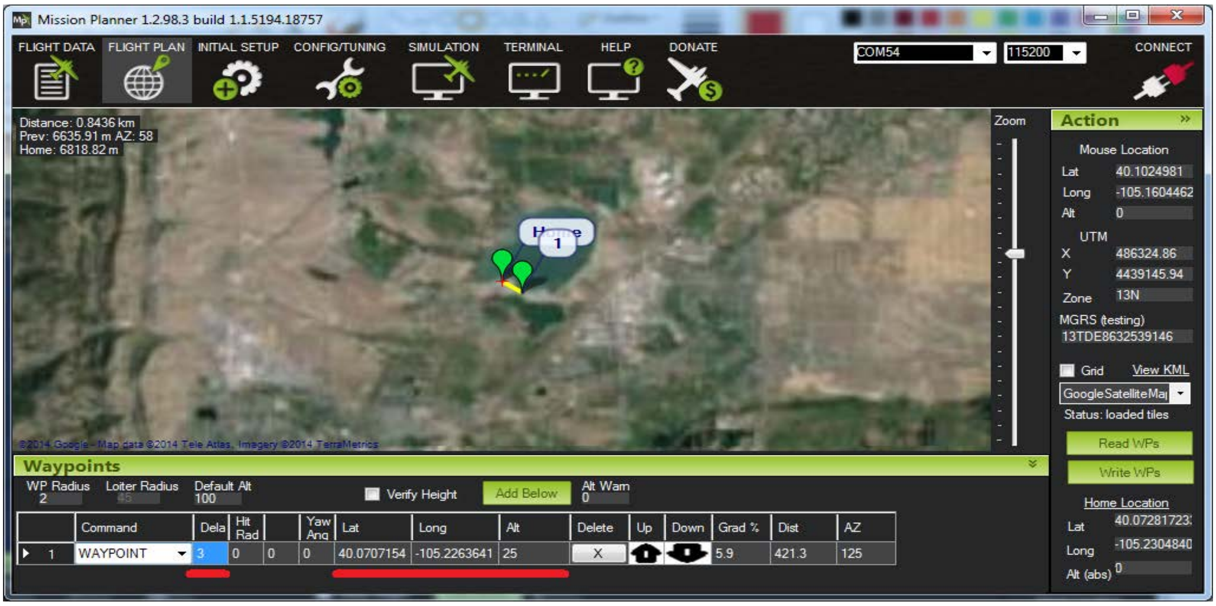


Figure 24 Change waypoint parameters in Mission Planner

To add your first waypoint, simply click on the map where you want it to be. You will notice that on the bottom section of the screen, the waypoint table will show your recently added waypoint.

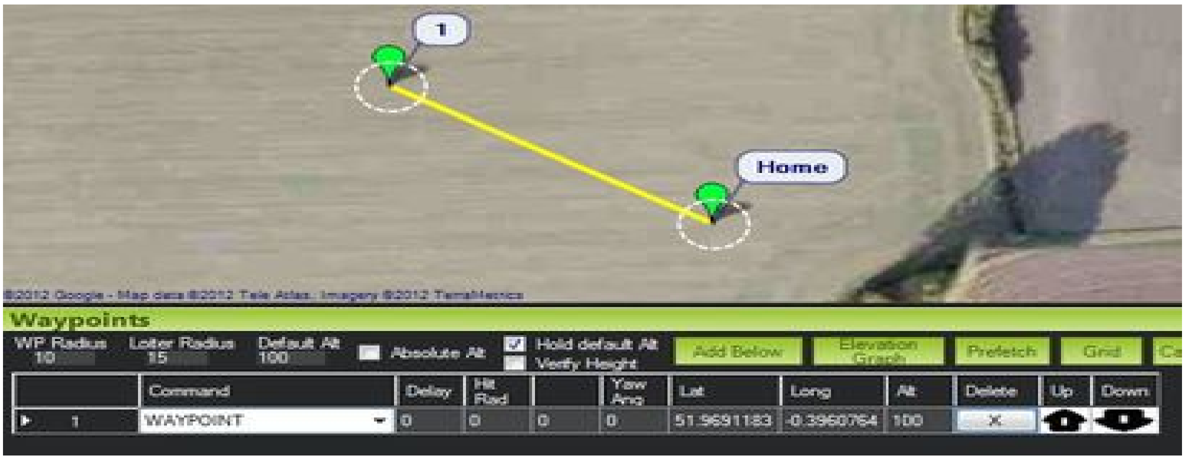


Figure 25 Add first waypoints

Continue to add as many waypoints and commands that you want.

