Activity and Fall Detection in the Habitational Environment

Subsystem:
Sensor Design and Hardware Abstraction Layer

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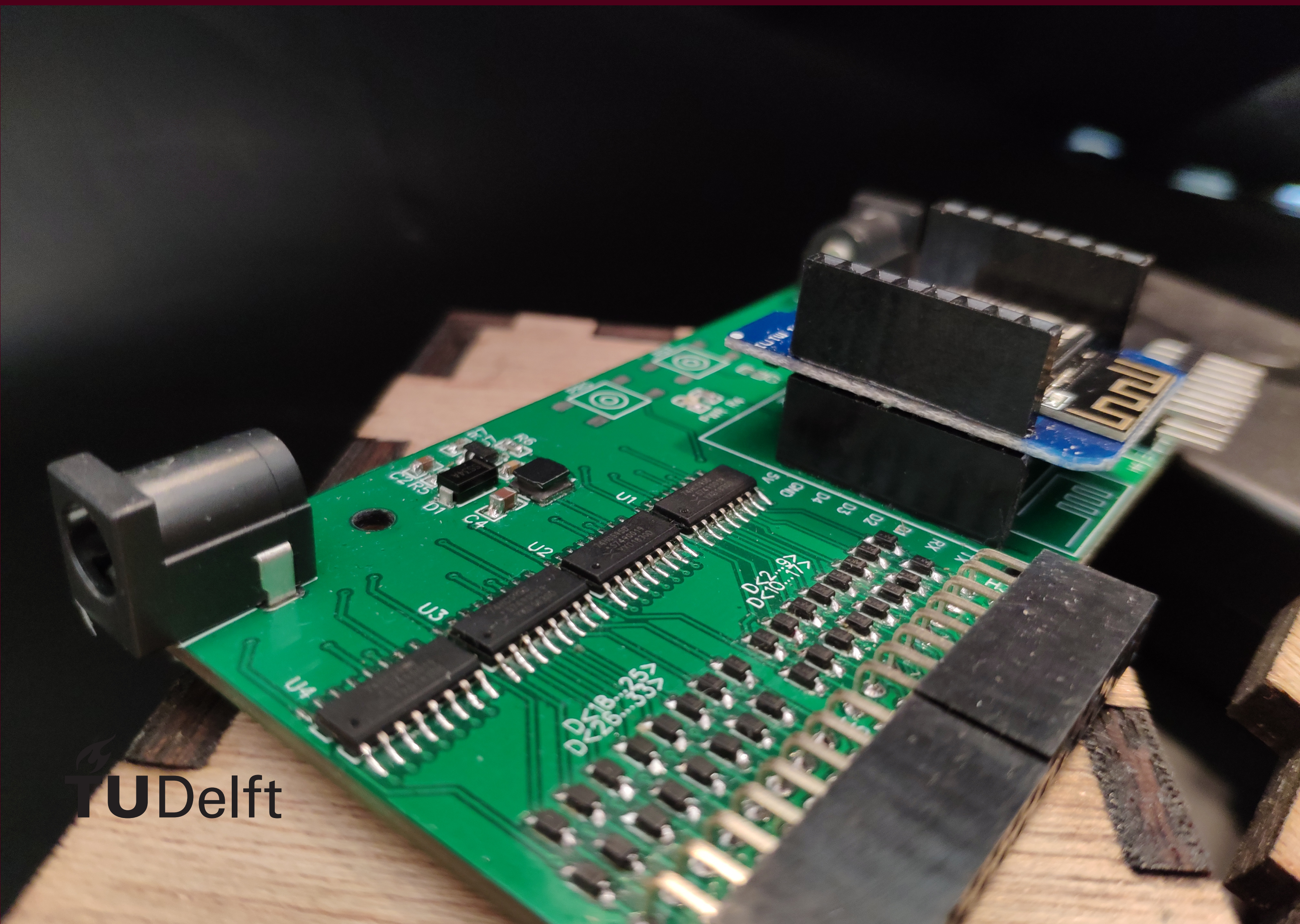

Activity and Fall Detection in the Habitational Environment

Subsystem: Sensor Design and Hardware Abstraction Layer

by

B. den Ouden & H. Kruijsse

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Preface

We would like to thank our project proposer and supervisor Paddy French for proposing this project and providing us with both a room and his advice throughout the project. We are very grateful to Kianoush Rassels for his involvement with this project and his efforts to lift this project to the next level. We would also like to thank Gerard Janssen for his great advice and feedback on tackling this project at an academic level.

The past weeks have been a mixture of a lot of fun, laughter, coffee and food. We would like to thank the interface team, Sander Delfos and Erik Granneman, for their witty remarks and keen eye for detail. We would like to thank the falling algorithm team, Izaak Cornelis and Sieger Falkena, for their enthousiams in thinking along with every problem we came across and their high spirited humour when moods were low.

B. den Ouden & H. Kruijsse
Delft, June, 2019

Abstract

This report is part of a bigger project to design a fall detection system for elderly and describes the hardware of the system. The importance of this research is that elderly can live longer in their home by alerting the correct instances in case of an accident.

The hardware consists of a 1x2 meter sensor grid below the surface of the floor. The sensor grid uses the piezoresistivity of linqstat to measure the pressure and the location of the pressured point on the floor. An ESP8266 microprocessor combined with 74HC595 shift registers and a 74HC4067 demultiplexer is used to gather the data and send it to a server. The design is modular allowing easy installation in differently sized or shaped rooms. Each individual sensor grid has an update frequency of 14Hz and uses wifi to connect to a common server. Each module has an average power consumption of 0,74W and a peak power of 1,6W.

Contents

1 Introduction

Falls of adults above the age of 65 are the leading cause of head injuries and broken hips, with one out of ten falls resulting in serious injuries [1]. This comes at a large medical care cost for society. Furthermore, these falls often go unnoticed for longer than necessary, and sending help earlier can prevent a large number of serious injuries [2]. Of course, preventing falling in the first place would be ideal. However, a single solution is impossible since falling has many causes. However, the result in many cases is the same: a person lies on the floor. Therefore, a more general solution that detects the effect, instead of the movement of falling, is easier to implement and can also help with reducing medical costs.

1.1. Project objective

To implement an activity [1] and fall detection system, an Electrical Engineering Bachelor End Project was proposed. This project is executed by six students, who need to design, implement and test a fall detection system. The project is split up in 3 subgroups of 2: The first subgroup has been responsible for the hardware design [3], the second group has been responsible for the interfacing, alarming and activity tracking [4], while the last group has been responsible for developing the fall detection algorithm [5].

1.2. Thesis Outline

As part of the activity and fall detection bachelor graduation project, this report will focus on the hardware.
To build and evaluate this hardware, three requirement levels were set:

- First, the **global requirements** will be discussed in chapter 2. These are the requirements as used by each of the subgroups.
- The **Subgroup requirements** will be discussed in section 4.3. These requirements are specific to the hardware subsystem and are used to evaluate the final design.
- Lastly, the **Power requirements** are stated in section 4.4.5. These requirements are applicable to the power distribution and are used to evaluate the design.

Chapter 3 discusses the initial design decision to create a floor based sensor whereas chapter 4 will further elaborate on the design choices.

The design choices will be evaluated in chapter 5. Chapter 6 will compare our evaluations to the requirements.

1.3. Background information

In the Netherlands in 2017, 3849 deaths among the elderly (65+) were because of falling [6]. Worldwide, falls are the second leading cause of accidental or unintentional injury deaths [7]. Therefore, fall prevention has been researched by many organizations, such as the WHO (World Health Organization) [8]. As stated before, not all fall incidents can be prevented. When an inevitably fall happens, it is undesirable that someone remains on the ground for longer periods. For example, when a bone fracture

[1] Activity is referred to as the indoor translocation of a person

is caused by a fall, the person should not try to stand up by themselves. Moving around with broken bones can increase pain and bleeding and can damage tissues around the injury. This can lead to complications in the repair and healing of the injury later on [9]. Furthermore, elderly could be in shock.

In research by Fleming et al. [10], 54% (144/265) of falls reported described the participant as being found on the floor and 82% (217/265) of falls occurred when the person was alone. It was found that of the people who fell, 80% were unable to get up after at least one fall and 30% had lain on the floor for an hour or more. It can be seen from table 1.1 that 83% of the participants were alone and unable to get up after 5 minutes. This research shows that a fall detection system can be useful.

Table 1.1: Time on the floor after fall during one-year follow-up. Figures are percentages of falls

Time on floor	All Falls (n = 265)	Participant Alone (n = 217)	Participant unable to get up (n=176)	Participant alone and unable to get up (n=143)
<5 min.	43%	36%	26%	17%
5 min. - 1 hr.	36%	39%	44%	48%
1-2 hr.	5%	6%	8%	10%
>2 hr.	10%	12%	15%	18%
Unknown	6%	7%	7%	7%

The fear of falling can lead to people deciding to move to an elderly care home. This has a great financial impact on the Dutch government as can be seen from figure 1.1 [11]. From this figure, it can be concluded that it is roughly 3 times less expensive for the government to keep people living at home (scale 4) instead of moving to an elderly home (scale 5).

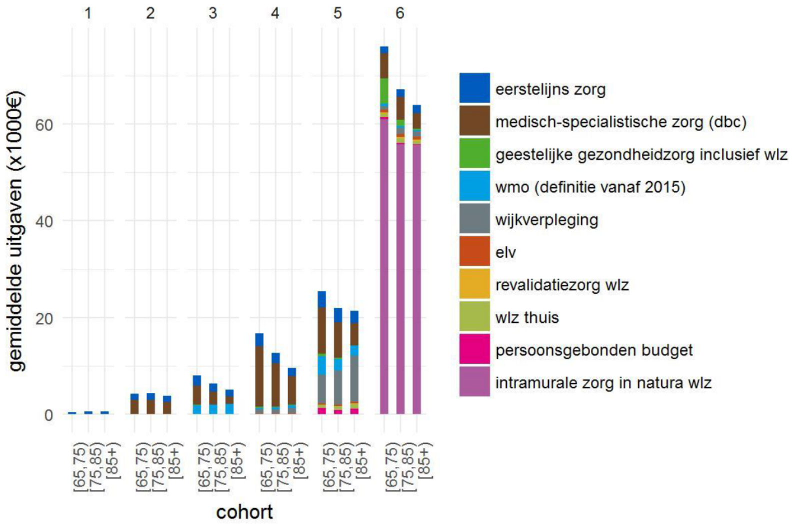


Figure 1.1: Care costs for the Dutch government in 2018

1.4. Definition of a fall

For a system that has to decide whether a person has fallen, it is very important to define properly what a fall is. First, a distinction needs to be made between falling and a fall. Falling is the act of coming to the ground, while a fall is the result of falling. Two papers define falling as:

> *"The rapid change from the upright or sitting position to the reclining or almost lengthened position, but not a controlled movement, like lying down."* [12]

In 1987 Gibson additionally defined falling as:

> *"Unintentionally coming to the ground, or some lower level not as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure."* [13]

However, this definition should be extended to include falls resulting from dizziness and syncope. Thus, a fall is not necessarily the result of a sudden change of body position, but could also be due to a slow collapse. Therefore, trying to detect a fall instead of falling is the more overarching solution.

1.5. Current state of the art solutions

Currently, fall detection is mostly done using wearable methods and cameras [14]. However, research has been done into other directions such as Floor mounted technology, Radar technology, more advanced vision technology, and Seismic technology.

1.5.1. Wearables

Most available wearable solutions use an accelerometer to detect a fall, such as the Philips Lifeline series [15]. Similar to the Philips solution, Yacchirema et al. [16] used an accelerometer and combined this with machine learning. The software was trained using publicly available data of a triaxial accelerometer in various scenarios [17]. Another way to detect falls using a wearable solution is to measure vertical velocity, again using an accelerometer. This was successfully demonstrated by Lee et al. [18].

Advantages of these systems can be found in the ease of detection, no requirement to alter the home and the ability for the person wearing them to call for help whenever they feel they require it. Commonly, wearable technology is cheaper compared to other solutions as well. Disadvantages of these systems are that they only work if the person actually wears them or is conscious, some users forget to wear them or decide not to wear the device [19]. Wearable systems are also vulnerable to the stubbornness and pride of the elderly. This might prevent a person who might require help from actually pressing the alert button.

