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Hand-in information

Anti-Collision System for LINAK HOMELINE

Technical Report

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Experts in Teams 2020

Anti-collision system for LINAK HOMELINE

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Abstract

This project investigates potential solutions to an anti-collision system for adjustable beds, to prevent pinching and other accidents. The project is in collaboration with LINAK, who manufacture actuators for furniture both for private and commercial use. Therefore, a market research has been performed by use of qualitative and quantitative research methods to investigate the market of bed users and retailers. The team for this project consists of 12 engineering students from three different engineering programs at SDU in Sønderborg. The State-Gate model was used to evaluate the progress at gate meetings with LINAK to access the solutions and their potential.

The outcome of the project is research with focus on the initial development of three different solutions that are ready for further development and implementation. These three ideas can be used as standalones or combined for a more robust system. Also, with a market research that substantiate a need for a safety feature, additional needs were uncovered, like easier cleaning and voice-control which could be a part of the future marketing strategy. The three potential solutions involve a mechanical solution which counteract the forces by use of springs and sensors, making the bed frame weightless and ease the way to clean and operate the bed. Second idea is with capacitive sensors which detect touch and collision making it possible to detect touch where needed. The stripes attached to the bed act like a sensor measuring for changes in the capacitance caused by e.g., the human body capacitance. Lastly, the idea of embedding a sensor in the actuator to measure collisions and thereby use machine learning to recognize future collisions. By use of data from collisions and movement then intention is to distinguish movement from dangerous accidents only implementing a small sensor in the actuator.

The solutions are not finalized; however, they pose a potential not only for a safety system, but open for new market opportunities as well. With an overview of the market and the need of the users it is possible to make a marketing plan suited for the right target group.

Preface

This report is written for the Experts in Teams project at the University of Southern Denmark in Sønderborg in collaboration with LINAK.

The report contains the structural approach of the project and the mechanical, electrical and embedded development of potential solutions for an anti-collision system for LINAK HOMELINE. Furthermore, a marketing strategy for this product is described, looking at the potential users and the current market.

The anti-collision system development team would like to express our gratitude to Roana Melina de Oliver, David Grube Hansen, Markus Hofmann, Morten Frost Lorenzen and Preben Jørgensen who were always available for any questions we had, provided us with the essential equipment and guided us throughout the entire process.

The project started in September 2020 and ends in January 2021.

Work contribution

Names	Work contribution – bullet points

Anina Hasse	▪ Ideation
	▪ Project Management
	  ▫ Agile Working structure
	  ▫ Retrospective
	  ▫ Gantt Time Plan
	▪ Marketing
	  ▫ User research - quantitative research
	  ▫ Value proposition canvas
	  ▫ Marketing strategy

Dennis Riess	▪ Mechanical Solution
	  ▫ Concept of the "counterreaction force device"
	  ▫ First idea
	    ▪ Concept of the model
	    ▪ Design of the model
	    ▪ Spring calculations
	    ▪ Mockup
	      ▫ Designing the model
	      ▫ Assembly of the model
	  ▫ Improved Idea
	    ▪ NX designing the new "levers"
	    ▪ Simulating stress and deflection to determine the size of levers
	  ▫ Test setup
	    ▪ Load needed to lift the bedframe
	      ▫ Force acting in the finger
	    ▪ Load added by a person lying in the bed
	  ▫ Assisted with beam deflection calculations and simulations
	  ▫ Assisted with simulating deflection and stress, in Strain gauge device (Embedded sensor solution)

Erik Winkler	▪ Basics of capacitive sensing for anti-collision
	▪ Time delay measurement
	  ▫ The first circuits and their problems
	  ▫ The final circuit
	  ▫ Implementation with Arduino
	  ▫ Final Arduino program
	▪ Electronics based capacitance detection (not included)
	  ▫ Theory behind the voltage drop solution
	    ▪ Measuring a voltage drop
	    ▪ Using 555 Timer as pulse generator
	    ▪ Determine the frequency and the resistors of the voltage divider
	    ▪ Configurations for 555 Timer

Esben Georg	▪ Mechanical Solution

Sørensen	▫ Beam theory ▫ Improved Idea ▪ NX Mockup ▪ Risk Management
Horia Iotu	▪ Mechanical Solution ▫ Beam theory - assisted ▪ Design and simulation of first circuit idea in LT-Spice – assisted ▪ Test of circuit ▫ Construction and test of circuit – assisted ▫ Implementation to bed actuator – assisted ▪ Simulation of the circuit for time delay measurements in LTSpice ▪ Capacitive sensor strip design ▪ Detecting a short in the circuit ▪ Combining the circuits ▪ Designing a PCB and circuit schematic
Ioannis Andromidas	▪ Exploring measurement circuits ▪ HX711 sensor and implementation attempts ▪ Differential Amplifier setups ▪ Assistance with Instrumentation Amplifier implementation
Magnus Christesen	▪ Mechanical Solution ▫ First Idea ▪ Mock up – NX models design and assembly ▪ Sensor selection ▪ Lever simulation – ANSYS ▪ Test setup and measurements ▫ Improved Idea ▪ Spring calculation
Maram Daood	▪ Instrumental Amplifier. ▪ Working principle ▪ Reason of using the instrumental amplifier. ▪ Circuit implementation of the Strain Gauge sensor. ▪ Testing and Results
Maria Lunau	▪ Project management ▫ Belbin team roles ▫ Group formation ▪ Marketing strategy ▫ Market research ▫ User research – qualitative research ▫ Value Proposition Canvas + sum up ▪ Responsible for report setup, abstract, combining the points from all groups to form a discussion and conclusion
Mohammed Mohammed	▪ Component research ▪ Simulation of the load to strain circuit ▪ Circuit and PCB design

Nicklas Lyck	▪ Design and simulation of first circuit idea in LT-Spice
	▪ Combining the circuits - assisted
	▪ Detecting a short in the circuit - assisted
	▪ Electronics based capacitance detection
	▪ Test of circuit
	    ▫ Construction and test of circuit
	    ▫ Implementation to bed actuator
	    ▫ Powering the capacitive sensor
	    ▫ Time delay of capacitive sensor

Pablo Paniagua	▪ Embedded sensor solution that recognizes collision
	    ▫ Concept for embedded sensor
	    ▫ Load to strain
	    ▫ Signal Processing Element Design
	    ▫ Measurement system results and discussion

Below are digital signatures from all group members who have contributed and agreed to the content of this report.

Anina Hasse

Dennis Riess

Erik Winkler

Esben Georg Sørensen

Horia Iotu

Ioannis Andromidas

Magnus Skov Christesen

Maram Daood

Maria Lunau

Mohammed Mohammed

Nicklas Lyck

Pablo Paniagua

Table of contents

Table of figures

Table of tables

Introduction

Breaking down the average person's life, it shows that nearly half of the lifetime is spend lying in bed. Also, a new study of 2.000 Americans from February 2019 found that only 53 percent of the Americans confidently say they like their bed, and one third would prioritize style over comfort [1]. Therefore, the bed market is focused on making stylish beds, adding functions, and changing colors according to the current demand. The bed market consists of beds in a price range from a few hundred DKK to several hundred thousand DKK. With the current technological development, the users expect more and more features from their bed, keeping the price low and style intact.

In collaboration with LINAK, who produce actuators for the market worldwide, the project revolves around adjustable beds and their actuators which are implemented in many of the beds sold on the Danish market. With an app on the market that makes it possible to control the bed, additional features are required to make it compatible with Smart Home ecosystems while meeting the incoming requirements for adjustable beds. The current requirements for motorized furniture states that the furniture should stop any movement when the control buttons are not pushed. This biased-off switch is not possible to implement if e.g., voice control is added to operate the bed. Therefore, a fully integrated Smart Home solution for adjustable beds will not live up to the future requirements on the market. Moreover, the safety of the users is a priority to LINAK and with the potential risk of getting pinched, an anti-pinching and collision solution is the focus.

The market for safety solutions has changed through the years, lowering the focus on safety due to a low interest from buyers and the fact that they were too complex. Major players on the market made solutions with sensors and foam, however most of them have chosen to discontinue the development of these solutions due to a low demand. Therefore, the project will investigate an alternative way of commercializing a safety feature.

For this project, potential solutions are explored combining 12 people with different knowledge bases with a common aim to create a safety feature for the users. The project is about exploring solutions that live up to the requirements made for adjustable beds. Therefore, this project will be conducted following some of the work processes used in Research and Development (R&D) departments. Moreover, a marketing strategy for the new feature is developed in collaboration with LINAK. Adding to this, the coding for communicating with the actuators are done by LINAK and the marketing plan will only focus on the Danish market and the end users and retailers. The solution will be tested by use of LINAK's test equipment and the findings will be published to use for LINAK and their further development.

Project formulation

Project background

The average person spends 26 years of their life sleeping. Add to these another 7 years spent trying to fall asleep, and the average person uses approximately 33 years in their bed [2]. Moreover, in recent years, studies have time after time concluded that sleep is important to maintain a healthy brain function and a general good physical health [3]. This has led to a higher focus on beds and how to secure a good night's sleep, in combination with people's desire for additional features in their bed. Therefore, the sales for adjustable beds are rising, taking the bed, known from the hospital, into people's bedrooms. The bed, which has an adjustable base, allows the user to raise or lower the head and foot section, making it possible to create different positions for sleeping. Furthermore, the adaptability is beneficial for the heavy snorers and people with physical conditions, as the bed can lead to pain relief and improved blood circulation when used [4]. Combined with the fact that many people watch tv or read a book in bed, the adjustable beds have become very popular. Many beds are sold today with a wide range of customizable features like wireless remote control or app connectivity. Even though the adjustable beds are heavy and expensive, the market for them is growing, and so is the variety of producers, and the features offered [5].

The project is made concomitant with LINAK who provides the actuator solutions for some of the adjustable beds on the market. LINAK HOMELINE is the branch that develops and commercializes the products made to improve comfort and ergonomic in so-called comfort furniture. With their market-leading solutions that ensures comfortable movements, they want to keep the market forefront and provide the customers with a system to avoid collision due to furniture movement. Adding this safety feature is not only important for them market wise, as their vision states, but also important in their mission of improving people's quality of life.

State of the art

With the increasing market of smart furniture [6], a certain amount of safety is needed in order to create maximum value for the customer. Depending on the kind of furniture the anti-collision system needs to support, different technical solutions are used. In the office furniture segment, multiple solutions exist. For example, LINAK DESKLINE is providing an external solution including a gyroscope sensor unit to detect any kind of change in acceleration and an internal solution based on a column integrated Piezo sensor. For electric beds only a few anti-pinching systems are on the market yet. One is called LPSense (from Leggett & Platt Smart Seating Technologies) and is described as a human-touch sensitive technology which stops the motor immediately. Laybrook.com provides an anti-entrapment safety feature which uses sensors alongside the bedframe in order to reverse the direction of the motor as soon as a small force is detected.

Other markets like the car sector need anti-collision systems as well in order to reach a certain level of safety. They use the solutions in order to prevent pinching when the electric windows are closing. A sensor in the motor can sense a resistance in form of pressure on the window and will stop the motor immediately.

In the growing cobot market most of the collaborative robots use force torque sensors in order to prevent injuries but new technologies are researched in order to make the collaboration even safer. Capacitive sensors could be used to measure the distance between the robot and the human. This would increase not only the safety but also the efficiency of cobots.

Another state-of-the-art safety feature can be found in revolving doors. By use of active infrared sensors motion of humans in critical areas is detected and the revolving doors slow down or stop entirely. A visualization of that can be found in Figure 1 [7].

Figure 1: Active infrared sensor for revolving doors

Problem formulation

The increased consumption of adjustable beds, along with increasing safety regulations, have risen safety concerns that need to be addressed. One of the biggest issues is associated with forces present on the movement of the mechanism, as there is currently no mechanism to avoid humans or animals from getting stuck between moving parts of the frame of adjustable beds. This problem has become even more alarming recently, as mattress technological improvements have resulted in thicker and heavier mattresses that exert even greater forces than before.

With this project the aim is to develop an anti-collision system to avoid accidents caused by furniture movement. Moreover, it needs to fit into LINAK's solutions and stop movement whenever a collision is detected. The main focus is to hinder collisions with humans and pets and develop the system based on adjustable beds. The additional safety feature will be developed in close cooperation with LINAK to ensure proper integration into existing actuator solutions.

In addition to that, a marketing strategy for the application will be made and a market research conducted. This is, as a part of LINAK's values to be customer oriented, important in order to know what creates value for the customers and retailers.

The feature will provide higher safety for the users of adjustable beds and ensure that for example humans do not risk getting their fingers jammed in any of the pinch points. This is especially a risk if children are operating/playing with the remotes or pets are curious and sneak under the bed unseen.

Requirements and desirables

The software, hardware and marketing requirements for the anti-collision detection system are as follows. The requirements are made in cooperation with LINAK to fit their values combined with the regulations on the market according to IEC60335-2-116. Moreover, desirables are added, marked with a *, to show that these are not of priority but would increase the value of the product. The final product (referred to as the device), and the TD5 (referred to as the actuator) are the focus of this list.

1. The device must be made for the HOMELINE product line
2. The device must detect collision
   - 2.1. The detection must occur underneath the bedframe in all/any clamping point
   - 2.2. The detection must focus on human beings and pets
   - 2.3. The detection can additionally focus on inanimate objects*
3. A collision must remain under the given values [8]
   - 3.1. 400 N for the first 0.75s at the contact point
   - 3.2. 150 N up to 5s at the contact point
   - 3.3. 25 N after 5s at the contact point
4. The device must be able to switch between idle and active mode
   - 4.1. The device must actively monitor collision after a key is pressed in the remote, through the actuator's movement and for 5 seconds after the actuator stops
   - 4.2. The device must be idle when the conditions of 3.1 are not fulfilled
5. After a collision the device must take a pertinent action
   - 5.1. The device must stop and reverse movement in the actuator, by sending a signal through LIN Bus, to remain under threshold outlined in point 2.1
   - 5.2. The device must stop movement in the actuator, by sending a signal through LIN Bus, when load is decreased to the threshold outlined in point 2.3
6. The device must be mountable on different bed frames
   - 6.1. The device must be possible to be installed in under X[1] minutes by a trained user
     - 6.1.1. A trained user is one that has mounted the device 10 times
   - 6.2. The device must be contained within the perimeter of the bed frame
7. The device must be powered from the actuator housing
   - 7.1. The device must have an idle power that complies with the 0.1 W idle consumption of the actuator
   - 7.2. The device must have a maximum voltage of 24V
   - 7.3. The device must draw less amps than what the actuator requires to operate at its maximum load

[1] The number is to be determined based on the selected idea. The ratio between product cost and assembly time must be analysed

8. The production cost of the device must be lower than that of the actuator
    8.1. The device must be less than half the price of the actuator
9. The device must have a durability of at least X[2] cycles
    9.1. The device can have the same durability as the actuator*
    9.2. The device must be shock resistant (as described in ISO 9688:1990)
    9.3. The device must be dust resistant (as described in IP5X)
    9.4. The device can be water resistant (as described in IPX3)*
10. The enclosure of the device must follow the aesthetic design of the actuator
11. The device must follow the IEC-60335-2-116 standard draft (valid until 2023)

*Requirement is a desirable and might not be fulfilled

The Marketing requirements for the LINAK anti-collision detection system are as follows.

1. The market research must be based on the Danish market
2. The marketing strategy will focus on the end-user, but will also take the bed retailers into account
3. The user research and marketing strategy will be developed for LINAK HOMELINE, therefore only focusses on home use of adjustable beds

[2] The number of cycles and exact definition of a cycle is to be determined based on the selected idea.

Time plan

As to better fulfil the requirements and attain a successful solution, a Gantt chart, seen in Figure 2, has been created. This chart contains all important tasks to be taken, as well as the milestones of the project. It is to mention that continuous update is required in the chart to adjust for new tasks and changes in direction that could present along the day due to corona virus or restrictions not yet foreseen.

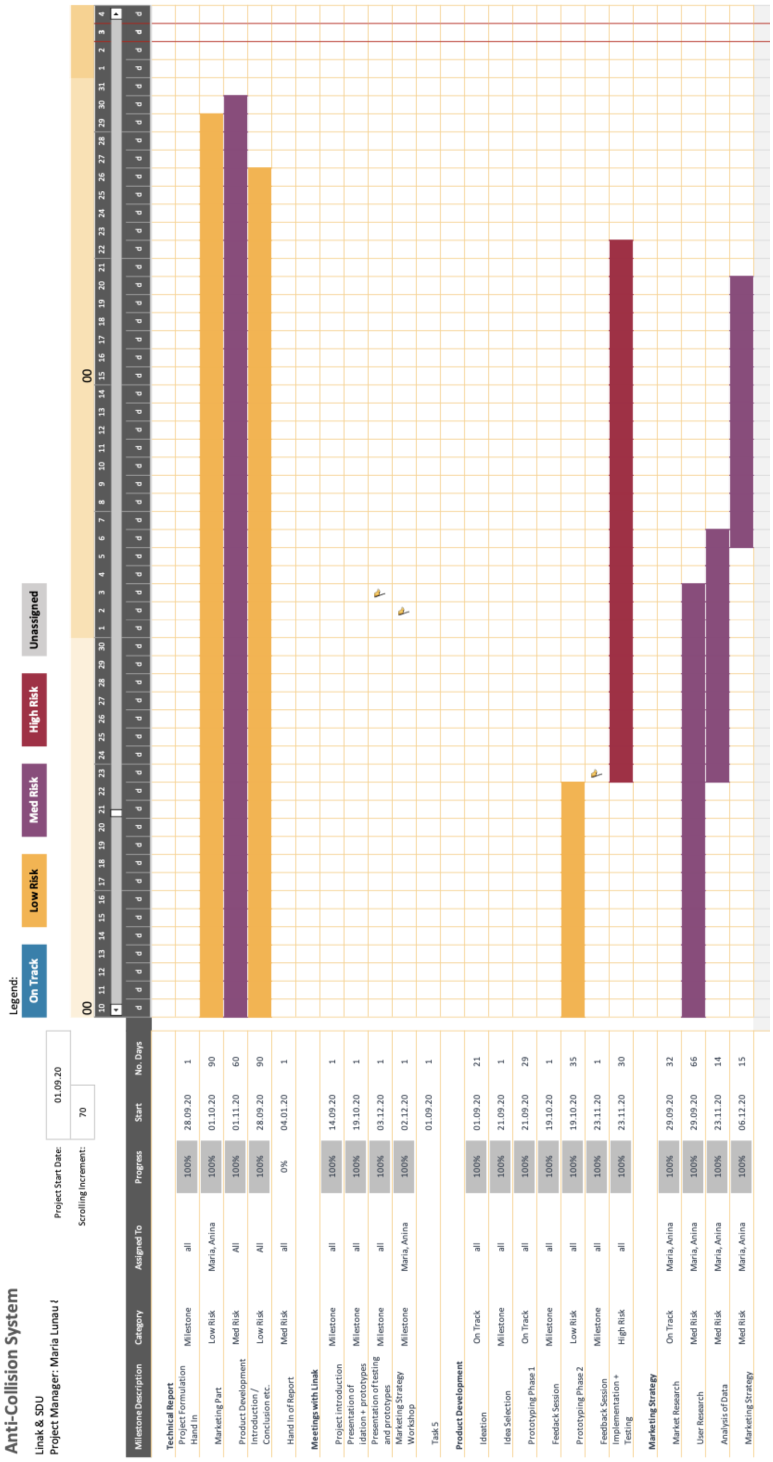


Figure 2: Gantt Chart for project

Milestones

The following list is visualized in the Gantt chart and will be the guideline for the time management throughout the entire project. Since the different milestones of the different departments depend on each other it is important to have a good overview of the structure and a common understanding of the time plan throughout the group. The specific tasks for each department are described in the following section "Objectives and tasks". The milestones for this project are as follows:

- Decision making for ideas to continue with
- Project formulation hand-in
- Prototyping testing 1
- Defining user research
- Decision making for the best prototype solution with LINAK
- Decision making for marketing strategy based on user research with LINAK
- Prototype testing 2
- Final marketing strategy
- Final prototype (proof of concept)

Objectives and tasks

The objectives and tasks for this project are steps towards a functioning prototype, a developed concept, a marketing strategy and a comprehensive report.

- Documentation tasks
  - Reflections throughout the project
  - Document and evaluate the project with a report
  - Identification of possible future problems and improvements

- Mechanical tasks
  - Integrate the system
  - Design the mechanical structure

- Electrical tasks
  - Integrate the electronics
  - Design the embedded structure
  - Design and make the power source to the system

- Business tasks
  - Make a market research by visiting bed retailers
  - Define the value created for end users and retailers
  - Create a marketing strategy
  - Get relevant users to test the prototype

- General tasks
  - Brainstorm for ideas
  - Interpret standard IEC60335-2-116 and define requirements
  - Create prototype and develop final concept
  - Make systematic mechanical and electrical tests
  - Design a user guide according to final concept

In case of a lockdown caused by COVID-19, the project will mainly consist of fictive data and simulations for the marketing section. The business tasks will remain the same. Electronical and mechanical parts are developed from home as far as possible and simulation is used to arrive to a solution.

Technology and Methods

The team is divided into their respective strengths and weaknesses to create an even distribution of workforce. With the mechanical, embedded and electronic people working in joint teams having team leaders and the business part conducted by the team members from Innovation and Business. Weekly meetings are held to update the entire team on the progress inspired by the agile sprints known from Scrum.

For the project, several methods will be used to provide a structured approach to the tasks. The project structure is inspired by The Stage-Gate Model by Cooper [9], as seen in Figure 3, with the gates being used to assess the progress together with LINAK and involve the customers.

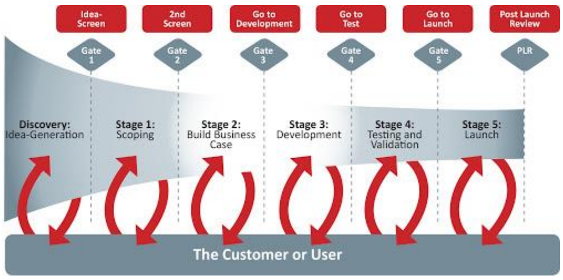


Figure 3: The Stage-Gate Model by Cooper

For the ideation phase the brainstorming method is used to generate ideas in a free-thinking environment. This ensures plenty of ideas without being critical. However, it also requires sorting out the ideas. For this the ideation funnel is used with first generating ideas, evaluating, and testing.

For the marketing part, the qualitative and quantitative research method is used to establish knowledge about the end users and retailers. The result of this research will be the basis for the marketing strategy. Moreover, the marketing part will be described with reference to the innovation model seen in Figure 4 [10].

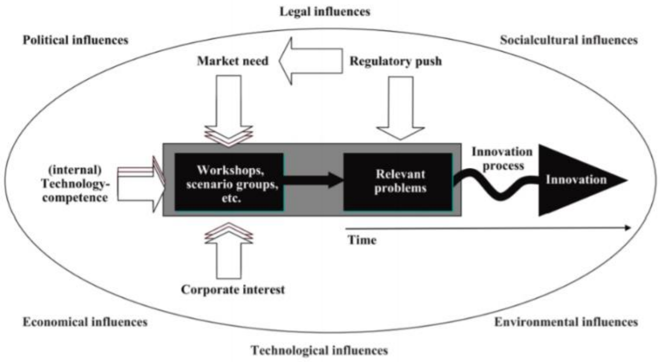


Figure 4: Innovation model

Project delimitations

The project is developed with the following delimitations:

- The system is developed for an adjustable bed.
- The programming of the actuators is done by LINAK.
- The resources used are provided by SDU and LINAK.
- The prototype will be developed within a budget of 10.000 DKK[3].

Amendment

The project goal was changed from one final prototype to an exploration project which finishes with different approaches on how to solve the project. The following things stated in the project formulation need to be changed to fit the new project. The requirements above will be those for the final product. Therefore, solutions were explored based on those requirements.

- The final solutions of this project will not be tested in LINAKs testing facilities
- The final milestone will be the outcome of the exploration project in form of different concepts
- The general tasks will not anymore include the development of a final prototype but the research and partial development of different concepts.

[3] The budget might be higher if additional funding is offered.

Project Management

Work distribution

The team structure was chosen to be dynamic to meet the project needs throughout its phases. Due to the project being changed into a more research-based project, the focus was to enhance the outcome of potential ideas, making it important to allocate the right resources as they are needed.

As explained in the Technology and section, the groups are based on strengths and weaknesses. Moreover, the group took a Belbin test to compare the work roles in the group and get an idea of the weak points in the group.

Belbin team roles

As a part of managing the group all members took a Belbin test and the result can be seen in appendix I figure 1. This helps assess the relative strengths and weaknesses to understand where to focus and improve performance. Based on Meredith Belbin's nine years of study it is found that a diverse representation of the different roles create a strong team [11]. The nine team roles describe how a person tends to behave and interact with the other teammates. Usually, the individual has a preferred role but according to circumstances the role can change. These roles are also divided into different categories being; action-, people- or thought-oriented roles as seen in appendix I figure 2. With action-oriented roles the focus is more on improving the overall performance and meeting deadlines. The people-oriented roles are more focused on bringing people and ideas together. Lastly, the thought-oriented roles analyze options meanwhile providing technical expertise. The overall distribution of roles in the team is analyzed in the radar chart as seen in Figure 5.

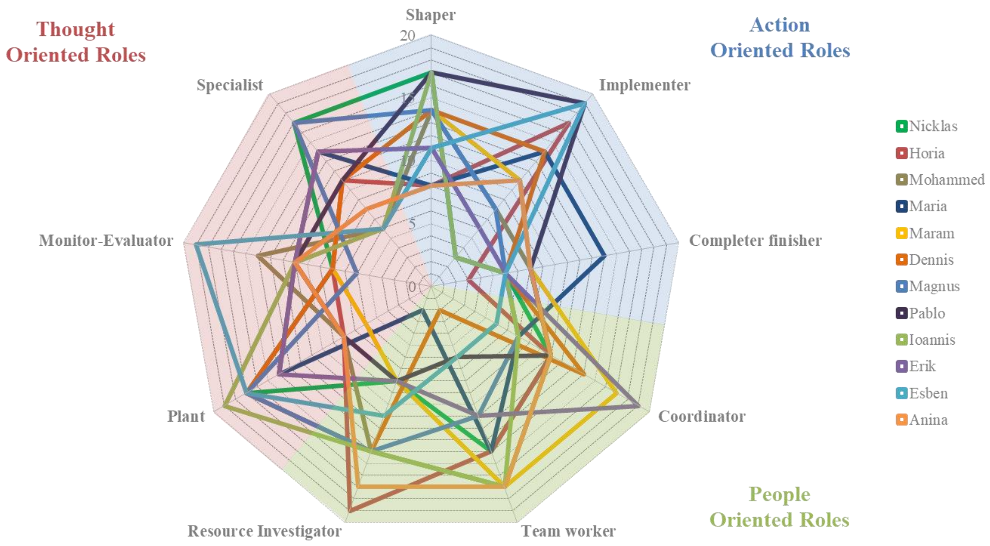


Figure 5: Radar chart of the different Belbin team roles

Furthermore, according to Belbin a small team should consist of one Coordinator, an Implementer and a Plant for optimal functionality and outcome [12]. This is something that should be considered when forming the groups.