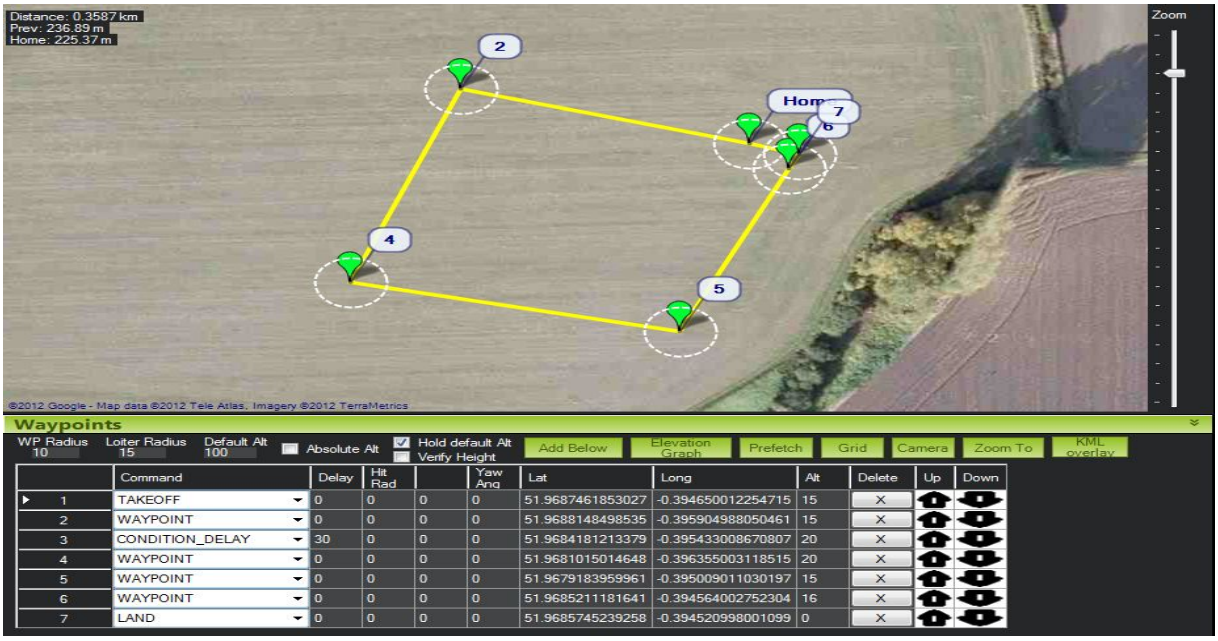


Figure 26 Add more waypoints

Finally your mission should end with a landing command. This is similar to the takeoff command where your arducopter will decend slowly while holding its position. The motors will not turn off until you turn off auto flight mode.

In the screenshot below, a Copter mission starts with an auto takeoff to 20 meters attitude; then goes to WP 2 rising to 100 meters altitude on the way, then waits 10 seconds; then the craft will proceed to WP 3 (descending to 50 meters altitude on the way), then returns to launch. Since the default altitude is 100 meters, the return to launch will be at 100 meters. After reaching the launch position, the craft will land. The mission assumes that the launch position is set at the home position.

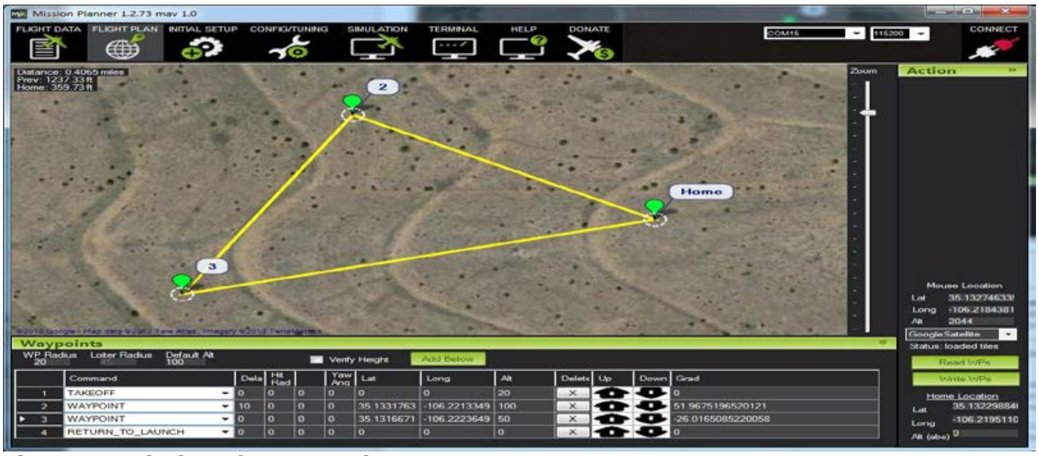


Figure 27 Mission Plan example

3.12 Auto grid

You can also have the Mission Planner create a mission for you, which is useful for function like mapping missions, where the aircraft should just go back and forth in a "lawnmower" pattern over an area to collect photographs.

To do this, in the right-click menu select Polygon and draw a box around the area you want to map. Then select Auto WP, Grid. Follow the dialog box process to select altitude and spacing. The Mission Planner will then generate a mission that looks something like this.