1.5.2. Cameras

Vision-based techniques are also very common when it comes to fall detection and have been seeing major improvements in the last 5-6 years [14]. A recent technique with a camera is to translate the images to curvature scale space (CSS), which means that an image is transformed into a silhouette. As a silhouette itself can be very noisy and have many local deformations, curve interpolation can be used to reduce a silhouette to a simple form [20]. This is a very valuable technique to detect different positions of a body with low-resolution measurements which can also be used in combination with other sensing techniques. Another more recent technique in vision technology uses infrared, there are even techniques that use both infrared and wearable solutions [21]. Most infrared techniques use the Kinect module since this is a readily available sensor, "The working principle of the Kinect depth sensor is to actively project near infrared spectrum by an infrared projector. When the infrared rays radiate to rough objects, the spectrum is distorted, and form some random reflection spots. Its infrared camera captures these changes in the reflected infrared spectrum." [22]. A large downside of this technique is the fact that it needs a 'base' image of a room (without people in it).

1.5.3. Radar and WiFi

The Doppler effect can be used to detect movement, by using either Continuous Wave Radar [23][24] or WiFi [25]. Machine learning can then be applied to let the system decide whether the movement detected is a fall or not. The main advantage of these techniques is that they do not form any visual image, but only measure movement speed, which is desirable from a privacy standpoint. The major downside of using machine learning is that there is not a lot of data available to train with. One could simulate falling and use that for training, but then the system is only trained for that particular person. Different body shapes and personal habits make it complex to get a system to work universally.

1.5.4. Floor Mounted

Floor mounted sensors can be capacitive [26][27] or work on vibration [28][29]. Vibration sensors can work well on hard falls but not so well on a slow collapse as these do not cause as much vibration. Differentiating between collapses and daily activities can become very complex. Capacitive sensors can detect stationary objects and therefore also people lying on the floor. This is a huge advantage for the capacitive sensor as they are sensitive to all kinds of falls, as long as the person lands on the floor. The disadvantage of capacitive systems is the more complicated hardware required to collect the desired data. This is due to the frequency requirements when building this type of sensor.

2
Global system requirements

The project group was tasked with developing an activity and fall detection system, as described in chapter 1. To realize this project, the system requirements will have to be observed first.

The functional requirements will describe the features that have to be implemented whereas the non-functional requirements will describe the workings and constraints of the system under certain conditions.

2.1. Functional requirements

R1.1 Both slow and fast falls should be detected.
In section 1.4, a fall was defined as coming to the ground as the result of both a sudden change in body position or a slow collapse. The systems must be able to detect both.

R1.2 The system must have alarmed a relevant person within 1 minute after a detected fall
The system should alarm about a fall detection so that the person contacted or notified is always aware of this.

R1.3 System must be operational for 99% of the time
A fall can happen at any given time, so the system should have minimal downtime.

R1.4 Furniture or static objects should not influence the detection process
Every home has furniture and furniture shading is a major obstacle for most sensor types. The system needs to be able to detect a person falling despite there being furniture present in the same room.

R1.5 The system should be scalable
It should be possible to deploy the system in any room and expand the system to multiple rooms or homes within a building.

R1.6 The prototype should have a demonstration mode, showing:

(a) **The location of a person in the room.**

(b) **If a person has fallen.**

This demonstration mode should operate as a showcase where people can walk across the room and see their live location on the screen alongside an indicator to show whether they have fallen.

R1.7 The system should only report falls when one person is present in the room.
When multiple people are present, there is no need for a detection system, as the other person can help.

2.2. Non-functional requirements

R2.1 A fall must be detected with false negative rate lower than 10%
False negatives should be avoided as much as possible, leaving an elderly person on the floor without alarming would mean the entire system has failed.

R2.2 A fall must be detected with a false positive rate lower than 20%
While false positives are less important to avoid than false negatives, calling many false alarms is undesirable and may cause people to act less serious on alarms.

R2.3 The system must not use camera systems for detection.
Due to privacy reasons, the project does not allow using a camera. This includes the use of any form of visual sensor which can be used to reconstruct a recognizable image, e.g. some types of infrared camera's.

R2.4 The system must not use audio recording systems for detection
Due to privacy reasons and the responsibility these recordings would add [30, Recital 51], the decision was made not to use audio systems to detect a fall. This includes any form of sensor that leads to understandable audio recordings.

R2.5 The system must not use devices placed directly on client for detection
Relying on elderly people to always wear a device harms the reliability of the system since forgetting to wear the device might result in a false negative.

R2.6 Complete system should not be noticeable
The system is aimed to be present in the homes of mostly elderly people. Since their feeling of independence should be preserved, the system is allowed to have at most one visible terminal or device for user feedback.

R2.7 The activity and falling detection should not rely on the feedback of a user
The system should be able to detect a fall without the user letting the system know that he or she has fallen, or in other words, the system should be able to detect a fall without the user being conscious.

R2.8 The system should be operational in 30 seconds after powering on
Powering on the system is seen as plugging the system into the power outlet, where operational means that falls and activities can be detected.

The following requirements apply to a room of 4 by 5 meters:

R2.9 A single person should be able to install the system within 4 hours
This includes only the installation of the fall detection system, finishing of the room is not included in this time.

R2.10 The maximum material costs per room (4m x 5m) should be €1.000
Including all the material cost, excluding the labor cost.

R2.11 The maximum operational costs per year for a room (4m x 5m) should be €250
This includes power and maintenance costs.

R2.12 The maximum end-of-life costs for a room (4m x 5m) should €1.000
This includes the removal of the system and processing of the materials.

3 Initial design decision

There are a lot of ways in which a person can fall. This makes it difficult, maybe even impossible, to detect all falls with a single type of sensor. Combining sensors can be a way to get better falling detection. Of course, every type of sensor works differently, thus implementing this can be a very time-consuming task. Another, more preferable option, is to decide on one type of sensor that can detect a large number of falls and optimize this. Covering 90% of all falls using a single type of sensor can end up being much cheaper and less time consuming for the development team. Therefore, a single solution will be selected that fits the requirements set in chapter 2 and this will be based on one of the solutions presented in section 1.5

3.1. Requirements compared to different implementations

In section 1.5 implementations using four different categories of sensors were described:

1. Camera
2. Wearable
3. Radar and WiFi
4. Floor mounted

A solution using a camera or wearable is not possible since they do not meet requirements **R2.3** and **R2.5**. This leaves radar/WiFi and floor mounted as possible options. Requirement **R1.1** states that slow falls (collapses) should also be detected. Radar and WiFi-based systems detect movement speed, meaning it is possible to detect hard falls, but slow falls will be near impossible to detect due to the low movement speed. This leaves a floor mounted sensor as the remaining option. Of this implementation, two kinds exist: Pressure based and vibration based. Again, a vibration based sensor would have a hard time detecting a slow collapse, because this would cause little vibration. Additionally, it could be possible to record audio using vibration sensors, depending on the sensitivity and the sampling frequency. As higher sampling rates and sensitivity are likely desirable for detecting a fall reliably, a vibration sensor could be privacy intruding.

The last option is a pressure based floor sensor. This type of sensor is able to detect a fall as described in section 1.4, and is thus able to detect a fall independent of how someone has come to the ground (i.e. fast or slow). Furthermore, furniture should not cause a problem, as these are static and should, therefore, be able to be filtered out, thus meeting requirement **R1.4**. Additionally, a floor mounted sensor can also be placed under carpet or vinyl, thus meeting requirement **R2.6**, concerning the notability. Finally, this solution is independent of feedback of the user, thus meeting requirement **R2.7**.

Summing up the advantages and disadvantages, it is chosen to use a pressure based floor type sensor system. The specific choice is elaborated in the hardware subsystem report [3].

3.2. Project outline

In section 1.1 the general setup of the project was described, dividing the system into three subsystems. A general overview of the system layers can be seen in figure 3.1. With the initial design decision now made in section 3.1, each subsystem's functionalities can be described in further detail. The subsystems are: **Sensor design and hardware abstraction layer**, **Interface**, and **Fall Detection Algorithm**. Figure 3.2 shows how the three subsystems are connected and what the data flow is.

Sensor design and hardware abstraction layer
The sensor design and hardware abstraction layer subsystem is responsible for reading out the sensor data of the pressure-sensitive floor. The subsystem will not only contain the necessary hardware but the Hardware Abstraction Layer (HAL) as well. The subsystem's responsibility ends at digitizing these signals.

Interface
The interface subsystem is responsible for the communication between the two other subsystems. This subsystem will pass along requirements about the communication methods used between subsystems. Additionally, this subsystem will also interface with the outside world and signal for help when a fall has been detected.

Fall Detection Algorithm
The final subsystem is responsible for the algorithm that is able to detect a fall based on the output of the pressure sensitive floor. The output of the algorithm is linked back to the interface subsystem.

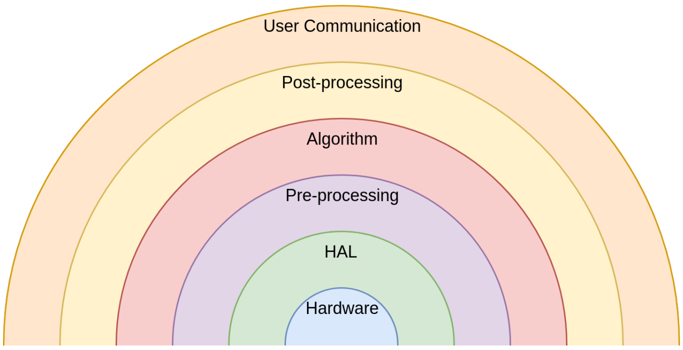


Figure 3.1: System layers

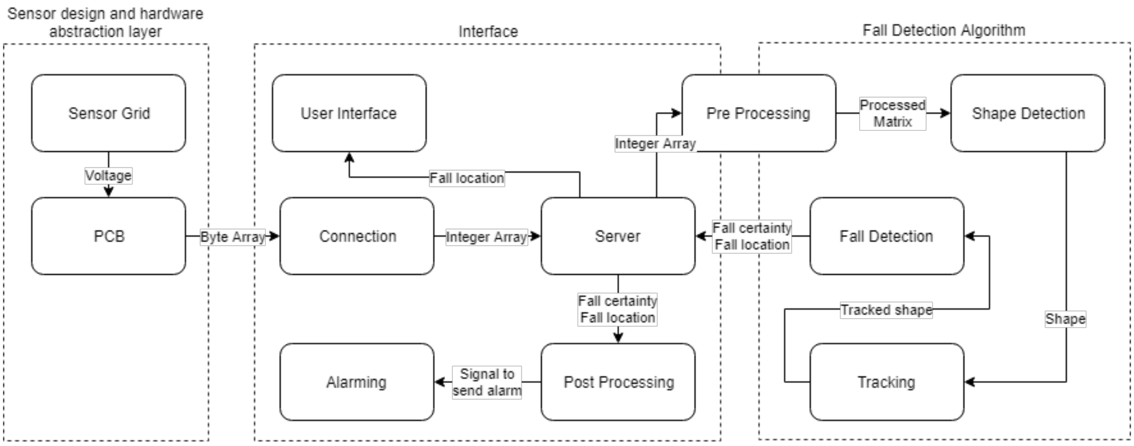


Figure 3.2: Advanced system overview with data flow

4 Design Description

4.1. Sensor choice

As discussed in section 1.5, there are a few different types of floor mounted sensors. To recap: a vibration based sensor works well on hard falls but fails to detect a slow fall. Capacitive sensors are not sensitive to furniture but have frequency requirements associated with them. Capacitive sensors also have intellectual property associated with them [31] making them difficult to develop without violating any patents.

A type of sensor that does not have a falling detection implementation associated with it is a resisitive based sensor. The advantages of this system are the straightforward hardware required to get useful data and its sensitivity to both slow and fast falls. Its disadvantage is its sensitivity to both human and furniture induced pressure.

