Modeling of building occupation using motion sensor data

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Summary:
An adaptive model of occupancy, based on simple motion data is proposed. The model predicts the occupation of the test building with a prediction horizon of one week.

In addition to this model, a simulator is proposed. This simulator has been used to simulate data, similar to the measured data from the test building.

Both the simulator and model have been implemented in C#, as PIRSim and PIRMod. This implementation has been done using the Unified Process and documented using UML documents.
Preface

This report is written to document the project performed as a part of the work of the SMART research group at USN. The goal of the project is to implement a model in C#, using UP, and document the software using UML.

The model is to predict the occupation of a building, using motion sensor data. This model has been implemented, and used to predict a week of occupation. If the data contains too many exceptions, the model will not be able to predict accurately.

In addition to the model, a simulator is implemented. This simulates a configured sensor setup. To complement the data from the simulator, data measured in a building is also used. This building is the home of a SMART group participant. As the data is of a personal nature, it is not available here. Only fragments of this data has been used to demonstrate the function of the model, and evaluate the simulator.

The source code for the software is available online, from [1] and [2] via azure devops services. It is also given to the supervisors via email.

The author would like to extend gratitude to the supervisors and the faculty of USN for their teachings and support.

Porsgrunn, 13th May 2019
Jørund Martinsen
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<td>A software environment</td>
</tr>
<tr>
<td>C</td>
<td>A programming language</td>
</tr>
<tr>
<td>C#</td>
<td>Programming language</td>
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<td>FDUC</td>
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<td>GUI</td>
<td>General User Interface</td>
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<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
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<td>MVVM</td>
<td>Model-View-ViewModel</td>
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<td>PIR</td>
<td>Passive Infrared sensor</td>
</tr>
<tr>
<td>UI</td>
<td>User Interface</td>
</tr>
<tr>
<td>UML</td>
<td>Unified Modeling Language</td>
</tr>
<tr>
<td>Unix</td>
<td>Operating system</td>
</tr>
<tr>
<td>UP</td>
<td>Unified Process</td>
</tr>
<tr>
<td>VS</td>
<td>Visual Studio</td>
</tr>
<tr>
<td>WPF</td>
<td>Windows Presentation Foundation</td>
</tr>
<tr>
<td>XAML</td>
<td>eXtensible Application Markup Language</td>
</tr>
<tr>
<td>XML</td>
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</tr>
</tbody>
</table>
1 Introduction

As SMART house technology has emerged, the need to estimate position of residents has been important for several cases. In this project, a model of PIR sensor data is presented. The model should be able to predict occupation status, now or in the near future. This does not include the location inside the house. Previous work in this area is summarized in [3]. Here, several approaches and methods are reviewed. Some of these are touched upon here and also implemented in the model. The software is written in WPF, C#, using the Unified Process as a development process. Documentation is done using UML schemes.

1.1 Background

As part of the work at USNs research group SMART, a model of movement in homes is required. This model will enable several other parts of a larger control system to function more efficiently. The main focus of this research is to be able to minimize energy consumption of buildings, while maintaining a comfortable environment. A large part of this work is to minimize heating efforts, as these contribute around two thirds of the energy consumption of residential buildings. [4]

In addition, the model could be used to improve burglary detection and prevention systems.

1.1.1 Previous work

In the previous work, the focus has been to predict where in the building residents are going to be. This has been done by using advanced sensory equipment and other SMART devices. Examples of this is described in Sanchez, Pfeiffer and Skeie, where several other applications are also mentioned. [3]

Dodier, Henze, Tiller et al. describe a system where the occupants are tracked using simple motion data, however the goal of the project was to determine future location of occupants. This is close to the work presented here, but does not consider the occupation status of the building. [5]
1 Introduction

1.2 This work

A simulator for motion data has been created. This simulator is made for simulating several setups. To test and validate the simulator, a house with a sensor system is used. Data from this house has been gathered since 2018, with additional sensor added in 2019. Section 2.1 describes the setup of the house.

To predict future occupation, a model has been created. This model uses a top-hat model. Several other model types have been considered, as described in section 2.5.

Both of these systems have been implemented and tested using C# and WPF. The development process has been Unified Process.

1.3 Report structure

This report is structured in three main parts; Theory, implementation and results.

Theory

In chapters 2 and 3, different methods for the model and simulator development are described. Chapter 2 describes the overall system, as well as the methods for simulation and modeling. Chapter 3 describes the methods for software development, and the technology used in the implementation.

Implementation

In chapter 4 the implementation of the theory is described. The software is documented by using class diagrams and descriptions. The documents created as a part of UP are also included here.

Results

The simulator and model are compared to biologically created data from the house. In addition the test results are included. These results are then commented on and discussed in the discussion chapter, chapter 6
2 System description

The system consists of a house, with PIR sensors and a centralized logging system. Two adults reside in this house, and trigger the PIR sensors naturally. Each trigger of a sensor is an event. These events are logged to a CSV file.

To develop and test a good model, more types of setups need to be used. To accomplish this, a simulator has been developed. This simulator has been compared to the naturally generated data. It is possible to configure the simulator to generate events for multiple sensors and floors. In addition, different rates of events for different time periods can be configured.

Finally, a model for estimating future occupation has been developed. This model can read the data from the house, or the simulator. It is adaptive, as it uses historic data to retrain itself periodically. Each part of the complete system is designed as a standalone system, so each part is reusable for future development.

2.1 Technical properties

When using a PIR sensor several issues need to be considered. In combination with the limitations of the sensors, there are issues to consider with a system to monitor a building. These issues are described in the following sections.

PIR sensor

A PIR sensor consists of two main parts. These parts are the actual sensor and a Fresnel lens. The sensor detects temperature, while the lens splits the detection area into sections. Separation of detection area allow for motion detection. As an item moves from one section to another, the temperature sensor will spike for each section. Consecutive spikes are then an indication of movement. This is shown in figure 2.1 [6]

The main limitation of this setup is the lack of static detection. If there is no movement, the sensor will not trigger, and the system will not detect occupation. Overcoming this limitation is a part of this work.
Sectioning the detection area modifies it. An example of a modified detection area is shown in figure 2.2.

To cover a large complicated area, like a building, several sensors are combined. If one sensor triggers, there is movement in the area. With a detection area like the one in figure 2.2, the location of sensors inside the building is an important factor when creating the system. To enable detection of occupation, all passages should be covered, especially the exit and entry points of the area.

House setup

Biologically created data is generated from a house with PIR sensors mounted at various locations. The building has two floors with sensors. Some of these sensors were installed in 2019. Two sensors were installed prior to 2018. For these two sensors, there is data for most of 2018.
These two sensors cover the upstairs living room and the kitchen. The newer sensors cover the second living room and the top of the stairs. None of these sensors cover the main door.

### 2.2 Simulator requirements

The simulator should be able to simulate different setups, like the one in the house. In addition, the simulation should be faster than reality, i.e. simulating a month should not take a month.

Simulated data should also be saved in a CSV file, using the same format as that which is generated in the house. The format is shown in appendix C, which also shows generated data from the simulator.

In addition to this, the simulator and the probabilities of events should be configurable.
2 System description

2.3 Simulator method

To generate events, a random function is used. This function already exists in the .NET library as a class. This class has the method Next. To be able to adjust the probability of an event, an array of integers is created. The Next function is used to select a random index of this array. Figure 2.3 shows the selection from the array. [7]

However, as the probability of a consecutive event is higher than normal events, the array is filled with the specified ratio of values, plus a margin. The margin area is filled with 1s, and the rest is filled with 2s and 0s.

If the randomly selected value is greater than or equal to 2, an event is triggered and the limit is set to 1. If the next value is greater than or equal to 1, a new event is triggered. Should the value be 0, the limit is reset to 2.

2.4 Model requirements

Prediction of occupation enables improvement of heating efficiency. By using a sensor array, that is already installed, the model is a cost efficient method for prediction. The model requirements therefore include the usage of PIR-sensors.

In addition, the model should be adaptive, to handle the change in habits from season to season, changes like summer-time, vacations, spending more time outside and/or less time outside.

The model should predict when occupants leave the house, and when they come back. The process of heating is a slow process, so the accuracy requirement is not very strict. An error of \( \pm 10 \) \( -15 \) min is acceptable. As the occupation is Boolean, the location is not of interest, nor the number of people.

This is a simpler model than what is presented in the chapter Previous work, and relies entirely on PIR sensors. This makes it available to most consumers, without a high investment. It is also applicable to several areas, such as burglary alarm and vacation light control.
2 System description

2.5 Different model methods

To model a process, there are many methods. Some of these methods have been considered and are described here. Each method has some properties that can help model the occupation state of the house. First, it is necessary to describe the process. This is done as a state-space model.

2.5.1 State space model

This process consists of many inputs, outputs and disturbances. However, there is only one state. The process can be described using several states, but here the focus is only occupation.