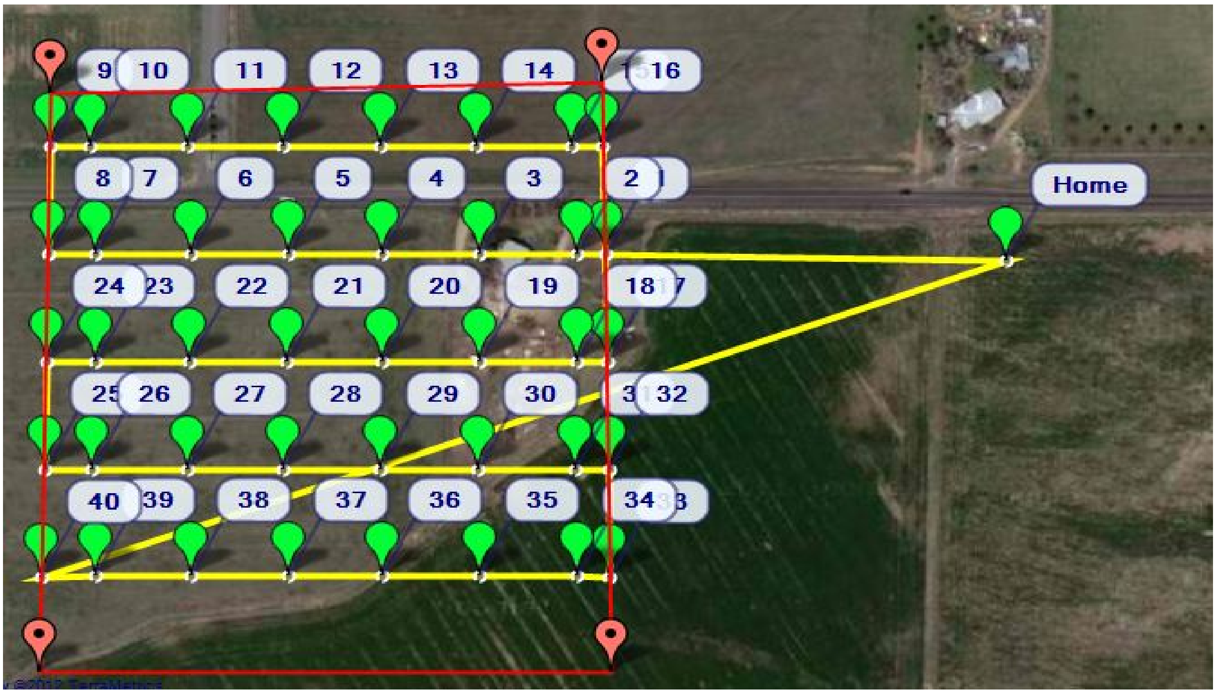


Figure 28 Mission Planner auto-generated grid

3.13 Saving, Loading, and Writing Missions

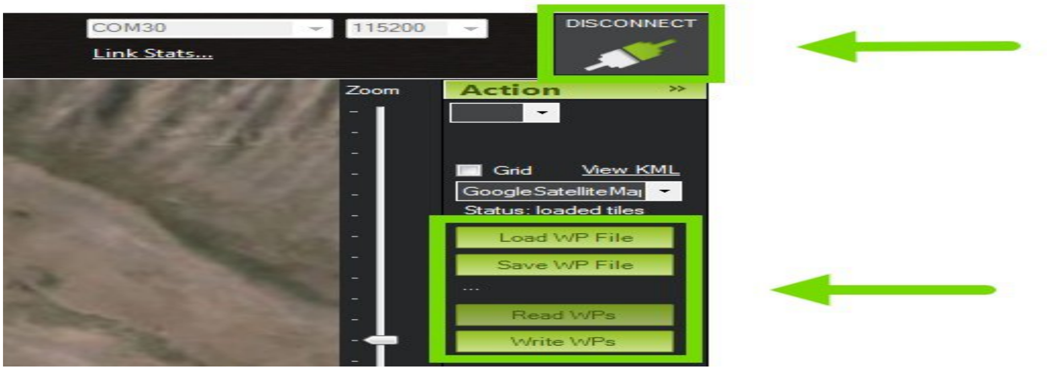


Figure 29 Saving, Loading and writing missions

Now that you have your mission planned you can go ahead and save it for later use by clicking Save WP File. To program the drone with new missions you must be connected to Mission Planner, then hit Write WPs. This will program the drone's memory to recall these WPs when you fly the auto-piloted mission.

If you want to load a previously planned mission click Load WP File and find the file that you saved the mission under. Then upload the mission to the drone by once hitting Write WPs.

The drone can only hold one mission at a time, so whenever you write a mission to the drone it will replace whatever mission used to be there. Whenever you are unsure about which mission is currently in use hit Read WPs. This will pull up the WPs of the current mission.

3.14 Regaining Manual Control

During a mission, keep the controller easily accessible, and be prepared to regain manual control at any time. To regain manual control during the mission, switch to standard mode using the controller. If your drone's flight behaviour becomes unstable or if the copter moves outside your designated safe flying area, switch to RTL. Turning off the controller automatically triggers an RTL and can be used in an emergency situation as a hard recall command.

3.15 Electronic Speed Controller (ESC) Calibration

1. Turn on your transmitter and put the throttle stick at maximum.

2. Connect the Lipo battery. The autopilot's red, blue and yellow LEDs will light up in a cyclical pattern. This means the it's ready to go into ESC calibration mode the next time you plug it in.

3. With the transmitter throttle stick still high, disconnect and reconnect the battery.

4. For PX4 or Pixhawk, press and hold the safety button until it displays solid red.

5. The autopilot is now in ESC calibration mode. (On an APM you may notice the red and blue LEDs blinking alternatively on and off like a police car)

6. Wait for your ESCs to emit the musical tone, the regular number of beeps indicating your battery's cell count (i.e. 3 for 3S, 4 for 4S) and then an additional two beeps to indicate that the maximum throttle has been captured.

7. Pull the transmitter's throttle stick down to its minimum position

8. The ESCs should then emit a long tone indicating that the minimum throttle has been captured and the calibration is complete.

9. If the long tone indicating successful calibration was heard, the ESCs are "live" now and if you raise the throttle a bit they should spin. Test that the motors spin by raising the throttle a bit and then lowering it again.

10. Set the throttle to minimum and disconnect the battery to exit ESC-calibration mode.

Safety Check!

Before calibrating ESCs, please ensure that your copter has NO PROPS on it and that the APM is NOT CONNECTED to your computer via USB

3.16 Calibrating ESCs individually

1. Plug one of your ESC three-wire cables into the throttle channel of the RC receiver. (This is usually channel 3.)

2. Turn on the transmitter and set throttle stick to maximum (full up).

3. Connect the LiPo battery

4. You will hear a musical tone then two beeps.

5. After the two beeps, lower the throttle stick to full down.

6. You will then hear a number of beeps (one for each battery cell you're using) and finally a single long beep indicating the end points have been set and the ESC is calibrated.

7. Disconnect battery. Repeat these steps forall ESCs.

8. If it appears that the ESC's did not calibrate then the throttle channel on the transmitter might need to be reversed.

9. If you are still having trouble after trying these methods (for example, ESCs still beep continuously) try lowering your throttle trim 50%.

10. You can also try powering your APM board via the USB first to boot it up before plugging in the LiPo.

3.17 Capturing arieal image with IR trough Mission planer

1. Mount the camera on a gimbal that is attacht to an UAV.

2. Open mission planer

3. Choose flight plan and choose home altitude

4. Right click and choose Draw Polygon—> Add Polygon Point

5. Close the area that is going to be mapped with the Polygon Points

6. Right click and choose Auto WP —>Survey(Grid)

7. Select Simple menu and choose camera type, flying altitiude, camera angel during flight and flight speed.

8. Select the wanted picture overlap and sidelap.

9. Choose camera cofiguration and control the calculated resolution in cm/pixel. If the resolution is ok proseed, to Triggering method and choose DO_DIGICAM-CONTROL to get IR controled image capturing.