Within the requirements of this project, resistive based pressure sensors are the most viable option and will thus be expanded upon in this report.

4.2. Overview

The fall detection system consists of a matrix of sensors below the floor. The electronics collect the sensor data and send it to the interface server using wifi. The server will determine if a fall occurred using the fall detection algorithm, see figure 3.2. This chapter will focus on the sensors and the electronics used in the design and will not contain a detailed description of the communication and fall detection algorithm.

4.3. Subsystem design requirements

SR1.1 The maximum power consumption per floor mat ($2m^2$) **is 5W.**
With an electricity price of €0,20 per kWh, a single mat consuming 5W would cost the user €8,72 per year.

SR1.2 Minimum update frequency of 5 Hz.
This is a requirement from the fall detection algorithm subsystem [5]. For more details, please see their report.

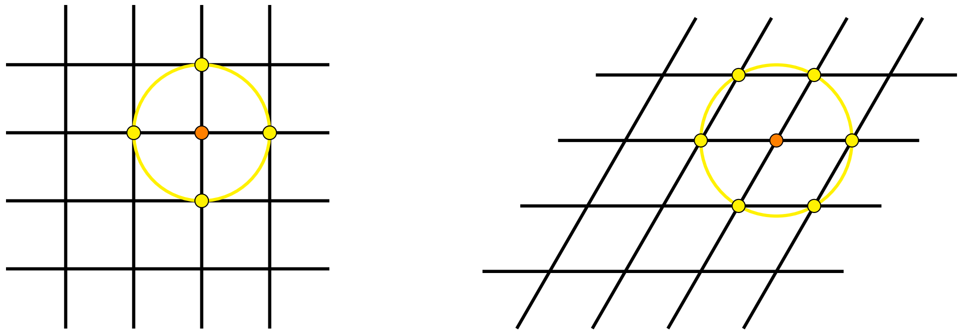
SR1.3 The distance between two nodes is less than or equal to 8cm.
In order to detect a footprint, the floor sensor must be triggered. A trigger occurs when at least a single node detects pressure. A medium-width size 35/36 woman's foot starts at 8,1 cm [32]. To detect this foot, the distance between two sensor nodes should not exceed the width of the foot. For this reason, the distance between two nodes of the floor sensor has been determined to be less or equal than 8 cm. Also see figure 4.2 for more clarity.

SR1.4 WiFi capability.
This is a requirement from the interface subsystem and as such, their design report will discuss this choice in detail.

4.4. Detailed description

4.4.1. Sensor grid

The sensor grid has five layers, two layers of PE sheet, two layers of copper tape and one layer of linqstat, see section 4.4.2 and see figure 4.3. The PE sheet is chosen because it is splash waterproof, robust and cheap. The copper tape is used because it has low resistance and is easy to apply. The linqstat is used because of its electric properties, see 4.4.2.



(a) straight grid (b) angled grid

Figure 4.1: Grid styles

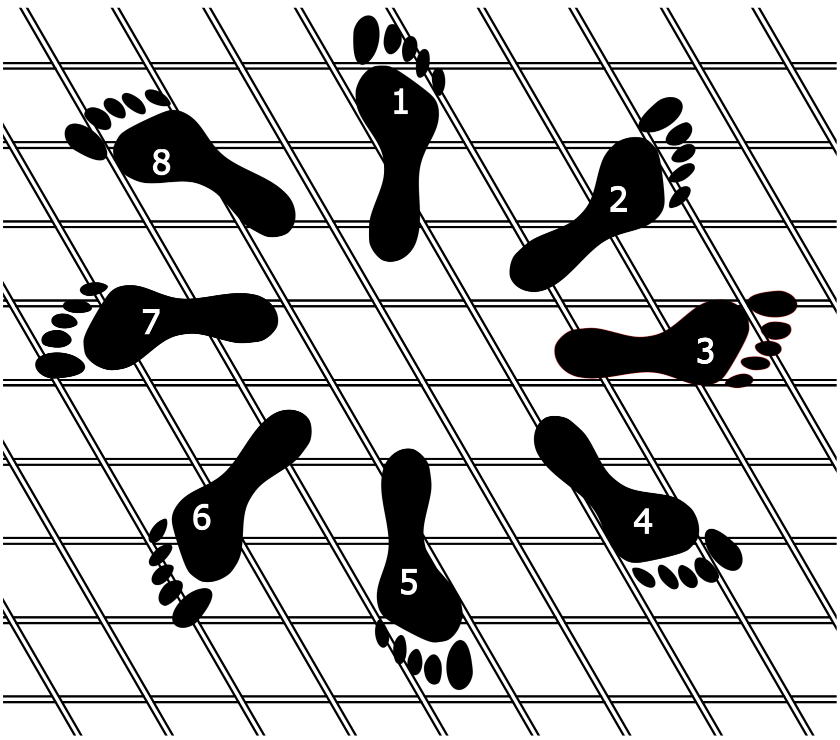


Figure 4.2: Different positions with a small woman foot (size 35, width 8,1cm).

The pattern of the grid is chosen in such a way that the distance between two nodes is always the same, see figure 4.1. When a square is used some neighbor nodes are further away than others so it is possible to stand between nodes without being detected.

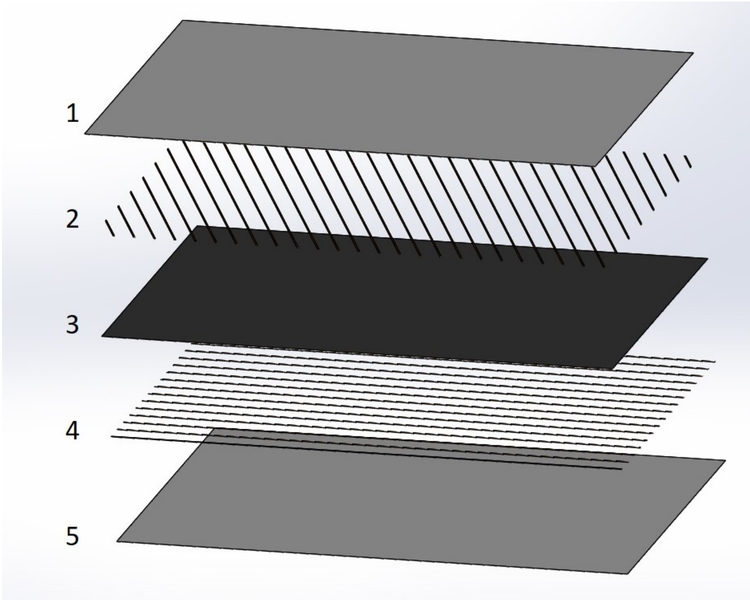


Figure 4.3: Overview of the sensor matrix

When equilateral triangles are used, all the neighboring nodes are at equal distance, see figure 4.6. Because of this, a foot on the floor can always be detected when the distance between 2 nodes is 8cm or less, see figure 4.2. The resolution doesn't need to be higher. Increasing the resolution beyond the minimum requirement would increase the required hardware, which would increase costs and power usage.

To realize this grid, 16 copper lines are placed along the length of the floor mat and, at the other side, 32 copper lines are placed under an angle of 60 degrees relative to the 16 copper lines, see figure 4.3. Because the grid exists of 16 by 32 copper lines, the maximum number of nodes is 512. However, due to the angle between the lines and a straight cut off at the side, a single mat contains 400 nodes.

4.4.2. Linqstat

Linqstat is a piezoresistive material [33]. There are different kinds of linqstat with different properties. To determine what type is best used for the sensor grid, the resistance against the pressure is plotted. The measuring setup consists of two plastic plates with a sheet of linqstat between them and a copper strip on both sides of the linqstat. This is put in a vice together with a load cell. The voltage across the load cell and the ground is measured to determine the weight. The voltage across the linqstat is measured to determine the resistance, see 4.4.

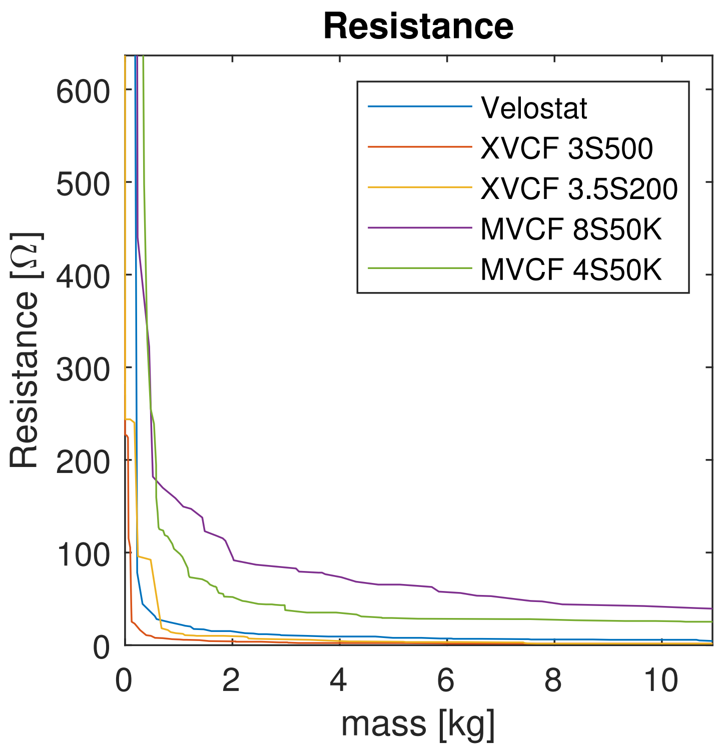


Figure 4.4: Resistivity characteristics of linqstat when different weights are applied.

The results of the test are represented in figure 4.4. The resistance of XVCF-series and the velostat are already at their threshold values with only two kilograms applied, which makes them too sensitive. The MVCF-8S50k is the least sensitive and knowing that an adult is about 60 kg to 100 kg, it would be ideal for the sensor floor. Unfortunately, it couldn't be delivered in time for the prototype, so the MVCF-4S50K is chosen for the prototype.

4.4.3. Circuit

The hardware used to collect the data from the floor is combined into a single printed circuit board (PCB). This PCB consists of a couple of different components:

1. A microprocessor
   - The microprocessor
   - Firmware
2. Hardware to map individual pressure points
   - Shift register
   - De-multiplexer
3. Power distribution
   - Input voltage & reverse polarity protection
   - 5 Volt line
   - 3.3 Volt line

Microprocessor & firmware

In order to take control of the individual components on the PCB and transmit this data, a programmable microprocessor is required. This section will discuss choices and considerations when selecting a processor and writing its firmware.

microprocessor The microprocessor must be able to communicate via wifi to satisfy requirement **SR1.4**. For this prototype, the ESP chip family was selected, specifically the ESP8266EX processor [34].

An assembly of the ESP8266EX microprocessor and its required components is commonly sold as a module. Of the available versions of this module, the ESP12F was chosen since it features the most available general purpose in- and output pins [35].
This module allows rapid development using an ESP microprocessor a lot easier but this ease can be improved even further by attaching this module to a breakout board called a WEMOS D1 mini [36]. This WEMOS module adds a reset button, a 5V to 3,3V linear regulator and a CH340 USB bus converter module [37]. Although this breakout significantly increases the processor's size, it allows for both direct USB programming and using a serial interface for debuging and logging purposes.
The advantages of this processor are its low price, broad community support and previous experience using them. Disadvantages concern the single analog input port and its relative slow analog-digital converter.

Firmware The firmware flashed onto the ESP chip translates the measured voltage into bytes and communicates these values to the interface server. Details on the communication protocol can be found in the interface report.
It obtains these values by selecting one of the 16 parallel copper strips and then cycles through the shift registers connected to the 32 angled strips sequentially. The analog-digital converter on board of the ESP chip will translate the measured values into an integer and insert these values into an array, which is then sent to the interface server.

4.4.4. Hardware to map individual points

As discussed in section 4.4.1, each individual sensor consists of multiple nodes. These nodes lie at the crossings of the 16 copper strips across the length (the X-axis in figure 4.6) and 32 angled copper strips.