Figure 2.5 shows a simple state space model. This model has input vector $u$, disturbance vectors $v$ and $w$, state vector $x$ and output vector $y$

The vectors $u, v, w$ and $y$ contain variables to describe the number of occupants, errors in the sensor system, changes in occupant schedule etc. Most of these are not observable to this system. The only observable input is the motion events.
2 System description

$x$ contains the occupation state. This state is Boolean, and with only one variable. Equation 2.1 shows this. $x$ is of course dependent upon the number of occupants and/or visitors, and their location, but these variables are not observable.

As a consequence of the state space model setup, several methods can be excluded, such as linear regression or other common machine learning methods.

$$x = x_1 = \begin{cases} True, & \text{for } u_{\text{number of occupants}} + v > 0 \\ False, & \text{for } u_{\text{number of occupants}} + v < 1 \end{cases}$$ (2.1)

Figure 2.5: State space model

2.5.2 Decision trees

This method consists of several 'decisions' and follows the choice to the next decision. This gives a tree structure as shown in figure 2.6. This figure is an example of part of a complex decision tree. Already, there is uncertainty in the model even without prediction. This is due to the probabilistic nature of the process. [8]

2.5.3 Bayesian models

When there is a set of observations, that infer hidden states, a Bayesian network can be utilized. This has been used successfully in [9], to predict the next location of a person. In this work it is of no interest where the person is going to be, unless it is inside the building.
Recursive Bayesian estimation or Bayesian filter is a probabilistic approach to the Kalman filter. Given linear transitions and normally distributed values, the Bayesian filter is equal to a Kalman filter [10, p. 56].

2.5.4 Markov chain

The Markov chain is a special implementation of the Bayesian network. Utilizing the present state, the next states can be inferred. There are many implementations of the Markov chain, including Hidden Markov Model (HMM).

This method has been implemented and tested in the work of Dodier, Henze, Tiller et al., where it showed the capability to estimate occupation of individual offices. [5] This is at a greater detail than the goal of this work.

2.5.5 Neural network

Neural networks are a way to find good estimates of a function. This requires a large dataset, containing both input data and output data. As the occupancy is not directly measured, this data is unavailable. Therefore, neural networks are not a good candidate for prediction of future state of this system. [11]
2 System description

2.5.6 Probability function

As an approximation, it is suggested to use a function to estimate the probability of occupancy. These functions should give an approximation of the probability of occupancy, based on the previous events. Two functions have been evaluated. These are a triangle function and a top-hat function.

To create a more complex model, several functions are combined as shown in equation 2.2

\[ F(x) = \max(f_1(x), f_2(x), \ldots, f_{n-1}(x), f_n) \] (2.2)

Triangle function

The triangle function is a simple triangle, consisting of two linear functions. This approximates the probability of occupation, which is between 0 and 1. A triangle function is seen in figure 2.7.

\[ P(t) = \max(0, \min(x - a, b - x)) \] (2.3)
Smoothed Top Hat Function

A similar function to the triangle is the top hat. There are two main differences that make the top hat a better model candidate. Firstly, the plateau, where the function is 1 for a defined period. Secondly, the inclination from 0 to 1 is a smooth sigmoid. This is a better representation of the probability of occupation, as there is a period of time where there is high certainty of occupation, before this moves towards 0. Figure 2.8 shows a top hat function. There are several parameters to define the shape of the top hat. These are listed in table 2.1. The equation for this is shown in equations 2 - 5 in Boyd. [12]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C$</td>
<td>Center of top hat function. This enables a shift of the function.</td>
</tr>
<tr>
<td>$\chi$</td>
<td>Physical region. This defines the area where the function is 1.</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Smoothing region. The area where the function moves between 0 and 1</td>
</tr>
<tr>
<td>$L$</td>
<td>Defines the shape of the smoothing region.</td>
</tr>
</tbody>
</table>

Combining the smoothed top hat with the max function gives an approximation of the probability of occupation throughout a given timespan. It also allows for a complex function that includes several regions where the probability is 1. An example of two regions is shown in figure 2.9

Definition of model regions

To combine several top hat functions, the regions must be defined. This is done by finding the first and last events in a series of events. This is described in section 4.2.2 and 4.2.3.

Each region is set to before and after a point in the day. This yields two regions per day, one for the morning and one for the afternoon. Each region has one top hat, with parameters.
2 System description

![Smoothed Top Hat function]

\[ C = 5, \chi = 1, \Psi = 2, L = 1 \]

Figure 2.8: Smoothed Top Hat function
Figure 2.9: Two Top hat functions overlapping
3 Software development methods

When developing software, there are a lot of development process to select from. Of these, the Unified Process is chosen. This process defines a work flow and a few documents. These documents aid the development process.

In the following sections, the Unified Process and the documents are explained and put in context with the development of the software.

In addition to the process, several technologies are used. These technologies are Windows Presentation Foundation, C#, Prism and Unit testing. Sections 3.2 to 3.5 describe these technologies and why they were chosen.

3.1 Unified Process

Among the many development processes, the Unified Process is one of the most descriptive. This process is also iterative, meaning it follows a defined pattern repeatedly.

Each step of the process is called an iteration. These iterations are organized in four project phases. These phases are:

1. Inception, where the project is planned, estimated and potentially started.
2. Elaboration, where the use cases and requirements are identified and architecture decided.
3. Construction, where the software is written, based on the Elaboration phase.
4. Transition, where the software is released.

Phase 2-4 builds upon the work of the previous phase. The following sections elaborate on each phase.
3 Software development methods

3.1.1 Inception

The first phase of a project is the inception phase. Here, the project is evaluated and cost estimations are performed. Based on these evaluations and estimations the project is moved to the next phase or terminated. The UP requires business use cases to be created at this stage.

For this project, the inception phase consisted of a brief literature study and defining the business use cases. As the development of the system is a part of the assignment, the cost estimation and the decision to carry out the project has already been made. The business use cases are also a part of the assignment, shown in appendix A.

A progress plan has also been made, describing the number of iterations. This is available as a GANTT chart in appendix B.

3.1.2 Elaboration

After the inception phase, the elaboration phase starts. This phase contains definitions of requirements, architecture, technology to be used, how many iterations and so on. The documents produced in this phase consist of use cases for the system.

Figures 3.1 and 3.2 show the use cases made for the simulator and model. Here, the use case is a short definition of the interaction between the user and the system.

![Diagram of Simulator use cases]

Figure 3.1: Simulator use cases

3.1.3 Construction

This is the phase where the software is written. Here, several iterations have been repeated. Each iteration generates several documents. The documents are the fully dressed use case, interaction diagram and class diagram. The interaction and class diagrams are updated in each iteration. The fully dressed use cases are made for each use case from
3 Software development methods

Figure 3.2: Model use cases

the elaboration phase, and as each iteration handles one use case, there is one FDUC for each iteration.

Fully Dressed Use Case

A FDUC consists of several sections. These sections are shown in table 3.1. Each section is numbered and the main parts are in bold text. Section 8 describes the main flow of the function, and section 9 describes the error handling or other exceptions, related to the items in section 8.

Appendices E and F shows the FDUCDs as developed. These appendices also contain the class and interaction diagrams.

Class diagram

As C# is an object oriented language, the use of classes and objects is necessary. To keep an overview of the architecture, one or more class diagrams are used. The class diagram is a representation of each class in the software, and the properties and methods within. It also shows the dependencies as links. The main class diagram for the simulator is shown in figure 3.3. Here, several classes are shown. These classes have defined parameters and methods, with inputs and a return type. The + and – signs indicate the access levels. To indicate interfaces, a stereotype is used, indicated by << and >>. Associations are shown as simple lines, while inheritance is shown with an arrow, pointing to the class inherited from.

Interaction diagram

As the class diagram shows dependencies, properties and functions, it does not indicate behavior over time. To show this behavior, an interaction diagram is used. One form of
3 Software development methods

Table 3.1: FDUC template [13]

<table>
<thead>
<tr>
<th>Section</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Use case name</td>
<td>Start with a verb</td>
</tr>
<tr>
<td>2. Scope</td>
<td>The system under design</td>
</tr>
<tr>
<td>3. Level</td>
<td>‘User goal’ or ‘Sub function’</td>
</tr>
<tr>
<td>4. Primary Actor</td>
<td>The main user of the function</td>
</tr>
<tr>
<td>5. Stakeholders and interests</td>
<td>Who cares and what they want</td>
</tr>
<tr>
<td>6. Preconditions</td>
<td>What must be fulfilled before starting</td>
</tr>
<tr>
<td>7. Success guarantee</td>
<td>What must be fulfilled at a successful completion</td>
</tr>
<tr>
<td>8. Main Success scenario</td>
<td>8.1 - A typical set of events</td>
</tr>
<tr>
<td>9. Extensions</td>
<td>9.1.a - Alternative scenarios of success or failure</td>
</tr>
<tr>
<td>10. Special requirements</td>
<td>Related non-functional requirements</td>
</tr>
<tr>
<td>11. Technology list</td>
<td>Different I/O methods and data formats</td>
</tr>
<tr>
<td>12. Frequency of occurrence</td>
<td>Investigation, testing and timing of implementation</td>
</tr>
<tr>
<td>13. Miscellaneous</td>
<td>Such as open issues</td>
</tr>
</tbody>
</table>

interaction diagrams is the sequence diagram.