Group formations

Based on the Belbin roles a SWOT analysis was made to clarify the strengths, weaknesses, potential threats and opportunities in the group. As seen in Figure 6, the focus should be on keeping the group interested and committed to the project. Moreover, the final phase of the project is in risk due to the lack of completers and therefore, having deadlines and milestones is important to assure the group reaches the goal.

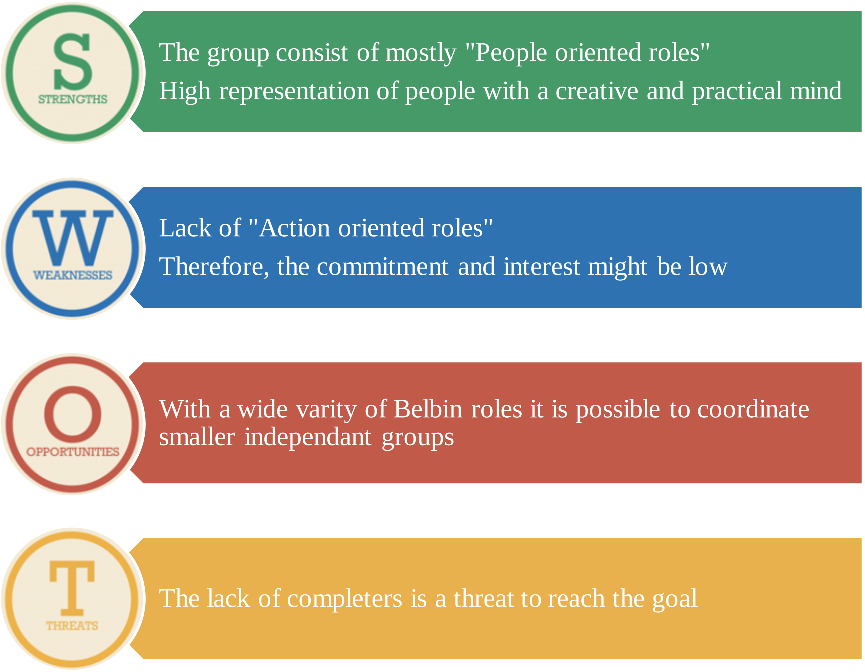


Figure 6: SWOT analysis of the Belbin roles

The project was intended to have three phases. The first phase is for testing out the ideas and evaluate the potential in each of the selected ideas. The phases are inspired by The State-Gate Model through including the relevant stakeholders in the important meetings when decisions need to be made. For this, the group of 12 people was divided into different groups to investigate further and show how the ideas could be implemented and used for the case. The groups are made to ensure an equal distribution of mechanic, embedded and electronic knowledge, taking the member's interests into account. These groups are each responsible for a specific area of ideas and have a team leader that distributes the tasks and reports back to the project manager as seen in Figure 7. In addition to this, the Belbin roles are represented in the radar chart for each group seen in appendix I figures 3 to 6. As recommended the groups should consist of one Coordinator, an Implementer and a Plant, which is fulfilled in the majority of the groups. However, the marketing group and group 3 lacks on the coordinator role and partly the implementer role, which could lead to poorly distribution of work tasks, delegation of work and clarifying goals.

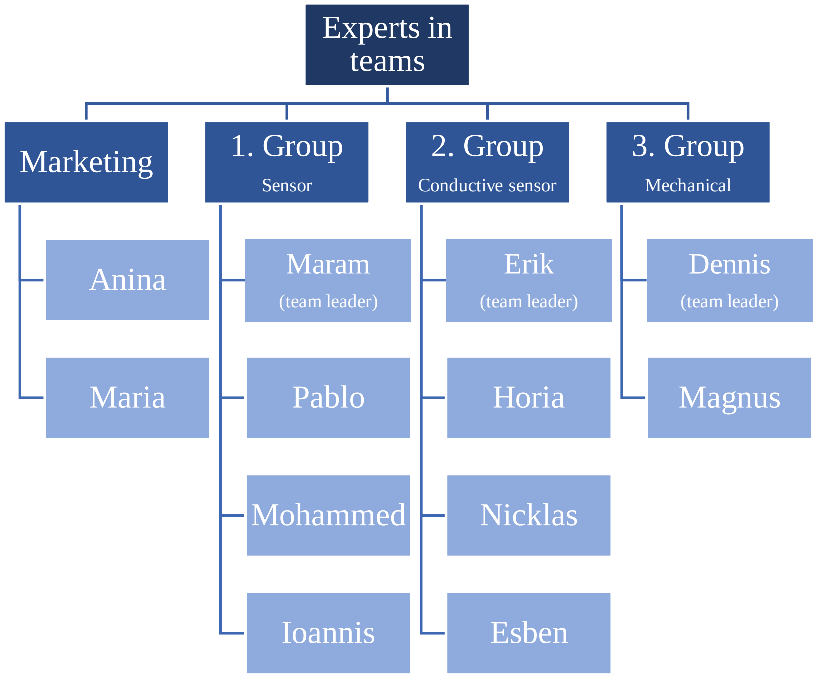


Figure 7: Group structure for the first phase.

The second phase was initiated after receiving feedback from LINAK at the gate meeting. Here LINAK was interested in the different ideas tested in the three groups. The feedback led to a reorganization of the groups moving more workforce towards the mechanical solution, as LINAK showed an interest in seeing this in action. The group structure therefore consists of people that join different teams according to their knowledge within the project. As seen in Figure 8 the group member marked in the green box, is appearing as a dynamic member and can be assigned tasks in both groups.

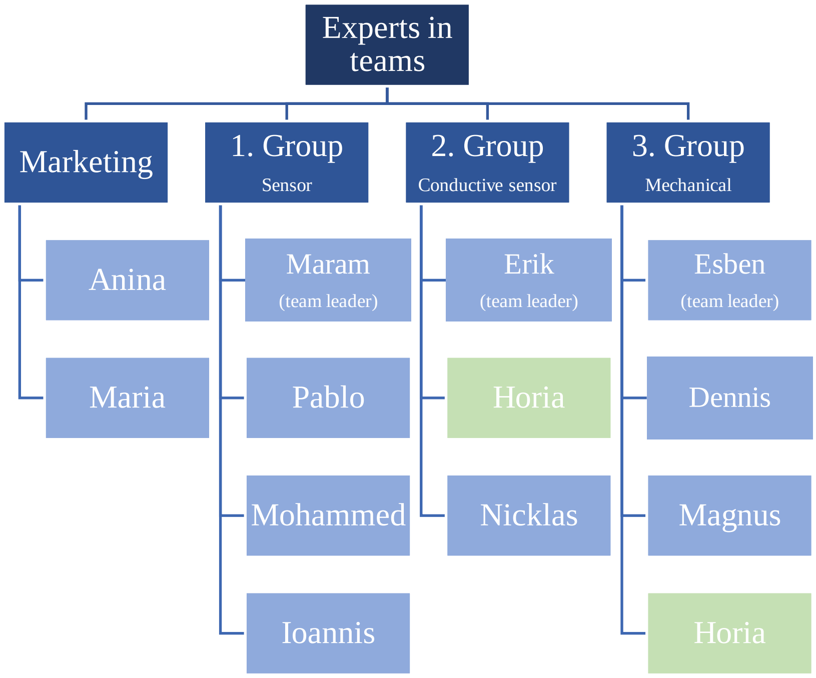


Figure 8: Group structure for second phase

The initial idea was to have a final phase for the development process, here the best viable idea would be chosen to work with. The team structure was intended to be re-evaluated, and people divided into different departments of responsibility. This should guarantee the right people are provided with tasks within their expertise and field of interest. However, since the project was changed into an exploration project, it has been chosen to continue with the group structure of second phase with an equal workforce for all solutions.

Retrospective Tool

The retrospective project management tool helps to have a structured reflection on specified project periods or a complete project. In this project it was used to evaluate the different product development phases in order to improve the future work environment for the project and to be more efficient and productive in the following development phases.

For executing this project management tool, a whiteboard was divided into six different parts as shown in Figure 9.

Start with …	More of …	Continue with …	Less of …	Stop with …

Figure 9: Retrospective categories whiteboard layout

All team members were able to add post-it's to those categories which were then evaluated in meetings after finishing a development phase and improvements for the following phase were decided.

Ideation

The ideation phase is always a critical phase for the project. Therefore, a lot of time and tools were used to gather many ideas to work with. The first step was to brainstorm about the background of the problem. For example, asking questions like "What is collision?", "Where does a collision occur?" and brainstorm about possible solutions. The brainstorming tool was a good fit for the project since no background knowledge or limitations are needed for the ideation process. The results of this divergent phase are shown in Figure 10. During the brainstorming, the ideas were not judged or categorized so a free way of thinking was enabled.

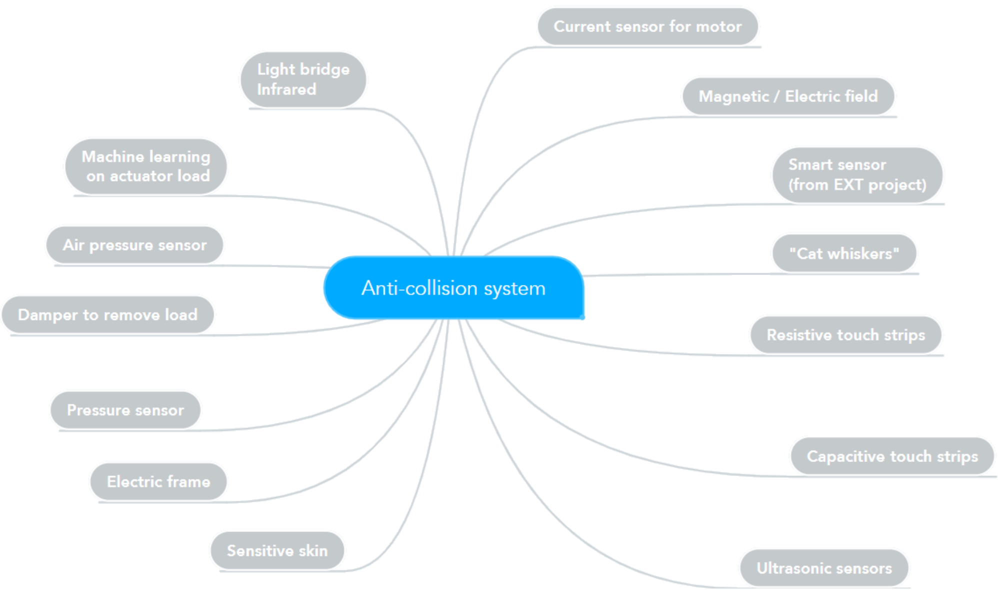


Figure 10: Brainstorming

Another part of the ideation process was a company visit at LINAK, where an insight into the production of actuators and the whole concept of HOMELINE was presented. With that it was possible to get an overview of the background and the limitations as well as opportunities of the project.

In order to select an idea to work with, some criteria for fulfilling the requirements of the project were developed. The cost, reliability and complexity were rated as the most important followed by the flexibility, durability, the design and the usability. The production was rated as the least important for the project. Each group member rated the ideas from the brainstorming regarding all the different categories. Afterwards, the ratings were added so in the end, the winning ideas to continue with were grouped and human resources were distributed depending on the knowledge which was needed for the development of a prototype. The idea selection scheme and the grouping can be seen in the Excel tables in appendix II. The ideas were rated and afterwards grouped as some were similar to each other, making six different groups in total. Based on this the groups were rated according to feasibility and the result were three overall ideas of solutions that should be investigated further. The ideas chosen were the load sensing with algorithm, stripes to detect touch and a mechanical force reduction approach.

Mechanical solution to counteract forces

Concept

The concept of the mechanical solution is to minimize the weight needed to lift area one and two of the bed, (Figure 11). This way, when a collision occurs, the pinching force acting is diminished compared to the full weight of either areas as a pinching force.

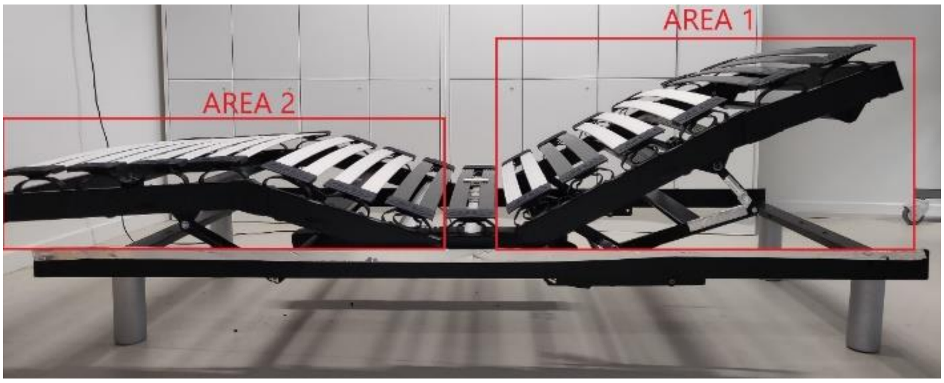


Figure 11: Bedframe with problem areas

The aim of this approach is to lower the initial force acting; therefore, it does not categorize as a collision, (project formulation requirement nr. 3). Thus, extending the reaction time of the anti-collision device, to allow for stopping the downward movement of the bedframe and reverse it to relieve the pinching. The load of the bedframe and the added weight on top (mattress, person etc.) has an initial vertical force direction, which is redirected from a vertical force to a horizontal force (Figure 12) via the rotational force, in form of a shaft with a finger or arm (Figure 13) that connects the bedframe to the actuator. Therefore, when designing a device that must counteract the load of the bedframe, the first thing to do was to find a suitable location, were this can be implemented.

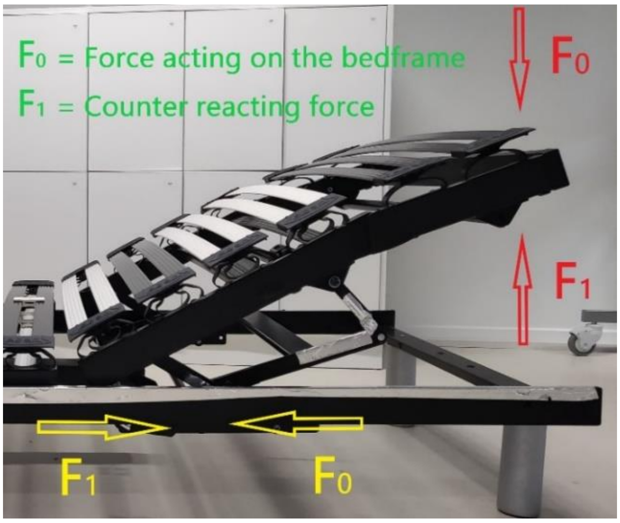


Figure 12: Forces act and react

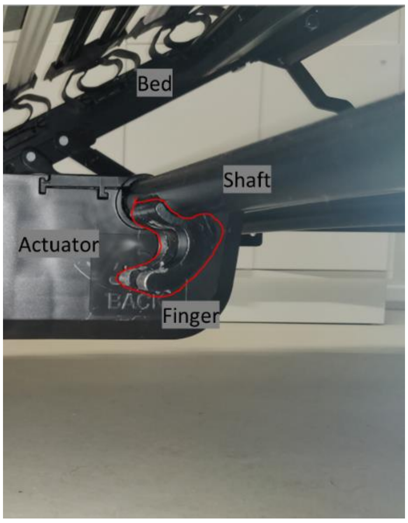


Figure 13: Arm/Finger where the load is transferred to the actuator

Since the bedframe has a lot of moving parts that are connected to the shaft, it would be difficult to make a device that fits on this part. For this reason, it was not a viable solution for the problem.

Furthermore, such a device cannot be fitted inside the actuator housing without developing the actuator from scratch, both solutions also go against the requirement (see project formulation requirement nr. 6 and 8.1) as the solution should be cheap and flexible. Therefore, the only feasible placement for a "counterreaction force device" is between the actuator and the tip of the finger. (Figure 14)

First idea

The problem is divided up in smaller subtasks to ease the ideation and innovation process of each task.

Counteracting

The first problem is to counteract the force coming from the actuator. It is obvious that, to counteract a force, a force in the opposite direction is needed. To get the bed area one and two (Figure 11) as weight-less as possible the sum of these two forces should be close or equal to zero (Figure 12).

$$\sum F_x => F_0 - F_1 = 0 \quad \rightarrow \quad F_0 = F_1$$

An intuitive method to counteract a force, is a spring. It could also be a piston, but as the device should be as cost effective as possible, as stated in project formulation requirement nr. 8, a spring is selected instead.

Dynamic force

The next problem is to nullify the weight impact of the bed, with or without a person on it, also when there is movement in the bed. To take this dynamic force into account the spring must have a working range in which it can operate. When looking at the formula for a spring it can easily be concluded that a change in the deflection of the spring changes the force acting of the spring. Therefore, the more a spring can deflect the larger a range, in which it can counteract a force it will have.

$$F_{sping} = x \cdot k$$

$$k = springstiffness\,; \;\; x = deflection\ of\ spring$$

Hence a spring is well suited to handle a dynamic load if the spring deflection is controlled relative to the dynamic load.

Deflection of spring

This is leading us to the next task, how to handle the deflection of the spring. This task can be performed by connecting a motor to the spring, thereby enable the possibility to deflect it thus the spring is loaded or unloaded. The best motor to handle such a task is a worm gear motor [13], because of the of self-locking and a high-ratio speed reduction ability of these motors. The self-locking aspect of the motor makes it an energy efficient solution, because it does not require any power to withstand the forces from the bed while turned off due to friction, also the high-ratio speed reduction is needed because this means that it can output a lot of torque hence it can handle a large force acting on it.

Lever design

As the main concept is stated, it must be converted to fit the project within the requirements. Knowing the only feasible place to mount this device is between the finger and the actuator. Therefore, this section must be analyzed to ensure that it is possible to mount a device between the finger and the actuator.

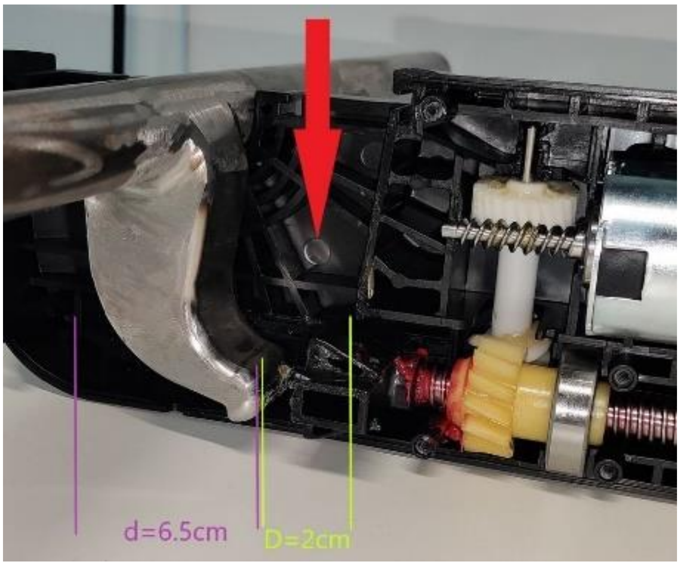


Figure 14: Mapping of the actuator housing

In the analysis, the layout of the actuator, placement of the shaft, finger, distance that the different parts move, as well as the dimensions of the housing were mapped. It turns out that it was possible to mount the device here, by use of the general lever concept. [14]

In order to mount the device and still be within the boundaries of the requirements, the placement of this device should be on top of the actuator housing, see Figure 14, were the arrow illustrates the mounting position. It also illustrates the placement in which the levers have access to the tip of the finger and the actuator. The analysis also shows that between the tip of the finger and the moving part of the actuator there is a gap of 2 cm, this means that the footprint of the devices can have a width of maximum 2 cm before compromising the movement of the bed, it also showed that to get the bedframe from the two outer positions fully raised and lowered translate to a travel distance of the finger of 6,5 cm. Moreover, the position of the fingertip goes under and past the shaft, hence the levers must be able to move freely within these restrictions. Therefore, a simulation of this were made in NX to visualize that it is possible to use this concept.

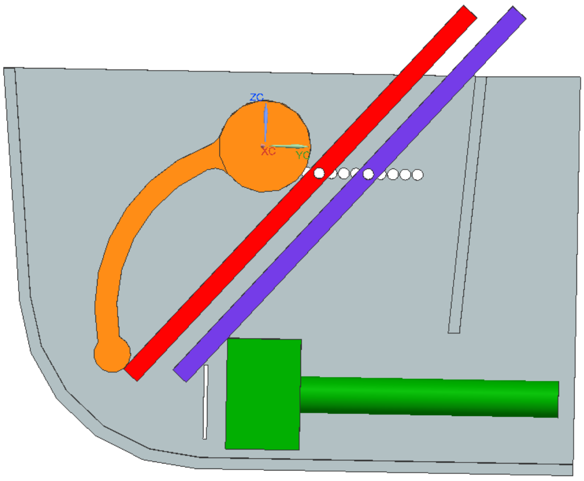


Figure 15: Overview of housing.

In Figure 15, were orange is shaft and finger, red lever is where the spring must be attached, blue lever is where the one moving the sled and green is the actuator. It can be seen that there is room for the levers when the bed is fully raised, it also shows that the fingertip is moved well past the shaft, and the angle and space for the levers are limited but within the limitations. The red lever is the one that must be connected to the springs to counteract the force created by the bed, whereas the blue lever has to be there to ensure that there is a distance between the actuator (green) and the fingertip (orange) and thereby engaging the springs, also the blue lever has to be connected to a sled, seen in Figure 16, that houses all the internal parts of the "device" (springs, motor, power screw etc.). This is the main features of the concept behind the mechanical solutions first try that failed, further explained in the section "Evaluation".

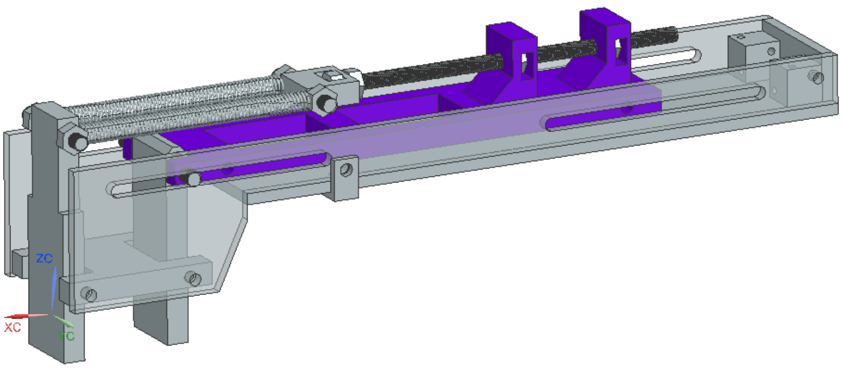


Figure 16: Sled that houses all internal parts (from mock-up)

Sensor selection

To make the device work, the two levers must move parallel to each other. To solve this, a sensor is required.

First option is to use an ultrasonic distance sensor (HC-SR04) [15], which sends sound waves and uses the echo to measure the distance. It costs approximately 20 DKK and according to the datasheet, it can measure from 2cm to 400cm with an accuracy of 3mm. The sensor can be seen in Figure 17 and Figure 18 shows where it should be installed.

Figure 17: Ultrasound distance sensor

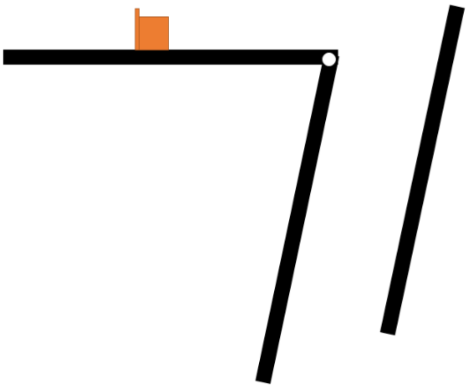


Figure 18: Ultrasonic sensor mounted on the back lever to measure the distance to front lever.

The second option is to use a sensor module combining an accelerometer and a gyroscope. Only the gyroscope will be used because the angle is needed, and the combined module is cheaper than only buying the gyroscope. It measures the angular velocity, and if there is one on each lever, the values can be compared. The 6DOF GY-521 [16] sensor can be used and costs approximately 38 DKK. Two of them are required. The sensor can be seen on Figure 19 and Figure 20 shows how the sensors should be installed.

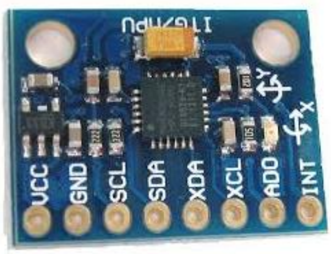


Figure 19: Combined sensor module

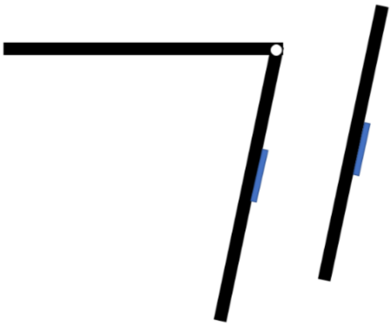


Figure 20: Sensors installed on the right side of the levers, in that way they won´t be in the way.

The third option is to use an IR sensor. Sharp Reflection sensor GP2Y0A41SK0F [17] is preferred because it has a short range. It sends light to the lever and measures the intensity on the reflecting light. The surface on the lever will therefore have an impact in the precision, this will be tested if the IR option is selected. The pression of the sensor is not given in the datasheet but it has a range between 4cm and 30cm. The sensor costs approximately 85 DKK and can be seen in Figure 21 and Figure 22 shows how it should be installed on the device.

Figure 21: IR sensor

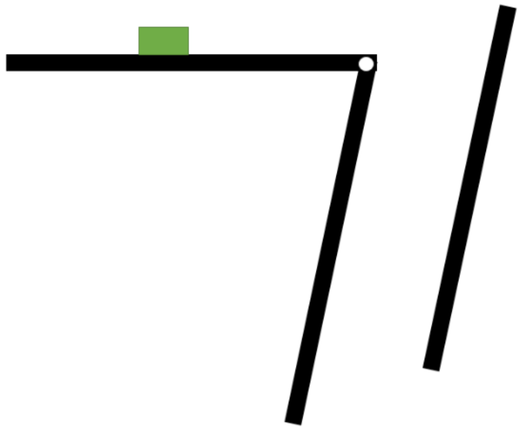


Figure 22: IR sensor used to measure the distance to the front lever.