The pressure on a single node is measured using a voltage division: the linqstat between two copper strips acts as a resistor whose resistance changes when pressure is applied to it. The reference resistor is a 270 Ω resistor connected to the ground. The voltage level across this 270Ω resistor is measured and will increase if pressure is applied to the linqstat. A simplified schematic of the measuring setup can be seen in figure 4.5.

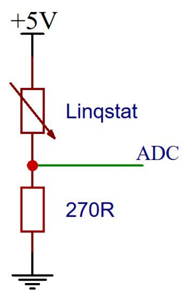


Figure 4.5: The measuring setup of a single node

In this section, we'll assume all copper strips have an infinite length and there are thus a total of 512 nodes. These nodes can't all be read at the same time due to both the interference they would cause with each other and the limited number of analog ports.

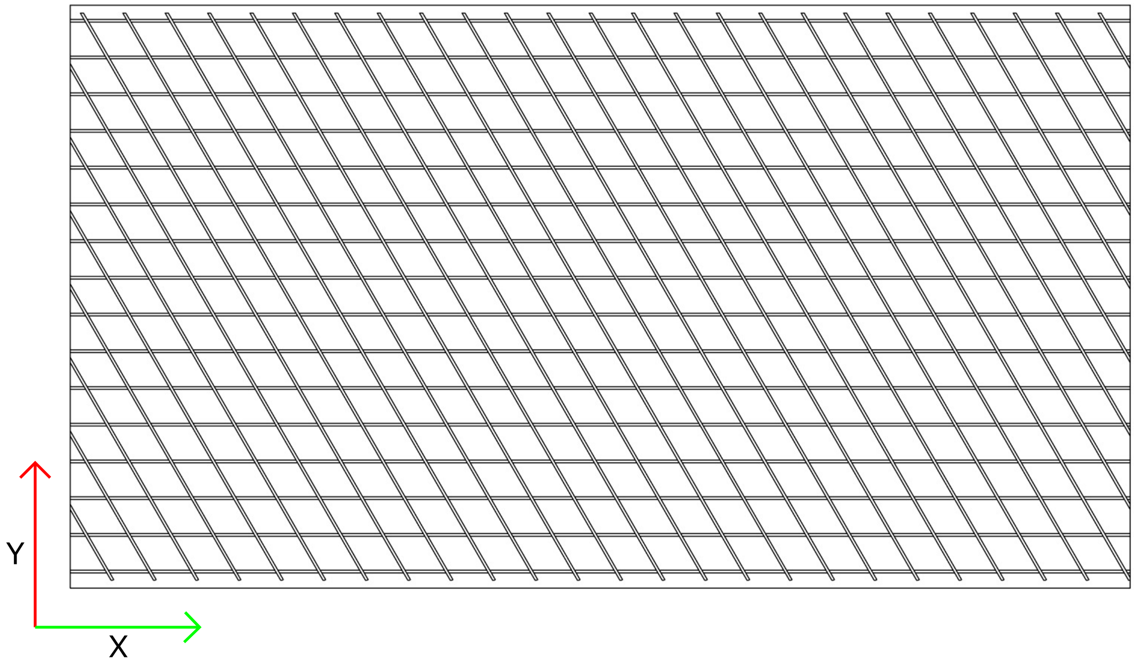


Figure 4.6: Top view of the sensor grid. The linqstat and top PE layers are removed

Interference
Each of the 32 strips can connect to each of the 16 strips if the resistance of the linqstat drops. Evaluating the analog value of the 16 strips whilst all 32 strips are at a high voltage level will allow us to determine the position in the Y dimension. At this time the X position is still unknown.
By evaluating the analog value of the 32 angled strips whilst the 16 strips are at a high voltage, the X position can be estimated within 58cm due to the angle, nothing is known about the Y position.

These methods can be combined by reading the analog value of the 16 copper strips whilst sequentially setting a single one of the 32 angled strips to a high voltage. This allows us to estimate both the X and Y position of a pressed node.

Shift register The components used to sequentially set the angled strips to the correct values are shift registers, the 74HC595 [38].
This shift register requires single data input, a clock, and a latch connection. It is possible to connect multiple shift registers in series, effectively creating a single larger shift register.
The output enable pin can be directly connected to ground to prevent the tri-state from reaching a high impedance, allowing for both sourcing and sinking of currents. The output enable must be connected to the ground to control the values of the outputs. Doing so allows current to flow to ground via a different copper strip connected to a shift register as well, negatively impacting the measurements. To prevent this current from leaking to ground, each of the 32 angled copper strips is placed in series with a Schottky diode. With a maximum current flow of 20mA [38, Table 7.1], these Schottky diodes would have a forward voltage of 0,22 Volt [39, Figure 1] at 25°C. The impact of this on the measurements will, therefore, be small and, more importantly, be the same for each node.

The frequency at which the grid will be sampled follows from requirement **SR1.2** and the number of points in a grid, see equation 4.1.

$$f_{s\_min} = 5Hz * 32 * 16 = 2560Hz \tag{4.1}$$

The shift register features a maximum switching frequency of 25MHz [38, Table 7.7] which is well beyond the minimum sample frequency f_{s_min}.

The shift register has a maximum supply current of 70mA [38, Table 7.1] and an input voltage range of 2 up to 6 Volt [38, Table 7.3] making it suitable for this design.

Analog port
As mentioned in section 4.4.3, the ESP chip only has a single analog port available. To be able to read the analog value of all 16 strips, a demultiplexer is required.

Demultiplexer The demultiplexer must be able to map 16 channels of analog channels to a single analog output. The selecte multiplexer is the 74HC4067 [40].
It features a switching frequency: 13,3MHz [40, Table 9], a supply voltage range of 2 up to 10 Volt [40, Table 5] and a maximum supply current of 50mA [40, Table 4]. The demultiplexer has a typical on-resistance of 90 Ω which, due to the high input impedance of the analog-digital converter, has a negligible impact on the measured signal.

4.4.5. Power distribution

Power requirements
Since this system requires different voltage and current levels at different points, a power distribution with its own requirements is necessary.

PR1.1 There must be a 5 ± 0,1 Volt line present able to supply at least 350mA.
The devices connected to the 5V line are the shift registers and the demultiplexer. Using the current specifications from section 4.4.4, the current consumption of the demultiplexer and shift register combined can be determined via equation 4.2:

$$I_{max} = 4 * I_{sh} + I_{dm} = 4 * 70mA + 50mA = 330mA \tag{4.2}$$

The current capability of the 5V line must be equal or larger then I_{max} and has therefore been chosen to be equal or larger to 350mA.

PR1.2 There must be 3,3 ± 0,1 Volt line present able to supply at least 500mA.
The only device connected to the 3,3 Volt line is the WEMOS D1 mini. The CH340, discussed in section 4.4.3, is not powered when the USB cable is disconnected since it requires 5V power from this USB port to operate. This means that the only active device on the WEMOS during operation is the ESP8266 chip.

According to the frequently asked questions on the site of Espressif, the creator of the ESP chip used in this design:
"The maximum analog power (instantaneous) may be considered to be 500mA and the digital circuits may draw a peak current of around 200 mA. ... Therefore, your design must provide for a voltage regulator that can provide 500 mA without suffering a drop in the output voltage which is outside the operating specifications." [41]

Therefore the current requirement for the 3,3 Volt line is set to be equal or larger than 500mA.

PR1.3 It must be possible to power an entire room from a single supply
In order to minimize the number of bulky power supplies, it must be possible to connect an entire room to a single power supply.

PR1.4 There must be reverse polarity protection.
Following requirement **PR1.3**, each PCB is connected to another. If the power supply was to be connected incorrectly, each of these PCBs might fail. To prevent this event from happening, each individual PCB must be protected from a reversed voltage polarity.

Input voltage
In order to satisfy requirement **PR1.3** there are 2 major issues that have to be addressed:

– The voltage drop over the length of the power cable.

– Current through the power cable.

The effect of both of these issues can be minimized using a good quality power cable.
Unfortunately, there will still be some losses across the length of the power cable. This will cause issues whilst reading the sensor data since the 5V used by the shift register and demultiplexer will fall below its specified value and thus not satisfy **PR1.1**. In order to overcome these issues, the input voltage should be higher than the required 5V and be regulated on-board of the PCB. For this application, an input voltage of 12 Volts was chosen. this is regulated back to the required 5V using a buck converter. The 12 Volts was chosen based on its wide availability of power supplies. The buck converter was chosen based on its high efficiency as compared to a linear regulator at these voltage differences. Using a higher voltage and a buck converter also means the power cables have to carry less current and can thus be much thinner and therefore cheaper.

Using a buck converter also means the voltage specifications on the power supply would become less strict since each PCB can regulate its supply voltage back to the desired voltage, thus resolving the issue concerning voltage drops over the length of the cable and satisfying requirement **PR1.3**.
A final issue concerning the input voltage is the reverse polarity protection from requirement **PR1.4**. By placing a diode in series with the input voltage and the buck module, each module has its own reverse polarity protection.

The 5 Volt line
As mentioned in section 4.4.5, the 5 Volt line will be generated from the input voltage using a buck converter. To determine the minimum specifications of this buck converter, the following properties have to be evaluated:

1. The range of its input voltage
2. The range of its output voltage
3. The output current capability
4. The switching frequency
5. The efficiency

Required input voltage As mentioned in section 4.4.5, the input voltage has been chosen to be approximately 12V. The buck converter must be able to handle inputs up to and preferably greater than 12V.

Buck output voltage The output voltage of the buck converter has to be 5V. The output voltage range of the buck converter thus has to include 5V but is otherwise not limited.

Required current capability There are 5 components in the design requiring 5V:

- 1 de-multiplier
- 4 shift registers

The function of these components has been discussed in section 4.4.4.
In addition to these components, a linear regulator will be used to generate the 3.3 Volts. Choices around this linear regulator will be discussed in section 4.4.5.
Adding this linear regulator to the 5V line means adding the current requirement of the 3.3V line (**PR1.2**)

to the 5V line as well. This will increase the 350 mA from requirement **PR1.1** by the 500mA required by **PR1.2**. The minimum current the buck converter must be able to supply (I_{buck_min}) in order to satisfy both **PR1.1** and **PR1.2** can be calculated via equation 4.3.

$$I_{buck\_min} = I_{\mathbf{PR1.1}} + I_{\mathbf{PR1.2}} = 350mA + 500mA = 850mA \tag{4.3}$$

The output current of the buck converter must thus be equal or greater then 850mA.

Required switching frequency Due to the workings of a buck converter, there will be an output voltage ripple visible. This ripple must not influence the measurements or the stability of the components. The switching frequency should be sufficiently high to minimize any impact this might have. An additional advantage of a higher switching frequency is the reduced size of the inductor and capacitor required to filter the output signal. Therefore the switching frequency has been chosen to be equal or greater than 1MHz.

Required efficiency A higher efficiency means less energy is wasted and thus less heat. Less energy wasted also means the costs of use will be lower due to the electricity bill.
For this buck converter, the efficiency should be equal or greater than 85%.

Buck selection A buck converter that matched all of these requirements is the Richtec RT8259 buck converter [42]:

1. Input voltage range: 4,5V up to 24V
2. Output voltage range: 0,8V up to 15V
3. Output current capability: up to 12A
4. Switching frequency of 1,2MHz up to 1,6MHz with a typical frequency of 1,4MHz
5. An efficiency of up to 92%. (see paragraph 4.4.5: Efficiency)

Efficiency The efficiency of the buck converter can be estimated using the graphs supplied by the datasheet. Figure 4.7 is taken directly from this datasheet. It shows us this buck converter matches the efficiency requirement of 85% over the entire range of the load current when the input voltage is at or below 12V and the output voltage is 5V.