A sequence diagram shows the threading, timing and interaction of the objects. Figure 3.4 shows a sequence diagram for the simulator. This diagram shows a continuation of the initialization of the simulator, the first part of which is shown in appendix E. In addition it shows the binding event handling, which is described in section 3.2.2.

Each instance is shown as a box with a ‘lifeline’. These lifelines are used to show interaction between the instances, as arrows with a function call name. To group function calls, a comment frame is used.

3.2 Technology

The software is developed using C#, WPF and Prism. C# is a programming language in the .NET suite. In combination with this language, WPF is used. This defines a
different language for the frontend language, XAML. To connect the frontend to backend, the Prism library is used. The following sections cover these topics, in addition to the development architecture used.
3 Software development methods

3.2.1 Programming languages

There are many programming languages to choose from. Each language has its advantages and disadvantages, and these are too many to list here. However, some comments on the most popular languages are included.

.NET is a suite of several languages and functions. These are documented in an online library from Microsoft. [14]
3 Software development methods

C family

C is one of the oldest software languages. This language is cross-platform between Microsoft products and Unix systems. As such it is also very detailed and memory handling must be configured by the developer. [15]

However, as it is interacting closely with the hardware, it is capable of very fast computations. This advantage has been reduced due to better hardware. Another disadvantage is that it is sequentially oriented.

A competitor to the C language is the C++ language. This is similar to C, but is object oriented.

Finally, the C# language, which is object-oriented and supports high abstraction. It does not support Unix systems, and is slower than its sibling languages. It has automatic memory handling and the syntax is simpler. It is similar to Java, but benefits from the functions of the .NET suite.

Java

Java is similar to C#, but is not in the .NET suite. It does support many platforms, and is a popular language for embedded devices.

3.2.2 WPF and XAML

Windows Presentation Foundation is a UI framework. It allows for defining the UI in XAML, a markup language. This setup allows for a clear separation of frontend and backend. There is also a function in WPF where bindings can be made. These bindings tie the data shown in the interface to the data in the system. In addition, commands can be invoked. [16]

This allows for a multithreaded program, with clear connections between the UI and the data behind it. To create a proper architecture, with separation of logic, data and UI, the Prism framework is used. This framework handles the binding and commands to simplify usage of the MVVM pattern by predefined event handlers and methods. [17]
3.2.3 Model-View-ViewModel

The architecture is chosen for its separation of logic, data and UI. This separation allows for re-usage of all parts, simplifying the implementation of this model in the external system. It is also a natural choice in combination with the other technologies. Figure 3.5 shows the MVVM pattern, with a databinding layer. There are three parts to the MVVM pattern, each explained in the following subsections. [18]

Model

The model consists of the data. This is where the events, configuration and model/simulator parameters are stored during runtime. As this layer is designed to be a storage layer, there should be little or no logic.

ViewModel

This layer is responsible for the logic and exposing data to the view. This is also where the commands are executed and error handling performed.

View

This is the UI layer. It utilizes binding to be able to connect to the ViewModel. In the Prism framework, each View is connected to a ViewModel, by using a naming convention. This convention is 'Name'View, 'Name'ViewModel and 'Name'Model. [17]
3 Software development methods

Figure 3.5: Model-View-ViewModel [18]
4 System development

The system is developed as two separate programs. These programs are the simulator and the model. These programs will be called 'PIRSim' and 'PIRMod'.

PIRSim is a standalone program for simulating events in a building. It produces a log file in a specified format that PIRMod can read. This is described in section 4.1. This section is separated in three parts, representing each use case.

PIRMod reads events from a log file, and generates a model from the data in that log file. Usually there are a lot of events per day, and most of these events occur consecutively. All events except the first and last of a series do not contribute any information about the occupation. Because of this, the data must be treated to a selection algorithm. The first selection is to find the bounds of series. The second is to select what series to use for the model parameters. This is explained in section 4.2. The first selection is described in section 4.2.2, the second in 4.2.3.

Testing plans have been made for the PIRSim software, and these tests have been performed. For the PIRMod software, Unit test plans have been implemented. These test are programmed in advance, and are run on each compilation. These unit tests are available in the source code. The test plan for PIRSim is available in appendix G. [19]

4.1 PIRSim

PIRSim generates data for a user specified time period. There are several parameters the user can set. These parameters are listed in table 4.1, with description of each parameter.

When developing the simulator, the configuration had to be created first. All other functions depend on the configuration and its parameters. Therefore, the configuration was created in the first iteration.

The second iteration elaborated the simulation use case. This function is responsible for creating the event data.

Finally, the 'present data' function was created. Here, the data is organized and shown in a chart in the UI.
4 System development

Figure 4.1: PIRSim user interface

4.1 Configure use case

To simplify debugging of the configuration, the GUI was created simultaneously. In the subsequent iterations, major changes have been done to both the configuration and the GUI. These changes have been performed after learning of other requirements and capabilities of WPF, MVVM and other technologies in the project.

The user interface shows the configuration, progress bars, a chart area and a notification area. All this is shown in figure 4.1. Table 4.1 shows the parameters in the configuration. Each parameter is represented by a control in the UI. The UI controls are bound to the ViewModel, where these parameters are exposed.

The ViewModel is connected to the Model, which holds the configuration. In addition, the ViewModel has the simulator and the event generator. In appendix E, the class diagrams show these connections.

In order to handle errors and exceptions, a message function has been created. This function adds the message to a string, which the UI subscribes to. This error handling gives a good indication of any errors that occur. It also simplifies debugging. Each part of the system throws events upon error messages or status messages. The ViewModel listens to these events and fires the message function.

4.1.2 Simulation use case

The second major function to be implemented was the actual generation of simulation data and saving it to file. This is separated in two main parts, the simulation and the organization of the data.
4 System development

Probability generator and simulator

To speed up simulation, the probabilities are generated first. These probabilities are generated for each minute for the entire time period, for each sensor on each floor. The formula for the probability is shown in equation 4.1, where ‘Base probability’ is the probability at that time of day. For a reference of base probabilities, see table 4.1.

\[
\text{Floor bias} + \text{Sensor gain} \times \text{Base probability} \quad (4.1)
\]

This list of probabilities are then made available to the simulator, which uses the probability to create the array as described in section 2.3. To simulate, a for-loop is used, iterating through the entire timespan. In each iteration, the flow chart in figure 2.4 is repeated.

Organizer

All events are stored in a list of events. This list is passed to an organizer, where it is organized and saved in the proper format. This format is shown in appendix C, where some example data can be seen. The table in this appendix is generated from a simulated CSV file, using a \LaTeX\ package, pgfplotstable [20].

4.1.3 Present data use case

As there is a lot of Boolean data, the presentation of this data is not readable. Therefore metadata is used in a histogram, showing the number of events grouped by a time period. This time period can be specified by the user and ranges from days to months. When selecting days, the plot displays number of events per hour, summing all days, as shown in figure 4.1. If the user selects week, the groups are the days of the week. For month, the days of the month.