10. Choose Simple menu and click accept to comfirm the hole prosess.

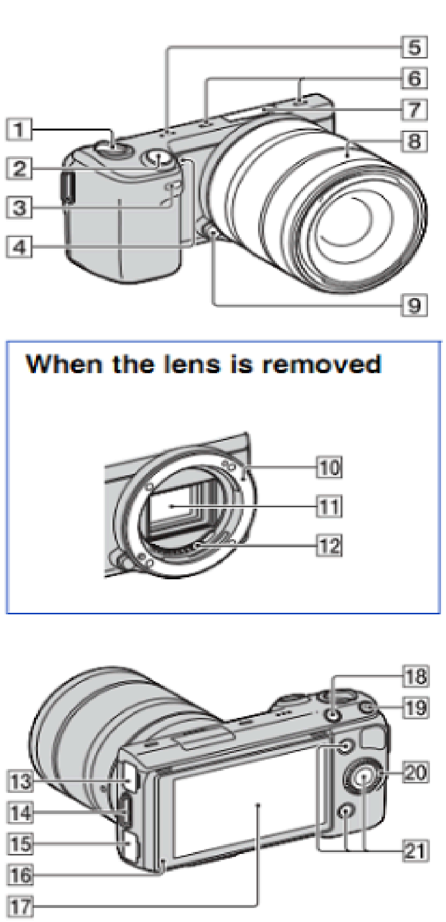
11. Upload information from Mission Planer to the APM and then the system are ready to forfill the aireal picture capturing.

4.0 Camera System

This user guide is made for the Sony NEX-5N camera system and will fokus on:

- Camera button configeration
- Camera menu
- Image capturing via Mission Planer Software

Identifying parts



See the pages in parentheses for details of operation.

1. ON/OFF (Power) switch
2. Shutter button (28)
3. Remote sensor (50)
4. AF illuminator/Self-timer lamp/Smile Shutter lamp
5. Speaker
6. Microphone [1]
7. Smart Accessory Terminal 2 [2]
8. Lens
9. Lens release button
10. Mount
11. Image sensor [3]
12. Lens contacts [3]
13. (USB) terminal (170)
14. Hook for shoulder strap
15. HDMI terminal (162)
16. Light sensor
17. LCD monitor/Touch panel (21)
18. ▶ (Playback) button (30)
19. MOVIE button (28)
20. Control wheel (19)
21. Soft keys (20)

[1] Do not cover this part during movie recording.
[2] Accessories for the Smart Accessory Terminal can be also attached.
[3] Do not touch this part directly.

Figure 30 Identifying parts

1 Select MENU.
2 Select the desired item by pressing the top/bottom/left/right parts of the control wheel, and then press the center.
Or, touch the item on the screen.
3 Following the instructions on the screen, select the desired item and press the center of the control wheel to make your choice.
Or, following the instructions on the screen, touch the desired item on the screen.

Figure 31 Sony photo camera

4.1 Shot mode

Allows you to select a shooting mode, such as exposure mode, panoramic, Scene Selection.

Intelligent Auto	The camera evaluates the subject and makes the proper settings. You can enjoy automatic shooting with the appropriate settings.
Scene Selection	Shoots with preset settings according to the subject or condition.
Anti Motion Blur	Reduces the camera shake when shooting a slightly dark indoor scene or a telephoto.
Sweep Panorama	Shoots with panoramic size.
3D Sweep Panorama	Shoots 3D panoramic images used for playback on a 3D compatible TV.
Manual Exposure	Adjusts the aperture and shutter speed.
Shutter Priority	Adjusts the shutter speed to express the movement of the subject.
Aperture Priority	Adjusts the range in focus, or defocuses the background.
Program Auto	Automatic shooting that allows you to customize settings, except for the exposure (shutter speed and aperture).

Figure 32 Shot mode selection

4.2 Camera mode

Allows you to set shooting functions, such as continuous shooting, self-timer, and flash.

Drive Mode	Selects the drive mode, such as continuous shooting, self-timer, or bracket shooting.
Flash Mode	Selects the method used to fire the flash.
AF/MF Select	Selects auto focusing or manual focusing.
Autofocus Area	Selects the area to be focused on.
Autofocus Mode	Selects the autofocus method.
Object Tracking	Keeps the focus on a subject while tracking it.
Prec. Dig. Zoom	Sets the digital zoom.
Face Detection	Detects people's faces automatically, and adjusts focus and exposure to suit the faces.
Face Registration	Registers or changes the person to be given priority in the focus.
Smile Shutter	Each time the camera detects a smile, the camera releases the shutter automatically.
Soft Skin Effect	Shoots the skin smoothly in the Face Detection function.
Shooting Tip List	Allows you to access all shooting tips.
LCD Display (DISP)	Changes the information to be displayed on the LCD monitor.
Finder Display(DISP)	Changes the information to be displayed on an Electronic Viewfinder (sold separately).

Figure 33 Shooting functions

4.3 Image size:

Allows you to set the image size and aspect ratio.

Still	
Image Size	Selects the image size.
Aspect Ratio	Selects the aspect ratio.
Quality	Selects the compression format.
3D Panorama	
Image Size	Selects the image size of 3D panoramic images.
Panorama Direction	Selects the direction to pan the camera when shooting 3D panoramic images.
Panorama	
Image Size	Selects the image size of panoramic images.
Panorama Direction	Selects the direction to pan the camera when shooting panoramic images.
Movie	
File Format	Selects AVCHD 60i/60p, AVCHD 50i/50p or MP4.
Record Setting	Selects the image size, frame rate, and image quality of movies.

Figure 34 Image size and aspect ratio

4.4 Brightness/color

Allows you to make brightness settings such as metering mode, and color settings such as white balance.

