Sensur av hovedoppgaver

Høgskolen i Buskerud og Vestfold
Fakultet for teknologi og maritime fag

Prosjektnummer: **2015-09**
For studieåret: **2014/2015**
Emnekode: **SFHO3201**

Prosjektnavn: Mosquito Defence Systems

Utført i samarbeid med: Kongsberg Defence and Aerospace, avd. Integrated Defence Systems.

Ekstern veileder: André Ruud

Sammendrag: Grunnet et stadig varmere klima er det større sjanse for at mygg med tropiske sykdommer får fotfeste i nord. For å kunne beskytte seg mot dette har Mosquito Defence Systems utviklet ett system som kan identifisere og immobilisere mygg.

Stikkord:
- Mygg
- Detektere/Identifisere
- Immobilisere/Destruere

Tilgjengelig: JA

Prosjektdeltagere og karakter:

Navn	Karakter
Ann Christin Tjensvold Barstad	
Christoffer Marius Ness Olsen	
Eirik Haavaldsen	
Hege Jeanette Blikra	
Jawad Qureshi	
Max Moeschinger	

Dato: 19. mai 2015

Sigmund Gudvangen	Karoline Moholth	Hans Ivar Østensen
Intern Veileder	Intern Sensor	Ekstern Sensor

Document Overview

Final PDF: Copy for school library.
Sensor Binder: Green binder for sensor.
DVD: Documents stored digitally on a CD/DVD.
Website: Documents available at Website.

Documents	Final PDF	Sensor Binder	DVD	Website
Final Report • Project Plan • Requirements Specification • Test Specification • Test Plan • Test Report • System Overview • Technical Specifications • Post Analysis	X	X	X	X
Technology Documents	X	X	X	
Research Documents	X	X	X	
Concept Documents	X	X	X	
Iteration Documents		X	X	
Prototype User Manual			X	
Electrical Design Schematics			X	
Software – Source Code			X	
UML Project			X	
Weekly Reviews			X	
Meeting Convenings			X	
Meeting Minutes			X	
Timesheets			X	
Expense Report			X	
Brainstorming Charts			X	
Presentations			X	
Blog posts				X

Document Links

Thesis

Final Report

Technology Documents

Detecting Mosquitoes with Microphone Arrays

Immobilization Systems

Laser

Image Processing

Research Documents

Mosquito – Entomology

Mosquito Detection Concepts and Methods

Microphone Array Concepts

Immobilization of Mosquitoes

Concept Documents

Concept Study Result

Entrance Concept

Outpost Concept

Photonic Fence (Non-MDS concept)

Final Report

Mosquito Defence Systems

v1.0 ● 16.05.2015

Abstract

In this document, the reader will be presented with the design process and documentation surrounding the Mosquito Defence System (MDS). MDS is a solution that may prevent the spread of mosquito-borne diseases. Due to a changing climate, there is an increasing risk of tropical mosquitoes in Nordic countries, and thus tropical diseases. There are currently no solutions available that has proven to solve this problem, that is, disrupting the life-cycle of tropical mosquito-borne diseases. The Mosquito Defence System consists of three main features: detecting and identifying mosquitoes, elimination of female mosquitoes and operate in close proximity without causing harm to humans, animals, other insects and inventory.

Document Version

Version	Date	Name	Description
0.1	11.05.2015	Christoffer M. N. Olsen	Document created and inserted chapter 1 through 9.
0.2	13.05.2015	Eirik Haavaldsen	• Grouped hardware and software separately. • More technical details appended concerning the actual laser. • Evaluation sheet inserted (First page) • Document overview inserted (second page) • Fixed other minor issues.
0.3	15.05.2015	Christoffer M. N. Olsen, Eirik Haavaldsen, Max Moeschinger, Ann Christin Barstad, Hege J. Blikra and Jawad Qureshi	• Added abstract • Fixed minor mistakes.
1.0	16.05.2015	Christoffer M. N. Olsen, Eirik Haavaldsen, Max Moeschinger, Ann Christin Barstad, Hege J. Blikra and Jawad Qureshi	MDS approved.

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1 Introduction

Most insects serve an important task, such as pollination of flowering plants, nutrition and population control. Mosquitoes act as a major part of the aquatic food chain, yet they may also transmit diseases. Due to a changing climate, there is an increasing risk of tropical mosquitoes in Nordic countries, and thus tropical diseases. Hence, it might be a scope for protecting citizens from this problem in the garden or at windows and entrances. Kongsberg Defence and Aerospace (KDA) provided a mission-brief concerning this issue, describing the requirements as well as the scope of the project effort. The main goal for this project is to protect humans against disease-bearing mosquitoes, as well as non-carriers of disease, while avoiding unintended consequences to the environment. This implies a preventative system that may decrease the spread of mosquito-borne diseases, especially in urban, well populated environments where rapid spread of diseases can have a major impact on the society. As a result, Mosquito Defence Systems (MDS) has developed a system that will incorporate these key features with an innovative and cost-effective design.

1.1 Scope

The reader will be introduced to the project planning, requirements and test specification prior to an in depth technical overview of the different modules and how they interact. Subsequently the test plan and results will be presented prior to a conclusion and after-analysis of the project.

Note that this document will not include all of the aspects of the project from the beginning to the end. The reader will be referred to other documentation, while maintaining the focus on the architecture from a technical and functional perspective. The reasoning for this is to avoid an exhaustive examination.

2 Project Planning

2.1 Goals

The main goals of the project are to design, analyze and if possible build a mosquito-immobilizing unit. The minimum requirements from KDA are that the project will provide drawings of the electrical- and software design, and if time and scope allows it, build and test the design. This is in order to ensure that the design is capable of meeting the requirements for a successful system.

2.2 Milestones

The major milestones of the project are seen in Table 1. The first presentation involved mainly the inception-phase, consisting of project planning and defining a set of appropriate requirements. The second presentation involved deciding on the concept with its corresponding sub-systems. For the third and final presentation the entire project with its documentation was delivered and presented, respectively.

Table 1: Major milestones

Milestone	Activity
1st presentation and documentation	Week 6, 2015.
2nd presentation and documentation	Week 11-16, 2015.
Hand-in of project	Week 20, 2015.
3rd presentation	Week 22, 2015.

2.3 Project Model

An incremental approach is chosen as the best project-management model for this project. This approach is executed sequentially from project conception until the architectural design is complete. The reasoning for using such an approach has its roots in the requirements for the system. The expected output of this project is a complete system, hence the group is responsible for the architecture as well as the modules. Although evolutionary and incremental development are similar in many ways, there are many different interpretations and implementations of both concepts. Figure 1 illustrates how MDS use the incremental approach. The main reasoning for choosing this model is early verification during iterations (in contrast to the waterfall model).

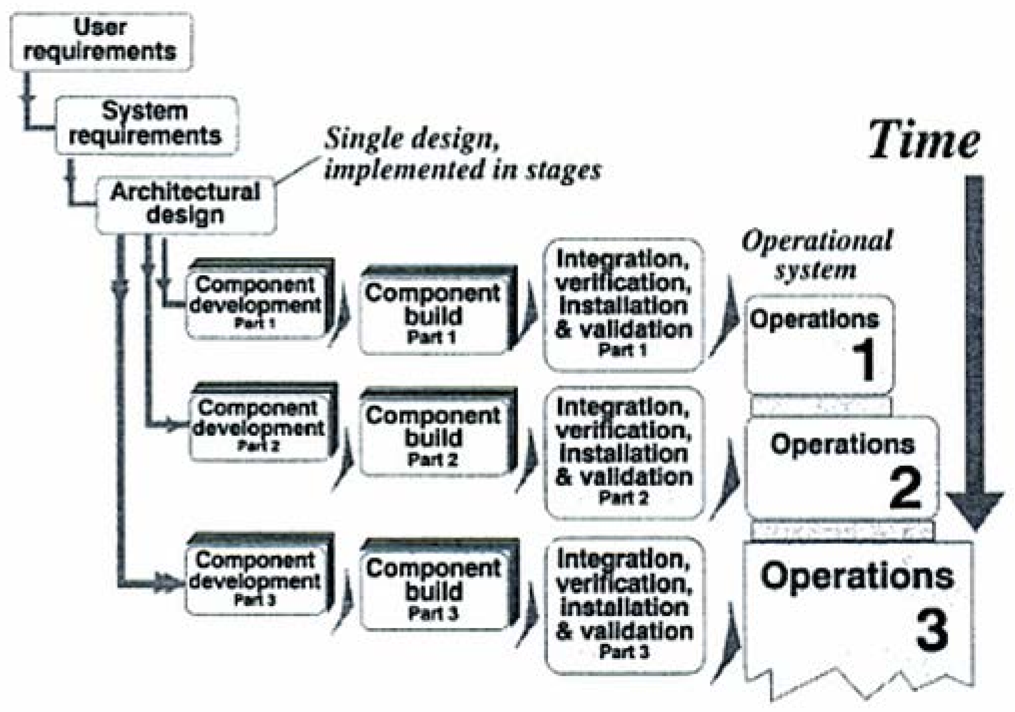


Figure 1: Incremental development from a systems engineering perspective [1]

2.4 Project Life-Cycle

The life-cycle for this project is decomposed into four major phases, namely inception, elaboration, construction and transition. The generic unified process directly inspires this, and each phase will contain tasks and methods tailored for this project. Figure 2 illustrates the unified process project overview.

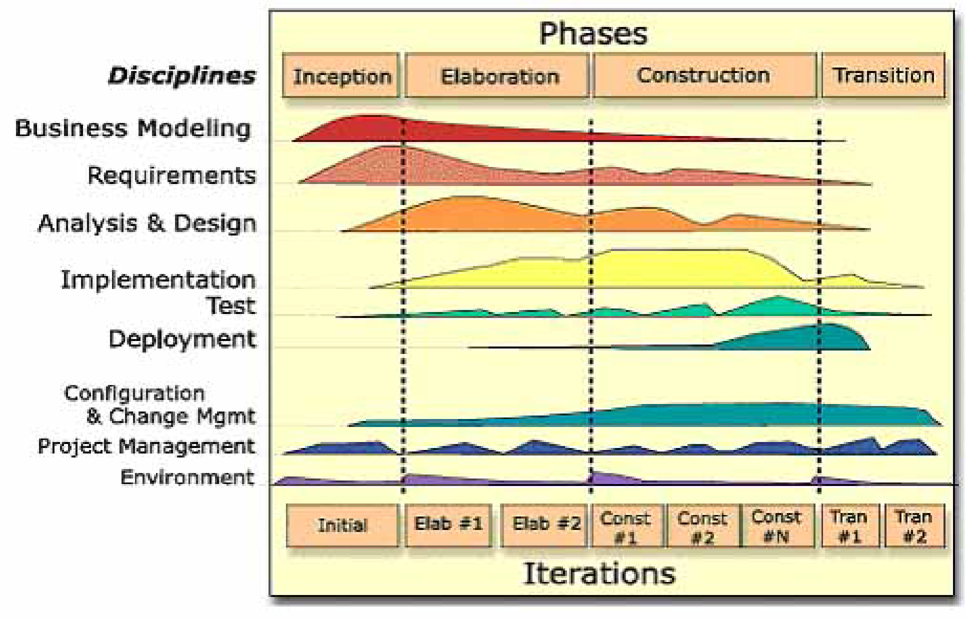


Figure 2: Unified process project phases [2]

2.4.1 Inception

Inception is the starting point where project planning begins and has focus towards:

- Project environment establishment
- Project charter/vision
  - Background
  - Goals
  - Milestones overview
- Project planning
  - Project model
  - Scope, constraints and assumptions
  - Preliminary scheduling
  - Work activities
  - Risks
  - Documentation
- Requirements
  - High level requirements

- Test
    - High level test specification
    - Acceptance criteria

2.4.2 Elaboration

The major parts of the elaboration phase consist of:

- Project planning
    - Update schedule
    - Risk assessment and acceptance
- Research
    - Concepts
    - Mosquito entomology
- Capture majority of system requirements
    - Detailed requirements
    - Validate
- Test
    - Evolve test specification
- Architecture (system design)
    - Identify and validate
    - Interfaces
- Plan for construction phase
    - Plan iterations
    - Plan communication (iteration plans and reports)

2.4.3 Construction

The construction phase moves the implementation and integration forward. Feedback is provided at the end of iterations, allowing for further elaboration as the project goes along. The major activities of this phase include:

- Project plan
    - Update schedule
    - Evolve Iteration plans
    - Transition phase planning
- Model
    - HW modeling
    - SW modeling
- Build
    - Prototyping (if feasible)
- Test
    - Add and improve test plans
    - Execute tests
- Documentation

o Iteration report

2.4.4 Transition

Transition is the final phase, where the system goes through its final validation and testing. The major activities of this phase include:

- Project plan
  - Update schedule
  - Evolve transition iteration plan
- System testing
  - High level testing
  - Validation
- System rework
  - Correct defects
- Stakeholders acceptance
- Documentation
  - Final report
  - Transition report

2.5 Project Schedule

Figure 3 roughly illustrates the ideal timespan for each phase and Figure 4 shows a Gantt chart for the entire project.

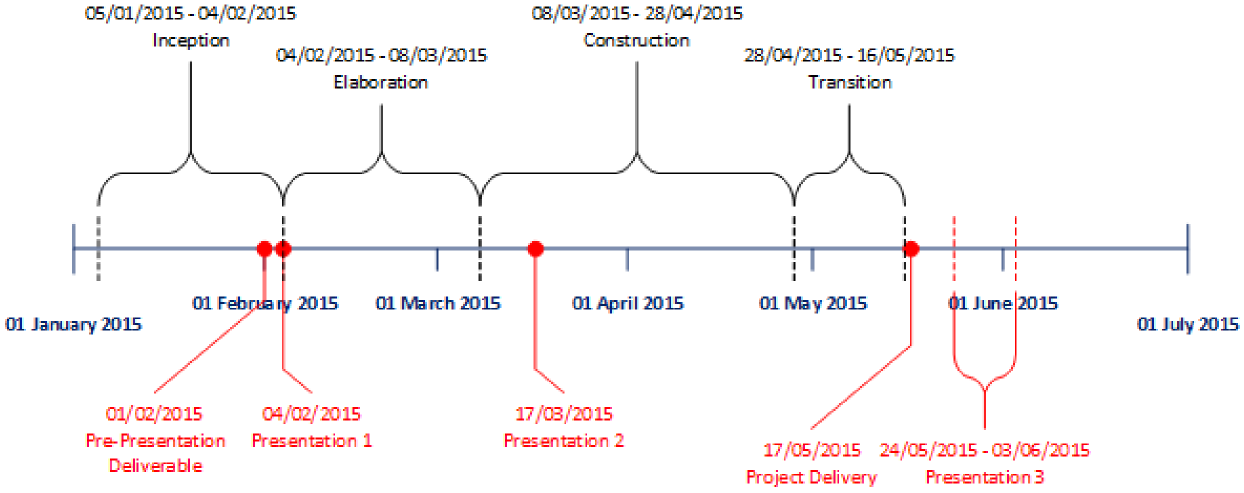


Figure 3: Timeline

ID	Task Mode	Task Name	Duration	Start
1		**Inception**	**17 days**	**Wed 14.01.15**
2		**Initiate Project**	**2 days**	**Wed 14.01.15**
3		**Prepare Project Environment**	**2 days**	**Wed 14.01.15**
4		Clean and Organize Project Location	3 hrs	Wed 14.01.15
5		Create and Organize File-Structure	1 day	Wed 14.01.15
6		Find and inform Richard of needs	1 hr	Wed 14.01.15
7		Set up Project Management Tool (ASANA	1 day	Wed 14.01.15
8		**Documentation**	**12 days**	**Fri 16.01.15**
9		Requirements Specification	7 days	Fri 16.01.15
10		Test Specification	5 days	Mon 26.01.15
11		Project Plan	5 days	Fri 16.01.15
12		Project Charter	6 days	Fri 16.01.15
13		Create Webpage	4 days	Fri 16.01.15
14		**Presentation 1**	**4 days**	**Mon 02.02.15**
15		Prepare presentation	3 days	Mon 02.02.15
16		Presentation 1	0 days	Thu 05.02.15
17		**Elaboration**	**20 days**	**Mon 09.02.15**
18		**Iteration #1**	**8 days**	**Mon 09.02.15**
19		Iteration planning	1 day	Mon 09.02.15
20		Requirements	5 days	Tue 10.02.15
21		Test Specifictation	2 days	Mon 16.02.15
22		Architectual Concepts	4 days	Mon 09.02.15
23		**Research**	**7 days**	**Mon 09.02.15**
24		Mosquito Entomology	7 days	Mon 09.02.15
25		Mosquito Immobilization/Destruction Te	7 days	Mon 09.02.15
26		Mosquito Detection Technology	7 days	Mon 09.02.15
27		Photonic Fence Methods and Technology	7 days	Mon 09.02.15
28		Iteration report	1 day	Wed 18.02.15
29		**iteration #2**	**12 days**	**Thu 19.02.15**
30		Iteration plan	1 day	Thu 19.02.15
31		Concept studies	5 days	Thu 19.02.15
32		Concept Selection	6 days	Thu 26.02.15
33		Iteration report	1 day	Fri 06.03.15
34		**Construction**	**46 days**	**Mon 09.03.15**
35		**Iteration #1**	**12 days**	**Mon 09.03.15**
36		Iteration plan	1 day	Mon 09.03.15
37		Test Plan & Cases	7 days	Mon 09.03.15
38		High-level Design	11 days	Mon 09.03.15
39		**Presentation 2**	**3 days**	**Fri 13.03.15**
40		Preperations	3 days	Fri 13.03.15
41		Presentation 2	0 days	Wed 18.03.15
42		**Iteration #2**	**33 days**	**Thu 26.03.15**
43		Iteration plan	1 day	Thu 26.03.15
44		Unit Design	21 days	Fri 27.03.15
45		Testing	5 days	Fri 01.05.15
46		Iteration report	0 days	Sat 09.05.15
47		**Transition**	**15 days**	**Sun 10.05.15**
48		**Iteration #1**	**15 days**	**Sun 10.05.15**
49		Final report	7 days	Sun 10.05.15
50		Iteration report	2 days	Wed 20.05.15
51		Final delivery	0 days	Tue 19.05.15
52		Presentation 3	0 days	Thu 28.05.15

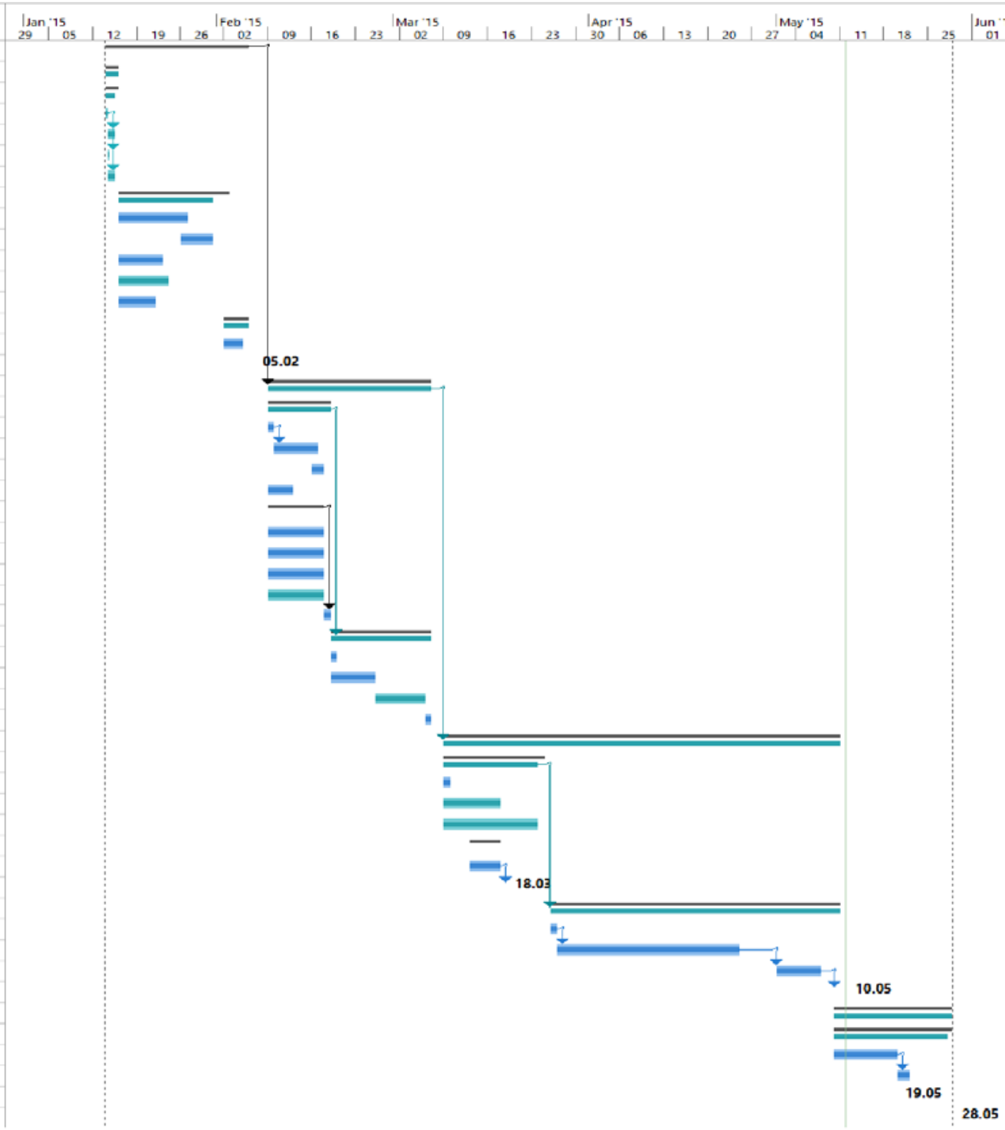


Figure 4: Gantt chart

2.6 Stakeholders

The stakeholders; the individuals or groups with interests in the project or the final outcome of it, are presented in Table 2.

Table 2: Key stakeholders

Name	Description	Stakeholder concerns
Mosquito Defence Systems (MDS)	Developers represented by group manager Eirik Haavaldsen, and group members Ann Christin Barstad, Christoffer Olsen, Max Moeschinger, Jawad Qureshi and Hege Jeanette Blikra.	Design, analyze, and develop a mosquito immobilizer unit.
Integrated Defence Systems (IDS)	Employer represented by external supervisor André Ruud and external sensor Hans Ivar Østensen.	Create project description and contribute with help regarding specifications and requirements of the project.
Sigmund Gudvangen	Internal supervisor represented by HBV.	Help with execution of documentation and project management, as well as technical guidance.
Government	The Norwegian government.	Concerns regarding Norwegian rules and regulations. Ensures the project complies with this.
Suppliers	Online- and/or physical-store vendors with appropriate products.	Provide products and services.
Community	Environment surrounding the system.	Concerns regarding noise, pollution, and disturbance.

2.7 Users

The main users of the system, and their requests, are presented in Table 3. They are defined as the end users or intermediate users of the final system.

Table 3: Users

Users	Request(s)
Users at risk	A commercial system to remove disease-carrying mosquitoes.
Users for comfort	A commercial system to remove mosquitoes.
Scientists	Use parts of the system for research (e.g. detection module for insect count).
Companies and/or organizations	System to remove disease-carrying- and/or irritating mosquitoes in extensive areas.

2.8 Risk Analysis

A preventative approach to the project involves risk analysis and management. Minor issues can result in major time constraints, and thus it is of much importance to consider the risks involved with the project. These are presented in Table 4, Table 5, Table 6 and Table 7, respectively.

Table 4: Risk consequence table

Consequences	Description	Scale
Insignificant consequences	The project is barely affected.	1
Minor consequences	The project experience problems without stopping.	2
Medium consequences	The project is very affected and measures should be evaluated.	3
Major consequences	The project stops and measures must be evaluated.	4
Disaster	The project is cancelled	5

Table 5: Risk probability table

Probability	Description	Scale
Unlikely	Less than 1 occurrence every 1000 hours	1
Less Likely	Average of 1 occurrence every 1000 hours	2
Likely	Average of 1 occurrence every 100 hours	3
More Likely	Average of 1 occurrence every 10 hours	4
Very likely	More than 1 occurrence every 10 hours	5

Table 6: Risk overview

		Probability				
		1. Unlikely	2.Less Likely	3. Likely	4. More Likely	5. Very likely
Consequence	5. Disaster	5	10	15	20	25
	4.Major consequences	4	8	12	16	20
	3. Medium consequences	3	6	9	12	15
	2. Minor consequences	2	4	6	8	10
	1. Insignificant consequences	1	2	3	4	5

Low	Acceptable risk, no measures must be taken
Medium	Acceptable risk, measures must be considered
High	Unacceptable risk, measures must be initiated

Table 7: Risk matrix

Event	P	C	R	Risk Reduction measures
Equipment damaged beyond repair.	1	4	4	Have documentation of all hardware at any time.
Loss of group member.	1	4	4	Have weekly summaries concerning the project objectives in order to keep the group members informed, such that potential setbacks are minimized.
Delay on delivery concerning prototype components.	2	3	6	Make sure to order with a time margin in case of delay.
Critical parts are defect	2	4	8	Order from reliable vendors and choose secure transportation methods. Place orders with appropriate time margins.
Loss of project directory and containing files.	1	5	5	Make sure that there is always a backup of all the project documents.
Interface incompatibility	2	3	6	Be sure to review all parts for interface compatibility.
Negative impact on the environment and potential harm to humans.	2	4	8	Be sure to always test in a safe environment and store potentially dangerous substance in a safe area.
Unsuccessful testing (unable to proceed with test)	1	4	4	Be sure to carefully write test procedures and make sure test equipment is adequate and functional for testing. Verification and validation in project plan.
Unable to complete development	2	5	10	• Perform high-level planning. An iterative approach is deemed appropriate to secure completion of the most fundamental requirements first, and complete more advanced, complementary requirements in later iterations. • Take the project group members competence into consideration while making design/concept decisions.
Research is more extensive than expected.	2	3	6	The schedule is flexible enough to handle 2-3 days of delay in the current iteration.
Extensive requirements specification rework.	2	4	8	Extra time put aside for requirement specification.
Extensive test specification rework.	2	4	8	Extra time put aside for test specification.
Need for concept change (architecture or design units)	2	4	8	Several different architectural and design unit concepts have been made.

2.9 Project Team

An overview of the MDS' team members are represented in Table 8.

Table 8: Project team overview

Information	Picture
Mohammad Jawad Shabbir Qureshi Software Engineering Embedded Systems	
Christoffer Marius Ness Olsen Electrical Engineering Audio Technology	
Hege Jeanette Blikra Electrical Engineering Cybernetics and Mechatronics	
Eirik Haavaldsen Software Engineering Embedded Systems	
Ann Christin Tjensvold Barstad Electrical Engineering Cybernetics and Mechatronics	
Max Moeschinger Software Engineering Embedded Systems	

2.10 Expense Report

An overview of prototype expenses for the Mosquito Defence System is represented in Table 9.

Table 9: Expenses

Product	Vendor	Quantity	Cost
Laser pen	Clas Ohlson	1	249 NOK
Galvanometer Scanner Set	Ebay	1	984,44 NOK
Thermal Sensor	Rs Components AS	1	566,36 NOK
Pitch Housing 4 way	Rs Components AS	10	369,89 NOK
SSHL Crimp Pin Connector Female	Rs Components AS	100	
DAC	Elfa Distrelec	3	115,80 NOK
TL082CN (Op-amp IC)	Elfa Distrelec	5	13,15 NOK
TL084ACN (Op-amp IC)	Elfa Distrelec	5	36,00 NOK
DC/DC converter	Elfa Distrelec	1	141,00 NOK
Capacitor 100nF	Elfa Distrelec	10	6,39 NOK
Aluminium electrolytic capacitor 4.7 µF	Elfa Distrelec	6	3,84 NOK
Aluminium electrolytic capacitor 100 µF	Elfa Distrelec	4	12,96 NOK
Shipping + taxes	Elfa Distrelec		161,80 NOK
MO-layer Resistor 1kOhm	Elfa Distrelec	4	18,04 NOK
SparkoCam Full Version	sparkosoft.com	1	396,62 NOK
		Sum	**3075,29 NOK**

2.11 Documentation

Documents and reports are named as followed: *Name_vVersion_Date.Month.Year*
e.g. "Requirements_v0.1_21.01.2015" or "ProjectPlan_v0.1_21.01.2015".

The version control works as follows: all officially, approved documents will increment the number on the left side of the dot. Internal version will increment the number on the right.

2.12 Meetings

As a formality, the group conducts meetings every Thursday at 09:00. This is noted as "Kernel hours" which will act as a weekly update where everyone report their activities and plans to the project group. The group also has meetings every Thursday at 10:00 with the internal supervisor, Sigmund Gudvangen.

3 Requirements

This section provides the requirements deemed necessary to achieve a successful system in regards to the assignment delivered by KDA/Integrated Defence Systems (IDS), within the development- and operational environment.

3.1 Abbreviations

All requirements are issued an ID that briefly describes the type of requirement, as seen in Table 10. The requirements are divided into two groups: high-level requirements, referred to as “REQ,” and business goals, referred to as “BUSG.” Each requirement is issued a unique number referred to as “x,” starting with “1,” proceeding to “2,” and so forth.

Table 10: Requirement-ID abbreviations

Abbreviation	Full name
REQ	Requirement
BUSG	Business Goals

The requirements are traced back to a stakeholder, under the column “Issued by”, in the tables below. The abbreviations for the stakeholders can be seen in Table 11.

Table 11: Stakeholder abbreviations

Abbreviation	Full name
KDA	Kongsberg Defence & Aerospace
MDS	Mosquito Defence Systems
HBV	University College, Buskerud and Vestfold, Department of Engineering in Kongsberg (Høgskolen i Buskerud og Vestfold)

3.2 Requirement Grading

In order to define the importance of each requirement, they are graded on a scale from A to C. A is regarded as the most important, and C the least. The definition of importance in this document is in regards to whether or not it is critical for a successful system that the requirement is achieved. Failing to meet a requirement issued priority A, is synonymous with system failure. All definitions can be seen in Table 12.

Table 12: Requirement-priority definitions

Priority Grade	Definition
A	Necessary in order to achieve a successful system.
B	The system will lack important features for a final system.
C	Desirable requirement that will not affect the system considerably.

3.3 Business Goals

Business goals provide the necessary information in regards to schedule and cost for final delivery of the system, as presented in Table 13.

Table 13: Business goals

ID	Requirement	Issued By	Priority
BUSG-1	Commercially available parts/modules	KDA	B
BUSG-2	Consumer affordable	KDA	B
BUSG-3	Final delivery May 19th 2015.	HBV	A

3.4 High-Level Requirements

High-level requirements provide essential information regarding what is expected of the system in a testable manner, which do not constrain the solution but states what is deemed necessary, as presented in Table 14.

Table 14: High-level requirements

ID	Requirement	Issued By	Priority
REQ-1	Immobilize/destroy mosquitoes in order to reduce the chance of infection caused by mosquitoes.	KDA	A
REQ-3	Issue warning when unintentionally inactive.	MDS	C
REQ-4	Area of effect may be adapted to the operational environment.	MDS	C
REQ-5	Should not harm other insects.	KDA	B
REQ-6	Shall not harm humans or animals.	KDA	A
REQ-8	Detect individual mosquitoes.	KDA	A
REQ-9	The system should not cause collateral damage to inventory and environment.	KDA	B

3.5 Constraints

In order to create a successful system there are primarily two tasks that must be fulfilled, namely safety and performance. Even though performance may not be a constraint in itself, it does pose some challenges that will eminently affect the design:

- The operational environment might consist of e.g. humans, animals, insects (other than mosquitoes) and inventory. Hence these shall not be disturbed significantly. It is deemed reasonable that some damage to other insects is within acceptance, though humans and animals must not be disturbed or subjected to harm. This implies a major constraint to the system, since it may be deployed in the vicinity of animals and humans, who must not be disturbed in their daily activities.
- The system is intended to decrease the potential risk of being bitten by disease-bearing

mosquitoes. This means that the system must be capable of immobilizing mosquitoes with a certain precision and efficiency. This comes especially about due to the fact that mosquitoes have a rather unpredictable flight pattern. This implies that the system must be capable of tracking moving objects with good precision and immobilize within the designated area of effect, prior to the mosquito potentially reaching a human and bites. This results in demanding real-time constraints.

It is worth noting that mosquitoes that are not carrying a disease will be infected after biting a human host of the disease. Hence, all female mosquitoes are in fact of interest to immobilize.

4 Test Specification

This section contains a test specification for each of the system-tests that are conducted and processed for the high-level requirements. It is important to test requirements in order to verify that they meet the expectations they have been issued. Each test includes verification methods and acceptance criteria description, as well as test responsibility, current status, and whether they are approved or not. Traceability back to the requirement being tested is also emphasized.

4.1 Abbreviations

All tests are issued an ID, consisting of a "T" followed by the requirement identification (ID). The "T" marks that it is a test, the requirement ID, here "REQ-X", is the ID belonging to the requirement being tested with the accompanying number. This is presented in Table 15.

Table 15: ID abbreviations

Abbreviations	Description
T	Marks a test
REQ-X	Requirement ID
T-REQ-X	Complete test ID

4.2 High-Level Requirements

The test specification for the high-level requirements are presented in Table 16 to Table 22.

Table 16: T-REQ-1

T-REQ-1	
Requirement description	Immobilize / destroy mosquitoes in order to reduce the chance of infection caused by mosquitoes.
Related to requirement-ID	REQ-1
Responsible	All of the group members.
Verification	Test case if possible.
Acceptance criteria	The system is able to accurately hit the targets within the target area.
Status	Tested
Approved	Yes

Table 17: T-REQ-3

T-REQ-3	
Requirement Description	Issue warning when unintentionally inactive.
Related to requirement-ID	REQ-3
Responsible	All of the group members.
Verification	Not to be tested at this phase.
Acceptance criteria	Confirm that warnings are issued.
Status	Untested
Approved	N/A

Table 18: T-REQ-4

T-REQ-4	
Requirement Description	Area of effect may be adapted to the operational environment.
Related to requirement-ID	REQ-4
Responsible	All of the group members.
Verification	Analysis.
Acceptance criteria	Confirm that the system functions within the adapted area of effect.
Status	Untested
Approved	N/A

Table 19: T-REQ-5

T- REQ-5	
Requirement Description	Should not harm other insects.
Related to requirement-ID	REQ-5
Responsible	All of the group members.
Verification	Test case.
Acceptance criteria	Able to differentiate between mosquitoes and other insects.
Status	Tested
Approved	Yes

Table 20: T-REQ-6

T- REQ-6	
Requirement Description	Shall not harm humans or animals.
Related to requirement-ID	REQ-6
Responsible	All of the group members.
Verification	Test case.
Acceptance criteria	Ensure that the system implements functionality that provides human and animal safety.
Status	Tested
Approved	Yes

Table 21: T-REQ-8

T - REQ-8	
Requirement Description	Detect individual mosquitoes.
Related to requirement-ID	REQ-8
Responsible	All of the group members.
Verification	Test case.
Acceptance criteria	The system is able to detect the presence of mosquitoes in the designated area.
Status	Tested
Approved	Yes

Table 22: T-REQ-9

T- REQ-9	
Requirement Description	The system should not cause collateral damage to inventory and environment.
Related to requirement-ID	REQ-9
Responsible	All of the group members.
Verification	Not to be tested at this phase.
Acceptance criteria	No vulnerable items are damaged.
Status	Untested
Approved	N/A

5 System Architecture

Prior to developing a system architecture, comprehensive research into already manufactured systems for immobilizing and detecting mosquitoes was deemed appropriate. It is of interest to develop an innovative system with a cost-effective design that will result in wide-spread use. This resulted in a system that will be presented next.

5.1 Feature Overview

The system architecture developed from the requirements resulted primarily in four sub-systems:

- Visual Detection System (VDS) deploys a camera and a processing unit that performs image processing on a video stream, to detect if there are objects in the designated area of effect.
- Auditive Detection System (ADS) deploys a microphone array that captures the sound waves produced by an insect's wing-beat. The signal is then analyzed to determine if the recorded sound source is in fact a mosquito.
- Inadvertent Damage Prevention System (IDPS) uses a thermal sensor and detection-software, which prevents the LCS of emitting its laser, if humans or animals are exposed.
- Laser Control System (LCS) consists of two mirrors attached to a galvanometer each for x- and y-positions, deflecting a laser beam in a specific predetermined direction to immobilize a mosquito. It is required that the microphone array confirms that a mosquito is present and that the thermal sensor confirms that no humans or animals are present.

An illustration of the system can be seen in Figure 5, and the prototype in Figure 6. Further explanation of the different systems is presented next.

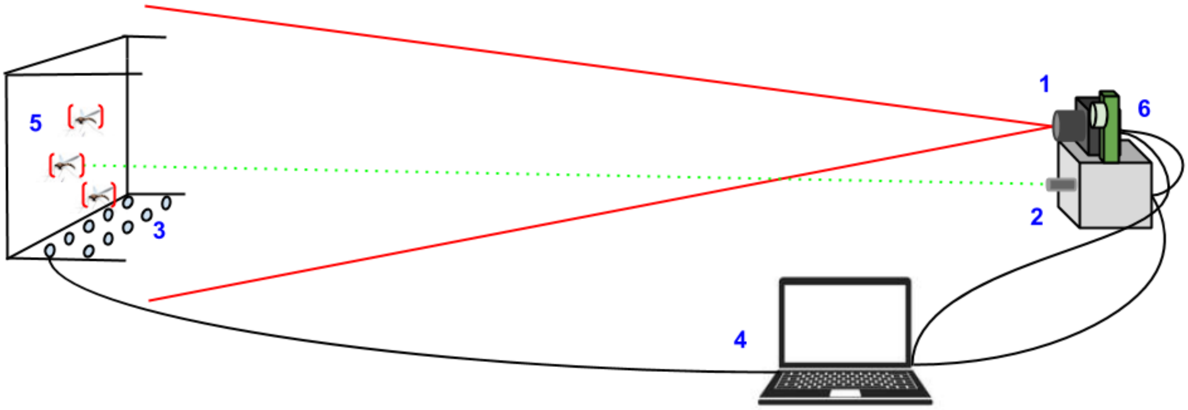


Figure 5: Illustration of the system provided by MDS: Camera (1),laser emitter (2), microphone array (3), data processing unit (4), mosquitoes (5) and thermal sensor (6)

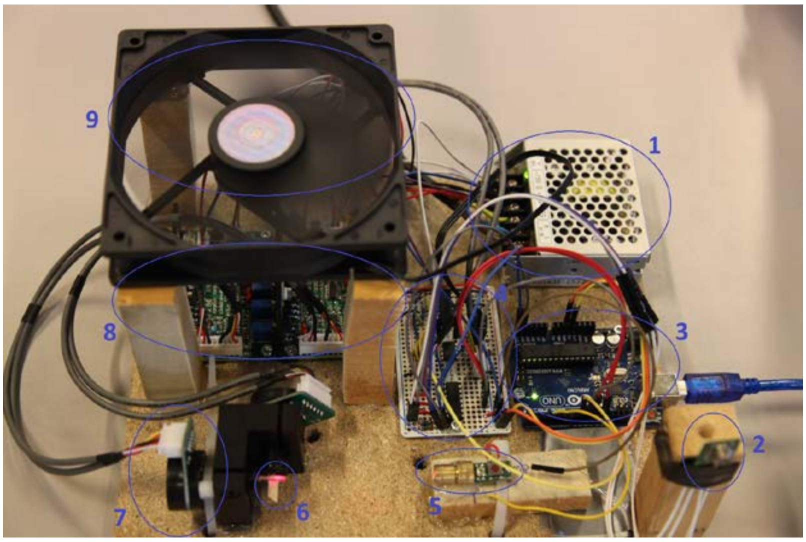


Figure 6: LCS Prototype. Power supply (1), thermal sensor (2), Arduino UNO (3), prototype board (4), laser (5), mirrors (6), galvanometers (7), control boards (8) and fan (9)

5.1.1 Visual Detection

The system is able to detect the presence of a mosquito in the designated area of effect by using image processing. The system deploys a digital single-lens reflex camera that sends a video stream through USB to a computer, running the image-processing software. The image-processing software detects any moving target about the size of a mosquito in the specified target area. The computer will obtain the objects relative position to the camera, but will not be able to classify or identify the objects as mosquitoes or other entities.

5.1.2 Auditive Detection

When a mosquito flies, the wing-beat has a specific sound signature, consisting of a fundamental frequency and over-harmonic frequency components. The system deploys a microphone array within the target area to obtain these sound waves as signals. The signals are recorded in short segments, or frames, allowing the computer to obtain the signals in real-time. When the computer obtains such a frame, it runs software that filters out noise and transforms the signal from the time domain into the frequency domain. This will reveal properties of the signal, such as the fundamental frequency and over-harmonic frequency components. This means that the software is able to distinguish certain sound signatures from each other, allowing the system to distinguish mosquitoes from other-flying insects given that they have different fundamental frequencies and over-harmonics.

5.1.3 Laser Control

In order to immobilize/ destroy a mosquito the system deploys a powerful laser. The amount of watts the laser should produce is determined by the amount of time needed to destroy the wings. It is necessary to aim the laser in the right direction relative to the given position by the camera continuously, in order to immobilize the mosquito as they tend to move sporadically. In order to meet the requirements for speed and accuracy, the system deploys mirrors attached to the galvanometers.

One mirror galvanometer controls the x-direction while the other controls the y-direction. As mentioned earlier, the relative position of the object being tracked is obtained through image processing. The computer sends the positioning data through a microcontroller and circuitry with digital-to-analog converters, which then tilts the mirrors.

5.1.4 Inadvertent Damage Prevention

Three criterions must be fulfilled before the system is allowed to emit the laser:

- The visual detection module must have detected a target about the same size as a mosquito.
- The audio detection module must obtain an audio signal that matches that of a mosquito.
- The safety module signals that there are no humans or animals within the target area.

When these three criterions are met, the system will emit the laser, without posing a threat to humans or animals.

5.2 System Overview

In order to present the reader with a basic understanding of how the system interacts internally, a block diagram of the complete system is seen in Figure 7. Since a presentation of each of the sub-systems is already presented, it will suffice with a brief overview of the entire system.

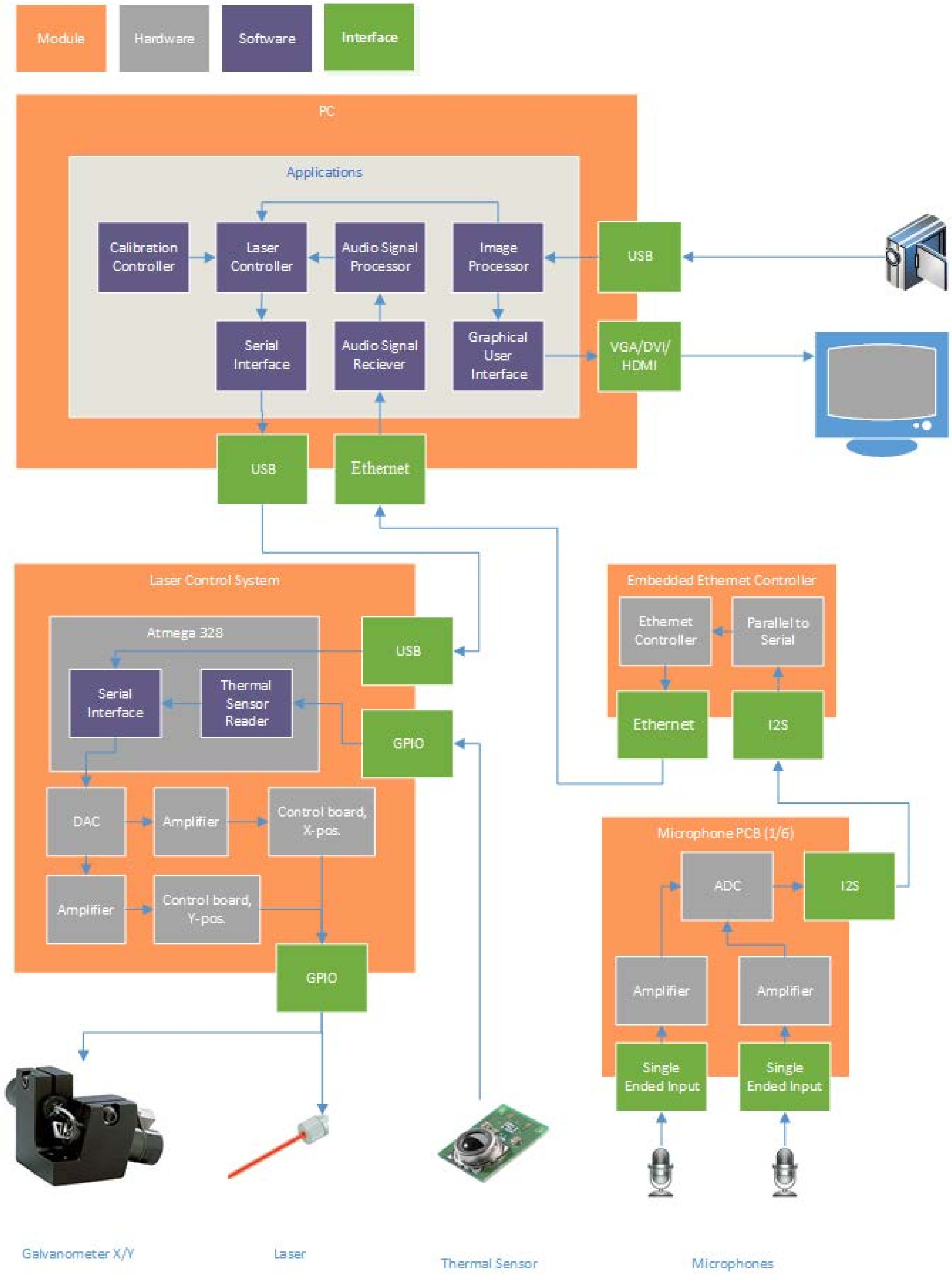


Figure 7: System block diagram

The uppermost module in Figure 7 consists of a PC that processes the camera- and audio feed. The camera feed is used to detect moving objects and the relative x- and y-positions. These positions are then used to steer the sensitivity of the microphone array to the relative angle of the object on the camera-feed. The resulting audio-signals are processed and used to determine if a mosquito is present. Given that a mosquito is present and the processed audio-signals confirm this, the relative x- and y-positions are transferred to the Laser Control System (LCS), as seen in *Figure 7*. The LCS has a thermal tensor attached to the Thermal Sensor Reader software-module. If the thermal sensor does not detect heat from humans or animals, the laser is activated and the relative x- and y-position of the mosquito are transferred to the galvanometers. The mosquito will be immobilized and the system may proceed with the next object within the area of effect

The reader has been presented with a basic understanding of the different sub-systems and how they interact. It is now of interest to provide an in depth technical presentation of the entire system, including the microphone array, auditive detection software, laser control system with its corresponding hardware and software, computer vision and thermal sensor.

6 Hardware Modules

6.1 Microphone Array

This section provides the necessary information for further development and production regarding the microphone array-module. The reader will be presented with the rationale for the design decisions concerning inter-microphone spacing, type of microphones, amplifiers, Analog-to-Digital Converters (ADCs), clock buffer and circuitry with the corresponding concerns, and how they may be remedied for a satisfactory result.

6.1.1 Equally Spaced Microphone Array

In [3] it was confirmed that a microphone array consisting of equally spaced microphones will outperform a sparse array in regards to the required number of microphones for a satisfactory narrow main-lobe, and thus the necessary length of the array. Hence it is deemed appropriate to design a microphone array with equally spaced microphones.

Inter-microphone spacing: In order to determine the spacing between the microphones, the wing-beat frequency of a mosquito must be taken to consideration. The wing-beat frequency of a mosquito depends on both the species and the sex. Anopheles is a genus of mosquitoes where several of the species are known carriers of malaria. The wing-beat frequency of a female mosquito is generally in the range of 300 to 500 Hz, though commonly around 400 Hz. In [3] it was determined that any harmonic frequency components beyond the third harmonic may be difficult to recognize, due to the rather low amplitude compared to adjacent peaks in the frequency domain. It is of interest to preserve these over-harmonic frequency components, in order to distinguish between mosquitoes and other noise contributions with the same fundamental frequency. Hence, the upper frequency of interest is 1500 Hz, though some headroom is deemed appropriate. An upper frequency of 1800 Hz, resulting in a potential fundamental frequency of 600 Hz and the third harmonic at 1800 Hz, respectively, seems satisfactory. The filtering of the audio signal to the frequency range of interest should be performed digitally on a processing unit, such as a computer or Field Programmable Gate Array (FPGA).

The spacing between the microphones is determined by

$$d < \frac{\lambda}{2} \qquad (1)$$

where λ is the wave-length of the maximum frequency of interest, and d is the spacing.

The upper frequency of interest to preserve while avoiding aliasing is f_{max} = 1800 Hz. The wavelength may then be computed by

$$\lambda = \frac{c}{f_{max}} \qquad (2)$$

where c is the speed of sound, 343 m/s at 20 degrees Celsius.

This results in an inter-microphone spacing of 0.095 m. The microphone array may be positioned in e.g. a windowsill in a house or office-building, hence it should be kept short in length while maintaining a rather narrow main-lobe. This is rather difficult, since the width of the main-lobe is proportional to the inverse of the length of the array. Hence a compromise is necessary. Simulations in MatLab by *linArrayDirectivity.m* and *ArrayPerformance.m* script proved that the spacing between the microphones did not result in major side-lobes, due to aliasing, until the microphone spacing was set to 0.18 m, with a maximum frequency of 1800 Hz. This is readily seen in Figure 8, though care must be taken since these are simulations. In order to ensure that the aliasing terms are indeed avoided, the spacing should ideally be 0.095 m, though this results in a very wide main-lobe for frequencies in the range of 300 to 500 Hz. This may be dealt with by increasing the number of microphones, though this will result in a microphone array that is rather long. Hence a compromise is struck with an inter-microphone spacing of 0.14 m.

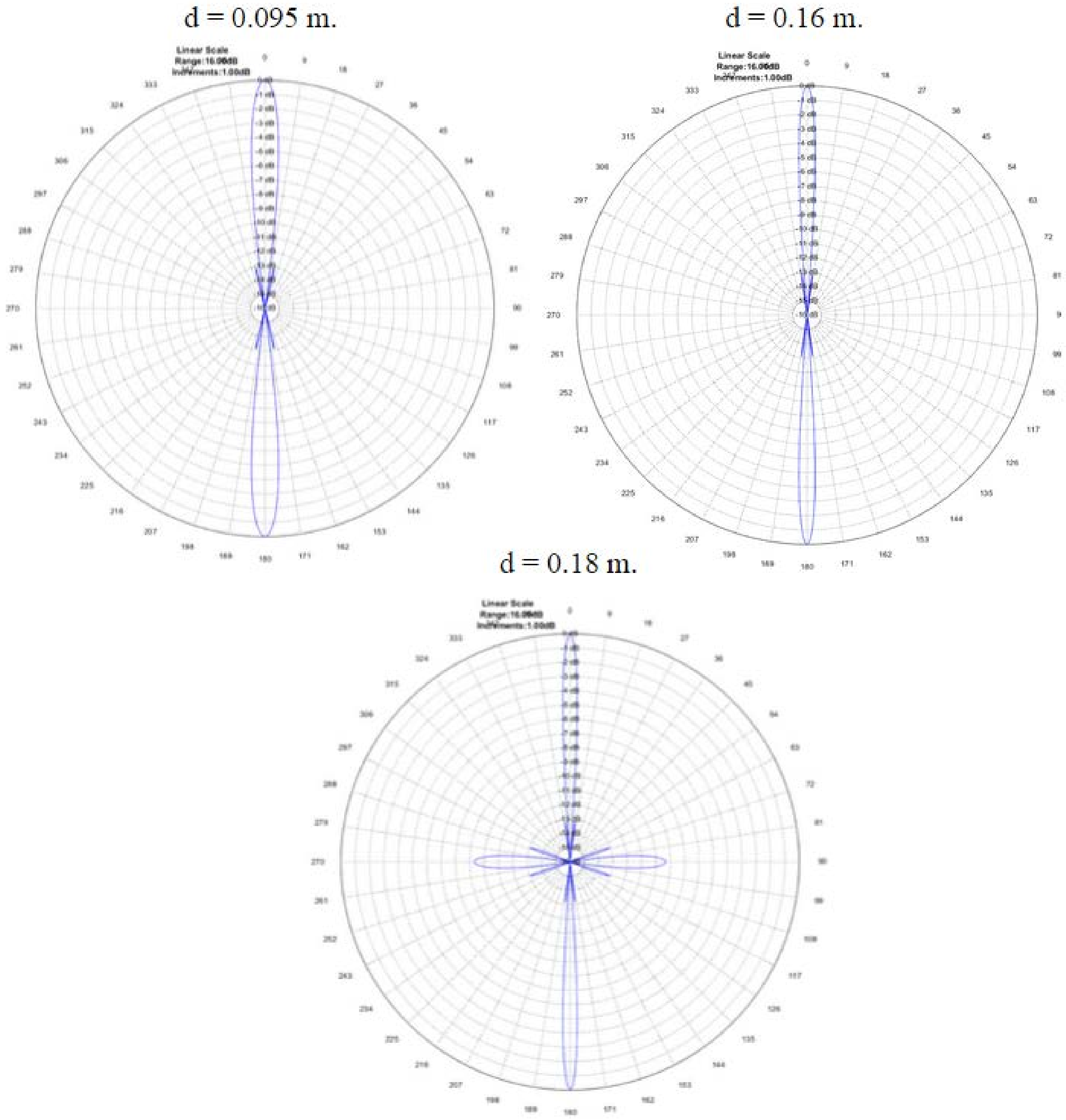


Figure 8: Polar pattern for a microphone array consisting of 13 microphones and three different inter-microphone spacings. The frequency of the incoming sound wave is set to 1800 Hz

The number of microphones in [3] was seen to result in good results with nine microphones, with a minimum frequency of 400 Hz. Since a mosquitos wing-beat might reach as low as 300 Hz, though closer to 400 Hz is more common, it should be taken into consideration. An inter-microphone spacing of 0.14 m with nine microphones results in a length of 1.12 m, which is rather long, and with eleven microphones, a length of 1.4 m is necessary. Though 1.4 meter might be excessive in some windowsills, it is appropriate for a narrow main-lobe at low frequencies. The resulting polar patterns at different frequencies can be seen in Figure 9, and corresponding data of interest in Table 23.