The fourth and last option is to use a linear potentiometer. Bourns PTB0143-2010BPB103 [18] is preferred because it has a travel of 100mm. The potentiometers vary $\pm 20\%$ in values, meaning that the position-voltage curve in one of them might be different in another. These values will be measured for our unit if this sensor option is selected. Because the levers will rotate, a rotating joint will be necessary were the arm is mounted (Figure 24). The sensor costs 43 DKK and can be seen in Figure 23.

Figure 23: Linear potentiometer

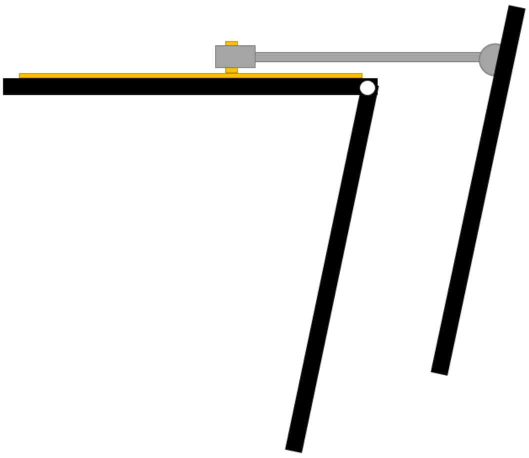


Figure 24: Potentiometer installed on the device

First mock-up

A proof of concept was constructed out of 3D printed pieces and acrylic. This was done before making a working model in a 1:1 scale, to ensure the concept works before spending any money on the parts needed for the final build. Furthermore, it is better to have a physical model, rather than looking at a computer model. The device was 3D-modelled in NX and can be seen in Figure 25, were the 3D-printed parts are shown in green, the laser cut in blue and the nuts, screws and threaded from the workshop in grey parts.

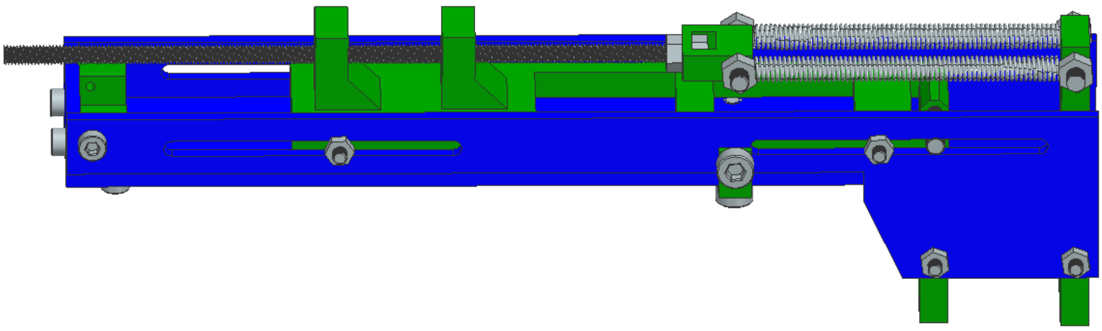


Figure 25: Proof of concept of the first idea.

The parts are imported in PrusaSlicer and are 3D printed on a Prusa printer in PLA, with some of the sliced parts displayed in Figure 26.

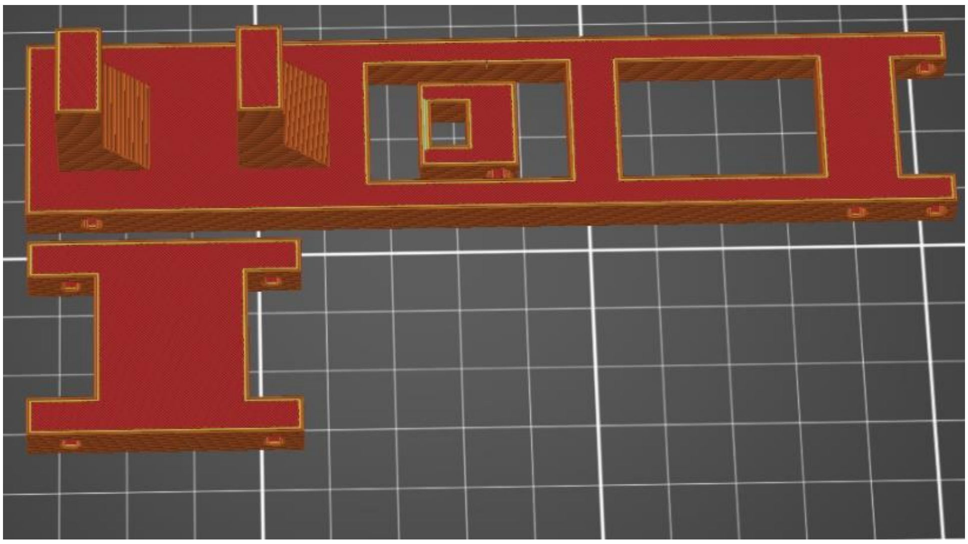


Figure 26: Some of the models imported as STL files in the PrusaSlicer software.

The DXF files from NX is imported in the software called RDWorks, which is used to prepare the files for the laser cutter. The enclosure is made of 3mm acrylic, and the parts are cut with the layout of the 2D drawing shown in Figure 27.

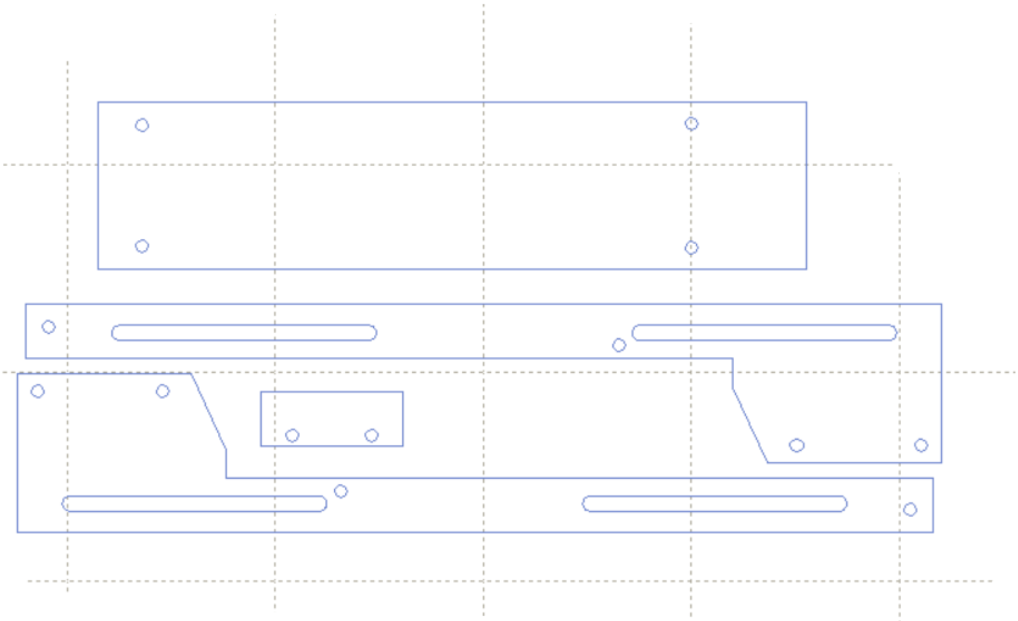


Figure 27: Drawings for the enclosure.

The device is now assembled and can be seen in Figure 28.

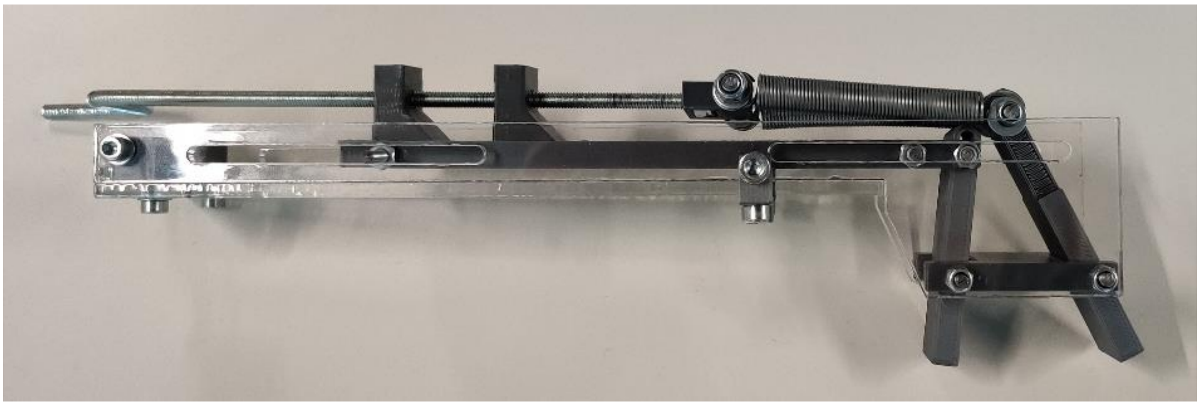


Figure 28: The assembled mock-up for the first solution.

Testing and calculating

After the muck-up has proven that the concept could work. A more thorough analysis of the problem must be performed. Therefore, before constructing the device, the critical areas must be identified.

The critical areas that should be tested are:

- The force acting in the "fingertip" of the shaft.
- How big an impact does a human lying in the bed have on the force acting.
- How much does the levers deflect under these conditions?
  - Hence how thick should they be to withstand these forces and deflection
- The size of the springs counteracting these forces.

Load test forces acting in the "fingertip"

To be able to find the magnitude of the combined forces acting on the "fingertip" of the shaft from the bedframe and what is on top of this, a test-setup had to be made that measures the magnitude of these forces.

The test is limited to only focus on Area 1 (Figure 11), because this is the area that must absorb the highest load while a person is lying in the bed, the whole upper torso compared to the legs. This test is performed by taking the existing bedframe delivered by LINAK, attaching a measurement device directly to it.

Test setup

The procedure for performing this test was to take a heavy-duty scale that has a range from 20 to 750 kg (Figure 31), securing one end so it could not move, and connecting the other end to the extra "finger" on the bedframe (Figure 30). The connection between these points is done with a heavy-duty ratchet lashing strap to ensure that it could withhold the forces generated and to ease the process of tightening and finding the right lifting force for area one. The setup required a fixed distance between the bedframe and the securing point, because there had to be room for the scale and for the ratchet, therefore a wooden frame was constructed that could withstand these forces while lifting the frame (Figure 29).

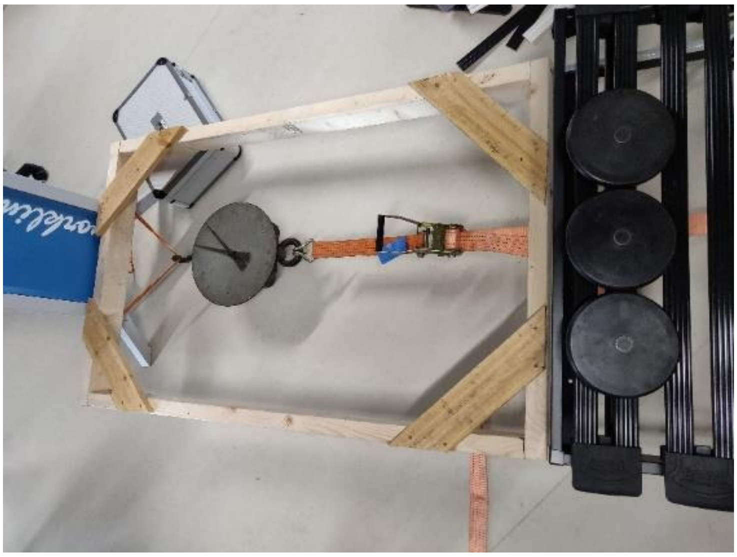


Figure 29: Test setup

Figure 30: Strap connected to the extra finger of the bedframe

Figure 31: Heavy-duty scale

Figure 32: Frame of area 1 lifted 20 cm

Test - Force needed to lift the frame

Each time executing a lifting test, the bedframe had to be lifted 20 cm above the starting point (Figure 32), the starting point is where the bedframe rests without any external interference.

Table 1: Table of the test runs

Weight needed to lift the bedframe				
test number	Added Weight			
	0	5	10	15
1	140	225		
2		252	310	
3	146	252	330	368
4	140	240	340	430
5	150	240	340	440
6	152	252	350	460
Avg	145.6	243.5	334	443.3333

The test is performed over 4 steps with a weight increment of 5 kg, the tests are then made for 0, 5, 10, 15 kg. The scale is placed near the top of the frame (Figure 32) to maximize the moment it creates around the shaft and in the "fingertip" ($M = F \cdot d$) and hereby maximize the efficiency of each increment. The full test is repeated four times and the average is calculated of each step. The result of these test runs can be seen in Table 1, the multiple runs are done to ensure viable data that could be calculated further on.

Because the force needed to lift the bedframe at the last increment was so high, it was decided to stop adding more weights on the bed. The shaft started to deflect because of the big forces. The four increments should be sufficient to make a linear regression from the dataset.

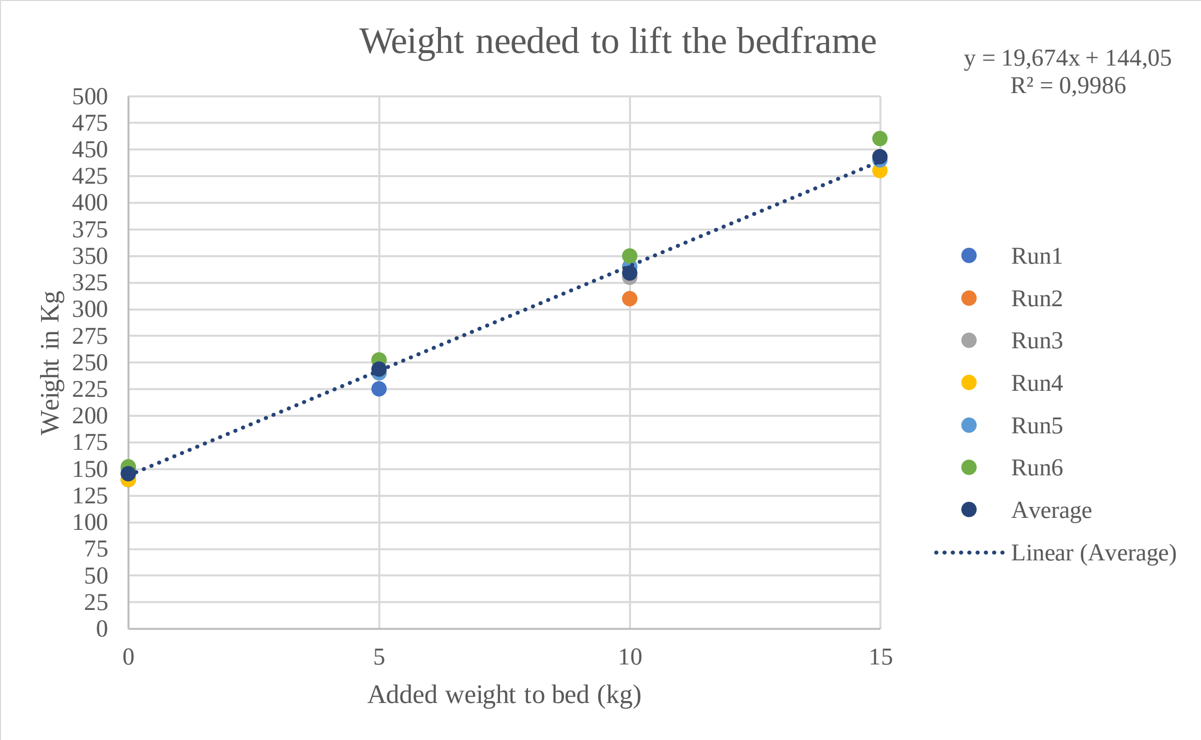


Figure 33: Graph of the force needed to lift the bedframe

As it can be seen in Figure 33, when making a linear regression over the average number from each step, the regression line fits with an accuracy of 99.86% ($R^2 = 0.9986$). Hence this linear regression is a good model for the behaviour of the bed and therefore the equation for its behavior is:

$$y = 19.674 \cdot x + 144.05$$

y = Weight needed to lift the bedframe in kg

x = Added weight to the bedframe

144,05 = Initial force needed to lift bed without any added weight

19.674 = The ratio between the added weight and the force needed to lift it.

This equation is later used to calculate the full force impact in the fingertip when a human is lying in the bed.

Test - Weight added by a person lying in the bed

The aim of this test was to find the weight added to area 1 by a human lying in the bed. This test is performed by hooking one end of a newton meter to the far end of the bed, and the other to a secure point in the roof (Figure 34). This generates a vertical weight scale where it is possible to measure the impact a human has to area 1 of the bed (Figure 11).

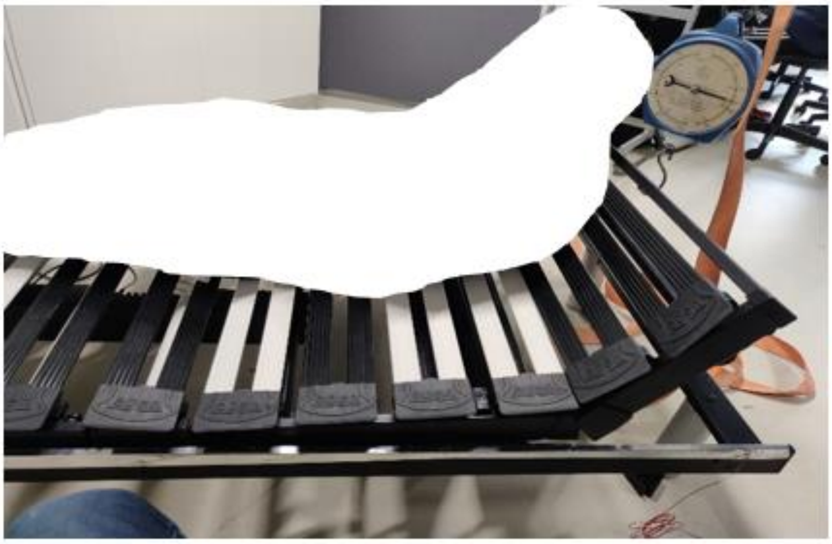


Figure 34: Vertical scale to measure the weight impact of a human

To ensure the highest yield when applying weight to the bed, the frame of area 1 positioned as close to horizontal as possible, this causes the maximum yield of force from the person/object while lying down/on the bed, because it has the highest initial gravitational force (Figure 34).

$$\sum F_y = m \cdot g \cdot \cos(\approx 0) => F_{person} = m \cdot g$$

A data sample of twenty people was selected with a range in body mass from 45 to 130 kg. It was important to test if an increase in body mass was proportional to a force increase in the fingertip (Table 2), therefore a wide body mass range was needed to test this. It turns out that the body-mass did not have a huge impact on the force generated in the finger, on the other hand the lying and sitting position had a larger impact. Table 2 shows the force generated from the different test persons, were the lightest and the heaviest person are not the ones in the top and bottom of the table. The error in this test and a learning point for next time is to write down the exact weights of the different test persons and add it to the table, thereby excluding that the connection between the weight of the person and force generated is proportional to each other. When calculating further with these numbers in the section “Spring Calculations” only the maximum value is considered, in this case it´s person nr. 19 (300N). Person nr. 20 (420N) was not lying “normal” in the bed and the data is therefore excluded.

Table 2: Force of people in the bed

Body mass of persons varies between 50 and 130 kg																				
Persons nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
force (N)	160	165	180	200	200	205	210	210	210	220	220	230	240	260	260	260	265	270	300	420
								person 20 is discarded because of bad lying position in bed												

Result of the tests

When the result of the force is calculated in Table 3, 50 N has been added to the maximum force (test person 19 - Table 2) due to the weight of a mattress, therefore the force generated by the bedframe, mattress and a person on top of the bed is 350N. From the Figure 33 the following equation was found:

$$y = 19.674 \cdot x + 144.05$$

This equation is then used to find the total force in the finger with a 20% safety factor, using the "kg added (in kg)" as the x-value:

Table 3: Force in the finger

Forces acting in the tip of the finger	
kg added (kg)	35,68
kg added (N)	350,02
Force in finger (kg)	846,02
Force in finger (N)	8299,44
Total force in finger (N)	9959,33

$$F = (19{,}674 \cdot 35{,}68 + 144{,}05) \cdot 1{,}2 \cdot 9{,}81 = 9959{,}3277\ N$$

Hence the force the anti-collision device must counteract is approximately 10 kN as seen in Table 3.

Spring Calculations

As regards to Hooke´s law [19] the spring scales linearly with respect to the deflection of the spring.

$$F = k \cdot x$$

F = force

k = spring stiffness

x = deflection in spring

Table 4: Calculation of springs

Spring Calculations								
Maximum force (N)	10000							
Minimum force (N)	2800							
Lever distance (ratio)	0,911764706							
Number of springs	1	2	3	4	5	6	7	8
Inital deflection of spring (mm)	10	20						

Distance to pivot point (m)	
side A to pivotpoint	side B to pivotpoint
0,068	0,062

K value 10mm initial def.	307,0967742	153,548	102,366	76,7742	61,4194	51,1828	43,871	38,3871
K value 20mm initial def.	153,5483871	76,7742	51,1828	38,3871	30,7097	25,5914	21,9355	19,1935

max def @ max load, 8springs, K= 5.83	71,42857143
max def @ max load, 6springs, K= 5.83	95,23809524
max def @ max load, 8springs, K= 7.78	53,57142857
max def @ max load, 6springs, K= 7.79	71,42857143
max def @ max load, 4springs, K= 7.80	107,1428571
max def @ max load, 8springs, K= 11.67	35,71428571
max def @ max load,6springs, K= 11.68	47,61904762
max def @ max load, 4springs, K= 11.69	71,42857143
max def @ max load, 2springs, K= 11.70	142,8571429
max def @ max load, 8springs, K= 23.33	17,85714286
max def @ max load, 6springs, K= 23.34	23,80952381
max def @ max load, 4springs, K= 23.35	35,71428571
max def @ max load, 2springs, K= 23.36	71,42857143

Table 4 shows the calculations of the spring stiffness coefficient, when the springs are deflecting either 10 or 20 mm under the initial load (bed without any added weight):

$$k = \frac{\frac{1}{n} \cdot \frac{F_{min}}{m}}{x_i}$$

Where

x_i is the initial deflection

m is the lever ratio

F_{min} is the minimum force with no weights

n is the number of springs

This is then used to find the maximum deflection of the springs when fully loaded:

$$x = \frac{\frac{1}{n} \cdot \frac{F_{max}}{m}}{x}$$

Where

x is the spring deflection

m is the lever ratio

F_{max} is the maximum force with all weights

n is the number of springs

These values are used when finding suitable springs for the system.

Mechanical Analysis

In this section the lever connected to the spring and the arm from the bed, will be analyzed. The goal is to find the deformation of the lever, to see, whether the solution is feasible or not. The analysis is done with the use of classical beam theory, using MATLAB. The results from the theory are compared to a simulation of the same beam in Ansys. The load diagram for the lever is illustrated in Figure 35.

Beam Theory

When the lever is static it will experience the most deformation, as it has nowhere to turn to, and thus must deform. This situation occurs when the device has reached equilibrium.

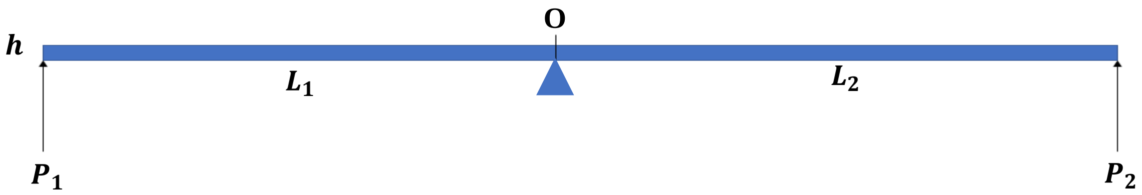


Figure 35: Load Diagram for the lever

Beam height is 5 mm: $h = 0{,}005\ m$

Beam width is 35 mm: $b = 0{,}035\ m$

Lengths $L_1 = 62\ mm$ and $L_2 = 68\ mm$

The arm from the bed, delivers $P_1 = 10.000\ N$ at a distance L_1 from O.

The spring force P_2 arises from the spring and works in the same direction as P_1. The spring force is at the opposite end of the lever, distance L_2 from O. When the lever is static, P_2 completely counteracts the moment from P_1

Material for the lever is steel, making the modulus of elasticity, $E = 200\ GPa$.

Sum of moments in O, were $M_{1,2}$ is the moment from $P_{1,2} \cdot L_{1,2}$, when the laver is static:

$$\sum M_O = 0 \rightarrow M_1 - M_2 = 0$$

$$\rightarrow P_1 L_1 = P_2 L_2$$

$$P_2 = \frac{L_1}{L_2} P_1 = \frac{0{,}062\ m}{0{,}068\ m} \cdot 10.000\ N = 9.118\ N$$

Moment of inertia for a rectangle

$$I = \frac{bh^3}{12}$$

Moment of inertia for both elements:

$$I = \frac{0{,}035\ m \cdot (0{,}005\ m)^3}{12} = 3{,}65 \cdot 10^{-10}\ m^4$$

Euler-Bernoulli beam equation:

$$M(x) = EI\frac{d^2y}{dx^2}$$

Were M(x), is the moment

Giving:

$$-V(x) = EI\frac{d^3y}{dx^3}$$

Were

$$\rightarrow EI\frac{dy}{dx} = \int_{-\infty}^{x} M(x)\ dx$$

$$\rightarrow EIy(x) = \int_{-\infty}^{x}\int_{-\infty}^{x} M(x)\ dx\ dx$$

Hence y(x) is the beam's deflection.