Exposure Comp.	Compensates for the brightness of the entire image.
ISO	Sets the ISO sensitivity.
White Balance	Adjusts the color temperature according to the ambient light conditions.
Metering Mode	Selects the method used for measuring the brightness.
Flash Comp.	Adjusts the amount of flash light.
DRO/Auto HDR	Corrects the brightness or contrast automatically.
Picture Effect	Shoots with the desired effects to express a unique atmosphere.
Creative Style	Selects the image processing method.

Figure 35 Brightness/color settings

4.4 Playback

Allows you to set playback functions.

Delete	Deletes images.
Slide Show	Plays back images automatically.
View Mode	Allows you to determine how to group the playback images.
Image Index	Selects the number of images to be displayed on the index screen.
Rotate	Rotates images.
Protect	Protects images, or cancels the protection.
3D Viewing	Connects to a 3D compatible TV and allows you to view 3D images.
Enlarge Image	Enlarges the image.
Volume Settings	Sets the sound volume of movies.
Specify Printing	Selects the images to print, or makes printing settings.
Display Contents	Switches the information to be displayed on the playback screen.

Figure 36 Playback functions settings

4.5 Setup

Allows you to make more detailed shooting settings, or change the camera settings.

Shooting Settings	
AF Illuminator	Sets the AF illuminator to assist auto-focusing in dim places.
Red Eye Reduction	Provides pre-flash before shooting when using the flash, to prevent eyes from being shot in red.
FINDER/LCD Setting	Sets how to switch between an Electronic Viewfinder (sold separately) and the LCD monitor.
Live View Display	Allows you to choose whether or not to show the value of exposure compensation, etc. on the screen display.
Auto Review	Sets the display time of the image right after shooting.
Grid Line	Turns on the grid line that helps you to adjust the composition of images.
Peaking Level	Enhances the outline of in-focus ranges with a specific color.
Peaking Color	Sets the color used for the peaking function.
MF Assist	Displays an enlarged image when focusing manually.
MF Assist Time	Sets the length of time the image will be shown in an expanded form.
Color Space	Changes the range of color reproduction.
SteadyShot	Sets camera shake compensation.
Release w/o Lens	Sets whether or not to release the shutter when there is no lens.
Eye-Start AF	Sets whether or not to use autofocus when you look through an Electronic Viewfinder (sold separately).
Front Curtain Shutter	Sets whether or not to use the electronic front curtain shutter function.
Long Exposure NR	Sets the noise reduction processing for long exposure shootings.
High ISO NR	Sets the noise reduction processing for high ISO sensitivity shootings.
Lens Comp.: Shading	Compensates for the shaded corners of the screen.
Lens Comp.: Chro. Aber.	Reduces the color deviation at the corners of the screen.
Lens Comp.: Distortion	Compensates for distortion on the screen.
Movie Audio Rec	Sets the sound for movie recording.
Wind Noise Reduct.	Reduces wind noise during movie recording.
AF Micro Adj.	Finely adjusts the autofocused position, when using the LA-EA2 Mount Adaptor (sold separately).
Main Settings	
Menu start	Selects a first-displayed menu from the top menu or the last menu screen.

Figure 37 Shootings settings

Custom Key Settings	Assigns functions to the various keys.
Touch Operation	Sets whether or not to operate the camera using the touch panel.
Beep	Selects the sound produced when you operate the camera.
Language	Selects the language used on the screen.
Date/Time Setup	Sets the date and time.
Area Setting	Selects the area where you are using the camera.
Help Guide Display	Turns the Help Guide on or off.
Power Save	Sets the time to turn the camera to the power save mode.
LCD Brightness	Sets the brightness of the LCD monitor.
Viewfinder Bright.	Sets the brightness of an Electronic Viewfinder (sold separately).
Display Color	Selects the color of the LCD monitor.
Wide Image	Selects a method to display wide images.
Playback Display	Selects the method used to play back portrait images.
HDMI Resolution	Set resolution when connected to HDMI TV.
CTRL FOR HDMI	Sets whether or not to operate the camera with a "BRAVIA" Sync compatible TV's Remote Control.
USB Connection	Selects the method used for a USB connection.
Cleaning Mode	Allows you to clean the image sensor.

Figure 38 Main settings

Version	Displays the versions of the camera and the lens/mount adaptor.
Demo Mode	Sets whether or not to display the demonstration with movies.
Reset Default	Resets the camera to the factory-settings.
Memory Card Tool	
Format	Formats the memory card.
File Number	Selects the method used for assigning file numbers to images.
Folder Name	Selects the folder name format.
Select Shoot. Folder	Selects the recording folder.
New Folder	Creates a new folder.
Recover Image DB	Repairs the image database file when inconsistencies are found.
Display Card Space	Displays the remaining recording time of movies and the recordable number of still images on the memory card.
Eye-Fi Setup*	
Upload Settings	Sets the upload function of the camera when an Eye-Fi card is used.

* Appears when an Eye-Fi card (sold separately) is inserted in the camera.

Figure 39 Memory card tool/Eye-fi Setup

5.0 Agisoft Photoscan

5.1 Download and install Photoscan

Photoscan can be downloaded from Agisoft's homepage:

http://www.agisoft.com

Click on downloaded file and follow instructions to install the software.

5.2 Open Photoscan

Double click on the Photoscan program icon in order to open the software. The main working environment looks like the image below.