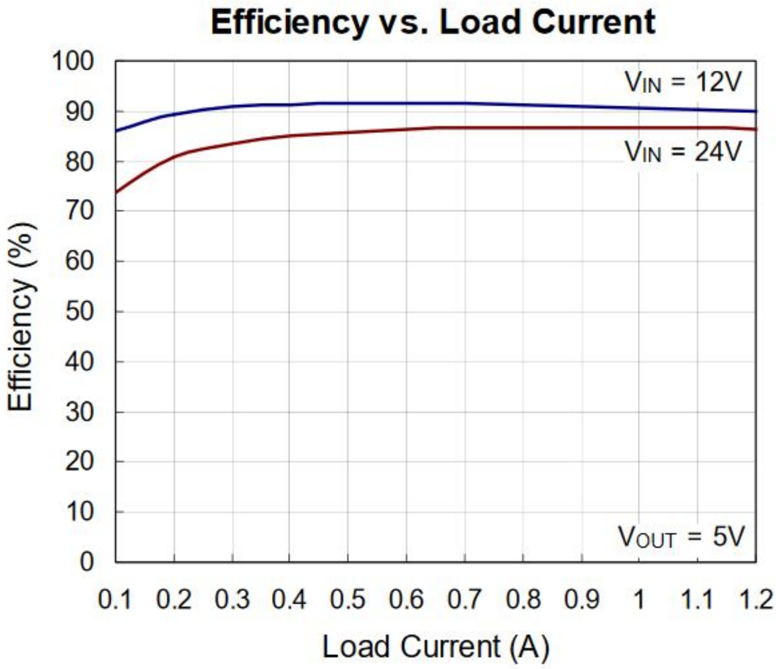


Figure 4.7: Buck efficiency vs load current at 5V out

Components For the correct working of any buck converter, some external components are required. The inductor, in-/output capacitor, and diode have been chosen according to the recommendations from the datasheet [42, table 2,3 and 4].

The resistor divider used to set the output voltage can be calculated using equation 4.4[42, Page 8] where $V_{FB} = 0,8$ [42, Electrical Characteristics].

$$V_o = V_{FB}(1 + \frac{R_1}{R_2}) \tag{4.4}$$

Filling in $V_o = 5$ results in resistor values of $R_1 = 49,9K\Omega$ and $R_2 = 9,53K\Omega$.

Voltage ripple The voltage ripple can be determined by combining equation 4.5 and 4.6 from the buck converter datasheet [42, Page 8, 9].

Table 4.1: Variables used in equations 4.5 and 4.6

ΔI_L	Current ripple	
ΔV_o	Voltage ripple	
V_o	Output voltage	5V
V_{in}	Input voltage	12V
f	Switching frequency	1,4MHz
L	Inductor value	4,7µF
C_o	Output capacitor	22µF
ESR	Effective Series Resistance of C_o	0,01 Ω [43, Page 2]

$$\Delta I_L = \left[\frac{V_o}{f * L}\right]\left[1 - \frac{V_o}{V_{in}}\right] \tag{4.5}$$

$$\Delta V_o \leq \Delta I_L\left[ESR + \frac{1}{8 * f * C_o}\right] \tag{4.6}$$

Filling in these equations for the variables from table 4.1 results in $\Delta I_L = 0,44A$ and $\Delta V_o = 6,23mV$. Since V_o is less than 0,1 Volt, requirement **PR1.1** is satisfied.

The 3,3 Volt line
As mentioned in section 4.4.5, the only device connected to the 3,3 Volt line is the ESP module. Since this module is responsible for the communication and sensitive to voltage swings, it requires a very stable power line to ensure correct operation. To ensure the 3,3V line would be sufficiently stable, a second buck converter could be designed. The output, however, would have to be filtered significantly. A second option is using a linear regulator connected to the 5V line.
Despite the lower efficiency of a linear regulator, its stability results in an advantage in this situation.

The linear regulator of choice is the TS1117B-3.3 low dropout regulator(LDO) [44]. This LDO regulates the output voltage within 1% of the output voltage. For this 3,3 Volt regulator, the deviation would be less than or equal to 33mV [44, Electrical Specification].
The maximum dropout voltage lies at 1,5 Volt [44, Figure 1] which allows it to be powered from the 5V line. Since its maximum output current lies at 1,1 Ampere [44, Electrical Specification], this LDO satisfies requirement **PR1.2**.

4.5. Deployment

To deploy the product, both the sensor grid and the attached PCB have to be placed underneath the surface of the floor. Every floor mat needs to be connected to the same network and have its own software id so it will not interfere with each other.

5 Evaluation

5.1. Overview

The testing was done by building a prototype. The different specifications are measured on this prototype. This prototype is important for the interface and the signal processing subsystem to get data to work with.

Description	Requirement	Design
Max average power consumption per floor mat	5 W	0,74 W
Max peak power consumption per floor mat	5 W	1.6 W
Update frequency	5 Hz	14 Hz
Material costs per room (4m x 5m)	€1000	€680

Table 5.1: Overview of the requirements and the actual design specification

5.2. Prototype

The prototype consists of two parts:

- The PCB
- The sensor grid

Each of these parts will be evaluated separately. Validation of the system as a whole will be conducted by evaluating the output of the system.

5.2.1. PCB

All components mentioned in sections 4.4.3 up to 4.4.5 have been placed onto a PCB. This PCB can be seen in figure 5.1. To view the complete design including schematics with corresponding component indicators, see Appendix A.

Components

- U1 up to U4 are the shift registers with their associated diodes discussed in section 4.4.4.
- U5 is the demultiplexer discussed in section 4.4.4.
- Each PCB contains two DC barrels and filtering capacitors. The DC barrels are connected in parallel so either one can be used as input or output and multiple PCBs can be linked together.
- Connectors: one 2x8 male pin connector (H1) is used to connect the sensor to the demultiplexer. Two 2x8 female pin connectors (H2 and H3) are used to connect the shift registers to the sensor.
- The buck converter discussed in section 4.4.5 consists of the components directly around U7 and are connected to the protected 12V line.
- Buttons for resetting and programming the ESP12F module have been added at the 'RST' and 'PRG' markers.

Since this PCB is designed for testing purposes, there are some extra features and modifications possible:

- **5V linear regulator**
  Since the buck converter itself has to tested as well, the footprint for a linear regulator was added as a back-up plan. For this back-up regulator, the LM7805 linear regulator was selected based on its ability to accept up to 25 Volts and output up to 1,5 Ampere [45]. This regulator must be bought in a TO-220 footprint, which allows for a heatsink to be installed.

- **WEMOS headers and ESP12F footprint**
  The final product will most likely not have the WEMOS module on it but rather use the ESP12F module or even a 'barebones' ESP8266EX chip. To allow for testing with the WEMOS as well as the ESP12F module directly, both the footprint for the ESP12F module and the WEMOS headers have been added. Next, to the ESP12F footprint, some external components have been added which are required if the WEMOS module is not used. The 'RST' and 'PRG' buttons are also required only if the ESP12F module is used.

- **Voltage divider analog port**
  The ESP12F module has an onboard ADC which accepts 0-1V. The WEMOS features a resistor voltage divider which increases the acceptable range to 0-3,3V. These voltage levels are still not enough for the output of the demultiplexer which has a range of 0-5V. Since the PCB was designed to be able to accept the ESP12F chip, the footprints for a resistor voltage divider were added to increase the range from 0-1V up to 0-5V. By replacing R2 with a resistor larger than 180K and removing R1, the WEMOS is now able to accept an input voltage in the range from 0-5V.

Input voltage
The capacitors used for the buck converter are rated up to 16V. This decision saved some costs but also limits the input voltage range to 16V.

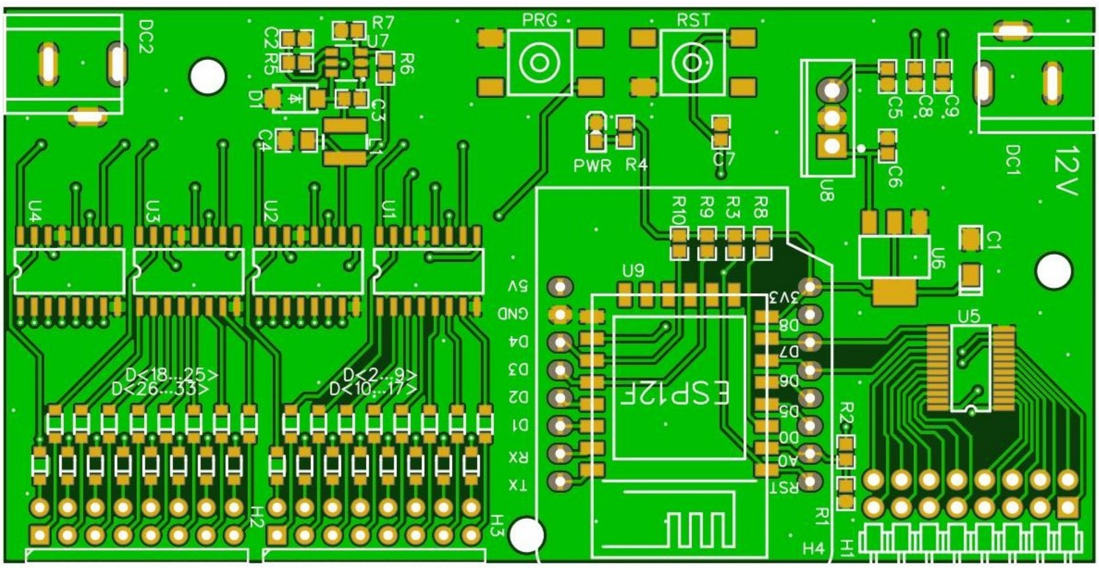


Figure 5.1: PCB as used in the final prototype

5.3. Testing and results

5.3.1. Validation of the sensor grid

The resistance of the copper tape and the wiring
The copper tape and the wiring have a resistance that might influence the accuracy of the sensors. To determine the resistance of the copper and the wiring, the bench multimeter RS PRO RSDM3055 is used

[46]. First, a calibration measurement was done by short-circuiting the probes of the multimeter. This offset value is subtracted from the measurements. The length of the copper tape is 198cm and the length of the wire is 168cm. The measured resistances over the copper tape and the wire are shown in table 5.2.

	Length	Measured value	Value after calibration	Resitance per meter
Calibration	-	0,14 Ω	0,00 Ω	-
Copper tape	198cm	0,61 Ω	0,47 Ω	ρ_{tape} = 0,31 Ω/m
Wire	168cm	0,54 Ω	0,40 Ω	ρ_{wire} = 0,32 Ω/m

Table 5.2: Resistance of wiring and copper tape

To determine the worst-case scenario for the resistances, the longest wire and the longest copper path are used to calculate the maximum resistance, see table 5.3 for the maximum lengths and equation 5.1 for the calculations. The layers that are referred to in table 5.3 are shown in figure 4.3. The total resistance of the wire in series with the tape is 2,45Ω in the worst-case, see 5.2.

$$R_{max,wire} = (l_{wire1} + l_{wire2}).\rho_{wire} = 1,47\Omega \tag{5.1}$$

$$R_{max,tape} = (l_{copper1} + l_{copper2}).\rho_{tape} = 0,99\Omega \tag{5.2}$$

Table 5.3: l_{wire1} and l_{tape1} are connected to layer 4. l_{wire2} and l_{tape2} are connected to layer 2.

l_{wire1}	168cm
l_{wire2}	291cm
l_{tape1}	198cm
l_{tape2}	120cm

The tape and the wire are also in series with R_1, a 270Ω resistor and the linqstat. For the worst case scenario consider the resistance of the linqstat to be 0Ω. In this case, the maximum voltage drop across the wire in series with the tape is given in equation 5.3.

$$V_{drop,max} = \frac{R_{wire+tape}}{R_{wire+tape} + R_1}.V_{in} = \frac{2,4}{2,4+270}.5 = 0,044V \tag{5.3}$$

A voltage drop of 0,044V means a deviation of 0,8% in the worst case, which has an influence on the measurements of the ADC of the microprocessor.