Table 23: Data for microphone array with eleven microphones equally spaced apart by 0.14m

Frequency (Hz)	Acceptance Angle (degrees)	First Zero (degrees)	Amplitude of side-lobes (dB, relative to 0 dB on-axis)
300	39.0	42.5	-13.5
350	33.0	36.4	-13.0
400	28.0	32.0	-13.0
450	25.5	28.0	-13.0
500	22.0	25.5	-13.0
800	14.0	16.0	-13.0
1200	9.0	10.6	-13.0
1500	7.0	8.5	-13.0
1800	6.0	7.0	-13.0

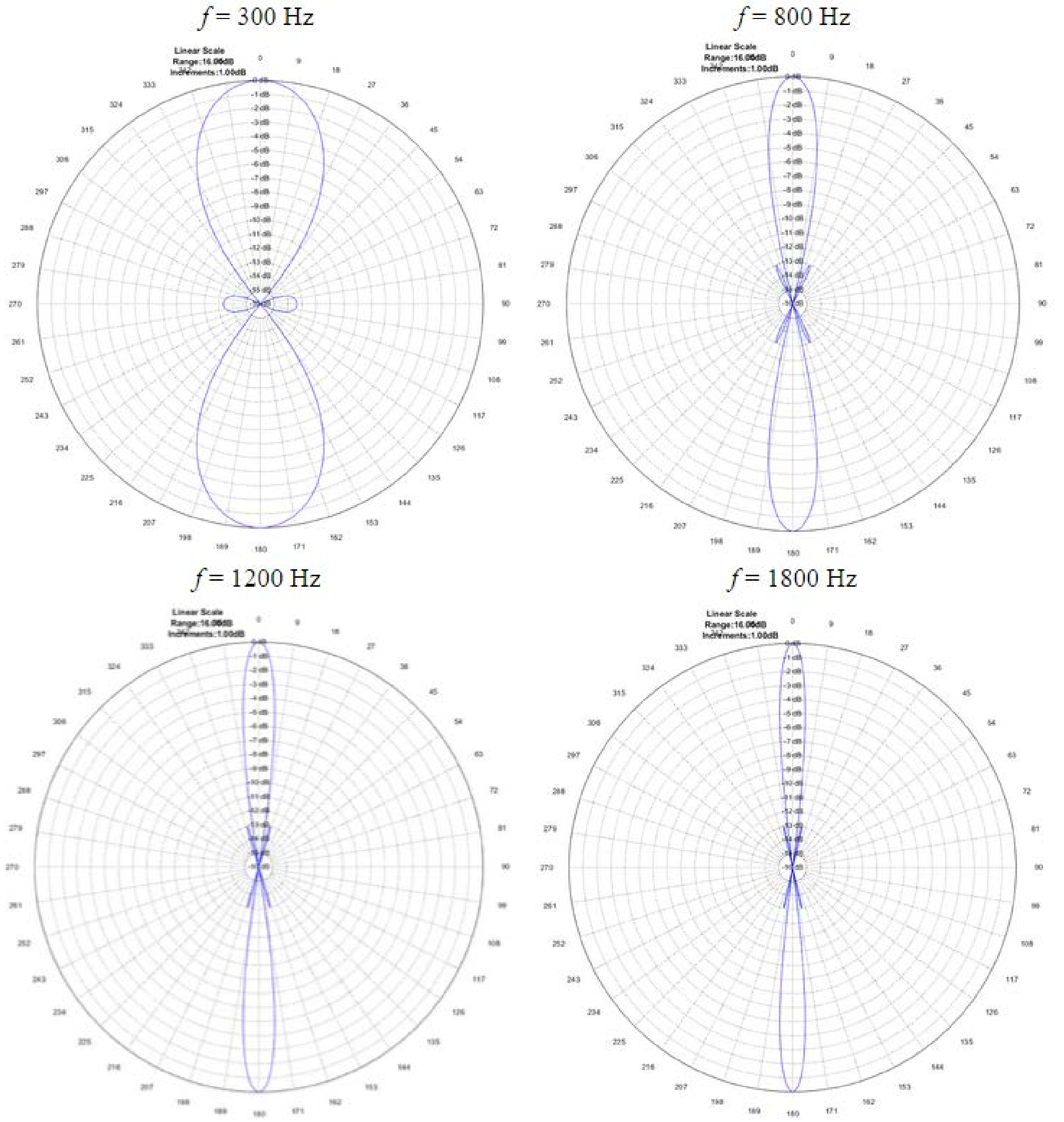


Figure 9: Polar patterns for a microphone array consisting of 11 microphones equally spaced apart by 0.14 m, when the incoming sound wave has a frequency of 300, 800, 1200 and 1800 Hz

6.1.2 Panasonic WM-61A Microphone

In [3] Panasonic WM-61A was found to be a cheap electret microphone with a flat frequency response up to about 2-3 kHz, and beyond this point it is only a matter of slight calibration. Since the frequency range of interest is limited from 300 to 1800 Hz, this will not pose as an issue. It was also discussed that the maximum allowable Sound Pressure Level (SPL) before clipping is approximately 109 dB. The WM-61A may be modified to handle greater SPLs as shown in [4], though considering that the microphone array is intended for recording mosquitoes, it is not considered necessary. Due to the microphones low cost of approximately 20 to 40 NOK per unit and good frequency response, it is considered as a good choice for the array.

It is worth noting that Micro-Electro-Mechanical System (MEMS) microphones are designed and manufactured for mobile applications and microphone arrays with digital (I^2S) outputs. Thus there is no need for a separate amplifier and ADC. These have generally a very uneven frequency response, hence WM-61A is a more reasonable choice, though it may be of interest if cost is a major constraint and worth following for future developments.

6.1.3 Microphone Amplifier

Due to the rather low sensitivity of the Panasonic WM-61A [3], it may be necessary to amplify the signal from each of the microphones in the array. There are several manufacturers of Integrated Circuit (IC) amplifiers for Printed Circuit Board (PCB) applications, such as Texas Instruments, Analog Devices, THAT Corporation and Cirrus Logic. There are a few considerations to take when searching for an appropriate amplifier, such as Signal-to-Noise Ratio (SNR), number of channels, complexity in regards to necessary external components, band-width, outputs and last but not least, gain.

THAT1583: After some comprehensive research, a strong candidate from THAT Corporation came about, namely THAT1583 [5]. THAT Corporation specializes in high-quality audio technology. The amplifier is a single-channel amplifier, intended for e.g. microphone preamplifiers, sonars and instrumentation, making it a good fit for the application of a microphone array. The Total Harmonic Distortion + Noise (THD+N) is 0.001% measured at an amplification factor of < 40dB and 0.006% at 60dB [5]. Note that THD is a measurement of the powers of all of the harmonic components relative to the fundamental frequency, by

$$THD = \frac{\sqrt{\sum_{i=2}^{M} y_i^2}}{y_0} \qquad (4)$$

where y_0 is the amplitude of the fundamental frequency and y_i is the amplitude of the different harmonic components [6].

When an amplifier is fed a sine-wave frequency component, it will add over-harmonic frequency components that are not present in the input-signal, hence a low THD is a relevant parameter to consider. THD + Noise is measured by

$$THD + N = \frac{\sqrt{\sum_{i=2}^{M} y_i^2 \ y_n^2}}{y_0} \qquad (5)$$

where y_n is the noise amplitude [6].

The SNR of THAT1583 is measured to -128.9 dBu at 60 dB gain. It has a bandwidth of up to 1.7 MHz. Adjustable gain from 0 to > 60dB and differential outputs suitable for Analog to Digital Converters. The amplifier is suitable for a vast range of low to high-cost microphones, hence the amplifier may still be used even though one would choose another microphone than the WM-61A.

The amplifier only requires three external components, consisting of two matched feedback resistors and a third that is used to set the amplification gain in the range of 6 to 60dB. If different feedback resistors are used it is possible to adjust the gain higher than 60dB if necessary. The value of the resistor that sets the amplification, R_G, must be in the range of 10 to 10kΩ, for an amplification of 60 down to 6dB. In order to evaluate the necessary amplification it will require some field trials and measurements, which will not be performed due to time-constraints. Hence in this note it will only be stated what range it may be set to, and not a final value.

With a low unit price of about 20 NOK and good SNR, amplification and THD + N, the THAT1583 serves the purpose of amplifying the signals from each microphone with parameters beyond what the WM-61A can produce. Hence there are no shortcomings due to the amplifier.

6.1.4 Analog to Digital Converter

In order to process the signals from the microphone array it is necessary to digitize the continuous voltage into discrete signals. These signals consists of binary words that represent the analog signal. This is achieved by an Analog-to-Digital Converter (ADC).

Concerning ADCs there are general purpose ADCs and Sigma-Delta (Σ-Δ) ADCs. Sigma-Delta ADCs are made specifically for audio applications, using noise-shaping and over-sampling to achieve a good dynamic range (low noise floor) with few bits [7]. Over-sampling is also of interest due to the anti-aliasing filter prior to the conversion. In order to reduce the required order of the filter, it is possible to use oversampling, resulting in a much wider transition region between the maximum frequency of interest and half the sampling frequency, $f_s/2$ (no frequency components above $f_s/2$ can be included, since this will result in aliasing [7]).

There are a few parameters of interest that needs to be taken into consideration when choosing an ADC for the microphone array, namely Signal-to-Noise ratio which depends on the number of bits, THD + Noise, sampling frequency and the serial audio interface. The serial audio interface is of interest since it is used to transfer uncompressed raw-format audio (Pulse-Code Modulation) to a processing unit. For ease of connection and programming it is desirable to use a standardized communication structure for equipment and ICs, such as I^2S [8], a serial link designed for digital audio. Due to I^2S being a standard for two channels, and the fact that stereo/two-channel ADCs are very common, it seems like a rational choice for interfacing between the ADCs and Digital Signal Processing (DSP) unit.

I^2S: In [8] a comprehensive description of I^2S is provided, though there are a few points that are worth mentioning for a quick introduction to the interface.

I^2S consists of three lines between the sender, such as an ADC, and the receiver. These are *clock SCK*, *word select WS* and *data SD*. *Clock* is the sampling frequency of the signal that is to be transferred, *word select* provides the necessary information for the receiver to determine whether it is channel one or two that is being transferred (e.g. low for channel one and high for channel two) and *data* is the data output, such as a Pulse-Code Modulation (PCM) bit-stream.

When using I^2S as the interface between an ADC and receiver, the ADC may be set to operate as slave or master. When the ADC is set to operate as master, the receiver is provided with the clock from the ADC, while when the ADC is set to operate as slave, the receiver provides the clock to the ADC. This has significance in audio applications, since the provided clock by the receiver when the ADC is set to operate as slave, may not have sufficiently low jitter, resulting in a reduced SNR. This means that when an ADC is connected to e.g. an FPGA, it is necessary to set the ADC as master with a high-precision clock on the master clock input, to ensure a satisfactory clock signal.

Texas Instruments PCM1804-Q1: Texas Instruments has several low-cost, 24-bit Sigma-Delta ADC ICs with good SNR, THD+N and several options regarding sampling and over-sampling frequencies for improved SNR. The PCM1804-Q1 is a Sigma-Delta ADC intended for digital recorders, digital mixers and audio/visual amplifiers for mid-to-high grade professional applications [9], making it a good fit. PCM1804-Q1 has differential inputs (making it resilient to noise), built-in linear-phase anti-aliasing digital-filter as well as a high-pass filter to prevent DC-offset. Thus there is no need for an external low-pass filter prior to the ADC, reducing the number of external components. It has both PCM and Direct Stream Digital (DSD)-output, though DSD is not of interest. It may be used in master or slave-mode, which is practical since all of the ADCs must be synchronized by the same low-jitter clock. The SNR is stated at -111 dB, dynamic range at 112 dB and THD+N at -102 dB.

The PCM1804-Q1 has a low cost of 30 to 60 NOK with great performance, making it suitable for the application of a microphone array.

6.1.5 Clock Fanout Buffer

The ADCs must be provided with a low-jitter master clock in order to ensure that the analog audio signal is sampled at the correct time, ensuring a satisfactory SNR. Since I^2S is a two-channel serial audio interface, each ADC may convert the signal from two microphones. With eleven microphones, this results in five ADCs with two-channel input and six ADCs with only one input. With six ADCs, it is necessary with a clock fanout buffer which can provide at least six clock-outputs, such that every ADC are synchronized by the same clock.

Texas Instruments CDCLVC1310: The CDCLVC10 by Texas Instruments is a high-performance clock buffer with ten clock-outputs and a noise floor of -169dBc/Hz, manufactured for e.g. high-end Audio/Visual equipment [10]. It is equipped with crystal oscillator input supporting frequencies from 8 to 50 MHz. Thus an ADC with a sampling frequency of e.g. 32 kHz and a oversampling factor of 128 results in a system clock frequency of (32000 Hz)(256) = 8.192 MHz, the minimum master clock frequency the PCM1804-Q1 supports. A crystal oscillator, such as SI510 [11] is appropriate. There are four unused clock outputs, hence the microphone array may be further expanded with an additional eight microphones, two per ADC, respectively.

AC-Termination: An important aspect regarding the connection between the clock-output from clock fanout buffer and the clock-input on the ADC, is proper termination. Hence a brief presentation is appropriate.

The importance of proper termination comes especially about when the distance between the fanout buffer and ADC is rather long, as for a microphone array. When the length

$$L > \frac{T_r}{2T_d} \qquad (6)$$

where *L* is the length of the line, T_r is the signal rise time and T_d is the propagation of the line, termination is strictly necessary [12]. This also holds true for high clock frequencies (> 20 MHz).

Improper termination results in an impedance mismatch between the output from the clock fanout buffer, Z_{OUT}, the clock-input on the ADC, Z_{IN}, and the impedance of the line, Z_0, which can severely degrade the clock signal, and thus overall performance [13]. This can be remedied by AC-termination of the transmission line, consisting of a resistor, R_{term}, in series with a capacitor, C_{term}, parallel to Z_{IN}. The value of the resistor should be set equal to the resistance of the line, $R_{term} = Z_0$, and the capacitor may be computed by

$$C_{term} = \frac{3T_r}{Z_0} \qquad (7)$$

where C_{term} is the termination capacitor.

6.1.6 Microphone Array Block Diagram

A block diagram of the theoretical system is shown in Figure 10. Each of the eleven omni-directional microphones are connected to an amplifier prior to an ADC. From each ADC the signal is transferred by the I^2S interface standard to e.g. a microcontroller. The microcontroller will convert the signals from parallel to serial form and frame the signal to Ethernet packets in order to transport the Ethernet frames over a twisted pair cable (cat6). By doing so the signals may be transferred to a computer that will process the signals in order to steer the main-lobe of the microphone array and process the resulting audio-signals. It is worth noting that in order to ensure as low delay as possible throughout the system to meet real-time constraints, it may be necessary to connect the signals from the ADCs to e.g. a FPGA where the signals may be processed. Hence using a microcontroller and a computer is reasonable for testing and developing, though not for a final product.

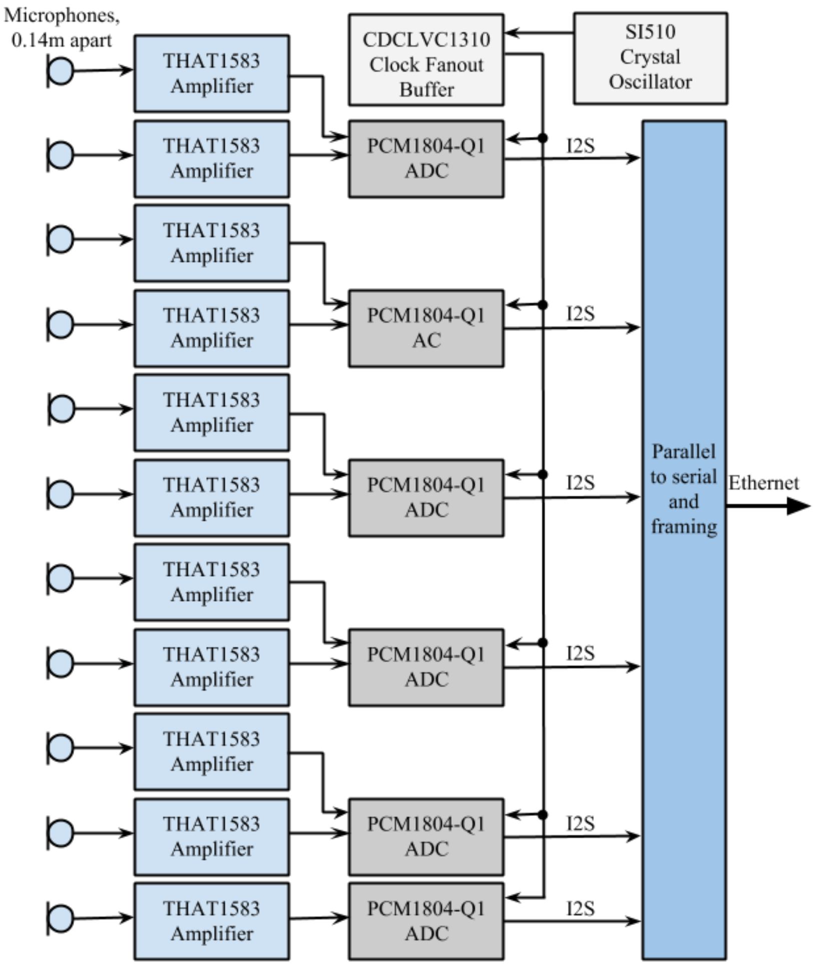


Figure 10: Block diagram of the microphone-array with the appropriate components

6.1.7 Microphone Array Schematic

The schematic for connecting the microphone to the amplifier and ADC can be seen in Appendix I. As stated earlier, each microphone will be connected to an amplifier and ADC mounted as close as possible to the microphone. The reasoning for doing so is to ensure that possible noise contributions will be as low as possible. Hence six PCBs should be manufactured as seen in Figure 11, with two THAT1583 amplifiers, a PCM1804-Q1 ADC, ground plane and separate ground for analog and digital connections. These should then be placed equally spaced in-between two microphones, with as little cable length as possible. The schematic is only presented since an appropriate PCB-design is rather time-consuming, and is deemed appropriate for potential work later on. The schematic design is based on recommended components and connections from the data-sheets of THAT1583, PCM1804-Q1 and CDCLVC1310. Note that only one THAT1583 amplifier is present on the schematic in the Appendix in order to make the schematic easier to read. Before manufacturing it must be two amplifiers present, though this is only a manner of copying the amplifier with its corresponding components and connect the outputs to the right inputs on the ADC.

There are some aspects of the schematic in the Appendix that requires some further explanation which will be presented next.

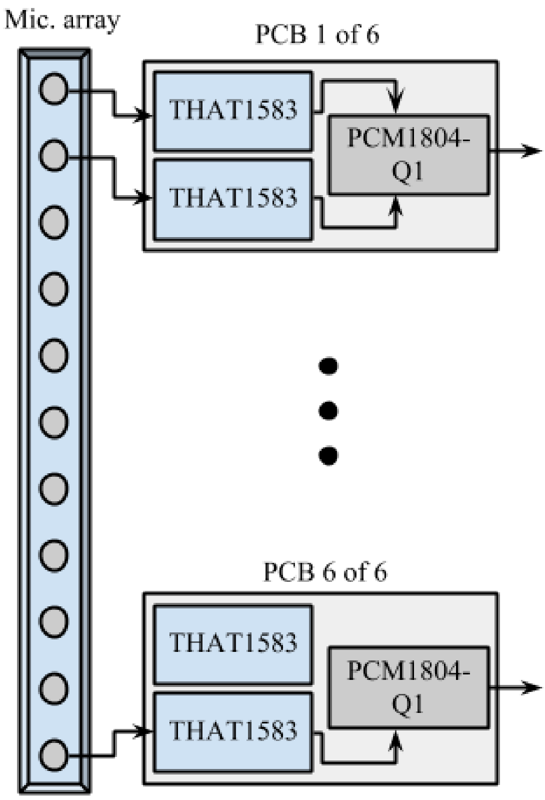


Figure 11: PCB setup illustration

THAT1583 Amplifier

Feedback resistors: The feedback resistors in the Appendix, *R5* and *R6*, should be equal, though a tight tolerance is not necessary. Hence +/- 5% tolerance may be sufficient. The value of the feedback resistors should be as low as possible in order to reduce low-gain noise. It is recommended that they are no lower than 2kΩ [5], hence 2k21Ω as used in the datasheet for noise measurements seems reasonable.

Gain resistor: The gain resistor, *R4*, may be chosen anywhere between 10Ω and 10kΩ, depending on the required amplification of the signal from the microphone. The gain in dB may be computed by

$$Gain = 20log_{10}(1 + \frac{R5+R6}{R4}) \qquad (8)$$

where *R5* and *R6* are the feedback resistors, and *R4* is the gain resistor, respectively.

As mentioned, it will require some field trials in order to choose a reasonable value for the gain resistor, hence a final value will not be stated in this document.

The differential gain of THAT1583 amplifier extends down to DC, and thus the differential DC-offset at the output varies with the gain. It is recommended to prevent this concerning audio recording, since a DC-offset may cause the clipping of the signal or low-frequency distortion. This comes about since the waveform will not be centered on 0V but e.g. 1V. This is easily prevented by inserting a capacitor in series with the gain resistor (*C8* in Appendix I), which will force the DC gain to unity regardless of the differential gain [5]. It is worth noting that the capacitor in series with the gain resistor will create a high-pass filter, with a lower frequency cut-off (-3dB) computed by

$$F_c = \frac{1}{2\pi(R4)(C8)} \qquad (9)$$

where *R4* is the gain resistor and *C8* is the capacitor in series with the gain resistor.

THAT Corp. recommends a 330µF capacitor as seen in the Appendix, resulting in a lower cut-off frequency of 48 Hz at 60 dB gain (*R4* = 10Ω) and 0.048 Hz at 6 dB gain (*R4* = 10kΩ). Considering that frequencies below 300 Hz are not of interest, the capacitor may be given a greater value, e.g. 150µF, resulting in a lower cut-off frequency of 106Hz at 6dB gain and 0.1 Hz at 60dB gain. THAT Corp. recommends a low-voltage electrolytic type capacitor, and 6.3V is usually sufficient [5].

Radio frequency interference: It is important to consider Radio Frequency Interference (RFI) in regards to high-gain amplifiers, since they cause audible interference [14]. The problem is remedied by using two Radio Frequency (RF) bypass capacitors shunting the input connectors to chassis ground, as seen in the Appendix by *C1* and *C2*. Inserting a third bypass capacitor, *C3*, as in Appendix I, further reduces incoming differential RFI and any RFI generated in the amplifier enclosure [14]. By doing so, RF will be stopped from entering the amplifier. Note that *C1* and *C2* must be connected to chassis ground.

PCM1804-Q1

The PCM1804-Q1 is configured by logic high and lows in order to ensure the desired functions and performance of the ADC. These will be explained as well as a few remarks on the components [9].

FMT0/FMT1: The format of the audio that is to be transferred is determined by pin 6 and 7, *FMT0* and *FMT1*, respectively. By setting *FMT0* to logic high and *FMT1* to logic low, the audio data format is set to 24-bit PCM with I^2S serial audio interface.

S/M: The PCM1804-Q1 can be set to operate as either a slave or a master. Setting it to slave-mode makes it dependent on receiving a master clock from the unit it is to transfer the data to, while master-mode lets the ADC provide the receiver with the clock frequency (sampling frequency). Due to this the PCM1804-Q1 is set to operate as master by setting pin 8 to logic low, since the clock provided by e.g. a microcontroller or FPGA has far too much jitter.

OSR0/OSR1/OSR2: The oversampling ratio is determined by pin 9, 10 and 11, respectively. Setting pin 10 and 11 to a logic high and 9 to a logic low, as seen in Appendix I, results in a single rate sampling frequency and an oversampling ratio of 128. This is sufficient when the upper frequency of interest for detecting mosquitoes is about 2 kHz.

BYPASS: in order to prevent DC-offset, the ADC is provided with the choice of a high-pass filter. By setting pin 12 to a logic low, as seen in the Appendix, high-pass mode is active.

SCKI, LRCK, BCK and DATA: As mentioned in the chapter concerning I^2S, the serial audio interface consists of three lines, namely *clock SCK*, *word select WS* and *data SD*, respectively. The same three lines and system clock input can be seen on pin 15, 16 and 17 on the ADC. *LRCK* is the same as *word select WS*, providing information regarding whether channel one or channel two is currently being transferred. *BCK* is the same as *clock SCK*, providing the receiver with the sampling frequency of the data that is transferred. *DATA* is the same as *data SD*, which is the line that transfers the PCM-bit stream. Since the ADC is set as master, *LRCK*, *BCK* and *DATA*, all three lines are outputs to the receiver. This is important since the ADC may then provide the clock (sampling frequency, *BCK*) to the receiver, and the quality of this clock may be chosen by the designer according to the needs. This is why the high-performance, low-jitter CDCLVC1310 with a crystal oscillator is chosen as the master clock.

The ADC can be set to operate at single rate, dual rate and quad rate, meaning sampling frequencies from 32 to 192 kHz. Since the frequency range of interest extends to no more than about 2 kHz, the sampling frequency should be set to 32 kHz and an oversampling ratio of 128, as stated above. In order to achieve this sampling frequency, the Crystal Oscillator connected to the *XIN* and *XOUT*, pin 11 and 12, on the CDCLVC1310 must operate at a frequency of 256(32 kHz) = 8.192 MHz. The output from the CDCLVC1310, e.g. *Y0*, pin 1, is then connected to the system clock input, *SCKI*, pin 18 on the ADC.

Capacitors: Texas Instruments recommends that capacitors *C10*, *C11*, *C12* and *C17* in Appendix I are 0.1μF ceramic, and capacitors *C9* and *C21* are 0.1μF tantalum, respectively. Between the positive and negative inputs for the left channel, *VINL+* and *VINL+*, and right channel, *VINR+* and *VINR+*, pin 4, 5, 24 and 25, Texas Instruments recommends 0.01μF film capacitors, as seen by capacitor *C18* in Appendix I. Note that the right channel has no inputs, though the required connections are the same as for the left channel, as seen in Appendix I.

CDCLVC1310

The CDCLVC1310 is configured by logic high and low in order to ensure the desired functions and performance of the clock fanout buffer. These will be explained as well as a few remarks on the components [10].

IN_SEL0/IN_SEL1: Pin 30 and 29, *IN_SEL0* and *IN_SEL1*, is used to select the desired input. Setting *IN_SEL0* to a logic low and *IN_SEL1* to a logic high enables crystal oscillator (XTAL) input, as seen in Appendix I. As mentioned, the crystal must operate at a frequency of

8.192 MHz in order to achieve a sampling frequency of 32 kHz and oversampling ratio of 128 in each of the ADCs. Note that the inputs that are set to a logic low, as well as those that are not in use (primary and secondary in, pin 13, 14, 27 and 28), are set to ground with pull-down resistors of 150kΩ, as recommended by Texas Instruments.

XIN/XOUT: The crystal oscillator circuit, connected to pin 11 and 12, respectively, should be provided with 18pF parallel-capacitors, as seen by *C5* and *C14* in Appendix I. The capacitors are provided to reduce parts per million (ppm)-error, that is, deviation from the nominal frequency oscillation value. If necessary, a resistor may be inserted in series with *XIN*, pin 11.

Y0…Y9: CDCLVC1310 has a total of 10 clock-outputs. In Appendix I it is seen that only one of the outputs are used, namely *Y0*, pin 1. The rest of the five outputs of interest, *Y1* to *Y5*, will be connected to the remaining PCBs with its ADC. This means that the clock fanout buffer, CDCLVC1310, will be mounted separately from the six PCBs, though it should be as close as practically possible. Note that proper termination must be taken into consideration, as seen by capacitor *C15* and resistor *R8*. The capacitor value must be computed according to (7) and the resistor set equal to the transmission line impedance. This must be performed for each output, *Y0* to *Y9*.

6.1.8 Receiver

The PCM audio-bit streams from each of the ADCs transferred over I^2S, must be received by a unit for either processing or transmission to a processing unit. To ensure that the transfer and processing delay is kept as small as possible it is recommended to transfer the bit streams to an FPGA. It will process the signals in regards to steering the main lobe of the microphone array and determine whether or not a mosquito is present. In regards to development and testing it might be sufficient to use e.g. a microcontroller with Ethernet output that may be connected to a computer by cat6-cable, as seen in Figure 10, and then process the signals in software such as MATLAB. Since the ADC is set to operate in master-mode, each ADC will have three outputs to the receiver. This results in a total of eighteen lines, and the receiver must then be equipped with a minimum of eighteen digital inputs.

6.1.9 Steering the Main Lobe of the Microphone Array

The main lobe of the microphone array must be steered towards a certain angle of interest based on the x- and y-position provided by a camera with a live feed. Hence when the processing software that detects objects within the view of the camera confirms that there is an object of interest, the x- and y-position of this object will be provided to the microphone array processing unit. The microphone array processing unit must then convert the relative x- and y-positions to an angle. This means that the center of the microphone array, microphone nr. 6, must be aligned with the center of the cameras view, alternatively the arrays position must be calibrated digitally relative to the camera.

A microphone array of n-microphones is steered to a certain angle by delaying the microphones relative to each other, this is seen by

$$D'(f,\phi) = (x+a)^n = \sum_{n=-\frac{N-1}{2}}^{\frac{N-1}{2}} a_n(f) e^{jknd[\cos(\phi)-\cos(\phi')]} \qquad (10)$$

where $k = \frac{2\pi}{\lambda}$, the wavenumber, *n*, the number of microphones, *d*, the inter-microphone distance, $a_n(f)$, the frequency dependent amplitude and the exponent is the delay term [15], and

$$\phi' = tan\frac{y}{x} \qquad (11)$$

where *y* is the relative position of the object in meters parallel from the surface of the microphone array, and *x* is the relative position of the object in meters perpendicular to the microphone array, as seen in Figure 12.

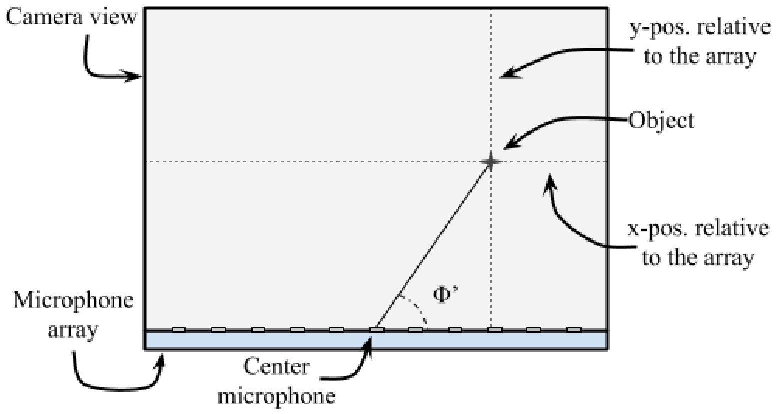


Figure 12: Position of the object relative to the microphone array

6.1.10 Future Contingencies

In order to obtain the sound waves produced by insects for processing, a microphone array has the benefit of suppressing noise contributions from surrounding sound sources, such as humans, animals, vehicles etc. This makes it possible to employ the system in urban, well populated environments, where the sound pressure level of a mosquito is easily masked by other sound sources [3].

The system presented has the benefit of being versatile in the sense that the components are chosen such that there is room for further development, in regards to different microphones, number of microphones, amplification and clock frequency. Hence it is possible to tailor the system to some degree, depending on the operational environment.

For future work there are a few tasks that need to be examined:

- Designing and manufacturing the PCBs in a manner that will result in a noise-resilient circuit.

- When the microphones are mounted in a windowsill or similar surface, it might be necessary to calibrate the microphones due to diffraction when the sound waves are short compared to the size of the surface. Hence this must be taken into consideration when designing the final product.
- The microphone array should be expanded to two or three dimensions in order to increase the effective area of the array. A one dimensional array is only presented due to time-constraints and the complexity of several dimensions.
- Programming an FPGA with at least 18 digital inputs to receive the PCM-bit streams over I^2S. The FPGA must process the received signals in order to steer the main lobe based on the provided x- and y-positions from the camera, and finally, determining if a mosquito is present. If a mosquito is in fact present, the immobilization-module must be alerted.

6.2 Laser Control System

It was concluded that mirror galvanometers were the best choice in terms of steering a lethal laser in order to immobilize mosquitoes [16]. This came about due to their ability to respond very quickly, something that is a necessity for the system to be able to hit the detected targets. The Laser Control System (LCS) is a vital part of the system as a whole, and includes several important elements such as the mirror galvanometers, the laser, and the control circuitry. All of the above is needed to communicate with the computer that is continuously fed by target coordinates obtained by the camera.

6.2.1 System Overview

The LCS consists of mirrors attached to galvanometers, which deflects a laser beam in a specified direction. The purpose of the system is to aim the laser at approved targets through software commands. The system includes a hardware control circuit needed to interface the software module and the galvanometers' control inputs. Figure 13 describes the system in a block diagram.

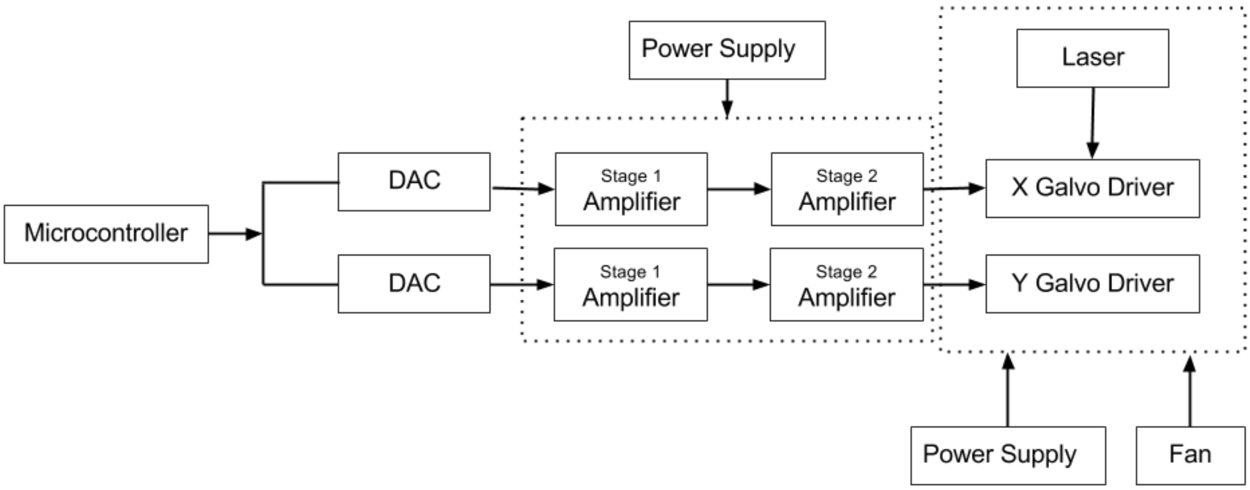


Figure 13: Laser Control System (LCS) block diagram [17]

As seen in the above diagram, a control circuit interfaces the microcontroller and the input signals of the galvanometers. This circuit includes several hardware components: digital to analog converters, operational amplifiers and power supplies. Electrical schematic of the LCS is attached and displays the actual components the prototype consists of and how they are coupled. The upcoming sections include a description of how the system is designed and the components that are used in order for the system to perform the desired functionality. Components are chosen after thorough research, where especially sources of building laser-shows were helpful [17] [18].

6.2.2 Electrical Design

In Appendix II the electrical design for the LCS is attached. This design is developed in CadSoft EAGLE, which is a PCB design software. It illustrates how the system is designed and how the components are coupled on the prototype. The first sheet of the electrical design as seen in Figure 46 includes a module overview, and the following sheets presents wiring diagrams for the applicable modules of the system. The first sheet also includes a LED coupled to a resistor and +5V as an indicator if the power is on or off, furthermore connectors to which the modules are connected, e.g. the fan connectors. It is arranged with inputs located on the left side of the sheet and outputs on the right side.

The module overview includes three modules: Arduino, Thermal, and DACOPAMP. These modules contain wiring diagrams displaying all connections in-between the related components. The wiring for module DACOPAMP is listed in a wiring list, as this module’s interconnections are essential for the actual prototype. Notice that the Arduino module contains a wiring diagram, but no wiring list. The prototype includes an Arduino UNO, which is replaced on the schematic as it contains hardware that is not necessary for the system’s functionality. Future developments of the system may include PCB design, and thus replacing Arduino UNO with only a serial controller and ATmega328P will lead to desired system functionality with minimal board size design. The THERMAL module is not described in this section as a detailed explanation will be presented later on.

The power supply is one of the main components of the system, but is not added in this design. A commercial component is used to power the system, thus there is no need for further wiring explanation. However, similar to the microcontroller, it is intended to make PCB design to develop a power supply featuring desired functionality. A proposed design is seen in Appendix III.

The galvanometers are the most important part of the laser control system. Both the x-galvanometer and y-galvanometer, including mirrors and control board, are added in one set. This set is a commercial galvanometer scanner used mostly in laser shows, but which in addition works well for tracking objects. The galvanometer scanner is not added as a module in the electrical design, since wiring is made internally on the control boards, by the manufacturer and thus out of scope for this project. However, there are some external connectors that needs to be coupled manually and that are present on the schematic. These connections are also included in the wiring list.

Wiring List

The wiring list is an addition to the design to make the couplings easier to trace. It includes wire and connector descriptions and is presented in Table 24. The list is to be used as a tool to do the actual coupling. The wires are equal in size, and the signals are identical on the actual prototype, but may be interchanged after own choice. The wire colors serve no significant effect, except of clarity of signals. Positive power signals are assigned the color red, negative power signals are assigned white wiring, and wires coupled to ground are assigned the color black. This is interchangeable and only a matter of own preference.

Table 24: WL DACOPAMP module

W.N. (1)	**From**			**Wire**			**To**		
	Part	**Pin**	**Connector** (2)	**AWG** (3)	**Color** (4)	**Signal**	**Part**	**Pin**	**Connector** (2)
1	Arduino	D4	Female 1" pin header	24	N/A	D4	LASER	1	Soldered
2	Arduino	D9	Female 1" pin header	24	N/A	~LDAC	MCP4922	8	Soldered
3	Arduino	D10	Female 1" pin header	24	N/A	~CS	MCP4923	3	Soldered
4	Arduino	D11	Female 1" pin header	24	N/A	SDI	MCP4924	5	Soldered
5	Arduino	D13	Female 1" pin header	24	N/A	SCK	MCP4925	4	Soldered
6	Arduino	5V	Female 1" pin header	24	RD	+5V	MCP4926	1	Soldered
7				24	RD	+5V	MCP4922	13	Soldered
8				24	RD	+5V	MCP4922	9	Soldered
9				24	RD	+5V	R3	1	Soldered
10				24	RD	+5V	R5	1	Soldered
11	C1	1	Soldered	24	N/A		MCP4922	1	Soldered
12	C1	2	Soldered	24	BK	GND	Power Supply	2	Screw Terminals
13	MCP4922	14	Soldered	24	N/A	VOUTA	TL082CN	3	Soldered
14	MCP4922	12	Soldered	24	BK	GND	Power Supply	2	Screw Terminals
15	MCP4922	10	Soldered	24	N/A	VOUTB	TL082CN	5	Soldered
16	R3	2	Soldered	24	N/A		TL082CN	2	Soldered
17	R4	1	Soldered	24	N/A		TL082CN	1	Soldered
18	R4	2	Soldered	24	N/A		TL082CN	2	Soldered
19	TL082CN	4	Soldered	24	WH	-15V	Power Supply	1	Screw Terminals

20	C3	1	Soldered	24	N/A		TL082CN	4	Soldered
21	C3	2	Soldered	24	N/A	GND	Power Supply	2	Screw Terminals
22	R5	2	Soldered	24	N/A		TL082CN	6	Soldered
23	R6	1	Soldered	24	N/A		TL082CN	6	Soldered
24	R6	2	Soldered	24	N/A		TL082CN	7	Soldered
25	TL082CN	8	Soldered	24	RD	+15V	Power Supply	3	Screw Terminals
26	C2	1	Soldered	24	N/A		TL082CN	8	Soldered
27	C2	2	Soldered	24	N/A	GND	Power Supply	2	Screw Terminals
28	TL082CN	1	Soldered	24	N/A	XOUT	TL048ACN	3	Soldered
29		1		24	N/A	XOUT	R7	1	Soldered
30	TL082CN	7	Soldered	24	N/A	YOUT	TL084ACN	10	Soldered
31		7		24	N/A	YOUT	R9	1	Soldered
32	TL084ACN	1	Soldered	24	N/A		TL084ACN	2	Soldered
33		1	Soldered	24	N/A	X+	Galvo Scanner		JST XH-3
34	TL084ACN	4	Soldered	24	RD	+15V	Power Supply	3	Screw Terminals
35	C5	1	Soldered	24	N/A		TL084ACN	4	Soldered
36	C5	2	Soldered	24	N/A	GND	Power Supply	2	Screw Terminals
37	TL084ACN	5	Soldered	24	BK	GND	Power Supply	2	Screw Terminals
38	R7	2	Soldered	24	N/A		TL084ACN	6	Soldered
39	R8	1	Soldered	24	N/A		R7	2	Soldered
40	R8	2	Soldered	24	N/A		TL084ACN	7	Soldered
41	TL084ACN	7	Soldered	24	N/A	X-	Galvo Scanner		JST XH-3
42	TL084ACN	8	Soldered	24	N/A		TL084ACN	9	Soldered
43	TL084ACN	8	Soldered	24	N/A	Y-	Galvo Scanner		JST XH-3
44	TL084ACN	11	Soldered	24	WH	-15V	Power Supply	1	Screw Terminals
45	C4	1	Soldered	24	N/A		TL084ACN	11	Soldered
46	C4	2	Soldered	24	N/A	GND	Power Supply	2	Screw Terminals
47	TL084ACN	12	Soldered	24	BK	GND	Power Supply	2	Screw Terminals
48	R9	2	Soldered	24	N/A		TL084ACN	13	Soldered

49		2	Soldered	24	N/A		R10	2	Soldered
50	R10	1	Soldered	24	N/A		TL084ACN	14	Soldered
51	TL084ACN	14	Soldered	24	N/A	Y+	Galvo Scanner		JST XH-3
52		1	Fan Connector	26	BK	GND	Power Supply	2	Screw Terminals
53	Fan1	2	Fan Connector	26	BK	+15V	Power Supply	2	Screw Terminals
54		3	Fan Connector	26	BK				
55		1	Fan Connector	26	BK	GND	Power Supply	2	Screw Terminals
56	Fan2	2	Fan Connector	26	BK	+15V	Power Supply	2	Screw Terminals
57		3	Fan Connector	26	BK				
58	Laser	2	Soldered	24	BK	GND	Power Supply	2	Screw Terminals

(1) W.N= Wiring Number

(2) Connector describes the connection between the wire and the related component with no reference to gender.

(3) AWG = American Wire Gauge

(4) Colors are coded: RD = Red, BK = Black, WH = White, N/A = not applicable

6.2.3 PCB Design

Laser Control System

For future developments of the system, a PCB design is created out of the schematics, using the EAGLE editor. The created board has as much as 4 layers. Even though this means the board probably will be more expensive to manufacture, it is a cleaner design and a more appropriate way to do it. The layer numbered 1 and 16 are signal layers, layer 2 is a ground layer and 15 is a +5V layer. There is via between each layer except layer 2 and 15, because there is no need for any connections between the power and the ground layer. Figure 14 illustrates the layer system.

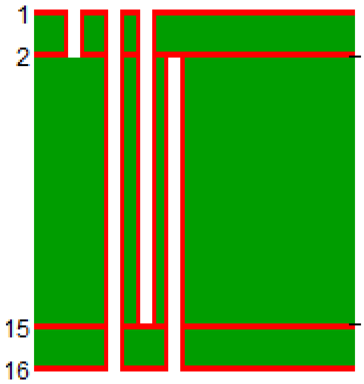


Figure 14: PCB layer system

The system should be as small as possible, thus a compact design is desirable. However, wide tracks are used in order to have a security margin in case of unexpected behavior. This results in a track size of signals of 25 mils (thousands of an inch) and 12.5 mils for necking, 50 mils for current tracks with 20 mils for necking, and if the component pads are even smaller the same width as the pad is applied. It is assumed that the track thickness is 1oz as this is a common value. This can be changed to a greater value if it is desired to have a smaller track width.

The board is setup of laying out the different groups with components together and making the connections in groups. The USB plug and the USB controller were laid out first, continuing with the ATmega328 microcontroller and the components that are coming with it. The DAC and op-amps were laid out last. Figure 15 illustrates the preliminary developed PCB design. This design is not yet manufactured, as time did not allow it.

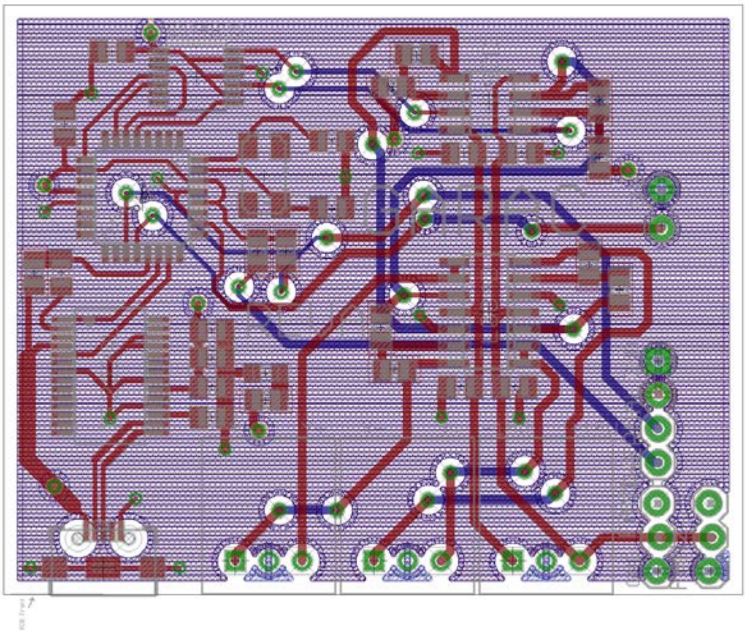


Figure 15: Preliminary PCB design

Power Supply

A proposed power-supply design is made in EAGLE, consisting of transformer, rectifier, filter, and regulator. This design is found in Appendix III. As the system requires a source of constant dc, a power supply converting 230V, 50 Hz ac voltage from wall outlet is needed. The transformer changes ac voltage based on the turns-ratio, which in this case is stepped down. The full-wave rectifier converts the ac input voltage to a pulsating dc voltage whereas the following filter eliminates fluctuations and produces a relatively smooth dc voltage. The regulator is added to maintain a constant dc voltage for variations in the input voltage or load [19]. Components for all measures are chosen after desired output voltages and currents: +15V/833mA, -15V/833mA. The filter capacitors are chosen after specifications of the low-dropout regulator (LDO): the first input capacitor is an electrolytic aluminum type capacitor of 470µF, second input capacitor is a ceramic capacitor of 100nF. The electrolyte has a large value and reduces the ripple to a reasonable level and a smaller value ceramic capacitor is as well needed in order to filter high frequency noises from the AC voltage [20]. The same method applies on the output filter. Note that a satisfactory result can only be obtained by practical measurements. Because this proposal is achieved by theoretical analysis it is not an ideal solution and needs further testing. The preliminary PCB design is illustrated in Figure 16.

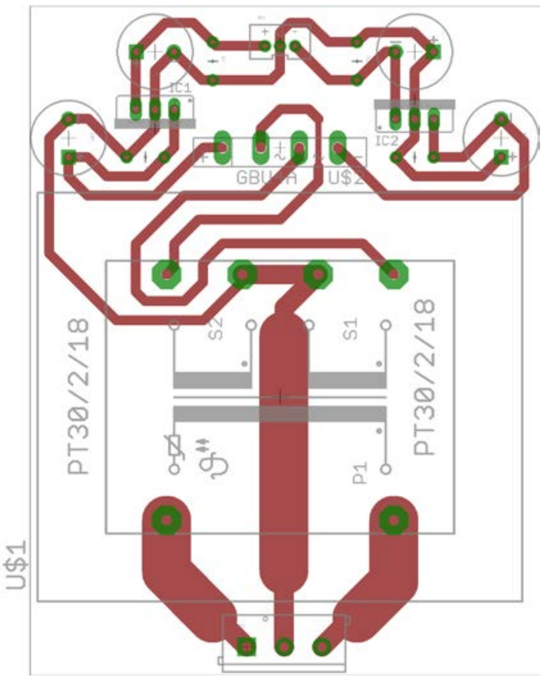


Figure 16: Power supply PCB design

6.2.4 Hardware Components

The following sections concerns the actual hardware used in the prototype.

Microcontroller

The microcontroller is an important part of the laser control system. The software running on the computer will direct the laser to the desired coordinates of the target obtained by the camera. The microcontroller communicates further with the DAC by deploying SPI (serial peripheral interface), which is a short distance communication protocol for serial full duplex data transmission.

The microcontroller used in this system is ATmega328 on Arduino Uno. Specification regarding the microcontroller board and the ATmega328 are presented in Table 25 [21]. Connections are illustrated on the electrical design, Appendix II, and on the wiring list, Table 24. Not all I/O pins are used in the configuration, since they are not required for the system features, as shown in the schematic. The necessary features are thus listed in Table 26.

Table 25: Arduino UNO specifications

Feature	Description
Microcontroller	ATmega328
Operating Voltage	5V
Digital I/O Pins	14 (6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40mA
DC Current for 3.3V Pin	50mA
Flash Memory	32KB
SRAM	2KB
EEPROM	1KB
Clock Speed	16MHz
Connector	USB 2.0
Dimensions	68.58×53.34 mm (1)

(1) Dimensions describes length and width respectively. USB connector and power jack may be extended beyond the former dimensions.

Table 26: Arduino UNO pin map

Pin	Function
5V	Supply voltage for DAC and reference voltage for amplifiers.
D4	On/off switch connected to laser.
D9	Simultaneous updates for all outputs connected to $\overline{LDAC}$ on DAC.
D10	SS (Slave Select) $\overline{CS}$ connected to DAC, which requires an active –low signal to enable serial clock and data functions.
D11	Serial Data Input (SDI) connected to the DAC. Data on this pin is clocked into the CLK pin. The most significant bit is loaded first.
D13	SCK, the SPI compatible serial data input connected to the DAC.

Microcontroller Communication and Power

Communication and power goes from the computer to the microcontroller through a USB cable; USB type A to mini USB type B. The USB delivers power to run the Arduino and a variety of components in the system.

6.2.5 Galvanometer Scanner

A RGB-SCAN20 galvanometer scanner is the main driver for the system, as seen in Figure 17. It runs the mirrors (x and y) which steers the laser in the obtained trajectory, and is thus an essential part of the system. It is supplied with a ±15V power supply for it to be able to run. A control signal is also required to perform operations, and this is obtained by amplifier circuits coupled to the scanner's control boards through a digital to analog converter. The speed is rated to 20,000 points per second with an optical angle of ±20º. Further information regarding the scanner is presented in the Galvanometer Scanner Technical Document [22]. The galvanometer scanner is interchangeable, and can be replaced by other commercial or non-commercial products of own preference. Control input signals may be unique depending on the device, which might lead to different implementations of creating the required control circuit. In Table 27 the inputs required to drive the scanner are presented. Internal connections are out of scope for this text.

Figure 17: Physical galvanometer setup [22]

Table 27: Input connectors

Pin	Function
Power Input	
3	+15V Supply voltage for x and y drivers
2	GND
1	-15V Supply voltage for x and y drivers
Signal Input	
3	Control + signal of -5V~ +5V
2	GND
1	Control - signal of -5V~ +5V

6.2.6 Digital to Analog Converter

The system requires a device that is able to convert binary numbers into voltage levels in order to control the galvanometer scanner. A 2-channel, 12-bit Digital-to-Analog Converter (DAC) is used for this purpose: MCP4922. This is a device with low-power, low DNL (differential non-linearity) and 2× buffered output with SPI interface. With 12 bits, the DAC is able to map numbers from 0 to 4095 into a voltage range of 0-5V. This device provides high accuracy and low noise performances, which is important for the functionality of this system. The main specifications of the DAC are presented in Table 28; further specifications regarding the DAC are presented in the datasheet [23].The device is selected in regards of the chosen scanner set and is interchangeable as there are many DAC ICs on the market. Table 29 presents an overview of the DACs pin map.