Element 1

P_1 only acts on the first element, and is the only force acting on this element, giving:

$$-V(x) = P_1\langle x - L_1\rangle^0 + a_1$$

$$M(x) = P_1\langle x - L_1\rangle^1 + a_1x + b_1$$

$$EI\frac{dy}{dx} = \frac{P_1}{2}\langle x - L_1\rangle^2 + \frac{a_1}{2}x^2 + b_1x + c_2$$

$$EIy(x) = \frac{P_1}{6}\langle x - L_1\rangle^3 + \frac{a_1}{6}x^3 + \frac{b_1}{2}x^2 + c_2x + d_2$$

Boundary conditions arise from element's supports. At x = 0 there is a free end giving:

$$V(0) = 0 \qquad M(0) = 0$$

At x = L_1, there is hinged support, giving these conditions:

$$y(L_1) = 0 \qquad y'(L_1) = 0$$

Using boundary conditions to find the integration constants. Results are from MATLAB:

$$a_1 = -5000 \quad b_1 = -250$$

$$c_1 = -\frac{25}{2} \qquad d_1 = -\frac{5}{24}$$

Element 2

Like the first element, only has one external force acting on it, P_2:

$$-V(x) = P_2\langle x - L_2\rangle^0 + a_2$$

$$M(x) = P_2\langle x - L_2\rangle^1 + a_2x + b_1$$

$$EI\frac{dy}{dx} = \frac{P_2}{2}\langle x - L_2\rangle^2 + \frac{a_2}{2}x^2 + b_2x + c_2$$

$$EIy(x) = \frac{P_{2_1}}{6}\langle x - L_2\rangle^3 + \frac{a_2}{6}x^3 + \frac{b_2}{2}x^2 + c_2x + d_2$$

The boundary conditions for the second element, are only slightly different from the first element:

$$V(L_2) = 0 \qquad M(L_2) = 0$$

$$y(0) = 0 \qquad y'(0) = 0$$

Using boundary conditions to find the integration constants. Results are from MATLAB:

$$a_2 = -2500 \quad b_2 = 250$$

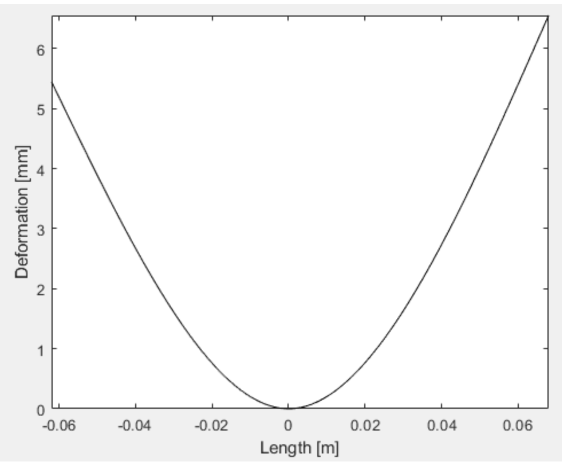


Figure 36: Deformation at lever, h = 5 mm (slim)

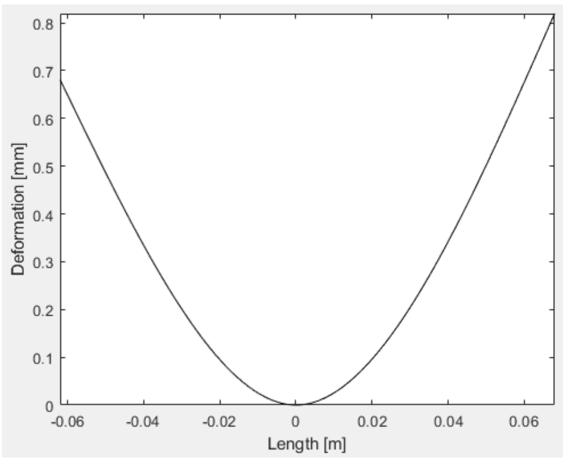


Figure 37: Deformation of the lever, h =10 mm (thick)

$$c_2 = 0 \qquad d_2 = 0$$

From Figure 36: The maximum deflection in the lever, were h = 5 mm, is y = 6.5 mm. The results from the simulations will show, whether this will be plastic deformation. However, beam theory has its limitations. From Figure 37: h = 10 mm gives a maximum deflection of 0.83 mm.

Simulations

The first thought was to use 5mm steel for the levers. However, simulations of the levers with forces in ANSYS have to be done, to compare it with the calculated deflections from MATLAB. The values used in MATLAB code will be used again, hence:

$P_1 = 10000\ N \qquad P_2 = 9118\ N$

$L_1 = 62\ mm \qquad L_2 = 68mm$

And the lever has a thickness of 5 mm.

The hole in point O, is 5mm in diameter, and has a frictional contact with the cylinder. The cylinder has a cylindrical support because it bends around that point. As seen in Figure 38, the lever will have a maximum deflection of $8{,}23mm$. This deflection is $1{,}73mm$ more than calculated in MATLAB, but the simulation is more accurate due to it being a large deflection compared to its size. The Beam Theory is more accurate the smaller the deflection is, and the simulation method is therefore more realistic. However, this deflection is way too high for our solution, therefore a thicker lever is used.

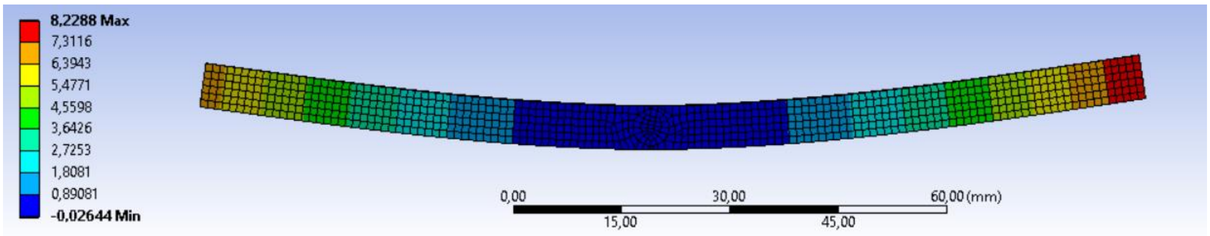


Figure 38: Deflection of 5mm lever.

In the next simulation, the pivot point outside of the lever is moved, thereby not weakening the lever by removing material. Then there is a worst-case scenario with the 5mm, and a best-case scenario with the 10mm. The values and boundary conditions are the same as in the first simulation, except the lever thickness of 10mm. As seen in Figure 39, the maximum deflection is 1,5mm, this is 0,67mm higher than the MATLAB simulation, but an acceptable deflection.

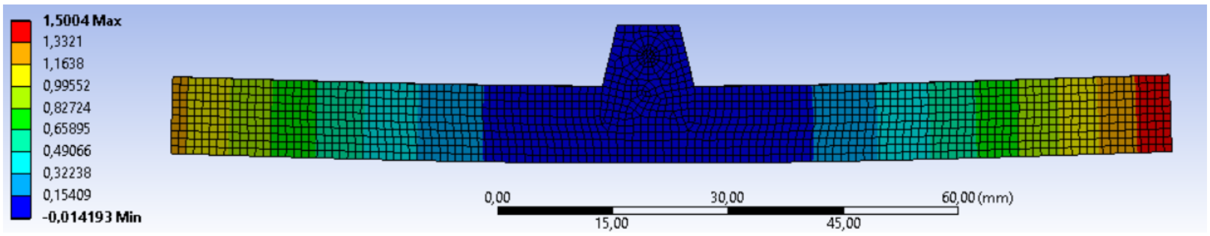


Figure 39: Deflection of 10mm lever.

In Figure 40, it can be seen that the lever will not go in the plastic deformation, because the stress-strain curve is linear. The lever will therefore not be deformed when returned to the rest position, with no external interference. The stress-strain values are found by looking at one node on the lever with the maximum strain/stress over time. The different values are then plotted on a combined graph with stress on the y-axis, and strain on the x-axis.

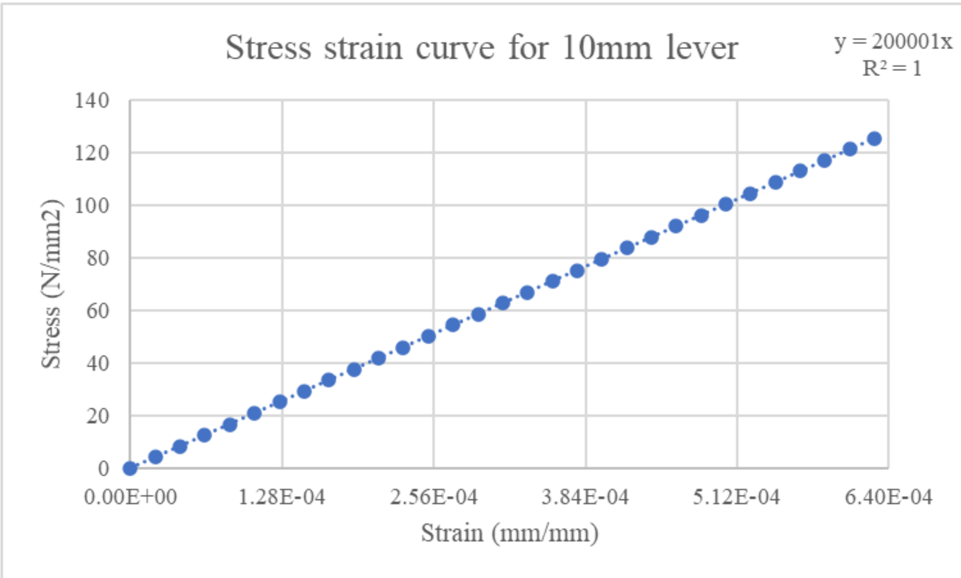


Figure 40: Stress strain curve for 10mm lever.

The simulations are not 100% accurate, because the forces will move on the lever when the actuator is moving. The simulations will therefore be the worst-case scenarios for the deflections because the forces will act on the ends of the levers, were maximum deflection will occur.

Evaluation

From the mechanical analysis several things can be concluded on the mechanical solution as it is presented in this report. From the load test (Load test forces acting in the "fingertip") the device should counteract a force of 10.000 N, giving rise to several problems.

There is 2 cm of clearance for the two levers in the actuator (see Figure 15). This means that each of them can have a thickness of a maximum 1 cm. However, if they fill up all the space inside the actuator there is no room for movement. Hence the levers should be thinner. From beam theory, the 1 cm thick beam fulfils the demand of a maximum deflection equal to 1 mm, see Load test forces acting in the "fingertip".

The simulation of a 1 cm lever, however, shows that the deflection is 1,50 mm, 50% more than the allowed deflection. As the results from the two analysis are still in the same order of magnitude, the discrepancy is determined to be acceptable. In any case the result from the simulation is used in this argument because it has a more limiting result, and the beam theory is recognized as giving an approximation to the true result. This problem can feasibly be negated with a similar, but revised version of the device, which will be explained in short terms in Load test forces acting in the "fingertip".

Furthermore, the spring calculations show that there should be several springs depending on the stiffness. This trade off means that the springs are to be numerous or compared to the device itself (see Table 4).

Concerning sensor selection, there is something to be desired. The main limiting factors for the sensor are the very small ranges in distance that the selected sensor should be working on and the even smaller changes in this distance as the levers move. Another limiting factor is the spatial requirement arising from the construction of the device, as there is a varyingly small space to place the sensor.

From the option of sensors, as listed earlier, there is the ultra-sonic or infrared sensor. The problem here is mainly the fact that most of these types of sensors are restricted by their working range which often is a few centimeters offset from the sensors, to the beginning of the working range. This is not desired as much space is lost inside the device. As both sensor types work on with reflection, there is additionally the problem of reflection from the levers. When the front lever turns around the pivot point, the reflection ever so slightly changes, making a false read, such that the distance measured is too large.

The gyroscope and accelerometer are another proposition to get the correct distance between the two levers. It so happens that the levers are parallel when they have the position for the spring to give the correct force. In comparing the angle measured from a gyroscope on each lever, this can be achieved.

Lastly there is the option of a linear potentiometer. The potentiometer can be used to detect distance from the back lever to the front lever, as it gives a resistance depending on the position of the potentiometer arm. To make the operation go smoothly, the potentiometer must be attached to a rotating joint on the front lever, also mentioned previously.

Improved idea

The team wanted to improve the device for the mechanical solution. Some changes were made to eliminate some of the problems that came to light during simulations and calculations of the first solution. The improved device can be seen on Figure 41.

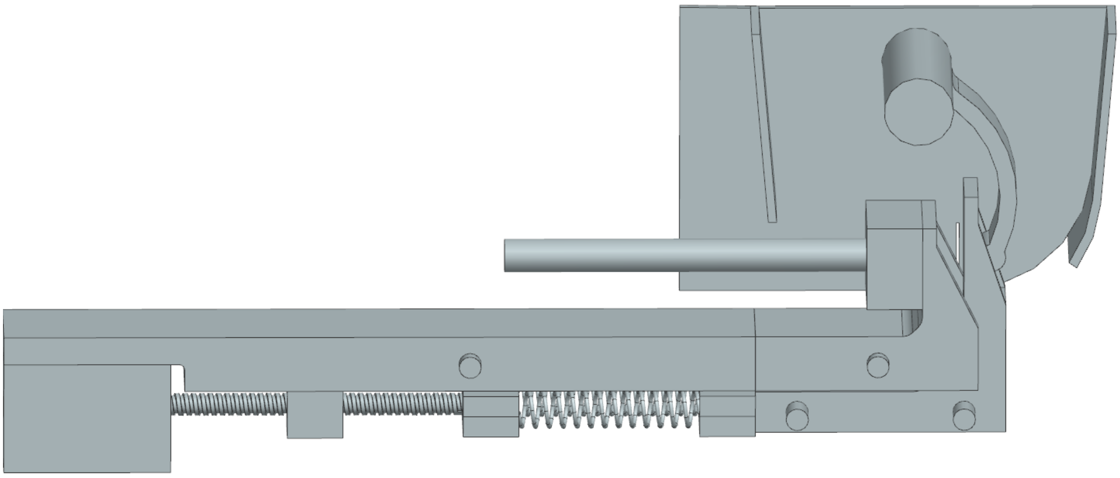


Figure 41: Improved solution.

The improved device uses linear motion instead of rotational. Moreover, it is installed under the actuator housing, resulting in more room for the levers to move. For the first solution the levers had to be made of 10mm thick steel because of the large deflection. This thickness has now been reduced to 5mm given that the levers can be reinforced (see Figure 42). The maximum deflection for this lever is $0{,}2mm$ with a force of $10kN$, this can be seen in Figure 43.

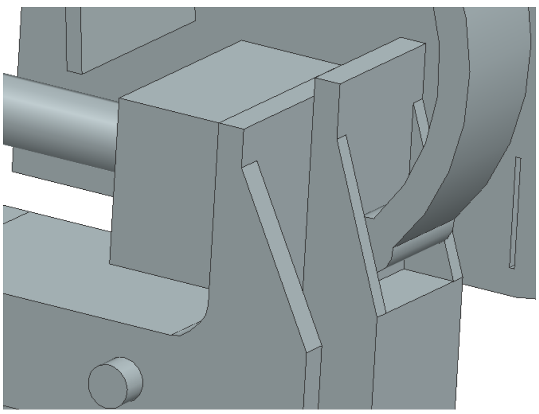


Figure 42: Levers reinforced

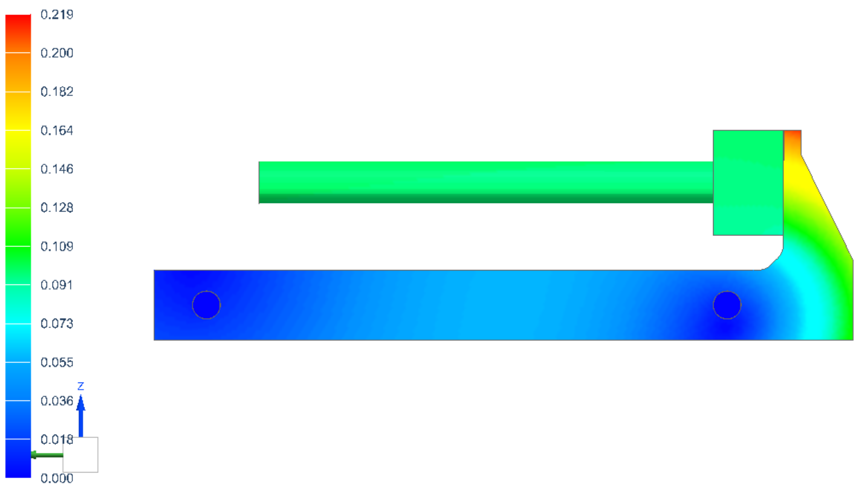


Figure 43: Maximum deflection in back lever

The same sensors can be used in this solution as in the previous one, except for the gyroscope. Nevertheless, it would be an obvious choice to select the linear potentiometer. The potentiometer is to be mounted like in Figure 44, the yellow part is the potentiometer, and the blue is the arm pushing and pulling in the pin.

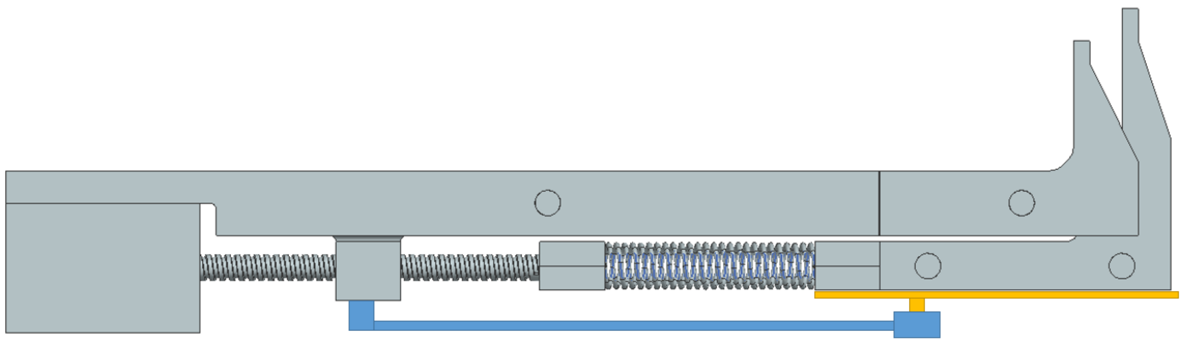


Figure 44: Linear potentiometer installed on the device.

Because it is a different motion, the springs need to be compression instead of tension. The calculations are almost the same except the ratio coming from the pivot point. The tables for calculating the spring size can be seen in Table 5. As an example, a spring was found [20] to fulfil the requirements for combination nr. 7, which has a deflection of 47,6 mm, but as it can be seen on the table, there must be 6 of them and they are 38mm in diameter and 155mm long. The springs would therefore take a lot of space and the total cost for 6 of them would be 2000 DKK. This problem has therefore not been solved making this a non-viable approach.

Table 5: Calculation of compression spring

Spring Calculations								
Maximum force (N)	10000							
Minimum force (N)	2800							
Number of springs	1	2	3	4	5	6	7	8
Inital deflection of spring (mm)	10	20						

K value 10mm initial def.	280	140	93,33333	70	56	46,66667	40	35
K value 20mm initial def.	140	70	46,66667	35	28	23,33333	20	17,5

	Deflection	Combi nr.
max def @ max load, 8springs, K = 17,5	71,428571	1
max def @ max load, 6springs, K = 17,5	95,238095	2
max def @ max load, 8springs, K = 23,33	53,571429	3
max def @ max load, 6springs, K = 23,33	71,428571	4
max def @ max load, 4springs, K = 23,33	107,14286	5
max def @ max load, 8springs, K = 35	35,714286	6
max def @ max load, 6springs, K = 35	47,619048	7
max def @ max load, 4springs, K = 35	71,428571	8
max def @ max load, 2springs, K = 35	142,85714	9
max def @ max load, 8springs, K = 70	17,857143	10
max def @ max load, 6springs, K = 70	23,809524	11
max def @ max load, 4springs, K = 70	35,714286	12
max def @ max load, 2springs, K = 70	71,428571	13

Capacitive sensors to detect touch/collision

Basics of capacitive sensing for anti-collision

One way to prevent collisions and injuries is to detect touches on the moving parts of the frame. Safety can be ensured through stopping the actuator as soon as something is touching the frame. A very cheap solution to implement such a detection is creating the sensor itself, by analyzing loading and de-loading processes of a capacitor. It is affected by touch due to the change of capacitance.

It is necessary to have either a metal-frame bed or additional metal stripes on top of the surface of the bed. The capacitor is created when the surface of the sensor (bed or stripe) is touched by a new object which contains both an insulating layer and a conducting layer such as: skin or furred skin (pets). There are two different ways to use the effect of the conductor to detect touch, which are explained in detail in this chapter.

Time delay measurement

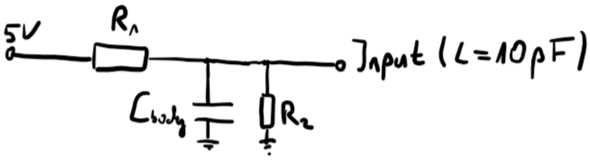


Figure 45: Time-based measurement

One way to use a capacitor to detect touch is to measure the time delay of a signal, caused by the required loading time of a capacitor. The general idea can be comprehended in Figure 45. An output pin is toggled and a rising potential edge is sent through the circuit to an input pin. The loading function of a capacitor is based on the natural constant e and the behavior is shown in Figure 46.

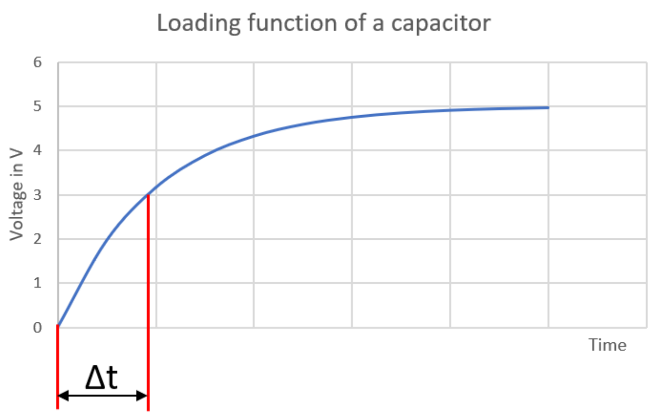


Figure 46: Loading function of a capacitor

For Arduino a signal at an input pin with a potential above 3V is defined as high [21].

The equation for the function is given as:

$$u(t) = U_{max} * \left(1 - e^{-\frac{t}{RC}}\right) \qquad \text{(I)}$$

For the time results:

$$t = -R * C * \ln\left(\frac{u(t)}{U_{max}}\right) \qquad \text{(II)}$$

This means, the measured time delay can be validated by calculating the time difference between sending and receiving the signal.

Tests of the human body capacitance (see appendix III) provided values of approximately:

$$\overline{C_{body}} \approx 1nF$$

To get expected time delay values in millisecond range, the circuit was designed with a resistance of more than 1MΩ - as a high resistance results in a long charge-time for the capacitor.

Where:

U, u = voltage t = time R = resistance C = capacitance

The first circuits and their problems

Firstly, the circuit was designed very rudimentary. The problem was that the state of the input pin was indefinite if the output pin was set to low. The charge could not be removed from the input pin. Therefore, a pull-down resistor was added to the circuit (R2). This did not work either because the connection to ground influenced the current too much (due to the Resistance of R1 > 1MΩ only the current in the range of µA passes, as seen in Figure 45).

→ Problem 1: **indefinite state**

In order to solve this problem, a transistor switch was implemented in the circuit. It connected the loaded capacitor directly to ground so it discharged immediately. The transistor itself was controlled by a toggling voltage signal, which determined the cycle time of one measurement.

Furthermore, the detection was not reliable if the touching object was too far away from ground for the circuits and measurement in the beginning of the designing process. Every circuit was based on a positive charge on the sensor side of the capacitor, which was completed by a negative one through touch.

That means that these solutions required a capacitive connection to ground at any point, either directly or by serial connected capacitors:

$$C = \varepsilon * \frac{A}{d} \qquad \text{(III)}$$

If the object was too far away from ground, the capacitance decreased and became too small to influence the time delay enough to measure it $\left(C \sim \frac{1}{d}\right)$.

→ Problem 2: **far ground**

Where:

ε = dielectric constant   d = distance   A = surface

The final circuit

To solve the ground problem as well, the idea was to use the ground state of the circuit not only to discharge the input pin to set it to low state, but also to use this ground as the opposing part of the positive side of the sensor. As collision in which one could get stuck requires at least two different frame parts, it is possible to use one frame part as the sensing one and the other one to provide a connection to ground.

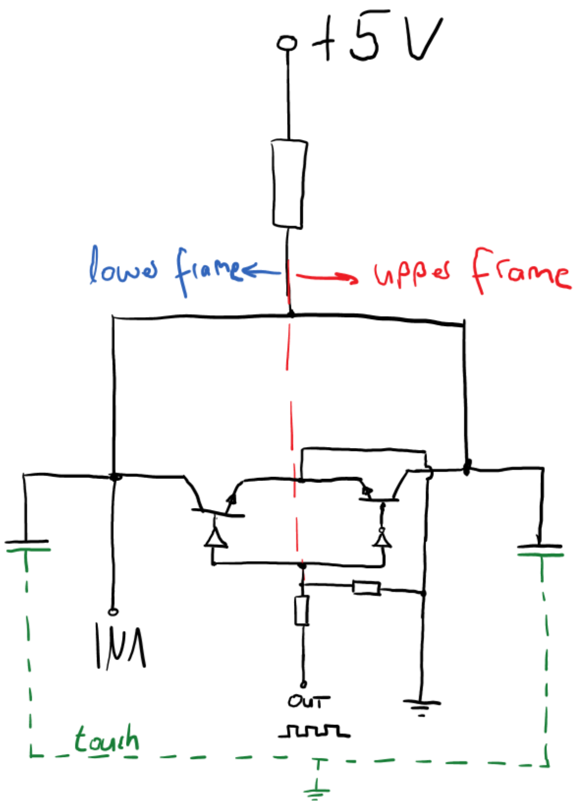


Figure 47: Ground providing capacitive sensor

The draft circuit shown in Figure 47 is based on the previously designed ones (see appendix IV). It consists of two of the previous circuits. Although, two output pins are required. One provides a periodic change of high and low state, while the other one has always the opposite state of it. This means one sensor surface is connected to ground while the other one is charged, at every point of time.

If an object gets stuck between those two sensor surfaces, the object is near ground because of the grounded surface of one sensor and is detected by the other one. As explained in chapter 'Capacitive sensor strip design', one stripe provides both ground and charging surface in one. This enables detection with touching only one dual stripe sensor.

Simulation of the circuit for time delay measurement in LTSpice

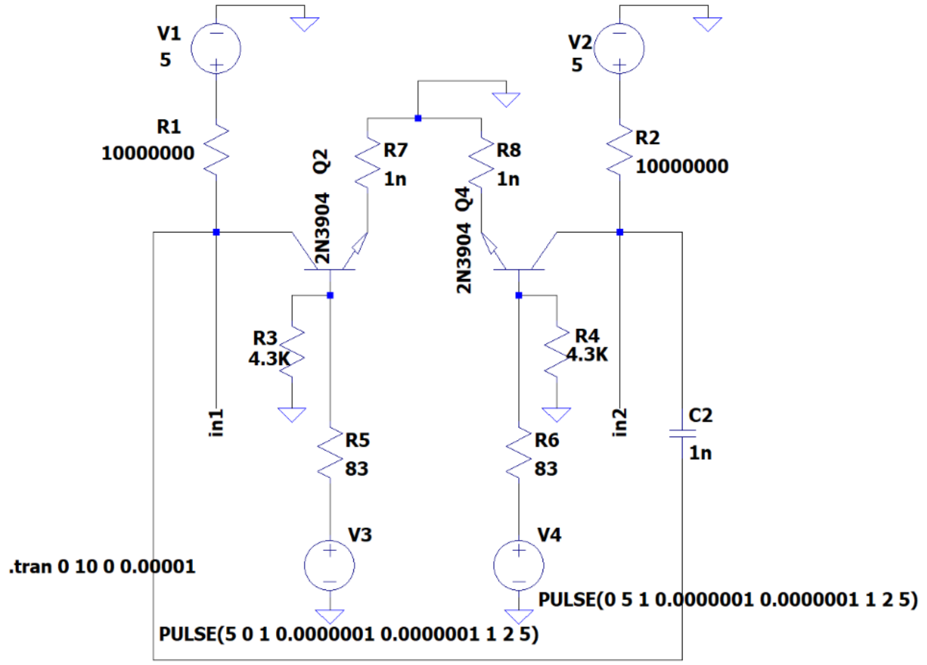


Figure 48: LTSpice model of the time measuring circuit

The electronics simulation software LTSpice is used to verify the behavior of the components.