This selection and generation of metadata is handled by the organizer. By exposing the data from the organizer to the UI, binding is possible. The controller used for displaying the histogram is from LiveCharts, published under the MIT license on GitHub. [21]
## 4 System development

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation time</strong></td>
<td>Time to simulate</td>
</tr>
<tr>
<td>From</td>
<td></td>
</tr>
<tr>
<td>To</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Base probabilities</strong></th>
<th>Probability of event at different times of day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacation</td>
<td>( t \in \mathcal{V}_{\text{Vacation}} )</td>
</tr>
<tr>
<td>Vacation travelling</td>
<td>( t \in \mathcal{V}_{\text{Vacation}} ) and travelling is true</td>
</tr>
<tr>
<td>Working</td>
<td>When occupant is at work</td>
</tr>
<tr>
<td>Nighttime</td>
<td>00:00 &lt; ( t ) &lt; 06:00</td>
</tr>
<tr>
<td>Evening</td>
<td>20:00 &lt; ( t ) &lt; 00:00</td>
</tr>
<tr>
<td>Home</td>
<td>When occupant is home</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Sensor setup</strong></th>
<th>Set sensor configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td># of floors</td>
<td>Sets number of floors. Each floor has a name, sensor bias and an array of sensors</td>
</tr>
<tr>
<td>Selected floor</td>
<td>Floor to configure</td>
</tr>
<tr>
<td>Floor bias</td>
<td>Probability to add to each sensor of the floor</td>
</tr>
<tr>
<td># of sensors</td>
<td>Sets number of sensors on the selected floor</td>
</tr>
<tr>
<td>Selected sensor</td>
<td>Sensor to configure</td>
</tr>
<tr>
<td>Sensor gain</td>
<td>Probability gain for selected sensor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Work time</strong></th>
<th>Sets the work schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work hours</td>
<td>Sets the work hours</td>
</tr>
<tr>
<td>Work days</td>
<td>Sets the workdays of the week</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Vacations</strong></th>
<th>Allows for configuring vacations</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>Datetime for when the vacation starts</td>
</tr>
<tr>
<td>To</td>
<td>Datetime for when the vacation ends</td>
</tr>
<tr>
<td>Travelling</td>
<td>Sets if the vacation is spent travelling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Configuration settings</strong></th>
<th>Sets the save location of configuration and data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration save location</td>
<td>Sets the save location for the configuration</td>
</tr>
<tr>
<td>Data save location</td>
<td>Sets the save location for the generated data</td>
</tr>
<tr>
<td>DateTime pattern</td>
<td>Sets the pattern used for the timestamp in the data file</td>
</tr>
</tbody>
</table>
4 System development

**Parameters**
- Nighttime - 0.01
- Evening - 0.05
- Home - 0.1
- Other - 0.0

Figure 4.2: Simulation of one day

### 4.1.4 Simulation realism

To verify the function of the simulator, the generated data is compared to the biological data. This comparison is made by loading biological data into the simulator, where it is plotted using the day setting, as described in section 4.1.3. This gives the two plots shown in figures 4.3 and 4.4.

The biological data is gathered from 01.01.18 to 30.11.18, using two sensors. The events are mostly registered during the morning and afternoon. This justifies the use of two main periods in the model, as described in section 2.5.6.

Compared to the simulated data, the main difference is the smooth transition between different periods of time in the biological data. There is also some events during the night.

In figure 4.4, the same time period has been used. By tuning the simulation parameters, it is possible to adjust these results. If more time periods are added, the smooth transitions are possible to achieve, however this will increase the number of parameters.

### 4.2 PIRMod

The model is based upon a top hat function as described in section 2.5.6. This top hat is used to define a probability function over a time period.
The top hat function does not describe a complete day or any length of time accurately. To extend the prediction horizon for the model, several top hats are combined. Sections 4.2.1, 4.2.2 and 4.2.3 describes how this combination is designed.

PIRMod is created, using the same architecture and technology as PIRSim. The exception is that the modeling functions are separated in a pure C# library and imported into the main software.

The use cases of PIRMod are described in sections 4.2.4, 4.2.5 and 4.2.6. Each use case has, as with PIRSim, several documents to describe the function of the software. These documents are available in appendix F. The use case diagram can also be seen in figure 3.2.
Results of the model are described in section 5.3. The UI is also shown there.

4.2.1 Top hat combination

Each day of the modeling time period is divided in two regions. These regions are assumed to be representative of an event series, as shown in figure 4.3 and described in section 4.1.4 and 4.2.2.

Each event defines a movement, and therefore, the probability of occupation is 1 at that point in time. Such events occur in a series, as movement usually is continuous for a certain time period.

If there is a long time between two movements, the building is probably not occupied during that period. If it is a short time, the building should be occupied. Movement periods occurring with a short time period between them, is therefore defined as a single event series. These event series are used to define the parameters for the top hats.

4.2.2 Event series bounds

The first period is in the morning, after residents wake up and perform their morning routine. Then most people leave for work or other activities. The second period is then the afternoon, when residents come home after their activity. This makes for a natural divide in the day. There are exceptions for this, like the weekend.

The top hat allows for handling exceptions in the smoothing region. If there is an overlap of the two top hats, the estimated probability can stay above the confidence limit, as shown in figure 2.9.

These periods are different for office or other business buildings, where there, usually, is one main period.

![Event extremities example](image-url)
To extend the model further, several days are combined to a prediction horizon of one week. The pattern throughout the week is estimated using data from the previous $n$ weeks. Data from each weekday is grouped and the extremities in the data is found. An example of this is shown in 4.5. These extremities are found for each weekday of several weeks, creating a set of candidates for parameters.

### 4.2.3 Parameter generation

After finding candidates for the desired time periods, the candidates are evaluated. This evaluation handles outliers and selects which candidates are used as parameters. Figure 4.6 shows four groups of candidates for a single day. These groups represent the extremities of that weekday from 4 weeks of data.

![Figure 4.6: Candidates example with matrix](image)

The parameters are found from the four groups. By finding the middle point of the first in G1 and the last in G2, and comparing each point to this middle point, the smallest and largest distances are used as parameters for the top-hat model. Repeating this for each day of the week and for G3 and G4, yields a complete model for an entire week. The resulting parameters consist of a matrix of four by $n$ values. The middle point is used for $C$, $L$ is set as a constant, the smaller distance is used for $\chi$ and the larger for $\Psi$

### 4.2.4 Predict future state use case

To predict the future state, several functions must be implemented. These functions are the top function itself, the combination of several top hats and the search for candidate
4 System development

parameters. This use case is concentrated around the two functions regarding the top hats.

To allow for reuse, the model is contained in a separate VS project, a library. In future systems, this library can easily be imported or referenced.

There is no defined model in PIRMod, as this role is filled by the model library and its functions. These functions are referenced and reused in the ViewModel, where they are made available to the View. This View is constructed in the same manner as with PIRSim. The main difference is the plotting and configuration areas.

The plotting function shows the predicted future state for the entire prediction horizon, along with the identified candidates.

4.2.5 Model use case

The identification of candidates and model properties is also included in the library. This function is created as described in section 4.2.3.

To find candidates, the events must be made available to the software. PIRMod is configured to be able to read the files generated by PIRSim, or the biologically created data file. These files contain the events.

After importing the events, these are iterated through and candidates are identified. After all candidates are identified, the average of each candidate group is found. If there are outliers from this average, they are removed and a new average is found and the process is repeated until no more outliers are found or a quarter of the candidates are removed.

The final set of candidates are used to create the parameters for the combined top hats.

4.2.6 Configure use case

The final use case is to allow for configuring the model. The configuration includes any planned vacations, the location of data files, limits for finding candidates and model mode. The mode is either business or residential. The difference between the modes is whether the building is occupied at night or not.

The probability of occupation is set to 0.95 at night, unless the last sensor triggered is an exit sensor. Should the last sensor be an exit sensor, it is assumed the building was left, and is therefore not occupied.

In addition, the 'Now' time can be set manually. This is for testing purposes and is not intended to be a part of the model.
5 Results

This chapter evaluates the PIRSim and PIRMod software. The first part handles the PIRSim software. Here the main focus is the speed performance and the similarity compared to biologically created data.

The second part evaluates the model created in PIRMod. Here, the model is created from biological data and then it is compared to the following week of data. As the biological data is gathered from a Norwegian household, there are several exceptions from the average week. In Norway, there were 251 working days in 2018. [22]

5.1 PIRSim speed performance

A requirement for the PIRSim software is a simulation time less than the time simulated. This requirement is met, as shown in table 5.1 and figure 5.2. These times are the average of 10 samples, gathered from 4 different settings. These settings are shown in figure 5.1. For different experiments, the setting changes, specifically number of sensors and simulation time.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Probabilities</th>
<th>Simulation</th>
<th>Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Month 1 Sensor (1)</td>
<td>1.76</td>
<td>1.89</td>
<td>0.08</td>
</tr>
<tr>
<td>1 Month 5 Sensors (2)</td>
<td>8.69</td>
<td>9.66</td>
<td>0.40</td>
</tr>
<tr>
<td>3 Months 1 Sensor (3)</td>
<td>11.99</td>
<td>5.64</td>
<td>0.18</td>
</tr>
<tr>
<td>3 Months 5 Sensors (4)</td>
<td>59.39</td>
<td>27.91</td>
<td>1.07</td>
</tr>
</tbody>
</table>

As these figures and table show, as the number of sensors increases, so does the computational time. However, the time span contributes more than the number of sensors, 5 times the sensors has approximately the same computational time as 3 times the timespan.

5.2 Simulation data comparison

Table 5.2 shows two random segments of data. One from the biological data and one from the simulated. The data is the same as shown in figures 4.3 and 4.4. From the table, the
5 Results

![Figure 5.1: Settings for time measurement](image)

biological data contains more clustered data than the simulated. Tuning of the margin, described in section 2.3 affects this.

The amount of data per time period is shown in the figures 4.3 and 4.4. These figures show approximately the same amount of data for the simulated and biological data. The difference being more smoothed transitions for the biological data.