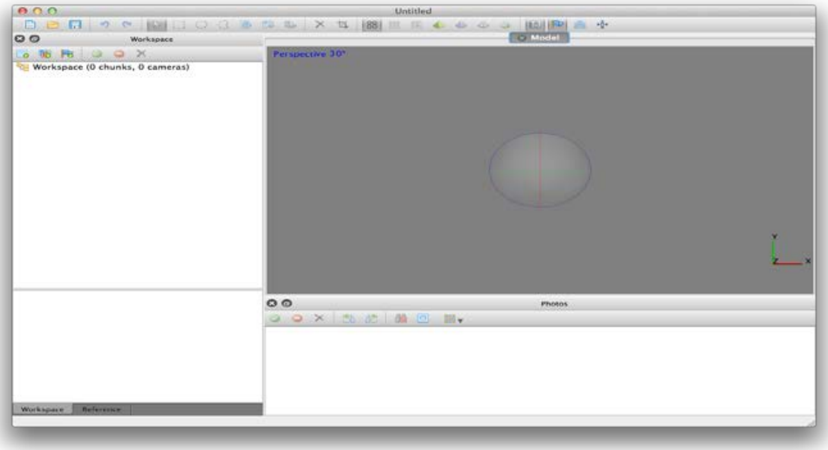


Figure 40 Main working environment

5.3 Import images

To import images, click on the add photos in the workspace toolbar. This creates a chunk consisting of the imported images as seen in the picture below.

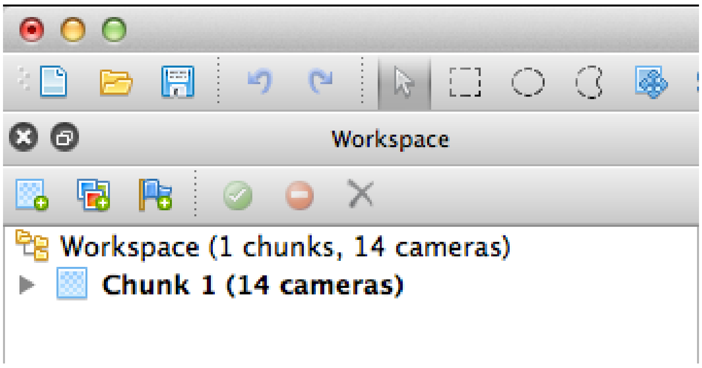


Figure 41 Import images in Photoscan

5.4 Aligning photos

To align the imported photos, select Align Photos from the Workflow menu. Photoscan finds position and orientation for the photos in the chunk and builds a sparse point cloud model.

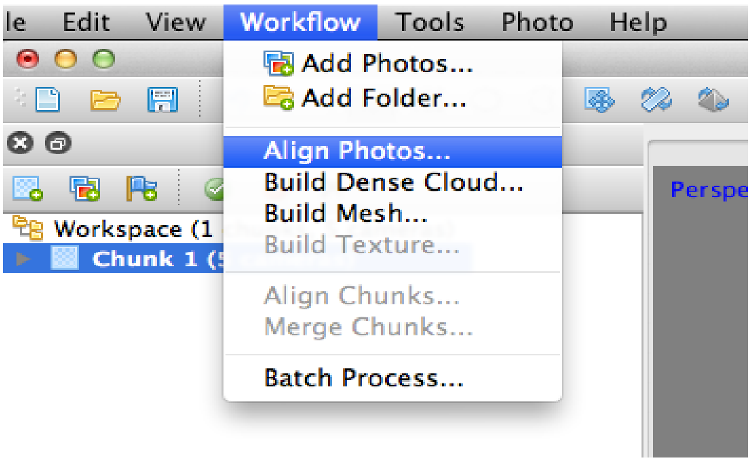


Figure 42 Align the imported photos

5.5 Quality check

Photoscan has a built in function to evaluate the quality of the individual images. Select the images that are to be processed in the photos window, right click and choose "Estimate Image Quality". To view the results, click on the change dropdown menu and select "details".

Images that score lower than 0.5 should be disabled and excluded from further processing.

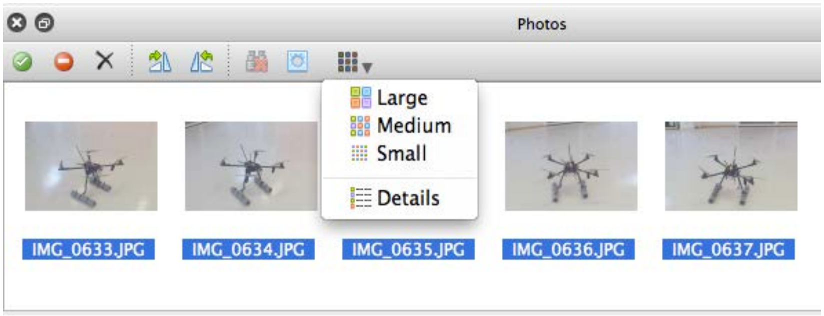


Figure 43 Quality check

5.6 Build dense point cloud

Adjust the reconstruction volume bounding box, in the model window and drag corners to the desired positions. Then click on Build Dense Cloud from Workflow menu, choose the desired quality. Photoscan now builds a single dense point cloud.

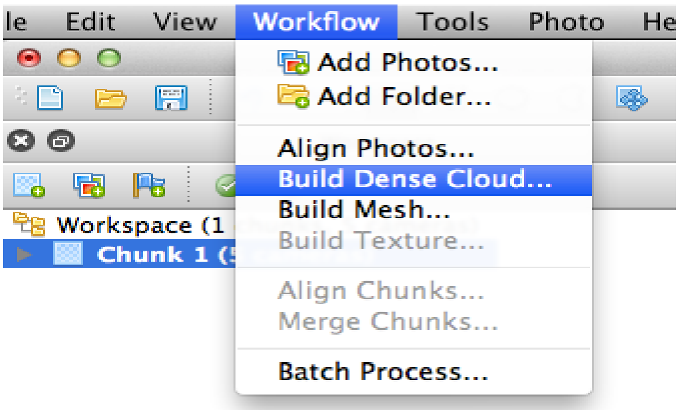


Figure 44 Build dense point cloud

5.7 Build mesh

After building the dense point cloud, click on the Build Mesh from the Workflow menu.