Noise

The copper tape can be seen as a noise source. To determine the influence of this noise the voltage across the copper tape is measured with an oscilloscope(5.2). The amplitude voltage of the noise is 2,5mV and the peak to peak voltage is 5,0mV. The step voltage of the ADC is calculated with equation 5.4, in which the 'M' is the number of bits of the ADC, in case of the ESP8266EX $M = 10$. The peak to peak voltage of the noise is higher than the step voltage. Because of this, the noise is able to add or subtract a single binary digit from the data from the ADC.

$$V_{step} = \frac{V_{in,max}}{2^M} = \frac{5}{2^{10}} = 4,88mV \tag{5.4}$$

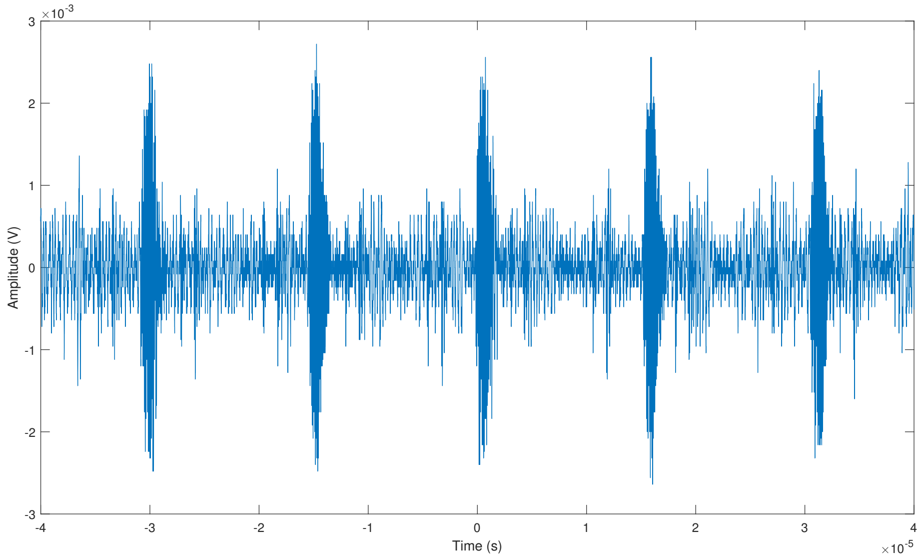


Figure 5.2: Noise on the copper traces of the mat

5.3.2. Power supply

Using the RSDS1102CML+ oscilloscope [47], the different voltage lines of the PCB were measured. The obtained measurements can be found in figure 5.3, 5.5 and 5.6. Each of these measurements has been performed with and without the ESP module present on the PCB in order to evaluate its impact.

Input voltage

The input voltage is generated by an available adapter. Instead of the intended 12 Volts, a 9 Volt adapter is used.
Its stability was evaluated by measuring the output of the adapter using the aforementioned scope whilst the PCB was connected. Figure 5.3 shows both the presence of a voltage ripple and a lot of noise. The frequency of the voltage ripple increases as the load increases and its peak to peak voltage remains at 13,6 mV. The noise occurs at an approximate frequency of 100kHz and has an amplitude of 3mV. Since its amplitude is low, it will not affect the design.

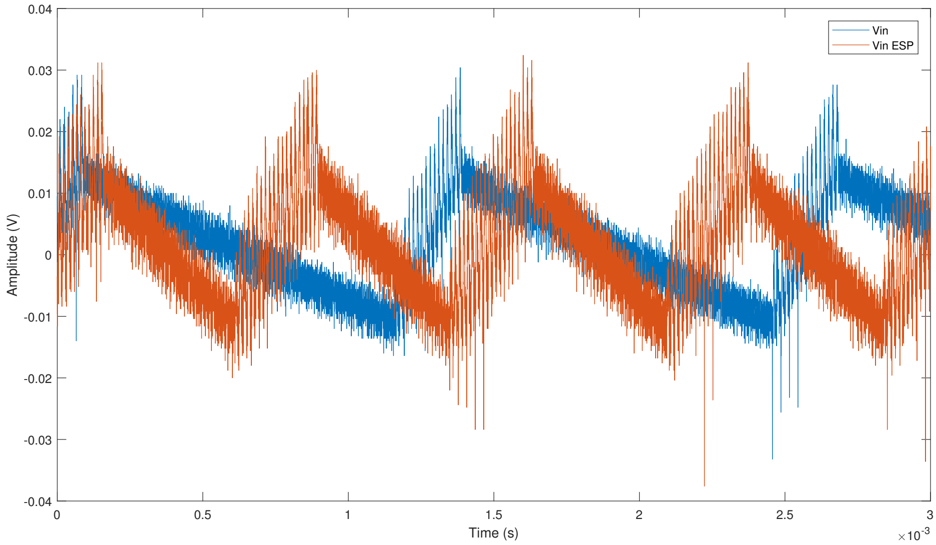


Figure 5.3: Input voltage with and without ESP module present

Whilst testing a deviation occurred when the input voltage approached the 5 Volt output of the buck converter. Further tests show that the RT8259 buck converter has a drop-out voltage of about 1,9 Volt (see figure 5.4), despite there being no mention in the datasheet.
These results are cause to adjust the input voltage range from the values determined in section 5.2.1 to 7 up to 16 Volt.

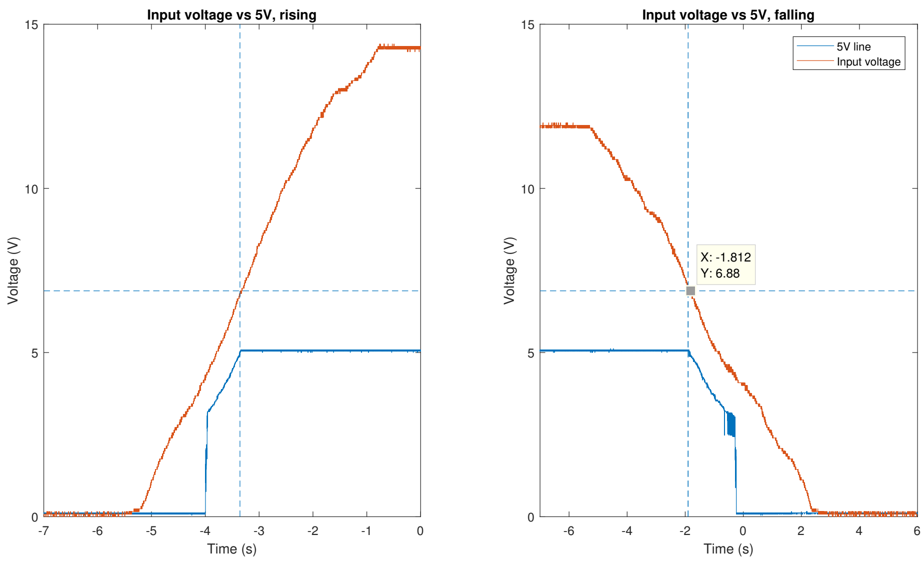


Figure 5.4: Input voltage versus the 5V line [1]

[1]Negative time axis are due to the triggering point of the oscilloscope used to acquire these plots

The 5 Volt line
Figure 5.5 shows the ripple present at the output of the buck converter. It shows an amplitude of ± 32 mV and a frequency of 1,4MHz. Neither one of these changes when the load is increased by adding an ESP module.
The frequency is equal to the switching frequency of the buck converter, as expected.
Since a 9 Volt power supply is used instead of the previously assumed 12 Volt, the expected voltage ripple has to be recalculated. Using equation 4.5 and 4.6 these calculations result in $\Delta I_L = 0,338A$ and $\Delta V_o = 4,75mV$.
Comparing the calculated values to the measured values concludes the voltage ripple is 7-fold bigger. This can be explained by deviations in the component values, like a higher ESR value for the output capacitor.

Despite these increased values, the voltage ripple is still within the required range of 5 ±0,1 V as per requirement **PR1.1**.

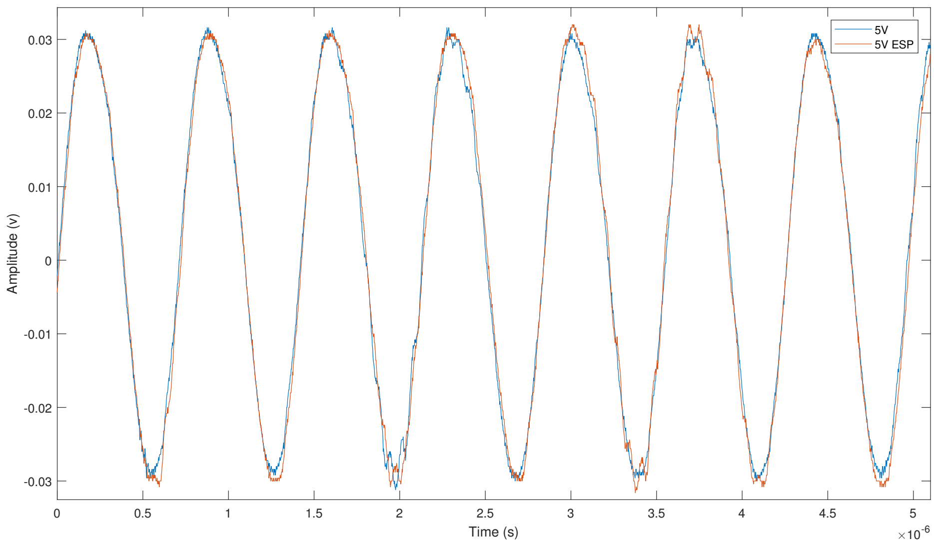


Figure 5.5: 5 Volt line with and without ESP module present

The 3,3 Volt line
Whilst comparing the voltage ripple of the 3.3 Volt line without load to the ripple when the ESP module is connected, the expected voltage spikes when the ESP is transmitting are visible.

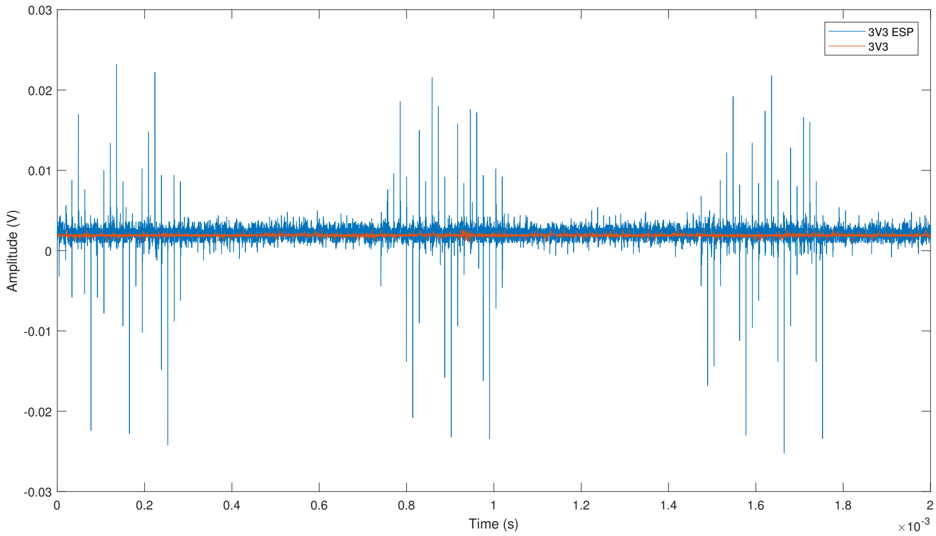


Figure 5.6: 3,3 Volt line with and without ESP module present

Since the maximum value of the voltage spikes is within 0,1 Volt, **PR1.2** is satisfied.

5.3.3. Power usage

Figure 5.7 shows both the power consumption over time during operation and the power consumption during the startup of the system. The average power usage of the system is 0,74W whilst the peak power during startup reaches 1.6W.

In both scenarios, the power usage lays well below the 5W specified by requirement **SR1.1**.
The peaks in power consumption can be explained by the ESP sending data. The frequency of these peaks varies between 14 and 15 Hz. Whether this is indeed the transmission frequency will be verified by section 5.3.4.
The power spikes directly after powerup indicate the connection to the network and server. Figure 5.7 indicates the startup time of each individual module to be 2,5 seconds. The startup time has been defined as the time between powerup and the last power peak associated with initialization.