5.3 PIRMod performance results

The model software shows the model as a line chart. This line chart is plotted with the candidates shown as points. The model sets the occupation probability to 0.95 at night,
5 Results

![Graph showing simulation times over experiment numbers](image)

Figure 5.2: Average simulation times, as shown in table 5.1

<table>
<thead>
<tr>
<th>Simulated Time</th>
<th>Time change</th>
<th>Biological Time</th>
<th>Time change</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:36:39</td>
<td>-</td>
<td>13:21:33</td>
<td>-</td>
</tr>
<tr>
<td>15:42:21</td>
<td>05:42</td>
<td>13:22:08</td>
<td>00:35</td>
</tr>
<tr>
<td>16:00:13</td>
<td>06:26</td>
<td>13:23:05</td>
<td>00:10</td>
</tr>
<tr>
<td>16:01:25</td>
<td>01:12</td>
<td>13:23:18</td>
<td>00:13</td>
</tr>
<tr>
<td>16:06:10</td>
<td>04:45</td>
<td>13:23:54</td>
<td>00:36</td>
</tr>
<tr>
<td>16:06:48</td>
<td>00:38</td>
<td>13:24:19</td>
<td>00:25</td>
</tr>
<tr>
<td>16:08:57</td>
<td>02:09</td>
<td>13:24:48</td>
<td>00:29</td>
</tr>
<tr>
<td>16:12:02</td>
<td>03:05</td>
<td>13:24:59</td>
<td>00:11</td>
</tr>
<tr>
<td>16:12:56</td>
<td>00:54</td>
<td>13:25:18</td>
<td>00:19</td>
</tr>
<tr>
<td>16:21:34</td>
<td>08:38</td>
<td>13:25:44</td>
<td>00:26</td>
</tr>
<tr>
<td>16:22:45</td>
<td>01:11</td>
<td>13:26:15</td>
<td>00:31</td>
</tr>
<tr>
<td>16:23:00</td>
<td>00:15</td>
<td>13:26:29</td>
<td>00:14</td>
</tr>
<tr>
<td>16:23:10</td>
<td>00:10</td>
<td>13:27:30</td>
<td>01:01</td>
</tr>
<tr>
<td>16:23:33</td>
<td>00:23</td>
<td>13:28:24</td>
<td>00:54</td>
</tr>
<tr>
<td>16:24:34</td>
<td>01:01</td>
<td>13:29:29</td>
<td>01:05</td>
</tr>
<tr>
<td>16:26:53</td>
<td>02:19</td>
<td>13:36:08</td>
<td>06:39</td>
</tr>
<tr>
<td>16:27:20</td>
<td>00:27</td>
<td>13:39:15</td>
<td>03:07</td>
</tr>
<tr>
<td>16:28:13</td>
<td>00:53</td>
<td>13:39:18</td>
<td>00:03</td>
</tr>
<tr>
<td>16:31:16</td>
<td>03:03</td>
<td>13:40:23</td>
<td>01:05</td>
</tr>
</tbody>
</table>

unless the last event of the day is created by a sensor defined as an exit point.

Figures 5.3 and 5.4 shows two models generated from 4 and 8 weeks of data. This shows the result of using more data for training; the more data, the more detailed the model is. When introducing more data, more error is also introduced.
5 Results

Figure 5.3: Modelling one week from 4 weeks data

Figure 5.4: Modelling one week from 8 weeks data

From these two figures, the model can be seen to be adaptive. If the model is retrained by intervals, it will adapt to changes in behavior.

5.3.1 Model performance

Three cases have been evaluated. Each case presents a model predicting one week of occupation. These cases are listed and commented in table 5.3.

Normal model

Figure 5.5 shows the model and the movement data from the predicted week. There are no known exceptions during this week, so the measured data is representative of the
5 Results

Table 5.3: Model cases

<table>
<thead>
<tr>
<th>Case name</th>
<th>Prediction horizon</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal model</td>
<td>05.02.18 - 13.02.18</td>
<td>A model with high quality training data. The data contains few exceptions.</td>
</tr>
<tr>
<td>Depraved model</td>
<td>05.07.18 - 13.07.18</td>
<td>This model is created from training data with some exceptions. Outliers have been removed, yielding a lack of candidates.</td>
</tr>
<tr>
<td>Friday model</td>
<td>30.11.18 - 07.12.18</td>
<td>This model is created on a Friday. There is little data to compare the model to, as there is no data from December.</td>
</tr>
</tbody>
</table>

occupation. The figure shows a good relation between the predicted and measured state. An exception is during Thursday and at night. The building is assumed to be occupied at night.

![Figure 5.5: Normal model with candidates and measured data](image)

**Depraved model**

The depraved model shows a strong mismatch between the model and the measured data, as seen in figure 5.6. The training data is not consistent enough for a complete model. As this is from summer, it is probably exceptions to the normal pattern that is the cause of the inconsistency.
5 Results

![Friday model with candidates and measured data](image)

Figure 5.6: Depraved model with candidates and measured data

**Friday model**

To demonstrate the effect of inconsistent data, the Friday model is included. It is shown in figure 5.7, where the only measured data is completely inconsistent with the model.

![Pattern consistency](image)

Figure 5.7: Friday model with candidates and measured data

**Pattern consistency**

As shown, the model is very susceptible to inconsistency in the behavior pattern. This is a consequence of the adaptive nature of the model.

If the behavior pattern is rigid, the model will be adequate for heating purposes, and the pattern created can be used for vacation light control. However, should the pattern change abruptly, or frequently, the model can not create the necessary parameters for the top hat function.
6 Discussion

From the previous work, several methods of determining resident location have been described. These methods often involve complicated sensory equipment or large amounts of data. This work has shown the function of a model, created from simple motion sensor data.

This data has been collected from a house in Norway, during the period of 1.1.18 to 1.12.18. In addition to this series of biologically created data, a simulator has been created.

The simulator method has been chosen for the capability of adjusting probability of event, and the margin parameter. This margin enables a higher probability of repeated events.

The model method has been selected for its simplicity and the possibility of defining time periods with slip, based upon previous events.

6.1 Model

Sections 2.3 and 2.5 describes the different methods considered. From the state space description, where the state is Boolean, Markov chain, Decision trees and Bayesian models are not suitable. Neural network requires a large amount of data, and preferably a target value, for training. As there is not target data, and the data collected is limited to a few sensors detecting motion, Neural network is not suitable for this model. Finally, a probability function is described, where the probability of occupation is approximated using a simple function. This function is then repeated for each time period.

The time periods are chosen to be the morning and afternoon. Other selections of time periods could improve the model. The function used is a smooth top hat, shown in figure 2.8. This function could be improved, by allowing for different smoothing parameters on rising and falling edge.

With the model chosen, the results shown in section 5.3.1 have been achieved. The results show an adaptive model that reflects the behavior pattern in the training data. As there are many exceptions to the behavior pattern, regarding occupation of a building, such as vacations, sick days and other non-working days, the model requires more input to achieve greater accuracy. This input is described in section 6.3.
6 Discussion

6.2 Simulator

The simulator implemented in PIRSim performs as described in the requirements. The simulation time can be further decreased, by using a faster language like C++. As the chosen language is C#, a language designed for desktop application, multithreading and automatic memory handling, the simulation time is increased.

Simulated data is not representative of the biologically created data. This is due to the harsh limits between the time periods, and the lack of repeating events. In section 6.3, several suggestions are made to improve the simulator.

Although the simulated data is not representative, the configuration allows for adjusting and simulating many setups. The adjustment of the probabilities controls the number of events that are created, similar to effect of more residents. The adjustment of the floor bias and sensor gain also allows for control of which sensors generate more events, similar to the location difference of the physical sensors i.e sensors in trafficked areas generate more events than other sensors.

6.3 Future work

PIRSim and PIRMod have been developed to a first working version. There are many errors in the code to amend. As the software is designed to create a model and simulate motion data, most of the auxiliary functions like the color of the charts, abort function, the possibility of running multiple simulations, certain execution exceptions and so on, are not listed as improvements here. These errors are assumed to be of minor consequence to the overall goal of this work.

The points of improvement listed here are therefore oriented towards the modelling and simulation. The simulation software, PIRSim, does not produce data that is comparable to the biologically created data. The modelling software, PIRMod, generates an adaptive model that predicts the occupation of a building, one week in advance, unless the pattern of the data is not rigid enough.

6.3.1 Improving the simulation

To make a data set that is comparable to the biologically created data, the method requires more tuning. The main difference is the smoothing of the transition between time periods and the lack of repeating events.
In order to create a smooth transition, the probabilities generator should ‘remember’ the last generated probability, and then move towards the goal. This creates a new smoothing parameter, used to control the rate of change.

The frequency of repeating events can be increased by increasing the margin parameter. This frequency is not shown in the software, but has been determined by evaluating the difference in time between the generated events. A function to show this in PIRSim should be included, and the margin parameter made available to the user.