The simulation (Figure 48) is designed with four separate voltage inputs. The first two are the 5V DC inputs while the latter two are 5V AC pulse inputs. The voltage supplies have their rise time and fall time set to 0.1us in order to simulate what would be a square wave output. The R7 and R8 are 1nΩ resistors added after the transistors with the sole purpose of measuring the current and the voltage after the switching. The capacitor C2 represents the human body capacitance of 1nF, as mentioned in chapter 'Time delay measurement'.

The in1 and in2 are the microcontroller pins where the voltage is measured to obtain either the high or low state. As it can be seen (Figure 49), the measured time is ~10ms which is like the calculation done using Equation II.

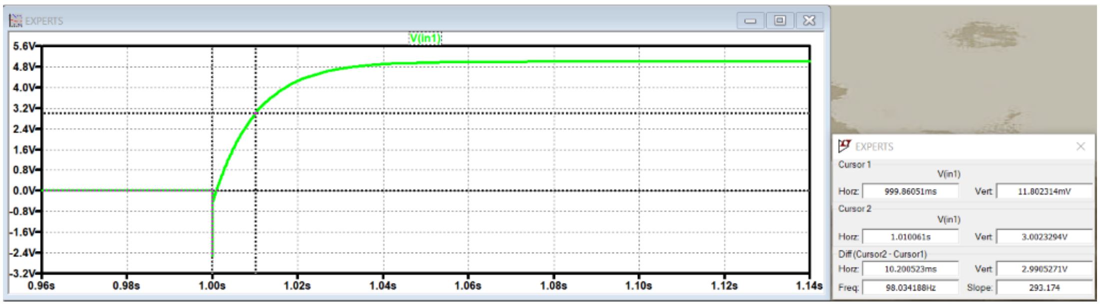


Figure 49: Time it takes to reach the 3.0V

Implementation with Arduino

The design was tested with an Arduino board with an ATMega 2560 chip. For testing purposes implemented circuit is shown in Figure 50.

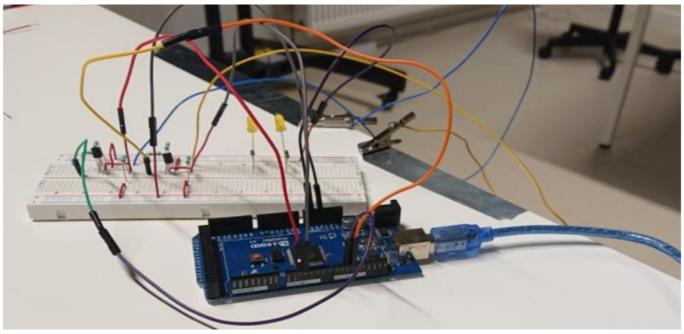


Figure 50: implemented two-part circuit

The developed Arduino program is attached to this report (see appendix V). It provides the measured time delay values via serial communication. The touch results can be seen in Figure 51 (for grounded human single touch).

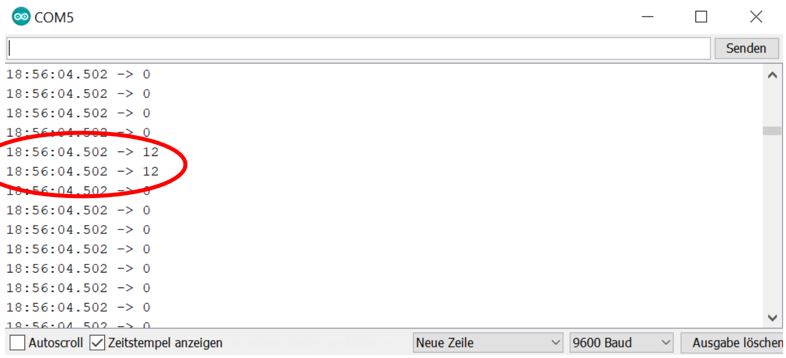


Figure 51: Time delay values - single touch

As only one sensor is touched, the other returns a zero for the time delay, while the touched one indicates a time delay of 12 ms in this case. For multi-touch, that means touching both sensor surfaces at a time, there are twice as many values. For no touch the program just prints ‘0’.

The Arduino still provides more zero values than expected. The reason could be a conflict of the interrupt function and the time function. Both use the same internal clock so they could affect each other [22]. It might also be possible that the interrupt function is entered more than one time with every rising edge of the signal. The timestamp of the printed values indicates this suggestion. There is more than one value at a time.

This can be solved by saving measured values in an array and check them for touch. One negative aspect of this way to measure the time delay is that it can't detect shorts because the signal is drawn to ground at any time, so the interrupt never occurs.

Final Arduino program

The final Arduino program is based on timers which are started as soon the output pin is toggled to switch the transistor. The sensor output is connected to the ICPx pins of the microcontroller. The current timer value is captured when a falling edge is detected at one of these pins (≙ microcontroller output pin turns to high state). As the microcontroller's internal clock has a speed of 16MHz the 16-bit timers are overfloating within 262 ms with a selected prescaler of 64. In Figure 52 the values of delayed and non-touched state are shown. A delay of 10ms per cycle is implemented in the code. As it takes two cycles to finish one measurement, the value for no time delay is 5000 ($\triangleq 20ms$).

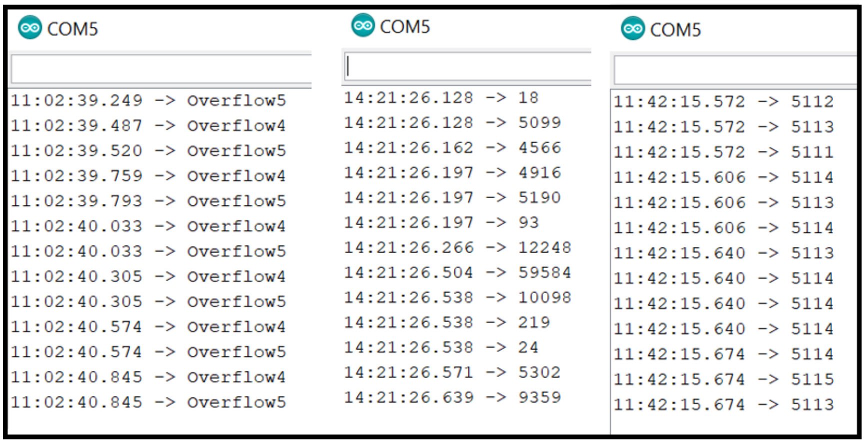


Figure 52: Left: overflow (shorted)->touch(>262ms); middle: touch(40ms); right: no touch(20ms)

With this program every kind of touch with uncovered skin can be detected so far. Further tests revealed that the detection works with some kinds of fabric as well (depending on the chosen resistor values). The Arduino code is attached to this report (see Appendix VI).

Capacitive sensor strip design

There are many ways of making a sensor for capacitive touch. It can vary from conducive tape strips and wires to even the frame blocks themselves.

The initial idea was to connect the circuit to the bedframe due to its material conductive material. The problem found, was the paint coating of the bed is insulating thus not allowing the touch to be detected by the circuit reliably.

The next solution was adding conductive tape strips onto the bed frame and connecting those to the main circuit. This solution brought another problem into the picture, the bed having its own large capacitance. In order to minimize this problem, the third and final solution was brought into the picture, an insulating layer between the bed and the strips was added. The insulating layer can be of any insulating material varying from simple insulating tape to a piece of wood. For the sake of ease of testing outside the bed, a 3mm thick MDF piece was laser cut in the form of a long thin rectangular stripe.

The MDF pieces (Figure 53) were then used to create and test two separate conductive options, wires, or conductive tape.

Figure 53: Sensors used for testing

After testing it was found that the main influencing parameter on the results was not the material but the surface area. Since the solution is supposed to not occupy a large volume and reduce the potential movement of the bed, the conductive tape was chosen due to it being able to cover more surface but also occupy less volume.

Electronics based capacitance detection

Another approach for using capacitive effects to detect touch is analysing the change of voltage when a touch occurs. In order to verify if a circuit to detect human touch has previously been created that could possibly be used, research had to be done. It was found that multiple capacitive-to-analog / capacitive-to-digital converters existed with prices within the project budget. Most of these sensors however were limited to detecting capacitances up to 200pF range. This meant they would likely be unreliable for this application since the original bed sensor alone had a measured capacitance of >250pF. Because of this, a device had to be developed by the project group.

Theory behind voltage drop solution

Measuring a voltage drop

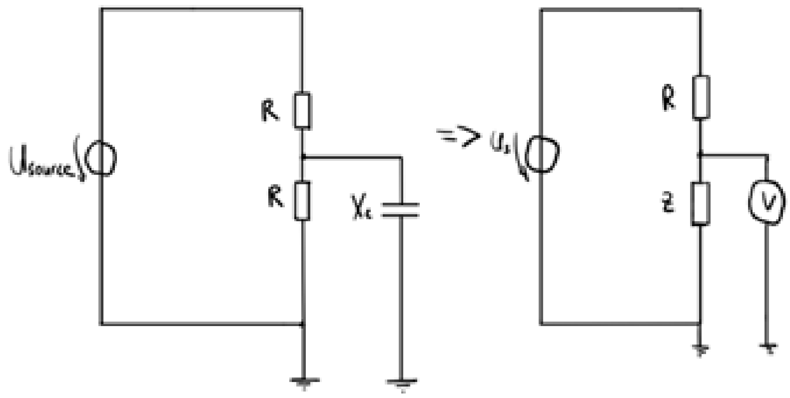


Figure 54: Voltage-based measurement

$$Z = \frac{R*X_C}{R+X_C} \qquad \text{(IV)}$$

$$X_C = \frac{1}{\omega*C} = \frac{1}{2*\pi*f*C} \qquad \text{(V)}$$

Alternating current can pass the capacitor to ground, so the voltage drops over Z decreases if the capacitor is added to the circuit by touching the surface. The idea behind was to short the circuit so the measured voltage drops to 0V as seen in Figure 54. Therefore, a high frequency is required (Equation VI).

$$\lim_{f\to\infty} X_C = \lim_{f\to\infty} \frac{1}{2*\pi*f*C} = 0;\ Z \to 0 \qquad \text{(VI)}$$

Where:

ω = angular frequency f = frequency Z = impedance X = reactance

Using 555 Timer as pulse generator

The 555 timer is an integrated circuit which produces a PWM (Pulse Width Modulation) signal with an adjustable duty cycle from 50% up to 100%. In addition to that the frequency can be set as explained in Equation VII from the datasheet.

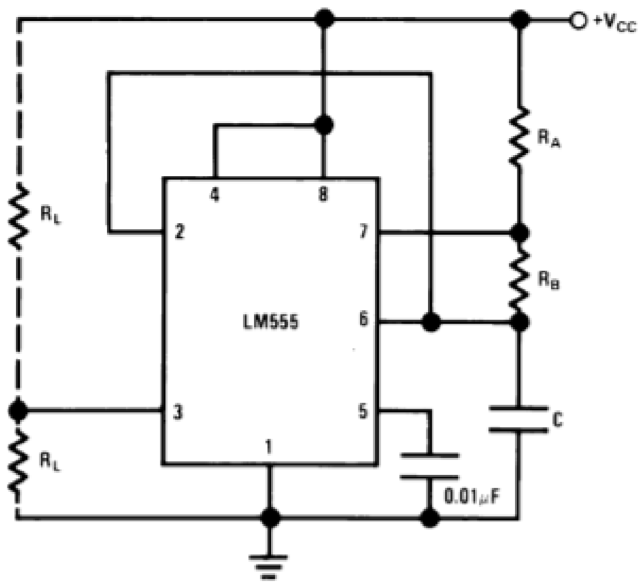


Figure 55: Setting the 555 timer [23]

$$t_1 = 0.693 * (R_A + R_B) * C \quad t_2 = 0.693 * R_B * C \qquad \text{(VII)}$$

As the times from Equation VII are dependent on capacitance and resistance, it was decided to set the capacitance to $C = 0.01\mu F$ (same value as for the recommended one for a stable operation mode in the circuit shown in Figure 55).

As $T = \frac{1}{f}$ and $T = t_1 + t_2$ the following equations result:

$$\frac{R_B}{R_A} = \frac{d-1}{1-2d} \qquad \text{(VIII)}$$

$$(R_A + 2R_B) = \frac{1{,}44}{f * C} \qquad \text{(IX)}$$

Where: d = duty cycle

Using these equations (Equation VIII and Equation IX), the resistor values can be chosen depending on the desired frequency and duty cycle.

The frequency was chosen, based on the desired voltage decrease at the voltage divider. The higher the resistance of the circuit in the beginning, the bigger the influence of the short through the capacitor will be. To get a signal in mA range the total resistance should be at least 10kΩ.

Determine the frequency and the resistors of the voltage divider

The frequency of the voltage source determines the total impedance of the lower part (Figure 54) of the voltage divider as explained in Equation V. In addition, the resistors affect the potential φ_0 in between them. This potential in no-touch state should be as high as possible to enable a large drop which increases the chance of a reliable detection.

As the applied sensor is already affected by the capacitance of the bed, the impedance is only determined by this influence, if $R_2 \gg X_C$.That's why a resistance of $R_2 = 100k\Omega$ was chosen.

The calculation to find the best pair of frequency f and resistor R_1 for the circuit are based on Excel and can be seen in appendix VII.

In order to obtain some actual body capacitance values, a small test was conducted. From the test it was concluded that the body capacitance using our sensor can be approximated to $1.48nF$.
(see appendix III).

For an expected parasitic capacitance of $C_{Bed} = 0.1nF$ (fifteen times smaller than the measured body capacitance), the frequency $f = 100kHz$ can provide a theoretical voltage drop of $\Delta\varphi = 42\% * U_{Source}$ with resistor $R_1 = 10000\Omega$.

Note:

- The actual capacitance should be validated after implementing the sensor on the bed. The calculation is also done with different bed capacitances to choose from.
- There are combinations of higher frequency with different resistor which would provide a slightly higher voltage drop (+0.02V). In the datasheet of the 555Timer, the graph for recommended capacitances, is drown up to 100kHz so it was decided to accept this small loose of accuracy.
- Firstly, it was attempted to convert a square wave signal generated by the 555-timer, to a sine wave signal, to more reliably calculate exactly how the capacitances of the circuit would affect the signals. It was however realized that having a square wave signal would only benefit this application. As can be explained by Fourier series theory, a square wave consists of the natural frequency of the initial signal, plus a lot of added harmonics. These harmonics would have a higher frequency, which would amplify the effect of the capacitances in the circuit. This means, a slower frequency would be required compared to a pure sine wave, for the same effect.

Configurations for 555 Timer

As explained in the previous chapter, the frequency of the timer should be 100 kHz. In order to increase the DC voltage equivalent of the generated AC signal, the duty cycle is set to 80%. This allows for a larger margin when setting a threshold voltage to detect the collapse of the AC signal.

Equation VIII therefore yields a ratio R_A to R_B of 0.33 (→ $R_A = 3 * R_B$).

Replacing R_A in Equation IX results in a resistance of $R_B = 288\Omega$. It was chosen to use a resistor of $R_B = 300\Omega$ which yields $R_A = 900\Omega$.

This results in a frequency of $f = 96kHz$ with a duty cycle of $d = 80\%$.

Design and simulation of first circuit idea in LT-Spice

Since a microcontroller could not be used to measure the voltage change of a signal faster than 4800Hz (Shannon's sample theorem with a system frequency of 9600Hz of Arduino reading), it was decided to use comparators to measure if the voltage passed specific thresholds instead. The idea was to use a comparator with a specific voltage threshold on the non-inverting input, and the voltage signal from the voltage divider on the inverting input. The output of the comparator switches high every time the signal passes below the threshold. This idea was simulated using LT-Spice (Figure 56)

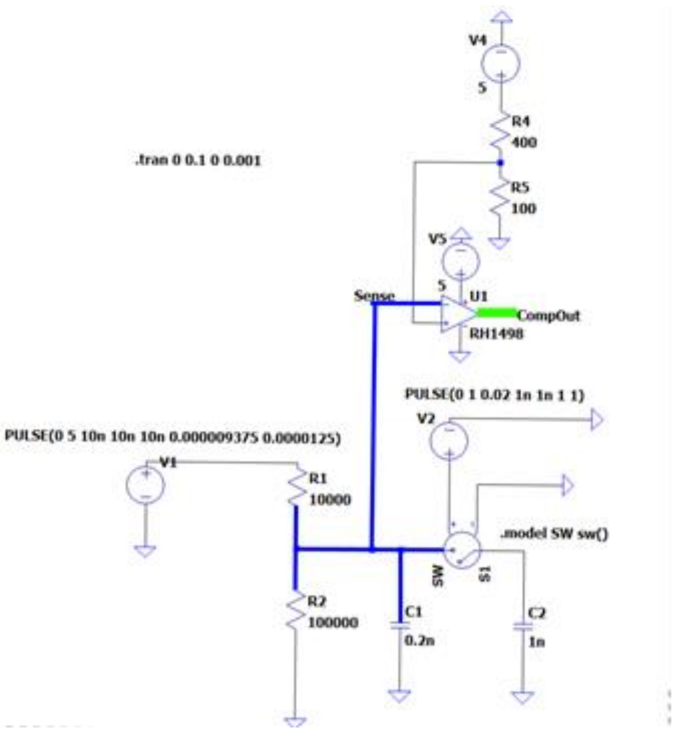


Figure 56: LT-Spice simulation of capacitive sensor principle

The circuit consists of a lm555-timer IC connected to a voltage divider. The point of the voltage divider was to create a "weak" voltage source that would be greatly affected by the addition of a capacitor to ground, loading the output. The output of the voltage divider (seen as the blue line) enters the inverting input of the comparator. The reference voltage of the comparator is created using a voltage divider with $R1 = 400$ and $R2 = 100\Omega$.

These relatively low resistances were picked because the op-amp (operational amplifier) used in the simulation has a high input bias current of a few mA. The output of the comparator is the green graph (Figure 57). At time $t = 20ms$ a switch is closed to simulate the addition of human capacitance to the circuit. This causes the AC component of the signal at the voltage divider to decrease, as can be seen on the blue graph (Figure 57). Setting a voltage threshold of $U_{thresh} \approx 1V$ as non-inverting comparator input, the comparator output drops to 0V upon "touch" of the sensor. Note that since a capacitor ideally does not affect the DC component of the system, this stays constant.

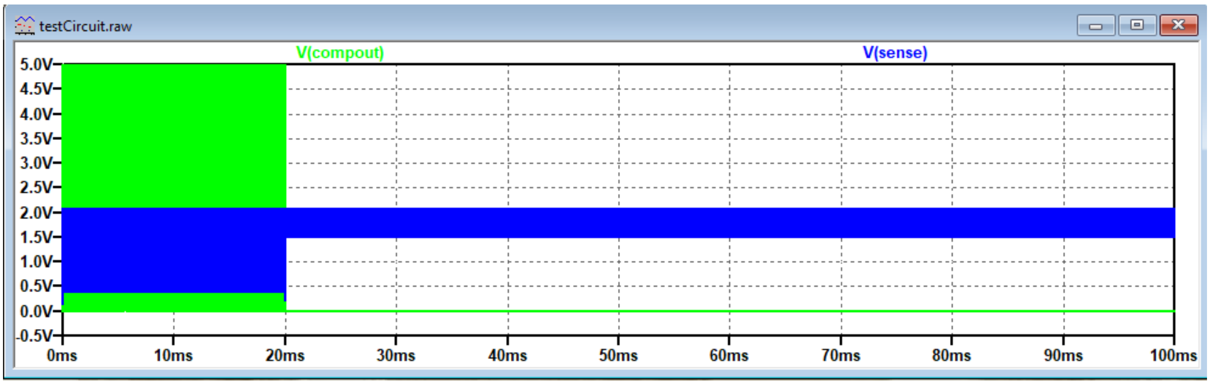


Figure 57: Simulation of capacitive touch at time t = 20ms

As the goal of this sensor is to get a steady high signal upon touch of the sensor, and a low while not touching, the output of the comparator would have to be inverted. Inverting it alone would not be enough however, as the comparator output with no human touch is not a constant 5V (Figure 58).

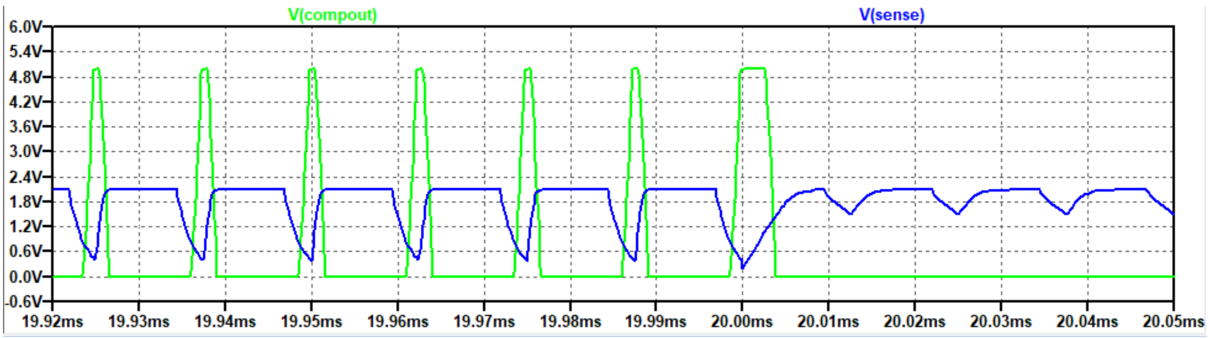


Figure 58: Zoomed picture of capacitive touch simulation

To combat this, a diode was placed at the comparator output and a capacitor would be charged on the anode side (Figure 59). The diode would allow the capacitor to charge over the duration of the 5V comparator output spikes, while not allowing the capacitor to discharge through the comparator. The capacitor would instead discharge slowly through a megaohm resistor. The goal would be to have a steady DC voltage on the capacitor while the comparator is pulsing, while discharging the capacitor to 0v when the comparator output is LOW.

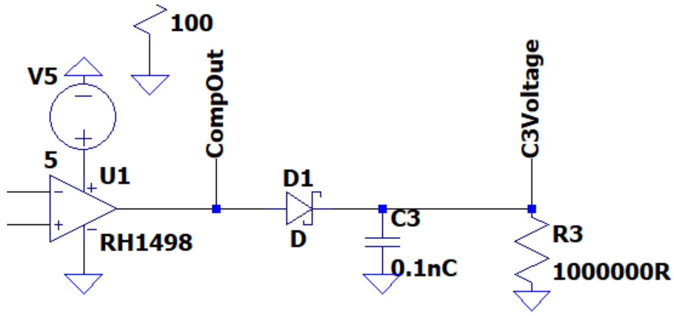


Figure 59: Simulation of capacitor to smooth comparator output

As it can be seen on the picture, a Schottky diode was chosen because of its low forward voltage of 0.3V at 25mA. This was needed over a normal diode, as losing voltage over the diode would result in not only a higher power-loss (Important because of LINAK's low-standby power requirements), but also result in a weaker signal, which would be harder to detect.

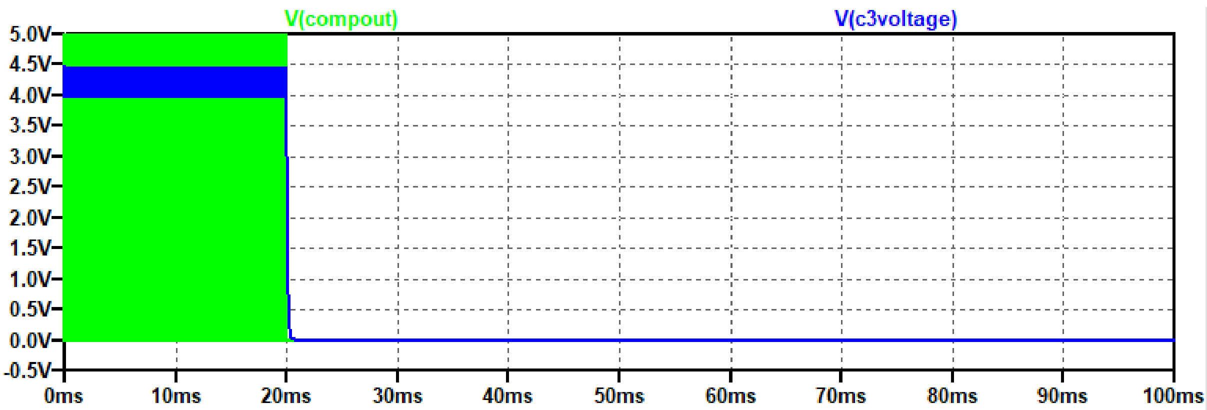


Figure 60: Simulation of capacitor charge over time

As can be seen on the blue line from the simulation (Figure 60), this method works, and the capacitor discharges to 0V in less than 1ms. Next step was to add a second comparator to give a high output if

$$V_{c3} < 1V$$

and a low otherwise. This would be done by having V_{c3} on the inverting input and a reference voltage of 1V on the non-inverting input (Figure 61). This effectively inverts the output signal.