Table 28: DAC specifications

Feature	Description
Part nr./name	MCP4922
Power Input	2.7V-5.5V
Package	DIL-14
Connector	14 pin
Bus	SPI
Resolution	12-bit
Design	2-channels
Dimensions	40×15×10 mm
Weight	2g
Operational temp. range	-40 to +125ºC
Manufacturer	Microchip
Vendor	Elfa Distrelec

Table 29: Pin map DAC MCP4922

Pin	Function
1	VDD +5V with decoupling capacitor.
3	SS (Slave Select) $\overline{CS}$ on DAC, which requires an active –low signal to enable serial clock and data functions.
4	SCK, the SPI compatible serial data input.
5	Serial Data Input (SDI). Data on this pin is clocked into the CLK pin. The most significant bit is loaded first.
8	$\overline{LDAC}$ Simultaneous updates for all outputs.
9	$\overline{SHDN}$ Hardware shutdown input +5V.
10	Voltage output cannel B to operational amplifier TL082CN.
11	Voltage reference input B. Analog signal utilized to set the reference signal on the string DAC. Equals +5V with decoupling capacitor.
12	Analog ground pin, GND.
13	Voltage reference input A. Analog signal utilized to set the reference signal on the string DAC. Equals +5V with decoupling capacitor.
14	Voltage output cannel B to operational amplifier TL082CN.

6.2.7 Operational Amplifiers

Operational amplifiers are used to rescale the voltage output from the DAC from 0-5V to control signals for the galvanometer drivers, with voltage ranging from -5V to +5V for both input control signals. This amplifier circuit includes six operational amplifiers with a variety of arrangements to form the desired output signals [17].

Amplifier Circuit

In order to split the signal from the DAC into four separate signals, two level-shifting circuit using op-amps is implemented in the first stage. Figure 18 illustrates this level-shifter.

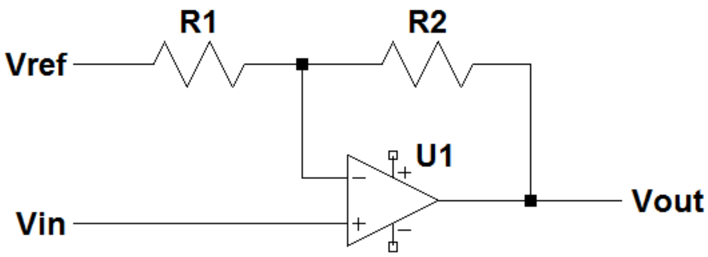


Figure 18: Level-shifter using op-amp

The output voltage is calculated using the following equation [24]:

$$V_{OUT} = \left(1 + \frac{R_2}{R_1}\right) V_{IN} - (\frac{R_2}{R_1}) V_{REF} \qquad (13)$$

The reference voltage is set to a stable 5V throughout the operation and both resistors are equal, while the input voltage varies from 0-5V which is the DAC output. The minimum voltage will be -5V and the maximum output voltage will be +5V with this alignment. Two op-amps are configured as level-shifters, one for each direction. Continuing, another two op-amps for each direction is added in stage two. This configuration allows the signal to be split into four separate signal outputs to be coupled directly to the control signal inputs of both galvanometer drivers. In stage two, one op-amp is coupled as a voltage follower, while the other is coupled as an inverter for both x- and y-direction; see Figure 19 and Figure 20 respectively, with associated equations.

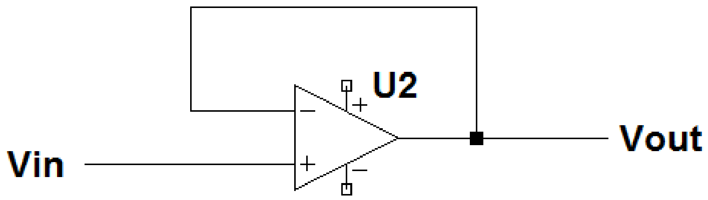


Figure 19: Voltage follower

$$V_{IN} = V_{OUT} \quad (14)$$

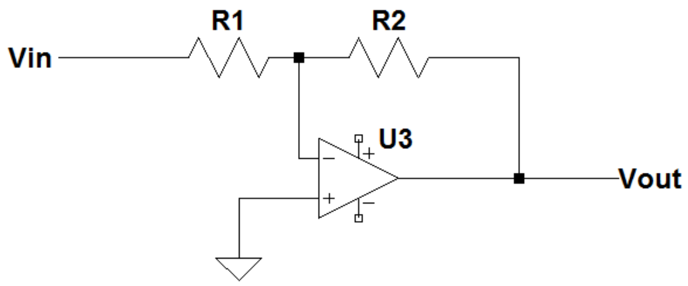


Figure 20: Inverting op-amp

$$V_{OUT} = -\frac{R_2}{R_1} V_{IN} \qquad (15)$$

This results in a total of six op-amp circuits for amplifier stage one and two; two level-shifter op-amp circuit for stage one, and two inverting op-amps and two voltage followers for stage two. The design for the whole control circuit showing the amplifier stages are presented in Figure 21. The circuit is simulated using LT Spice and following output voltages are shown in Figure 22. Notice that ideal op-amps are used in this simulation and that signals may differ in practice.

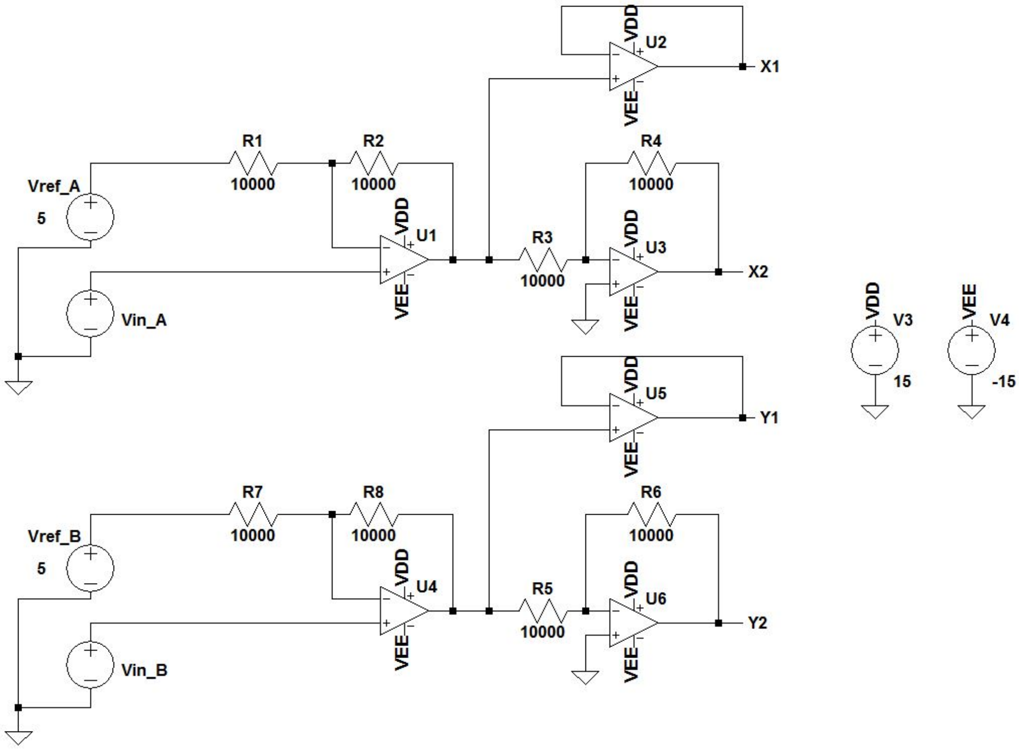


Figure 21: Amplifier circuit

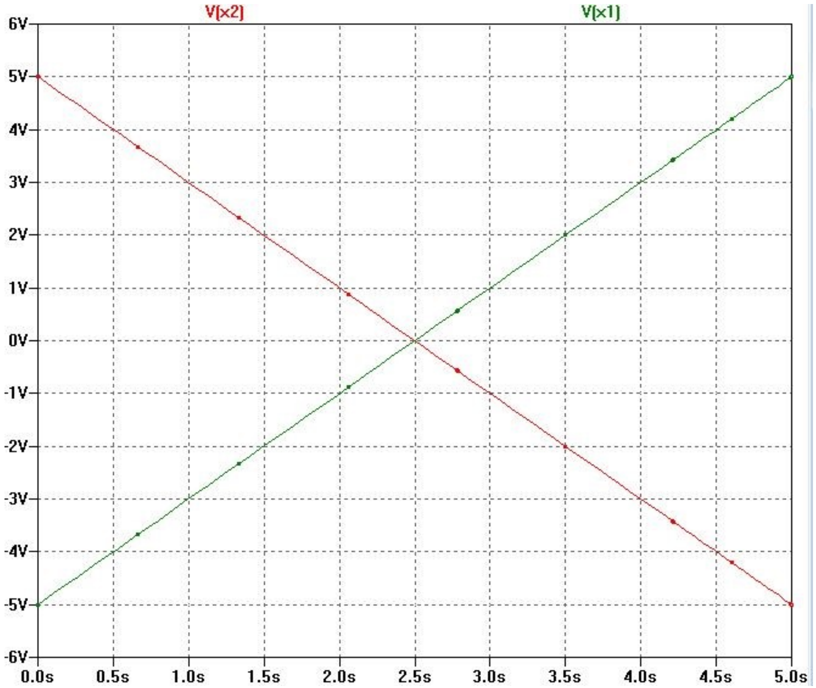


Figure 22: Output voltages

The above simulation shows the output voltages on the x1 and x2 nodes. The same output is obtained on the y1 and y2 nodes. This simulation is run with input voltage varying from 0V to

5V, reference voltage of 5V, and 10kΩ resistors. The two output signals increase/decrease with the same value of voltage for the given time, and correspond with the desired galvanometer control signals.

The components used for this purpose were two operational amplifier ICs: TL082CN and TL084ACN, which includes two and four op-amps respectively. TL082CN is a general purpose JFET dual operational amplifier with wide common-mode and differential voltage range. TL084ACN is a JFET quad operational amplifier with similar specifications as TL082CN. Both devices feature high slew-rates and low input bias and offset current [25], [26]. Table 30 presents specifications, Table 31 and Table 32 presents the pin maps of both amplifiers.

Table 30: Op-amps specification

Feature	Description	
Part nr./name	TL082CN	TL084ACN
Power Input	±4 - ±15V	±3.5 - ±18V
Package	DIL-8	DIL-14
Connector	8 pin	14 pin
Bandwidth	4 Mhz	3 Mhz
Slew Rate	16 V/µs	13 V/µs
Design	Dual	Quad
Dimensions	10×10×10mm	20×8×8mm
Weight	0.45 g	1 g
Operational temp. range	0 - 70ºC	0 - 70ºC
Manufacturer	ST Microelectronics	Texas Instruments
Vendor	Elfa Distrelec	Elfa Distrelec

Table 31: TL082CN pin map

Pin	Signal	Function
1	1OUT	Forms an level-shifter with pin 2 and 3, Vout for x signals (xout)
2	1IN-	Coupled as an level-shifter with voltage reference +5V
3	1IN+	Input voltage reference A +5V
4	VCC-	VCC-, -15V with decoupling capacitor
5	2IN+	Input voltage reference B +5V
6	2IN-	Coupled as a level-shifter with pin 5 and 7 with voltage reference +5V
7	2OUT	Forms a level-shifter with pin 6 and 7, Vout for y signals (yout)
8	VCC+	VCC+, +15V with decoupling capacitor

Table 32: TL084ACN pin map

Pin	Signal	Function
1	1OUT	Forms a voltage follower with pin 2 and 3, output control signal x+
2	1IN-	Forms a voltage follower with pin 1 and 3, coupled to pin 1
3	1IN+	Forms a voltage follower with pin 1 and 2, input signal xout
4	VCC+	VCC+, +15V with decoupling capacitor
5	2IN+	Forms an inverter with pin 6 and 7, coupled to GND
6	2IN-	Forms an inverter with pin 5 and 7, input signal xout
7	2OUT	Forms an inverter with pin 5 and 6, output control signal x-
8	3OUT	Forms a voltage follower with pin 9 and 10, output control signal y+
9	3IN-	Forms a voltage follower with pin 8 and 10, coupled to pin 8
10	3IN+	Forms a voltage follower with pin 8 and 9, input signal yout
11	VCC-	VCC-, -15V with decoupling capacitor
12	4IN+	Forms an inverter with pin 13 and 14, coupled to GND
13	4IN-	Forms an inverter with pin 12 and 14, input signal yout
14	4OUT	Forms an inverter with pin 12 and 13, output control signal y-

6.2.8 Laser

The laser is vital for the system capability, as it is the lethal component of the system, but due to regulations a lethal laser is not used in this context [27]. For illustration purposes it is important that the used laser is visible, and at the same time not harmful to people, animals, or other nearby objects. The laser needs interfaces that match the other components of the system, especially with regards to turning on/off by commands.

The laser used in the prototype of this project is a low-powered, generic laser pen. It has a wavelength of 630-660nm, which produces a clear, red color. The laser pen is disassembled in order to be used in the required configuration. The maximum output is less than 1mW, which is within the Norwegian laser regulations. The laser is interchangeable as it is a generic laser module. Table 33 presents the laser pin map.

Table 33: Laser pin map

Pin	Function
1	On/off switch signal from computer, signal D4, +5V
2	GND

Figure 23 is added for illustration purposes only. It does not represent the actual device, but it has identical design. The laser pointer was disassembled and the laser module was modified such that it could be used as desired. The push button in the center of the LD driver was bypassed on the actual device in order to control the laser from the microcontroller. The battery was also removed for the same purpose. On the right, the actual coupling is shown with wires and signal names.

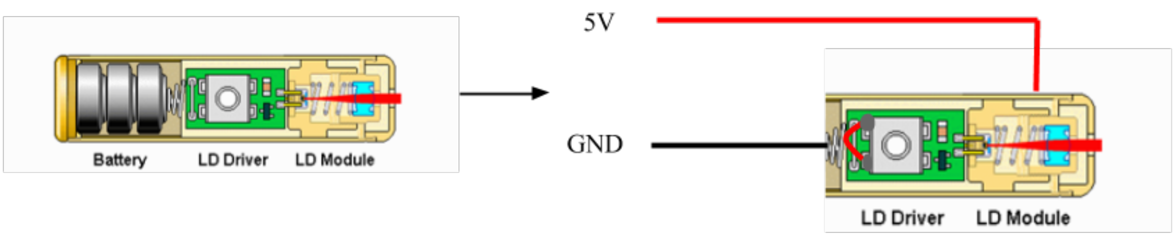


Figure 23: Laser coupling [28]

After extensive research, it was clear that to kill one mosquito per second, a 50-100mJ laser would be needed with an effect of 100mW [29]. To kill five mosquitoes per second a 500mW laser is needed. It is not guaranteed that all of the 500mW will hit the mosquito fully; some of the beam might hit the wall. This is because the calibration has to be extremely accurate to hit only the mosquito, and MDS have neither the time nor the knowledge to accomplish this. Therefore some of the 500mW might be "lost" and a 500mW laser could possibly kill less than 5 mosquitoes per second. A laser that has an effect of 500mW is a class 3B laser. It is necessary to apply for authorization from the State Radiation Protection to use a laser with that amount of effect [30]. A 500mW laser is strong enough to set fire to solids. Therefore a fireproof board of some sort is needed where the laser beam hits the wall. The board has to be non-reflective. The beam diameter should be up to 5 mm, more than that is not necessary. The color of the beam is irrelevant as long as it is visible. That means that the laser beam wavelength has to be between 400nm to 700nm. The wavelength should be a continuous wave due to the fact that a large concentration of heat is needed to burn the mosquitoes as fast as possible [31]. The laser would need a 110-240V input of 50-60 Hz. Which type of laser to use is irrelevant as long as it contains the characteristics that are needed for a laser for MDS use. An example for a laser that has the given characteristics is called L404P400M [32].

6.2.9 Fan

There are components in the laser control system that can be exposed to overheating. In order to prevent this, two fans are coupled to the configuration. The fans should preferably run on the same power supply as the other components, and have sufficient effect in terms of cooling the exposed components. The fans used for this purpose were regular computer fans running on 15V/1.0A. They are coupled to the power supply and are constantly running when the system is on. The fans are optional and interchangeable as to own preference in regards to amount of heat dissipated in the system. A pin map for the fans is presented in Table 34. Detailed specifications are presented in Table 35 [33].

Table 34: Fan pin map (each fan)

Pin	Function
1	GND
2	Input voltage supply +15V
3	Unconnected

Table 35: Fan specification

Feature	Description
Part nr./name	Case Fan
Power Input	15V/1A
Casing	Plastic
Dimensions	120×120×21 mm
Connector	3 pin
Quantity	2
Manufacturer	Cooler Master

6.2.10 Power Supply

The Laser Control System requires a supply voltage of +/-15V to run a majority of all the components. It is important that the power supply's connectors are appropriate for the environment the system is designed for, and that it is enclosed in a safe manner to prevent any accidents. The power supply used for this system is a power supply of 15V/1.0A, -15V/0.5A. It is coupled directly to a standard Norwegian AC socket. Detailed specifications are presented in Table 36 and a pin map is presented in Table 37 [34]. This power supply was included in the galvanometer scanner set, but is interchangeable and can be procured by other means. Wires and connectors for -15V, GND, and +15V (JST connectors) were included in the galvanometer scanner set. To connect the ports of FG, N, and L a regular CEE7/7 to IEC320C13 power cord was applied.

Table 36: Power supply specifications

Feature	Description
Part nr./name	KHD15-15
Power Input	100-240VAC/0.5A
Input Frequency	47 ~ 63Hz
Output	+15V/1.0A, -15V/0.5A
Casing	Metal case / aluminum base
Connector	6 ports
Operating temp. range	10 ~ + 50 ℃ @ 100%, 60 ℃ @ 60% load
Efficiency	78 %
Dimensions	74×68×27 mm
Weight	0.15 kg
Brand	Kaihui

Table 37: Power supply pin map

Pin	Function
1	-15V
2	GND
3	+15V

6.2.11 Breadboard

The DAC, TL082CN, TL084ACN, resistors, and connection wires are placed on a solderable, small-sized breadboard. This is optional, but may provide less noise, which is important for the signals in the system. Detail specifications regarding this breadboard are presented in Table 38 [35].

Table 38: Breadboard specifications

Feature		Description
Part nr./name		Adafruit Perma-Proto ½ Sized Breadboard
Connection Holes		30 rows of double 5-hole rows
Power Connections		4 power rails with +/- markings
Dimensions	Board	82×55×1.6 mm
	Connection Holes	1.2 mm (diameter)
	Mounting Holes	2×3.2 mm (diameter)

6.2.12 Resistors

Resistors are used in the control circuit to reduce the current and for stabilization means. Detailed specifications are added in Table 39 with a pictorial representation in Figure 24 [36]. For the laser control system all resistors are 10kΩ.

Table 39: Resistor specifications

Feature	Description
Part nr./name	Metal Oxide Power Resistors
Series	282
Case Size	Small
Watts	2W
Quantity	8
Value	10kΩ
Operational Temp. range	-55 ºC ~ +235 ºC
Tolerance	±5%

Dimensions	12×5×25 mm(1)
Manufacturer	Xicon

(1) Dimensions are measured in length (of resistor head) × diameter × length of wires ±3 mm, see Figure 11 for the Metal Oxide Power Resistors.

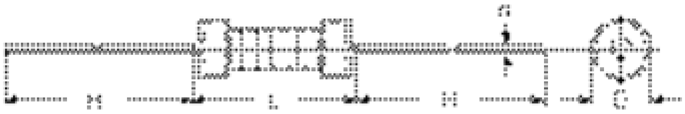


Figure 24: Xicon resistor [36]

6.2.13 Wires and Connectors

An overview of all connectors and wires are added in the wiring list, Table 24. Consistently, wires of size 26 and 24 according to American Wire Gauge and Arduino connectors on jumper wires, with both female and male connectors are applied. The galvanometer scanner set contained its own connectors of the type JST XH-3 [37] which are coupled to header male strips on opposite ends [38], [39]. Wires and connectors are interchangeable and may vary in size.

6.3 Thermal Sensor

In order to prevent the laser from causing harm to humans and animals, a thermal sensor is implemented as an inadvertent prevention damage system.

The OMRON D6T MEMS thermal sensor is a high sensitivity sensor that uses unique MEMS and ASIC technology to achieve a high signal to noise ratio (SNR). There are two different sensors that OMRON manufactures [40], the D6T-44L-06 and the D6T-8L-06, hereby referred to as 44L and 8L. The D6T MEMS use infrared thermal sensors in arrays, with each entry being a pixel. The 44L has a 4 x 4 array and the 8L has a 1 x 8 array.

D6T thermal sensor, as seen in Figure 25, can detect human presence by detecting body heat from humans, as well as animals. The significance of OMRON D6T is that it does not rely on motion to detect humans or animals, as it detects different temperatures within each of its pixels. The sensor element-arrays are connected to an amplifier, which then talks to a digital processor which sends data over to the microcontroller through I^2C.

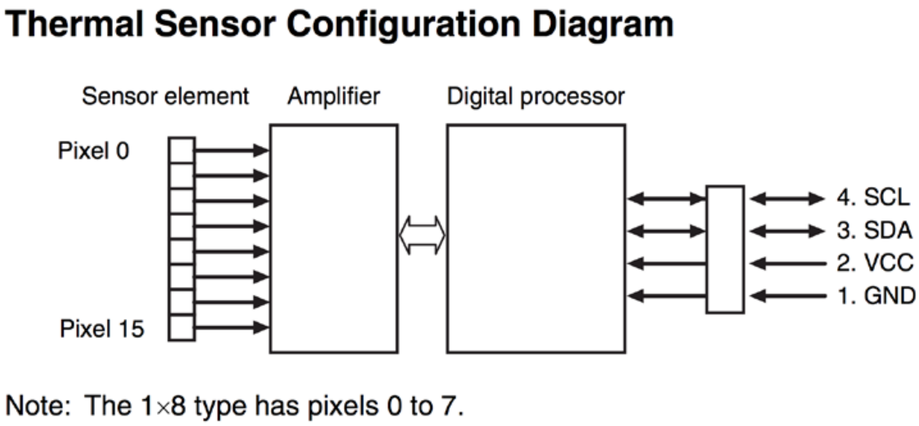


Figure 25: Thermal sensor configuration diagram [41]

6.3.1 Thermal Sensor vs PIR Sensor

Omron D6T is used in the system as a human presence detector, instead of a conventional Passive Infrared Sensor (PIR). This is due to the fact that PIR sensors have certain flaws that Omron D6T sensor can solve. One of the shortcomings of a PIR sensor is that it cannot detect stationary people, because the sensor only detects the signal from people in motion, while Omron D6T will keep detecting the far-infrared ray of an object. A PIR sensor also has a delay of approximately 2 seconds to 9 minutes [42]. This problem may be solved by changing one of the internal resistors. The IC doing all the work in the PIR sensor is the BISS0001 Motion Detector [43], and via the timing diagrams in the data sheet it is seen that the master output, called VO, goes high for a period called T_X and goes low for a period called T_i [44]. It can be seen that when Tx equals 0, Ti will approximately equal 5 seconds. By changing out one of the resistors it is possible to shorten Ti, hence desoldering the old resistor, and soldering a smaller resistor in place will solve this issue. This results in a much lower Ti time, but the sensor will become unstable, and hence the PIR sensor is not usable and the OMRON D6T is deemed appropriate to use.

6.3.2 System Overview

Structure

The OMRON D6T is a high precision sensor with a silicon cap to collect far-infrared rays. It consists of a MEMS thermopile sensor with a dedicated analog circuit, and a logic circuit for converting data to digital temperature values and emitting through I^2C. The connector is a special connection made by JST (Japan Solderless Terminals) [40]. On OMRON D6T there is a female housing called SM04B-GHS-TB, as seen in Figure 26. To connect to the board it is necessary to buy the male equivalent housing and a contact called GHR-04V-S, as seen in Figure 27. The cables used to connect the sensor to the microcontroller must be coated with SSHL-002T-P0.2 using a SSHL hand crimp tool, Figure 28, [40].

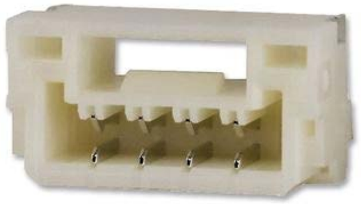


Figure 26: GHR-04V-S [40]

Figure 27: SM04B-GHS-TB [40]

Figure 28: SSHL-002T-P0.2 [40]

44L vs 8L

The 44L, as seen in Figure 29, has an X and Y view angle of 44.2 and 45.7 degrees and this sensor has 16 different pixels. While the 8L, as seen in Figure 30, has 8 sensors in the same row, its view angles are 62.8 degrees in x-direction and 6 degrees in the y-direction.

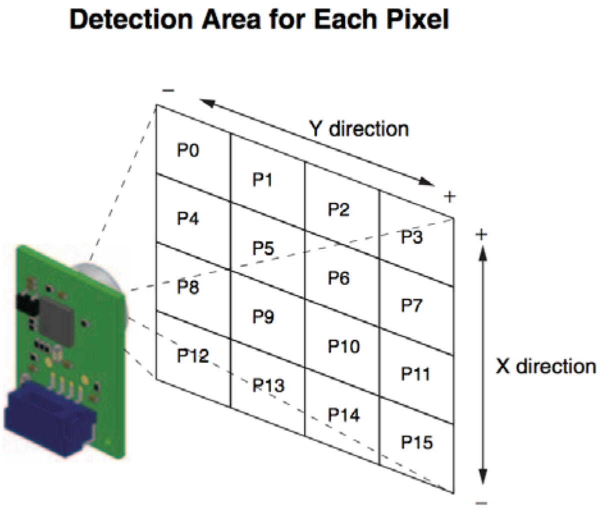


Figure 29: 44L [41]

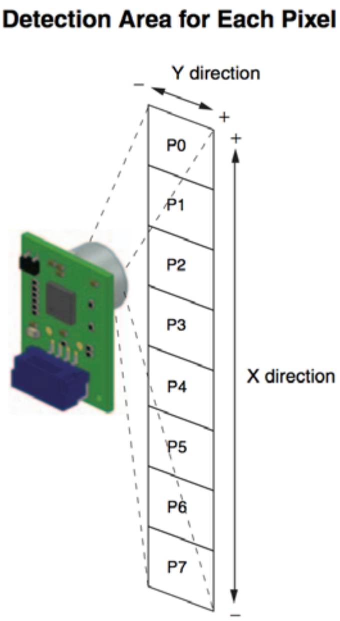


Figure 30: 8L [41]

I²C

To communicate with the microcontroller the sensor sends data through the two-wire protocol called I²C.

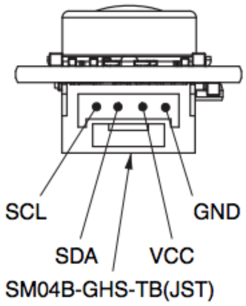


Figure 31: I²C Connector [45]

The I²C address of the sensor is 0x0a and the start command is 0x4c. To initiate communication the start command has to be sent from the microcontroller. When the sensor receives the start command it will transmit thermal data until it is reset.

6.3.3 Operating Principle

Omron D6T sensor works on the Seebeck effect [46]. Every object emits radiated heat, and the silicon cap on Omron D6T collects their far-infrared rays into the thermopile sensor in the module. The radiated heat produces electromotive force on the thermopile sensor. The analog circuit inside then calculates the temperature by using the electromotive force created and saves the measured value inside the logical circuit, which then sends the value out through the I²C bus, onto the microcontroller. Since OMRON uses a vacuum-sealed design sensor, it seals the thermopile in a vacuum preventing the heat created from the rays to disperse into the air, thus increasing the sensitivity of the sensor [41], as seen in Figure 32.

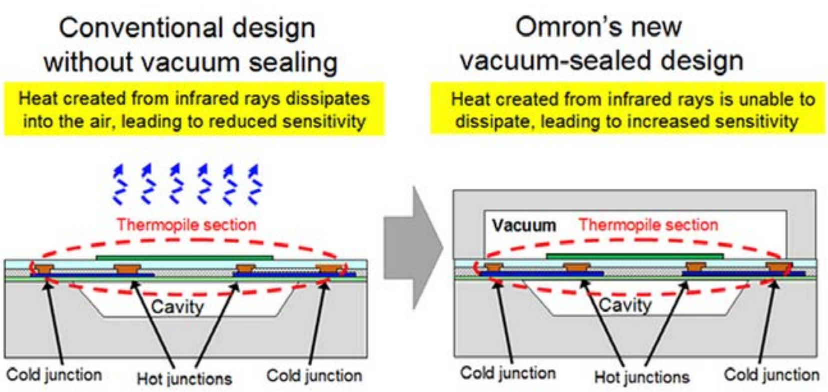


Figure 32: Conventional vs. Omrons new vacuum-sealed design [41]

Since the system is connected to the 8L, the sensor has 8 pixels and they are shown in Figure 33.

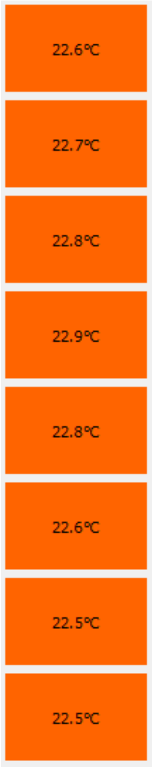


Figure 33: Thermal data GUI QT-application

6.3.4 Interface

To get reliable I^2C connection the SDA and SCL needs to be connected to a 4.7kΩ resistor, which is then connected to a stable 5V reference in order to keep the signals steady. Figure 34 shows a circuit diagram on how to get a stable connection with the OMRON D6T and microcontroller.

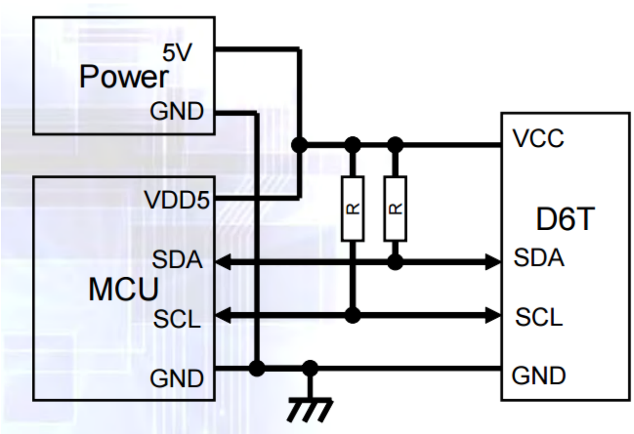


Figure 34: Microcontroller and thermal sensor circuit [40]

6.3.5 Future Contingencies

Omron is currently developing a 16x16 version of D6T sensor. This sensor broadens both the view angles and pixels of the system, and will dramatically improve the safety-system. With the 1616L one can easily find the approximate position of humans and animals in a room, and also using simple algorithms to see movement, and try to predict the movement path [47]. This will be a reasonable choice for future development.

7 Software Modules

7.1 Auditive Detection

Detecting a female mosquito through computer technology is no trivial task. Mosquitoes have revealing signatures such as their shapes, and the sound produced by their wing-beat frequency. For a wide range of female mosquitoes, from various species, the fundamental frequency tend to be in the frequency range of 300-500 Hz, as well as several over-harmonic frequency components. This may be extracted from the physical world in the form of sound waves, into the virtual domain of computing as discrete signals. The purpose of this module is to inspect input signals, and determine whether they match the properties of a mosquito audio signal or not. In addition there are real-time requirements for this task, forcing the system to process on a limited number of samples.

7.1.1 Overview

The basic idea of auditive detection of mosquitoes is to obtain their wing-beat frequency in the form of a signal. When such a signal is obtained, one may extract revealing features, such as fundamental frequency, over harmonics and power. The signals captured by this system are obtained by recording sound with a microphone array. The different methods for signal processing have been tested and developed in MATLAB [48].

The signal is recorded in segments, where each individual segment is processed independently. At a sample rate of 44100 samples per second, the signals are recorded in segments with 4096 samples. This is roughly 100 milliseconds of data for each processing cycle. For the purpose of detecting mosquitoes, finding the first four harmonics is sufficient. The harmonics are always multiples of the fundamental frequency, but may vary in amplitude.

The programs execution cycle as shown in Figure 35 has four major tasks. The first task is to capture an audio frame. The second task is filtering the signal to remove unnecessary data, to reduce the amount of data to process. The third task determines properties of the signal that may be compared with a predefined signature, in this case that of a mosquito. The last conditional task will alert any subscribers if there is a signature match and repeat the process. If there is not a signature match the module will start again from the beginning.

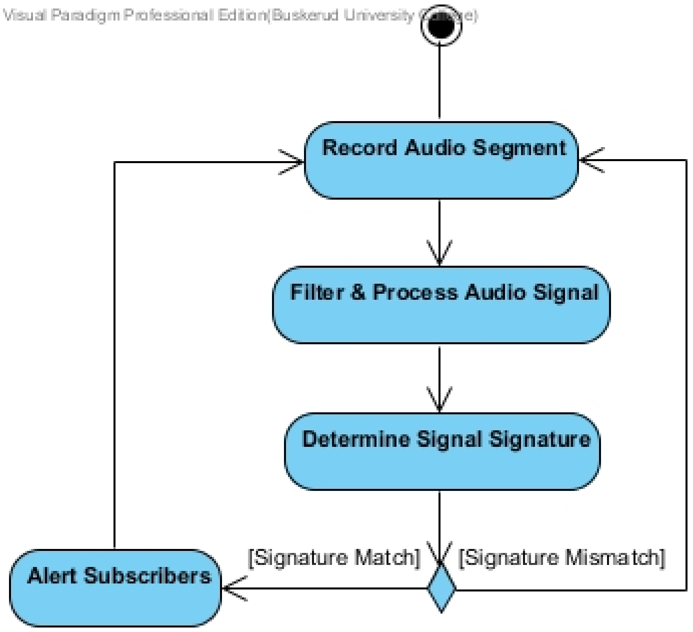


Figure 35: Activity diagram covering function execution cycle

7.1.2 Frequency Domain Analysis

To obtain the fundamental frequency of a signal as well as the over-harmonics, one may look for them in the frequency domain. By taking the Fast Fourier Transform of the signal, the frequency spectrum is obtained.

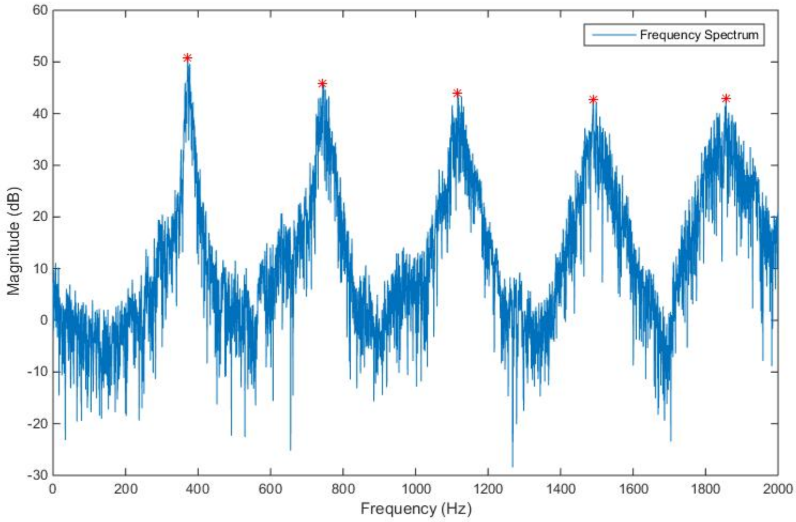


Figure 36: Frequency spectrum of a mosquito audio recording

As seen in Figure 36, the Fourier transform displays quite unambiguous peaks. However Figure 36 is the Fast Fourier Transform of a 10 seconds long mosquito recording. In real time, working on sound samples of 100 milliseconds, producing the same result, but has variations in the height of the peaks for each segment.

Program Details

Step 1: Take the Fast Fourier Transform of the filtered signal to obtain the frequency spectrum. In order to reduce leakage, one may apply a hamming smoothening-window to the function.

Step 2: To obtain the first four harmonics, the signal is not required to contain information about higher frequencies than about 2000Hz. From the Fourier transform, the peaks may be found and their corresponding frequencies, between 0-2000Hz.

Step 3: If four peaks are discovered and the first thee harmonics are multiples of the fundamental frequency, the program interprets the results as a match.

7.1.3 Cepstrum Analysis

To obtain an estimate of the fundamental frequency of a signal one may apply cepstrum analysis. Cepstrum is a Fourier analysis of the logarithmic amplitude spectrum of a signal. In practice, this is treating the spectrum as a signal by looking for periodicity, which allows for estimating the fundamental frequency [49].

The x-axis of the cepstrum has units of quefrency, which is a measure of time in the sense of samples, not the time domain. The unit displayed at the x-axis will be in seconds, but each entry in the storage vector will represent samples successively. The y-axis has units of rhamonics, which relate to periodicities in the spectrum. A peak will indicate periodicity at a given number of samples expressed in quefrency (seconds).

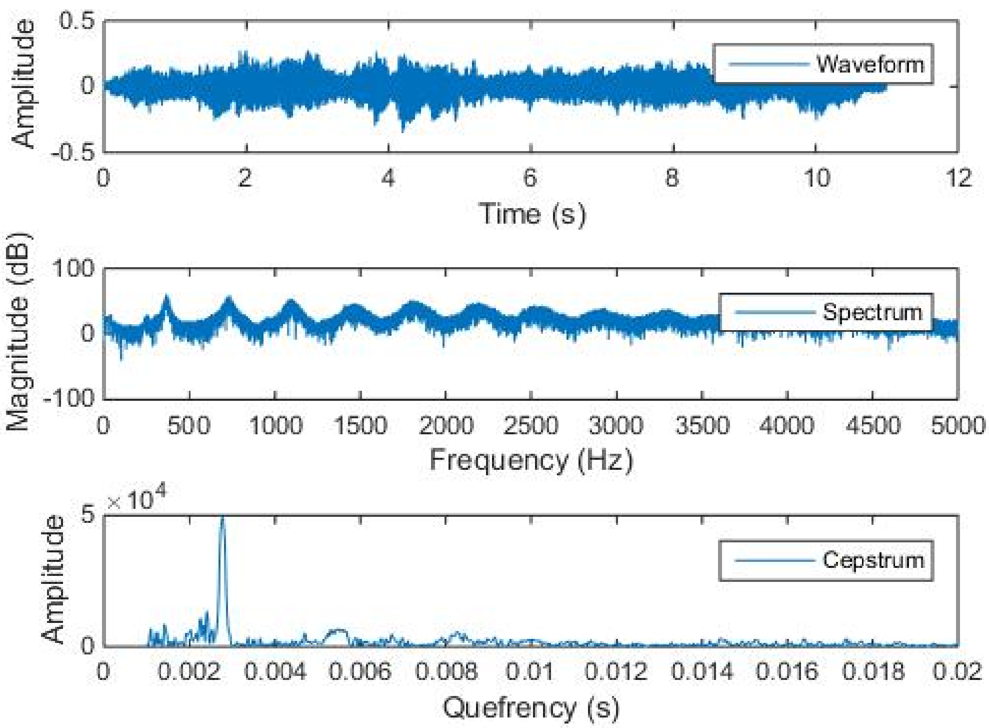


Figure 37: Waveform (top), frequency domain (middle) and cepstrum (bottom) of a mosquito recording

Figure 37 graphically demonstrates how this works in practice. It shows the waveform in the time domain, frequency domain and cepstrum for a mosquito recording. The waveform is sampled at 44100 samples per second. The peaks are found at multiples of 359Hz and represent the frequency components of the mosquito signal. In the cepstrum, a great peak is found at position 123 in the cepstrum vector, which reveals that there is a strong periodic component every 123 sample. 44100 divided by 123 equals about 359. This means that the fundamental frequency is estimated to be 359 Hz and there is at least one harmonic component present. Note that the number of samples between periodicities also may be obtained by dividing the sample rate by peak position in seconds multiplied by the sample rate.

$$Fundamental\ Frequency = \frac{Sample\ rate\ (Hz)}{Samples} = \frac{Sample\ rate\ (Hz)}{(Sample\ rate\ (Hz))(\ peak\ position\ (s))} \tag{16}$$

This confirms not only the presence of the fundamental frequency, but also at least one harmonic. However if the cepstrum analysis is performed on a signal with only one peak, such as a pure sinusoidal tone, it will not be able to detect the fundamental frequency. This is useful considering a signal may have the same fundamental frequency as a mosquito but not contain the harmonics, such as a pure sinusoidal tone.

Program Details

Step 1: Discrete Fourier Transform Function obtains the power spectrum of the segment, using a hamming window to reduce leakage. With a sampling rate of 44100 Hz and 4410 samples per segment, this gives a frequency resolution of 10 Hz.

Step 2: Acquire the cepstrum of the signal by using the natural logarithm of the power spectrum and use Inverse Fourier Transform on the result.

Step 3: Now that the cepstrum of the signal is obtained, one may find periodicity between the major peaks in the frequency domain if present. The fundamental frequency is obtained by dividing the sample rate by the number of samples between 0 and the largest peak in the cepstrum.

Step 4: If the calculated frequency is between 320 and 480Hz, the program will interpret that as a signature match for the wing-beat frequency of a mosquito.

7.1.4 Autocorrelation

Another approach is to look for the fundamental frequency in the time domain. This can be done by using autocorrelation on the signal directly. The autocorrelation function takes a segment of a waveform and correlates it with itself at different time lags. Given that the waveform is periodic, it will correlate well with itself at short delays, and delays corresponding to a multiple of the fundamental frequency. E.g. 44100 (samples/s) / (44100 (samples/s) * 0,0027s) = 370Hz.

$$\text{F}undamental\ frequency = \frac{Sample\ rate\ (Hz)}{(Sample\ rate\ (Hz))(Peak\ Correlation\ (s))} \tag{17}$$

As seen in Figure 38 the correlation is high for a specific interval. In this case it is easy to see that the correlation peaks are periodic, and the decline in each successive peak is naturally proportional to the amount of lag.

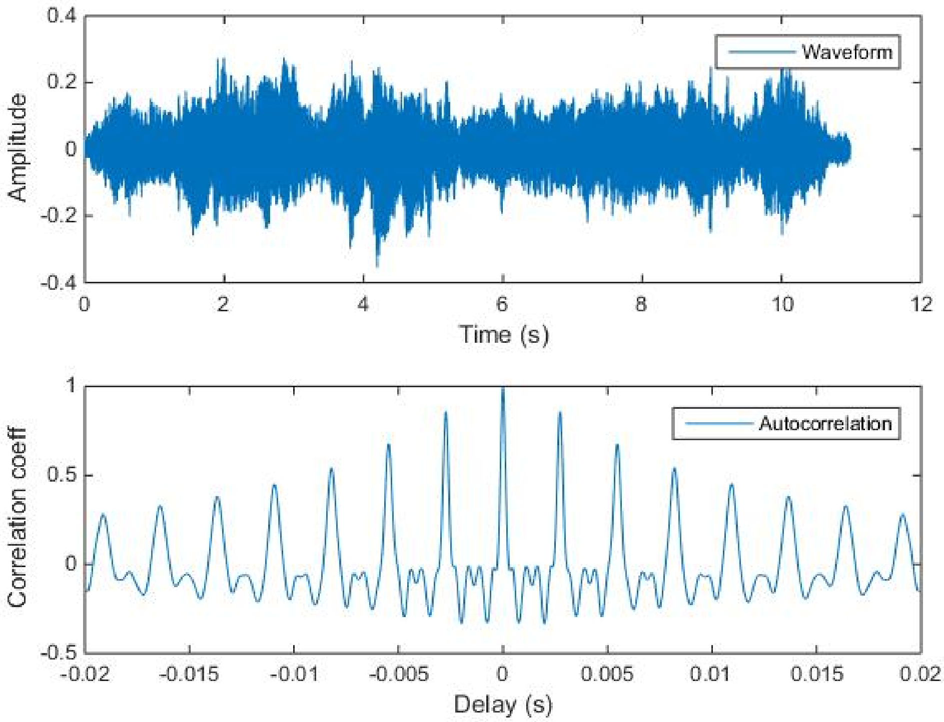


Figure 38: Waveform (top) and autocorrelation (bottom) of a mosquito sound signal

Program Details

Step 1: Obtain the correlation coefficients by cross correlating the signal with itself. A maximum lag may be specified in order to spend less computation time.

Step 2: Find peaks in the coefficient correlation graph. The peaks represent at which lags there is high correlation (the peak at time lag 0 is ignored). In this instance, the distance between peaks represents the periodicity in the signal in terms of frequency.

Step 3: Calculate the fundamental frequency by dividing the sample rate with the sample rate times the time between peaks.

Step 4: If the calculated frequency is between 320 and 480Hz, the program will interpret that as a signature match for the wing-beat frequency of a mosquito.

7.1.5 Future Contingencies

At this stage the software was written in MATLAB as a prototype to test different methods and concepts. However for the module to become an integral part of the final system, and possibly more efficient, rewriting it in lower level languages such as C or C++ is recommended. Since the majority of software in the system is written in C++ using the QT framework, this platform would constitute the methods well with the rest of the software. When it comes to rewriting the code, digital signal processing libraries such as Aquila [50], may be used to implement the mentioned methods. For example the cepstrum requires Fast Fourier Transform, Natural Logarithm and Inverse Fast Fourier Transform functions to process the signal. These are common libraries and are found in many forms, both open source and proprietary.

The three methods described above all provide the fundamental frequency of the input signal. However the autocorrelation method does not cover over harmonic components like the others, but is the fastest of the three methods. Cepstrum analysis looks at the periodicity in the frequency spectrum, and will return the strongest results for the most dominant signal. Unlike Frequency Spectrum Analysis, the cepstrum will only confirm one harmonic, but is more capable of detecting frequencies for various levels of amplitudes. The bottom line is that autocorrelation is better when it comes to performance, compared to the cepstrum. However the cepstrum provides estimations of higher quality and reliability. Again, this only applies when there are harmonic components in the signal, which is the case for sound produced by mosquitoes in flight.

7.2 Laser Control Software

In the preliminary work it was determined that galvanometers would be used. In order to control these, a control system is required. Thus several interfaces has to be taken into consideration:

- The thermal sensor on the prototype uses I^2C for communication with the microcontroller.
- The main computer and LCS communicates through UART.
- The DACs communicate with the microcontroller through the SPI protocol.

Considering that this system is a prototype, an Arduino microcontroller is sufficient, and this document will be written assuming that an Arduino microcontroller is being used.

7.2.1 System Overview

Technologies

The system is coded using the Arduino IDE (integrated development environment) which supports C and C++ programming languages.

Application Overview

The goal of this system is to create an interface from the computer to the DAC that is controlling the galvanometer and the laser. It should be very easy as it will only take commands from the main controller application. This application will communicate through serial at a baud rate of 115200.

7.2.2 System Architecture

Architectural Design

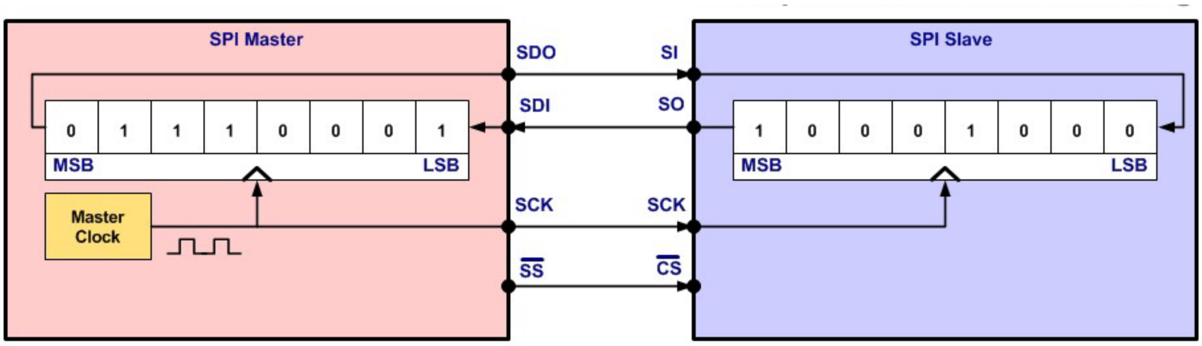
The system is waiting for serial data in order to steer the mirror galvanometers. When this data arrives, it assumes that the message is 11 bytes, of which 5 bytes is for each galvanometer and 1 byte is for the laser.

For outputting to the DAC, a library called OLSD (Open Laser Show DAC) is used [18]. The important function of this library is OuputPoint() which takes five arguments. Only the first two are used in the configuration as the other three are for controlling the color of the laser, which is not included in the system hardware. The two first arguments should be “unsigned int” which is a 16 bit number on the Arduino. The function transforms the 16 bits number to a 12 bits number as the DAC is 12 bits, and then outputs it using SPI.

In order to control the laser, a digital pin is set high when 1 is received, otherwise it is low. The digital pin 4 on the Arduino, is used for this purpose.

SPI

SPI is a short distance communication protocol for serial full duplex data transmission, illustrated in Figure 39.



PIN	Description	Direction
SDO	Serial Data Out, This pin also called as MOSI (Master Out Serial In) in AVR Type Microcontroller	Out
SDI	Serial Data In, This pin also called as MISO (Master In Serial Out) in AVR Type Microcontroller	In
SCK	Serial Clock (SPI Master)	Out
SS	Serial Select (could be any I/O Port)	Out

PIN	Description	Direction
SI	Serial In	In
SO	Serial Out	Out
SCK	Serial Clock (SPI Slave)	In
CS	Chip Select (usually active low)	In

Figure 39: SPI [51]

SPI consists of at least two devices: one master device and at least one slave device. There may be several slave devices in such as system. The communication pins are usually referred to as [51]:

- SCK = serial clock
- MOSI = master output, slave input
- MISO = master input, slave output
- SS = slave select

The master is setting the slave select to low when it wants to talk to a device and sends a clock signal to the slave. The slave and master then swap their buffers. The buffer size varies, but is usually 8-bit, 12-bit, or 16-bit.

I^2C

I^2C is also a communication protocol which uses only two signals:

- SCL = clock signal
- SDA = data signal

The setup consists of at least one master and one slave. The masters communicate with a specified slave device by addressing them with a specific address. The current protocol, with 10-bit addresses, allows for communication with up to 1008 slave devices [52].

7.2.3 Serial Controller

The serial controller is used to communicate with the ATmega328 from the computer via an USB cable. The serial controller outputs connected to the ATmega328 are:

- RXD: connected to the TX pin of the Arduino
- TXD: connected to the RX pin of the Arduino
- DTR: connected to the reset pin of the Arduino via a 100nF capacitor

7.2.4 Thermal Sensor

In order to communicate with the thermal sensor, the Arduino sends a start signal to the sensor and then receives data as it operates. This thermal data is partially parsed and sent to the computer serially, where further computations are made.

The main application is running in QT, and to supplement it with human presence sensor technology, OMRON D6T is connected through an Arduino. The Arduino collects the sensor data in a buffer and transmits it serially to the computer. The data is split up and stored in an array, the array is then displayed in QLabels and the color of the QLabel is changed according to the temperature of the pixel.

7.3 Computer Vision

In the preliminary work it was determined that the software would control all the different components of our system such as the laser, galvanometer, and the thermal sensor would be needed. To connect these modules together, the software implements the following interfaces:

- The communication with the LCS will be done using Universal Asynchronous Receiver/Transmitter (UART).
- The live feed from the camera is transferred via an USB cable and through a driver on the computer.

7.3.1 System Overview

Technologies Used

The system is coded using C++ with the Cross-Platform Application Framework (QT) Integrated Development Environment (IDE), meaning all the libraries which ships with it.

Camera

The initial research showed that the optimal distance between the laser and the target would be 5 meters, based on the depth of the killing zone, width of the laser and the distance from the camera to the laser [53]. If a camera is put 5 meters away and still detects small objects, such as mosquitoes, a zoom lens is required. A Digital Single-Lens Reflex (DSLR) mounted on a tripod, with a long-range zoom lens is then required. The Canon 550D and the Sigma 70-300mm macro lens [54] was used, but any DSLR with zoom lens can work.

SparkoCam

The OpenCV library, and MATLAB Image processing mainly uses USB web cameras as a video source. To get live feed from a DSLR to the computer SparkoCam [55] is needed. SparkoCam is a cheap (50$) solution, and can transmit live feed from all Canon and Nikon DSLR cameras, and emulate them as webcameras, with HD resolution, and a good frame rate.

PC

To run SparkoCam and image processing in OpenCV/QT, Dell Alienware M14X has been used as the processing unit for the prototype. This computer has a quad-core i7 processor that runs at 2.3 GHz, and 8GB DDR3 ram.

Application Overview

The goal of this system is to put together the laser hardware, the camera feed, and the thermal sensor and make them all work together. The application is created in a modular way so that it is possible to replace components easily as the concept evolves. It is a simple design which does not set high demands to the user's technical background.

7.3.2 System Architecture

Architectural Design

The components are mostly communicating with slots and signals, which emphasizes a modular architecture. The main interfaces from the software are to the laser controller and to the SLR Camera.

Image Processing Controller

The image-processing controller uses a library called OpenCV [56]. This is the place where everything in relation to the image processing is performed such as detecting mosquitoes or other targets. Figure 40 illustrates an activity diagram describing the use of the image processing controller.