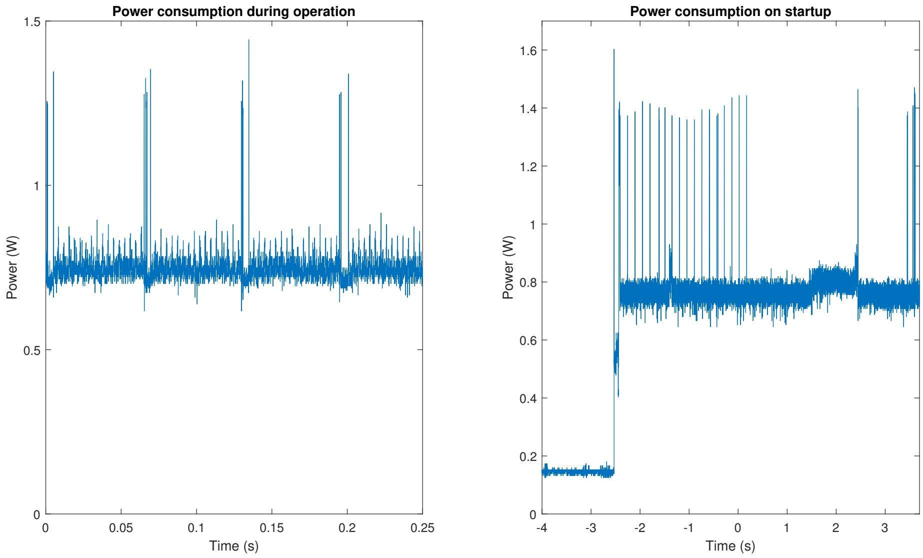


Figure 5.7: Power measurements during startup and operation [2]

5.3.4. Update frequency

The update frequency should be high enough to be able to collect all the required data. Requirement **SR1.2** states that it should be at least 5Hz.

Test setup

To measure the readout frequency, a logic analyzer was connected to the ESP-module, such that all the control signals were measured with Saleae Logic Software. The sample rate of the logic analyzer is 24MHz. The measured channels are:

- The clock signal for the shift register.
- The latch signal for the shift register.
- The data signal for the shift register.
- The S0, S1, S2, and S3 for the multiplexer.

The signal S3 that goes to the multiplexer is representative for the update frequency of the matrix because the firmware is written in such a way that the data of a complete mat is updated within a single cycle of S3.

Results

As seen in the measurement, the frequency of S3 is 14 Hz. The update frequency for a single node is 8,7 kHz as seen in figure 5.9. This can be concluded because the clock signal goes up and down before every readout of a node.

[2] Negative time axis are due to the triggering point of the oscilloscope used to acquire these plots

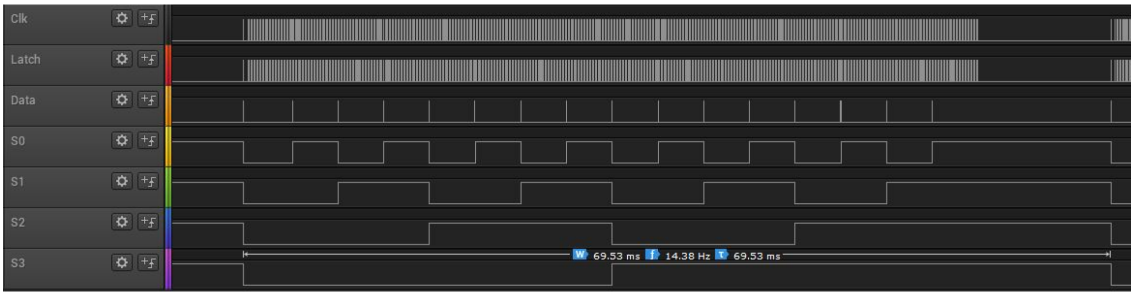


Figure 5.8: Control signals from the ESP-module to control the shift register (Clk, Latch, Data) and the multiplexer (S0, S1, S2, S3).

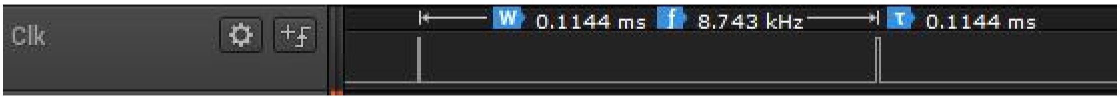


Figure 5.9: Clock frequency for the shift register.

Conclusion
The minimum update frequency requirement is 5Hz **SR1.2** and the measured update frequency is 14Hz.

The measured update frequency is 14Hz, which is higher than the minimum update frequency of 5Hz stated in the requirements, see requirement **SR1.2**. By measuring the clock cycle for the shift register, the maximum sample frequency of 8,7 kHz is found.

5.3.5. Reliability

Although the reliability is not tested separately, the hardware did run eight hours a day for four weeks without breaking down. This suggests that the hardware is reliable and can run for a longer time without failing.

5.3.6. Material and operation cost

The costs are consists of material cost, operational costs, and end of life costs.

Material costs
The total cost of the system per room is seen in table 5.4. The total price is €680 per room this is below the requirement of €1000 so this requirement is fulfilled.

Material	Costs per floor mat (2m x 1m)	Total costs per room (4m x 5m)
PE sheet	€3	€30
Linqstat	€10	€100
Copper tape	€12	€110
Wires	€2	€20
PCB	1	€10
Components	22	€220
Computer (pi)	-	€60
Power supply	-	€20
Total	€49	€570

Table 5.4: Total costs per floor mat (2m x 1m) and per room (4m x 5m).

The operational costs
The operational costs consists of electricity costs and the maintenance costs. The average power is 0,74W per floor mat (1m x 2m) so the cost are €1,30 per year on electricity consumption. For a complete floor

(4m x 5m), the costs are €12,96. The electricity costs of the server are not included in this calculation. For the maintenance the costs are still unknown.

The end of life costs
The end life cost of the mat is estimated based on man-hour cost and if the materials are recyclable. The estimated man-hours are 8 hours and will cost about €50 per hour, so the total cost will be €400. Also, the transport costs need to be considered, see table 5.5. The total costs are estimated at €450, however, this is a very rough estimation so the actual cost could differ a lot.

	Estimated costs
Man-hours	€400
Transport	€50
Recycling	unknown
Total	450

Table 5.5: Estimated end life cost of the system.

5.4. Assessment

The floor mats are created to be modular, which is very useful for when the size of the room is unknown, also some parts could be cut to fit the mat in tight corners. On the other hand, the size of a single floor mat is 1 by 2 meters, so there are a lot of pieces needed to cover the whole floor. The PCB that is used to collect the data is quite big. This makes implementing the system into a house unpractical. However, for the prototype, it was a good solution to test and measure the characteristics. But for the final version, it should be implemented on a smaller chip.

5.5. Future work

Before the product can be brought to the market, there are some things that need improvement and some things that need more research.

5.5.1. Improvements

The prototype has a single big PCB per floor mat. This is unpractical when you want to cover the whole floor. It should be redesigned in such a way that it fits in a small chip below the floor itself. That way it is less noticeable for the user, which was a design requirement. Also, the prototype consists of floor mats with the dimensions of 1m x 2m. By creating bigger mats less PCB's are needed and it is easier to cover bigger surfaces. The current design of the sensor grid is based on the linqstat MVCF-4S50K. As shown in figure 4.4 the thicker variant, MVCF-8S50K, has preferred resistive characteristics. At the time, this material wasn't available but for the next generation, MVCF-8S50K could be used.

The microprocessor could also be replaced with a faster microprocessor like the ESP32. This processor has a higher resolution ADC and a higher clock frequency.
Since the sensor is placed below the surface of the floor, it might get in contact with any liquid spilled on the floor. To prevent this liquid from causing damage, the sensor needs to be waterproof. In the prototype, the floor is not waterproof yet, so this needs to be done by sealing the sides of the upper and bottom PE sheet together.

5.5.2. Additional research

In the prototype, copper tape is used as a conductor. Because the copper is in contact with the air and its humidity, it is possible that it can oxidize. The influence of this on the working of the system should be researched in the future. Right now no information is known about the lifetime and the robustness of the system. This should be tested in a house for a longer time period and push the system to the limit. It is hard to simulate the way elderly fall because, elderly move slower than young people. It is also hard to fake a real fall, because of those two the system should be tested in a retirement home to get data from real elderly that fall.

6 Conclusion

The goal of this project is to build a fall detection system for elderly. The design that is chosen is a sensor grid below the floo. Both the sensor grid and the PCB have been designed according to requirements. This chapter will summarize the results found in chapter 5.

6.1. Requirements

Requirements for this project were divided into different levels: Global requirements, Subsystem requirements and Power requirements. Each of these requirement levels will be evaluated in order to draw a conclusion about the hardware subsystem.

6.1.1. Power requirements

The power requirements of the voltage lines state that both the 5 Volt and 3,3 Volt line are within ± 0,1 Volt of their specified values and have sufficient output current. Section 5.3.2 shows the voltage requirements are met, the datasheets state the current requirements are met.
In addition to the voltage requirements, it must be possible to power an entire room from a single power supply and each individual module must feature reverse polarity protection. The PCB design and schematic show this requirement is met since each module can be powered or deliver power to the next PCB via either of the 2 DC barrels.

6.1.2. Subsystem requirements

As discussed in section 5.3.3, the average power use is only 0.74W. Despite the peak power reaching 1.6W, requirement **SR1.1** is met. Both section 5.3.3 and section 5.3.4 show the update frequency is around 14 to 15 Hz, which satisfies requirement **SR1.2**.
Requirement **SR1.3** and **SR1.4** state that the sensor grid must have a maximum distance of 8cm between each node and that wifi communication is required. Both requirements are met based on the design decisions made in 4.4.1 and 4.4.3.

6.1.3. Global requirements

Functional requirements
Requirement **R1.4** states furniture must not influence the detection process. Chapter 3 discusses the considerations made whilst choosing a floor based sensor, including its insensitivity to furniture.

Section 5.3.5, evaluates the reliability of the system, fulfilling **R1.3**.

As stated by requirement **R1.5**, the system must be scalable, not only on room level but on home level as well. The currently developed hardware is scalable to room level as concluded in section 6.1.1. By copying this to multiple rooms, the hardware does not have a limit when it comes to scalability. Since the interface team has also met this requirement, it has been satisfied.

Non-functional requirements
Requirements **R2.3**, **R2.4** and **R2.5** state that no camera, no audio recordings and no wearables are to be used respectively whilst detecting if a person has fallen. Requirement **R2.6** additionally states the system must have a maximum of one terminal visible. The choice to create a sensor grid that lays beneath the

surface of the floor, as stated in section 4.5, satisfies all these requirements.

Requirement **R2.7** states the system should not rely on feedback from the user. The current design does not require the user to interact with the hardware of the system. However, hardware alone does not satisfy this requirement. The signal processing and interface subsystems are required for this.

According to requirement **R2.8**, the system must be operational within 30 seconds of powering up. Section 5.3.3 indicates the startup time of a single module to be 2,5 seconds. All modules in a room receive power at the same time (as per requirement **PR1.3**) and will thus boot at the same time. Despite the delays that might be caused by the synchronous attempts to connect to the server, it is realistic to assume a single room will be operational within 30 seconds after powering up. Although this requirement cannot be fulfilled by the hardware subsystem alone, the hardware will not be the limiting factor in fulfilling this requirement.

Requirement **R2.9** states a single person should be able to install this product within 4 hours. If the floor is already removed and there are no obstacles in the way whilst installing the system, it is possible to satisfy this requirement.
Realistically, however, furniture would have to be relocated and the floor would have to be removed before starting. After the system has been installed, the floor must be put back in place. Considering the amount of work this takes, this requirement is not satisfied.

Section 5.3.6 shows a clear overview of the costs per mat and per room. According to table 5.4 the total cost per room would be €570. Since €570 is below the €1000 specified by **R2.10**, this requirement is satisfied.

The electricity cost per year per room (4m x 5m) is €12,96, excluding the electricity of the server, see paragraph 5.3.6. The maintenance costs are still unknown so the operational cost are at least €12,96, this satisfies requirement **R2.11**.
The estimated end of life costs of the system are €450, see paragraph 5.3.6, which satisfies requirement **R2.12**.