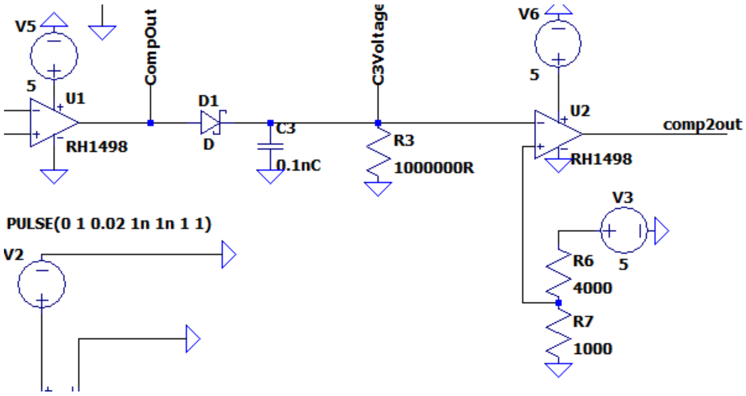


Figure 61: Second comparator to invert sensor output

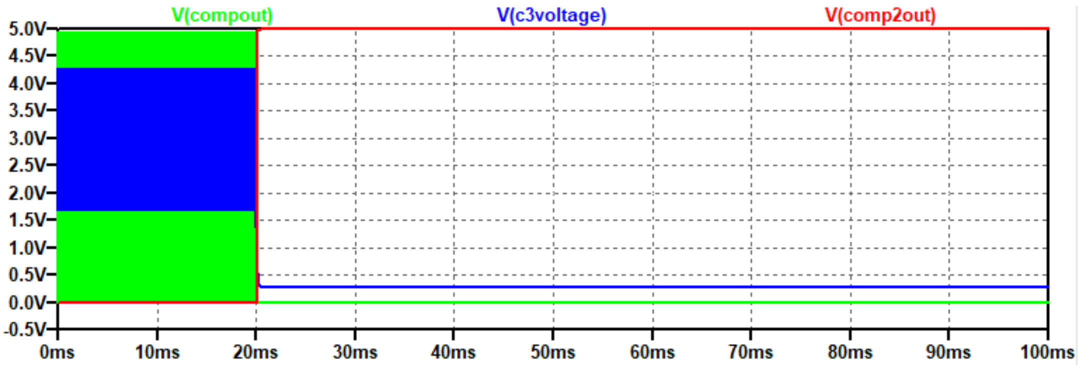


Figure 62: Graph of all simulation voltages

From the simulation (Figure 62) we can see that the output of the second comparator, "V(comp2out)", switches from low to high when the "body capacitance" is added at $t = 20ms$. Now the circuit is ready be constructed on a breadboard and tested.

Test of circuit

Construction and test of circuit

A circuit like the simulation circuit was constructed on a breadboard (Figure 63). An LED was added to the output of the final comparator to indicate a successful collision-detection.

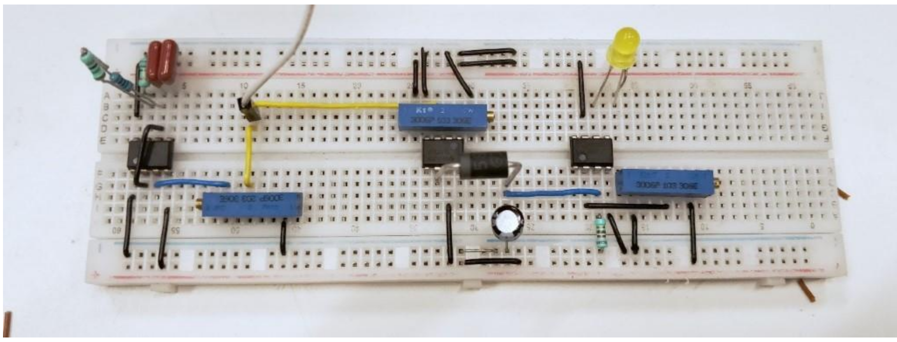


Figure 63: setup of simulated circuit on breadboard

This circuit originally used the TL071 op-amp as comparators. Upon connection of power to the circuit, the output LED instantaneously turned on, revealing a problem. This was because the TL071 op-amps used were not rail-to-rail as specified on the RS-Components sales page initially checked. This meant the output of these op-amps could not decrease below 3V for

$$U_{cc+} = 5V \quad \text{and} \quad U_{cc-} = 0V$$

Because of this, the op-amps were switched to lm211 comparators with output pull-up resistors of 500Ω as specified in a datasheet example. Potentiometers were also used to create the voltage dividers of the circuit, to allow for quick adjustments of the threshold voltages of the comparators.

Unfortunately, there was a problem with the circuit, resulting in the capacitor voltage never increasing above 0.5V. This means the output would always indicate a human touch. It was suspected that this was caused by the comparator output being too weak to charge the capacitor. Because of this, it was decided to instead charge the capacitor to 5V using a pull-up resistor, and then discharge it through a MOSFET to ground, using the comparator output to control the MOSFET gate. This eliminates the need for the second comparator, as the capacitor would charge to 5v upon human touch, while continuously dis-charging to 0V, through the MOSFET, when no touch is detected.

An oscilloscope was used to verify the behavior of the circuit:

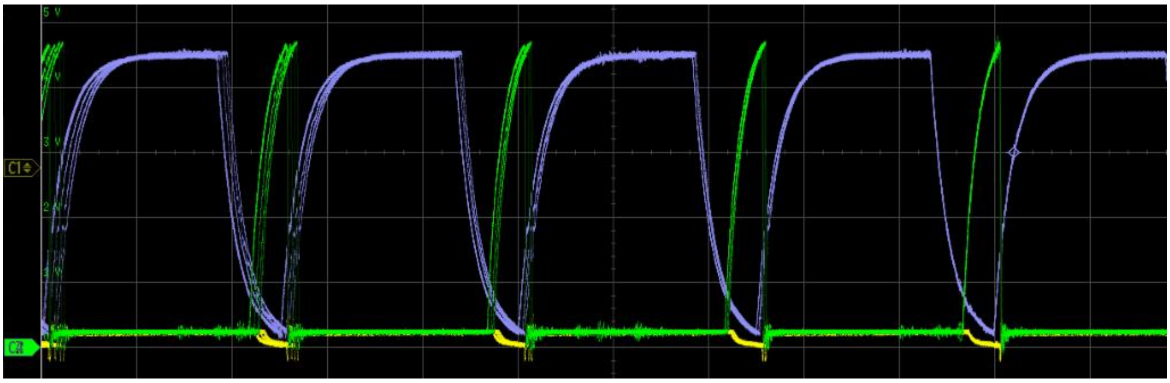


Figure 64: Oscilloscope readings before human touch

As seen on the oscilloscope (Figure 64), the blue line is the output of the voltage divider connected to the 555-timer. The green line is the output of the comparator, rising high when the voltage divider output drops below 1V. The yellow line is the MOSFET output which increases when the comparator output is below the threshold voltage.

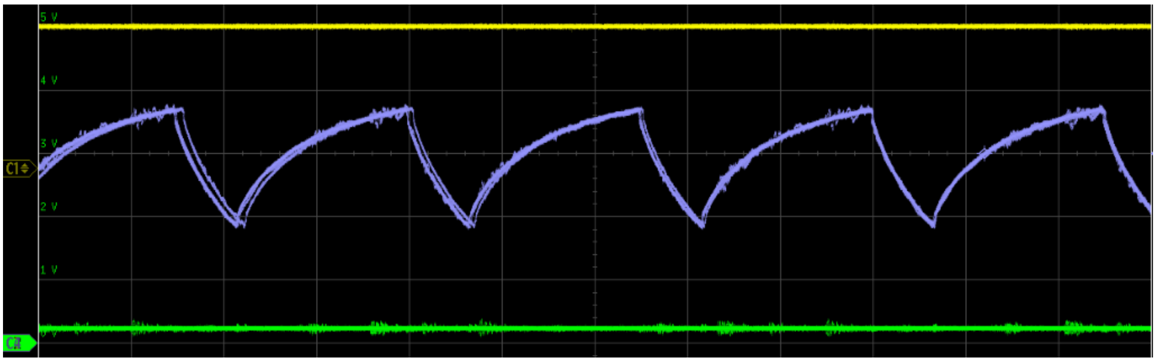


Figure 65: Oscilloscope readings after human touch

The comparator output goes low when the voltage divider output "collapses" due to human touch, which causes the MOSFET output to go high (Figure 65).

Implementation to bed actuator

To stop the bed upon detection of a human touch, the output of the capacitive sensor would have to be feed into the LINAK actuator. According to information provided by LINAK, this could be easily achieved by feeding a constant high or low signal into the signal wire on the actuator LAN connector.

To identify the signal wire, a diagram provided by LINAK was used (Figure 66).

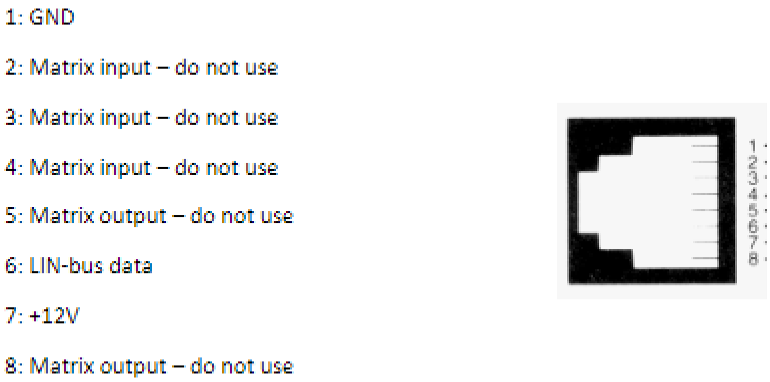


Figure 66: LIN-bus pinout

From the diagram it was determined that pin number 6, corresponding to the green wire of the LAN cable, was the data wire.

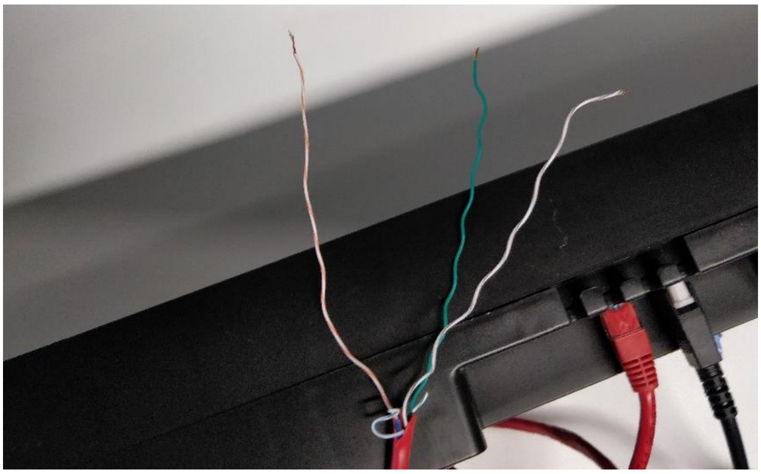


Figure 67: LAN cable connection to actuator

A quick test was done, shorting the data wire to ground while the actuator was running, which successfully stopped the actuator. As both a high and a low signal could stop the bed from running however, the output of the capacitive sensor would ideally have to be an open circuit while the sensor is not triggered. A solution to this could be connecting the data wire to the drain of an NMOS with the sensor output on the gate. Turning on the MOSFET would then short the sensor wire to ground, while keeping it isolated from ground when the MOSFET is not enabled.

Powering the capacitive sensor

Originally the plan to power the capacitive sensor consisted simply of tapping into the voltage of the actuator power supply. This would allow the sensor to always receive power while the bed was plugged into a 230V outlet. Upon further inspection of the LAN cable connector however, it was realized that the 12V output of the LAN connector (Figure 67) was only enabled when the actuator was moving. Using this 12V output to drive the capacitive sensor, would cause the capacitive sensor to only draw power when the actuator is moving, eliminating all idle power consumption of the circuit. Considering LINAK's goal of 0.1W idle power consumption, as advertised on their power supplies, this was an attractive feature.

Time delay of capacitive sensor

As the capacitive sensor operates as a safety device, the delay of touch detection is important. Using an oscilloscope, the rise / fall times of the output signal after a human touch was measured.

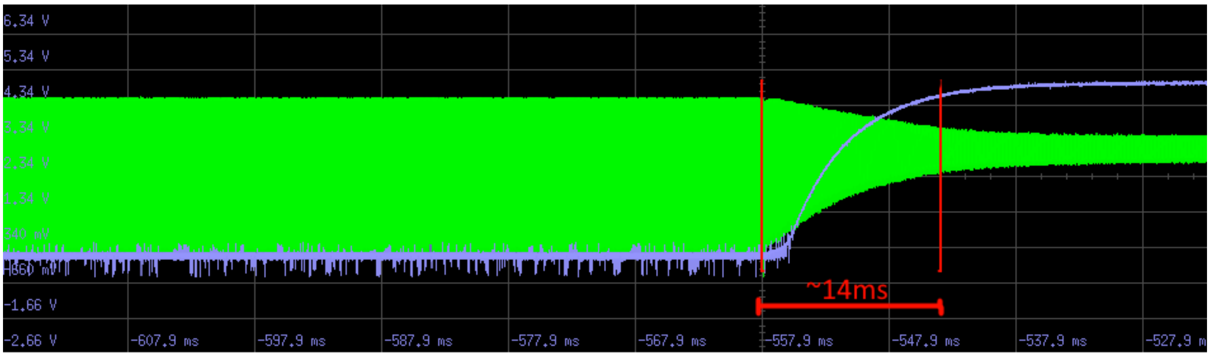


Figure 68: Oscilloscope measurement of rising output signal to human touch

Using graphical analysis of the oscilloscope readings (Figure 68), it was determined that the reaction time of the sensor output to a human touch was approximately 14ms. This is satisfactory as the project requirements demand times lower than 0.75 seconds.

Detecting a short in the circuit

As mentioned previously in the report in the section

Using 555 Timer as pulse generator, the decided duty cycle is 80% which in turn would give a DC voltage of 8V from the 10V measured that the actuator provides. After the first voltage divider (which contains a 10kΩ and a 100kΩ resistors) and the added capacitor of the bed, it was found that a voltage of around 7V DC was measured going into the first comparator (LM211N). Taking also into account the human capacitance, a total of 6.7V DC was measured prior to the LM211N.

A short in the sensor of the system was found when the two sensor strips (as mentioned in chapter 'Capacitive sensor strip design', one of them being ground and the other the detection strip) were overlapping or when a highly conductive piece of material (such as iron or aluminum) was placed over both simultaneously. Compared to the previously measured DC voltages prior to the LM211N, during a short there was found to be a 0V DC potential in the same part of the circuit. Based on this knowledge a new secondary system was designed to stop the bed during a short.

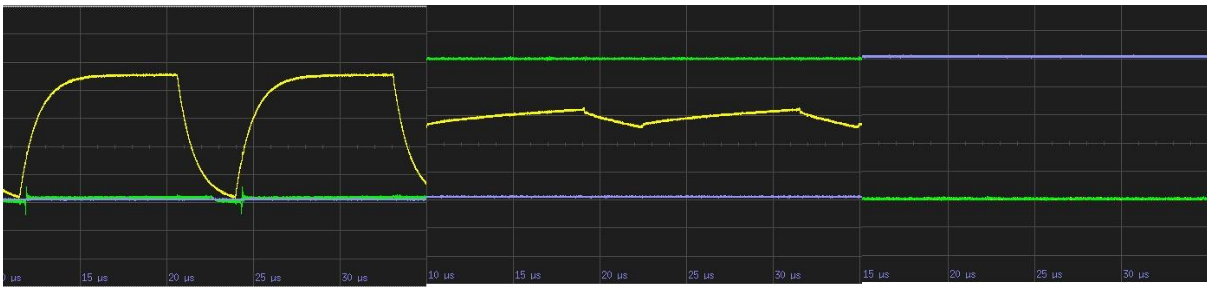


Figure 69: No touch/Touch/Short

The blue line represents the short detection output with a 5V supply (Figure 69). Using this information, a secondary circuit was designed in order to detect the short which would cause the actuator to not work.

The secondary circuit, seen in Figure 70, starts from prior to the LM211N comparator. It is composed out of two op amps. Firstly, a unity gain op amp was used to separate the circuits from one another. This was achieved using the TS358CD op amp due to its rail-to-rail characteristic and slew rate fast enough to support 100kHz signal. After the first op amp, a capacitor to ground was added to filter out the AC part of the output. The second part of the circuit is made of a comparator (LM211N) which contains a voltage divider that supplies 0.5V to the non-inverting input. The inverting input of the comparator represents the DC output of the TS358CD. Thus, the output of the secondary circuit is determined by the whether the inverting input or the non-inverting input is higher. During no touch or touch, the inverting input is higher raging from 6V to 7V which gives a 0V output. During a short, the inverting input is lower thus leading to a VCC output from the comparator, in this case 10V.

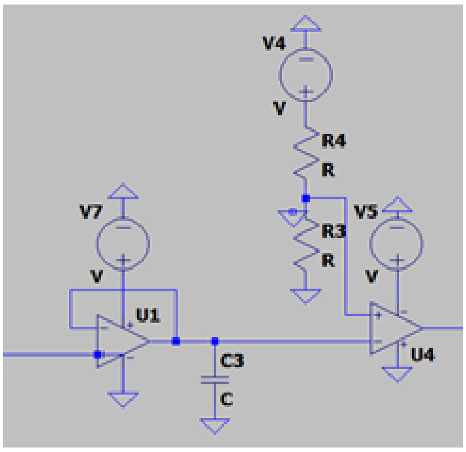


Figure 70: Secondary circuit

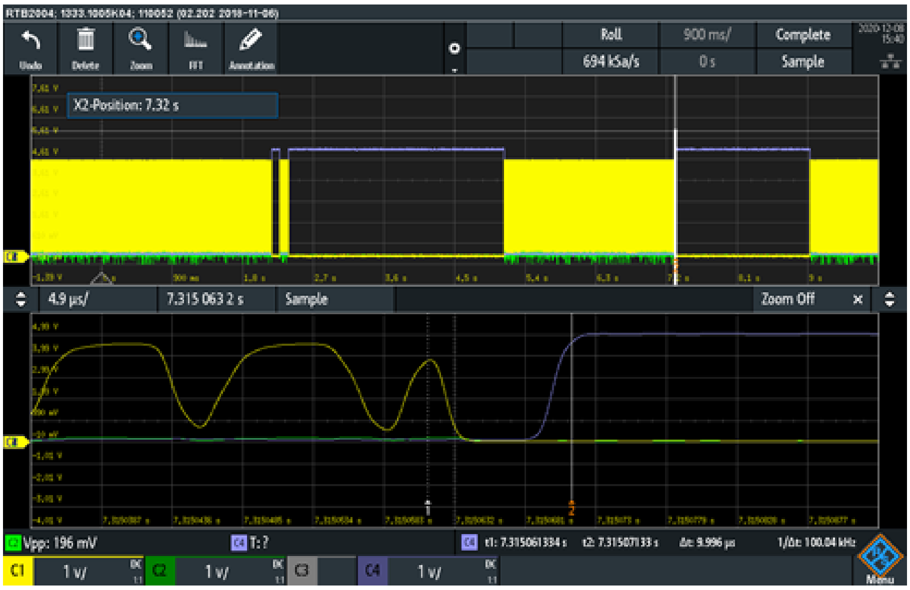


Figure 71: Time to detect a short during a rising sine wave

As seen in the oscilloscope measurements (Figure 71), the longest time it takes to trigger is in the range of microseconds, during the rising of the 555-timer signal wave.

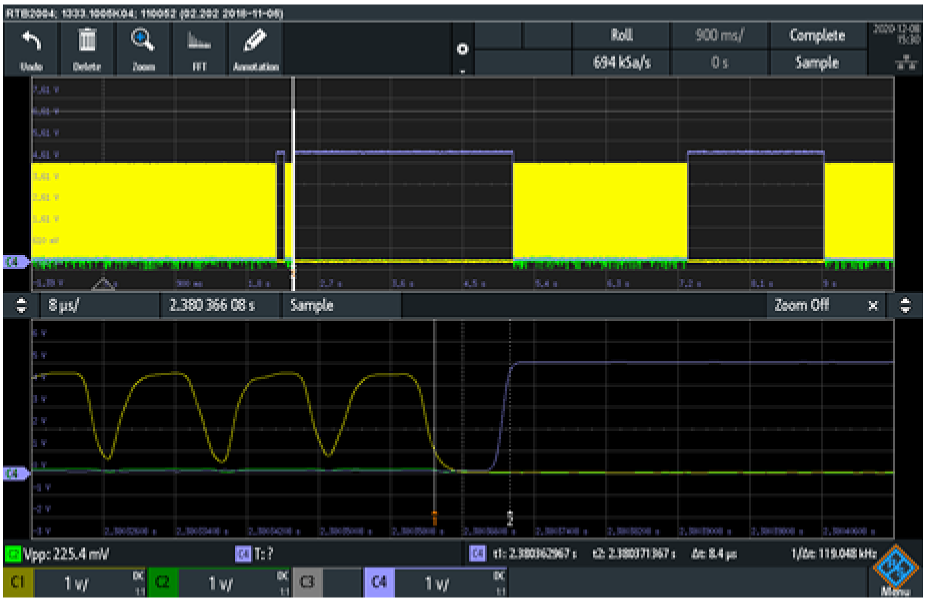


Figure 72: Time to detect the short during a falling square wave

During the fall time of the 555-timer, the detection was shorter due to having the square wave voltage already close to its lowest value seen in Figure 72.

Figure 73: Fall time of the secondary circuit

The fall time, seen in Figure 73, of the short detection mechanism is also in the same range, taking less than five microseconds.

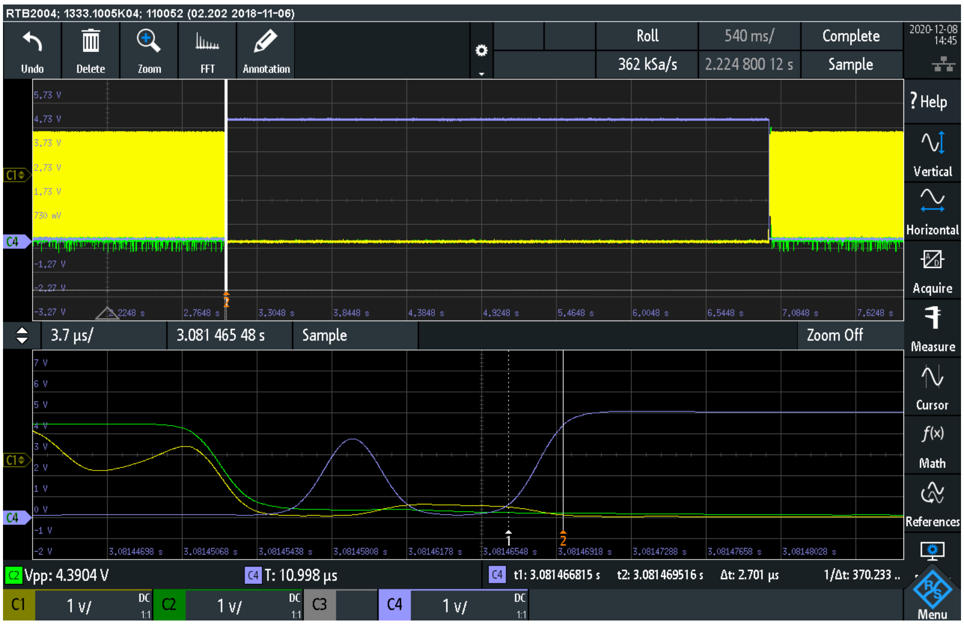


Figure 74: Rising time

The rising time, seen in Figure 74, of the signal is in the range of microseconds, faster than the fall time.

Combining the circuits

After both the main and the secondary circuits were tested and found to be working as expected, it was time to combine them. The main difficulty was the output of each circuit interfering with the other one. Since their outputs are always opposite, they cannot be connected to one node and sent to the signal wire. Thus, the final part of the circuit was designed with two BJTs as seen below. Two 2n2222 transistors were used to ground the signal wire and drive two LEDs.

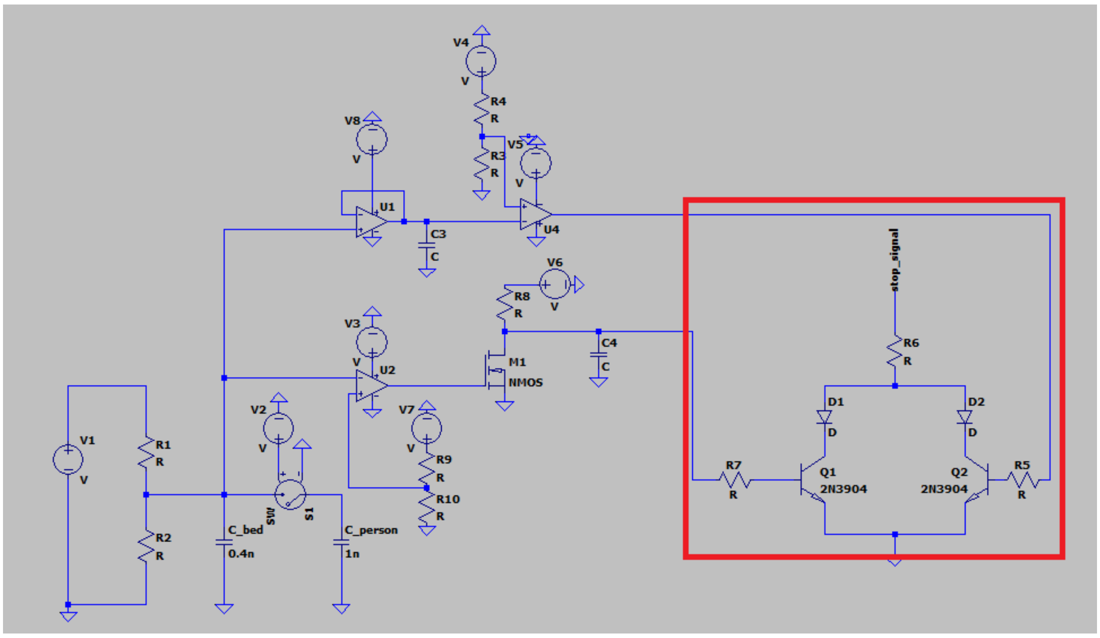


Figure 75: Combining the circuits with the BJTs

As previously mentioned, and shown, the two outputs (left from the main circuit and right from the short detection) will always have opposite values due to triggering on high or low of the signal. The two resistors prior to the BJTs on each side are placed to limit the base current of the BJTs. The resistors used were calculated for a base current of approximately 5mA.

Designing a PCB and circuit schematic

A schematic (Figure 76) and PCB (Printed circuit board) (Figure 77) were designed using EAGLE 9.6.0. The schematic contains the full circuit shown in LTSPICE, the 555-timer in a stable configuration and a LAN cable port with the purpose of having the solution as a separate module for the actuator that can be powered with a LAN cable and have the sensors connected to the bedframe. Most of the components in the schematic were found either in Eagles main library or in other online available libraries. The unity gain op amp was the only one not available thus a similar 3D package and pinout was used and then connected based on its datasheet.