The configuration of sensors should be made more intuitive. A suggestion is to allow for a graphic drawing of the floor, with rooms and doors and then placing the sensors on the drawing.

6.3.2 Improving the model

The choice of model has limitations in compensating for exceptions in the behavior pattern. Other models should be implemented and tested. To allow for better testing and more models, the collection of data should include a measured occupation. Simple motion data shows only the occupation at a moment in time. If the occupation was directly measured, Neural Network or other machine learning methods could be used.

When using the top hat function, the smoothing regions should be made independent, as the time for leaving for work is very consistent, and the time when one gets out of bed is varying. This is not represented by making the smoothing regions dependent upon each other.

In addition, more sensor setups should be included. This work has been limited to one building. The system was extended early in 2019, but the amount of data collected from 2019 is very limited. There is no sensor covering the exit points in the building, and therefore, functions including exit sensors have not been tested.

The model has not been implemented in the external system. This should be done, so that the model can be tested in a real system.
7 Conclusion

This work has shown a simple model for predicting occupation from simple motion data. The model accuracy has not been measured, as there is no measured data that shows the occupation. However, the model is shown to predict the approximate occupation, when compared to the motion data.

Several modeling methods have been considered, where the Probability function method was chosen. This method uses a max of smoothed top hat functions, combined with an algorithm for creating parameters for the top hats, using the motion data.

Further, a simulator has been created. The data generated from this simulator, does not show the same properties as the biologically created data. Suggestions for improving the simulator are made.

Both of these programs have been created using the Unified Process. As described in the process, several UML documents have been created, available in the appendices. These documents describe both PIRSim and PIRMod.

If improved, the model can be used for controlling heating and burglary detection in residential and business buildings. Other usage for the model is vacation light control.
Bibliography


Bibliography


Appendix A

Task description - Model development for building usage patterns based on PIR sensor data
FMH606 Master's Thesis

**Title:** Model development for building usage patterns based on PIR sensor data

**USN supervisor:** Nils-Olav Skeie  
**Co-supervisor:** Veralia Gabriela Sánchez  
**External partner:** SMART Research group at USN

**Task background:**  
Some of the research areas for the SMART Research group at USN are energy efficiency and welfare systems in SMART buildings. When a building is not in use, reducing the energy usage is the main goal. Assisting the people in the building will be the main goal of the welfare systems. A prediction of the building usage is thus important to decide how and when to use the energy and welfare systems.

The basis for the model development is the inputs from a set of simple Passive InfraRed (PIR) motion detection sensors. These PIR sensors will indicate motion of any objects in the monitored area, with a higher temperature than the environment temperature. These sensor devices are also common in alarm systems, and in future systems this information should be shared among the different systems within a SMART building environment. A sensor should be located in almost each room of the building and the sensor information will give an overview of which room is in use at which time. Based on a set of historically indications from these sensors, a data driven model has to be developed. This model will predict if the building is in use or not at a specific time and date.

**Task description:**  
1. Make a literature survey of any equivalent systems,  
2. Make a literature survey of methods that can be used when developing such a model,  
3. Develop a C# simulator that will generate a set of movement events and saving these events on a log file. Develop the simulator using UP and UML.  
4. Develop a C# application that will include the model, generated based on the historical movement events, for predicting the usage of the building. Develop the application using UP and UML.  
5. Make a test plan and test the application according to the test plan.  
6. Test the application with a real data set from a building.  
7. Discuss an extension of the model for handling each floor of a building.  
8. Discuss an extension of the model for burglary estimation.  
9. Some suggestions for making the system autonomous, using an adaptive model.

**Student category:** (PT, EET or IIA students)  
Student with interest for software engineering and C# programming

**Address:** Kjølnes ring 56, NO-3918 Porsgrunn, Norway. **Phone:** 35 57 50 00. **Fax:** 35 55 75 47.
Practical arrangements:
A data set from a SMART building will be available.

Supervision:
As a general rule, the student is entitled to 15-20 hours of supervision. This includes necessary time for the supervisor to prepare for supervision meetings (reading material to be discussed, etc).

Signatures:
Supervisor (date and signature): [Signature] 22-04-19

Student (write clearly in all capitalized letters): Jørund Martinsen

Student (date and signature): [Signature] 22.1.19
Appendix B

Project Schedule - GANTT
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Appendix C

Example data file from simulator - PIRSim generated data
PIRSim generated data

Jørund Martinsen

Faculty of Technology, Natural Sciences and Maritime Sciences
Campus Porsgrunn
Simulator UI

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The chart shows the comparison between two datasets (YLO, YLU) over different days. Each bar represents the number of occurrences for a given day. The bars are color-coded, with blue for YLO and orange for YLU.
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Appendix D

Specification for PIRSiMo
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1 Introduction

This is the specification of the PIRSiMo software (PIR data, Simulation and Modeling). The requirements are also included, to keep the information in a single document. In addition to this, two separate documents are created. These contain the test specifications and are separated pr. program, i.e. the simulator and model.
The next chapter describes the specification for PIRSiMo, and the next two contain the requirements from each program.

2 Specification

To extend the SMART house technology being developed at USN Porsgrunn, an important part is to be able to determine whether someone is currently occupying a house, or will be in the future. To generate data, a simulator should be created. To model that data, a model program must be developed.

2.1 Simulator

This simulator must generate data at a semi-random rate. This rate should be controlled by a schedule reflecting the normal usage of the building. Two types of buildings should be included; residential and business. The data generated should be stored in a CSV file of the format shown in table 2.1. Each Boolean sample is represented by the value 0.0 (False) or 100.0 (True). These values are event driven, meaning that each entry should be triggered by a rising or falling edge event. In addition, a sensor can have several rising edge events without a falling edge, within the same timestep, as shown in figure 2.1.
The number of sensors should be configurable and should include which sensors cover the entry/exit points of the building.
The data generated should be displayed in a readable manner. Suggestion is to use a histogram with different bars pr. sensor. In addition, the simulator should be able to import a set of data or configurations.
To adapt to each implementation, or house, the model needs to consume the data file from table 2.1. This file is generated by either using sensors or the simulator. This model should be able to receive a request containing a timestamp and reply with an indication of whether someone is occupying the building or not. To make the model usable by high-rise office buildings, each floor is to be treated as a separate building. This is also usable by residential homes.

The model should be a data driven model, utilizing probabilistic properties of the motion patterns. It should be able to predict the state, with good accuracy, 24 hours into the future. It should also be able to predict at least one week ahead, where lower accuracy is accepted.

Model logic should be separated from the graphics, to make it simpler to re-use model in other projects.
3 Requirements

The requirements of the system are shown in sections 3.1 and 3.2. These reflect the information in the previous chapter and is divided in the same manner, as the two programs should function independently. The requirements are collected using the FURPS+ list as described in [1].

3.1 Simulator

3.1.1 Functional

F1 Generate Boolean PIR data for separate sensors as numeric value 0.0 for false and 100.0 for true. Rising edge events can occur multiple times before a falling edge.

F2 Use different rates to generate data. These rates are based on a schedule provided by the user.

F3 Store event based data in a CSV file, using the format provided in specification. Store both rising and falling edge.

F4 Use a configurable number of sensors and persons.

F5 Simulate data for a specified time span. The simulation should be faster than realtime.

F6

F7

3.1.2 Usability

U1 Graphical interface should be one page only.

U2 Graphics must include a way to enter work hours and vacation time.

U3 Graphics should display the generated data in a histogram.

U4 Be able to import dataset and configuration. Check validity of files on import.

U5 Store last configuration for use later, with a configurable name.
3 Requirements

U6 Indicate simulation progress.
U7 Document the software in a .pdf manual

Figure 3.1 shows a proposal for the GUI used with the simulator

![GUI proposal for simulator program](image)

Figure 3.1: GUI proposal for simulator program

3.1.3 Reliability

R1 The generated data should not be repeatable. There should however be a pattern reflecting the calendar configuration.

R2 Configuration should include; Type of building, number of floors, number of sensors on each floor and maximum number of people.

R3

R4
3 Requirements

3.1.4 Performance

P1 The simulation should not wait for an amount of time. Do simulations as fast as possible.

P2

P3

3.1.5 Supportability

S1 Write in C# on WPF platform.
S2 Use a Model-View-ViewModel pattern.
S3 Write software in English.
S4 Software supports Win10.

S5

S6

3.1.6 Other

O1 The software should run on a standard WIN 10 operating system.
O2 The software should run without administrator privileges.