7 Global System Evaluation

As can be read from the three subsystem reports, most, but not all requirements have been met. The current system is able to detect falls when a single person is using the hardware, which means that it can be used in many elderly homes already. All three reports mentioned improvements that could be made to this system in the future, and with these improvements the current system would become usable in almost all elderly homes. However, the goal set within the Bachelor Graduation Project was to detect the fall of a single person, which is what the current system is able to do. Therefore it can be concluded that a fall and activity detection system using a pressure sensitive floor can be considered a feasible solution to detect falls amongst elderly.

A
PCB design

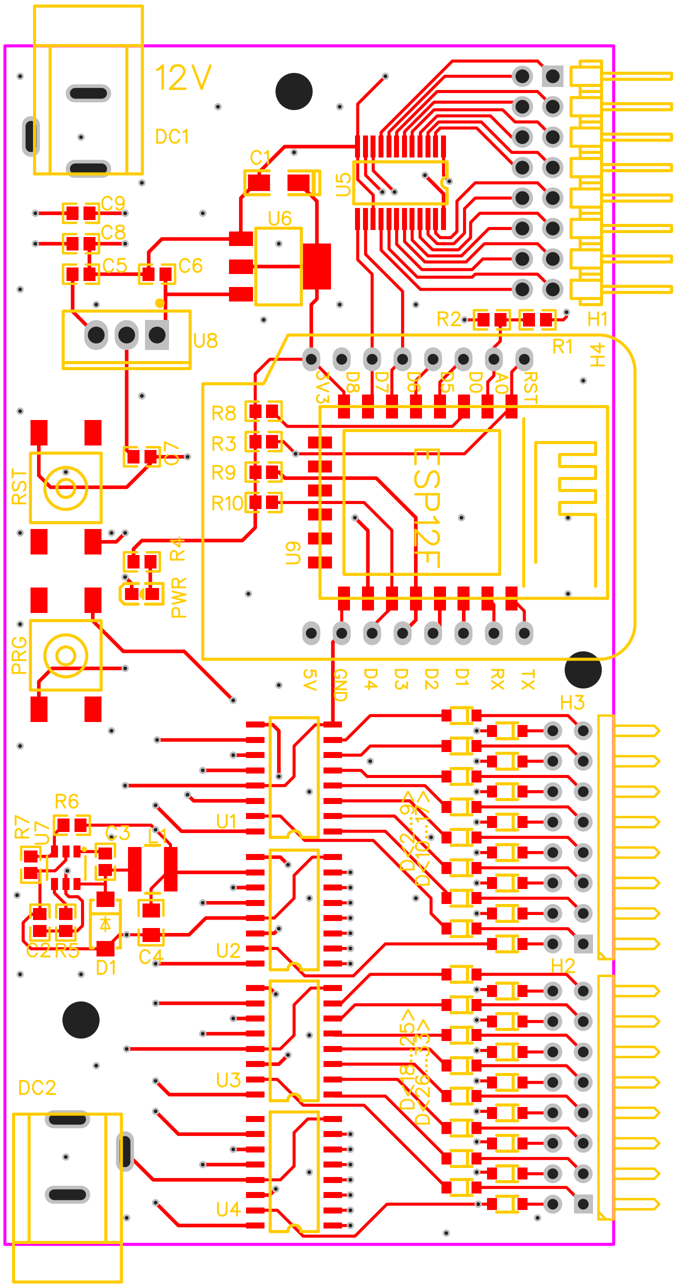


Figure A.1: Top side of PCB design

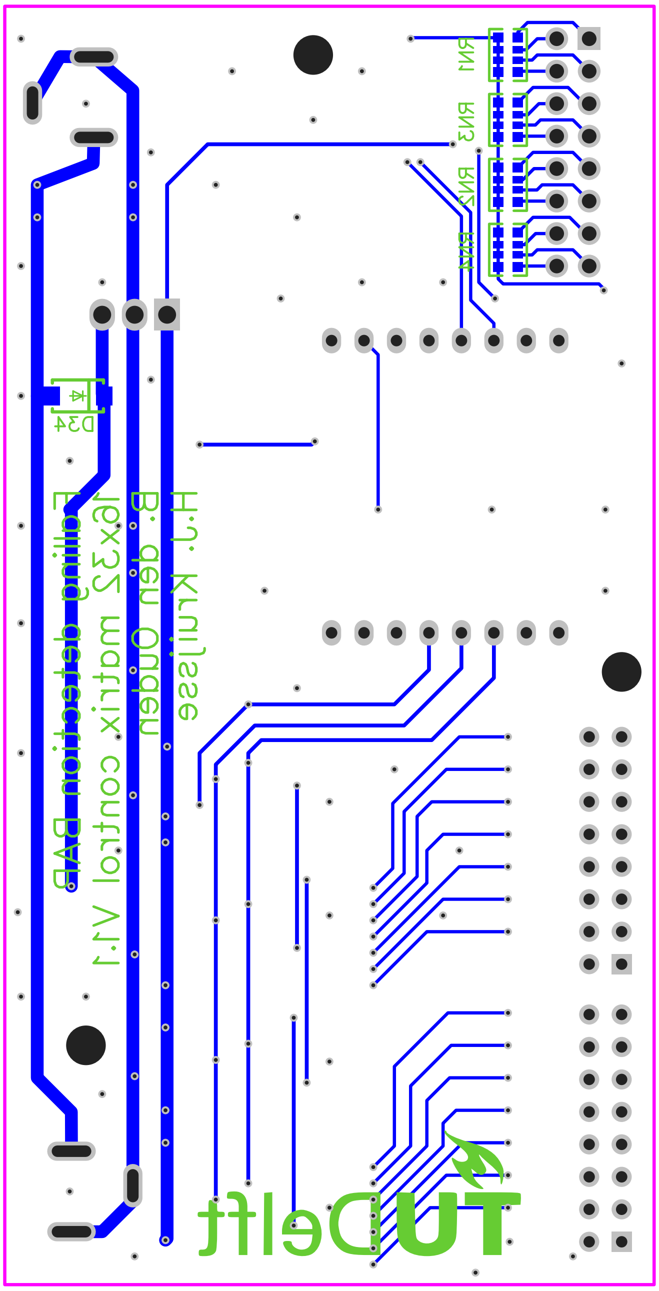
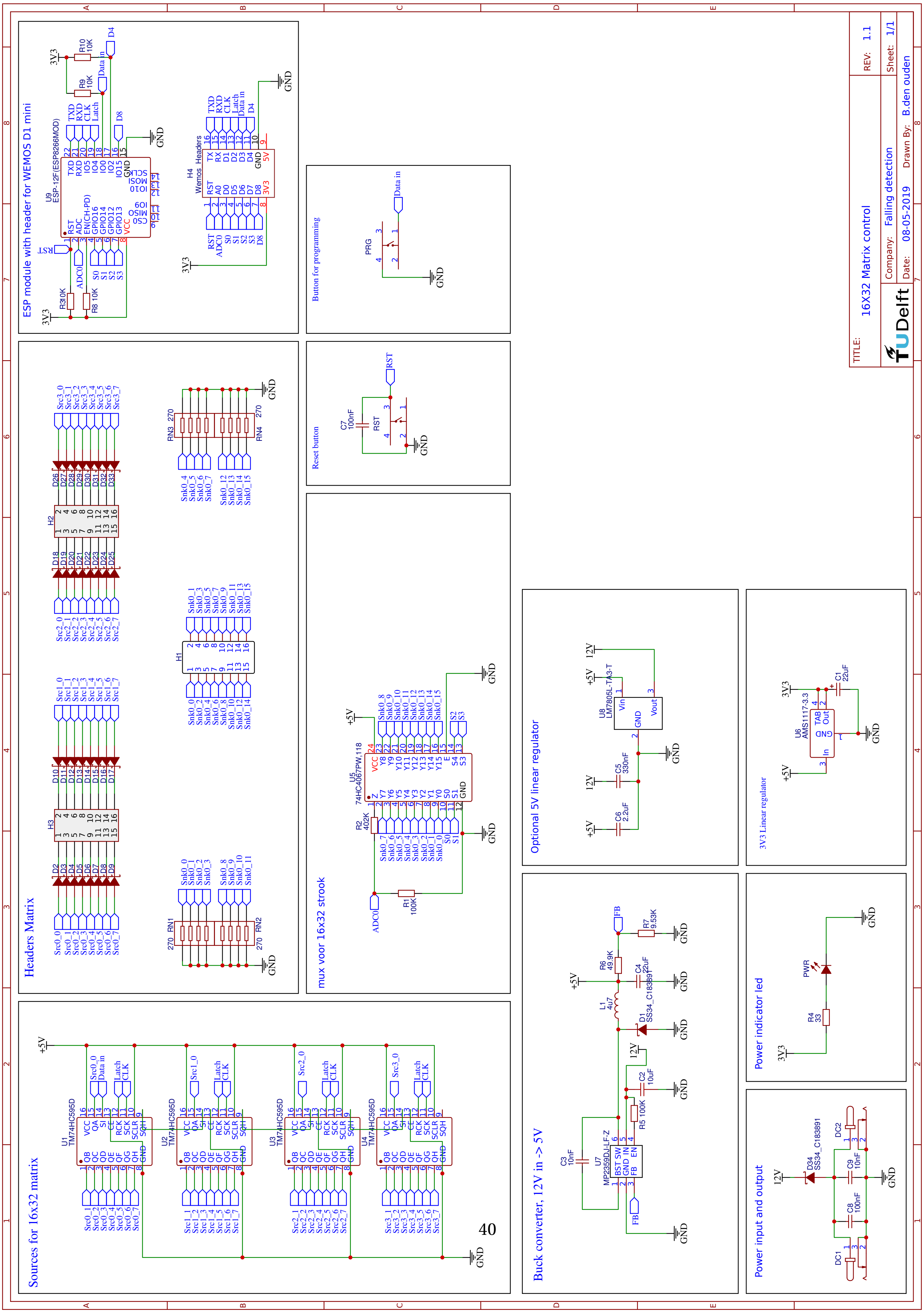


Figure A.2: Bottom side of PCB design


ESP module with header for WEMOS D1 mini
Button for programming
Headers Matrix
Reset button
mux voor 16x32 strook
Sources for 16x32 matrix
Buck converter, 12V in -> 5V
Optional 5V linear regulator
3V3 Linear regulator
Power indicator led
Power input and output
TITLE: 16X32 Matrix control
REV: 1.1
Company: Falling detection
Sheet: 1/1
Date: 08-05-2019
Drawn By: B.den ouden
TUDelft

A.1. Bill of materials

The bill of materials specified below contains all components required to assemble three complete PCBs. Availability and price are checked the 20^{th} of June, 2019 and are subject to change over time. The PCBs themselves have not been included in this list.

Farnell ordercode	amount	description	price
9332006	10	0603 33R resistor	€ 0.03
7208359	5	TS1117-3.3	€ 1.04
2984492	3	header male	€ 2.08
2827959	6	header female	€ 5.80
2463987	3	74HC4067D	€ 3.78
2688534	5	0805 22uF capacitor	€ 2.04
2677205	5	4x4mm 4u7 power inductor	€ 1.81
2581045	10	0603 100nF capacitor	€ 0.22
2508350	100	schottky diode	€ 5.02
2491479	5	1206 22uF tantalum capacitor	€ 4.90
2447452	10	0603 9.53K resistor	€ 0.06
2447380	10	0603 49.9K resistor	€ 0.06
2447366	10	0603 402k resistor	€ 0.06
2447230	20	0603 10k resistor	€ 0.12
2426958	10	0603 10uF capacitor	€ 3.23
2426215	10	0603 green LED	€ 0.51
2362986	5	buck converter IC	€ 5.15
2320087	10	6x6mm tactile switch	€ 1.92
2296029	5	7805 linear voltage regulator	€ 1.87
2101195	10	SS34 schottky diode	€ 3.26
2060095	20	resistor network	€ 0.84
2008366	10	0603 100k resistor	€ 0.06
1759404	10	0603 0.33uF capacitor	€ 0.64
1458901	10	0603 2.2uF capacitor	€ 1.35
1201269	20	74HC595	€ 6.04

subtotal	€ 51.89
btw	€ 10.90
total	€ 62.79

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