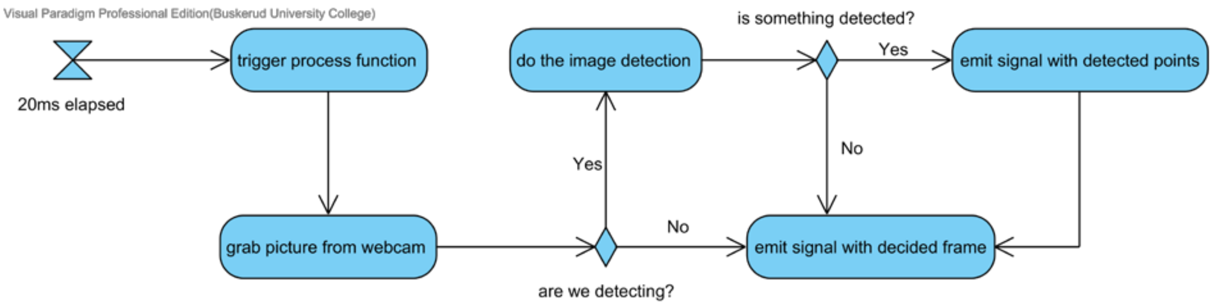


Figure 40: Activity Diagram OpenCV Controller class

The figure above explains how the process of the OpenCV Controller class is working. Every 20 millisecond a signal is triggered, which runs the process frame slot. The first step is to grab a picture from the DSLR Camera. A tracking algorithm may be chosen in the graphical user interface, displaying results or effects on a monitor. The user may choose whether to display original frames or processed frames. If a detection algorithm function is selected, it will return detected points through an emitted signal. The last signal being triggered in a cycle is the one containing a frame. The current system has three different detection-tracking objects:

1. Red laser (for calibration purposes)
2. Green laser
3. Fish fly (attached to a thin fishing thread)

There is room for expanding the number of tracking objects. A future contingency may be to track other kinds of objects. This is perfectly doable with the current setup.

The following sections will go into more details concerning how the detection algorithms work. When the detection methods are called, the image input is provided in HSV format. The image is used as an argument to a function called inRange, with the following description: “Checks if array elements lie between the elements of two other arrays” [57]. The two other arrays are representing lower and higher threshold. The output image is in binary format, that is only black and white pixels. The white pixels are where the inRange algorithm detected a pixel that was in-between the two arrays. Then the image is dilated so that all the white spots are expanded. The last step is to actually detect the circles, such as the laser points. This is achieved by calling an OpenCV function called HoughCircles. The output of this function is a vector of circles. The procedure to detect the red laser is the same as the green laser except for the arguments of the inRange function.

Next up is the fish fly, which is used to simulate the shape of a mosquito (for testing purposes). The background of the image should be white, to facilitate high contrast between the tracking object and background. The image becomes converted to gray scale and thresholding is performed on each pixel. If the pixel is greater than the threshold, the pixel value will be set to 1 or else the value is set to 0. Then a contour finding function is applied to the binary image, and returns a vector of vector points. This vector is then transformed into a list of rectangles, which is returned from the function.

Serial Controller

QT has many components that are integrated where serial communication is one of them. The serial controller runs in its own thread using QTs serial library. The component checks if there are changes on the serial setup (if new a COM port is available), and performs two-way serial transmission.

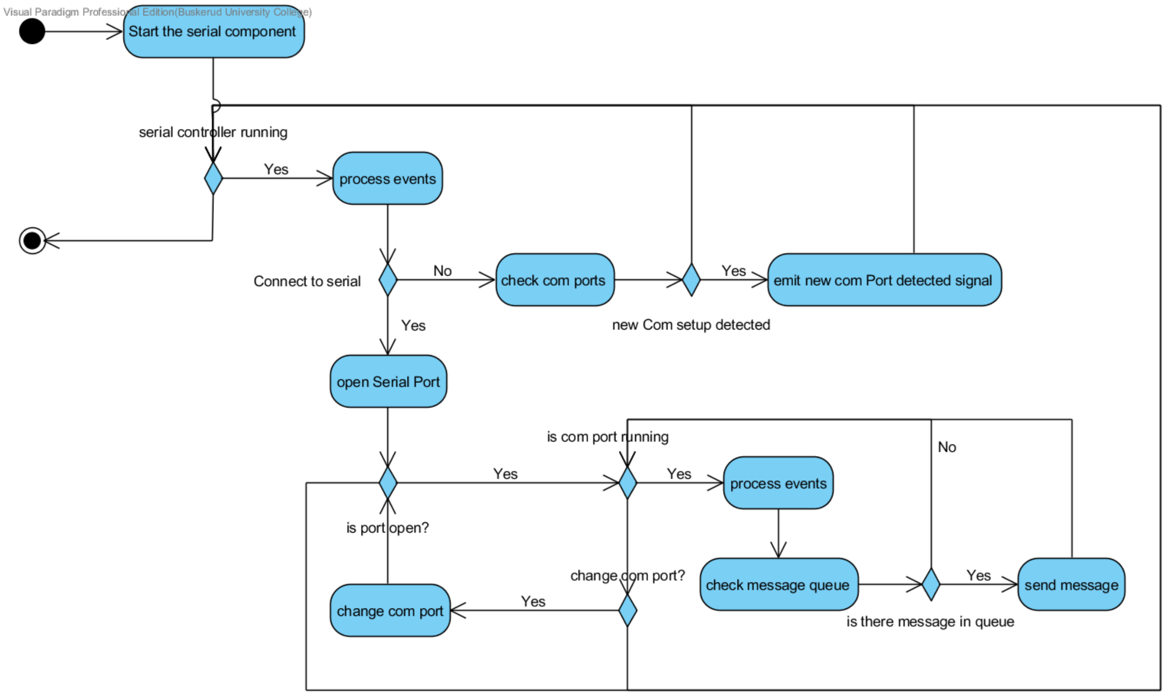


Figure 41: Activity diagram for serial controller class

Figure 41 illustrates how the serial thread works. The diagram emphasizes especially on the transition between different states. As seen in the bottom right end of the diagram there is a loop. This is where the serial port opens, so that messages on the queue are sent. Received messages are obtained using signals which is handled with a slot, and is therefore not included in this diagram. Another important part of this diagram is the loop at the top, which is only running when there is no connection to a serial port. It is not necessary to check the COM port setup if a connection to a serial port is confirmed. If however a new COM port setup is detected, a signal is emitted with the new setup.

Calibration

The calibrate component is very important as this is where the camera field is mapped to the galvanometer field. This is illustrated in Figure 42.

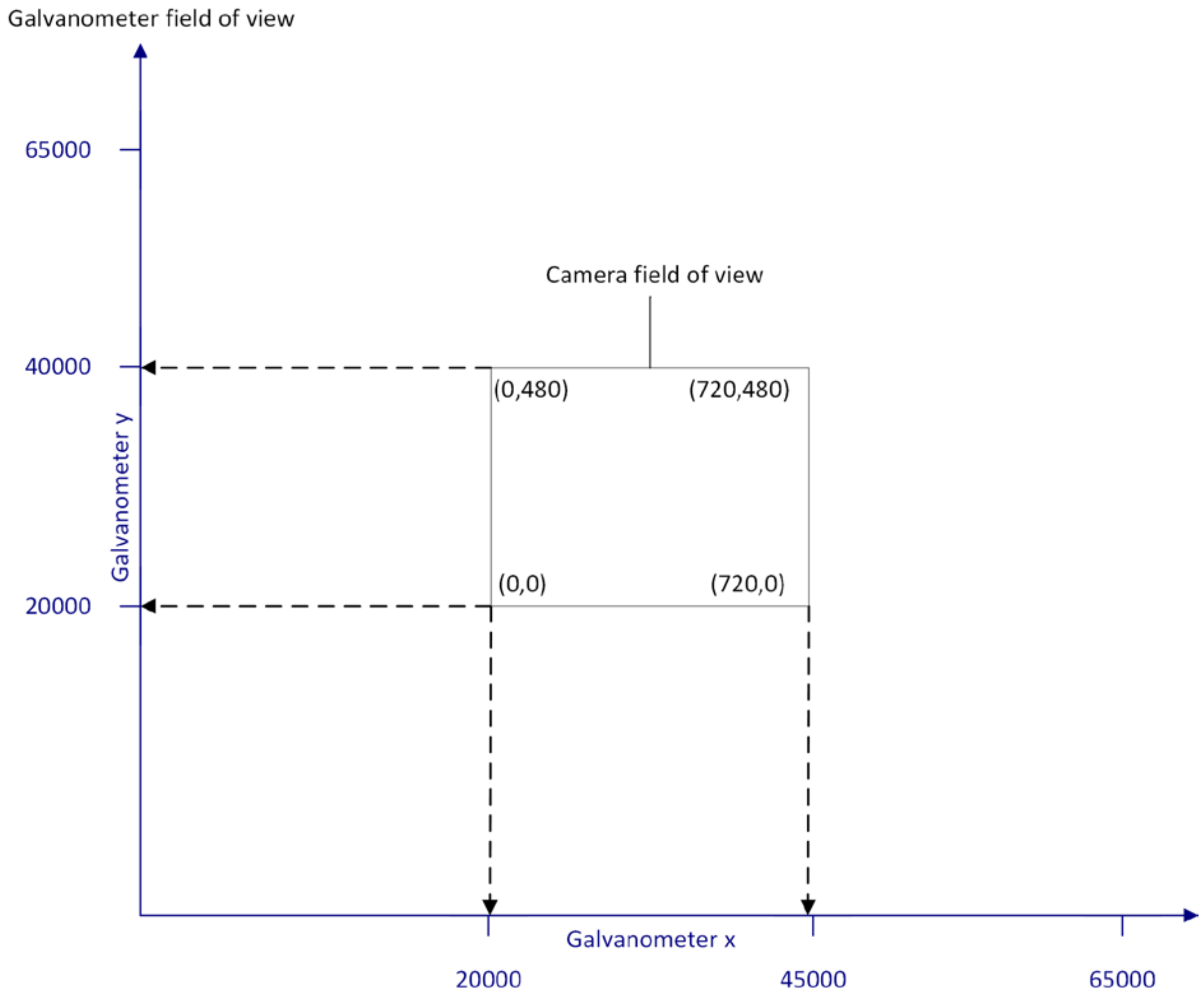


Figure 42: Mapping illustration

The purpose of the calibration is to establish a relationship between the camera field of view and the mirror galvanometers deflection angle. By achieving this, the laser may be emitted at a point by referencing it from the camera perspective. As an example the bottom left corner of the camera field of view contains the value (0, 0), which equals (20000, 20000) on the galvanometer field of view.

To detect the camera field of view, a simple method is applied consisting of swiping the entire area until the camera detects the laser. The start point is (0, 0) on the galvanometer field of view with increments to the right. When the end of the galvanometer field of view is reached, the laser goes back to the start point and moves about 1000 points in the y-direction. Then it proceeds with increments to the right until the end field is reached. This process continues until the camera detects the laser, meaning the laser is in the camera field of view, and is moved to every border of this field in order to obtain the values to map the camera coordinates.

This process takes time, but once it is completed, the system is calibrated and unless the hardware setup is rearranged there is no need to repeat the process. If the program finds stored calibration information it will use this data unless the calibration routine is started over.

Protection Controller

The ProtectionController class takes in data from the SerialController class, and parses it into an array. After parsing the input data, it checks for thermal presence of humans and/or animals. If such presence is detected, meaning a human or animal is residing in front of the OMRON D6T thermal sensor, a safety-flag is generated in order to stop the laser. Whenever new data is parsed and is available for the system to use for safety and other purposes, a signal is emitted. It is called newDataReady and includes all parsed data and flags.

The protectionController class also updates the GUI colors to get a visual representation of the thermal values in front of the sensor. The system is using a 1x8 pixels thermal sensor, which means that it is possible to have an 8-pixel array of QLabels on the right side of the main GUI. Figure 33 shows a screenshot of the thermal sensor GUI.

7.3.3 Laser Controller

The laser controller class is the one controlling the laser and galvanometers. It communicates with the galvanometer controller via serial communication; this means that the serial controller component is applied. The main tasks this class can perform are to convert the coordinates obtained by the camera to the coordinates of the galvanometers, turn on and off the laser, and calibrate the camera axis to the galvanometer axis. To convert the coordinates, the calibrate class is used, which is described earlier in this text.

The current setup allows for flexibility when it comes to controlling the laser and the galvanometers. The laser can by choice be turned on/off dependent on object detection, and is in addition turned off if there is no activity for 100 milliseconds. The galvanometers are able to move regardless if the laser is on or off. However, because of security measures, the laser is never firing if the safe-flag is on. This is constantly controlled prior to each laser firing.

7.3.4 Settings

QT provides a class which handles the storing and retrieving of settings (QSettings). It stores these settings in a key-value pair, so in order to modify a setting all that is needed is the key, which is a static component. Since the key is static, a static variable with the key for each setting in the class that handles the user interface is created and allows for changes in the settings. Typically, COMport or baud rate are types of settings stored with QSettings.

7.3.5 Human Interface Design

Overview of User Interface

The user will always be presented with the main screen of the application, be able to access a setting tab, and adjust some of the settings. On the main screen there are different parameters the user will be able to change, which is further described in the below sections.

Main Screen

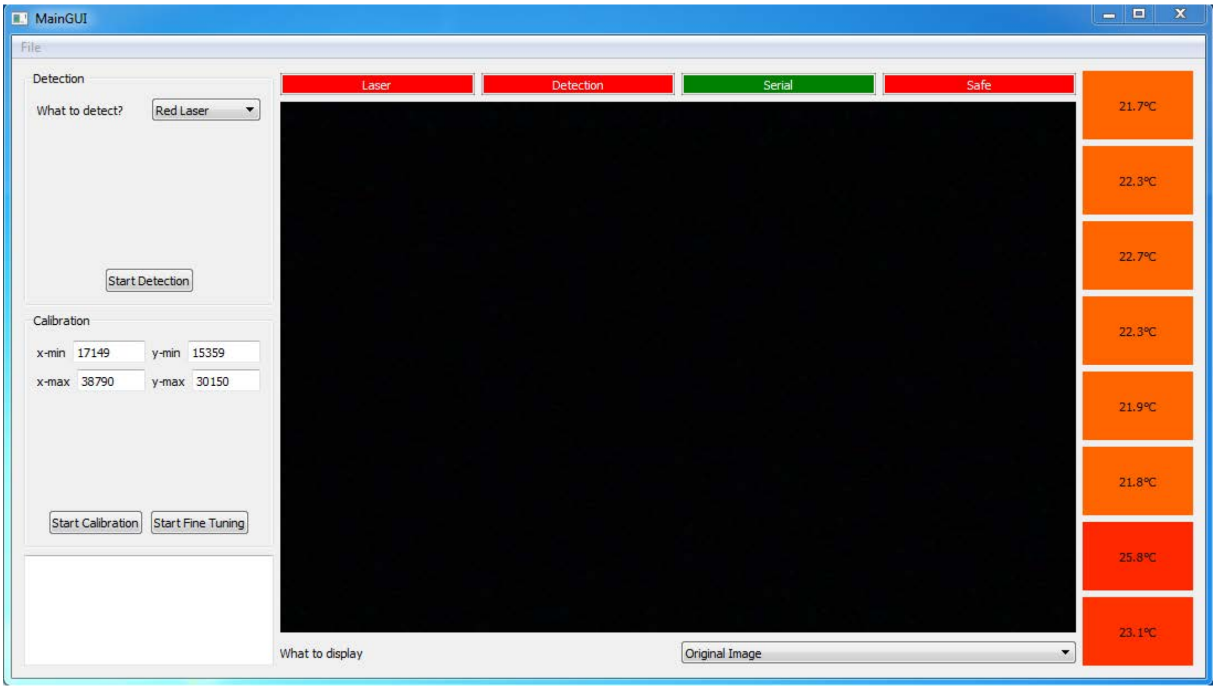


Figure 43: GUI main screen

Figure 43 represents how the graphical user interface is designed, and it includes many components. The black area is the frame obtained by the camera, which includes two different modes:

1. Original Image
2. Processed Image

Above the frame area, there are four status labels:

1. Laser Status: confirms whether the laser is on or off
2. Detection Status: confirms if the system is currently detecting something
3. Serial Status: confirms if the serial port is connected
4. Safe Status: confirms that no humans/animals are present in the killing zone

Status labels turn green when the confirmation criterions are reached.

In the top left area, there is a square called detection which gives the user the possibility to choose what to detect. When a target type is chosen, the “start detection” button starts the detection mechanism, which disables the calibration mode. The detection label turns green in this mode.

Under the detection square the calibration setup is located. The calibration includes several values that represent the camera field of view on the galvanometer field of view. To start calibration the “start calibration” button is pressed. The system goes in calibration mode which means that the system detects the red laser automatically. When the calibration is done, a message is displayed in the log box on whether it was successful or not.

The last component on the GUI is the log box, which is placed in the bottom left corner of the window. It displays the log information in order to update the user of occurrences.

Settings Screen

The settings screen of the GUI is presented in Figure 44. In this section, the user has the possibility to adjust the settings of the application:

1. Serial com port: Change the serial port where the laser controller is located.
2. Serial baud rate: Change the baud rate of the serial communication.

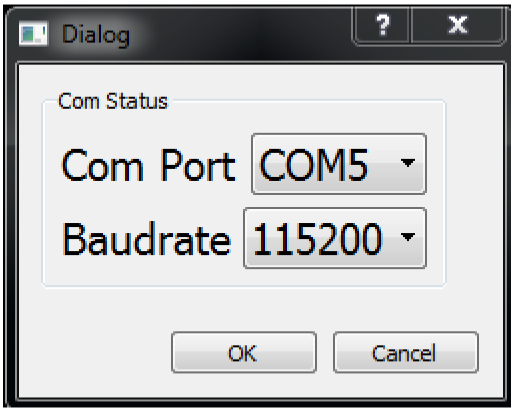


Figure 44: GUI settings

8 Test Plan

Testing a system is vital to evaluate whether the system complies with the specified requirements or not. If a system is not tested, there is no way to verify that it will work as stated. Due to time constraints it will not be possible to develop and manufacture the entire system, and thus testing a final system. The modules that are provided with a prototype will be tested. Therefore these will be marked with "procedure for proof of principal prototype", while the modules that are not prototyped nor ready for testing will be marked "procedure for final system".

The test design specifies how to test each individual requirement, while the test case specifies what the test items will be, expected results and implementation terms.

8.1 Test Planning

8.1.1 Requirements to be Tested

The following requirements shall be tested:

- REQ-1: Immobilize / destroy mosquitoes in order to reduce the chance of infection caused by mosquitoes.
- REQ-3: Issue warning when unintentionally inactive.
- REQ-5: Should not harm other insects.
- REQ-6: Shall not harm humans or animals.
- REQ-8: Detect individual mosquitoes.
- REQ-9: The system should not cause collateral damage to inventory and environment

8.1.2 Requirements not to be Tested

The following requirements shall not be tested:

- BUSG-1: Commercially available parts/modules.
- BUSG-2: Consumer affordable.
- BUSG-3: Final delivery May 19th 2015.
- REQ-4: Area of effect may be adapted to the operational environment.

8.1.3 Responsibilities

Everyone in the group are responsible for safety during the testing, concerning both their own safety and others. Everyone is responsible for making sure that the tests are completed according to the test design and test cases. Health, Safety and Environment (HSE) should be a focus during all tests.

8.1.4 Schedule for Testing

Table 40: Schedule for system-testing

Week	Date	Test	Location	Responsible
18	30.04.2015	T-REQ-1	School, Dronesonen	Ann Christin Barstad, Max Moeschinger
19	05.05.2015	T-REQ-5	School, Audio-room	Ann Christin Barstad, Christoffer Marius Ness Olsen and Eirik Haavaldsen.
19	05.05.2015	T-REQ-6	School, Audio-room	Ann Christin Barstad, Hege Jeanette Blikra, Jawad Qureshi and Max Moeschinger.
19	05.05.2015	T-REQ-8	School, Audio-room	Ann Christin Barstad, Christoffer Marius Ness Olsen, Eirik Haavaldsen and Max Moeschinger

8.1.5 Risks and Contingencies

There are not too many risks associated with this project, but there are some. The laser and the galvanometer could potentially cause harm to a human while the system is tested. If the laser beam is too strong it can cause a burn to the skin or cause impaired vision. If the galvanometer is up and running, it is possible to get fingers stuck or squeezed. To prevent this, the laser beam has to be with an effect that is not dangerous and while the galvanometer is running no one should touch it.

8.2 Test Design and Test Cases

8.2.1 REQ-1

The test design and test case for REQ-1 are presented in Table 41.

Table 41: T-REQ-1

T-REQ-1	
Requirement Description	Immobilize / destroy mosquitoes in order to reduce the chance of infection caused by mosquitoes.
Related to requirement-ID	REQ-1
Responsible	Ann Christin Barstad and Max Moeschinger.
Verification	Test case.
Acceptance criteria	The system is able to accurately hit the targets within the target area.
Status	Tested
Approved	Yes

Features to be Tested

For this test the galvanometer precision and the corresponding targeting software is to be tested. Make sure to verify that the laser covers all of the target area.

Features Pass/Fail Criteria

The system has to be able to accurately hit mosquitoes while they are in motion. The system must be able to hit mosquitoes anywhere within the target area. If these criterions are not obtained, the test fails.

Procedure for Proof of Principle Prototype

Since it is not possible to test on mosquitoes at this time of year, the test object will be a fake fly instead. Let the camera track the moving fly, and manually shoot the fake fly at the white background. Verify the test by visual inspection and analysis of the video recording. Verify that the system is able to accurately hit the target regardless of whether the target is moving or standing still, and within the entire target area.

Test Items

The test items will consist of a fake fly, white background, camera, galvanometer and laser.

Expected Results

The system has to be able to track the fake fly. It also has to hit the fly regardless of whether the fly is moving or standing still within the entire target area.

Environmental Needs

For this test it is necessary with daylight. The camera will not be able to function properly in darkness. It is also necessary to have a white background so that the camera can perceive fly in great contrast to the background.

8.2.2 REQ-3

The test design and test case for REQ-3 are presented in Table 42.

Table 42: T-REQ-3

T-REQ-3	
Requirement Description	Issue warning when unintentionally inactive.
Related to requirement-ID	REQ-3
Responsible	All of the group members.
Verification	Not to be tested at this phase.
Acceptance criteria	Confirm that warnings are issued.
Status	Untested
Approved	N/A

Features to be Tested

The system will have a built-in alarm system that has to be tested. If the system unintentionally does not work how it is supposed to, the alarm is supposed to go off.

Feature Pass/Fail Criteria

For this test to pass, the alarm has to go off by the time there is a fault in the system. That is for example if the power is cut or a system component fails. If this criteria is not met, the test fails.

Procedure for Final System

The testing of the alarm could be done by making the system fail and see if the alarm goes off. In order to test if the alarm goes off, components and power could be set to intentionally fail. A functional component could be changed with one that is defected, or the power could be intentionally cut.

Test Items

The test items will consist of: software, alarm and other hardware components.

Expected Results

It is expected that the alarm will go off if an error is imposed to the system, such as hardware or software issues.

Environmental Needs

There are no specific environmental needs for this test. It can be tested wherever as long as there is electricity available at the test scene.

8.2.3 REQ-5

The test design and test case for REQ-5 are presented in Table 43.

Table 43: T-REQ-5

T- REQ-5	
Requirement Description	Should not harm other insects.
Related to requirement-ID	REQ-5
Responsible	Ann Christin Barstad, Christoffer M. N. Olsen, Eirik Haavaldsen.
Verification	Test case.
Acceptance criteria	Able to differentiate between mosquitoes and other insects.
Status	Tested
Approved	Yes

Features to be Tested

The following feature will be tested: mosquito-identification software.

Feature Pass/Fail Criteria

The system has to be able to differentiate between different sound-frequencies and only return "true" when the frequency is within 350-450 Hz.

Procedure for Proof of Principal Prototype

Produce sounds resembling different wing-beat frequencies from different insects, including mosquitoes, in the area of effect. Verify that the software is able to distinguish the different wing-beat frequencies.

Test Items

The test items will consist of: sounds with wing-beat frequencies from different insects, including mosquitoes, and the corresponding software.

Expected Results

It is expected that the software is able to distinguish the different wing-beat-frequencies, and return "true" when the fundamental frequency is within 350-450 Hz.

Environmental Needs

A sound-isolated room in order to test the features without unwanted noise contributions is needed.

8.2.4 REQ-6

The test design and test case for REQ-6are presented in Table 41.

Table 44; T-REQ-6

T- REQ-6	
Requirement Description	Shall not harm humans or animals.
Related to requirement-ID	REQ-6
Responsible	Ann Christin Barstad, Hege Jeanette Blikra, Jawad Qureshi and Max Moeschinger.
Verification	Test case.
Acceptance criteria	Ensure that the system implements functionality that provides human and animal safety.
Status	Tested
Approved	Yes

Features to be Tested

The following features will be tested: thermal sensor and the corresponding software.

Feature Pass/Fail Criteria

If the system immobilizes or harms humans or animals, the acceptance criteria is not met.

Procedure for Proof of Principle Prototype

Insert an object with thermal heat in the area of effect. Verify that the thermal sensor detects the test object and that the system refrains from immobilizing it.

Test Items

The test items will consist of: human, animal or an item that emits the same amount of heat, the thermal sensor and the rest of the hardware components and also the corresponding software.

Expected Results

It is expected that the system will stop the process of immobilizing any object while there is a human or animal in the thermal sensors active area.

Environmental Needs

There are no environmental needs for this test.

8.2.5 REQ-8

The test design and test case for REQ-8 are presented in Table 45.

Table 45: T-REQ-8

T - REQ-8	
Requirement Description	Detect individual mosquitoes.
Related to requirement-ID	REQ-8
Responsible	Ann Christin Barstad, Christoffer M. N. Olsen, Eirik Haavaldsen, Max Moeschinger.
Verification	Test case.
Acceptance criteria	The system is able to detect the presence of mosquitoes in the designated area.
Status	Tested
Approved	Yes

Features to be Tested

The following features will be tested: microphone array, camera and corresponding software.

Feature Pass/Fail Criteria

If the system is not able to detect individual mosquitoes, the test fails.

Procedure for Proof of Principle Prototype

Insert several test objects (test sounds) with the wing-beat frequency of a mosquito in the area of effect. The camera software will provide a constant stream of coordinates. These coordinates have to correspond with the actual relative position the mosquito has to the camera. Verify that the microphone array and the camera are able to detect the test objects individually.

Test Items

The test items will consist of: several items (sounds) with the wing-beat frequency of a mosquito, microphone array, camera and corresponding software.

Expected Results

It is expected that the system will be able to detect the different test items (sounds).

Environmental Needs

The microphones poorly tolerates wind and humidity, therefore it ought to be tested inside or outside when it is not windy nor raining. It is necessary with daylight because the camera will not be able to function properly in darkness. It is also necessary to have a white background so that the camera can perceive the different test items.

8.2.6 REQ-9

The test design and test case for REQ-9 are presented in Table 46.

Table 46: T-REQ-9

T- REQ-9	
Requirement Description	The system should not cause collateral damage to inventory and environment.
Related to requirement-ID	REQ-9
Responsible	All of the group members.
Verification	Not to be tested at this phase.
Acceptance criteria	No vulnerable items are damaged.
Status	Untested
Approved	N/A

Features to be Tested

The following feature will be tested: laser beam.

Features Pass/Fail Criteria

If the laser beam is so effective that it sets marks or sets fire to any inventory or the environment, the test fails.

Procedure for Proof of Principle Prototype

Power up the system and set the laser-software to activate the laser. Aim the laser at inventory and environment.

Test Items

The test items will consist of: laser and corresponding software.

Expected Results

It is expected that the effect of the laser beam will not be strong enough to cause damage to any inventory or environment.

Environmental Needs

It will be necessary to have furniture to test on, and for example some grass or a tree. It is important that the attendees wear safety goggles.

9 Test Report

This section provides the result of every test that is conducted. This is to get an overview of what has been tested, how it has been done and whether the test was approved or not. The safety precautions that had to be considered are listed under each test, as well as the equipment used in each test.

9.1 Report on T-REQ-1

Immobilize / destroy mosquitoes in order to reduce the chance of infection caused by mosquitoes.

Attendees

The following group members were present: Ann Christin Barstad and Max Moeschinger.

Safety Precautions

The following safety precautions had to be taken to consideration: safety goggles, no humans or animal in testing area while the test is performed, and no reflective surfaces (windows, mirrors etc.) in the test area.

Equipment

The following equipment was tested: the whole system (except the human/animal tracking device) consisting of all the hardware components and all the finished software, and a white background plasterboard. The test object is a fake fly.

Test Results

The galvanometer works better than first anticipated. It changes angles fast and aims the laser beam precisely. The test of the targeting software had to be done twice. The first test was not approved. There was a calibration error that made the laser hit the fake fly about 5 mm off to the left. For the second test, Max Moeschinger modified the software, and this time the calibration was more precise and the laser hit the fake fly 2 mm from the middle of the fly. This means that the fly was hit and would be immobilized or destroyed if the laser beam was effective enough. Due to this, the test was now approved. The test for making sure that the laser covered all of the designated area, also needed two tries. The first test showed that there was a deviation when the laser reached the end corners. When it reached either the upper-left, upper-right, lower-left or lower-right corner, the laser jumped approximately 2 cm above the test object. Except from this, the laser managed to track the fly perfectly all over the designated area. For the second test, Max Moeschinger modified the software and managed to eliminate the error. This resulted in the laser being able to follow the fly in all of the designated area, also the corners. The test was now approved.

Test Conclusion

The reason the software did not work properly the first times it was tested, was because the system and hardware components were moved to another location, and therefore some modifications had to be made. The software had been customized for the surroundings at the bachelor-room, and therefore had to be modified to fit the surroundings at Dronesonen. After these modifications the system worked as anticipated and the tests were approved.

9.2 Report on T-REQ-6

Shall not harm humans or animals.

Attendees

The following group members were present: Ann Christin Barstad, Hege Jeanette Blikra, Jawad Qureshi and Max Moeschinger.

Safety Precautions

The following safety precautions had to be taken to consideration: safety goggles, no humans or animal in testing area while the test is performed (except when it is planned), and no reflective surfaces (windows, mirrors etc.) in the test area.

Equipment

The following equipment was tested: the whole system consisting of the hardware components (including the human/ animal tracking device) and the finished software. The test object was a green laser.

Test Results

The following equipment was tested: first the software was tested. A green test laser was used to check that the red laser turned off when the green laser was turned off. This proved to work at the first try. Further on, the thermal sensor was tested with the previous tested software. For this part of the test the green test laser was also needed. A test person walked into the designated area, with the lasers aiming at the feet (for safety reasons). When the thermal sensor sensed the body heat, the red laser turned off. The test was therefore approved. It turns out though that the hardware components in the system are not operating at the speed that is needed for the test to be approved if this was a final product. If the test person walked fast, only the software was able to function properly. The laser would not have enough time to be turned off before the test person was already past the designated area. At this phase of the project that is not critical. If a test was carried out on a final system, the test would not have been approved.

Test Conclusion

For a prototype the test results are acceptable. If this was tested on a finished product, the test would not have been approved. To increase the performance, a better microcontroller or a FPGA is needed.

9.3 Report T-REQ-5 and T-REQ-8

REQ-5: Should not harm other insects.
REQ-8: Detect individual mosquitoes.

Attendees

The following group members were present for the first part of the test: Ann Christin Barstad and Max Moeschinger. The following group members were present for the second part of the test: Ann Christin Barstad, Christoffer Marius Ness Olsen and Eirik Haavaldsen.

Safety Precautions

The following safety precautions had to be taken into consideration for the first part of the test: safety goggles, no humans or animal in testing area while the test is performed, and no reflective surfaces (windows, mirrors etc.) in the test area. For the second part of the test, no safety precautions needed to be considered.

Equipment

The following equipment was tested: camera and corresponding software, RØDE nt-5 condenser microphone, EDIROL UA-25 sound card, Stello DA220MKII DAC, HEGEL H200 integrated amplifier, Martin Logan vantage loud speakers and MATLAB code.

Test Results

The first part of the test (half of T-REQ-8), the camera and corresponding software was tested. Two different black objects were placed in the designated area, and the camera detected both of them. The test was approved on the first try. The second part of the test (T-REQ-5 and half of T-REQ-8) started with some problems with the MATLAB software. Eirik and Christoffer managed to fix it and the tests could begin. The three test subjects were mosquito, wasp and bee recordings. The purpose of the test was to see if the system was able to distinguish between them, and how well it performed. The mosquito and bee sounds are very different in the spectrum, but the wasp sometimes overlap with mosquito sound. The tests were run for 30 seconds for each recording. The results are listed in Table 47, Table 48 and Table 49. It shows that the system managed to detect individual mosquitoes as well as detecting other insects.

Table 47: Test results with recording of a female mosquito.

	Total number of readings.	Readings between 320-480Hz.	Readings outside 320-480Hz.
Cepstrum	322	319	3
Autocorrelation	161	161	0
Frequency Spectrum	192	192	0

Table 48: Test results with recording of a wasp.

	Total number of readings.	Readings between 320-480Hz.	Readings outside 320-480Hz.
Cepstrum	322	3	319
Autocorrelation	161	0	161
Frequency Spectrum	188	79	109

Table 49: Test results with recording of a bee

	Total number of readings.	Readings between 320-480Hz.	Readings outside 320-480Hz.
Cepstrum	322	2	320
Autocorrelation	161	0	161
Frequency Spectrum	183	13	170

Conclusion

The camera detects different objects in the designated area very well. The MATLAB-code manages to detect mosquitoes by wing-beat frequency to an acceptable level. Due to the fact that this is tested on a prototype, the acceptance criteria is not as high as if it was a finished product.

10 Component Overview

In Table 50 a full overview of the components for the prototype can be seen.

Table 50: Component overview for the system

Ref.	Name	Brand/Model	Quantity	Description
Visual Detection System	Video Capture Device	Canon EOS 550D	1	Captures video stream.
	Lens	Sigma	1	70-300mm
	Tripod	Velbon C-600	1	Camera support.
	Mini-USB		1	Interface to computer.
Immobilization unit	Laser	Laser pointer	1	Weak generic laser pointer.
Processing unit (CPU)	Computer	Alienware M14	1	Image processing.
	Mini USB		1	Connector to Laser Control System
Galvanometer System	Galvanometer mirrors	RGB-SCAN20 close-loop scanner	2	7mm*11mm*0.6mm
	Control boards	RGB-SCAN20 close-loop scanner	2	-5V~+5V
	Power Supply	KAIHUI	1	+15V/1A, -15V/0.5A
	Cooling fan	Cooler master	2	DC 15V, 1A
Galvanometer Control Circuit	DAC	MCP4922	1	12 bit
	Operational amplifier	TL082CN	1	Dual 4 MHz
	Operational amplifier	TL084ACN	1	Quad 3 MHz
	Resistor		8	10kΩ ohm
	Microcontroller	Arduino UNO	1	Transmits digital signal received from computer, and outputs it through the digital output pins.
Microphone Array	Microphones	Panasonic WM-61	11	Electret microphones.
	ADC	PCM1804-Q1	6	Sigma-delta analog to digital converter.
	Amplifier	That 1583.	11	Microphone pre-amplifier.
	Clock Fanout Buffer	CDCLVC1310	1	High performance crystal buffer.
	Crystal Oscillator	Silicon Labs Si510	1	100 kHz to 250 MHz Oscillator. Operation

				frequency at 8.192 MHz.
Safety Measures	Thermal sensor	Omron D6T 1x8	1	Detects far infrared rays.
	Resistor		2	4.7kΩ

11 Post Analysis

The outcome of this project is a prototype capable of tracking moving objects, while steering a laser directly at it. It can determine if a mosquito is in fact present, and avoid firing the laser if a human or animal is within the designated area of effect. This is a system with strict real-time constraints, and the group had some doubts due to the necessary expertise to develop a system of such complexity. The galvanometers had to be calibrated and adapted to the designated area of effect automatically, while maintaining a satisfactory accuracy for the laser to target the mosquito, or some part of it, for immobilization. The system had to be capable of determining if a mosquito is present and distinguish it from other insects, such as a bee, while avoiding unintentional harm to humans, animals and also the environment. The group was able to overcome each of these obstacles through comprehensive research, as well as an extensive knowledge base from the group members with each of their specialized fields within electrical, audio and computer engineering. The amount of time that was allocated to this project made it necessary to prioritize which aspects of the system that would be prototyped, and which that had to be performed theoretically through extensive documentation and simulations. This means that the group has indeed proven that the system is capable of performing as required by KDA/IDS and MDS. Table 51 shows an overview of the requirements and how they were fulfilled, as well as which aspects that were not prioritized.

Table 51: Requirements fulfillment

ID	Requirement	Fulfillment	Priority
REQ-1	Immobilize / destroy mosquitoes in order to reduce the chance of infection caused by mosquitoes.	The laser control system demonstrates that accurately hitting small objects with a laser is possible. However, the prototype does not deploy a high-powered laser and the actual destruction of mosquitoes is not demonstrated by MDS.	A
REQ-3	Issue warning when unintentionally inactive.	This requirement is important, because the system should not give the user a false sense of safety. However, MDS decided that implementation of such a feature depends on the final hardware and software, and is not rewarding to implement on a conceptual prototype.	C
REQ-4	Area of effect may be adapted to the	The system may operate on backgrounds with various surface area and at different distances from the system.	C

	operational environment.		
REQ-5	Should not harm other insects.	The system will not emit the laser, unless a mosquito is detected through the auditive detection system. However, there are many insects that may have similar sound signatures, but the system is able to distinguish mosquitoes from bees, wasps, flies and many other insects.	B
REQ-6	Shall not harm humans or animals.	The system has a thermal sensor, which will detect the presence of humans and animals in the designated area of effect. If the sensor detects heat, the system will not be allowed to emit the laser.	A
REQ-8	Detect individual mosquitoes.	The detection of individual mosquitoes is fulfilled by combining several detection methods. First computer vision software will detect the presence of any flying insect about the size of a mosquito. Then it will in collaboration with a microphone array extract the audio signal produced by the flying insect's wing-beats. The properties of this signal will determine whether the system identifies the flying-insect as a mosquito or not.	A
REQ-9	The system should not cause collateral damage to inventory and environment.	Although there are three conditions that must be true, in order to emit the laser, the fact that the system deploys a powerful laser, may cause damage to inventory and environment. This may be everything from misuse to unanticipated flaws. However, for the system to emit the laser, the following conditions must be met: A small object or visual phenomena must be spotted by the computer vision. An audio signal with specific properties must originate in close proximity to the object. And finally no thermal signatures are detected by the thermal sensor.	B

Many milestones were reached and completed during this project, and the final prototype is better than what the group anticipated. The detection and tracking algorithm operates in real-time with little delay and great accuracy. Humans and animals are protected by the thermal sensor which is proven to be very reliable. Detecting the wing-beat frequency of a mosquito was proven possible using algorithms made in MATLAB. Several proof of principals were achieved and the result is beyond satisfactory.

11.1 Working Process

In the beginning, the group wanted to use the V-model as a guideline for the project process. The reasoning for this was that time limitations would not allow for do-overs or major changes in regards to hardware. It was quite certain that the system would consist of several hardware components, and therefore not as susceptible to change as software. The bottom line is that it was deemed appropriate with a process that would favor stability and quality over rapid and changeable development. Although the V-model favor such things, it is rather sequential if not practiced properly. Remove the “Verification & Validation” mantra, bend the V to a straight line and what is left is the waterfall model. However, the group decided early on that changing the project model was appropriate.

The group ended up using an incremental approach; the unified process framework.
This framework is focused towards architecture, risk and incremental/iterative development. Considering that the members are an interdisciplinary team, and were aware of many concerns and risks early on, this approach seemed suitable. The architectural focus has been very useful, considering that the system is running software on several hardware units, where their collaboration is essential for the system to function.

The project was planned in cohesion to the unified process terminology. Transition between major phases are referred to as increments, and transitions between sub phases are referred to as iterations. An increment should not occur unless a certain criteria is met, which is different for each phase. E.g. one should not increment from elaboration to construction without a stable/complete architecture. This has been the guiding principle during the project planning. Each increment concluded with a meeting with the external counselor providing feedback and validation. All iterations were planned with an iteration document, specifying purpose, context, tasks, deadlines, quality control, responsibility and category. In order to keep track of different tasks, Microsoft project was used for general progress and to estimate remaining hours, while Asana served as a platform for assigning tasks. Asana is a simple web application that allows the user to assign tasks, set deadlines, update progress and give a project overview. This is a simple tool, but for communication purposes the simplicity of Asana was much appreciated.

11.2 Group Dynamics

The major decisions concerning both the design and the process were made as a group. The decision-making process was rather democratic, meaning that decisions the group disagreed upon, were decided by vote. However, since there were six group members, the group leaders vote would count as two if the vote resulted in a draw. Luckily, there were few disagreements about the fundamental design decisions. The group recalls two such occasions when major design decisions were settled by vote due to disagreements. Although discussions were sometimes heated and intense, the issues were always resolved. Both sides were able to present their views, and their justification, and later on, the decisions were made by vote. Furthermore, everyone always accepted the decisions regardless of their opinion.

11.3 Counselors

11.3.1 Internal Counselor

The internal counselor for the group was Sigmund Gudvangen. He is an audio and electrical engineer and lecturer, and his expertise in microphones and audio was much needed. He has done a good job mentoring the group on microphones and electrical schematics. There has been weekly meetings with Sigmund where he has been updated on the projects process, and discussions about technical issues the group has faced.

11.3.2 External Counselor

The group’s external counselor was André Ruud, a project engineer at KDA, dep. IDS. He has helped the group with technical issues and given advices about technical documentation. The communication has been through e-mail and meetings, and he has been of great help.

11.4 Requirement Specification and Test Specification

Not every requirement was fulfilled, due to the rather short amount of time allocated to the project. All the A-priority requirements and one B-priority requirement was fulfilled, and all of them have been tested. The group has been very fortunate when it comes to fulfilling requirements and testing them. First of all; all the parts that were ordered to build a prototype arrived quickly and all the parts worked as stated. It did not take long to put the parts together and making them work with the software made, resulting in more time to upgrade the system in more detail. Second of all; all of the tests were approved either the first, second or third time they were tested. With these two factors combined, there was no need to extend the allocated time to testing.

11.5 Group Reflection

The team collaboration has worked well. In the beginning of the project the group worked with the same types of tasks. There was a lot of discussions and everyone participated in the decisions considering the system. Further on in the project every group member had their own field of responsibility that they primarily worked on. Everyone has had something to work on at all times, and everyone has participated in each field.

11.6 Individual Reflection

11.6.1 Ann Christin Barstad

This project has been an educational process. I have learned a lot about working in a group over time, collaboration, gained new knowledge about technological issues and learned a lot about how to test requirements. The task we were assigned was fun to work with because it was to some extend innovative and there were no guidelines from IDS on how we should solve it. This gave us the opportunity to create the system exactly how we wanted. The fact that we barely had any requirements that IDS wanted us to fulfill, made the project really complex from the start of. We had to decide everything regarding requirements, design and which technology to use. This has given me good experience on how to solve complex projects from the beginning to a prototype.

11.6.2 Christoffer M. N. Olsen

During this project, I have gained insight in how a project may be handled during a short period, and what it involves to work together as a group with a common objective. It can be demanding to merge the path from six different members in order to achieve a successful system, involving compromises and democratic decisions. This has resulted in a better understanding of the importance of an open dialogue in every step of the project. Furthermore, I have gained a better technical insight in regards to designing and simulating microphone arrays, audio signal processing, electrical circuits, IC-amplifiers, ADCs and clocking with its corresponding pitfalls. It has given me the opportunity to practice the knowledge I have gained during my electrical engineering degree with audio technology, in order to gain a bigger view of what this involves.

11.6.3 Eirik Haavaldsen

This project has given me experience in project management, signal processing, and a better understanding of analog electronics. This project has in my opinion given me a much greater understanding and familiarity with project models and methods than before. Unified process was something the group experienced for the first time during this project (including myself) and it has worked well for us. It has given us a taste of iterative and incremental work methodologies, and I believe each of us benefitted greatly from it.

As for technical work, I spent most of my time prototyping in MATLAB and researching methods for identify mosquitoes by their wing-beat frequency. I have been working close with our audio-engineer, Christopher, on the detection module and we have learned a lot while working on the auditive detection module.

I feel very lucky that we got this assignment. Not only is it an exciting subject, but we had a great amount of freedom of choice regarding design and technology. Through our imagination and by the inspiration of other solutions; we designed a system from scratch. I am proud of what the group has achieved during this project and I have enjoyed the experience.

11.6.4 Hege Jeanette Blikra

Working on this bachelor thesis has been an educational journey. By getting the chance to develop an innovative system from scratch, working in a group for a long period of time, as well as cooperating with engineers at Kongsberg Group and personnel at HBV, I feel very fortunate and more prepared to enter a work environment. I have gained technical knowledge through such as designing schematics by using new tools and contribute in building a prototype, which made us use theory acquired in courses in practical manners. Overall, I am pleased on how we as a group worked together and solved problems, and the results that came out of it.

11.6.5 Jawad Qureshi

During this project I have learned enormously about working together as a group. During this whole process I have used a good amount of knowledge I have acquired through my time at this school, at the same time I have learned about technology such as computer vision, and tools as MATLAB. I have also been responsible for communications such as the web site, which I built from ground up using PHP and MySQL. I also developed a blog and a backend system to manage the website content directly from the website. I am very satisfied with the end product, and have learned valuable lessons concerning teamwork, and have gained a lot of technical knowledge.

11.6.6 Max Moeschinger

During the course of this project, I have learned many things. I have learned how to work in a group, how it is to have a project over a period of time, and many technical aspects as well, such as how to create schematics and PCBs, how to work with image processing libraries, how to program in a modular way, how to design software with UML, and surprisingly a lot of electronic as I contributed quite a bit in the electrical design. But I think the most important thing I have learned is how to work in a group and that you don’t know anything until you have actually done it. All in all I am very happy with the result of this project and with the group, even though we had our differences, but it is part of the game.

11.7 Conclusion

This project has been very educational and given the group a thorough introduction to engineering work. The group is very satisfied with the outcome of the project; it could be argued in favor for the MDS being an innovative and new way to immobilize mosquitoes and possibly other insects if that is desired. The group has developed a lot in terms of professional skills and knowledge of general project work and cooperation. The project has taken the group far beyond the curriculum and subject areas, which have proved to be challenging, exciting and educational.

12 References

[1] R. Stevens, P. Brook, K. Jackson and S. Arnold, Systems engineering coping with complexity, Edinburgh: Pearson Education Limited, 1998.

[2] "Wikipedia," 29 01 2015. [Online]. Available: http://en.wikipedia.org/wiki/Image:RationalUnifiedProcess.png. [Accessed 2015].

[3] C. M. N. Olsen, "Detecting Mosquitoes With Microphone Arrays," Mosquito Defence Systems, Kongsberg, 2015.

[4] L. Riley, "Linkwitz Lab," Linkwitz Lab, 11 04 2015. [Online]. Available: http://www.linkwitzlab.com/sys_test.htm.. [Accessed 2015].

[5] T. Corporation, "Low-Noise, Differential Audio Preamplifier IC," THAT Corporation, 2015. [Online]. Available: http://www.thatcorp.com/datashts/THAT_1583_Datasheet.pdf. [Accessed 2015].

[6] S. Gudvangen, "ADC and DAC Errors," Sigmund Gudvangen, Kongsberg, 2014.

[7] C. M. N. Olsen, "Digital Audio: Course Work II," Christoffer M. N. Olsen, Kongsberg, 2014.

[8] P. Semiconductors, "I2S Bus Specification," Phillips, 1995.

[9] T. Instruments, "Full Differential Analog Input 24-Bit, 192-kHz Stereo A/D Converter," Texas Instruments, 08 2012. [Online]. Available: http://www.ti.com/lit/ds/symlink/pcm1804-q1.pdf. [Accessed 2015].

[10] T. Instruments, "Ten-Output Low-Jitter Low-Power Clock Buffer and Level Translator," Texas Instruments, 01 2014. [Online]. Available: http://www.ti.com/lit/ds/symlink/cdclvc1310.pdf. [Accessed 2015].

[11] S. Labs, "Si510/511: Crystal Oscillator (XO) 100 kHz to 250 MHz," Silicon Labs, 2013. [Online]. Available: https://www.silabs.com/Support%20Documents/TechnicalDocs/si510-11.pdf. [Accessed 2015].

[12] B. Technologies, "AC-Termination," BI Technologies, [Online]. Available: http://www.bitechnologies.com/pdfs/acterm.pdf. [Accessed 2015].

[13] J. Patoux, "Termination of High-Speed Converter Clock Distribution Devices," Analog Devices, 01 2014. [Online]. Available: http://www.analog.com/library/analogdialogue/archives/44-01/clock_termination.pdf. [Accessed 2015].

[14] T. Corporation, "That Corporation Design Note 140. Input and Output Circuits for THAT Preamplifier ICs. Phantom Power, Mic-Input Pads, Line Inputs,," THAT Corporation, 2014. [Online]. Available: http://www.thatcorp.com/datashts/dn140.pdf. [Accessed 2015].

[15] S. Gudvangen, "Introduction to microphone arrays," Sigmund Gudvangen, Kongsberg, 2014.

[16] H. J. Blikra and A. C. Barstad, "Immobilization System," Mosquito Defence Systems, Kongsberg, 2015.

[17] Damo, "Building a laser show," 05 11 2013. [Online]. Available: http://www.damow.net/2013/11/05/building-a-laser-show/. [Accessed 23 03 2015].

[18] Me & Mr. Cranky Pants, "Me & Mr. Cranky Pants," 21 09 2012. [Online]. Available: http://www.fab-favreau.com/index.php/Main/OLSDRev3. [Accessed 02 05 2015].

[19] Floyd, Electronic Devices: Conventional Current Version, New Jersey: Pearson, 2012.

[20] Electro-Labs, "Bypass Capacitors - Why and How to Use them?," Sana Syed, 30 01 2014. [Online]. Available: http://www.electro-labs.com/bypass-capacitors-why-and-how-to-use-them/. [Accessed 14 05 2015].

[21] Arduino, "Elfa Distrelec," [Online]. Available:

https://www1.elfa.se/data1/wwwroot/assets/datasheets/uno_eng_tds.pdf. [Accessed 2015].

[22] H. J. Blikra, "Galvanometer Scanner Technical Document," Mosquito Defence Systems, Kongsberg, 2015.

[23] Microchip, "Elfa Distrelec," 2007. [Online]. Available: https://www1.elfa.se/data1/wwwroot/assets/datasheets/MCP49214922_eng_tds.pdf. [Accessed 25 March 2015].

[24] W. Kester, "Analog," [Online]. Available: http://www.analog.com/library/analogDialogue/archives/39-06/Chapter%206%20Interfacing%20to%20Data%20Converters%20F.pdf. [Accessed 27 April 2015].

[25] ST, "Elfa Distrelec," 2008. [Online]. Available: https://www1.elfa.se/data1/wwwroot/assets/datasheets/tl082_a_b_eng_tds.pdf. [Accessed 28 March 2015].

[26] Texas Instruments, "Elfa Distrelec," 2004. [Online]. Available: https://www1.elfa.se/data1/wwwroot/assets/datasheets/tl081-tl084_eng_tds.pdf. [Accessed 28 March 2015].

[27] A. C. Barstad, "Laser," Mosquito Defence Systems, Kongsberg, 2015.

[28] S. M. Goldwasser, "Photonlexicon," 2010. [Online]. Available: http://www.photonlexicon.com/repairfaq/sam/laserpic/glpdpics.htm. [Accessed 2015].

[29] J. Kare, "Backyard Star Wars," IEEE Spectrum, 30 04 2010. [Online]. Available: http://spectrum.ieee.org/consumer-electronics/gadgets/backyard-star-wars. [Accessed 02 05 2015].

[30] Statens Strålevern, "www.nrpa.no," 10 01 2014. [Online]. Available: http://www.nrpa.no/fakta/90813/laserklasser. [Accessed 29 03 2015].

[31] "CW Welding vs. Pulse Welding," LITRON, 2011. [Online]. Available: http://www.litron.com/CW-vs-Pulsed-Weldings.asp. [Accessed 02 05 2015].

[32] T. Labs, "Laser Diodes," Thor Labs, 2015. [Online]. Available: https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=5260&pn=L404P400M. [Accessed 05 05 2015].

[33] "Cooler Master," Cooler Master, [Online]. Available: http://www.coolermaster.com/product/Lines/case-fan/. [Accessed 27 April 2015].

[34] "1688," KAHUI, [Online]. Available: http://detail.1688.com/offer/39288020912.html. [Accessed 29 April 2015].

[35] "Adafruit," Adafruit, [Online]. Available: http://www.adafruit.com/products/571. [Accessed 30 April 2015].

[36] Xicon, "Metal Oxide Power Resistor," 6 April 2009. [Online]. Available: http://www.arduino.cc/documents/datasheets/Resistors.pdf. [Accessed 1 May 2015].

[37] Farnell, "XH Connector," [Online]. Available: http://www.farnell.com/datasheets/5448.pdf. [Accessed 30 April 2015].

[38] Arduino, "Connectors," Arduino, 2015. [Online]. Available: http://store.arduino.cc/product/C000028. [Accessed 30 April 2015].

[39] Arduino, "Jumper Wires," Arduino, 2015. [Online]. Available: http://store.arduino.cc/index.php?main_page=advanced_search_result&search_in_description=1&keyword=jumper+wires&btnG=search. [Accessed 30 April 2015].