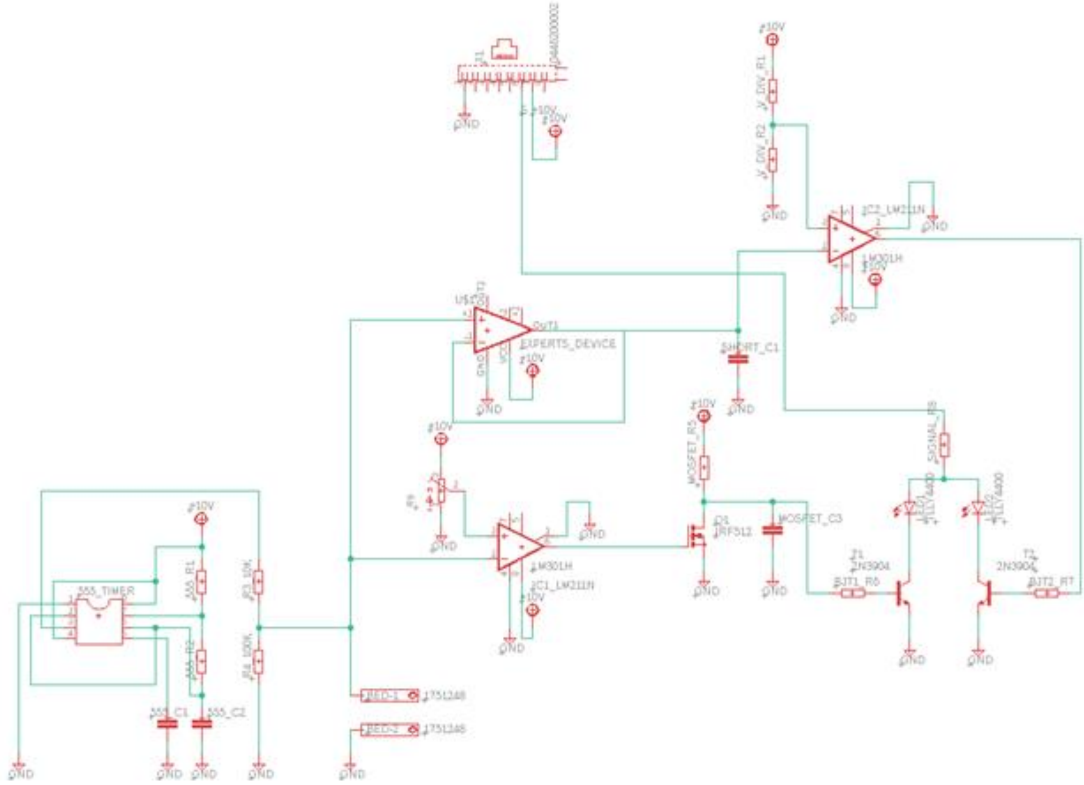


Figure 76: Schematic of the voltage solution

Due to the size and complexity of the circuit, the PCB was designed to be double layered in order to reduce its size as much as possible. The PCB is sized to be 85 mm x 74 mm. There were some problems with the first draft of the PCB due to lane width and pad size. Thus, the lane width was updated to be almost six times the initial width and the pad size an extra 50% wider. These values were the thinnest lane widths found which still allowed for LINAK to create the PCB using their CNC machine. The goal was to design the PCB as small as possible while keeping the important components on the edges for ease of access.

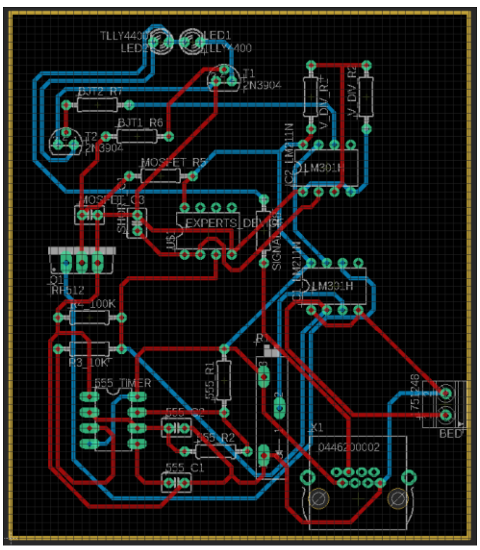


Figure 77: PCB design of the voltage solution

Embedded sensor solution that recognizes collision

Concept for embedded sensor

As defined in the project formulation, a collision occurs when certain amount of load is removed from the actuator and laid upon another object or person. The embedded solution investigated the construction of a measurement system (Figure 78) with which the load removal, present in a collision, could be identified, and used to take the pertinent actions. This is possible since the actuator works in a push configuration, and only gravity is responsible for the bed coming down.

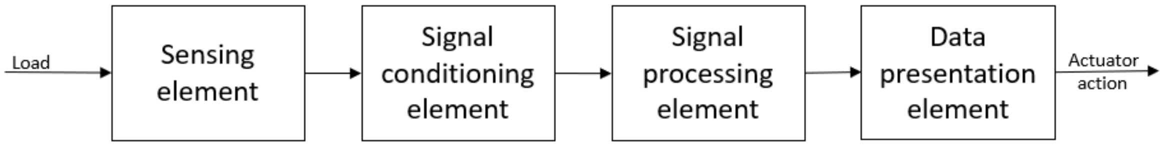


Figure 78: General structure of measurement system [24]

For the measurement system to work, the load needed to first be converted to an electrical signal that could be interpreted by a microcontroller to determine a collision. Furthermore, and given that many things (other than collisions) happen constantly on beds, data needed to be gathered to determine if the collision load change behavior was particular enough for this solution to be viable. Given the complexity of the data and precision required, machine learning algorithms were used to aid in this task.

The final proposed measurement system (Figure 79) consists of a load cell (load to strain), strain gauge (strain to resistance), Wheatstone bridge (resistance to voltage), amplifier (millivolts to volts), filter (for noise reduction), Analog to Digital Converter (ADC) (voltage to binary), a micro-control (µC) (to process the data and the algorithm) and the actuator itself through the LinBUS (to give action to the actuator).

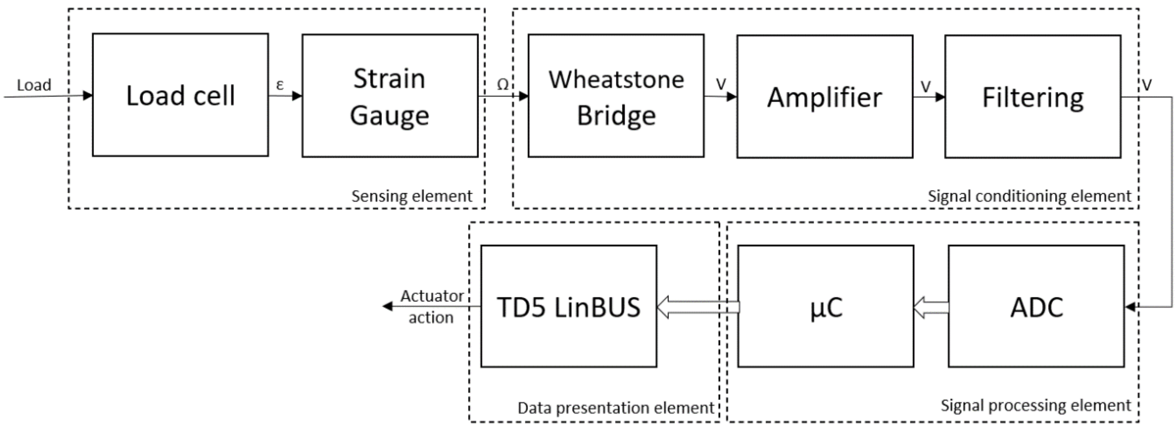


Figure 79: Final measurement system of embedded solution

Sensing element selection and design

To be able to convert the load to some quantity that can be interpreted by the microcontroller, a load to voltage sensor must be used. The goal is to convert the load applied to a voltage in a range such that a microcontroller input can detect and read properly. After doing research on the different options available on the market, a couple of options appeared.

The first one is a Piezoelectric Sensor. The piezo sensor has a structure that can convert the load applied to it to voltage that can be read by the microcontroller. A piezoelectric sensor is a crystal reacting to a force applied to it. A DC voltage can be applied to the sensor and when a force is applied to the sensor, a voltage spike occurs. Because of the crystal structure of the sensor, after the voltage spike the structure settles at the original value before the force was applied. If the force is applied gradually, then the output is represented by a sin wave which eventually drops down to the original state. But because of the sensors structure, a constant influence of DC voltage can destroy the sensor. So, another, mostly used, application is by the resonance produced by the sensor. When the sensor is exposed to an AC voltage, the crystal structure vibrates at the frequency applied, but when a force is applied the bandwidth changes. Then, by checking the pattern of the signal coming out of the sensor, the load applied to it can be determined. The piezoelectric sensor used is directional, meaning that the spike will be different depending on what side the load is applied to.

The piezoelectric sensor, although having very sensitive response, has one major disadvantage. If a DC voltage is applied, it can only detect sudden loads, and not constant. Also, an AC signal can be used, but it would overcomplicate the solution to an extent that would make it not viable for just one semester of work. Since this type of application is not used very often, it was very hard to find some reliable sources of information, which will make the project take even longer. Therefore, it was decided to disregard the piezo sensor.

Another type of sensor found was the Strain Gauge. A Strain Gauge works by changing length and width of some traces when a strain occurs, which in turn changes the resistance of the gauge. Any specific Strain Gauge has a property called gauge factor, where this defines how much it changes in relation to how much strain the gauge is exposed to. The gauge factor is set according to the formula:

$$GF = \frac{DR/R_G}{\epsilon}$$

DR: *The total Change in resistance due to strain*

R_G: *The nominal resistance of the gauge without strain*

ϵ: *The strain*

A typical value for the gauge factor is 2, which is the factor for the sensor used. Another factor to be taken into consideration is how much the resistance changes due to temperature changes. As it is with every resistor, the resistance changes with temperature, so the gauge resistance change for the sensor used according to the datasheet is: ±2µ strain per C°.

The Strain Gauge is to be attached to a steal structure that will convert the load applied to strain on the gauge. Because of the load that the steel must undergo, the flex is very minimal thus the resistance change of the gauge will be small. So, in order to convert the resistance change to voltage, a quarter Wheatstone bridge circuit was used. (Figure 80) Using a half bridge or a full bridge could have been used to reduce the effect of temperature, but due to the lack of space and the expected small change in temperatures the quarter bridge was used.

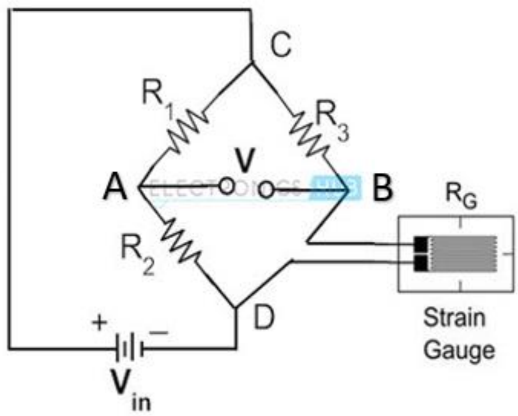


Figure 80: Wheatstone Bridge circuit

The working principal of a Wheatstone bridge is two voltage dividers, where the Strain Gauge is making the last connection in the bridge. The voltages at the points A and B can be expressed as:

$$V_A = \frac{R_2}{R_1 + R_2} * V_{in} \ , \ V_B = \frac{R_G}{R_G + R_3} * V_{in}$$

Finally, the output voltage V can be calculated as:

$$V = V_A - V_B$$

Both voltage dividers are supplied with the same voltage supply, and the resistor values are chosen such that when the Strain Gauge has no load on it $V_A - V_B$, thus the voltage V will be zero (balanced bridge), otherwise the voltage will vary based on how much the $V_A - V_B$ is. As mentioned before the resistance change is very small due to the small strain applied to the gauge, so the signal is connected to an amplifier circuit that feeds into an ADC after being filtered. (Figure 81)

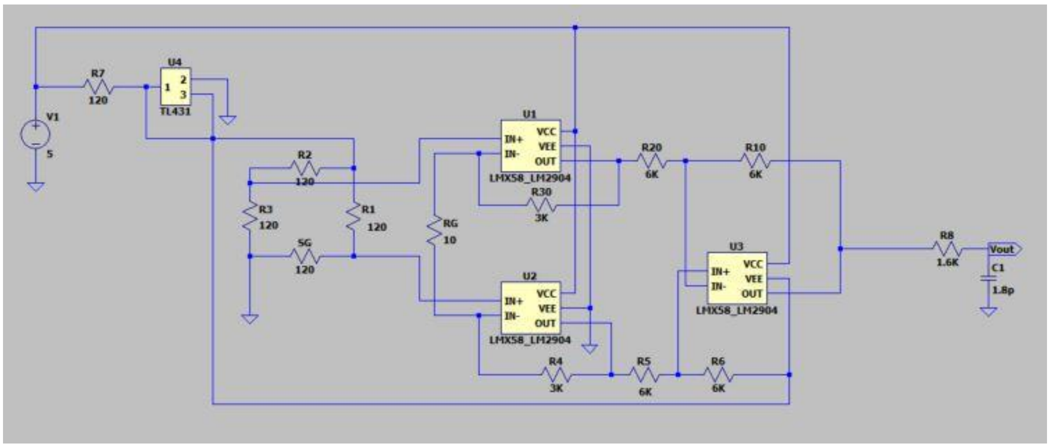


Figure 81: Strain Gauge Circuit

V_{out} in the above circuit goes to the ADC of the Arduino to be recorded and analyzed.

Load to strain

To convert the load into an electrical signal, the strain gauge is placed in a mechanical element (load cell) acting as a transducer of load to strain.

The conventional bar load cell was not feasible for the application given that the space available for the cell was very reduced. Additionally, the wide range of motion of the surface area where the load is being applied made it for the element to require a load surface area as big as the actuator head itself. Taking this into account, a mechanical element that behaved similarly to the load cell was constructed (Figure 82).

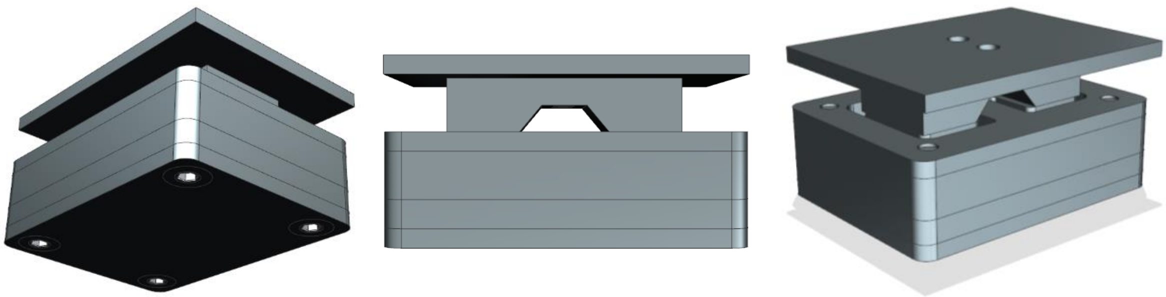


Figure 82: NX model of mechanical element

The construction is to be placed between the actuator and arm finger as shown in Figure 83. The compression exerted on the mechanical element generates strain on the smaller link between both surfaces. The strain gauge is therefore placed there to measure the deformation (Figure 84).

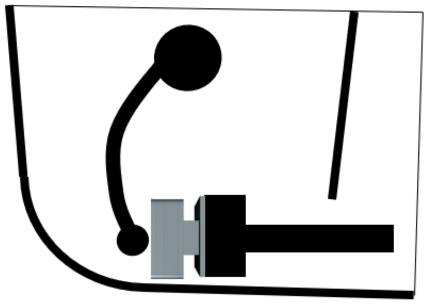


Figure 83: Mechanical element placement in actuator

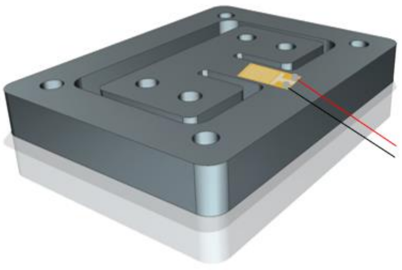


Figure 84: Strain gauge placement in SGFLEXER

Given the exploratory nature of the project, the design was made with manufacturing costs in mind. All pieces were designed in a way that they could be cut in the water jet (except for the SGEXTENDER), as this was the cheapest method (other than the team should them manually) with which the desired tolerances could be achieved. The parts list and materials of each can be found in appendix VIII.

A big challenge in the design of the modified bar load cell presents with the big forces exerted between the actuator and the arm finger, since, as shown in the mechanical solution, this reaches values of over 1000 kg under normal operation. To ensure proper functionality of the design, finite element analysis was run on the construction. Variations in both the thickness and width of the flexing piece were made.

The simulation focused on the total deformation of the piece, as well as the strain on the region where the strain gauge was to be located. After determining a mesh resolution of 5 through the Mesh Convergence Method, the results gave a maximum deformation of 0.38151 mm at the maximum load of normal operation (Figure 85). Given the expected inaccuracies of simulations, the test was run with twice the normal load (20 kN) and showed a reasonable maximum deformation of 0.76302 mm (Figure 86). Additionally, the strain values gave a range that would allow for the strain gauge to detect.

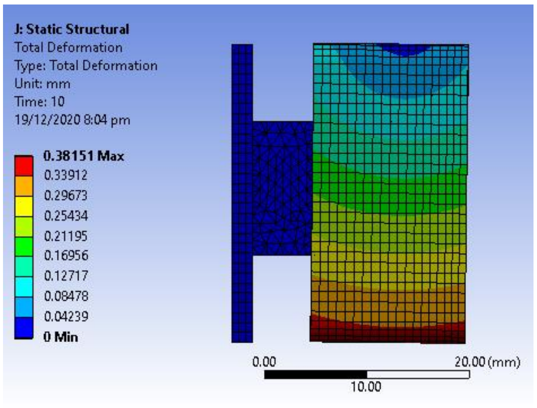


Figure 85: Mechanical element deformation ANSYS R19.2 simulation 10kN load

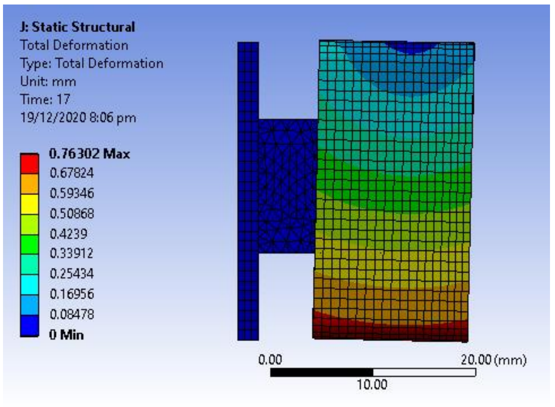


Figure 86: Mechanical element deformation ANSYS R19.2 simulation 20kN load

Additional to the consideration of the deformation, a strain vs stress graph was constructed (Figure 87). The relation between them remains linear under the simulated loads, showing that the mechanical element will remain under the elastic deformation region and operate without deformation. Given that the relation remains with twice the normal operation load, it can be expected for the piece to operate well over time (but lifetime test must be performed to ensure).

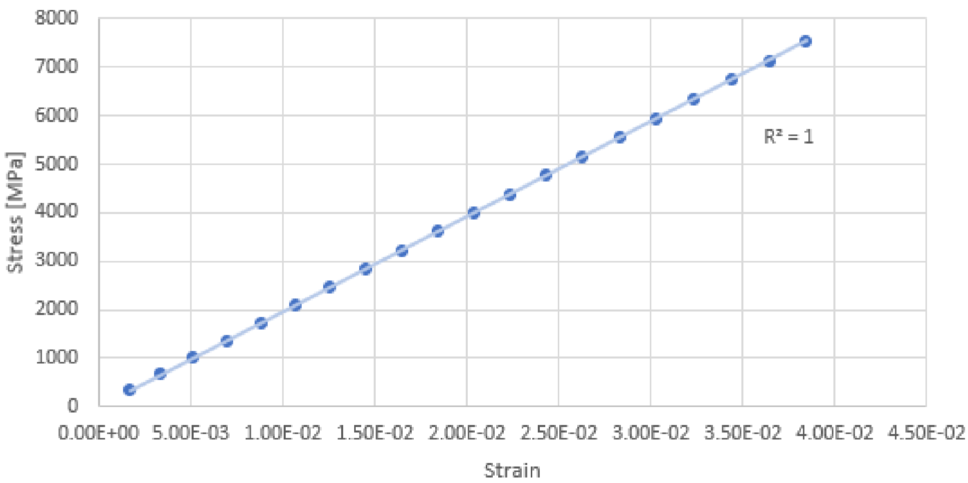


Figure 87: Strain vs Stress [MPa] of Mechanical element

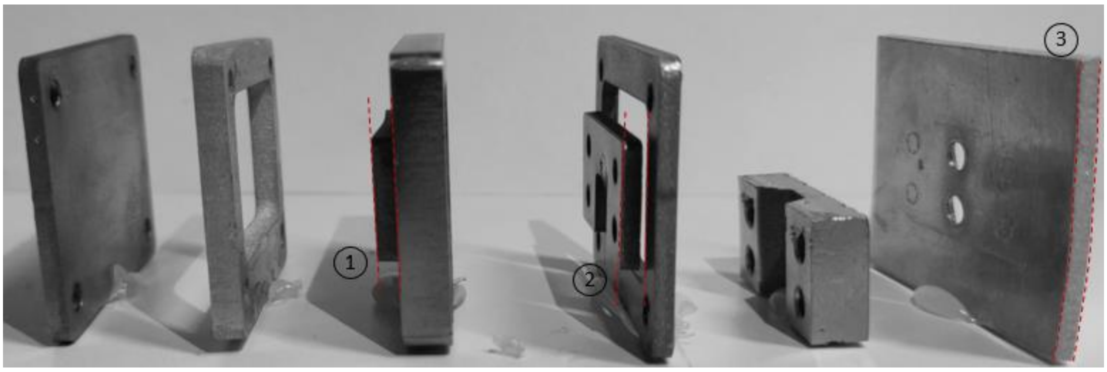
It is to mention that the simulation considers a load being applied evenly over the complete surface area of the base plate (SGBASE), while the arm finger applies the load over a moving linear area (displacing upward as the frame moves up). This is expected to have a minor effect on the application of the load, given that the extender covers the whole area of movement of the arm finger.

After manufacturing and placing the strain gauge in location, the construction was placed inside the actuator for some preliminary measurements (Figure 88). A multimeter was used to verify if any changes in resistance could be detected when moving the bed in full range of motion without any load on it (Figure 89). This resulted in a small increase in resistance (from 120.3 to 120.5). The variation, though small, was present on the piece as the actuator moved. This was expected given that the behavior of a constant load on the actuator has a quasi-linear relation with the position of the actuator, increasing as the back rest moves upwards.

Figure 88: Mechanical element in actuator

Figure 89: Preliminary test setup of mechanical element

During the preliminary testing process, to gather information of the mechanical element's output resistance over different loads, a complete mechanical failure was reached (Figure 90). Under a closer inspection, a plastic deformation on the two pieces forming the flexing plate (1 and 2) and the plate glued to the actuator (3) was found.



(1) and (2) Plastic deformation on SGFLEXER pieces (3) Plastic deformation on SGBACK piece
Figure 90: Mechanical element separated pieces after failure

The simulation was revisited in Ansys and no error was found. Additionally, a simulation was built in NX for the same construction. The resulting parameters showed similar as the ones in Ansys, with a deformation displacement of 0.494 mm (Figure 91), and similar stress and strain values.

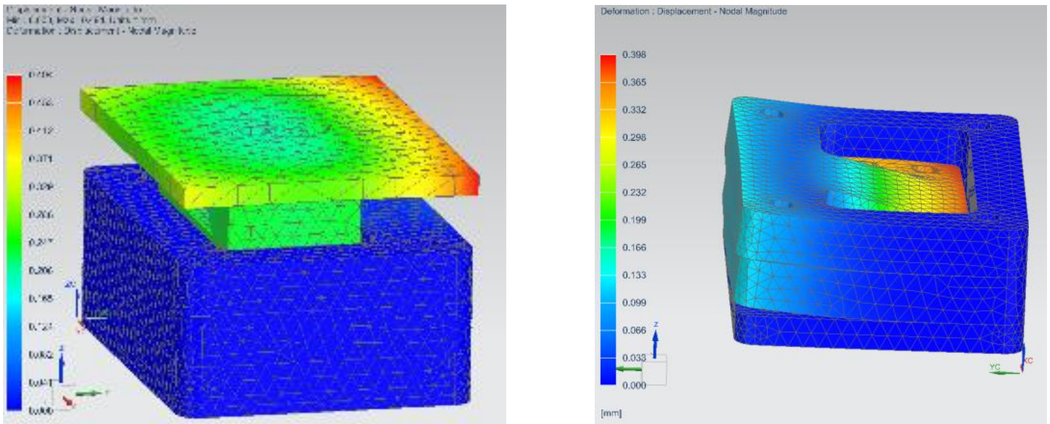


Figure 91: Mechanical element deformation NX11 simulation

The failure is attributed to a load outside of the normal operation region being applied on the edge of the back rest of the bed. This load took the piece way out of the simulated limits. Given that the bed is to operation regardless of the load placed on the bed, a re-design with a mechanical mean to stop overload on the piece is required. Additionally, further test of the loads under extreme conditions need to be input in simulation to ensure proper operation.

Due to time constraints, re-design and re-manufacturing of this pieces was not feasible. Nevertheless, the preliminary test showed that a change in resistance was measurable from the device. A smaller scale test, with a 6 mm acrylic flexing piece, was conducted using the same construction (Figure 92). This to further test the mechanical element concept. The test showed changes in resistance from 119.4 to 119.6 ohm, with a varying load of 0 to 3 kg (after which mechanical failure was achieved).

Figure 92: Mechanical element with 6mm acrylic flexer test

Signal Conditioning Element Design

When working with the Wheatstone Bridge at such small variations in resistance, the voltage difference between the unloaded state and loaded state will be very small. Also, the used gauge has a very small nominal resistance thus the output fluctuates causing noise at the output. To solve these problems, some additional circuit components were added. First, to overcome the low voltage difference an instrumental amplifier circuit is used. The circuit used was taken from the internal structure of the INA163 instrumental amplifier. (Figure 93)

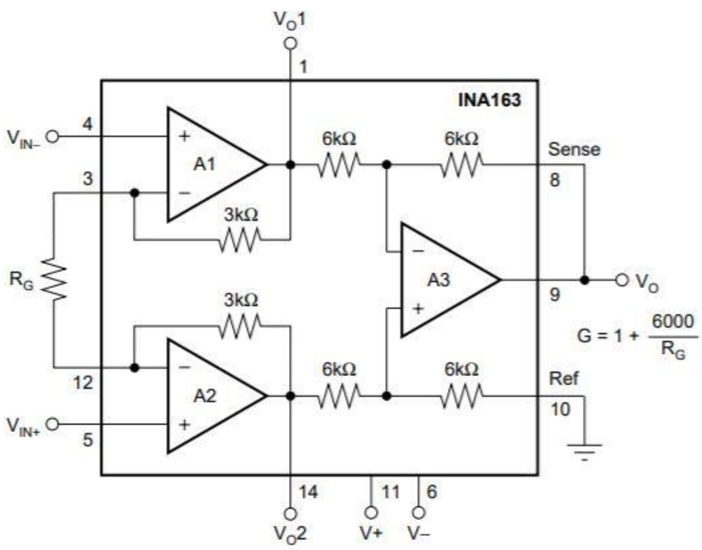


Figure 93: INA163 internal circuit

Second, to overcome the noise problem, a low-pass filter was used at the output of the amplifier circuit, (Figure 94). To determine the cutoff frequency, the gauge was connected to an Oscilloscope that gave a noise in the range of 50MHz. So, a circuit in the following configuration is used:

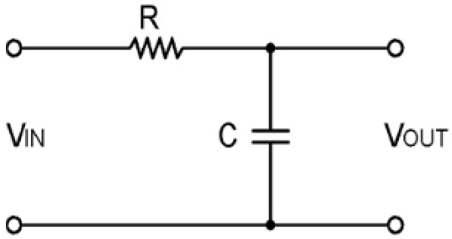


Figure 94: Low-pass Filter

The component value calculations were made such that the cutoff frequency is 53MHz, which will give values of 1.6KΩ and 1.8pF for the resistor and the capacitor, respectively.