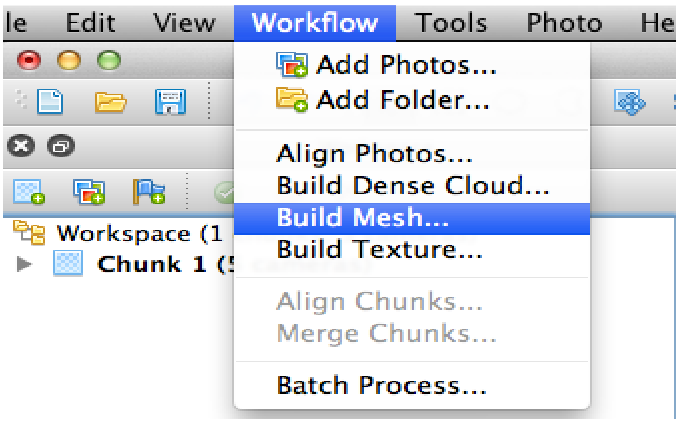


Figure 45 Build mesh

5.8 Build Model Texture

After building the mesh, select Build Texture from the Workflow menu. Select the desired texture parameters and click ok.

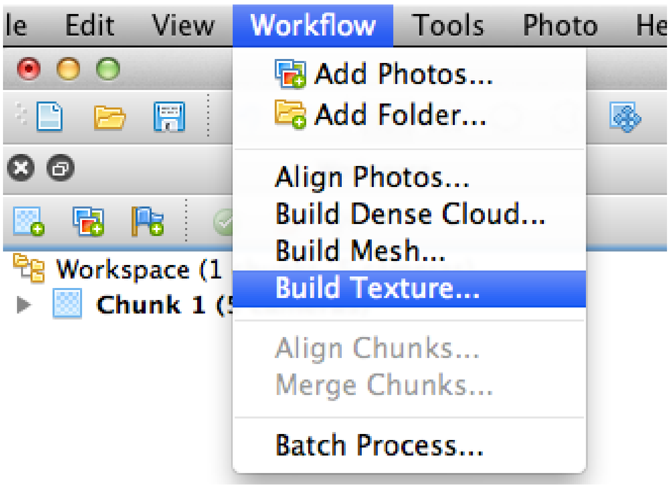


Figure 46 Build model texture

5.9 Review 3D Model

Your 3D model should now be rendered and viewable in the model window. Export options can be found under the File menu.

5.10 Advanced Features

For more advanced features and in depth explanations, refer to the Agisoft Photo scan user manual.

6.0 Battery Safety Instruction

The battery is not just a power source; it could be costly and very dangerous if you don't follow the instructions which are given by the battery company. For efficiency and safety case the fallowing parameters should be considered when using the LiPo battery.

6.1 Discharge rate

As mentioned, the battery is able to deliver safely the amount of current which is given by C rating times the total capacity. If you pull out more current than that rate, the battery will get hot. This cause the batteries life cycle to be significantly shorter and even catch fire or explode. To avoid this problem use a battery with high enough C rating that could deliver the amount of current to your system safely.

6.2 Charging

A battery pack should be charged with the right voltage level with a balance charger, because all of cells are not exactly the same. When charging the battery that we have chosen, the current should be limited to 5C level for the case of life cycle and safety. In case if one cell in battery pack charging faster than other, the balancing charger will stop charging that cell. It would help the battery cells to be fully charged correctly and avoid safety issue which connected to the heat.

6.3 Capacity level

The discharging battery level is also important for the life cycle of LiPo battery. The safer limit for a LiPo type is 80% of the total capacity. Discharging the battery frequently more than 80%, the life cycle of battery will considerably decrease. Therefore the capacity should be hold less than 80% limit.

6.4 Charging place

The lithium ion batteries are very sensitive to direct sun light and heat. The battery should be disconnected from the UAV and charged in a fire safe area and never unattended.

It is proved to be very difficult to extinguish when a battery catch fire, because the battery chemical contains enough oxygen to burn up. In case of battery firing, don't try to extinguish the fire and run away from the firing place, because it produces health hazard gas.

6.5 Battery condition

The Lip battery could be damaged externally and internally over time. The internal damage will occurs when one or more cells in a battery pack fails and external damage usually occurs when a UAV crashes. To avoid safety issue, the battery voltage level should be checked frequently when the battery gets older. External damage can be checked visually and in both case the battery will not be safe to use it.

Post Project Analysis

Bachelor project: 3D Ground Mapping

Rev	Date	Reviewed by	Approved by	Status
1.0	15.05.2015	NGA	BJD	Released

Summary:

This document is intended to give an analysis and evaluation of the project as a whole and the project team.

Owner: Therese T. Poverud

Document Revision History

Rev	Date	Author	Description	Status
0.1	13.05.2015	TTP	Initial draft	Obsolete
1.0	15.05.2015	TTP	Final version	Released

Table of Contents

1.0 Introduction

1.1 Purpose of this document

This document is intended as an overview and analysis of expectations, work process, team dynamic and the results of the 3D Ground Mapping project after the completion of the project lifecycle.

1.2 Abbreviations

List of abbreviations and corresponding description used in this document

Abbreviation	Description
3D	Three dimensional
HBV	Buskerud and Vestfold University College
UAV	Unmanned aerial vehicle

Table 1 Abbreviations

1.3 Related documents

This section provides a list of other documents referenced in this document

Doc. number	Description
002	Project Plan

Table 2 Related documents

2.0 Expectations

We are a team of seven engineering students from different study directions, different living locations, different working experience and different nationalities. Because of this we thought we would run into some kind of issues regarding meeting time, understanding and communication internally in the group, but it went surprisingly well.

At first we got an internal bachelor project from HBV from Olaf Graven, but one of our team members put us in contact with Cube AS who gave us an external project for them instead. Before we got the new project scope, we were invited to Cube AS's office in Tranby for introductions. We were introduced to Karls who challenged us to think out of the box before we got our bachelor project from Stig Førrisdal.

This project scope was a challenge for the team as none of us had any experience regarding UAVs or 3D mapping systems. Our expectations were from the start that this project would be very challenging and educational to solve the project scope in an academic way.