[40] OMRON, "Usage of D6T-44L / D6T-8L Thermal sensor," 1 1 2013. [Online]. Available: http://www.mouser.com/pdfdocs/D6T01_ThermalIRSensorWhitepaper.pdf. [Accessed 6 May 2015].

[41] OMRON, "OMRON," OMRON, 29 May 2013. [Online]. Available: http://www.omron.com/media/press/2013/05/e0529.html. [Accessed 06 May 2015].

[42] Luxo, "PIR Sensor," 8 September 2014. [Online]. Available: http://glamox.com/upload/2014/09/08/pir-sensor-bru-303-0106-rev-no-0.pdf. [Accessed 06 May 2015].

[43] S. Studio, "BISS0001 Micro Power PIR Motion Detector IC," Seeed Studio, [Online]. Available: http://www.seeedstudio.com/wiki/images/2/2f/Twig_-_BISS0001.pdf. [Accessed 14 05 2015].

[44] K. Neufeld, "Parallax Motion Sensor from Radio Shack," 5 January 2008. [Online]. Available: http://www.neufeld.newton.ks.us/electronics/?p=208. [Accessed 06 May 2015].

[45] "OMRON," OMRON, 2015. [Online]. Available: http://www.omron.com/media/press/2013/05/e0529.html. [Accessed 2015].

[46] FAMU-FSU College of Engineering, "Thermoelectric effects," Quantum Mechanics for Engineering, 1 1 2009. [Online]. Available: http://www.eng.fsu.edu/~dommelen/quantum/style_a/nt_pelt.html. [Accessed 6 May 2015].

[47] SimonSKChan, "Test and concept video of D6T-1616L prototype," 17 October 2014. [Online]. Available: https://www.youtube.com/watch?v=18EbrEiepkg. [Accessed 2015].

[48] E. Haavaldsen and C. M. N. Olsen, *Auditive Detection*, Kongsberg: Mosquito Defence Systems, 2015.

[49] D. G. Childers, "Cepstrum," IEEE, 10 10 1977. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1455016. [Accessed 30 04 2015].

[50] Aquila, "Aquila DSP," Aquila, [Online]. Available: http://aquila-dsp.org/features/. [Accessed 02 05 2015].

[51] rwb, "ermicro," rwb, 12 09 2010. [Online]. Available: http://www.ermicro.com/blog/?p=1846.. [Accessed 05 05 2015].

[52] SFUptownMaker, "Sparkfun," Sparkfun, [Online]. Available: https://learn.sparkfun.com/tutorials/i2c. [Accessed 05 05 2015].

[53] J. Q. Max Moeschinger, "MDS Controller," Mosuqito Defence Systems, Kongsberg, 2015.

[54] Sigma Photo, "Sigma Photo," Sigma Photo, 2015. [Online]. Available: http://www.sigmaphoto.com/product/70-300mm-f4-56-dg-macro#undefined. [Accessed 08 May 2015].

[55] SparkoCam, "Sparkosoft," Sparkosoft, 1 2012. [Online]. Available: http://sparkosoft.com/sparkocam. [Accessed 08 May 2015].

[56] M. Moeschinger, "OpenCV_v0.1_25.03.2015," Mosquito Defence Systems, Kongsberg, 2015.

[57] OpenCV, "OpenCV," Itseez, 2015. [Online]. Available: http://opencv.org/. [Accessed 30 04 2015].

13 Appendices

13.1 Appendix I: Microphone Array Schematic

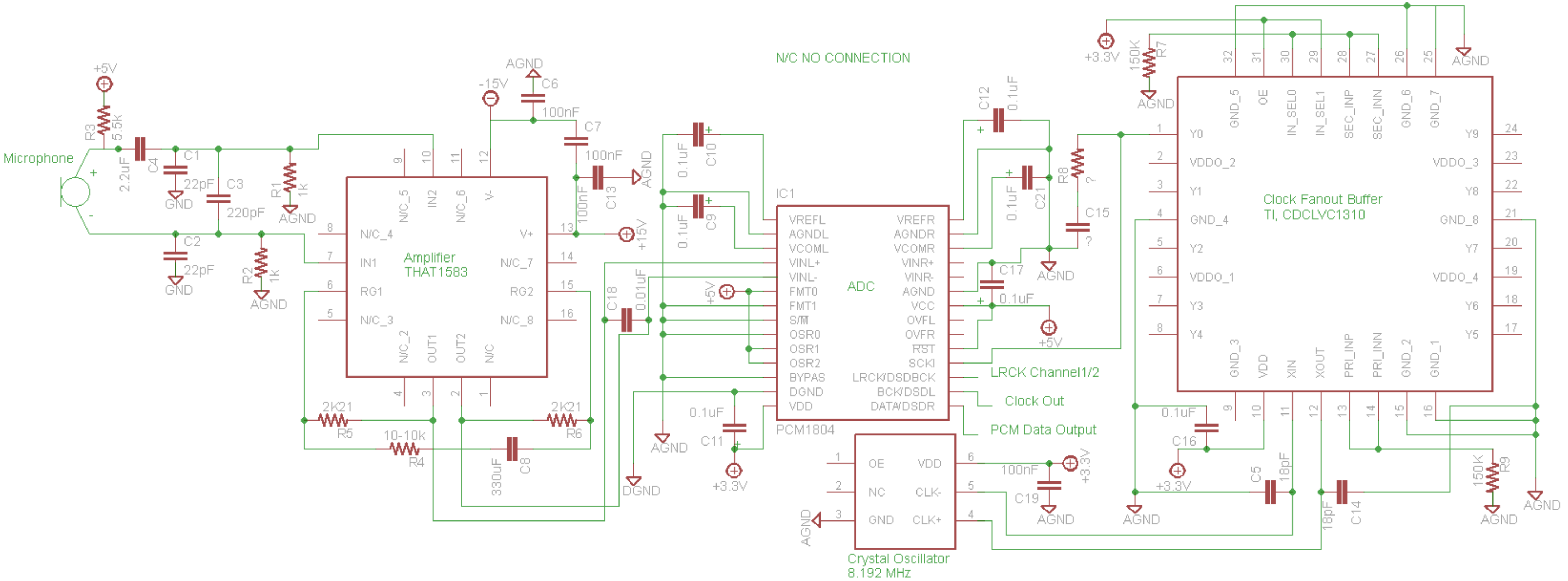


Figure 45: Microphone Schematics

13.2 Appendix II: Laser Control Schematics

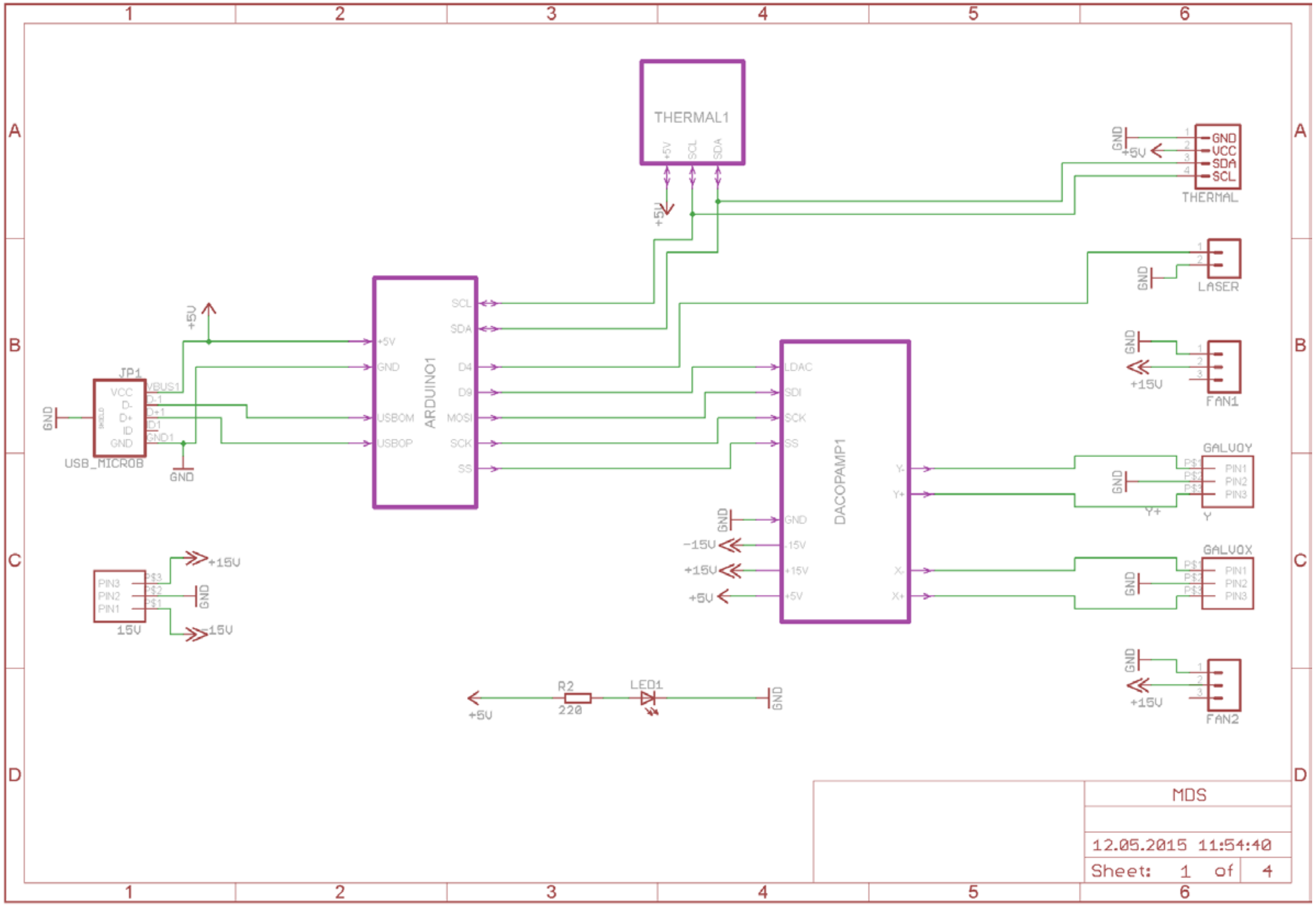


Figure 46: Module overview

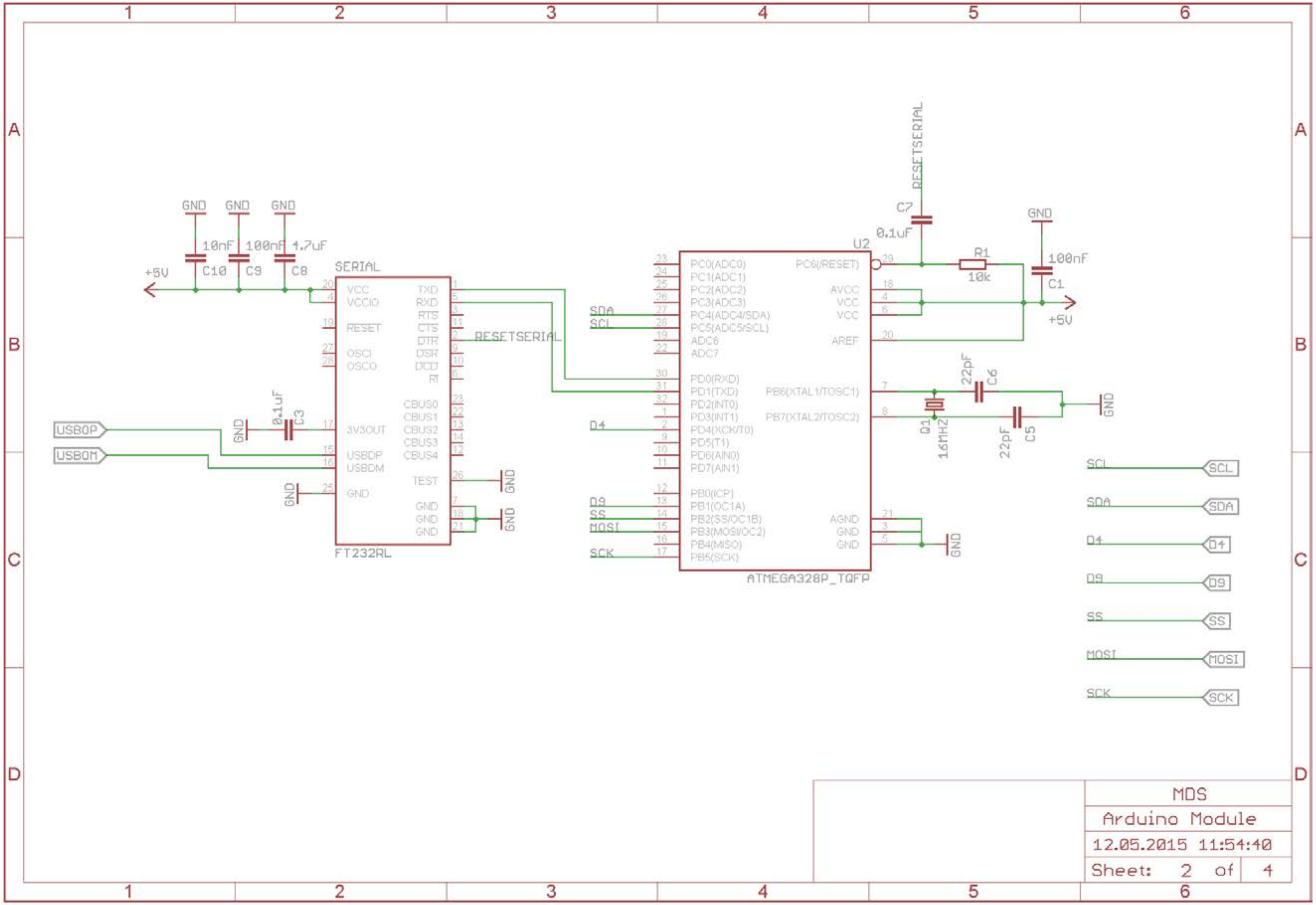


Figure 47: Arduino wiring diagram

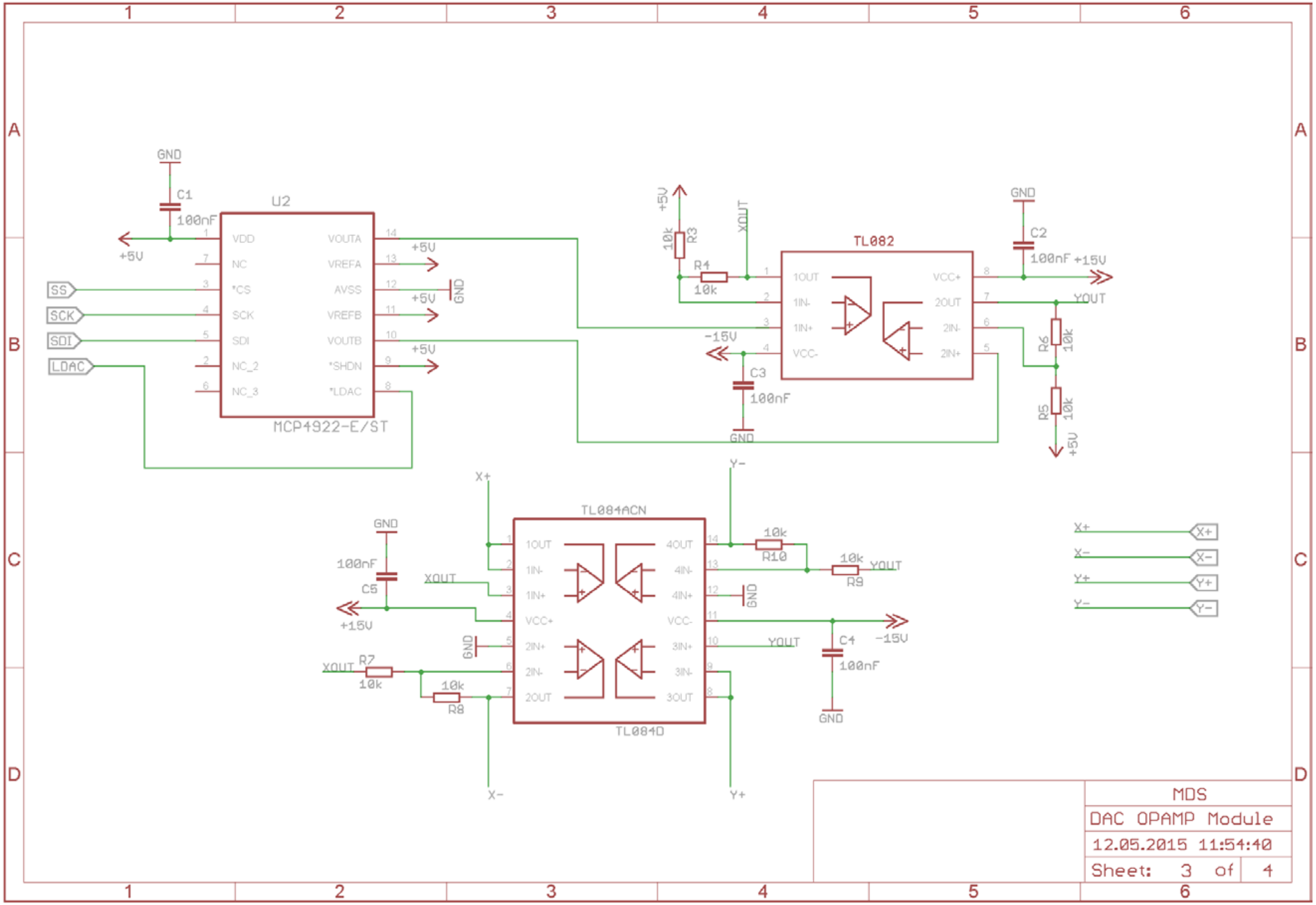


Figure 48: DAC and op-amp wiring diagram

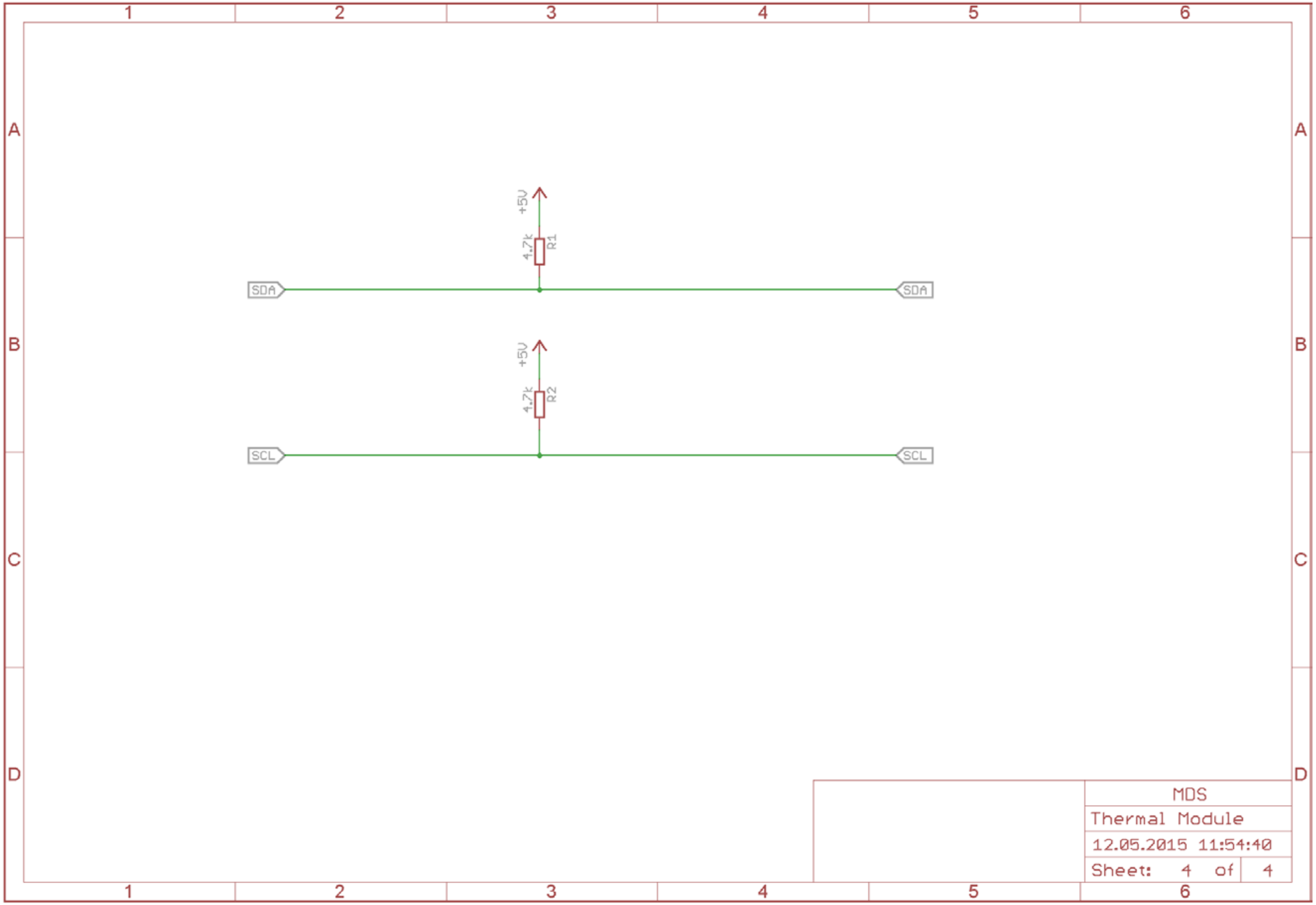


Figure 49: Thermal sensor wiring diagram

13.3 Appendix III: Power Supply Schematic

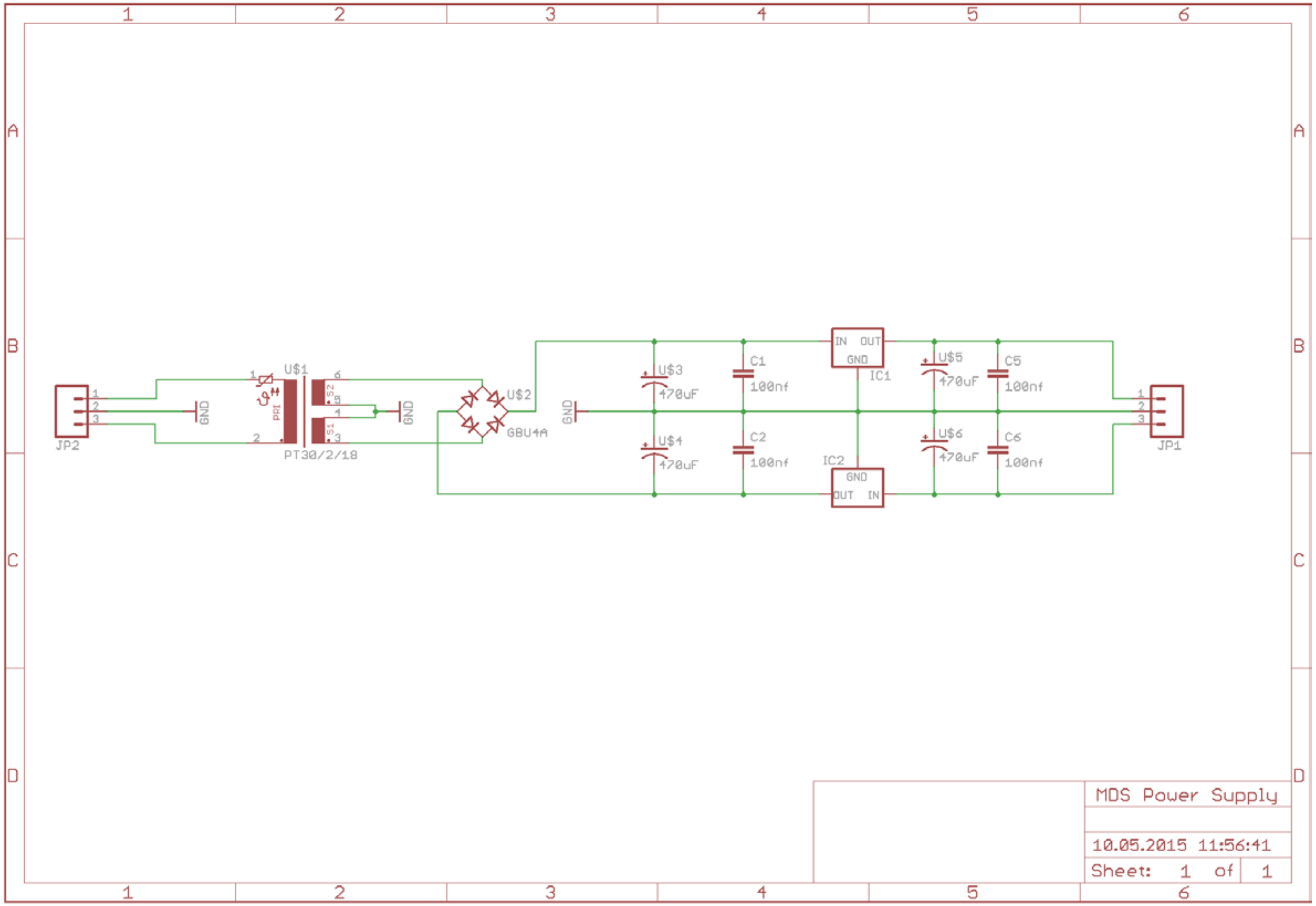


Figure 50: Power supply wiring diagram

Detecting Mosquitoes with Microphone Arrays

Mosquito Defence Systems

v2.0 ● 14.04.2015

Abstract

This document gives an introduction to whether or not it is practical to implement a microphone array in order to localize and detect mosquitoes. The reader will be presented with a brief presentation of why mosquitoes might be difficult to record in urban environments, noise measurements, basic principles of pressure and pressure gradient microphones and microphone arrays.

Document Version

Version	Date	Author	Description
0.1	01.03.2015	Christoffer M. N. Olsen	First complete draft.
0.2	05.03.2015	Christoffer M. N. Olsen	Added Chapter 2.5.
1.0	12.03.2015	Christoffer M. N. Olsen	First final version.
1.1	13.04.2015	Christoffer M. N. Olsen	Added Chapter 2.6, some extra information to 2.5.3 and the conclusion.
2.0	14.04.2015	Christoffer M. N. Olsen	Document complete.
2.0	09.05.2015	Ann Christin Barstad	Proofreading

Table of Contents

1 Introduction

The main issue with acoustic location (detection) of insects by microphones, is the rather low sound pressure level produced by e.g. mosquitoes. According to studies on behalf of the U. S. Department of Agriculture [1], a swarm of Aedes taeniorhynchus, more commonly referred to as black salt marsh mosquito, may produce sound pressure levels in the range of 25-35 dB. In a remote area away from traffic and other urban disturbances, the background noise might be as low as around 20 dB, and thus the mosquito swarm is detectable. That being said, in urban areas the background noise is in the range of 60 dB (speech/conversation) to 80 dB (traffic at a distance of a few meters) or higher. This means that even a swarm of mosquitoes will be rather difficult to detect, yet alone a single mosquito. At a distance of 0.03 m, a single mosquito will produce a sound pressure level of approximately 23 dB in the range of 0.3 to 3.4 kHz [1]. In order to make some sense of what this means, the sound pressure level from a single mosquito according to [2] is shown in Table 1 with a few different distances. The SPL is readily seen to decrease by 6 dB per each doubling of distance.

Table 1: Sound Pressure Level from a Single Aedes taeniorhynchus, recorded with one omnidirectional microphone

Distance (m)	Sound Pressure Level (dB)
0.03	25
0.12	13
0.24	7
0.48	1

2 Detecting Mosquitoes in Environments with Noise

The data from Table 1 does introduce some difficulties in regards to the ever present background noise, and especially in urban areas with considerable traffic. The sound pressure level of the mosquito must be greater in order to detect it.

2.1 Microphone Sensitivity

The sensitivity of a microphone is proportional to the effective area of the diaphragm. Doubling the number of microphones, e.g. from one to two, will thus increase the sensitivity for correlated sounds by 6 dB, and 3 dB for uncorrelated signals, such as noise. This means that the Signal-to-Noise Ratio (SNR) is increased by 3 dB. In other words, the noise is 3 dB lower than the sound from the mosquito, when using two microphones compared to one. This holds true per each doubling of microphones, hence increasing the number of microphones from one to four results in an increased SNR of 6 dB, and the mosquito may be positioned twice as far away for the same SPL as with one microphone.

2.2 Noise Measurements

Noise measurements conducted at the University College in Kongsberg in a classroom and an auditorium [3], resulted in a noise level that decreases with frequency. This is readily seen in Fig. 1, where the power spectrum of noise in a quiet auditorium is shown. This means that the SNR can further be improved by band pass filtering. Since the male and female mosquitoes has a wing beat fundamental frequency of 700 to 800 Hz and 400 to 500 Hz [1], respectively, any noise components below a minimum frequency of e.g. 300 Hz can be removed by a low pass filter. In Order to detect the species of a mosquito and whether it is a female or male, it might be of interest to preserve the first harmonic frequencies of the fundamental wing beat. This is of interest considering that only female mosquitoes bite humans. According to recordings of mosquitoes [2], the fundamental (first harmonic) of a mosquito has a sound pressure level of 26 dB compared to adjacent inter-peaks, the second harmonic a SPL of 8 dB compared to adjacent peaks, and the third harmonic a SPL of 4 dB compared to adjacent peaks. Hence it might not be of practical interest to preserve any higher frequency components for detection. A female Aedes taeniorhynchus has a fundamental frequency of 400 to 500 Hz. If 500 Hz is used as a reference for the fundamental frequency of the wing beat, the second harmonic is 1000 Hz, and the third harmonic at 1500 Hz. Hence it is a scope for removing frequencies above e.g. 2000 Hz by a high pass filter. This results in a band pass filter with a lower cut off frequency of 300 Hz and an upper cut off frequency of 2000 Hz. The computed power spectrum in Fig. 1 has a noise level of 20 to 29 dB in this range, compared to 13 to 43 dB for 30 to 8000 Hz. A band pass filter may be achieved by e.g. an analogue RLC-filter or a digital filter.

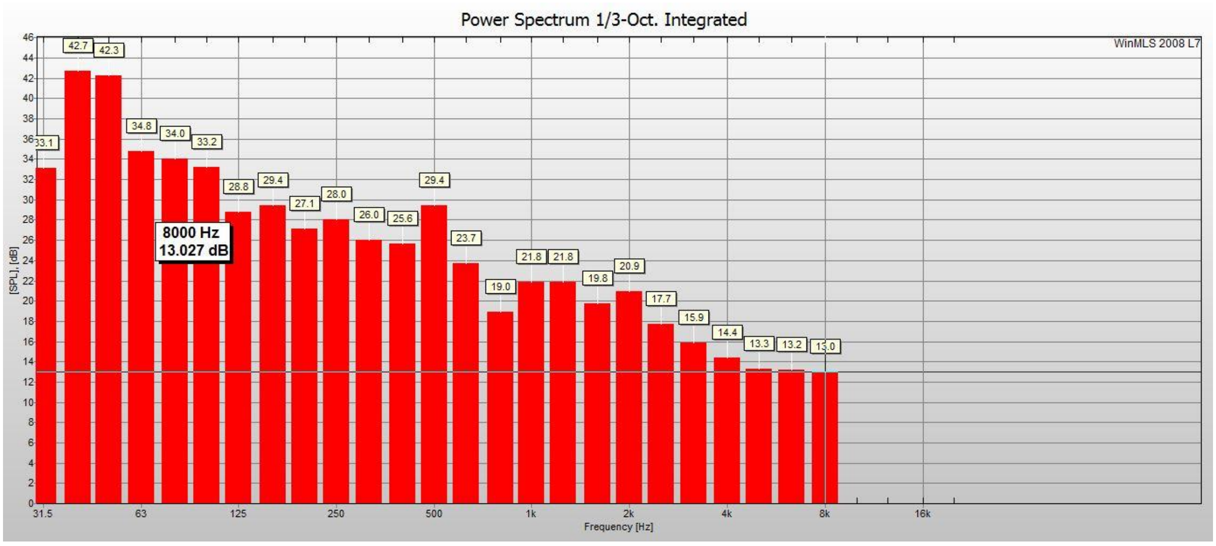


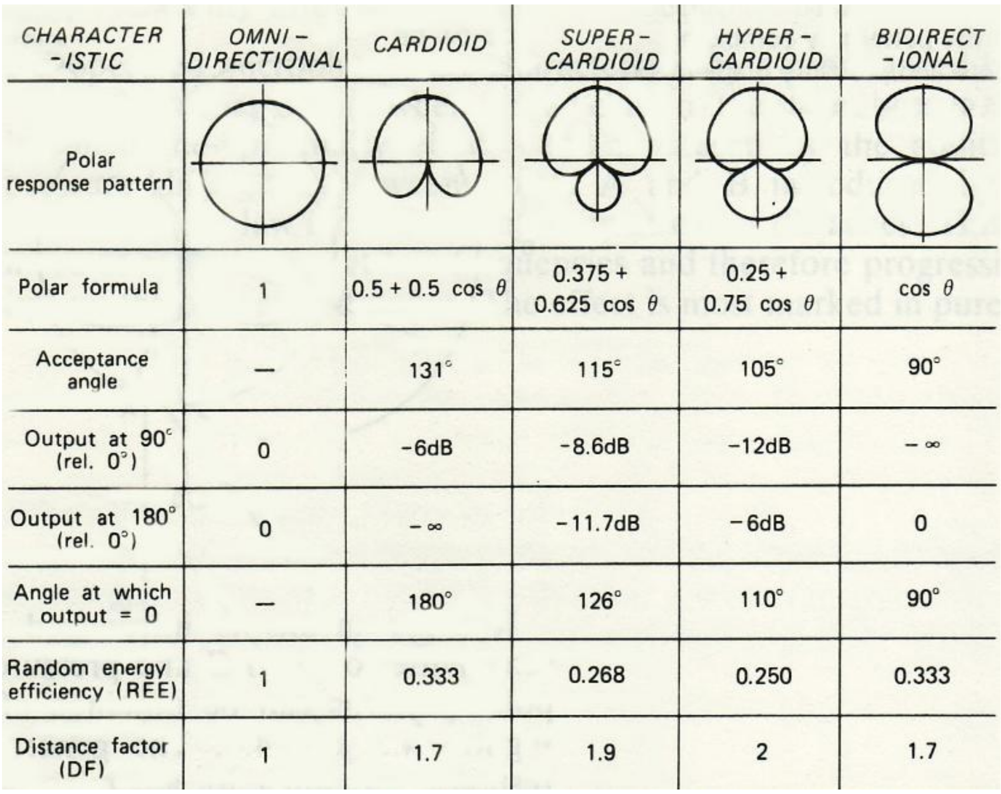
Figure 1: Power spectrum of background noise in auditorium B120, University College in Kongsberg.

2.3 Directional Microphones

Doubling the number of microphones, or the effective area of the diaphragm, will increase the SNR by 3 dB. In connection with a band pass filter a further improvement in SNR is likely, though it might be necessary to implement other tools in order to suppress the ever surrounding noise contributes from traffic, speech, other insects etc.

The main difficulty of an omnidirectional microphone is, not so surprisingly, that the microphone will be equally sensitive to sound waves arriving at arbitrary angles in 4π steradian (sr). This type of microphone is known as a pressure microphone, and only receives sound waves through a single active opening. It is worth noting that at the main axis of the microphone, some directionality is introduced due to diffraction when the wavelength approaches the circumference of the diaphragm. This is mainly from $ka = 1$, where $k = (2\pi f)/c$ is the wavenumber, c is the speed of sound and a the radius of the diaphragm. A directional microphone, at the other hand, is not equally sensitive for all angles of arrival. The basic working principle of pressure microphone is that it only receives sound waves through a single active opening, meaning the front of the diaphragm, and thus not sensitive to a pressure difference acting at the back of the diaphragm. A directional microphone has an opening to the back of the diaphragm. A single sound wave acting at the front of the diaphragm will have a small delay until it reaches the back of the diaphragm causing constrictive and destructive interference. By adjusting this time difference it is possible to achieve different directional polar patterns, as seen in Fig. 2.

In order to make some sense of this, it is common to use the Directivity Index (DI) and the Distance Factor (DF). The Directivity Index is referenced as 0 dB for an omnidirectional microphone, and e.g. 6 dB for a microphone with a hypercardioid polar pattern, as seen in Fig. 2. As previously stated, doubling the distance from a sound source will result in a 6 dB decrease in SPL. Hence a directional microphone with a DI of 6 dB, will make it possible to be distanced twice that of an omnidirectional microphone from the sound source, for the same measured SPL. Hence, a hypercardioid microphone will have a Distance Factor of 2 compared to an omnidirectional microphone, since it can be twice as far away from the sound source and still detect the same SPL. Another interesting parameter is the acceptance angle, as seen in Fig. 2. The acceptance angle is a measure of how wide an angle a sound wave can arrive from referenced to on-axis, without a greater reduction in SPL than 3 dB. For a hypercardioid, the acceptance angle is seen to be 105 degrees. What this means, is that a sound source arriving at an angle of 105/2 = ±52.5 degrees referenced to on-axis, will be 3 dB lower in SPL compared to on-axis. Beyond this point the sensitivity will only decrease to a minimum at110 degrees, where the sensitivity is 0, and there will be no output from the microphone for sound waves arriving at this angle. Sound waves arriving at an angle of 90 degrees in reference to on-axis (0 degrees), will have a 6 dB decrease in SPL, as seen in Fig. 2, and will thus be perceived as being twice as far away as a sound wave with equal SPL arriving on-axis.



CHARACTER-ISTIC	OMNI-DIRECTIONAL	CARDIOID	SUPER-CARDIOID	HYPER-CARDIOID	BIDIRECT-IONAL
Polar response pattern					
Polar formula	1	0.5 + 0.5 cos θ	0.375 + 0.625 cos θ	0.25 + 0.75 cos θ	cos θ
Acceptance angle	—	131°	115°	105°	90°
Output at 90° (rel. 0°)	0	−6dB	−8.6dB	−12dB	−∞
Output at 180° (rel. 0°)	0	−∞	−11.7dB	−6dB	0
Angle at which output = 0	—	180°	126°	110°	90°
Random energy efficiency (REE)	1	0.333	0.268	0.250	0.333
Distance factor (DF)	1	1.7	1.9	2	1.7

Figure 2: Directivity patterns, from [4].

2.4 Microphone Array

The use of directional microphones, filters and an increase in the effective diaphragm area will improve the SNR, and thus the possibility of detecting mosquitoes in a noise filled environment. Hence it seems appropriate to combine these methods in a system that can detect the mosquito as well as the position. Using e.g. two directional microphones with a certain amount of space between will only be sensitive to sound waves arriving on-axis, and might not be able to detect the mosquito if it is positioned between the microphones. Hence it seems rather impractical to use directional microphones to compute where the mosquito is positioned relative to the microphones, making omnidirectional microphones in an array a more attractive approach. It will be assumed that the sound source is in the far-field, which is true for sound sources at a distance of $r_c > 2L^2/\lambda$, where L is the length of the array and λ the wave length of the incoming sound wave.

2.4.1 Beamforming

When a mosquito is omitting sound between e. g. two, spaced pressure (omnidirectional) microphones, the sound wave will be captured at different times in the time domain and thus with a different phase in the frequency domain at each microphone (since the microphones are omnidirectional, they are equally sensitive for all directions of arrival), as seen in Fig. 3. This is a result of the varying distance from the sound source to the microphones. As previously mentioned for microphones who are directional, a single sound wave acting at the front of the diaphragm will have a small delay until it reaches the back of the diaphragm, resulting in constructive and destructive interference, and thus an increased sensitive on-axis. What this means for the two, spaced omnidirectional microphones, is that by delaying the signal from one omnidirectional microphone relative to the other, the summed signal from the microphones will result in constructive and destructive interference. This is known as a Delay-and-Sum beamformer. The microphone array can therefore be set to be highly sensitive to a certain direction of arrival by an appropriate time delay. This is computed by

$$D'(f,\phi) = (x+a)^n = \sum_{n=-\frac{N-1}{2}}^{\frac{N-1}{2}} a_n(f) e^{jknd[\cos(\phi)-\cos(\phi')]} \qquad (1)$$

where $k = \frac{2\pi}{\lambda}$, the wavenumber, n the number of microphones, d the inter-microphone distance, $a_n(f)$ the frequency dependent amplitude and the exponent the delay term.

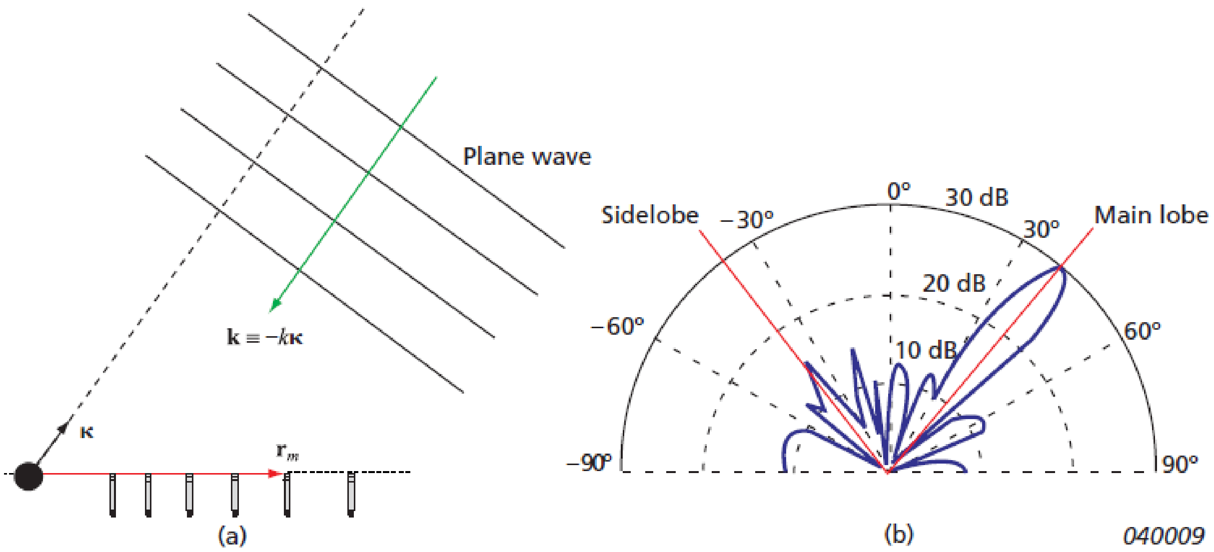


Figure 3: a) Incoming sound wave off-axis relative to the array b) main lobe of a delay-sum beamformer array. From [5].

2.4.2 Spatial Sampling

The position of the mosquito can be found by the time delay between e.g. two omnidirectional microphones, and correspondingly a microphone array can be steered to be more sensitive to certain angles by delaying the signal from one of the microphones relative to the other. This will result in a reduced sensitivity to sound sources with other directions of arrival, and an increased SNR. Since a mosquito is rather small, and the SPL accordingly, it is of interest to avoid noise from all other directions as much as possible. How sensitive the array is to sound waves approaching at other directions of arrival, relative to the steered angle of the array, depends on the distance between the microphones relative to the wavelength of the incoming sound wave. The spatial sampling theorem [6] states that the distance between the microphones, d, in an array, must be less than half the wavelength of the incoming sound wave, $d < \lambda/2$, where $\lambda = c/f_{max}$, where c is the speed of sound and f_{max} the maximum frequency of the incoming sound wave. For an incoming sound wave with a max frequency of 1000 Hz, the distance between each microphone must be no more than 0.1715 m. Increasing the distance will result in side lobes who are equally sensitive as the main lobe. Decreasing the distance will result in an increased sensitivity to sound waves from other directions. This can be seen in Fig. 4, where the polar patterns for a microphone array consisting of two omnidirectional microphones, an incoming sound wave with a frequency of 1000 Hz and four different inter-microphone distances. It is clear that the distance should be $d = \lambda/2$, that is, 0.1715 m.

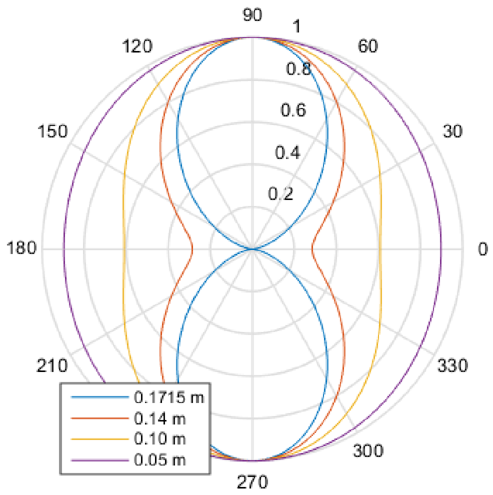


Figure 4: Polar pattern for equi-spaced microphone array with two omnidirectional microphones, an incoming sound wave with a frequency of 1000 Hz, and an inter-microphone distance of 0.1715 m, 0.14 m, 0.10 m and 0.05 m.

If the distance between each microphone is equal, it will have a good Directivity Index and Distance Factor for wavelengths who are equal to twice the distance between the microphones. If the incoming sound wave has a wave length shorter than this, meaning a higher frequency, the microphone will be more sensitive to sound waves approaching from other angles. This means that the equally spaced microphone array will only work well for detecting mosquitoes at a certain frequency. Considering that the wing beat of a mosquito contains several harmonics, this reduces the efficiency of the microphone array. This may be solved by using a sparse array. Sparse arrays have equal directivity (DI, DF), and thus noise suppression, for all frequencies, by varying the distance between the microphones.

2.4.3 Resolution

The angular resolution, that is, the microphone arrays ability to distinguish between e.g. two closely spaced mosquitoes at a distance from the array, is inversely proportional to the diameter of the array measured in units of wavelength [5]. This means that in order to distinguish between two closely spaced mosquitoes in regards to localizing the position, the length of the array must be much larger than the wavelength from the wing beat of the mosquito for a fine resolution. The fundamental frequency of 400 Hz for a female mosquito [1] equals a wavelength of c/f = (343 m/s)/(400 s^{-1}) = 0.8575 m ≈ 1 m, where c is the speed of sound and f the frequency in Hz. Hence the diameter of the array must be considerably larger than 1 meter for a fine resolution. The beamformer resolution may be expressed by

$$R(\theta) = \frac{\alpha}{cos^3\theta}\frac{z}{D}\lambda \qquad (2)$$

Where α = 1 for a linear array, z is the distance from the array to the sources, D is the length of the array, θ is the angle to the closest sound source relative to on-axis and λ the wavelength. See Fig. 5.

If the array is D = 0.5 m long, the sound sources are z = 0.5 m away from the array, the wavelength is λ = 343 m/s / 400 Hz = 0.8575 m and θ = 0.523598 Rad/s = 30° in accordance to Fig. 5, (1) results in 0.8849 m. This means that the two sound sources must be separated by 0.8849 m in order to detect them as two separate sound sources. In other words, they must be separated more than the length of the array. Increasing the array length, D, to 2 m, results in a necessary separation of 0.22 m, and increasing D further to 4 m results in a necessary separation of 0.11 m. Hence it is clear that the length of the array must be long compared to the wavelength, which might prove troublesome.

A microphone array may be used in order to detect that the incoming sound waves are in fact coming from a female mosquito, by steering the sensitivity towards its position if it is obtained by other means. Obtaining the position by the array on the other hand will be troublesome.

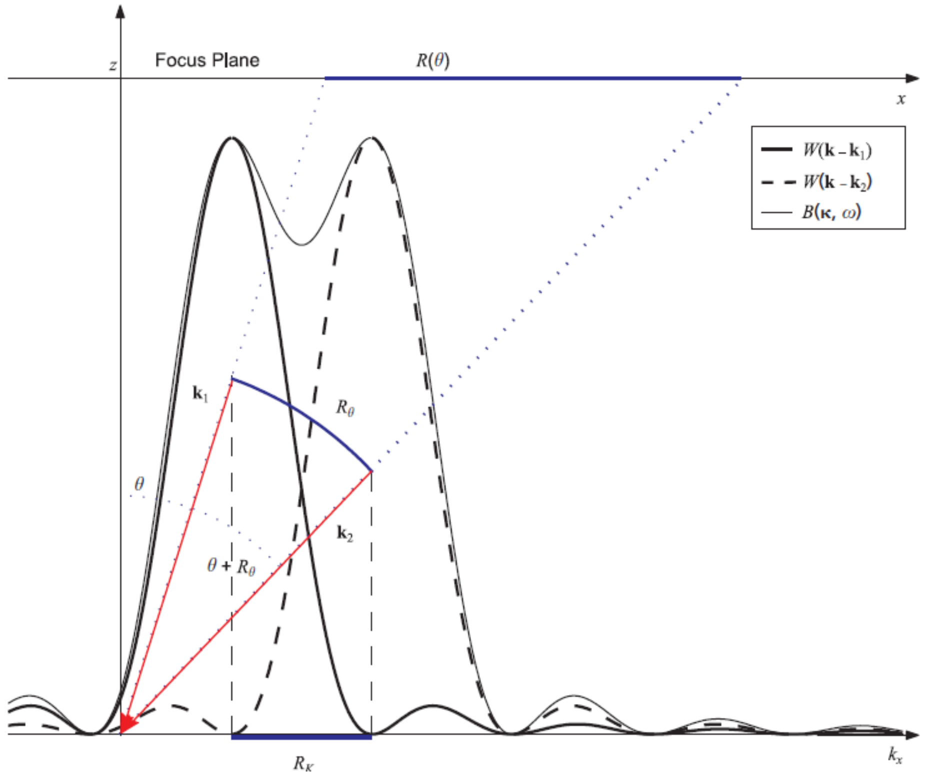


Figure 5: Beamformer resolution. W(k-k$_1$) and W(k-k$_2$) are two separate sound sources (plane waves), B(κ,ω) are the beamformer output. From [5].

2.5 Simple 1D Microphone Array Design with Electret Microphones

A brief presentation of electret microphones and how they may be implemented in a simple one dimensional microphone array design will be presented. This is strictly theoretically.

2.5.1 Electret Microphone

Electret materials makes it possible to design capacitor microphones with good performance at a low cost, eliminating the need for polarization voltage. The electret is given a permanent electrostatic charge by placing it under a strong electric field as well as under heat [7]. Removing the heat does not alter the electric charge, and it might not decay for hundreds of years. This makes electret microphones a reasonable choice in connection with microphone arrays, where several microphones might be necessary. This comes especially about when making prototypes.

2.5.2 Panasonic WM-61A

Panasonic WM-61A is an omnidirectional electret microphone with a cost of roughly 20- to 40,- NOK per unit, and measures 3.4 mm in height and 6 mm in diameter. It can be connected directly to e.g. a computer or sound card, as long as a voltage is applied to the JFET. The maximum sound pressure level is approximately 109 dB before clipping [8]. For higher SPLs the microphone must be modified in order to reduce high distortion levels because of a lacking source resistor in the inbuilt JFET amplifier.

Several measurements have been conducted of the WM-61A, showing a flat frequency response up to 2 to 3 kHz, though with no more deviation than about +/- 2 dB up to 20 kHz. Hence for applications where accuracy is not necessary beyond 2 to 3 kHz, no means of calibration is necessary [9]. This good news considering that the third harmonic of a female mosquito is about 1.5 kHz. The drawback of using a microphone of this size is that the sensitivity will be very poor, and high distortion levels at moderate SPLs due to the lacking source resistor [10].

A proposed schematic with the WM-61A drawn from [10] can be seen in Fig. 6. From the datasheet of WM-61A [11], a supply voltage of 2V in series with a 2.2kΩ resistor is recommended, thus using a 9V battery as the voltage supply results in a 10kΩ resistor.

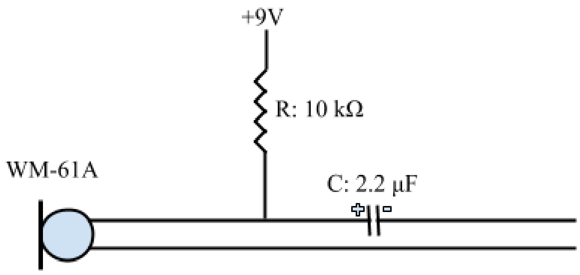


Figure 6: WM-61A with supply voltage, resistor and DC blocking capacitor

2.5.3 Microphone Positioning

In order to determine the distance between the microphones, that is, the position on an array, one must consider the maximum frequency of the incoming sound wave. The maximum frequency can be set to the third harmonic of the wing beat of a female mosquito of 400 Hz, that is, 1200 Hz. Hence the distance between each microphone must be less than half the wavelength of 1200 Hz, $d < \lambda/2$. The wavelength at 1200 Hz is $\lambda = c/f$ = (343 m/s)/(1200 s^{-1}) = 0.2858 m. This yields a distance, d < 0.1429 m. This means that a reasonable distance between each microphone will be 0.14 m.

With a distance of 0.14 meters between each microphone, using five microphones and an incoming sound wave of 400 Hz, 800 Hz and 1200 Hz, the resulting polar patterns will be as seen in Fig. 7. For 800 and 1200 Hz the microphone array is highly directive, with heavily suppressed side-lobes. At 800 Hz the first null in the polar pattern is seen to be 30 degrees off-axis, considering 90 degrees as reference on-axis. For 1200 Hz the first null is already at approximately 15 degrees. For an incoming sound wave of 400 Hz, the fundamental frequency of a female mosquito, the polar pattern is seen to inherent no nulls, and only a reduction from 1.0 to 0.8 in sensitivity is achieved for incoming sound waves 30 degrees off-axis. In order to suppress noise from other directions, the directivity of the microphone array must be increased. This may be achieved by increasing the number of microphones, from five to nine microphones, respectively. The resulting polar patterns can be seen in Fig. 8. Now the first null for an incoming sound wave of 400 Hz at approximately 40 degrees. With nine microphones the length of the array will be L = (0.14)(9-1) = 1.12m, as seen in Fig. 9. The acceptance angle at 400 Hz will approximately be 34 degrees, resulting in a main-lobe radius, *r*, of *r = (tan(34/2))(x)* where *x* is the distance from the microphone array to the sound source. Hence at a distance of 0.5 m the radius will be 0.15 m, and at 1 m it will be 0.3 m. This is rather large, considering that it might be several insects within a diameter of 0.3 and 0.6 m.