O3

O4
3 Requirements

3.2 Model

3.2.1 Functional

F1 Read data from file
F2 Create model from patterns in data
F3 Respond to requests, with an indication of occupation

F4

F5

3.2.2 Usability

U1 The user interface should be one page only.
U2 Graphics should include a way to enter work hours and planned vacations.
U3 There should be a way to set location of the datafile.
U4 Configuration should be stored to a file.
U5 Configuration should be imported from file at startup
U6 Creation of model should be possible from user interface
U7 There should be a way to test model performance
U8 Document the software in a .pdf manual

U9

U10
3 Requirements

3.2.3 Reliability

R1 Indicate error messages
R2 Store errors to a log file
R3 There should be a configuration for each floor.
R4 Configuration should include type of building
R5 ... typical work time
R6 ... planned vacations
R7 ... number of sensors
R8 ... if a sensor is at an entry/exit point of the floor

R9 ..............................................................................................................

R10 ..............................................................................................................

3.2.4 Performance

P1 The accuracy of the model should be more than 70% for a time period of 24h
P2 The accuracy of the model can be less than 70% for a time period exceeding 24h

P3 ..............................................................................................................

P4 ..............................................................................................................
3 Requirements

3.2.5 Supportability

S1 Graphic interface should be written in C# on WPF platform
S2 Graphic interface should use a Model-View-ViewModel pattern
S3 Model logic should be written in C#
S4 Model should be in a separate project to enable simple import in later projects
S5 Software should be written in English
S6 Software should support Win10

S7

S8

3.2.6 Other

O1 The software should run on a standard WIN 10 operating system
O2 The software should run without administrator privileges

O3

O4
Bibliography

Appendix E

UML documents for PIRSim
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Use case diagram:

- User
  - Simulation
  - Configure
  - Present data
  - CSV-file
  - XML-file
## 1 Use cases

<table>
<thead>
<tr>
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<td>2. Scope</td>
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</tr>
<tr>
<td>3. Level</td>
<td>User goal</td>
</tr>
<tr>
<td>4. Primary Actor</td>
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</tr>
<tr>
<td>5. Stakeholders and interests</td>
<td>'XML-file'</td>
</tr>
<tr>
<td>6. Preconditions</td>
<td>'Simulation’ not running</td>
</tr>
<tr>
<td>7. Success guarantee</td>
<td>Configuration saved to XML-file</td>
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<tr>
<td>8. Main Success scenario</td>
<td>8.1 ‘User’ enters data</td>
</tr>
<tr>
<td></td>
<td>8.2 ‘User’ selects ‘start’</td>
</tr>
<tr>
<td></td>
<td>8.3 Configuration is checked for errors</td>
</tr>
<tr>
<td></td>
<td>8.4 ‘Simulation’ is started</td>
</tr>
<tr>
<td></td>
<td>8.5 Configuration is saved to file</td>
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*Continued on next page...*
## 1 Use cases

*Continued from previous page...*

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<td>9.1.a Data is entered manually</td>
</tr>
<tr>
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<td>1   Check data as it is entered</td>
</tr>
<tr>
<td></td>
<td>2   If error - Show error in data field</td>
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<td></td>
<td>9.1.b Data is entered from saved file</td>
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<tr>
<td></td>
<td>1   Check file format</td>
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<td></td>
<td>2   If error - Show error message</td>
</tr>
<tr>
<td></td>
<td>3   Update fields with data from file</td>
</tr>
<tr>
<td></td>
<td>4   Go to 9.1.a</td>
</tr>
<tr>
<td></td>
<td>9.2.a User selects 'save' - Skip 8.4</td>
</tr>
<tr>
<td></td>
<td>9.3.a If error in configuration - Show error message</td>
</tr>
<tr>
<td></td>
<td>9.5.a If 'Create rates using config' does not start - Show error message</td>
</tr>
<tr>
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<td>9.+.a 'Cancel' is selected</td>
</tr>
<tr>
<td></td>
<td>1   Ask user to confirm</td>
</tr>
<tr>
<td></td>
<td>2   If yes, fire cancel event</td>
</tr>
<tr>
<td></td>
<td>3   If no, continue</td>
</tr>
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<td>Upon request</td>
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<tr>
<td>13. Miscellaneous</td>
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<td>Section</td>
<td>Comment</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------------</td>
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<td>2. Scope</td>
<td>System</td>
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<td>3. Level</td>
<td>User goal</td>
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<td>4. Primary Actor</td>
<td>'User'</td>
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<tr>
<td>5. Stakeholders and interests</td>
<td>'CSV-file'</td>
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<tr>
<td>6. Preconditions</td>
<td>Configuration is created/loaded, and simulation is started</td>
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<td>Data is generated and stored, using the configuration</td>
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<td>8.2 Configuration checked</td>
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<td>8.3 Start generating probabilities</td>
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<td>8.4 Probabilities are generated</td>
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<td>8.5 Start simulating values</td>
</tr>
<tr>
<td></td>
<td>8.6 Wait for simulation to complete</td>
</tr>
<tr>
<td></td>
<td>8.7 Build data set</td>
</tr>
<tr>
<td></td>
<td>8.8 Save data to file</td>
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<tr>
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<td>8.9 Send data to 'Present data'</td>
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<td>9. Extensions</td>
<td>9.2.a Error in configuration - Show error message and stop</td>
</tr>
<tr>
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<td>9.4.a Probabilities &lt;= 0 - Show error message and stop</td>
</tr>
<tr>
<td></td>
<td>9.7.a No data - Show error message and stop</td>
</tr>
<tr>
<td></td>
<td>9.8.a File access denied - Show error message and stop</td>
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*Continued on next page...*
# Use cases

Continued from previous page...

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<thead>
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<th>Comment</th>
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</tr>
<tr>
<td>9.+.b</td>
<td>Cancel requested - Show cancel message and stop</td>
</tr>
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</table>
| 9.+.c  | Data file imported  
|        | 1 Check file format - If error, Show error message and stop.  
<p>|        | 2 If no error, go to 8.9 |
| 10. | Special requirements | None |
| 11. | Technology list | None |
| 12. | Frequency of occurrence | Upon request |
| 13. | Miscellaneous | None |</p>
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<tr>
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<td>User goal</td>
</tr>
<tr>
<td>4. Primary Actor</td>
<td>‘User’</td>
</tr>
<tr>
<td>5. Stakeholders and interests</td>
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<tr>
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<td>Data is presented in a chart</td>
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<td>8.1 Data is received</td>
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<td>8.2 Select data based on config</td>
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<td>8.3 Show selected data in chart</td>
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</table>
2 Interaction diagrams

Figure 2.1: Initialization interaction diagram
Figure 2.1: Initialization interaction diagram, continued
2 Interaction diagrams

Figure 2.2: Configuration interaction diagram
2 Interaction diagrams

Figure 2.3: Simulation interaction diagram
2 Interaction diagrams

MainViewModel | Simulator | Organizer | ProbabilityGenerator | Configurator

If:

- simulationStatus is ok

- NotifySimulationComplete()

- Message(statusMessage)

Else:

- simulationStatus is not ok

- Message(errorMessage)

UnLockConfig()

Figure 2.3: Simulation interaction diagram, continued
2 Interaction diagrams

Main ViewModel

Organizer

Simulator

Case: Message from Main ViewModel

ImportData(file)

CheckImportedFile()

If:

error in file

Message(errorMessage)

Else:

LoadDataFromFile()

Message(statusMessage)

Case: Data received from simulator (See simulation)

OrganizeData()

Set status

Case: Chart parameters updated event

Chart Parameters updated

GetChartParameters()

UpdateChart()
3 Class diagrams
3 Class diagrams

MainViewModel
- message: object
- SaveConfig: Command
- ImportData: Command
- ImportConfig: Command
- SetGraphRange: Command
- Cancel: Command
- Message(string message)
- UpdateStatus(status)
- NotifySimulationComplete
- GetChartParameters(): chartParameters

Command properties are used from View to ViewModel in WPF

MainView
- IBindableBase
- View is written in XAML and does not implement properties or methods

Main class diagram
3 Class diagrams

Configuration
- simulationTime: TimeSpan
- individuals: int
- workTimes: List<TimeSpan>
- vacations: List<Vacation>
- floors: List<Floor>
- saveLocationConfig: FilePath
- saveLocationData: FilePath