3.0 Project execution and challenges

The team worked on the project at Cube AS's premises in Tranby, at home and sometimes also in the group-room we were given at HBV, Kongsberg. We have members from two different engineering studies; this meant that we had lessons on different days and had to plan our work week after this.

For the first three phases our work plan has been Monday/Tuesday subject lessons and individual project work. Wednesdays started with a group-meeting, at Tranby, where we did a status update and then continued working. Thursdays was either work at Tranby or individual work at home depending on where we were in the project. Fridays was either meeting with internal supervisor in Kongsberg or group-meeting at Tranby where we continued working where we were.

Since we are a big group with seven team members, we had to split into sub-teams to be effective. It was a challenge to work with a big team, but we have a good dynamic and managed to work out any issues that rose up. Another small challenge was that we had team members living far away and this made it difficult to meet or cancel at short notice.

In the first phase of the project, Inception, we started with an internal project scope that was changed to an external project for Cube AS two weeks before the 1st presentation. We did manage to finish everything we needed in time for the presentation, but we had to work in the weekends as well to reach the delivery of documents milestone.

In the second phase, Elaboration, we decided on the architecture of system we were to build. In the beginning we had thought this would take one iteration, this is 2 weeks, but we found out that this was too little time already after the first week. We spent a lot of time researching and learning both how to build an architecture and information we needed for the system. We solved this by adding a second iteration to this phase. We are using Agile Unified Process as a project model so this worked well. We finished the documents needed for the 2nd presentation in this phase.

We found during this phase that we had split up after wrong area of interest and therefore in wrong sub-teams. We had split the 3D Ground Mapping system into an electrical sub-system, mechanical sub-system and camera sub-system. We changed this to an UAV sub-system, camera sub-system and image processing sub-system where electrical and mechanical were merged and the camera part split up in the camera itself and the processing software. This made the project work run more smoothly and therefor also made us more effective with less dead time.

We held the 2nd presentation in the beginning of the third phase, Construction. We started testing software for image processing, tested the individual UAV components and built up the UAV with these components from Cube AS inventory. We did more research than we expected in this phase and started making a CAD model of the UAV to test the frame since the motors was stronger than the frame we had were made for. We found out when we were nearly done building that we lacked a proper power board as the one we had was too big and not in good shape. We ordered a new power board together with wires and gimbal suspenders and got everything over Easter.

We started the last phase, Transition, with rebuilding the UAV and soldering the new power board. When we starting the first system test we found that the power module didn't work with the battery we had. This was because it was for a four cells battery, not a 6 cells like ours. We ordered a new one the same day and had to wait nearly a week for it. We started to do a new system test the same day we got the new power module only to find that the power board shortage destroyed several other components that had to be changed out.

One of the challenges we faced in this phase was that we couldn't do a system test with flight without Tommy Larsen, from Cube AS, since we needed an experienced drone pilot to fly and we therefor had to wait till he had the time to test with us. We had all practiced flying an UAV, but none of us had the skillset to fly during a test. We got the UAV into the air, but it crashed before we could do most of our testing. We reviewed the flight log from Mission Planner to figure out why we crashed as we thought it was the battery, but it wasn't the battery and we had to find what else could be the problem.

We repaired the UAV and tried again only to crash it a second time, but now we found why it went wrong. We already knew that the motors were too powerful for the frame, it could work, but it had too little weight to stabilize during testing and that led to crashing the UAV twice before we found the problem. This can be fixed by making adjustments to the controllers and adding more weight to the UAV, but too much had been destroyed in the last crash for us to have the time to repair and test it again before the end of the project deadline.

We had a few backup plans in case something went wrong during testing and we ended up buying a picture set from Isachsen so while we couldn't finish the UAV part of the project, we could finish testing our image processing software. We used Cube AS's computer to do the processing as planned.

4.0 Evaluation

After four months of hard work and several hundred pages of documentation, the project is now ready to be handed in. Our project team was put together pretty late, but after an intensive first couple of weeks we eventually started to catch up for lost time and progress went according to plan.

From the very beginning of the project, the team has maintained a very good communication scheme; meeting up regularly to discuss important matters and planning the course of action, while keeping productivity and efficiency up with flexible hours and individual study. This is something we are particularly proud of, seeing as this is a large student group – with members living in various locations – communication can often be problematic during projects like this. Team building and having a safe working environment has been an important aspect for the project team and the project owner (Cube AS).

Keeping everybody busy with tasks and activities during the project has worked out great in most cases, thanks to a well-balanced work distribution. In cases where the workload has proven to be very heavy for some of the members, other team members have been quick to offer help and re-distribute the work. This has kept the moral up for individual members and strengthened the team spirit.

The project group has put great effort into following the project plan and making sure that all the required documentation is provided. This has led to a great deal of papers being handed in. Contrary to the agile philosophy ("keep it simple") the team found it necessary to make the documentation this extensive. This is a student project, and it's important for us to showcase all the hard work that has gone into the project.

The group is naturally very disappointed that the UAV crashed and rendered us unable to fulfil the project scope. However, for the most part we are happy with how the project has unfolded and the learning process. None of the members had any experience with UAV's, so this was uncharted territory for all of us.

In hindsight, we probably would have done wise in starting the build a little bit earlier, thus having more time to fix potential issues. On the other hand, the project period is not that long, and there is a limit to how early we actually could have been able to finish the build. The team remains certain that with a little more time and knowledge we could have finished our product according to specification.

All in all, the group is very satisfied and left with a positive experience. There have been some good arguments and discussions along the way, but always in a friendly and constructive manner; there has been very little bickering and hostile behaviour. The team has had a good dialogue with our internal supervisor and Cube AS, and the project has kept moving in the right direction the whole time.

We are very thankful for Cube AS involvement and the opportunity they provided us with. Working on a project that is requested by the industry has been both exciting and challenging. This has been a learning experience for all of us.