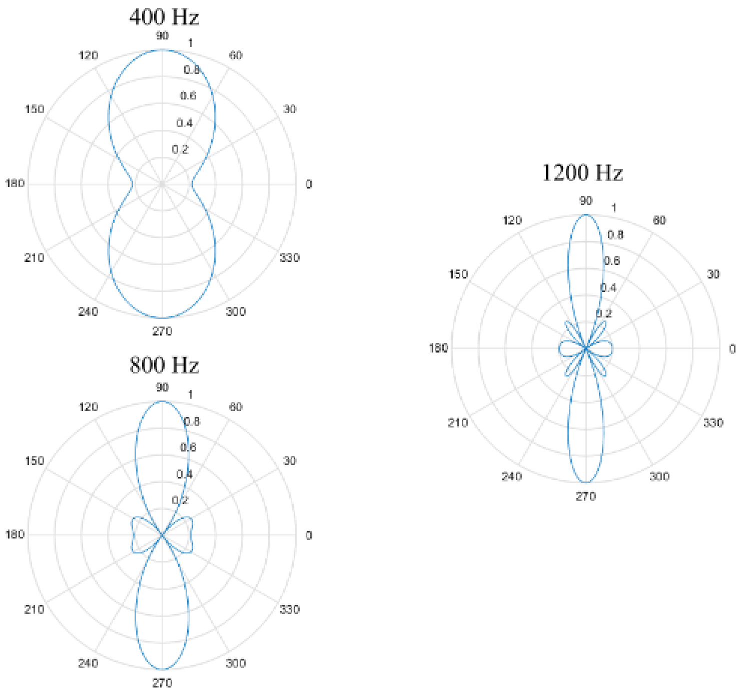


Figure 7: Polar patterns for incoming sound waves of 400, 800 and 1200 Hz, 5 microphones with 0.14m between each

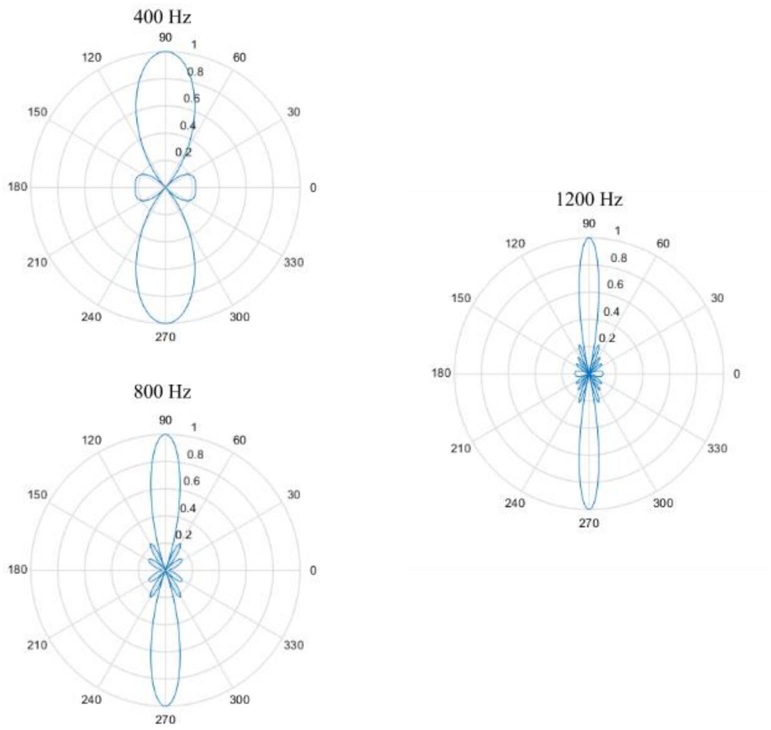


Figure 8: Polar patterns for incoming sound waves of 400, 800 and 1200 Hz, 9 microphones with 0.14 m between each

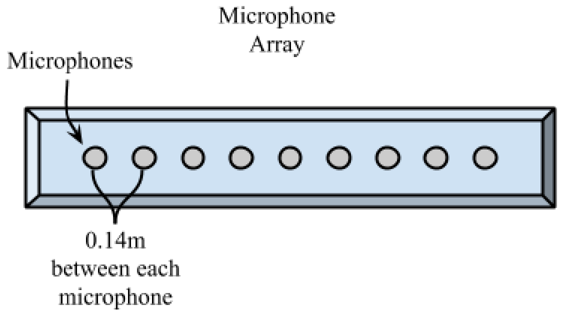


Figure 9: Microphone Array

2.6 Sparse Microphone Array

From chapter 2.5.3 it is clear that the array will require several microphones in order to achieve a narrow main-lobe, when using a microphone array with equally spaced microphones. This might be unpractical considering the length of the array, if it is to be installed in e.g. a windowsill or other openings to a building. Hence it is of interest to explore possible means of reducing the width of the array, while achieving as good, or preferably, better results considering the main-lobe of the microphone array. This may possibly be achieved by a sparse microphone array.

2.6.1 Working Principle

In sparse arrays the microphones are positioned with different spacing. A dense, equally spaced packing of microphones are concentrated in the center of the array, with increasing distance towards the ends, as seen in Fig. 10. By combining the microphones with equal spacing to a sub-array, it will result in several sub-arrays with different inter-microphone spacing. Band-pass filtering each of the outputs from the sub-arrays will then result in a constant beam-width microphone array over a frequency range of interest, f_{min} to f_{max}, as seen in Fig. 11. Hence the problematic nature concerning the beam-width of equally spaced microphones are avoided, and the array will obtain good noise suppression for the fundamental and over-harmonic frequencies from a mosquito.

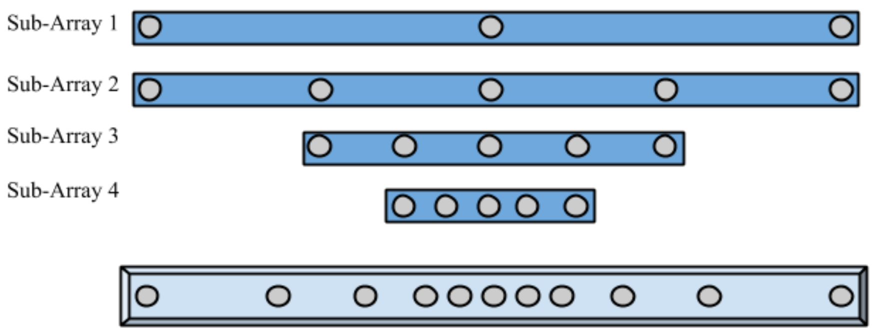


Figure 10: Sparse Array and corresponding sub-arrays

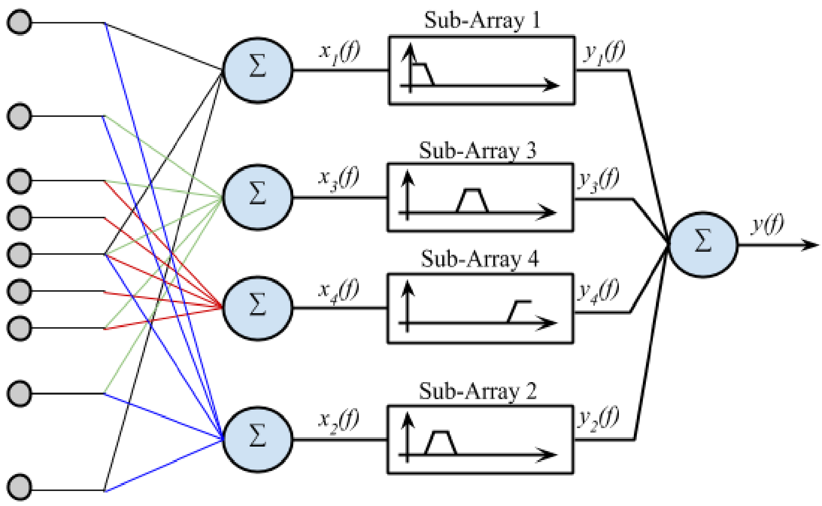


Figure 11: Spare Array Signal Processing

2.6.2 Inter-Microphone Spacing

Since there is a fundamental frequency and two over-harmonic frequencies that might be of interest to preserve, it seems expedient to arrange the sparse array with three sub-arrays, in order to suppress unwanted sound waves at this frequency range. Since the female mosquito have a fundamental frequency of 400-500 Hz, and thus a third harmonic at approximately 1500 Hz (if 500 Hz is considered as the fundamental), the frequency range of interest will be f_{min} = 300 to f_{max} = 1800 Hz to ensure some headroom. The upper frequency of the sub-arrays may be computed by

$$f_{max\_subarrays} = f_{min}\left(\left(\frac{f_{max}}{f_{min}}\right)^{\frac{1}{N}}\right)^{i} \qquad for\ i\ = 1, 2 \ldots N \quad (3)$$

where f_{min} and f_{max} is the lower and upper frequency of interest, and N is the number of sub-arrays.

The required inter-microphone distance for each sub-array is then computed by

$$d = \frac{c}{2(f_{max})} \qquad (4)$$

where c is the speed of sound (343 m/s at 20 degrees Celsius), and f_{max} the upper frequency in the sub-array.

With three sub-arrays, the upper frequency for each sub-array will be as seen in Table 2 with its corresponding inter-microphone distance. Table 3 shows the same data when four sub-arrays are employed, Table 4 when five sub-arrays are used, and finally Table 5 when six sub-arrays are employed, respectively.

Table 2: Upper frequency of the sub-arrays and inter-microphone spacing with 3 sub-arrays

	Sub-Array 1	Sub-Array 2	Sub-Array 3
f_{max} (Hz)	545	991	1800
d(m)	0.315	0.170	0.095

Table 3: Upper frequency of the sub-arrays and inter-microphone spacing with 4 sub-arrays

	Sub-Array 1	Sub-Array 2	Sub-Array 3	Sub-Array 4
f_{max} (Hz)	470	735	1150	1800
d(m)	0.365	0.233	0.150	0.095

Table 4: Upper frequency of the sub-arrays and inter-microphone spacing with 5 sub-arrays

	Sub-Array 1	Sub-Array 2	Sub-Array 3	Sub-Array 4	Sub-Array 5
f_{max} (Hz)	429	614	879	1258	1800
d(m)	0.400	0.280	0.195	0.136	0.095

Table 5: Upper frequency of the sub-arrays and inter-microphone spacing with

	Sub-Array 1	Sub-Array 2	Sub-Array 3	Sub-Array 4	Sub-Array 5	Sub-Array 6
f_{max} (Hz)	404	545	734	991	1335	1800
d(m)	0.425	0.315	0.234	0.173	0.128	0.095

Though it seemed appropriate with three sub-arrays, considering the maximum frequency for each of the sub-arrays, the use of four sub-arrays seems to result in a better fit when the fundamental is in the frequency range of 400-500 Hz, second harmonic at 800-1000 Hz and the third at 1200-1500 Hz.

2.6.3 Sparse Array Design with Four Sub-Arrays

In order to evaluate if a sparse array may result in a narrower main-lobe across the frequency range of interest, in comparison to the microphone array in chapter 2.5.3, a proposed design with nine microphones will be presented. The spacing between the microphones will be as stated in Table 3 with the corresponding upper frequency limits for the sub-arrays. Hence the microphone array will equal that of Fig. 11 in regards to layout of the microphones. Fig. 12 illustrates the spacing for a better understanding.

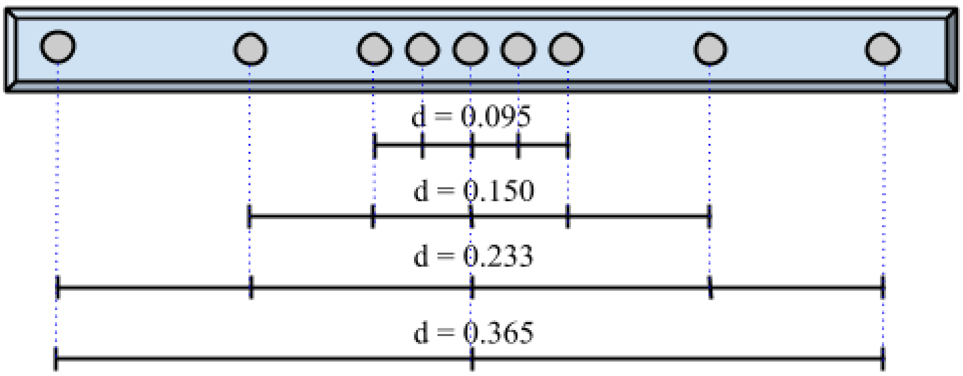


Figure 12: Sparse Array with 9 microphones and 4 sub-arrays. Minimum frequency of 300 Hz and maximum frequency of 1800 Hz.

It is clear from the Fig. 12 that length of the microphone array will be twice that of the inter-microphone spacing for sub-array 1 with a maximum frequency of 470 Hz, corresponding to (0.365m)(2) = 0.73 m. This is considerably shorter than 1.12 m as for the microphone array with equally spaced microphones, though it is seen that sub-array 1 will consist of 3 microphones, while sub-array 2 through 5 will consist of 5 microphones, respectively. Hence for lower frequencies the main-lobe will be slightly wider. That is, for the frequency range of 300 Hz to 470 Hz. Now it is of interest to see how the different sub-arrays will perform at the key-frequencies of interest: 400, 800, 1200 Hz. Considering that the number of microphones per sub-array is less than the nine microphones for the equally spaced microphone array, it might not prove appropriate.

2.6.4 Sparse Array Performance

An easy way to evaluate whether or not the sparse microphone array presented so far outperforms the microphone array presented in chapter 5.3.1, is by evaluating where the first zero in the polar pattern is located in regards to 0 degrees on-axis. In Table 6 the results are presented.

Table 6: First null in the polar pattern for equally spaced microphone array and sparse microphone array, with 9 microphones.

	400 Hz	800 Hz	1200 Hz
First null for equally spaced microphone array	39.0 degrees	19.5 degrees	13.0 degrees
First null for sparse microphone array	45 degrees	33 degrees	35 degrees

As a sparse array shall, it is seen that the first null for 800 Hz and 1200 Hz is almost the same at 33 and 35 degrees, which is the premise for a sparse array: equally narrow main-lobe in the intended frequency range. At 400 Hz the first null is at 45 degrees. This should not come as a surprise, considering that there are only 3 microphones used in sub-array 1. From Table 6 it is seen that the equally spaced microphone array outperforms the sparse array for the same amount of microphones, though there are room for more microphones in a sparse array due to the varying spacing between the microphones. Hence it is expedient to increase the number of microphones to at least equal 9 microphones per sub-array, though by doing so, the length of the array will be far longer than that of the equally spaced microphone array of 9 microphones.

3 Conclusion

It is clear that the SNR can be improved by numerous methods in regards to detecting and localizing mosquitoes with a microphone array. Even though it is possible to make the main lobe of the beamformer very narrow, and thus suppress sound sources with other directions of arrival than the angle the beam is steered, it will not be able to separate two sound sources from each other if the fundamental frequency is 400 Hz, without making the array at least 4 meters long at a distance of 0.5 m. This might be impractical in regards to private houses and homes. Hence it seems appropriate to use a microphone array to record the sound produced by the mosquito in order to process the signal and determine if it is in fact a mosquito. This is possible if the position of the mosquito is first determined by other means than a microphone array, and then sending the information to the microphone array that then may be steered towards this particular angle of interest.

Both equally spaced microphone array and sparse microphone array have been evaluated for the best performance without resulting in an excessively long array, since it should be possible to mount it in homes and other buildings, in windowsills and the like. It is seen that the sparse array must be very long in order to meet the performance of an equally spaced microphone array, when the length of the array is kept short. Hence, it seems appropriate to employ an equally spaced microphone array, with e.g. 9 microphones, or more for a narrower main lobe at low frequencies.

4 References

[1] R. W. Mankin, "Acoustical detection of Aedes taeniorhynchus swarms and Emergence exoduses in remote salt marshes," 1994.

[2] D. R. Raman, R. R. Gerhardt and J. B. Wilkerson, "Detecting insect flight sounds in the field: Implications for acoustical counting of mosquitoes," 2007.

[3] C. M. N. Olsen, "Acoustics and sterephony: Course Work 2," 2014.

[4] S. Gudvangen, "Directional microphones," 2014.

[5] J. H. B. &. K. J. J. Christensen, "Technical review: Beamforming," 2004.

[6] S. Gudvangen, "Introduction to microphone arrays," 2014.

[7] J. Eargle, The Microphone Book, Second Edition, Focal Press, 2005.

[8] S. Gudvangen, Notes on electret microphones and JFET amps, 2015.

[9] G. Danavaras, "Testing Panasonics WM-61A Mike Cartridge," *Audio Xpress,* 2007.

[10] S. Linkwitz, "Linkwitz Lab," 10 03 2015. [Online]. Available: http://www.linkwitzlab.com/sys_test.htm.

[11] P. Corporation, "Omdicrectional Back Electret Condenser Microphone Cartridge, WM-61A," Panasonic, [Online]. Available: http://industrial.panasonic.com/lecs/www-data/pdf/ABA5000/ABA5000CE22.pdf.

Immobilization Systems

Mosquito Defence Systems

v1.0 ● 15.03.2015

Abstract

This document includes a technical overview of possible immobilization systems with component explanations and set-up examples in order to give a basis for further design selections. High-speed galvanometers with coupled mirrors are used to move laser beams to desired positions and are in this text introduced as an immobilization system. In addition, a dual axis servo system with an implemented laser module is presented for the same purpose.

Document Version

Version	Date	Name	Description
0.1	11.03.2015	Hege J. Blikra	First draft.
0.2	15.03.2015	Hege J. Blikra	Added Ann Christin's section 2.1.1 (Galvanometer)
1.0	15.03.2015	Hege J. Blikra	Document Revision
1.0	09.05.2015	Ann Christin Barstad	Proofreading

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List of Figures

1 Introduction

Most insects serve an important task, such as pollination of flowering plants, nutrition and population control. Mosquitoes act as a major part of the aquatic food chain, yet they may also transmit diseases. Due to changing climate, there is an increasing risk of tropical mosquitoes in Nordic countries, and thus tropical diseases. Hence, it might be a scope for protecting ourselves from this problem in the garden or at windows and entrances. In order to immobilize possible threats, the system is in need of a unit that receives position data and hits the target within a short time frame. Tracking a flying object's position requires fast-responding and precise equipment, because in spite of mosquitoes low flight speed, they tend to have unpredictable flight patterns. In this regard, to hit a mosquito in-flight with e.g. a pointing laser sets high demands to the equipment and its interfaces with the rest of the system. There are several applicable immobilization methods to solve this problem, though in this text a galvanometer-laser system and a servo-laser system are of main interest.

2 Immobilization Systems

2.1 Galvanometer-Laser System

The galvanometer system consists of galvanometers, mirrors, and a laser module. How these components function and how they are coupled together, including overall system interfaces are described in the following sections.

2.1.1 Galvanometer

A galvanometer is an instrument for detecting electric current. It is an electromechanical actuator that experiences a torque that is proportional to the current through its coil in a magnetic field [12]. It is used to indicate the presence, direction, or strength of a small electric current. It is also used to detect and compare currents [3].

HowStuffsWorks asserts the following about galvanometers: "The galvanometer makes use of the fact that an electric current flowing through a wire sets up a magnetic field around the wire. In the galvanometer, the wire is wound into a coil. When current flows through the coil, one end of the coil becomes a north magnetic pole, the other a south magnetic pole. When a permanent magnet is placed near the coil, the two fields—the one from the coil and the one from the magnet—interact. The like poles will repulse each other and the unlike poles will attract. The amount of attraction and repulsion increases as the strength of the current increases. In the moving-magnet galvanometer, the permanent magnet is a needle (much like a compass needle) mounted on a pivot and surrounded by the coil, see Fig. 1. In the moving-coil galvanometer—the most common type—the coil is mounted on pivots or suspended by thin metal strips. The coil lies between the poles of a permanent magnet in such a way that it rotates when current flows through it. The direction of the rotation depends on the direction of the current through the coil, and the amount of rotation depends on the strength of the current. A galvanometer is often used to indicate when the current in a circuit has been reduced to zero, as in the operation of the Wheatstone bridge, a device for measuring electrical resistances precisely" [3].

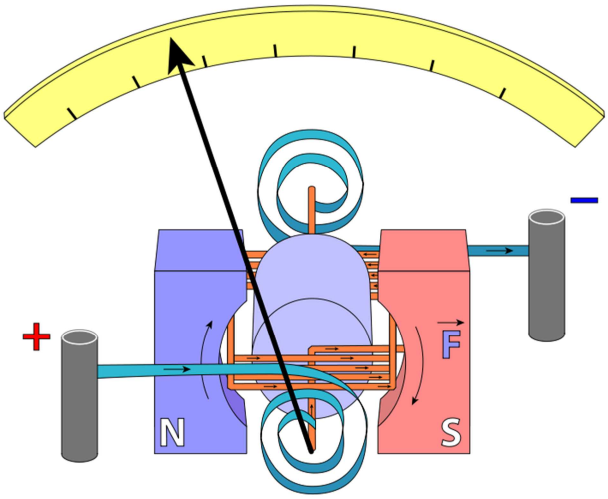

Figure 1: Galvanometer as Ammeter Indicator, [10]

2.1.2 Mirrors

To obtain x and y coordinates of the flying targets, the system needs two mirrors. The mirrors are usually mounted at the end of the actuator, and deflect the light beam over the angular range of the motor shaft [1]. When choosing mirrors it is important to look at the performance parameters of the rest of the system, such as the laser's wavelength, power, beam diameter, and spot size [5]. A balance between low inertia and high stiffness is also significant for selecting the right mirrors for the specific application.

2.1.3 Laser

There are several factors that are important when choosing the laser module, as mentioned above. For a lethal laser, power has to be carefully considered, and for illustration purposes wavelength is significant. The size of the module is also important for mounting and on/off button or switch circuit is also relevant. More information about lasers is presented in Laser Technology Document [9].

2.1.4 Set-up

A normal set up would be as illustrated in Fig. 1. Mirror 1 is used to set the beam to the desired point on the surface of the second mirror which is placed at a small distance [2]. The second mirror is used to direct the beam in the required direction.

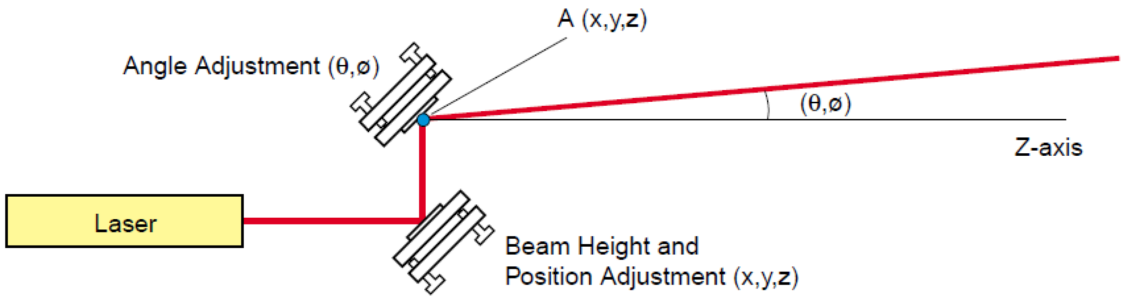

Figure 2: Two-Mirror Laser Set-Up, [2]

Galvanometers are coupled to the two mirrors, one galvo for each mirror, and ensure high-speed laser output on the desired position. In Fig. 3, an actual dual axis galvo mirror assembly is presented [1].

Figure 3: Dual Axis Galvo Mirror Assembly, [1]

2.1.5 Interfaces

The input of the immobilization system is x, y coordinates obtained by the detection/position unit (camera) and processing unit. These coordinates need to be converted into voltages applied to the galvanometer, due to the fact that the galvanometer system moves certain degrees for the certain induced current a DAC (digital to analog converter) is the interface between the camera output and the galvanometer system input as seen in Fig. 4.

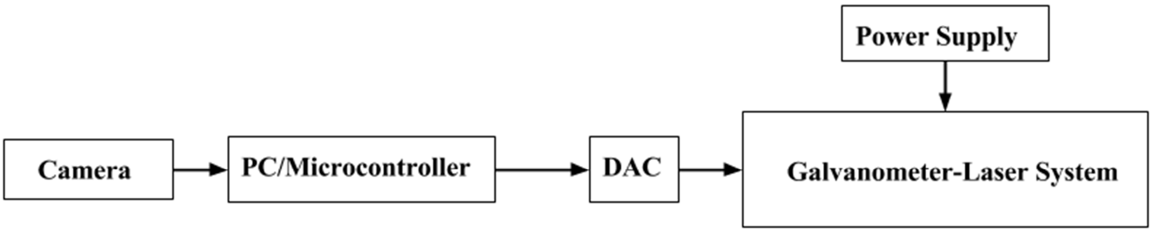

Figure 4: Galvanometer-Laser System Interfaces

2.1.6 Kinematics

A kinematic model must be derived in order to find the relation between the angular positions of the mirrors that correspond to the applied voltages and the position of the reflected laser beam .The theoretical model from [6] is based on ideal assumptions, whereas in practice the positioning of the laser beam in x and y direction is very sensitive to mirror size, orientation of the laser, distance between mirrors, distance from the sample of interest, and limitations in drive electronics [6]. Fig. 5 illustrates the geometry of laser light reflection and effect of the galvanometers' rotation on the beam reflected to the x, y plane. The laser beam first hits mirror X, reflected beam then hits mirror Y and appears on the x, y plane as a spot. When mirror X and Y are rotated, the beam moves in x and y direction. The relation between optical angles and x and y coordinates is expressed in equation (1) and (2) [6].

$$x = \left(r + \sqrt{d^2 + y^2}\right) \tan \theta_x \qquad (1)$$

$$y = d \tan \theta_y \qquad (2)$$

In equation (1) and (2), x and y coordinates are calculated by optical rotation angles of mirrors (θ_x , θ_y), the distance between the mirrors (r), and the distance from mirror Y to the x, y plane (d). The necessary voltage to rotate the actuators to the desired x and y coordinates are presented in equations (3) and (4), these are based on vendors' specifications [6].

$$V_x = \frac{1}{2}\alpha_x = K_x\theta_x \qquad (3)$$

$$V_y = \frac{1}{2}\alpha_y = K_y\theta_y \qquad (4)$$

According to vendors, applied voltage is half of mechanical rotation angle where mechanical angle is proportional to optical angle [6]. K_x and K_y are scaling constants due to commercial driver input voltage to output mirror angle relations. Substituting equation (3) and (4) into (1) and (2) results in equation (5) and (6) [6].

$$x = \left(r + \sqrt{d^2 + y^2}\right) tan\frac{V_x}{K_x} \qquad (5)$$

$$y = d\, tan\frac{V_y}{K_y} \quad (6)$$

If x and y coordinates are known, required voltages can be obtained by equation (7) and (8).

$$V_x = K_x\, tan^{-1}(\frac{x}{r+\sqrt{d^2+y^2}}) \quad (7)$$

$$V_y = K_y\, tan^{-1}(\frac{y}{d}) \quad (8)$$

When x and y coordinates for the target is obtained by the camera, the reference voltages V_x and V_y are calculated and fed to the galvanometer system to get a position for the lethal laser [6].

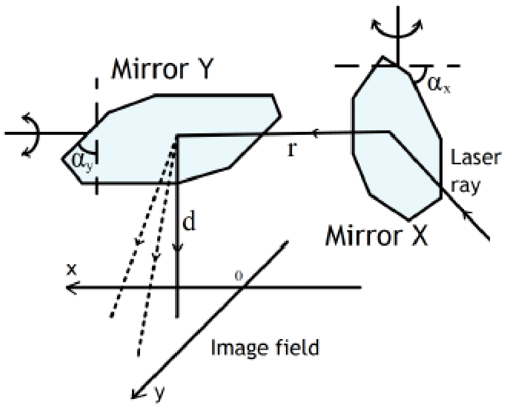

Figure 5: Laser Reflection [6]

2.2 Servo-Laser System

The servo-laser system consists of two servos and a laser module. How these components function and how they are coupled together, including overall system interfaces are described in the following sections.

2.2.1 Servo Basics

A servo is a small device that has an output shaft that can be positioned to angular positions when receiving a coded input signal [7]. The servo's position will remain the same as long as the input signal is the same, if not it will change. Servos have a built in control circuitry, and are generally powerful compared to their small size. Most servos contain a control circuit and a potentiometer that is connected to the output shaft. The potentiometer makes it possible for the control circuitry to monitor the current angle of the servo motor. The possible rotation angle depends on the servo's specifications, but normally it rotates somewhere between 0 and 180 degrees. The amount of power is proportional to the distance it rotates. The angle is determined by the duration of a pulse that is applied to the system (pulse coded modulation) [7], where the length of the pulse will decide how far the motor turns. The parameters of this pulse are that it has a minimum, neutral, and maximum pulse. In neutral position, the servo has the same amount of potential rotation in the clockwise direction as it has in the counter clockwise direction. The amount of milliseconds for the different positions will always vary from servo to servo. Examples of these positions are shown in Fig. 6 [8].

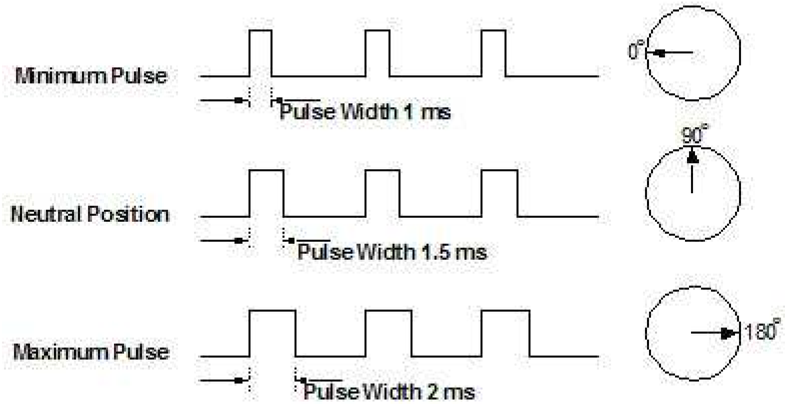

Figure 6: Servo Rotation Positions, [8]

2.2.2 Laser

The laser specifications are mostly the same for this unit as for the galvanometer-laser system discussed in above sections. However, the size of the laser will in this case be crucial because of the servo's torque specifications. It is important to consider these specifications and compare to the size and weight of the laser module. More information about lasers is presented in Laser Technology Document [9].

2.2.3 Set-Up

A possible set-up for this unit would be to use two servos aligned on top of each other for it to be used to steer a laser beam in both x and y direction. This configuration have to allow the laser to be mounted either on top of the second servo or placed in an excess module coupled to the servos. Fig. 7 illustrates how two servos can be coupled together where motion in x direction is generated by the bottom servo and the y direction is generated by the upper servo. Fig. 8 illustrates a possible mount solution for the servo-laser unit.

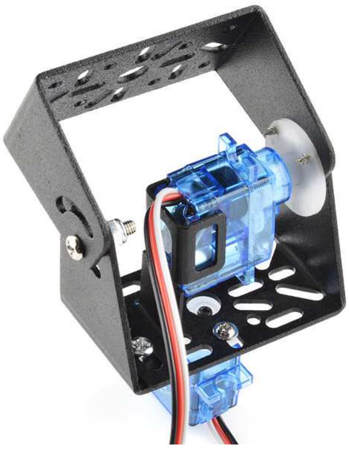

Figure 7: Dual Axis Servo Set-Up, [11]

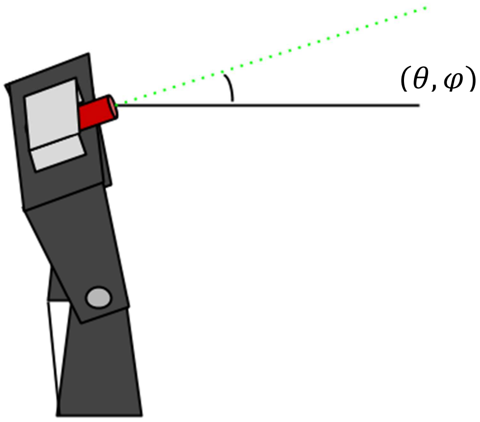

Figure 8: Servo-Laser Mount

2.2.4 Interfaces

X and y coordinates are obtained by the camera and processed through a PC or microcontroller. This position signal is then converted to a readable signal for the servos, i.e. a pulse modulated signal that matches the rotation angle required. See Fig. 9 for illustration.

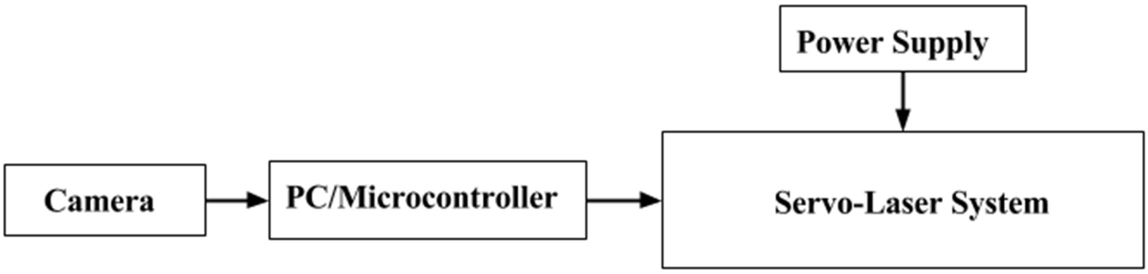

Figure 9: Servo-Laser Unit Interfaces

3 Conclusion

In regards of immobilizing mosquitoes by receiving position data from a detection unit, a galvanometer-laser system would work. Galvanometers are fast and precise, and with the right calibration it would be able to hit a moving target in a short time frame without trouble. However, this requires further investigation and thoroughly considerations when choosing components. A servo-laser system would also work as an immobilization system, but it is not as fast or precise as a galvanometer-laser system. For the system as a whole, a galvanometer-laser system is the best option of these two systems, based on the preliminary research.

4 References

[1] "GVS011 and GVS012 Large Diameter Scanning Galvo Systems - User Guide." ThorLabs, 7 July 2011. Web. 5 Mar. 2015. http://sites.fas.harvard.edu/~phys191r/Bench_Notes/D4/Thorlabs_gvs012.pdf.

[2] Mitchell, Phillip V. "Fast Steering Mirror Technology: Active Beam Stabilization." *Application Note: Opto-Mechanics 2*: 1-5. Print.

[3] "Galvanometer." *HowStuffWorks*. HowStuffWorks.com, 25 Aug. 2009. Web. 26 Feb. 2015. http://science.howstuffworks.com/galvanometer-info.htm.

[4] Mishin, Hannah. "Laser Scanner- Camera/projector." *RSS*. 25 Oct. 2010. Web. 9 Mar. 2015. http://hannahmishin.com/blog/2014/10/25/laser-scanner-cameraprojector.

[5] "Laser Scan Mirrors." *Galvo Motors*. Cambridge Technology. Web. 5 Mar. 2015. http://www.camtech.com/index.php?option=com_content&view=article&id=89&Itemid=77.

[6] Zhakypov, Zhenishbek, Edin Golubovic, and Asif Sabanovic. "Galvanometric Optical Laser Beam Steering System for Microfactory Application." Print.

[7] "Whats a Servo?" Seattle Robotics Society. Web. 11 Mar. 2015. http://www.seattlerobotics.org/guide/servos.html.

[8] "How Do Servos Work?" *How Do Servos Work?* Web. 11 Mar. 2015. https://www.servocity.com/html/how_do_servos_work_.html#.VQADi_mG_vE.

[9] A. C. Barstad, "Laser," MDS, MDS, 2015.

[10] "Galvanometer." Wikipedia. Wikimedia Foundation, 5 Mar. 2015. Web. 15 May 2015.

[11] "Pan and Tilt Bracket." Coolcomponents.co.uk. Web. 7 Mar. 2015. https://www.coolcomponents.co.uk/pan-and-tilt-kit-no-servos.html

[12] "Galvanometer." Galvanometer. Hyper Physics. Web. 11 Mar. 2015. http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/galvan.html

Laser

Mosquito Defence Systems

v1.0● 08.05.2015

Abstract

This is a paper about lasers. It is written to get an overview of; how they work, the different laser types, laser effect etc. It was necessary to collect all this information to be able to figure out which kind of laser the mosquito immobilizing system would need.

Document Version

Version	Date	Author	Description
0.1	05.03.2015	Ann Christin Barstad	First draft.
0.2	12.03.2015	Hege Jeanette Blikra	Added sections 2.1, 2.2.
0.3	27.04.2015	Ann Christin Barstad	Continued to write the document.
0.4	28.04.2015	Ann Christin Barstad	Changed the setup and most of the content in the document. In section 2.2 I only rewrote some sentences.
1.0	08.05.2015	Hege Jeanette Blikra	Proofreading

Table of Contents

1 Introduction

A laser is to be used in the mosquito immobilizing system to kill the mosquitoes. It was thoroughly discussed what to use to kill the mosquitoes, and a laser was the solution. The reason a laser was chosen is because there is no other device that is proven to work. All the existing products; mosquito spray, gas, creams, candles with odor, are actually not proven to have a good effect. With a laser, the mosquitoes would be burnt, hence they die. The downside of using a laser is that it comes with some risks. If a laser is effective enough it could possibly cause harm to the environment, humans and animals. If some precautions are made, it should not be a high risk to use a laser to kill the mosquitoes.

2 Laser

Laser is a short word for "Light Amplification by Stimulated Emission of Radiation".
It is a designation of sources where the radiation is amplified by stimulated emission.
A laser may emit visible light, or be in the ultraviolet or infrared range. The radiation that is amplified in lasers occurs in atoms or molecules. The light emitted from a laser, the laser beam, is characterized by its very intense and sharply defined direction, it is monochromatic and coherent [1].

2.1 Application

The laser light or laser beam has been applied in a number of areas where its light coherence is useful. The coherent beam can be strongly limited in space, and therefore it is suitable for light-transmissions over great distances. Lasers have many applications in everyday life, for example; by reading bar codes, in DVD and CD players and laser printers. It can also be used to drill holes in diamonds; it is possible to direct the beam so that the hole is shaped as desired. In the electronic industry, lasers are used for welding, they are used for micro drilling and to burn away excess fabric and thereby obtain the correct size of electrical resistors and capacitors. A laser is also used to process the surface of metals to achieve desired properties, for example; sharp edges with great durability. Lasers are also used for medical purposes. It is used to treat skin tumors, during operations on the liver and eye-surgeries. The greatest medical application has been laser with endoscope, which has made it possible to treat internal bleedings and tumors in the gastrointestinal tract, bladder and respiratory tract, without a usual operation. Those kinds of operations are pain free and do not lead to internal bleedings. It has also been discussed if lasers should be used in the military to destroy missile weapons at an early stage after launch. In short; it is the major energy concentration within a well-defined region that is utilized [1].

2.2 Operating Principle

The laser contains a lasing medium which is “pumped” to get the atoms into an excited state. The medium contains a collection of atoms with electrons in excited levels. When the electrons return to their original level, they release energy. This emitted energy comes in the form of photons (light energy) with a specific wavelength. The laser light is therefore very different from normal light, because of the specific wavelength, i.e. one specific color. This case is referred to as monochromatic light. In addition, the released light is coherent; it is organized in a way that each photon moves in step with each other. It is also directional, meaning that the laser light has a tight beam, it is strong, and concentrated [2]. The laser includes two key components; a pair of mirrors. These are placed next to the lasing medium, one at each side. Photons reflect off the mirrors and travel back and forth through the lasing medium. In this process the photons stimulate other electrons to make the same “jump” and cause emission of more photons of the same wavelength and phase, resulting in a cascaded effect. One of the two mirrors has a partially transmitting coating (“half-silvered”), i.e. it reflects some light and lets some light through. The light that goes through is the laser light [2], [3].

2.3 Types of Lasers

Lasers are often described by the kind of lasing medium they use - solid state, gas, excimer, dye, or semiconductor [4].

2.3.1 Solid State Lasers

Solid-state lasers consist of a host and an active ion doped in the solid host material. The Active ion must have sharp fluorescent line, broad absorption bands and high quantum efficiency for the wavelength of interest. The host material must be strong, and fracture resistant, with high thermal conductivity and high optical quality. Glasses and crystalline materials have shown to have these characteristics, when doped with rare earth ions. Pumping of the gain media is usually performed with optical pumping, electrical pumping or chemical pumping. As far as solid-state lasers are concerned, it is mainly the optical pumping, which is being used. Optical pumping uses either continuous wave or pulsed light emitted by a powerful lamp or a laser beam. Optical pumping can be realized by light from powerful incoherent sources. The incoherent light is absorbed by the active medium so that the atoms are pumped to the upper laser level. This method is especially suited for solid state or liquid lasers whose absorption bands are wide enough to absorb sufficient energy from the wide band incident incoherent light sources [5].

2.3.2 Semiconductor Laser

Semiconductor lasers are referred to as diode lasers or laser diodes. The main challenge was to operate these lasers at room temperatures continuously with low threshold current densities. Continuous developments have resulted in laser diodes with shorter and shorter wavelengths, increasing output power and an improved beam quality [5]. The semiconductor lasers works like this; electrons are injected into the diode, they combine with holes, and some of their excess energy is converted into photons, which interact with more incoming electrons, helping to produce more photons—and so on in a kind of self-perpetuating process called resonance. This repeated conversion of incoming electrons into outgoing photons is analogous to the process of stimulated emission that occurs in a conventional, gas-based laser. In a conventional laser, a concentrated light beam is produced by "pumping" the light emitted from atoms repeatedly between two mirrors. In a laser diode, an equivalent process happens when the photons bounce back and forth in the microscopic junction (roughly one micrometer wide) between the slices of p-type and n-type semiconductor. The amplified laser light eventually emerges from the polished end of the gap in a beam parallel to the junction [9]. Today, reliable laser diodes stacks with powers in the range of kilowatts are available on the market. In addition, compared to other types of lasers, laser diodes use very little power. Most laser diodes can operate with voltage as low as 2 V with power requirements determined by their current setting. In this way, laser diodes have thus grown to a key component in modern photonics technology. As compared to other lasers, semiconductor lasers are compact and rugged. This ruggedness and small size allow laser diodes to be used in environments and spaces in which other types of lasers cannot operate. It has a high efficiency, direct excitation with small electric currents, possibility of direct modulation with applied current, small beam waist, low costs due to mass production and high reliability. However, there are few drawbacks in semiconductor laser diodes as compared to other solid state and gas lasers. These include their sensitivity to temperature, large beam divergence, and lower spectral purity [5].

2.3.3 Gas Lasers

Gas Lasers are used in applications that require laser beams with long coherence lengths, very high beam quality, or single mode operation. Gas Lasers are lasers that use an electric current discharged through a gas medium to produce a beam. Common Gas Lasers include helium neon, argon, or carbon dioxide. The type of gas used can determine or influence the laser's wavelength, efficiency, or power [7]. In gas lasers, the active medium is in the gaseous state. Since the laser media is a gas, it is kept in a plasma tube, with proper electrodes for electrical discharge to produce ionization, enclosed with dielectric mirrors. One may think that gas laser is a simple device, as there is no basic preparation required for the lasing medium, as in the case of a solid state laser. But in practice, it is a complex device, as it needs optimization of gas mixture, gas discharge parameters, mirror and container configuration etc. The same have to be properly designed to create suitable conditions for population inversion. Further, gas discharge produces heat and it has to be removed to avoid detrimental effect on gas discharge and the optical components [6]. Gas lasers are widely available in almost all power (milliwatts to megawatts) and wavelengths (UV-IR) and can be operated in pulsed and continuous modes. Most of the gas lasers are pumped by electrical discharge. Electrons in the discharge tube are accelerated by electric field between the electrodes. These accelerated electrons collide with atoms, ions, or molecules in the active media and induce transition to higher energy levels to achieve the condition of population inversion and stimulated emission [8].

2.3.4 Dye Lasers

Dye Lasers use an organic dye as the gain medium. The wide gain spectrum of available dyes allows these lasers to have high degree of tunability with high resolution and high power. Since the dyes used in tunable dye lasers are fluorescent, another light source is always required to pump the dye in order to achieve the population inversion. The pump beam used to excite the large dye molecules and produce the population inversion is a strong light source either a flash lamp or another laser focused on the dye stream. The dye will absorb only those wavelengths of light, which are shorter than those which it emits, since some input energy will always be absorbed in the form of vibrations or heat. The characteristics of the light used in the excitation determine the characteristics of the laser. If a pulsed source like flash lamp is used to pump the dye laser, the beam will also be pulsed, further on, if a continuous-wave laser like argon laser pumps the laser, the dye laser's beam will also be continuous. The energy absorbed by the dye creates a population inversion, moving the electrons into an excited state. Typically, the dye molecule de-excites spontaneously into a meta stable state having relatively longer lifetime. The most important attribute of the dye laser is its tunability, which gives the user access to essentially any wavelength in the visible and near-visible spectrum. The spectral range of ion-laser-pumped CW dye lasers is essentially complete coverage from 400 to 1000 nm. It is even possible to extend their CW tuning range by using nonlinear optical methods to generate wavelengths further into the ultraviolet and infrared region. Since most organic dyes have a large range of wavelengths over which amplification can occur (called the gain bandwidth), lasers built around them can be composed of light waves spanning a range of wavelengths in the spectrum. This makes possible the ability to select the wavelength of the laser light through the adjustment of a prism or grating. This tunability feature allows certain specific applications to be performed at minimal cost as compared to having large number of different monochromatic lasers. A Negative aspect of dye lasers is that the dyes have limited productive lifetimes. The factors that limit the lifetime of laser dyes are mainly the chemical and photochemical degradation of the dye in solution. Representative lifetimes of the typical CW dyes range from 300 to 4000 hours depending on the dye. Average output power is a few milliwatts to a few watts [5].

2.3.5 Excimer Lasers

The name excimer refers to the electronically excited types such as monomers, dimers and other complexes, which exist in the electronically excited state only. Excimers are characterized by short radiative lifetimes of the order of nanoseconds and large cross sections for stimulated emission, which enables an efficient laser operation. The term excimer stands for 'excited dimer' where a dimer refers to a molecule of two identical or similar parts. The excimer laser is really an exotic laser in the sense that the lasing molecule exists only in the excited state and separates into the original atoms in the ground state. The excimer laser contains about 90-95 % helium or neon, less than 0.2% of halogen, the rest being the corresponding noble gas. The entire laser unit consists of discharge chamber (gas tube), an optical resonator, high voltage system, and the system serving for pumping and mixing of gases. The electrical high voltage discharge is transverse with respect to the length direction of the gas tube. As the gain of the laser medium is high, it is sufficient to use a fully reflecting rear mirror and an ordinary window as the output coupler. The wavelength output of an excimer laser can be changed simply by changing the gas mixture. However, the laser mirrors may have to be replaced to obtain maximum output. The efficiency of these lasers is relatively high as a result of the high quantum efficiency and the high efficiency of the pumping processes. With time, the corrosive gases used in excimer lasers chemically react with the laser tube and its components. This process can significantly limit the lifetime of a gas fill and can affect laser beam quality and pulse energy stability. Further, corrosion also limits overall tube lifetime and increases the frequency of routine optics component cleaning and replacement. The development of ceramic technology has helped to extend the life of excimer lasers. Specifically, all insulators and high voltage feed-through in the laser chamber are made from corrosion resistant high-density ceramics. Excimer lasers are typically used in machining materials which are hard to machine with other types of lasers, or where very high precision is required. These lasers are also useful for cutting biological tissue where a clean cut is required without thermal damage to the surrounding tissue [6].

2.4 Risk

When a laser beam is absorbed in a substance, a huge energy concentration arises with a strong local heating. The total energy transmission could be small enough to not cause any harm, but any solids can be made to evaporate or burn when hit by a laser beam. Due to the large energy density from the beam, it can be harmful to be exposed to direct light from a laser. Even over vast areas the beam can cause harm. Because of this, the laser beam is sometimes called the death ray [1].

Eye hazard: For direct damage to the eye, the exact severity will be due to many factors: beam power, exposure time, beam/eye relative motion, distance from the laser, and retinal injury location. If a person deliberately stares into a laser, even a small 1 milliwatt beam could cause a spot on the retina. Fortunately, the eye's natural "aversion response" causes a person to involuntarily blink and/or turn away from a bright light. Taking this into account, an accidental exposure to a 5 milliwatt beam is considered tolerable, as long as the person is not overriding their blink reflex. After some point, even blinking and moving isn't fast enough to prevent injury. As a very rough approximation for laser pointer use, above 10 milliwatts the potential hazard from general use outweighs the benefit of a brighter beam. At around 100 milliwatts, an accidental exposure at close range will cause a change to the retina which can be defined as an eye injury. The victim may or may not notice it depending on where the spot is on the retina. The injury may heal after a few days or weeks if the exposure is not too severe [10].

Skin hazard: At around 150 milliwatts, the beam from a laser can be felt on the skin, depending on the beam focus, skin color (absorption), etc. At roughly 500 milliwatts, the laser beam begins to be a skin burn hazard if the person is within a few meters of the beam [10]. Direct exposure to very high power radiation above 800nm may produce irreparable damage like, ulceration, depigmentation, blisters, skin burn, scarring etc. If the power of the laser is very high, underlying connecting tissues and organs like sweat glands, blood vessels, nerve cells and hair follicles could also be damaged [11].

2.5 Visibility

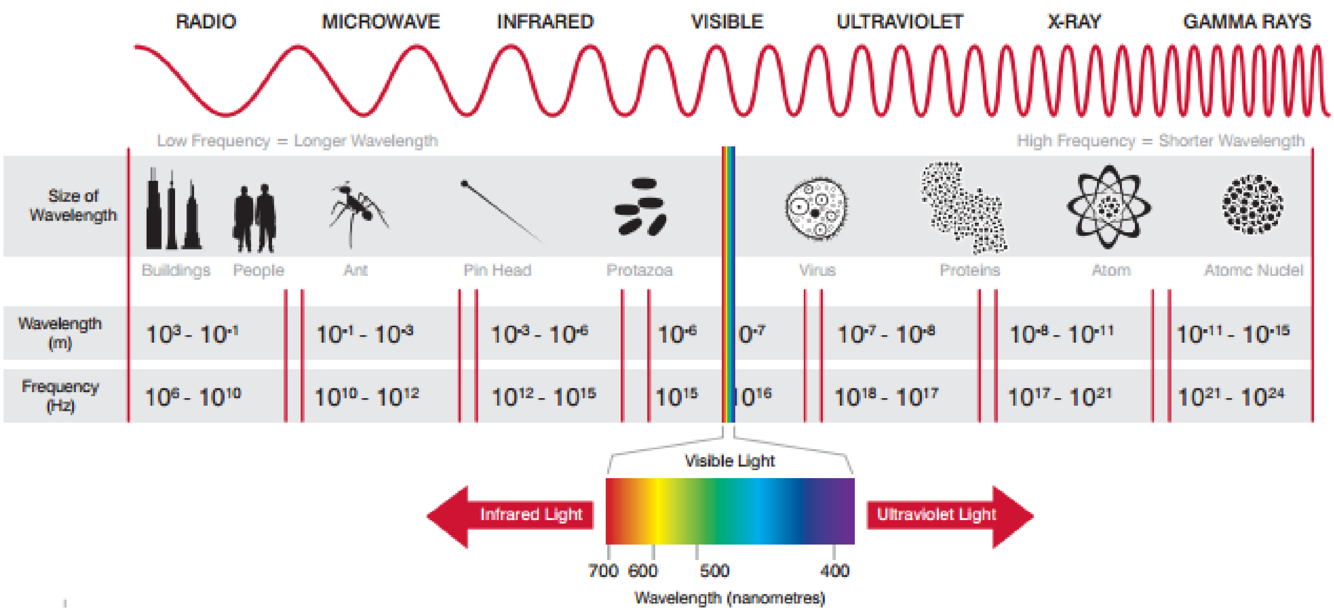

Figure 1: Visibility Chart

2.6 What type of laser is needed for MDS?

After a lot of research, it was clear that to kill one mosquito per second, a 50-100mJ laser would be needed with an effect of 100mW [12]. To kill five mosquitoes per second a 500mW laser is needed. It is not guaranteed that all of the 500mW will hit the mosquito fully; some of the beam might hit the wall. This is because the calibration has to be extremely accurate to hit only the mosquito, and MDS have neither the time nor the knowledge to accomplish this. Therefore some of the 500mW might be "lost" and a 500mW laser could possibly kill less than 5 mosquitoes per second. A laser that has an effect of 500mW is a class 3B laser. It is necessary to apply for authorization from the State Radiation Protection to use a laser with that amount of effect. A 500mW laser is strong enough to set fire to solids. Therefore a fireproof board of some sort is needed where the laser beam hits the wall. The board has to be non-reflective. The beam diameter should be up to 5 mm, more than that is not necessary. The color of the beam is irrelevant as long as it is visible. That means that the laser beam wavelength has to be between 400nm to 700nm. The wavelength should be a continuous wave due to the fact that a large concentration of heat is needed to burn the mosquitoes as fast as possible [13]. The laser would need a 110-240V input of 50-60 Hz. Which type of laser to use is irrelevant as long as it contains the characteristics that are needed for a laser for MDS use. An example for a laser that has the given characteristics is called L404P400M [14].