Vacation
- startTime: DateTime
- endTime: DateTime
- traveling: bool

Floor
- id: string
- sensors: sensor[]
- bias: double

Sensor
- sensorId: string
- gain: double

PIRData
- value: bool
- time: DateTime
- sensorId: string

Probability
- value: double
- sensorId: string
- timespan: TimeSpan

Types class diagram
Appendix F

UML documents for PIRMod
PIRMod Documents

Jørund Martinsen

Faculty of Technology, Natural Sciences and Maritime Sciences
Campus Porsgrunn
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<tr>
<td>1. Use case name</td>
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<td>2. Scope</td>
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<tr>
<td>3. Level</td>
<td>Sub-function</td>
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<td>4. Primary Actor</td>
<td>None</td>
</tr>
<tr>
<td>5. Stakeholders and interests</td>
<td>Predict</td>
</tr>
<tr>
<td>6. Preconditions</td>
<td>Configuration completed</td>
</tr>
<tr>
<td>7. Success guarantee</td>
<td>Model created</td>
</tr>
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</table>
| 8. Main Success scenario | 1 Import Configuration  
2 Import data  
3 Find first event of each weekday  
4 Find last event of each weekday, before 12:00  
5 Find first event of each weekday, after 12:00  
6 Find last event of each weekday  
7 Add candidate events to lists  
8 Remove outliers  
9 Find first and last event of candidates per weekday  
10 Create top hat parameters from candidates |
| 9. Extensions | 1.a If no configuration, notify user and stop  
1.b If configuration error, notify user and stop  
2.a If no data, notify user and stop  
8.a If number of outliers exceeds limit, move to 8.9 |
<p>| 10. Special requirements | XML reader, CSV reader |
| 11. Technology list | None |
| 12. Frequency of occurrence | Upon request |
| 13. Miscellaneous | |</p>
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<tr>
<td>6. Preconditions</td>
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<tr>
<td>7. Success guarantee</td>
<td>Result of top hat function returned</td>
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<tr>
<td>8. Main Success scenario</td>
<td>8.1 External system asks for $P(t)$</td>
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<tr>
<td></td>
<td>8.2 Use model parameters to create top hat function</td>
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<tr>
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<td>8.3 Return value of top hat function at $t$</td>
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<td>9.3.a If value &lt; 0 return 0</td>
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<td>9.3.b If value &gt; 1 return 1</td>
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<td>8.3 Configuration is checked for errors</td>
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<td>8.4 Configuration is saved to file</td>
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<td>2 If error - Show error in data field</td>
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<tr>
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<td>9.1.b Data is entered from saved file</td>
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<td>2 If error - Show error message</td>
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<td>3 Update fields with data from file</td>
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<td></td>
<td>4 Go to 9.1.a</td>
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<td>1 Ask user to confirm</td>
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<td>2 If yes, fire cancel event</td>
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<td>3 If no, continue</td>
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</table>
2 Interaction diagrams

![Diagram showing interaction between Bootstrapper, MainView, and MainViewModel]

Figure 2.1: Initialization interaction diagram
2 Interaction diagrams

Figure 2.1: Initialization interaction diagram

Figure 2.2: Data Binding interaction diagram
invoke SaveConfigurationCommand

Save(Configuration)

status

execute TrainModelCommand

If: Configuration IsValid

Save(Configuration)

Figure 2.3: Command interaction diagram, Save
2. Interaction diagrams

Figure 2.4: Command interaction diagram, Train model
3 Class diagrams
3 Class diagrams

Saver
- `SaveAsync(): bool`
- `Save(): bool`
- `SaveAsync(Configuration): bool`
- `Save(Configuration): bool`
- `LoadConfiguration(string): Configuration`
- `LoadConfigurationAsync(string): Configuration`
- `LoadData(string): List<PIRData>`
- `LoadDataAsync(string): List<PIRData>`
- `LoadData(string, ObservableCollection<Sensors>): List<PIRData>`

ModelMethods
- `now: DateTime`
- `parameters: List<Parameters>`
- `E(double, double): double`
- `Erf(double): double`
- `SetNow(): void`
- `SetNow(DateTime): void`
- `TopHat(double x5): double`
- `TopHats(double, double[] x4): double`
- `TopHats(DateTime, String): double`
- `TopHats(DateTime, List<Tuple<double x4>>): double`
- `Triangle(double, double, double): double`
- `Triangles(double x2): double`
- `Triangles(DateTime, String): double`
- `Triangles(DateTime, List<Tuple<double x2>>): double`

ParameterGenerator
- `timer: Timer`
- `Parameters: Parameters`
- `CreateParameters(Configuration, out PIRModel, string)`
- `CreateParameters(Configuration, out PIRModel)`
- `CreateParameters(Configuration)`
- `CreateParameters(Configuration, string)`
- `CreateParameters(Configuration)`
- `TimerElapsed(object, ElapsedEventArgs): void`

PIRModel
- `Parameters: Parameters`

MainViewModel
- `Model: PIRModel`
- `Configuration: Configuration`
- `ParameterGenerator: ParameterGenerator`
- `Message: Message`
- `SaveConfigurationCommand: DelegateCommand`
- `TrainModelCommand: DelegateCommand`
- `MessageHandler(object, MessageEventArgs): void`
- `ErrorHandler(object, ErrorEventArgs): void`
- `ExecuteSaveConfigurationCommand(): void`
- `CanExecuteSaveConfigurationCommand(): bool`
- `ExecuteTrainModelCommand(): void`
- `CanExecuteTrainModelCommand(): bool`

MainView XAML
3 Class diagrams

Configuration
- AfternoonLimit: DateTime
- ConfigName: String
- DateTimePattern: String
- FloorCount: int
- Floors: ObservableCollection<Floor>
- MorningLimit: DateTime
- OutlierLimit: TimeSpan
- OutlierMaxCount: int
- PredictionLimit: int
- Residential: bool
- SaveLocationConfig: String
- Vacations: ObservableCollection<Vacation>
- Weeks: int
- NotifyError: EventHandler<ErrorEventArgs>
- NotifyMessage: EventHandler<MessageEventArgs>
- IsValid(): bool
- LoadSensors(): void
- IsVacation(DateTime): bool

Parameters
- Events: List<PIRData>
- FloorID: String
- TopHatParameters: List<Tuple<double, double, double, double>>
- TriangleParameters: List<Tuple<double, double>>
- LastEvent(DateTime): PIRData

Types class diagram
Appendix G

PIRSim test document
PIRSim Test document

Jørund Martinsen

Faculty of Technology, Natural Sciences and Maritime Sciences
Campus Porsgrunn
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Introduction

This is the test document for the simulation part of the PIRSiMo software (PIR data, Simulation and Modeling). The requirements are available in a separate document. The chapters describes the test for PIRSim, following the FURPS+ procedure, as described in Skeie 2017.

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<tr>
<td>Passed all</td>
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</tr>
<tr>
<td>Comment</td>
<td></td>
</tr>
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</table>
**1 Function**

Data file

(TF1) has at least two records ________________________________

(TF2) has at least one data value of 0.0, if two sensors or more ________________

(TF3) has at least one data value of 100.0 ________________________________

(TF4) has one column for timestamp ________________________________

(TF5) has one column for each sensor configured ________________________________

(TF6) is accessible after simulation ________________________________

(TF7) is in a CSV format ________________________________

(TF8) follows the format given in specifications ________________________________

(TF9) has exactly one header row ________________________________

(TF10) header row has as many columns as data ________________________________

Rates

(TF11) are higher for nonworking hours, residential ________________________________

(TF12) are lower for nonworking hours, business ________________________________
(TF13) are lower for weekend, residential and business ____________________________

(TF14) are never less than zero ____________________________

(TF15) are, overall, higher for higher number of persons ____________________________

PIR data
(TF16) is generated for the configured timespan ____________________________

Configuration
(TF17) accepts number of sensors greater than one ____________________________

(TF18) saves in a XML format ____________________________

(TF19) file is accessible to user after saving ____________________________

(TF20) file can be imported ____________________________

(TF21) errors are notified and discarded ____________________________

(TF22) file format errors are notified and import is stopped ____________________________

(TF23) name is configurable ____________________________

(TF24) is saved before simulation ____________________________

2 Usability

Graphical user interface
2 Usability

(TU1) is shown in one window

(TU2) is one page only

(TU3) includes inputs for configuration

a probabilities for each type

b number of floors

c number of sensors on each floor

d simulation timespan

e residential or business

f workdays

g work time

h vacations, when?, traveling?

i config name

j save location

(TU4) includes status presentation

(TU5) includes message box for errors, status etc

(TU6) includes simulation presentation, histogram

(TU7) histogram time selection
a  day ________________________________
b  week ________________________________
c  month ________________________________
d  year ________________________________

(TU8) includes method for importing data ________________________________

(TU9) includes method for importing configuration ________________________________

(TU10) includes method for storing configuration ________________________________

3  Reliability

Data

(TR1) reflects configured schedule. (Pattern matches) ________________________________

(TR2) is not repeatable ________________________________

Configuration includes

(TR3) type of building ________________________________

(TR4) number of floors ________________________________

(TR5) number of sensors on each floor ________________________________
4 Performance

(TP1) Simulation is faster than real time

(TP2) Simulation does not wait for a time

5 Supportability

(TS1) Written in C#

(TS2) Uses WPF platform

(TS3) Uses Model-View-ViewModel pattern

(TS4) Uses English for labels and content

(TS5) Runs on Windows 10
6 Other

(TS1) Runs on a normal laptop

(TS2) Does not require administrator privileges