2.7 Conclusion

There are many different kinds of lasers. They have different characteristics, but some of them also share some of the same properties. Which type of laser to use is irrelevant as long as it contains the characteristics that are needed for a laser for MDS use. A laser effect of 500mW could potentially be harmful, but if the right precautions are made, it should be possible to use without high risks.

3 References

[1] Store Norske Leksikon, *laser - intens lyskilde*, 29.04.2015, https://snl.no/laser%2Fintens_lyskilde

[2] Matthew Weschler, *How Lasers Work*, 30.04.2015, http://science.howstuffworks.com/laser3.htm

[3] *Basic Laser Principles*, 30.04.2015, http://www.bgu.ac.il/~glevi/website/Guides/Lasers.pdf

[4] Oregon State University, *Laser Types and Classifications*, 30.04.2015, http://oregonstate.edu/ehs/laser/training/laser-types-and-classification

[5] *Solid State Lasers*, 01.05.2015, http://www.worldoflasers.com/lasertypes-solid.htm

[6] *Gas Lasers*, 01.05.2015, http://www.worldoflasers.com/lasertypes-gas.htm

[7] *Gas Lasers*, 01.05.2015, http://www.edmundoptics.com/lasers/gas-lasers/

[8] Subhash Chandra Singh, Haibo Zeng, Chunlei Guo, and Weiping Cai, *Lasers: Fundamentals, Types, and Operations*, 01.05.2015, http://www.wiley-vch.de/books/sample/3527327150_c01.pdf

[9] Chris Woodford, *Semiconductor diode lasers*, 01.05.2015, http://www.explainthatstuff.com/semiconductorlaserdiodes.html

[10] *Frequently Asked Questions -- General interest questions*, 02.05.2015, http://www.laserpointersafety.com/FAQ/FAQ.html#When_does_a_laser_pointer_get_d

[11] *Laser Safety*, 02.05.2015, http://www.worldoflasers.com/lasersafety.htm

[12] Jordin Kare, *Backyard Star Wars*, 02.05.2015, http://spectrum.ieee.org/consumer-electronics/gadgets/backyard-star-wars

[13] *CW Welding vs. Pulse Welding*, 02.05.2015, http://www.litron.com/CW-vs-Pulsed-Weldings.asp

[14] *Laser Diodes*, 05.05.2015, https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=5260&pn=L404P400M

Image Processing

Mosquito Defence Systems

v2.0 ● 13.05.2015

Abstract

This document contains an initial research about computer vision, and a brief overview of how it is used in image processing to extracts objects out of a digital image.

Document Version

Version	Date	Name	Description
0.1	26.03.15	Jawad	Initial document (v0.1) created.
1.0	11.05.2015	Ann Christin Barstad	Proofreading
1.1	11.05.2015	Jawad Qureshi	Added more detailed content in thresholding.
2.0	13.05.2015	Jawad Qureshi	Added conclusion

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1 Introduction

Computer vision is a very large field in today's technology, to be used in autonomous applications such as robots. Computer Vision includes methods for acquiring images, and process, analyze and to some extent understand images. The direction of computer vision technology lately has been to duplicate the abilities of human vision.

2 Image processing

2.1 Image segmentation

Image segmentation is to partition an image into multiple sets of pixels. The goal is to simplify the representation of an image so it is easier to analyze. Image segmentation is typically used for object detection, boundary detection and object tracking. The simplest method of image segmentation is called the thresholding method [1].

2.2 Thresholding

Thresholding separates pixels of an image into classes that are distinct based on a defined threshold. Thresholding is a conversion from gray level image to a binary image. You can use grey level image, or the individual channels (red green and blue). A gray level image has pixel values from 0 to 255, as does each of the channels of a picture, while a binary image has either a 0 or 1 as pixel value. The resulting binary image contains all information concerning the number, position and shape of objects. Since the desired objects should be segmented out, the background is considered noise and you want to get rid of most of it.
Foreground objects pixels are set to 1, and the background objects are set to 0 in a binary image. Thresholding is done by selecting a value T, and compare each pixel to the value. Each pixel (X) in a gray level image is then compared to T, if T is greater than X, then it is set to 1, if $T < X = 0$.

2.2.1 Otsu's method

Thresholding is an effective way of partitioning an image into foreground and background elements, and is most effective in images with high levels of contrast. To make thresholding completely automated, it is necessary for the computer to automatically select the threshold. Computation of threshold value is difficult, but there are some algorithms that can automate the process, and give decent results. For example Otsu's method that takes histograms of pictures and calculates the best T value for the image. Otsu's method performs best on histograms that has bimodal distribution. Bimodal distribution often occurs in images with high contrast, and the objects are easily separable. The bimodal distribution histogram looks like the back of a two-humped camel. In Matlab there is a function called "graythresh" is using Otsu's method to select a threshold value to create binary images.

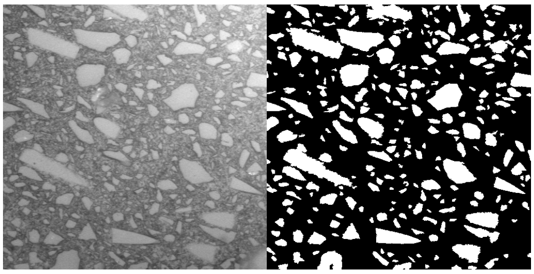

Figure 1 Before and after thresholding using Otsu's method. [2]

2.2.2 Color thresholding

Color thresholding is a method to find and separate specific colored objects. To threshold for a specific color, each of the RGB channels has to be used, and a threshold applied to each of them. Once a threshold has been applied to all the channels, the resulting binary image is made up of only the desired object.

For example to only keep yellow colored objects from an input picture (figure 2).
The perfect yellow color is R: 255, G: 255, B:0, therefore the threshold values of each channel should be close to these values.

The red channel pixels will be set to 1 in the binary image. If the pixel value is above 180 (R > 180), the green values greater than 180 will be set to 1 as well (G > 150). And if the blue values will be set to 1 only if they are less than 10(B < 10) giving us a threshold value of :

R > 180 & G > 150 & B < 10

These values will render a binary image [3] (figure 3). Sometimes the binary image that is rendered will not be perfect, and have "holes" inside that looks like noise as shown in figure 3. In Matlab there is a function called imfill(x, 'holes) that can easily filter these holes where x is the object that should be filled. Figure 4 shows the binary image, with the imfill function applied. It is still not perfect, so we can either dilate or erode this binary image to further clarify our foreground object. By eroding we would increase the amount of black pixels, and by dilating we would increase the amount of white pixels. Figure 5 and 6 shows the results of eroding, and dilating where figure 5 has the clearest object representation left. The object that is left now is called a blob.

Figure 2 The input picture that should be threshold to keep only yellow colored objects.

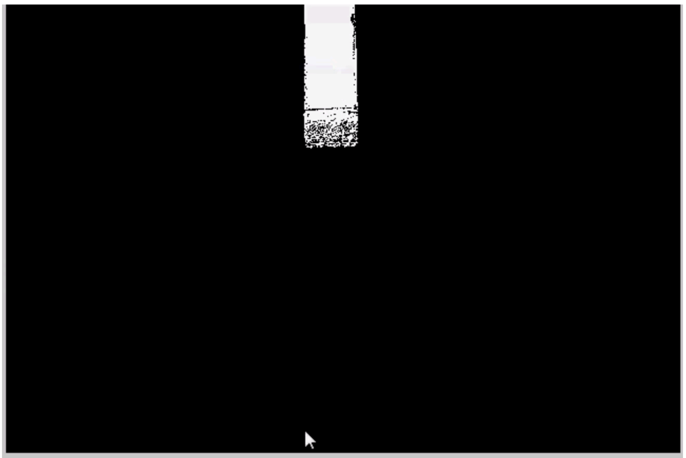

Figure 3 Resulting binary image after initial color thresholding

Figure 4 imfill(x, 'holes') function has been applied and most of the noise is gone

Figure 5 Eroding the object increases the black pixels

Figure 6 Dilating increases the amount of white pixels

2.2.3 Blob

A Blob is a group of connected pixels in an image that share some common property, for example connected pixels in a binary image [1]. By connecting a group of pixels that are connected, it is possible to filter out noise, and get a stronger representation of an object. By using “dilation” it can cause the bright regions in the image to “grow”. If to grow the darker parts is wanted, the “Erosion” operation can be used. By using “dilate” and “erosion” it is possible to make blobs appear stronger in the binary image [4].

Figure 7(from left) Original image, dilated image, and eroded image.

2.3 Stereovision

A single camera that is calibrated can determine the pose of an object where the geometry of the model is known. This is called model based pose estimation, and works only for known models.

Systems with two cameras that are calibrated and the relative pose between them is known we can find 3d information from an arbitrary scene, where we don't have to know the geometry of the objects in the scene.

Stereovision is two cameras that are placed horizontally from one another, and are used to obtain images from two different sources of the same scene, to get 3d information from 2d images of an arbitrary scene. Stereovision is similar to human vision. By comparing two different images, information such as depth, can be obtained using disparities.

Computational stereovision has been studied for over 25 years, and is still a difficult problem that is being researched, but some commercial products are available.

To be able to rectify a stereovision setup it is necessary to calibrate cameras. By using printed out checkered board where the size of each pixel is known, we can determine the position of the cameras relative to all the objects in the scene, and compare sizes against the reference squares. Image rectification is a transformation process to project several images onto a common plane. This way it is possible to evaluate the object distance, and get a disparity map [5].

3 Conclusion

Stereovision is an interesting concept, but the algorithms require hardware implementation (FPGA) or other ways of hardware acceleration to be able to use it in real time applications. Computer vision in general has made huge advancements lately, and although it may seem like basic operations it is a huge step in right direction.

There are several ways of detecting what the segmented object is, but they require large databases to compare and decide what the object is.

4 References

[1] Rob Phillips Group. (2015, May) [Online]. http://www.rpgroup.caltech.edu/courses/PBL/bootcamp2011/protocols_and_references/AdvancedMatlabTutorial.pdf

[2] Engineering Virtual Organization for CyberDesign. (2014, August) Engineering Virtual Organization for CyberDesign. [Online]. https://icme.hpc.msstate.edu/mediawiki/index.php/Image_Processing_with_MATLAB_1

[3] Mathworks. (2015, Jan.) Mathworks. [Online]. http://se.mathworks.com/help/images/ref/im2bw.html

[4] OpenCV. (2011, Jan.) OpenCV documentation. [Online]. http://docs.opencv.org/doc/tutorials/imgproc/erosion_dilatation/erosion_dilatation.html

[5] J. B. Calvert. (2000, November) [Online]. http://mysite.du.edu/~jcalvert/optics/stereops.htm

Mosquito Research Document

Mosquito Defence Systems

v1.0 ● 13.03.2015

Abstract

This document contains general information regarding mosquitoes. It is to be used as a tool for further research for the members of the project group. The text concerns mosquito species, lifecycle and breeding, attractants, repellents, flight behavior, and spreading of deadly diseases.

Document Version

Version	Date	Name	Description
0.1	20.02.2015	Hege J. Blikra	Initial draft.
1.0	13.03.2015	Jawad Qureshi	Proof Reading
1.0	08.05.2015	Ann Christin Barstad	Proofreading, edited the introduction

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1 Introduction

Mosquitoes are insects that have surrounded humans and animals for millions of years. They are known for their annoying buzzing sound and their itchy bites. In the northern part of the world they are annoying, but they do not carry any diseases. Unfortunately, this is just a fraction of what they are really capable off. In the southern parts of the world, mosquitoes are also carriers, vectors, of several deadly diseases prevalent in tropical regions.

2 Mosquitoes

2.1 Culicidae Lifecycle and Breeding

Mosquitoes are groups of arthropods with a significant role in ecological food chain, at the same time they are prominent bloodsuckers and a bi cause of many deaths a year [1].
The *Culicidae* familiy of mosquitoes are biting mosquitoes, and these can transmit diseases by transmitting parasites. Culicidae contains 3500 species of mosquitoes divided in 41 genera around the world. They go through four stages in life: egg, larvae, pupa, and adult. The three first stages are mostly aquatic, while the adult stage takes place on shore. The aquatic habitats can vary significantly and are presented in Figure 1.

Habitats*	Examples of mosquitoes	Remarks
1. Flowing streams	*Culex fuscocephala, gelidus; Anopheles kochi; An. spp.*	Include creeks, drainage and irrigation ditches
2. Ponded streams	*An. kochi; Cx. annulus, bitaeniorhynchus; Lutzia fuscanus*	Include flooded stream beds, Chlorophyta-rich habitats, polluted ponds
3. Lake edges	*An. farauti, maculipennis An. quadrimaculatus, pseudopunctipennis Cx. annulirostris, squamosus*	Margins of lakes
4. Swamps and marshes	*An. farauti, gambiae, kochi, punctulatus An. sinensis; An. spp. Cx. annulus, bitaeniorhynchus, gelidus, sitiens Cx. tritaeniorhynchus; Lutzia fuscanus*	Include coastal marshes, mangrove swamps, irrigated fields
5. Shallow permanent ponds	*Aedes longirostris, An. kochi, sinensis Cx. gelidus, tritaeniorhynchus Mansonia uniformis, Mimomyia chamberlaini*	Include fishponds, duckweed ponds
6. Shallow temporary pools	*Ae. communis, excrucians, hexodontus, impiger An. dirus*	Include snowmelt pools
7. Intermittent ephemeral puddles	*An. gambiae, kochi, punctulatus Cx. annulus, fuscocephala, tritaeniorhynchus*	Common in road construction sites resulting from rainy season downpours
8. Natural containers (plant origin)	*Aedes (Aedimorphus, Finlaya, Stegomyia,) spp., Anopheles spp., Armigeres spp., Culex spp., Ficalbia spp., Haemagogus sp., Orthopodomyia spp. Sabethes spp., Toxorhynchites spp., Tripteroides spp. Uranotaenia spp., Wyeomyia spp.*	Include tree holes, internodes, leaf axils, flower bracts, fronds, nuts, pods, pitchers [Graminae(bamboo), Pandanaceae (screwpines), Palmae (palms), Agavaceae (Dracaena), Araceae (taro), Musaceae (banana, abaca), Bromeliaceae (bromeliads, pineapples), Cytanaceae (rafflesias), Nepenthaceae (climbing pitcher plants), Sarraceniaceae (terrestial pitcher plants)]
9. Natural containers (animal and other origins)	*Aedes (Cancraedes, Geoskusea, Levua, Lorrainea) Ae. (Rhinoskusea, Skusea, Stegomyia) spp. Anopheles spp., Culex spp., Culiseta spp. Deinocerites spp., Eretmapodites spp. Uranotaenia spp.*	Include shells of snails, clams, arboreal ant nests, crab holes
10. Artificial containers	*Aedes spp., Culex spp., Toxorhynchites spp.*	Include tires, cans, flower vases, bottles, tanks, troughs, drums, gutters, etc.

* Adapted from Laird (1988) and other references

Figure 1: Habitats of the mosquito larvae [1]

This figure presents information on where mosquitoes breed, which is of great importance in order to control the mosquito population, thus eventually prevent diseases of spreading. Sources of standing water are most common for mosquito breeding, which makes it important to eliminate as many of these as possible, e.g. empty flower pots and clogged gutters.

After the egg, larvae, and pupa stages, the adult mosquito is ready to fly. The adult Culicidaes are between 5-8 mm long, have a tenuous body, and long legs [3]. They have two pairs of cutting stylets which slide against each other and slice through the skin at the end of the proboscis [1]. Figure 2 shows the anatomy of mosquitoes.

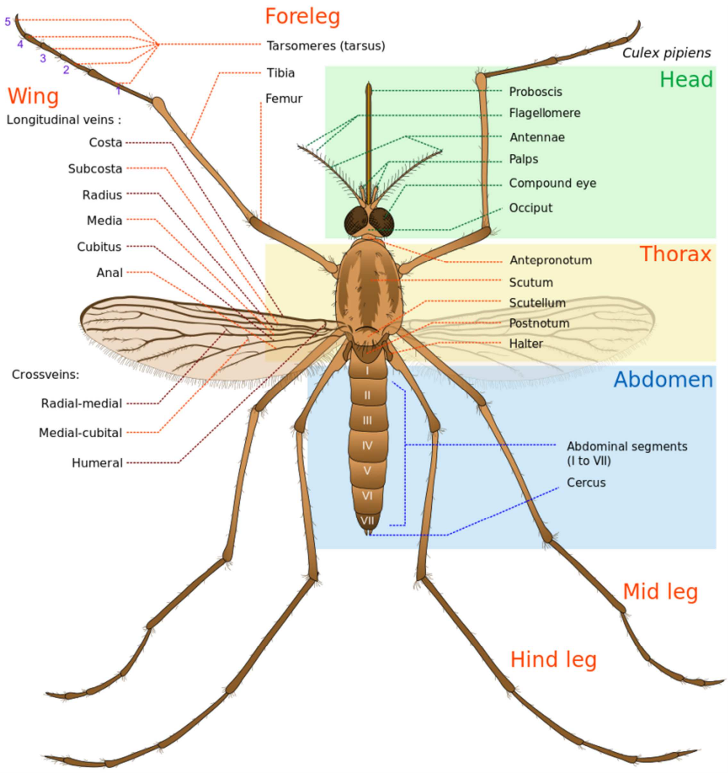

Figure 2: Mosquito Anatomy, [7]

Both male and female mosquitoes gather nutrition from nectar and sugar from plants. However, female mosquitoes also feed on blood from tiny blood vessels, as one of the hollow tubes of the proboscis injects salvia into the wound, and the other extracts blood. This is necessary for the production of eggs. After a “meal” she can lay 50-200 eggs. Some mosquitoes have preferable victims, while others feed on blood from a random selection of humans or animals. Some species feed on humans one year and switches off to animals the next. In this way they can transmit diseases from animals to humans and vice versa. Mosquitoes can live from 5-7 days to about a month, depending on the different species. The different species of mosquitoes each have their own preferences of what time they like to feed; e.g. *Anopheles* prefer to feed at dusk, twilight, or nighttime, while e.g. *Aedes* bite mostly during the day [1].

2.2 Sensors and Attractants

Equipped with chemical, visual, and heat sensors, mosquitoes locate hosts. They are attracted to body temperature, odors, movement, and exhaled carbon dioxide from both humans and animals (including mammals and birds). They are also attracted to IR light, this is because mosquitoes have poor eyesight, and have to rely on body warmth to know where to find hosts. Infrared-light-based traps trick mosquitoes into believing a warm-blooded host is near. Emitted infrared light also reflects off of water in a way that allows mosquitoes to recognize potential breeding areas [2]. The sense of smell seems to be most important when the mosquitoes are near a victim. For flight orientation, visualization has greatest significance. Mosquitoes that bite during the day seem to orientate after moving humans or animal hosts [1]. Wearing clothing that contrasts with the background are easier to see, thus a more attractive victim [4]. Humans release more than 300 compounds as by-products of metabolism, and 100 of these can be detected from human breath. Carbon dioxide is primarily released from breath and skin, and is known as the most common attractant. Both carbon dioxide and octenol are used as attractants in monitoring and surveillance of mosquitoes.

2.3 Repellents

There are many known sources of consumer repellents against mosquitoes, e.g. mosquito spray and candles. These are not highly effective, and are not sufficient enough as protection against deadly mosquito carriers. However, DEET (NN-diethyl-meta-toluamide/yellow oil) is used as personal protection against biting insects and proves to me more effective than its predecessors [1].

2.4 Flight Behavior

Tracking insect flight behavior is not an easy task. However, recent studies show that it is not impossible, and at the same time important when it comes to overcome e.g. disease-carrying mosquitoes. According to Jeroen Spitzen & CO, female mosquitoes use odor and heat as cues to navigate to an appropriate landing site on their blood host. Many insects’ flight patterns are affected by the host’s pheromones, and they navigate upwind while making reiterative contact with packets of odor in a relatively narrow odor plume. Heat from hosts is also a parameter which affects the mosquitos’ flight, but only at close range [5]. This study is conducted by a group of scientists. The results are included in Figure 3, which presents flight tracks of Anopheles gambiae affected by different sources.

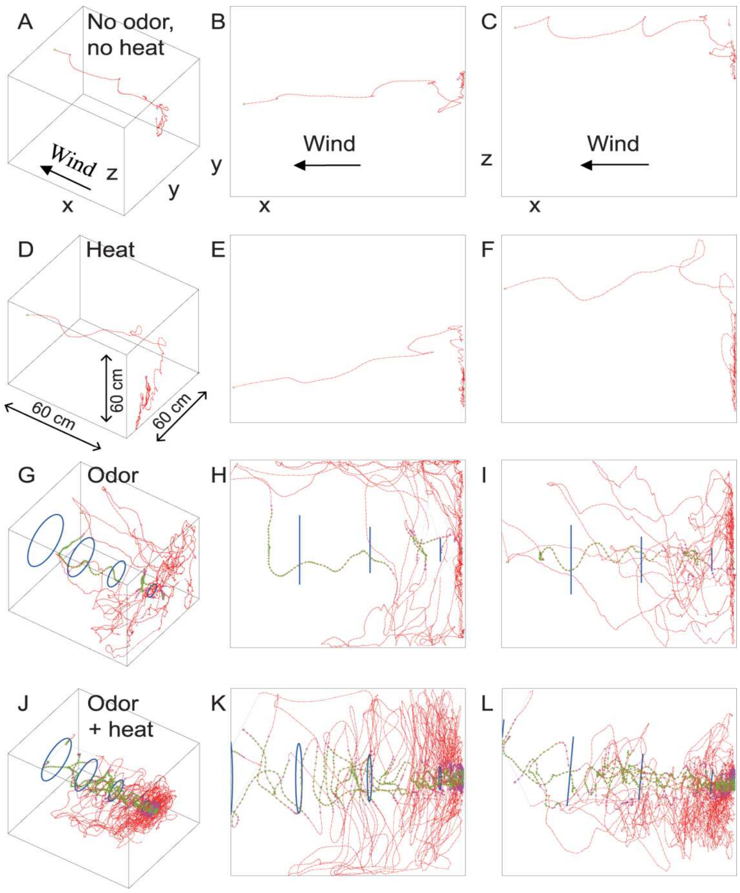

Figure 3: Anopheles Gambiae Flight Tracks

Differentiate species by the wing-beat frequency is possible. This is researched by many scientists, using different methods. One way to identify insects is by the noise of their beating wings. The wing-beat frequency differs slightly between the species, also between males and females. For instance *culex stigmatosoma* (female) has a wing-beat frequency of about 350 Hz; whereas *culex tarsalis* (male) wing-beat frequency is around 550 Hz. Figure 4 illustrates different wing-beat frequencies by type of mosquito. Theoretically, because of this information, it should be possible to separate the different species, even the sex. However, in practice it is a lot more complicated [7].

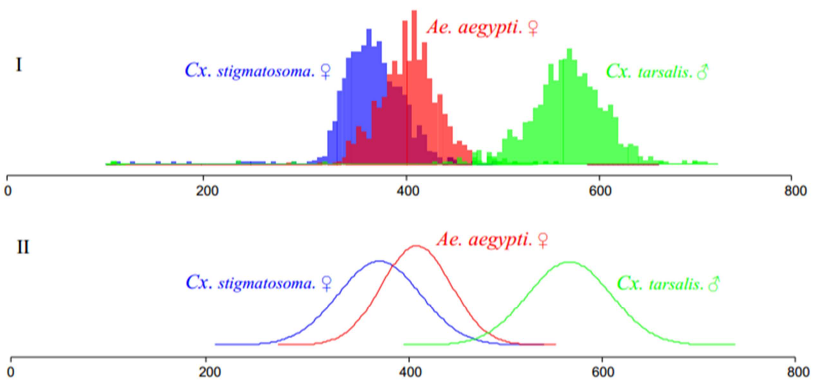

Figure 4: Mosquito Wing-Beat Frequency [7]

2.5 Vectors

The Culicidae family is divided in three sub-families where two is relevant in this case: Anophelinae and Culicinae. In the sub-family Anophelinae, genera like *Anopheles*, are carriers of deadly diseases, and within the Culicinaes we find, *Aedes* and *Culex* as the most dangerous ones [3]. The *Culex* mosquito is a vector of elephantiasis (parts of a person's body swell to massive proportions), encephalitis (inflammation of the brain), and the West Nile Virus (mostly no signs or symptoms, in some cases infected people suffer from inflammation of the brain). The *Aedes* mosquito is a vector of yellow fevers (acute viral disease, vaccine exist) and of encephalitis. The *Anopheles* is the deadliest mosquito; it is a carrier of the most threatening disease, malaria (flu-like symptoms). The *Anopheles* can also transmit W. bancrofti (filarial worms), various arboviruses, onyongnyong, tataguine, elephantiasis, equine encephalitis, and other viruses [3].

As mentioned above, malaria is the most serious vector-borne disease affecting humans. Most deaths caused by Malaria occur in Africa, south of Sahara, where malaria vectors exist in large numbers and are very difficult to control [1]. The malaria parasite *Plasmodium falciparum*, has good living conditions in this part of the world, mainly because of the warm and tropical climate. As for now, the temperatures in Norway are too low for the parasites to develop within the mosquitoes, but as the climate gets more tropical it might become a problem in the future. Antimalarial drugs have been available for many years, but there are no highly effective vaccines offered today [3].

3 Conclusion

Mosquitoes are arguably annoying to most people, but they also serve an important role in the eco-system, especially in freshwater habitats. The larvae for instance are usually at the base of the food chain. It is food for small fish, which is thereafter food for larger fish. These fish might be a meal for animals or humans, and so forth. It is important to consider the consequences before large quanta of insects are removed, because it might cause even bigger problems. However, deaths caused by mosquito borne diseases are hundreds of thousands today, and an effective solution to this problem is absolutely necessary.

4 References

[1] Rueda, Leopoldo M. "Global Diversity of Mosquitoes (Insecta: Diptera: Culicidae) in Freshwater." (2007): 477-89. Web. 10 Feb. 2015. http://www.mosquitocatalog.org/files/pdfs/MQ0307.pdf.

[2] Powell, Stephen. "Insects That Are Attracted to Infrared Light." *EHow*. Demand Media, 26 Nov. 2010. Web. 11 Feb. 2015. http://www.ehow.com/list_7560697_insects-attracted-infrared-light.html.

[3] Gjerde, Bjørn. "Parasittiske Arthropodar I Veterinærmedisinen." *Kompendium I Veterinærmedisinsk Parasittologi* 11 (2011): 66-68. Print.

[4] Freudenrich, Craig. "How Mosquitoes Work - HowStuffWorks." *HowStuffWorks*. 5 July 2001. Web. 13 Feb. 2015. http://animals.howstuffworks.com/insects/mosquito.htm.

[5] Spitzen, Jeroen, Cornelis W. Spoor, Fabrizio Grieco, Cajo Ter Braak, Jacob Beeuwkes, Sjaak P. Van Brugge, Sander Kranenbarg, Lucas P. J. J. Noldus, Johan L. Van Leeuwen, and Willem Takken. "A 3D Analysis of Flight Behavior of Anopheles Gambiae Sensu Stricto Malaria Mosquitoes in Response to Human Odor and Heat." *PLOS ONE: A 3D Analysis of Flight Behavior of Anopheles Gambiae Sensu Stricto Malaria Mosquitoes in Response to Human Odor and Heat*. 2 May 2013. Web. 10 Feb. 2015. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0062995#s3.

[6] "Entomologists Have Never Been Able To Identify Flying Insects Automatically...Until Now."*Medium*. 19 Mar. 2014. Web. 13 Feb. 2015. https://medium.com/the-physics-arxiv-blog/entomologists-have-never-been-able-to-identify-flying-insects-automatically-until-now-ee4d93067443.

[7] "Mosquito Anatomy Diagram - Insect Pictures, Photos & Images of Animals." Mosquito Anatomy Diagram - Insect Pictures, Photos & Images of Animals. Web. 10 Mar. 2015. http://www.sciencekids.co.nz/pictures/animals/mosquitoanatomydiagram.html

Mosquito Detection Concepts and Methods

Mosquito Defence Systems

v1.0 ● 13.03.2015

Abstract

This document is intended to give a brief overview of some existing methods and concepts of detecting moving objects. The working principles for each method will be presented without a need for technical insight.

Document Version

Version	Date	Author	Description
0.1	11.02.2015	Ann Christin Barstad	First draft.
0.2	19.02.2015	Ann Christin Barstad	Added Christoffer's research.
0.3	19.02.2015	Ann Christin Barstad	Added Hege's research.
0.4	19.02.2015	Ann Christin Barstad	Added Max's research.
0.5	19.02.2015	Ann Christin Barstad	Sorting sources
0.6	03.03.2015	Jawad Qureshi	Proof reading/ Formatting
1.0	13.03.2015	Christoffer M. N. Olsen	Editing, removed chapter 2.7.5 to 2.7.8
1.0	08.05.2015	Ann Christin Barstad	Proofreading

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1 Introduction

The need for tracking moving targets, both under water, in air and ground are vital for e. g. military defence and commercial airlines. Hence there are developed several technologies that are in use every day, such as radars, motion sensors and microphones. Though for the most part, these techniques of detecting moving targets are designed for rather large objects, such as planes, boats, vehicles and humans. Detecting smaller targets, such as insects, introduces thus a challenge, though this will not be presented in detail in this document.

2 Concepts

2.1 Radar

2.1.1 What is it?

Radar is the use of radio waves to detect and monitor various objects.

2.1.2 How does it work?

A radio transmitter is a device that oscillates an electrical current so the voltage goes up and down at a certain frequency. This electricity generates electromagnetic energy, and when the current is oscillated, the energy travels through the air as an electromagnetic wave. A transmitter also has an amplifier that increases the intensity of the electromagnetic energy and an antenna that broadcasts it into the air. A radio receiver picks up electromagnetic waves with an antenna and converts them back into an electrical current.
The radar device emits a concentrated radio wave and listens for any echo. If there is an object in the path of the radio wave, it will reflect some of the electromagnetic energy, and the radio wave will bounce back to the radar device. Radio waves move through the air at a constant speed (the speed of light), so the radar device can calculate how far away the object is based on how long it takes the radio signal to return.
Radar can also be used to measure the speed of an object, due to a phenomenon called Doppler shift [1].
Most radar systems determine position in two dimensions.

2.1.3 Black box

Figure 1 shows a black box of the radar system.

Figure 1: Black Box Radar

2.2 Microphones

2.2.1 What is it?

Microphones operate by sensing the difference in sound pressure by displacing a small diaphragm. The diaphragm may only sense the pressure difference from sound in front of the diaphragm, or both front and back. This results in pressure and pressure gradient microphones, respectively. These are of interest since the pressure microphone is Omni-directional up to a certain frequency, where diffraction makes the microphone increasingly directive. This happens when the wave length is short compared to the diameter of the microphone. What this means is that the microphone is equally sensitive in all directions. The pressure gradient microphone on the other hand, is designed to be directive for all frequencies. This by having an opening to the back of the diaphragm, giving it a delay compared to the direct sound wave at the front of the diaphragm. This makes it possible to make the microphone less sensitive at certain angles due to the phase differences causing cancellation.

2.2.2 Microphone Array

In certain situations, such as a conference, it might be a lot of noise, reflections and reverberation. When someone in the audience is given the opportunity to ask a question, it is cumbersome to pass the microphone around, and thus a steerable microphone array can solve this problem. The sensitivity of the microphone can be set in such a manner that reflections and other disturbances will be excluded, at least to a certain extent, and the person in the audience will be the main sound source. An adaptive algorithm can be used in order to identify the direction of arrival [2].

2.3 Camera

2.3.1 What is it?

Motion Capture (mocap) is simply the recording or capturing of motion. They accurately capture a movement for later use on digital characters, numerical analysis, or simple archiving and study [3].

2.3.2 How does it work?

The sensor regularly compares snapshots taken by the camera. If the picture changes, the camera will interpret this as an alarm in the monitored area. The sensitivity of the detection is adjustable. The detector will register either only bigger changes in the picture e.g. opening a gate (low sensitivity) or also smaller changes in the picture e.g. a ball flying in the air (high sensitivity). It is also possible to ignore parts of the picture during detection (e.g. movement of branches of a tree in the picture). The detector is suitable for outdoor applications [4].

2.4 Motion Sensor: TMD

2.4.1 What is it?

It is a device that detects motion in a given area.

2.4.2 How does it work?

Several sensors are placed in a room to be able to cover every corner, wall, floor and ceiling [5]. This basic principle could possibly be used to detect movement and position without any other components (ex. IR/ HD camera).

2.5 Infrared camera

2.5.1 What is it?

Infrared camera is a device that forms an image using infrared radiation. This radiation has a longer wavelength than the visible light. Visible light has a wavelength of 380 nm-700nm and Infrared from 700 nm – 1mm. Infrared camera can also be called thermographic camera [6][7].

2.5.2 How does it work?

Infrared light has a different wave length than visible light and therefor a different sensor. There is two type of sensors. The first one is cooled infrared detectors. The negative with this cooling is that it is both energy-intensive and time-consuming. The camera might need several minutes to cool down before I can begin working. The positive is that it provides superior image quality. The second type is uncooled infrared detectors. This type is smaller and less costly but the resolution is not as good as cooled detectors [6] [7].
The resolution of this kind of camera is mostly only 160x120 or 320x240 although it is possible to find camera up to 1280x1024 but these are really expensive.
There is 3 categories of infrared [8]:

- Near-infrared: closest to visible light
- Mid-infrared
- Thermal-infrared: this one is occupying the largest part of the infrared spectrum.

2.6 Photodetector with Targeting Laser

2.6.1 What is it?

A system consisting of a targeting laser and a photodetector can detect the presence of objects. The photo detector provides a measurable electrical response (current, voltage) to the incident light the laser produces. This response is coherent with the amount of light that hits the detector, i.e. detecting passing objects is possible.

2.6.2 How does it work?

This system can be constructed as it is in Figure 2, or it can simply be constructed of only a laser pointer and a photo detector. The principle of operation is the same in both arrangements. The system from [9] consists of a low-powered laser, a phototransistor connected to an electronic board and a total internal reflector (a surface with reflective index, α, equal to 1, where $0 \leq \alpha \leq 1$). The laser and phototransistor is mounted side-by-side, pointing at the reflective surface, as seen in Fig. 2. When an insect flies by the sensor, the slightly scattered laser beam is reflected and is perceived by the phototransistor. Due to the wings of the insect, the reflected lights will inherent minor light fluctuations.

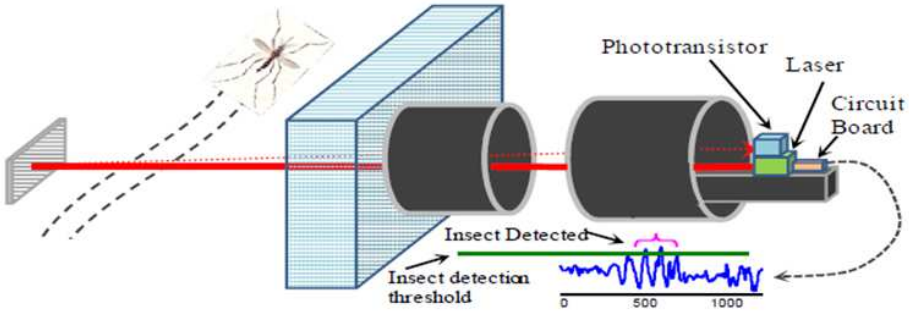

Figure 2: Photodetector with Targeting Laser

2.6.3 Black Box

Figure 3 shows a black box presentation of the concept.

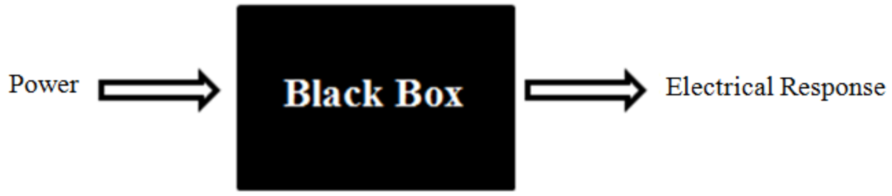

Figure 3: Black Box Photodetector with Targeting Laser

2.6.4 Functional input/output

A probable system input will be a battery driven low-powered laser, which is driven by e.g. a battery. Solar driven lasers are also a possibility. The functional output of the system will be a measurable electrical response, either current or voltage, from the chosen photo detector.

2.6.5 Interfaces

Photo detector and laser interfaces must be carefully considered. The photo detector responds to a certain frequency range, similarly the laser output frequency is specific. These two have to match in order to get the expected results.

2.7 Electronic Imager with IR LED Illumination and Retro Reflective Surface

2.7.1 What is it?

This is a system that can detect the presence of moving objects, by combining an electronic imager (e.g. CCTC) with infrared LEDs and a retro reflective surface. Infrared LEDs (light-emitting diodes) sends out light with longer wavelengths than visible light. Even though it's not visible to the eye, some digital cameras can see it. These kinds of LEDs are used as illumination in the dark. Retro reflective surfaces reflect light back at the light source. See Figure 4 for illustration of a retro reflective surface compared to diffusing surface and specular surface [11].

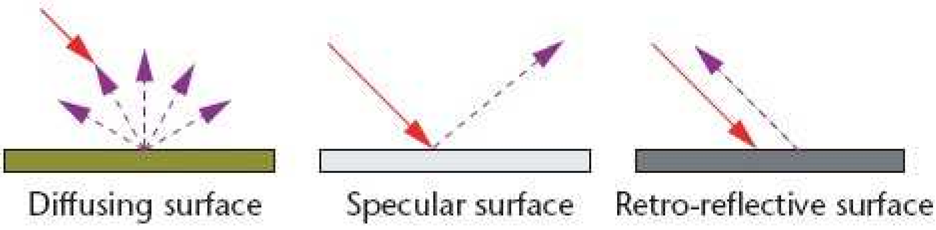

Figure 4: Different Reflective Surfaces

The electronic imager detects if objects are positioned in-between the reflective surface and the light source by capturing the shadows of the object.

2.7.2 How does it work?

This system is similar to *photonic fence* by Intellectual Ventures. An array of IR LEDs is with an electronic imager is placed in one end, while the retro reflective surface is placed at a distance. If an insect or any moving objects are positioned in-between this area, it is detected by the imager. With secondary imager sensor (using e.g. a laser and a photodiode), the system can provide accurate information on the wing-beat frequency, even the object's shape and size. This system includes using a powerful processor [12], [13]. See figure 5 for illustration.

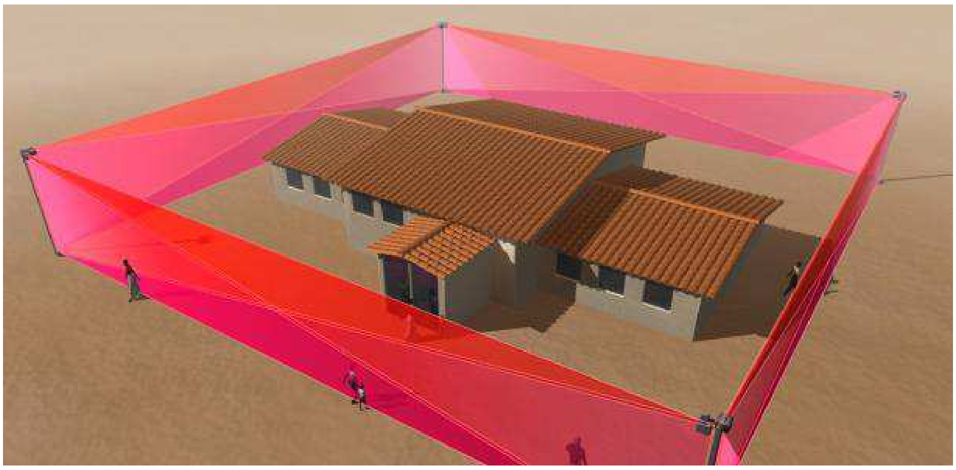

Figure 5: Photonic Fence Idea

2.7.3 Black Box

Figure 6 shows a black box description of the photonic fence concept.

Figure 6: Black Box Photonic Fence

2.7.4 Functional input/output

The infrared LEDs are driven by voltage input. Output will be an object classification based on wing-beat frequency, shape, and size contained by image processing.

3 References

[1] Tom Harris, *How Radar Detectors Work*
http://auto.howstuffworks.com/radar-detector1.htm

[2] Sigmund Gudvangen, *Introduction to microphone arrays*, Nov. 2014.
http://acoustics.ippt.gov.pl/index.php/aa/article/viewFile/716/634

[3] University of Michigan, *How Does Motion Capture Work*
http://um3d.dc.umich.edu/portfolio/how-it-works-mocap/

[4] Jablocom, *How do the camera detectors and sensors work?*
http://jablocom.com/help/how-do-the-camera-detectors-and-sensors-work/

[5] Xandem, *Tomographic Motion Detection.*
http://www.xandem.com/motion-detection

[6] Wikipedia, "wikipedia thermographic camera," 08 02 2015. [Online]. Available: http://en.wikipedia.org/wiki/Thermographic_camera. [Accessed 17 02 2015].

[7] Wikipedia, "Infrared Wikipedia," 08 02 2015. [Online]. Available: http://en.wikipedia.org/wiki/Infrared. [Accessed 17 02 2015].

[8] How Stuff Works, "How Stuff Works," How Stuff Works, [Online]. Available: http://electronics.howstuffworks.com/gadgets/high-tech-gadgets/nightvision1.htm. [Accessed 19 02 2015].

[9] Gustavo Batista, Eamonn Keogh, Agenor Mafra Neto, Edgar Rowton, *SIGKDD Demo: Sensors and Software to Allow Compuational Entomology, an Emergin Application of Data Mining*, http://users.cis.fiu.edu/~lzhen001/activities/KDD2011Program/docs/p761.pdf.

[10] "Patent US7511624 - Optical Detection of Oscillating Targets Using Modulation of Scattered Laser Light." *Google Books*. 31 Mar. 2009. Web. 17 Feb. 2015. http://www.google.com/patents/US7511624.

[11] Mims III, Forrest M. "How to Make and Use Retroreflectors." *Make*. 7 Oct. 2013. Web. 17 Feb. 2015. http://makezine.com/projects/make-35/how-to-make-and-use-retroreflectors

[12] "How the Photonic Fence Works." *How the Photonic Fence Works*. 17 Feb. 2010. Web. 18 Feb. 2015. http://www.intellectualventureslab.com/invent/how-the-photonic-fence-works

[13] "Patent US20140226860 - Photonic Fence." *Google Books*. 14 Aug. 2014. Web. 17 Feb. 2015. http://www.google.com/patents/US20140226860.

Concepts on Detecting Mosquitoes with Microphone Arrays

Mosquito Defence Systems

v1.0 ● 14.03.2015

Abstract

It is a scope for detecting mosquitoes in e. g window- and door-openings in order to reduce the risk of being bitten by disease-bearing mosquitoes at home, work, etc. Hence, two potential concepts on how microphone arrays may be implemented in order to detect mosquitoes will be presented. This is only intended to be a brief, non-technical document.

Document Version

Version	Date	Name	Description
0.1	20.02.2015	Christoffer M. N. Olsen	First draft
1.0	14.03.2015	Hege J. Blikra	Document revision.
1.0	08.05.2015	Ann Christin Barstad	Proofreading

Table of Contents

1 Introduction

In order to reduce the risk of being bitten by a disease-bearing mosquito, it is a scope for finding a method of determining that it is in fact a mosquito that is present and not another flying insect, such as a Bumble Bee. This may be possible by using microphone arrays in e. g. door- and window openings.

Microphone arrays are typically used in connection with e. g. conferences and meetings with several persons attending. The main lobe of the array can be steered towards the different persons in the room, in order to avoid background noise from other noise contributions such as ventilation, people talking at the same time, traffic from outside the building etc. The very same method may be used to steer the microphone array towards individual mosquitoes, or sound sources considering that it may be several different insects present, such that the sound signal can be processed and determined to be e. g. a certain species and sex. This is possible by having a constant input signal from each microphone, and then process the signals in real-time. By doing so, the microphone array can be steered towards several positions at once. For further information the reader is referred to [1].

2 Microphone Array

2.1 Detecting Mosquitoes in Window and Door Openings

2 Dimensional microphone arrays may be implanted in a windowsill, as seen in Fig. 1. If the microphone array's main lobe is sufficiently narrow and thus suppresses noise from other directions, it may be possible to have a 2 dimensional array in one of the four surfaces of the windowsill. By doing so, the direction in both x- and y-direction can be obtained, and an immobilizing system can be directed at this exact point. A similar system might be possible to implement in a doorway in the same manner.

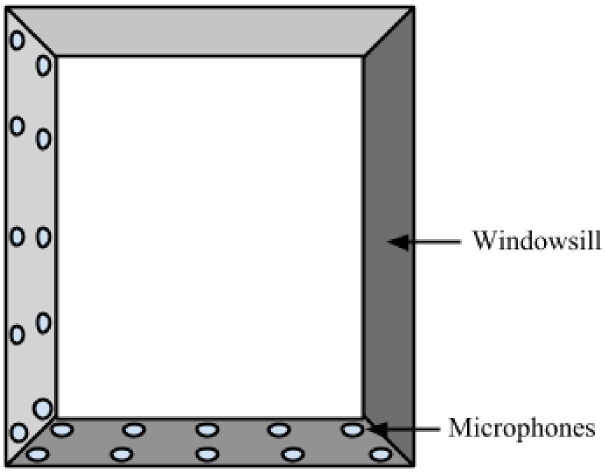

Figure 1: 2 Dimensional microphone array in a windowsill

2.2 Detecting Mosquitoes in a Room

A 2 Dimensional array can be implanted in a room as seen in Fig. 2. The principle is the same as for the windowsill. The array will sweep the room, and by processing the input signals, it may be determined whether or not it is a good chance for being a mosquito.

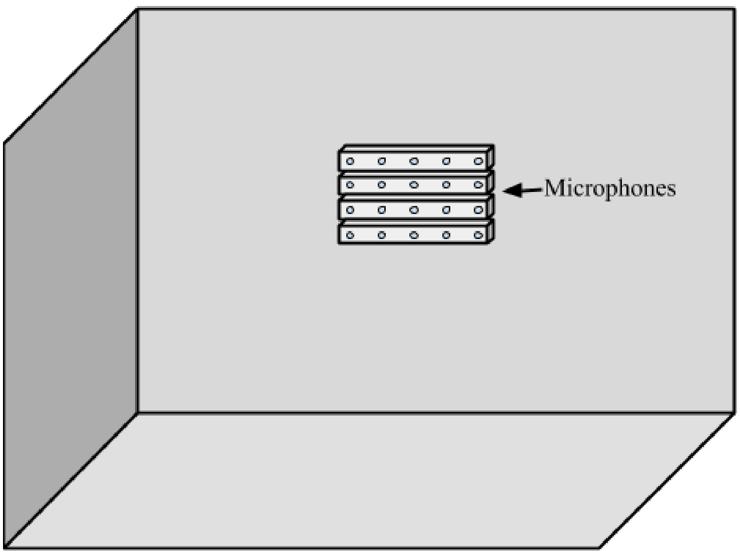

Figure 2: 2 Dimensional microphone array in a room.

3 Conclusion

With a sufficiently narrow main lobe of the array that suppresses noise from other directions, it may be possible to detect mosquitoes, even though there is some noise present. The number of microphones, position and realistic distance from the array to the microphones must be investigated further.

References

[1] Christoffer M. N. Olsen, *Localizing Mosquitoes With Microphone Arrays v1.0*, 12.03.2015.

Immobilization of Mosquitoes

Mosquito Defence Systems

v1.0● 08.05.15

Abstract

This document contains an overview of different ways to immobilize mosquitoes, and how the different immobilization techniques work. There is also a discussion of the advantages and disadvantages of the different immobilization techniques.

Document Version

Version	Date	Name	Description
0.1	11.02.15	Jawad Qureshi	Initial version
0.2	20.02.15	Ann Christin Barstad	Document setup
0.3	20.02.15	Jawad Qureshi	References update
0.4	20.02.15	Ann Christin Barstad	Introduction, document setup
1.0	08.05.2015	Ann Christin Barstad, Jawad Qureshi	Proofreading, edited the abstract, fixed figure labels and size

Table of Contents

1 Introduction

It is necessary to have good knowledge about the different ways to immobilize mosquitoes. By gathering information about the different methods in one document, it easier to get an overview of all the possibilities.

2 Immobilization Techniques

2.1 High Powered Fans

2.1.1 What is it?

Using fans against mosquitoes is a well-known practice in many countries. A low powered fan is very effective against mosquitoes and a table fan in your room may protect you from getting bitten [1], as mosquitoes are generally very weak fliers. To amplify this effect there is a possibility to use high-powered fans to disrupt mosquitoes flight to redirect them away from the area you want free of mosquitoes. A high-powered fan will also suck in mosquitoes if the direction of the blade is reversed. That way you can put in a meshed screen on one side of the fan and the mosquitoes will be sucked into this screen, and be trapped there and eventually die.

2.1.2 How does it work?

A high-powered fan will generate heavy airflow to disrupt mosquitoes designated flying pattern causing the mosquitoes to either blow away, or suck them in, and through depending on the direction of the blades are turning. After the fan sucks in a mosquito it will not be able to fight the airflow current and will be stuck against a meshed screen.

2.1.3 Black Box

Figure: Black box high-powered fan

2.1.4 Functional input/output

Electricity will run the fans, preferably from solar panels. The fans are going to consume a lot of power, as fans tend to do that.

2.1.5 Interfaces

Choose direction of airflow.

2.1.6 Efficiency

Is proven to be very effective compared to cost on small fans, so much that the AMCA (American mosquito control association) lists using a table fan as one of the most effective ways to repel mosquitoes. There are several implementations using a high powered fan in an area with very high density of mosquitoes, and the areas are being cleared of mosquitoes this way.

2.1.7 Compatibility

Not very compatible inside homes, but outside on open areas this works good, especially for use in gardens or other open areas where you want a mosquito free zone.

2.1.8 Recommendation

Although a very low-tech solution, with minimal risks a high-powered fan is too noisy, and consumes too much power to be considered a good solution.

2.2 Electric fence

2.2.1 What is it?

An electric fence is a barrier that uses electric shock as a way to prevent mosquitoes or other things trying to breach through a barrier. A small version of this is commonly used in a “bug zapper”.

2.2.2 How does it work?

An electric fence delivers a voltage that is lethal to small flying objects, but only causes discomfort for humans. It can instantly kill mosquitoes if they get close enough.

2.2.3 Black Box

Figure 1: Black box of electric fence

2.2.4 Functional input/output

Feed in power and your fence will be looking for ways to complete the circuit. As a bug or a mosquito comes too close the desired voltage will flow through the target and immobilizing it, depending on the output voltage, and how much voltage the target can tolerate.

2.2.5 Efficiency

Electric fence is quite effective given that a mosquito comes close enough. Different attraction techniques can be used to lure mosquitoes to come so close that the circuit will close.
A combination of a high-powered-fan sucking mosquitoes into a high voltage electric fence is even more effective as you can suck in targets, and immobilize them instantly.

2.3 Lasers

2.3.1 What is it?

Laser is a term originated as an acronym from “Light Amplification by Stimulated Emission of Radiation”. [2]

When you have atoms that are in an excited state that is hit by a photon of particular energy, it will simultaneously emit a daughter photon that has exactly the same energy and direction. This is called stimulated emission, and it essentially means that you can amplify a photon signal and produce a million photons that emit light. This process is called Light amplification by stimulated emission, or LASER. A container with a mirror in both ends filled with excited atoms that are excited either by light, electricity or chemicals, will start emitting photons in all direction almost simultaneously. Most of these photons are absorbed by the walls of the container, except for the ones that are bouncing back and forth between the mirrors. One of the mirrors is engineered so it only reflects 99% of the light, and with a tiny hole in the mirror the 1% of the light is allowed to escape, and that is the laser beam. The light in a laser beam is coherent, and will not spread, that is why the laser beam is so focused and straight.

2.3.2 How does it work?

A strong enough laser beam will also emit heat at its focused point. A laser beam focused on a target can immobilize it almost immediately, depending on the laser strength.
To immobilize mosquitoes using laser beams, we need to know the exact position of each mosquito at any given time, and a way to aim a strong enough laser beam at the mosquitoes. This can be done using galvanometer and two mirrors that aim the laser beam, and get the targets position dynamically from the desired detection system that we intend to use.

2.3.3 Black Box

Figure 2: Black box of laser-galvanometer system

2.3.4 Functional input/output

It needs to know the mosquito's position at any given time. Before firing a lethal beam (for the mosquitoes) it needs to have a confirmation that it is safe to fire.

2.3.5 Interfaces

Galvanized mirrors.

2.3.6 Recommendation

Using lasers to immobilize mosquitoes you can always keep track of how many mosquitoes that have been immobilized, you have a set perimeter that you can keep control of and immobilize almost all of the mosquitoes. Safety of using lasers is the concern.

3 References

[1] American Mosquito Control Association®, *Frequently Asked Questions*
http://www.mosquito.org/faq

[2] Andrew Zimmerman Jones, *Lasers*
http://physics.about.com/od/physicsitol/g/laser.htm

Concept Study

Mosquito Defence Systems

v2.0 ● 08.05.2015

Abstract

This document includes a short concept study conducted by the project group. It includes a Pugh matrix regarding three possible concepts that are further investigated in separate documents, a current concept sketch, as well as an activity diagram illustrating how the current system will work.

Document Version

Version	Date	Name	Description
1.0	15.03.2015	Hege J. Blikra	First version initiated.
1.1	17.03.2015	Max Moeschinger	Updated Figure 3
2.0	08.05.2015	Ann Christin Barstad	Proofreading, edited document setup

Table of Contents

1 Introduction

By means of how and where detecting individual mosquitoes and immobilization will take place there are many possibilities. The main goal is to protect people from disease-carrying mosquitoes in an effective and safe manner, and this can be done by placing a system at entrances and windowsills, setting up a “fence” around the house, or setting up outposts in the area around the house. All of these concepts with different detection and immobilization methods are discussed in [1], [2], [3], and [4].

2 Concept Study

2.1 Pugh Matrix

Figure 1 shows a pugh-matrix of the three possible concepts discussed by the project group. Several criteria are rated and are given appropriate weighted points, and each concept is given points from -1 to 1 for each criterion which is summarized at the bottom. The concept ending up with the most points have scored highest on the criteria listed and can be considered as the best concept selection at this point on. Comments regarding the evaluation are listed and a table briefly describing the concepts, Table 1.

		Concepts		
Criteria	Weight (1-3)	Fence	Entrance	Outposts
1. Sustainability in regards to power consumption	1	1	1	-1
2. Susceptible to weather	1	-1	1	-1
3. Shall not cause harm to humans, animals and surroundings.	3	-1	-1	1
3. Performance in regards to protecting humans	3	1	1	-1
4. Maintainability (Location & number of units)	2	0	1	-1
5. Adaptability	1	1	0	1
6. Portability	1	-1	-1	1
7. Noise exposure in regards to e. g. wind and movement	1	-1	0	1
8. Independence (Stand Alone System)	1	1	1	-1
Sum		0	3	-1
Weighted Sum		0	4	-2

Figure 1: Pugh Matrix of Concepts

Comments to criteria and concept evaluation:

1. The concepts for detection and immobilization may require a lot of power. Hence a battery as a voltage source may not be practical in regards to the outpost.
2. Temperature, humidity, wind, rain, snow, hail etc. Both the fence and outposts concepts are intended for outdoor use, hence the entrance concept is less vulnerable to such weather conditions.
3. Humans and animals are potentially exposed to immobilization concepts. The outposts will only cause harm to objects within the enclosure and is thus not considered as a potentially harmful.
4. The entrance and fence concepts are in the vicinity of humans, and thus may provide a greater assurance in regards to reducing the risk of being bitten by a mosquito.
5. The Outposts concept may require several units over an area, resulting in a greater maintenance effort. The Fence is outside in the vicinity of humans, animals etc., which makes it exposed to external impacts.
6. The Outposts effective area may be adapted to the area by the number of units, as with the Fence concept. The Entrance concept requires a vast number of window/door sizes.
7. The Fence may be difficult to relocate and calibrate, as with the Entrance concept.
8. The fence is highly susceptible to noise, the Entrance concept may be less exposed and the Outpost can be shielded by the enclosure.
9. The Outposts requires a wireless transmission of alarms in case of errors

Table 1: Concept Description

Concept	Description
Fence	Immobilize mosquitoes within a confined area by implementing a virtual fence in the outskirts of e. g. a yard, playground, house etc. The mosquitoes will be detected and immobilized when passing through.
Entrance	Immobilize mosquitoes within building entrances and openings, such as doors and windows. The mosquito will be detected and immobilized when passing through.
Outposts	Immobilize mosquitoes within a larger area, by placing traps that attract them into an enclosure where the mosquitoes are detected and immobilized. May be positioned at difference locations in a neighborhood, forest etc.

2.2 Current Concept

The current concept is illustrated in Figure 2. This system is based on the entrance concept, but with some modifications. An activity diagram is added to give a better explanation on how the system will operate.

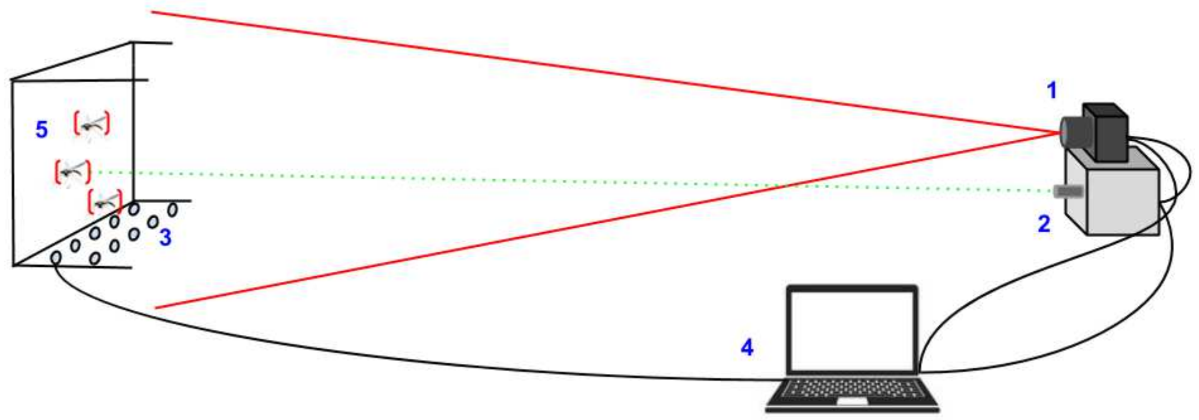

Figure 2: Current Concept

Legend:

1. Camera
2. Immobilization System
3. Microphones
4. Processing Unit
5. Targets

2.2.1 Activity Diagram

Figure 3 presents how the concept works.

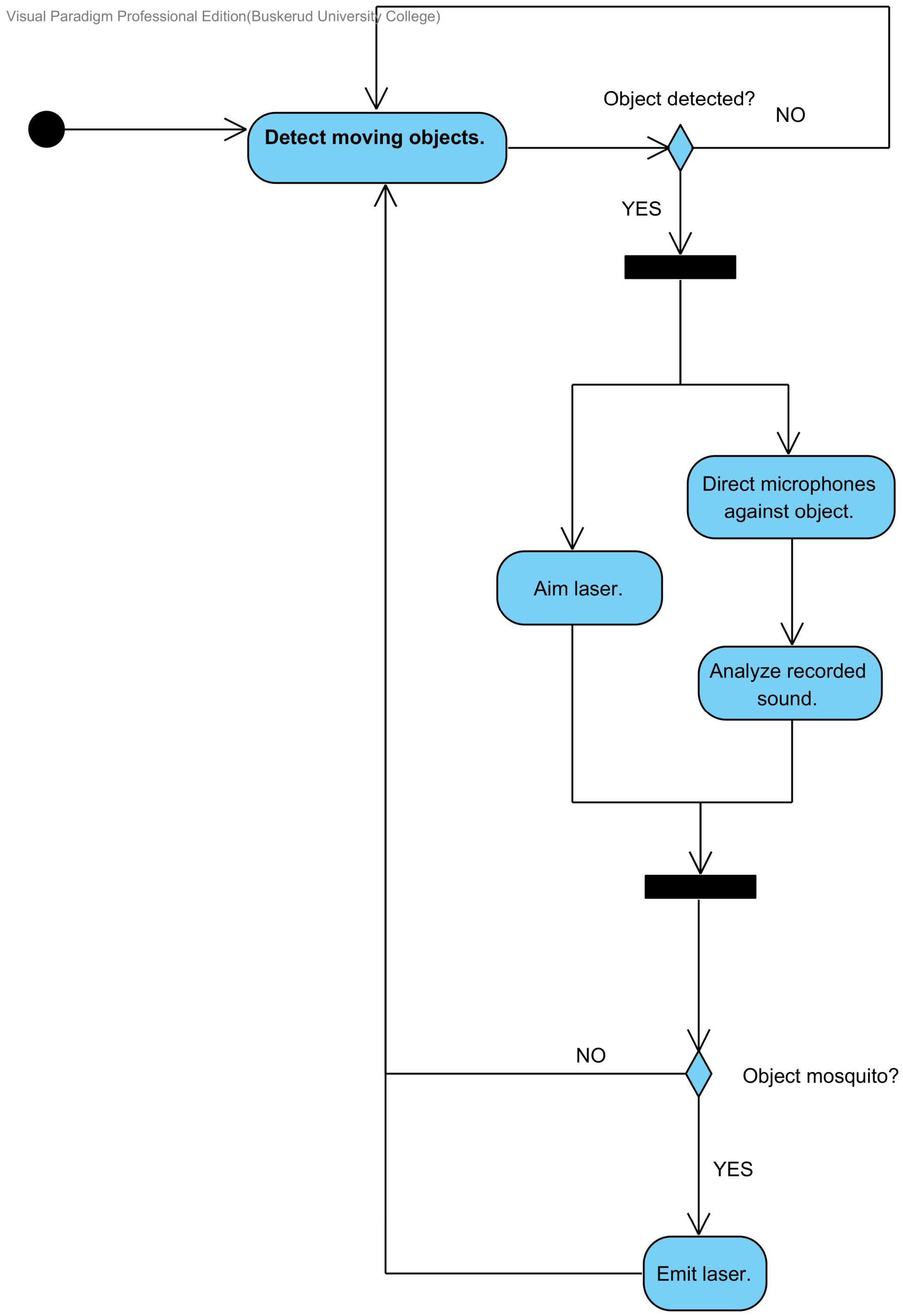

Figure 3: Activity Diagram

3 Conclusion

This document presents a concept study and a current concept selection. This concept is considered as a possible solution for the problem and seems doable to implement in the given time frame. Further investigation on the specific components is needed in order to go into more technical detail.

4 References

[1] MDS. "Outpost Concept Document" *OutpostConcept_v1.0_14.03.2015*. (2015). Web. 14. Mar. 2015.

[2] MDS. "Photonic Fence Concept Document" *Concept_Photonic_Fence_v1.0_13.03.2015* (2015). Web. 14. Mar. 2015.

[3] MDS. "Entrance Concept Document" *Entrance_concept_v1.0_13.03.2015* (2015). Web. 14. Mar. 2015.

[4] MDS. "Concepts on Detecting Mosquitoes with Microphone Arrays" *MicrophoneArrayConcepts_v1.0_14.03.2015* (2015). Web. 14. Mar. 2015.

Entrance Concept

Mosquito Defence Systems

v1.0 ● 13.03.2015

Abstract

This document concerns a concept development regarding entrance protection. It includes a selection of detection methods as well as immobilization means with accompanying figures.

Document Version

Version	Date	Name	Description
0.1	19.02.15	Max Moeschinger	Initial document created
1.0	13.03.2015	Hege J. Blikra	Document revision.
1.0	08.05.2015	Ann Christin Barstad	Proofreading

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List of Figures

1 Introduction

Most insects serve an important task, such as pollination of flowering plants, nutrition, and population control. Mosquitoes act as a major part of the aquatic food chain, yet they are carriers of deadly diseases. As the tropical weather is predicted an appearance in Nordic countries in the future, control of the mosquito population is an absolute necessity in order to save lives. In this regard, the entrance concept is an idea developed to decrease the mosquito population around the entrances of houses. The system will be able to detect individual mosquitoes and proceed to immobilization when position is obtained.

2 Entrance Concept

The entrance concept consists of a detection unit and an immobilization unit. Both the detection and immobilization can be implemented in different ways and these are explained further on in this document. The entrance system will detect and immobilize mosquitoes without causing harm to humans or animals, by the use of a motion detector which deactivates the system when motion is sensed. The sensor is not triggered by mosquitoes; hence the system is able to perform as required. The system will be working on standard power outlet and will not be energy consuming. A concept sketch is shown in Figure 1.

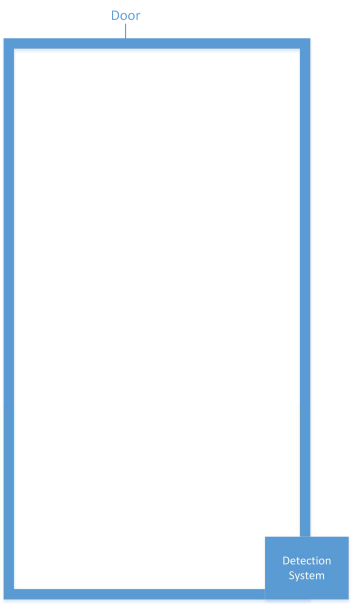

Figure 1: Concept Sketch

2.1 Detection

The detection of the mosquitoes can be implemented in several different ways, explained in the below sections.

2.1.1 Infrared Camera and Directional Microphone

In this case we have two-step detection. At first an infrared camera detects the presence of objects, but because infrared cameras do not have the needed resolution to distinguish between mosquitoes and other similar insects, a directional microphone has to be added. The microphone is directed towards the detected object, and by frequency comparisons, it is possible to determine whether it is a mosquito or not.

2.1.2 Infrared Camera, Laser, and Photodiode

This detection method is similar to the above method. The difference is in the second detection step, where a laser and a photodiode are replacing the microphone. This concept also requires a retro reflective surface. The infrared camera obtains an object's contour and by pointing a laser in this direction, the beam will reflect off the retro reflective surface, hit the object, and the scattered beam will be sensed by the photodiode. Insect identification is possible because of the laser flickering made by the insect's wing beat. A distinct frequency is obtained and can be read by a processing unit.

2.1.3 Microphone Array

This detection method contains a microphone array placed in an entrance. It will both detect the presence of objects by sound and hereby determine the specie, and also obtain its exact position. This concept is illustrated in Figure 2.

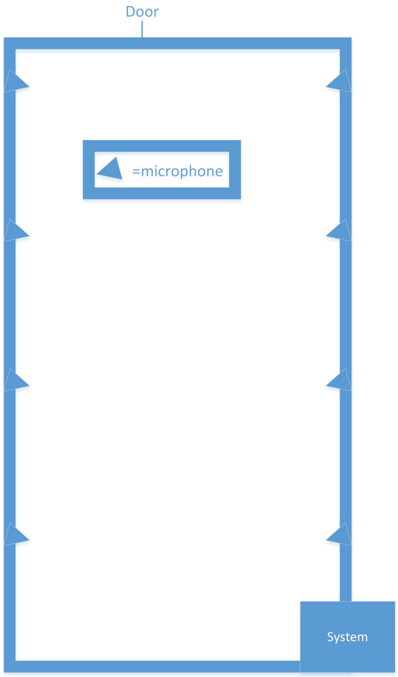

Figure 2: Entrance Microphone Array

2.1.4 Suck and Sort

In this detection method a vertical tube with holes are placed in, or near, the door frame. When insects are close to the entrance, a fan mechanism pulls them through the holes to the inside of the tube. The holes are of certain size, so only small insects, such as mosquitoes, fit through. Inside the vertical tube there is a sorting mechanism which distinguishes between mosquitoes and other insects. This particular method can be performed in several different ways:

- An infrared camera might be able to distinguish mosquitoes from other insect when there is only a small area to cover.
- A laser and a photodiode including a retro reflective surface are able to identify mosquitoes by their wing-beat frequency, as described above.

This concept is illustrated in Figure 3.

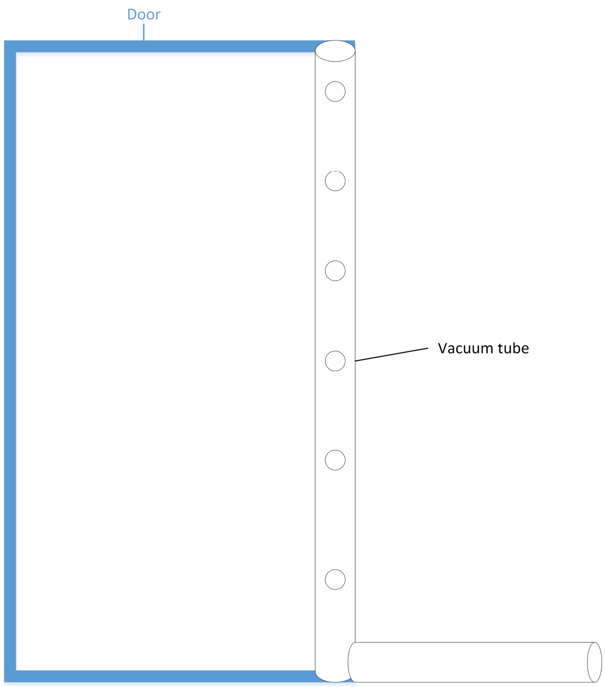

Figure 3: Suck and Sort

2.2 Immobilization

Two different ways to immobilize mosquitoes are described in the following sections: lethal laser and electric fence.

2.2.1 Laser

A precise and lethal laser covering the entrance at all points can be used as immobilization technique in detection methods 2.1.1, 2.1.12.1.2 , and 2.1.3, as illustrated in Figure 4.

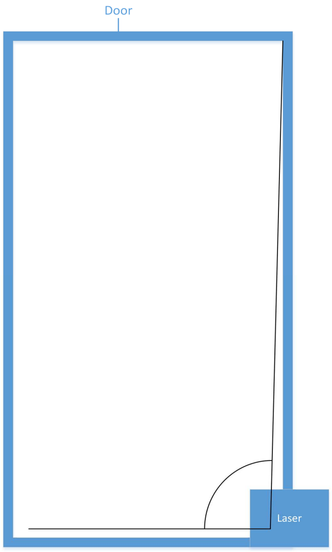

Figure 4: Entrance Laser

2.2.2 Electric Fence

An electric fence would be used on detection method 0, by means of forcing the mosquitoes inside a separate chamber where they are pushed onto and executed by an electric fence.

3 Conclusion

By conducting this research study, it seems doable to implement a similar concept as a design for the final system. The entrance concepts show that it is possible to fully protect entrances from disease-carrying mosquitoes when and if they were to invade this country. Compared to existing mosquito nets, which only prevents mosquito entrance; these entrance concepts have the advantage of both keeping the mosquitoes from entering the house and immobilize them in a safe manner. In this regard, the entrance concepts are considered as much more effective solutions. However, the different detection and immobilization techniques have to be further researched and discussed in order to ensure that they will work optimally in a final system.

Outpost Concept

Mosquito Defence Systems

v1.0 ● 14.03.2015

Abstract

This text concerns an outpost concept based on the Mosquito Killing System (MKS). MKS is an existing trap-based system used to reduce mosquito populations in designated areas. Using this system as inspiration, this text discusses a similar concept with added features, such as singular detection and related immobilization methods.

Document Version

Version	Date	Name	Description
0.1	19.02.2015	Hege J. Blikra	First draft.
1.0	14.03.2015	Hege J. Blikra	Document revision.
1.0	08.05.2015	Ann Christin Barstad	Proofreading

Table of Contents

1 Introduction

Most insects serve an important task, such as pollination of flowering plants, nutrition, and population control. Mosquitoes act as a major part of the aquatic food chain, yet they are carriers of deadly diseases. As the tropical weather is predicted an appearance in Nordic countries in the future, control of the mosquito population is an absolute necessity in order to save lives. On today’s market, there are no sufficient solutions for this purpose. However, commercially available supplement systems exist. To decrease the number of mosquitoes in residential areas systems such as the *Mosquito Killing System* (MKS) are available. With inspiration from this system, MDS is able to develop a similar concept that is safe. In addition, the outpost system will reduce the mosquito population by singular detection and destruction.

2 Outpost

2.1 Existing Concept

Systems referred to as Mosquito Killing Systems (MKS) are commercially available products with the purpose of reducing mosquito populations in residential areas. MKS use heat and carbon dioxide (CO_2) as attractants, to mimic the presence of human beings and animals, including a vacuum effect to trap mosquitoes inside a small area, and then proceed to destruction [1]. Working principle is illustrated in Figure 1.

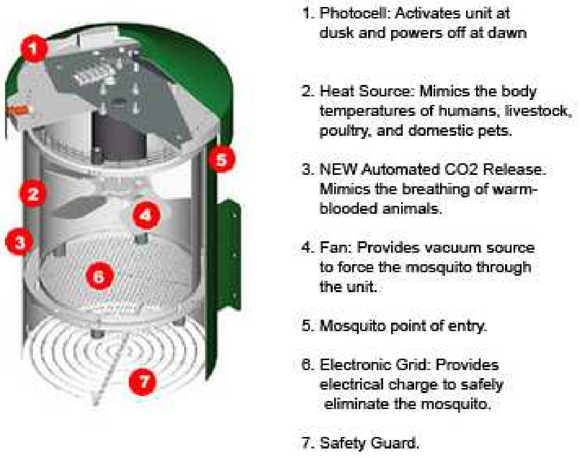

Figure 1: Mosquito Killing System Working Principle

There are several versions of this product available on the market and all work by the same principle. To implement parts of this concept in a system that complies with MDS’s vision, some necessary features have to be implemented. In addition, the design architecture will be different. The system has to be able to detect individual mosquitoes and then proceed to execution to fulfill requirements.

2.2 Outpost Concept

The outpost system will work as a lure to capture mosquitoes of different types. The attractants will, similar to MKS be heat and CO_2, in order to develop an effective system as well as to shield the environment as much as possible. When insects are located on the specific unit, they will be drawn inside by a fan and selectively identified, by audio or image processing. Captured mosquitoes are immobilized by chosen execution method, while other insects will be led to a separate gate and released to the free.
The system will be enabled at the time mosquitoes are most active and disabled at the time they're not. The outpost will include different parts, and these are explained further in the following sections.

2.2.1 Attraction

The system will use CO_2 and heat as attractants to mimic the presence of human beings and animals. By using a CO_2 tank and e.g. infrared light for the illusion of warmth, the system is able to attract mosquito blood-feeders.

2.2.2 Trap

When mosquitoes are located on the unit, a fan inside will work as a vacuum and drag the mosquitoes inside. This opening is made small, such that larger insects will not fit through.

2.2.3 Detection

There are several methods that can be used to detect and identify mosquitoes. For this specific concept two detection methods will be discussed: microphones and image recognition. Using microphone as detection method is possible because of the mosquitoes' buzzing sound. This detection method is explained in [2]. If the background noise is not interfering, using microphones is an option. The second detection method is image recognition which will use a camera to detect the shape of the mosquito and run this image through a database. If it is a match, the system proceeds to immobilization, and if not, the insect will be let out of the unit.

2.2.4 Immobilization

There are several possible immobilization methods to be used for this concept: laser, electrocution grid, water etc. The existing concepts (MKS) contain an electrocution grid which immobilizes the mosquitoes in an instance. It is also possible to use a high-powered laser to kill the mosquitoes. This method is more advanced and requires more fast response components than the electrocution grid.

2.2.5 Disposal

A disposal bag will be attached at the bottom of the system, and collect the immobilized mosquitoes. This bag will be removable and changeable. Insects not identified as mosquitoes will be let out through a gate on the side. The gate is controlled and does only open when non-mosquitoes are identified.

2.2.6 Power

The system will need to be powered by an electrical source (standard power outlet, battery, solar panel), to run the fan and other electrical components. In addition a standard CO_2 tank is needed to run the system. This tank needs to be non-flammable, non-explosive, and non-toxic, and easy to store and transport. The system will be implemented with functions so that it is on when needed and otherwise off. In this way electricity and CO_2 is saved.

2.2.7 Concept Sketch

Figure 2 illustrates the outpost concept. There are some parts missing from the sketch, such as the CO_2 tank and power source.

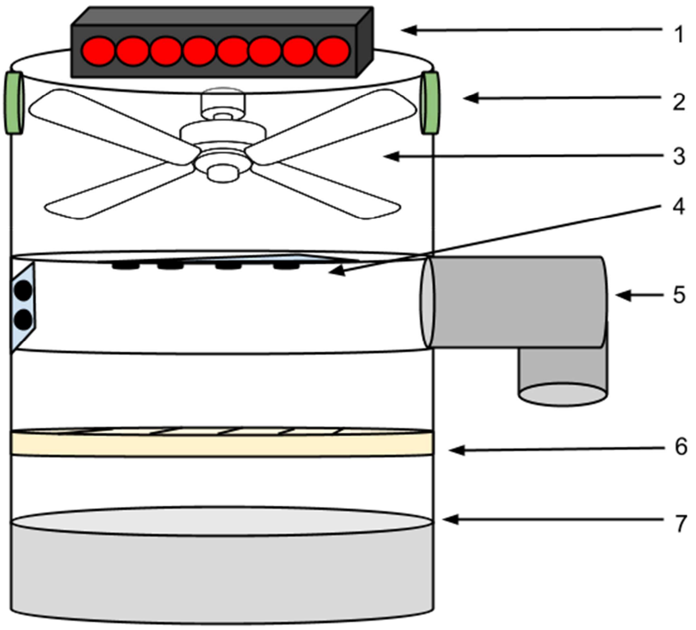

Figure 2: Outpost Concept Sketch

Legend:

1. Infrared Light Source
2. Mosquito Opening
3. Fan
4. Detection Area (Microphone Array)
5. Insect Gate
6. Immobilization Area (Electrocution Grid)
7. Disposal Bag

3 Conclusion

In this text a trapping method to reduce the mosquito population is discussed. A system using attraction, detection, and immobilization is theoretically a good way to control mosquitoes. However, such a system will not fully protect human beings from deadly diseases. The outpost will work as a supplement to partly clear areas for mosquitoes and prevent some potential bites.

4 References

[1] "Healthilife." *Healthilife*. Web. 20 Feb. 2015. http://www.healthilife.net/mks.html

[2] Ann Christin Barstad, Max Moeschinger, Hege Jeanette Blikra, and Christoffer Olsen. "Mosquito Detetction." (2015). *MosquitoDetectionConceptsAndMethods_v0.5_19.02.2015*. Web. 20 Feb. 2015. Pages 5-7.

Photonic Fence Concept

Mosquito Defence Systems

v1.0 ● 13.03.2015

Abstract

This paper is a literary study of the photonic fence concept, a technology developed with the purpose of protecting humans against disease-carrying mosquitoes. This document will provide information about how the photonic fence works, and how we may apply some of the same techniques for our own project.

Document Version

Version	Date	Name	Description
0.1	19.02.2015	Eirik Haavaldsen	Document Creation.
1.0	13.03.2015	Hege J. Blikra	Document revision.
1.0	08.05.2015	Ann Christin Barstad	Proofreading

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1 Introduction

Malaria is a serious problem in some areas today; it is the cause of hundreds of thousands deaths every year. It is important to decrease these numbers, and several programs have been developed in that matter. However, there are no programs or methods that have proven to be very effective so far, and that was the basis for the "Photonic Fence" developed by *Intellectual Ventures.* On their website [1], they write the following about malaria and their product:

"According to the World Health Organization, an estimated 207 million cases of malaria and an estimated 670,000 malaria deaths occurred worldwide in 2012. Governments and aid agencies have set up many programs to distribute antimalarial drugs, insecticides, and bed nets in endemic areas, and these important tools have curbed malaria's spread through the poorer parts of the world. However, existing measures have only held the epidemic in check. To have a real chance of conquering this disease, we need truly new approaches.

One way to break the malaria transmission cycle is to prevent the primary vector–the female Anopheles mosquito–from reaching the age where it can infect a healthy host. As part of IV's Global Good program, our team at IV Lab is developing a device capable of identifying the discriminating characteristics of a mosquito (wing beat frequency, shape, size, airspeed, etc.), training a laser on it, and delivering adequate photonic energy to kill or incapacitate it.

This approach could offer a new tool for mosquito control that works without constant human attention and with no collateral damage to the local ecology. It would be used to complement bed nets, insecticides, and other existing vector control techniques.

One potential use of the Photonic Fence is to create a virtual fence that detects insects as they cross its plane. When an invading insect is detected, our software is able to estimate the insect's size and measure its wing beat frequency. Using this method, not only can the system distinguish between mosquitoes, butterflies, and bumblebees, but it can even determine whether a mosquito is male or female. This is important to know because only female mosquitos bite humans. Once the software establishes that the insect is a valid target, it tracks the mosquito in flight, runs a safety check to ensure no innocent bystanders are in view, and then activates a laser to zap the mosquito. The Photonic Fence could be set along the perimeter of clinics or other strategic areas to control mosquitoes without endangering humans or other animals.

Alternate uses:

Elements of the Photonic Fence could also be used to monitor and catalog the presence of mosquitoes, or other flying insects in a given area of interest. In this scenario, the device might be useful as a passive means of evaluating potential insect repellants, attractants, or other interventions. Outside of malaria eradication efforts, alternative applications for the Photonic Fence could include crop protection against pests or as a research tool to better-understand insects" [1].

2 Photonic Fence

2.1 How the Photonic Fence Works

2.1.1 Concept sketch

Figure 1 illustrates the concept sketch of the photonic fence with accompanying legend [2].

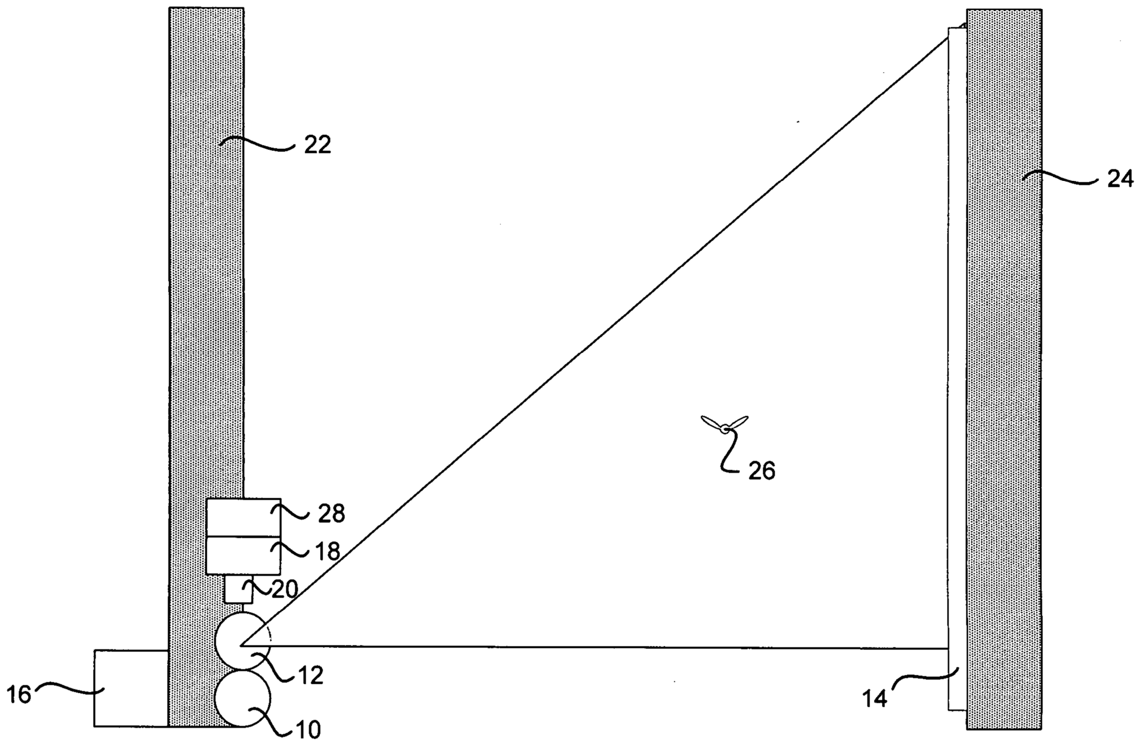

Figure 1: Concept Sketch

Legend:

- **10:** Imager. (Camera)
- **12:** Illumination source
- **14:** Retro Reflective Surface
- **16:** Processor (Analyze images)
- **18:** Targeting Laser
- **20:** Photodiode
- **22:** Support Post
- **24:** Adjacent Support post spaced apart from 22
- **26:** Undesirable Organism
- **28:** Dosing Laser

2.1.2 Concept Components

This section provides a description of each component (as written in the patent) [2]. Please take note that the patent contains more information about the components and their context.

Imager:

"In some embodiments, processor **16** may incorporate a graphics processing unit (graphics card) for analysis. The graphics processing unit (GPU) may have a parallel "many-core" architecture, each core capable of running many threads (e.g., thousands of threads) simultaneously. In such a system, full-frame object recognition may be substantially speeded as compared to traditional processors (e.g., 30 times as fast). In some embodiments, a field-programmable gate array may be directly connected to a high-speed CMOS sensor for fast recognition" [2].

Illumination Source:

"This may be, for example, a laser, an LED, an incandescent light, a mirror reflecting sunlight, or any other suitable light source" [2].

Retroflective surface:

"The width of retro reflective surface **14**, and of the field of view of imager **10**, may be selected as a function of the flight speed of the target(s) of interest and the frame rate of imager **10**, such that the silhouette of an insect will be within the field of view for at least one full frame interval, and as a function of the flight speed and the desired wingbeat sensing accuracy, such that the silhouette will be within the field of view for a sufficient period to make a measurement of the desired accuracy" [2].

Processor:

"In some embodiments, processor **16** may incorporate a graphics processing unit (graphics card) for analysis. The graphics processing unit (GPU) may have a parallel "many-core" architecture, each core capable of running many threads (e.g., thousands of threads) simultaneously. In such a system, full-frame object recognition may be substantially speeded as compared to traditional processors (e.g., 30 times as fast). In some embodiments, a field-programmable gate array may be directly connected to a high-speed CMOS sensor for fast recognition" [2].

Targeting laser:

"In addition to the higher-speed camera imaging of the organism, the system may also employ a targeting laser **18** (or other suitable nonlaser light source) and detector (such as photodiode **20**) to confirm characteristics of organism **26**. For example, if processor **16** identifies a morphology or frequency suggestive of an organism of interest (such as a mosquito), targeting laser **18** may be directed at organism **26** using location information from processor **16**. The reflection of targeting laser **18** from organism **26** is detected by photodiode **20**. In some embodiments, this reflection may have relatively lower image resolution but a very fast frame rate, wide frequency response, or a high sensitivity to changes in cross section of the organism. The signal from the photodiode may be used, for example, to measure wingbeat frequency or harmonics very accurately to identify the organism or to otherwise classify the organism into an appropriate category, or otherwise distinguish the organism. Targeting laser **18** may also or alternatively provide additional light for higher frame rate or higher resolution image acquisition by imager **10**" [2].

Photodiode:

"In addition to the higher-speed camera imaging of the organism, the system may also employ a targeting laser **18** (or other suitable nonlaser light source) and detector (such as photodiode **20**) to confirm characteristics of organism **26**. For example, if processor **16** identifies a morphology or frequency suggestive of an organism of interest (such as a mosquito), targeting laser **18** may be directed at organism **26** using location information from processor **16**. The reflection of targeting laser **18** from organism **26** is detected by photodiode **20**. In some embodiments, this reflection may have relatively lower image resolution but a very fast frame rate, wide frequency response, or a high sensitivity to changes in cross section of the organism. The signal from the photodiode may be used, for example, to measure wingbeat frequency or harmonics very accurately to identify the organism or to otherwise classify the organism into an appropriate category, or otherwise distinguish the organism. Targeting laser **18** may also or alternatively provide additional light for higher frame rate or higher resolution image acquisition by imager **10**" [2].

Support post (22) and adjacent support post (24):

"The width of support posts **22** and **24** is selected to provide adequate support and surface area for components including retroreflective surface **14**; in the illustrated embodiment, the support posts are 10-20 cm wide, and are placed 100 m apart. The width of retroreflective surface **14**, and of the field of view of imager **10**, may be selected as a function of the flight speed of the target(s) of interest and the frame rate of imager **10**, such that the silhouette of an insect will be within the field of view for at least one full frame interval, and as a function of the flight speed and the desired wingbeat sensing accuracy, such that the silhouette will be within the field of view for a sufficient period to make a measurement of the desired accuracy" [2].

Dosing laser:

"In some embodiments, once the organism has been identified or otherwise categorized or characterized, it may be desirable to take action to disable or destroy the organism. For example, in some embodiments, when a mosquito has been detected as entering the field of view, a countermeasure such as a laser beam may be used to disable or destroy the mosquito. In such embodiments, location information for the organism **26** may be passed from the imager **10**, the processor **16**, the targeting laser **18**, or an associated targeting processor, not shown, to a dosing laser **28**. In some embodiments, other countermeasures might include a sonic countermeasure transmitted by an acoustic transducer, a physical countermeasure such as a solid or liquid projectile, or a chemical response, in lieu of or in addition to dosing laser **28**. In some embodiments, targeting laser **18** and dosing laser **28** may be the same component, for example using a higher amplitude for dosing than for targeting. In other embodiments, targeting laser **18** and dosing laser **28** may be separate components. In this case, they may optionally use a common aiming mechanism such as a beam splitter or beam combiner that allows dosing laser **28** to fire along the same path as targeting laser **18**. FIG. 3 is a control flow diagram for an implementation of the tracking and dosing system, illustrating cooperation of imager assembly **40**, processor **42**, targeting laser assembly **44** and dosing laser assembly **46**" [2].

2.2 Activity Diagram

Figure 2 illustrates how the photonic fence works presented as an activity diagram [2].

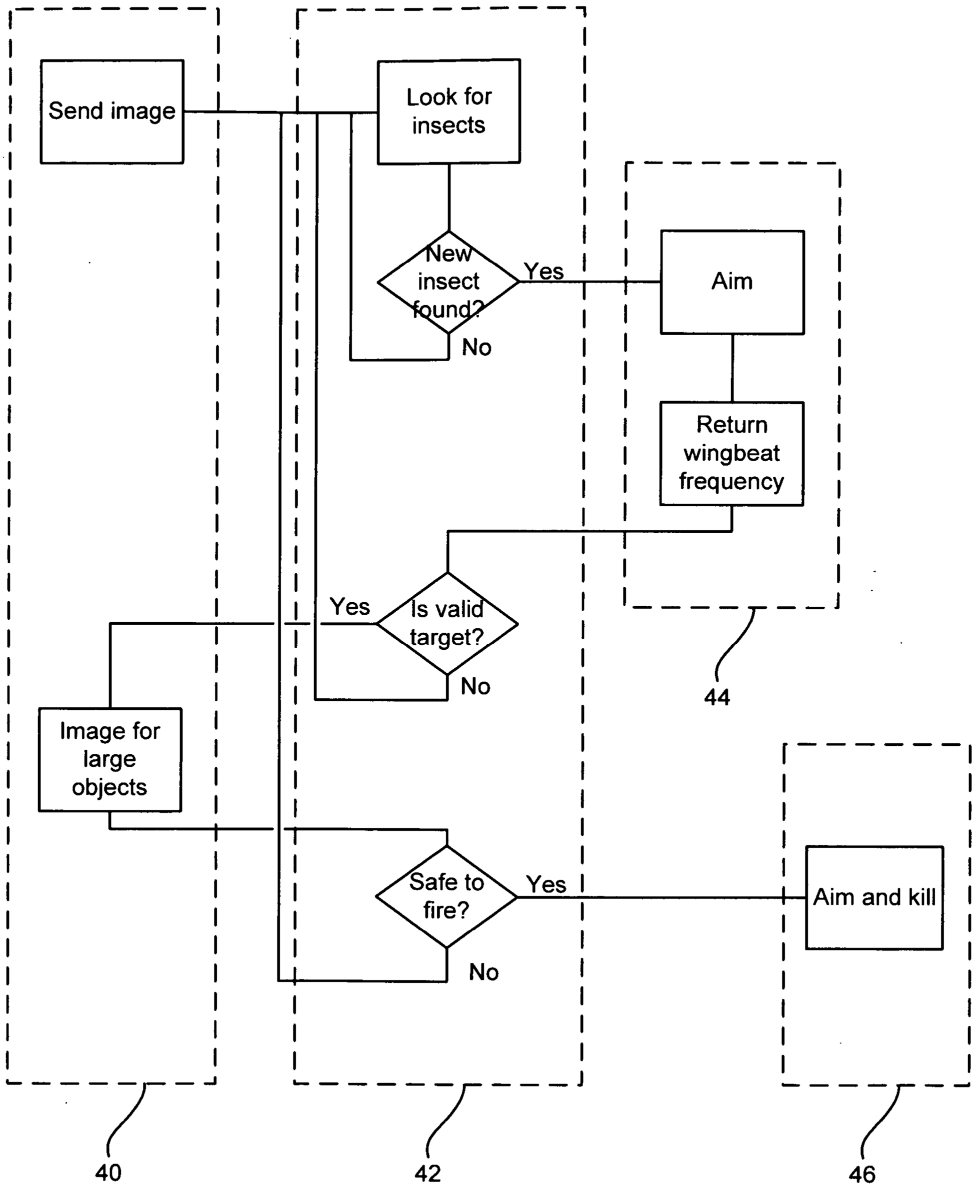

Figure 2: Activity Diagram for the photonic fence

2.3 List of Prototype Components

Modules, as written on the photonic fence website [3]:

- Three Femotosecond Lasers
- Zeiss/BioRad Multiphoton and Scanning Laser Confocal Microscope
- Optical Parametric Oscillator
- Ultrafast Amplifiers
- High-Sensitivity Spectrometers
- Beam Profilers
- Auto-Correlators
- Reflective and Refractive Optics

Figure 3 and 4 illustrates the prototype module of the photonic fence in two parts, from [4] and [5].

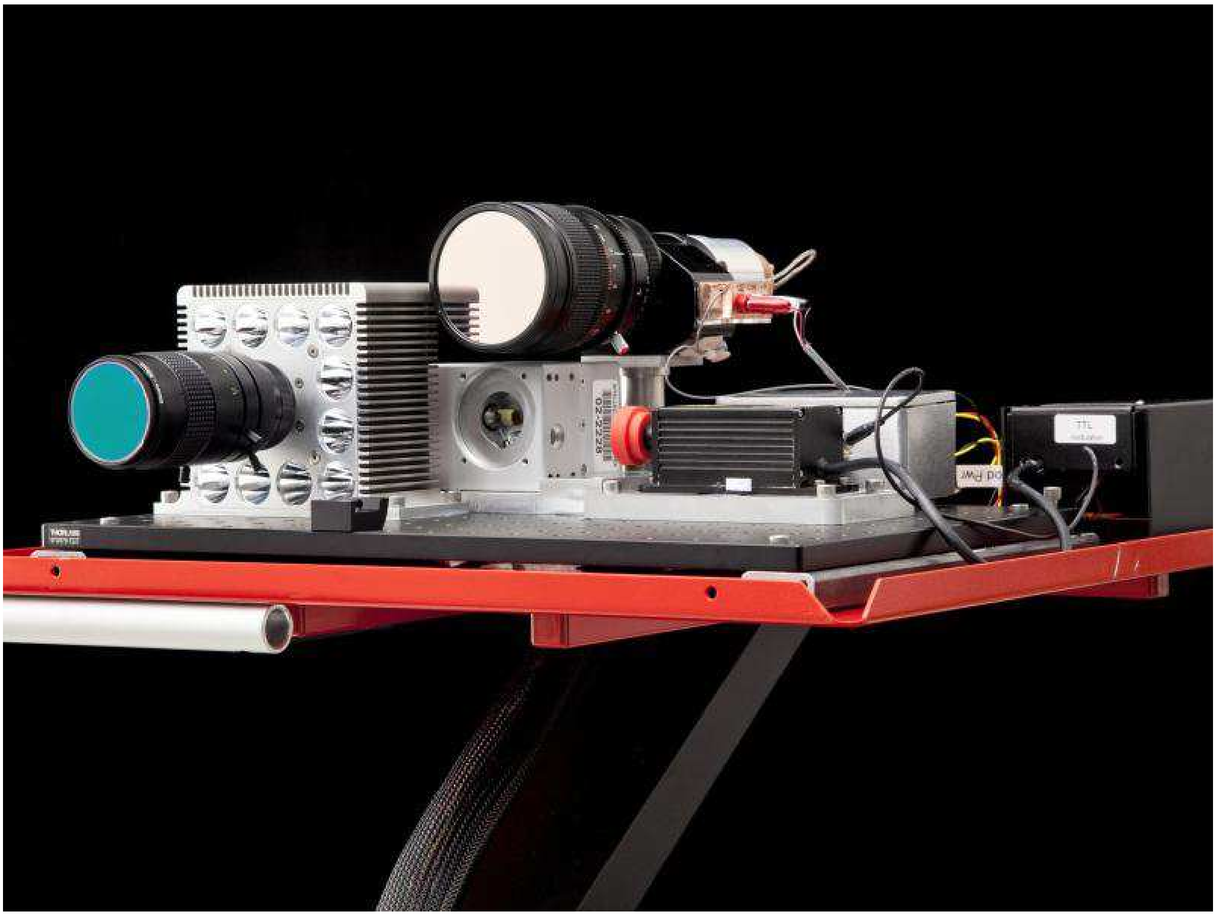

Figure 3: Prototype (First half)

Figure 4: Prototype (Second Half)

2.4 Operational Concepts

This section provides several figures showing different uses and purposes of the system. (Found in the image gallery at the intellectual ventures webpage) [6].

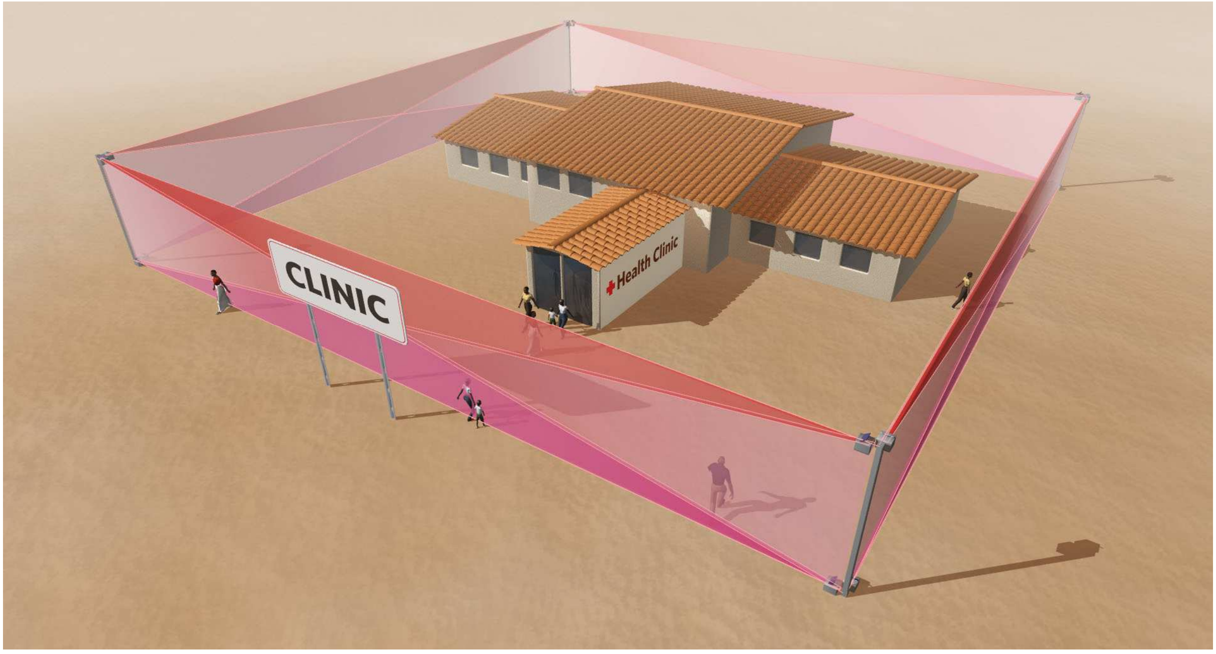

Figure 5: Photonic Fence Clinic Protection

Figure 6: Photonic Fence Household Protection

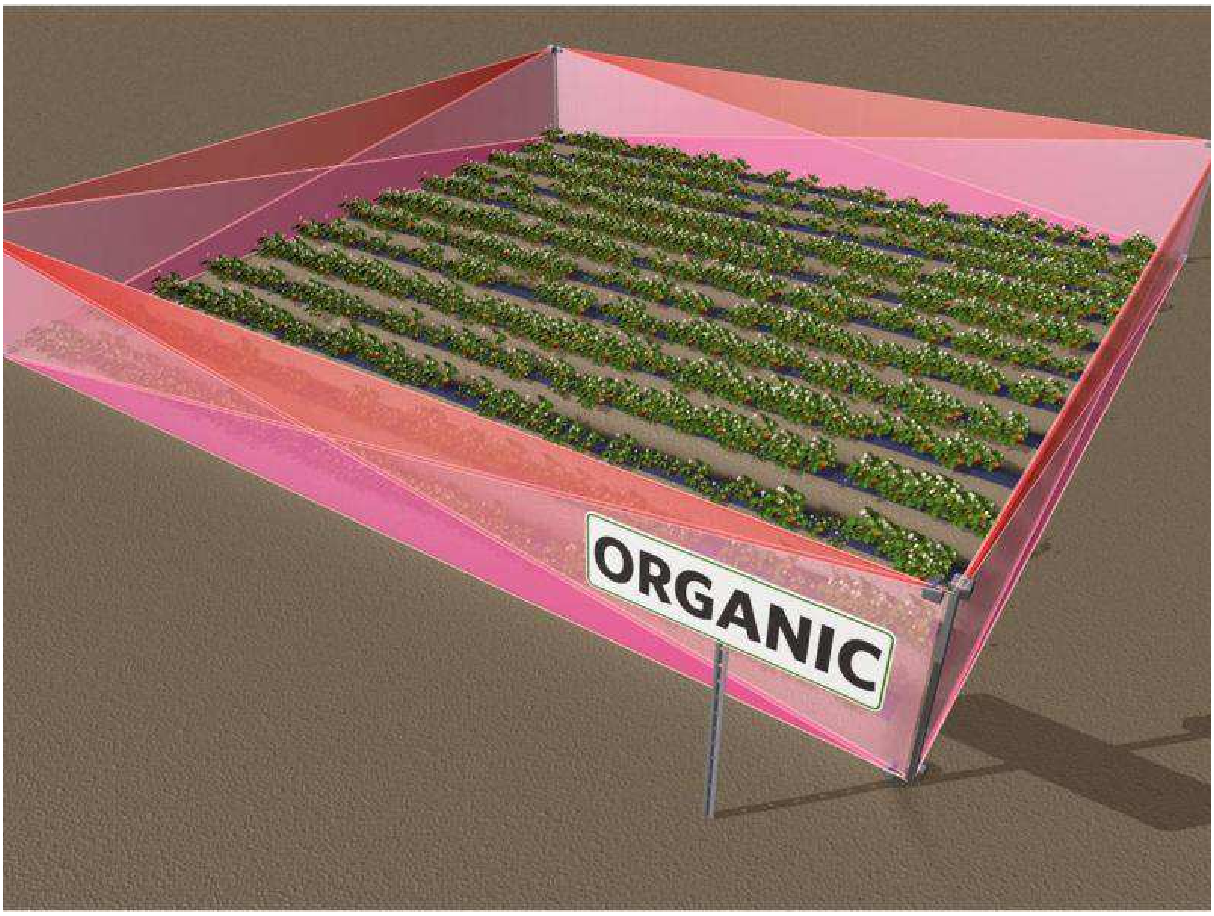

Figure 7: Photonic Fence Agriculture Protection

3 Conclusion

A user going by the name of “Katherine Clouse” on quora.com, which also happens to be the name of a senior manager at Intellectual ventures; wrote the following:

“From Intellectual Ventures: The prototype Nathan Myhrvold showed at TED in 2010 proved that the basic idea of a photonic fence is feasible. The company's focus since has been on adapting the technology to fight malaria in the developing world. It's not yet been commercialized” [8].

I find the lack of information concerning the future of the photonic fence, as a sign that the concept is feasible (as shown at TED 2010), but not adequate (as of now). All the blog posts and articles on their website are several years old, and they have rarely given public statements concerning the status of the project.

I believe that Intellectual Ventures has been struggling, trying to make a cost-effective version of photonic fence (Feasible for parts of the third world.) The most recent posts on their website suggest that they are still researching vector-defense. They might have chosen a different direction. Perhaps they focus on other solutions, such as vaccines, or biological warfare against mosquitoes.

4 References

[1] Intellectual Ventures, "The Photonic Fence," Intellectual Ventures, [Online]. Available: http://www.intellectualventureslab.com/work/photonic-fence. [Accessed 19 February 2015].

[2] Intellectual Ventures, "Photonic Fence patent," Intellectual Ventures, [Online]. Available: http://www.google.com/patents/US20100186284. [Accessed 19 February 2015].

[3] Intellectual Ventures, "Photonics," Intellectual Ventures, [Online]. Available: http://www.intellectualventureslab.com/lab/photonics. [Accessed 19 February 2015].

[4] Intellectual Ventures, "Prototype (First Half)," Intellectual Ventures, [Online]. Available: http://www.intellectualventures.com/assets_inventions/142/mobile+photonic+fence+(top+view)__large.jpg. [Accessed 19 February 2015].

[5] Intellectual Ventures, "Prototype (Second Half)," Intellectual Ventures, [Online]. Available: http://www.intellectualventures.com/assets_inventions/142/mobile+photonic+fence+(full+cart)__large.jpg. [Accessed 19 February 2015].

[6] Intellectual Ventures, "Image gallery," Intellectual Ventures, [Online]. Available: http://www.intellectualventures.com/inventions-patents/our-inventions/photonic-fence. [Accessed 19 February 2015].

[7] Photonics media, "YouTube," 29 October 2014. [Online]. Available: https://www.youtube.com/watch?v=OsELkJVqyDs. [Accessed 20 02 2015].

[8] K. Clouse, "quora," 14 November 2014. [Online]. Available: http://www.quora.com/Where-is-Nathan-Myhrvolds-anti-mosquito-laser-now-2014. [Accessed 19 February 2015].