Instrumental Amplifier

The Instrumental Amplifier (IA) is an Integrated Amplifier IC to amplify a signal. It is a type of differential amplifier equipped with input buffers that remove the need to change the input impedance and thus make the amplifier more appropriate for measurement and test equipment use. The important use of an instrumentation amplifier is that it can remove the noise that is collected by the circuit. This process of rejection noise or unwanted signals is called the common- mode rejection ratio (CMRR). Due to the high CMRR of the IA and other characteristics that it has, like high open-loop gain, low DC offset, and low drift, makes this IC a very important circuit design to use.

Working principle

For the instrumental amplifier to provide a large gain, low frequency signals of less than 1MHZ must be used. What it does is amplify the input signal while rejecting the common-mode noise present in the signal itself. Figure 95 represents the configuration of the instrumental amplifier (INA163) using two op-amps where V_{IN-} and V_{IN+} are the input voltages and V_{O1}, V_{O2} are the outputs of the buffer op-amp A1 and buffer op-amp A2 respectively. The "output phase" of the Instrumentation Amplifier is a differential amplifier, whose output V_{Out} is the amplified difference of the input signals of the buffer op-amps.

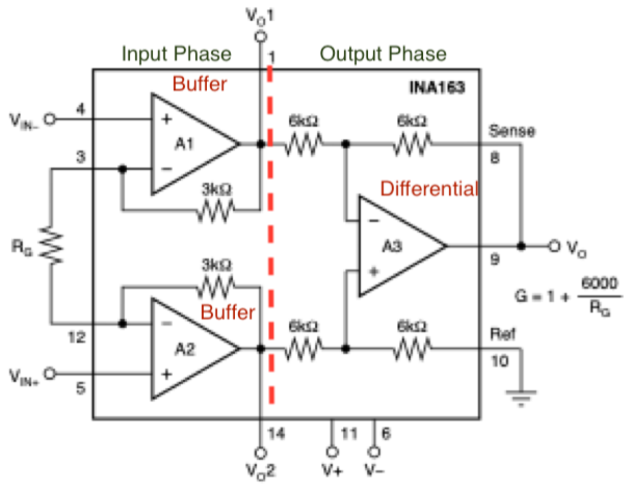


Figure 95: Instrumental amplifier (INA163) configuration [31]

Reason of using the instrumental amplifier

After building the circuit of the strain gauge sensor with the TS358 amplifier [25], which is an operational amplifier, this op-amp introduced several problems and difficulties in design (Figure 96). The main issue of using a single op-amp as a differential amplifier is the lower CMRR. Having the Wheatstone bridge in the design produces a lot of noise, after the signal passes through the op-amp, the output signal is an amplified signal with amplified noise, it is shown in Figure 97. To avoid this issue, the decision of using the instrumental amplifier was made. Because the IA can amplify the signal while removing the noise.

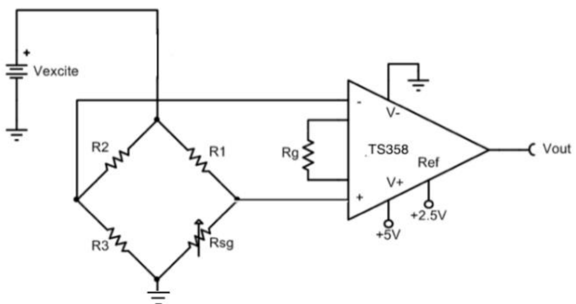


Figure 96: Schematic of the Strain Gauge with TS358

Figure 97: Test result of the strain gauge circuit with OP-amp in a digital oscilloscope

Circuit implementation of the strain Gauge sensor

Figure 98 shows the design of the strain gauge which precisely measures the resistance of a strain gauge taking a place in the Wheatstone bridge configuration. The changes of the resistance of the strain gauge make a differential voltage, which will be amplified by an instrumental amplifier. The instrumental amplifier reference voltage and the bridge excitation voltage is supplied using the shunt regulator TL431. During the process of preparing to build the circuit, the order of the instrumental amplifier chip got delayed and did not come in time. So, our own instrumental amplifier was designed by using the internal schematic design of the INA163. After the chip arrived, the circuit has been rebuilt by using the actual chip of the IC. But it made a lot of noise in the results that was not introduced by the designed circuit. It was decided to stick with the first built circuit.

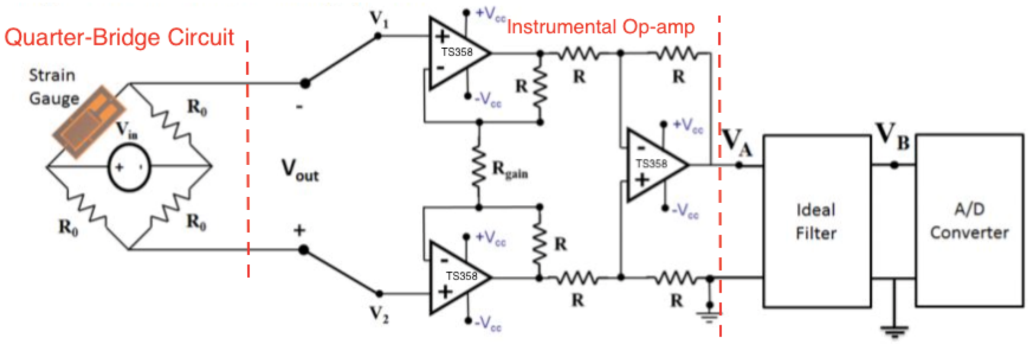


Figure 98: Schematic of the Strain Gauge Circuit [48]

Designed details/measurements:

- Supply Voltage: 5 V
- Bridge Excitation Voltage: 2.5 V
- Strain Gauge Nominal Resistance: 120 Ω
- Resistors of the bridge, Ro: 120 Ω to balance the bridge and measure the change of the sensor's resistance.
- Reference Voltage: 2.5 V
- V_A: Output Voltage of the circuit before filtering. / V_B: output voltage after filtering.
- $R_{gain} = 10\ \Omega$. from $G = 1 + \frac{6000}{R_{gain}} = 600\ \Omega$
- Gauge Factor: 2.00 (Nominal) [26] $\frac{\Delta R}{Ro} = K \cdot \varepsilon$

$$\rightarrow \Delta R = K \cdot Ro \cdot \varepsilon = 2 \cdot 120 \cdot 0.005 = 1.2\ \Omega$$

Where K: gauge factor ε: mechanical strain of the sensor = 0.005 Ro = 120 Ω

The change of the resistance of the strain gauge:

Minimum Resistance = $120\ \Omega - 1.2\Omega = 118.8\ \Omega$

Maximum Resistance = $120\ \Omega + 1.2\Omega = 121.2\ \Omega$

The range of the output voltage of the bridge can be calculated by the equation bellow:

$$V_{out} = \left[\frac{R_{SG}}{R_{SG} + Ro} - \frac{Ro}{Ro + Ro}\right] \cdot Vexc$$

$$V_{out-MAX} = \left[\frac{118.8\ \Omega}{118.8\ \Omega + 120\ \Omega} - \frac{120\ \Omega}{120\Omega + 120\Omega}\right] \cdot 2.5\ V\ =\ 0.006281V$$

$$V_{out\_MIN} = \left[\frac{121.2\ \Omega}{121.2\ \Omega + 120\ \Omega} - \frac{120\ \Omega}{120\Omega + 120\Omega}\right] \cdot 2.5\ V = -0.006218V$$

These voltages are the input voltage to the amplifier, so that the Arduino can read the signal and collect some meaningful data.

Shunt regulator TL431 [27]

As it has been mentioned before, the shunt voltage regulator is used to get the instrumental amplifier reference voltage and the bridge excitation voltage to be 2.5 V. By using an external voltage divider, the 5V can be regulate down to a voltage of 2.5V by using the TL431. Figure 99 shows the designed circuit, it is a very simple circuit of a TL431 chip with a resistor. When the voltage on the reference pin is above 2.5V, the current flow will be between the cathode and anode pins by the transistor output.

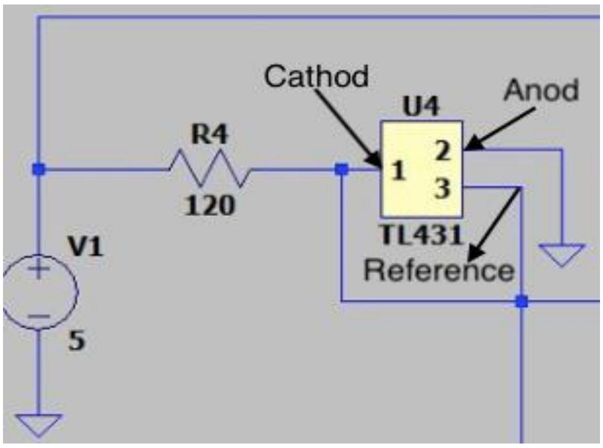


Figure 99: Schematic of the shunt regulator circuit

Testing and Results

Before doing any real-life testing, a simulation model was built (Figure 81). The goal of the simulation was to make sure that the circuit is visible before actually attempting to build it on a breadboard. When simulating, the Strain Gauge was represented by a resistor with the value of the Gauge available (Figure 100).

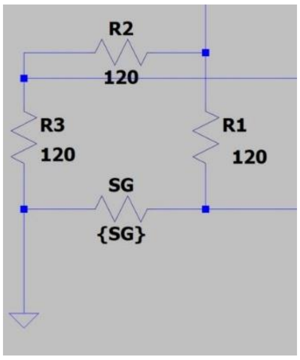
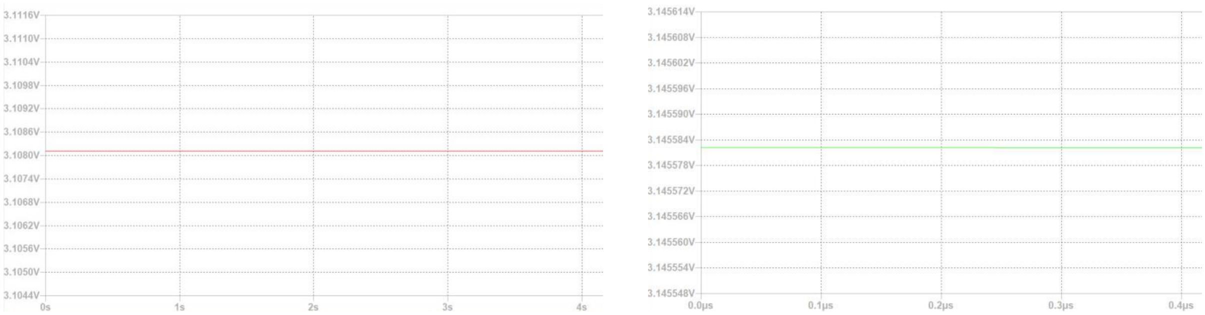


Figure 100: Strain Gauge representation

The simulation was build using the IA INA163 and with the internal circuit of the IA. The two circuits behaved very similarly, with both circuits giving a value of around 3.1V. (Figure 101)



(a) Simulation result with IA internal circuit

(b) Simulation result with INA163

Figure 101: Circuit Simulation results

The testing phase was divided to two parts, first one is testing the full circuit with a power supply and a multi-meter to see the output voltage of the circuit. The result of this test is shown in Figure 102 and Figure 103.

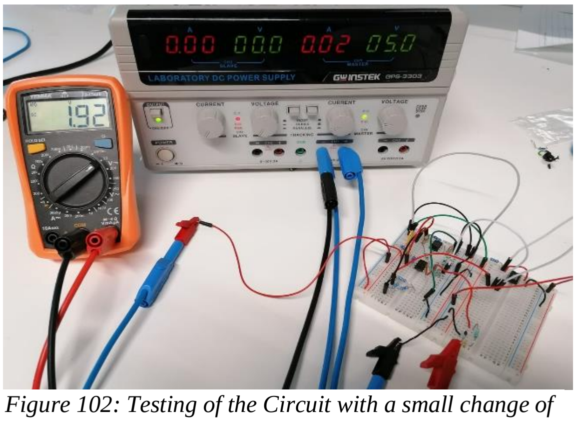


Figure 102: Testing of the Circuit with a small change of the resistance of the Strain Gauge

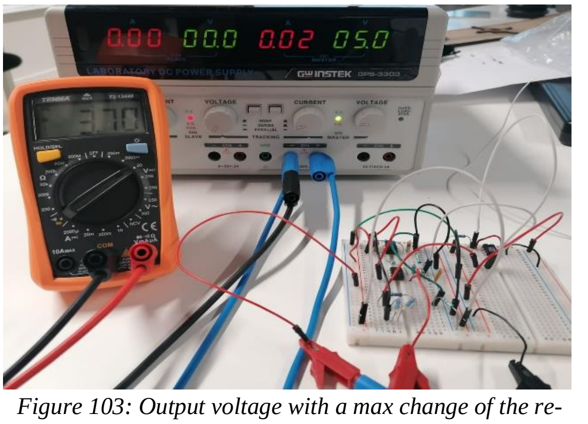


Figure 103: Output voltage with a max change of the resistance of Strain gauge

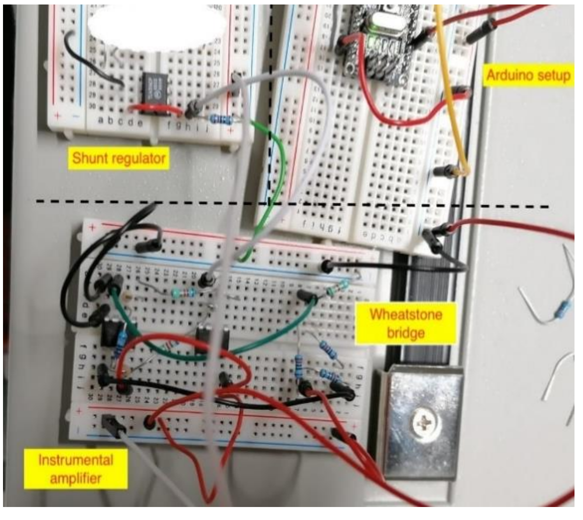


Figure 104: Close-up picture of the circuit

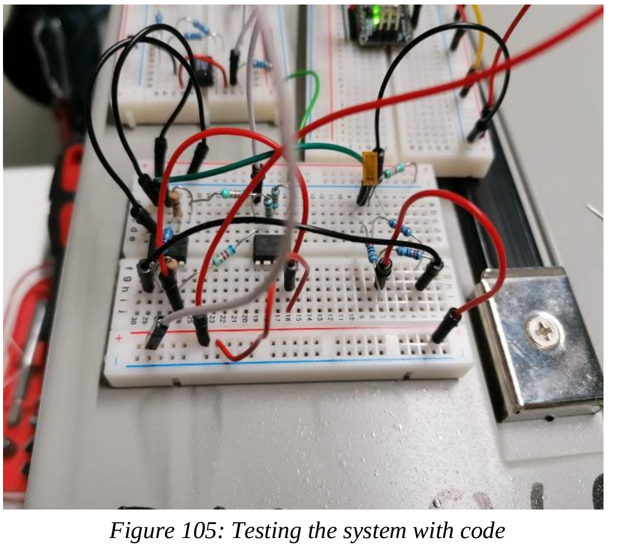


Figure 105: Testing the system with code

It clearly shows the output voltage of the circuit not the same 1.92Volts and 3.7Volts, and that is due to the change of resistance of the strain gauge. The small difference in voltage between the simulation and real-life, is due to the gauge being bent a bit during real-life testing and the gauge being so fragile, it was just kept the way it is. The second part is to test with the Arduino. Once both sides of this part of the project were put together, they could be tested and calibrated together as seen in Figure 104 and Figure 105. The results of these tests proved that a working system for measuring and gathering data has been accomplished.

After finalizing the circuit and the components, an eagle design was made. (Figure 106)

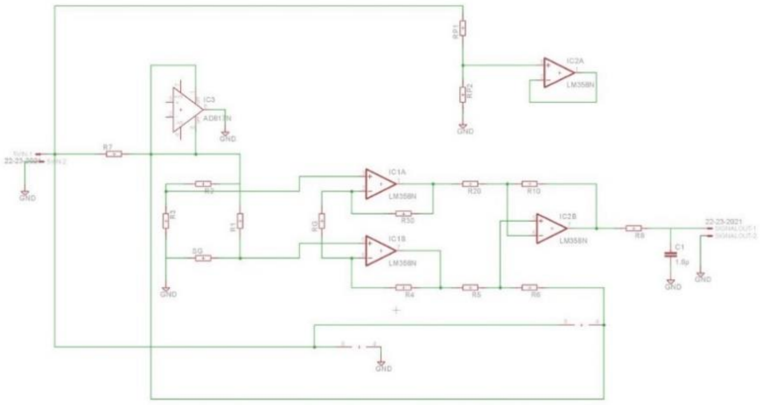


Figure 106: The design of the circuit on Eagle

From this circuit a PCB was designed. (Figure 107)

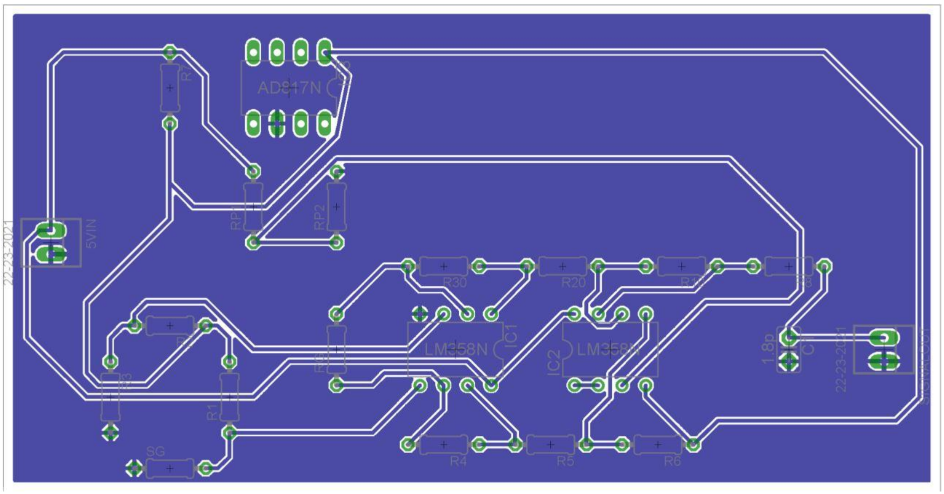


Figure 107: PCB layout

HX711 solution

The HX711 is 24-bit analogue to digital converter and is designed to facilitate the use of weight scales as well as interface in a direct manner with strain gauge and bridge configurations. It is suitable for industrial process control and it incorporates a programmable gain amplifier (Figure 108).

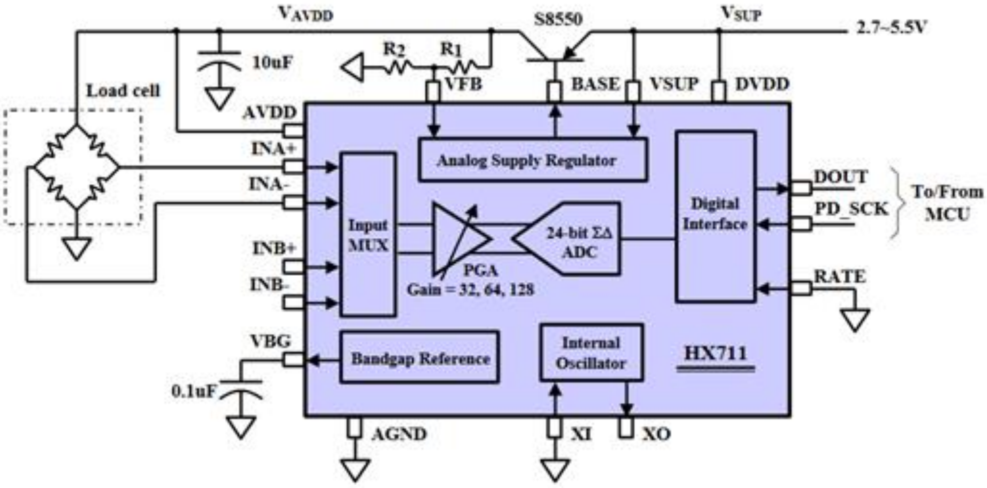


Figure 108: The HX711 internal schematic with a Load cell

Function

A load cell using a strain gauge can be directly powered by the board and the input signals can be connected either to channel A or channel B of the input multiplexer. Channel A is connected to the programmable gain amplifier and the amplification rate can be selected as 128 for a full-scale differential input of ±20mV or 64 for a differential input of ±40mV respectively with a 5V power supply connected to the AVDD pin. Channel B offers a fixed ratio of 32. To ensure an accurate output data rate, the microcontroller's clock is selected. The maximum sample per second the amplifier can provide is 80 SPS and the data is transmitted in a 24-bit format, according to the 2nd complement. Should the differential input signals get out of the range of 24 bits, the output data gets saturated at values 800000h and 7FFFFFh for minimum and maximum range respectively until the signal returns to the 24-bit range.

The serial communication is achieved through the DOUT and PD_SCK pins which facilitate data retrieval as well as channel, gain and power control selection.

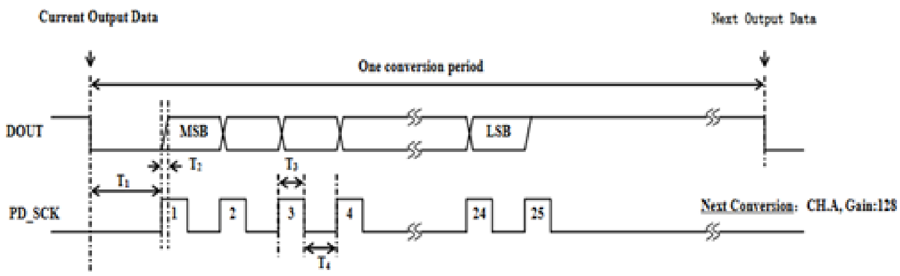


Figure 109: Timing diagram for HX711

Once the DOUT pin is set to low, the data extraction can start. The clock signal is providing 25 pulses and the output is initiated, shifting 1 bit from the convertor to the output per pulse. On the rising edge of the 25th pulse, the DOUT is set again to high, to prepare for the next conversion (Figure 109). However, if an interrupt occurs in the microcontroller and the T3 is delayed more than 60 μs [28], then the chip is powered down, until the PD_SCK returns to low. After such reset, the default settings are applied, which mean channel A is selected along with the 128 gain.

Calibration

The module initially reads a voltage stored in 24 bits. To properly calibrate it, a known strain has to be applied to the strain gauge. An adequate method is to use 2 calibration tests with 2 different strain values. Let us assume the equations will be as following:

$$Value1 = ADC_{value1} \cdot Coefficient + C$$
$$Value2 = ADC_{value2} \cdot Coefficient + C$$

For known values of strain (values 1 and 2) the microcontroller will receive the digitalized ADC values. From there, since it is a 2x2 system, the coefficient and the constant C can be calculated. From an early experimentation, mostly the first 16 bits of the ADC were reliable. Last 8 bits seemed to be affected from noise, so eventually they would have to be cut off from the code.

Advantages of HX711

The main advantage of using this specific module is the 24-bit resolution. The implementation of the instrumentation amplifier can be more precise and offer higher amplification rates, however it relies on the microcontroller's analogue to digital converter. In the case of Arduino's ADC, the digit range is 10 (1024 value), so some accuracy has to be sacrificed.

Disadvantages and arguments against the use of HX711

Load cells tend to have a relatively low frequency response; hence it was thought that the particular chip with 80 SPS would be integrated in the final solution. However, for more reliable data that are ultimately fed to the Artificial Intelligence, a higher sample speed was selected, constituting the HX711 hard to integrate in the embedded solution.

Another point to be made, is that the input signals might get lower that the suggested threshold. This means that it would be hard for the amplifier to detect whether the actual differential signal is a signal and not noise, which can be addressed on a custom board, but this stands as an argument against the use of HX711.

An approach to the sensor circuit

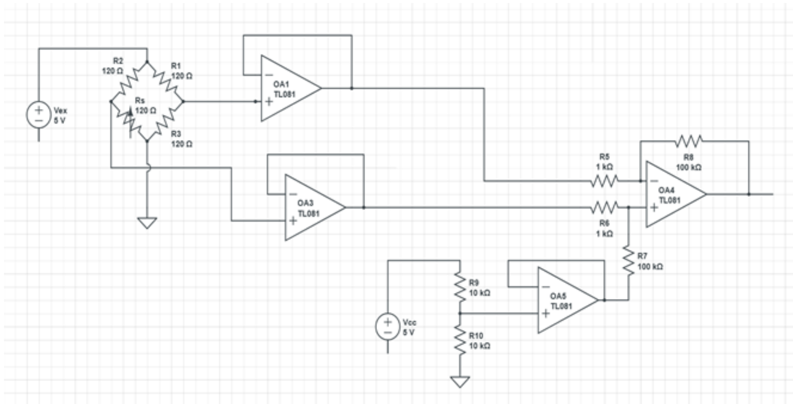


Figure 110: An early alternative to instrumentation amplifier

The above circuit (Figure 110) utilizes a Wheatstone bridge with the strain gauge and 5-volt excitation voltage to obtain 2 differential signals. These signals are then fed to unity feed buffers, which protect the signals from interference from the differential amplifier's impedance difference. The non-inverting part of the differential amplifier is also lifted to theoretical 2.5 volt from a voltage divider circuit powered by the supply.

The output voltage of the above circuit is calculated as [29]:

$$V_{out} = A \cdot V_{diff} + V_{offset}$$

Where A is the Gain and V_{diff} is the full range differential input. The concept behind the addition of the offset voltage is to raise the output of the amplifier and force it to swing around 2.5 volts, which is the middle range of the Arduino's ADC.

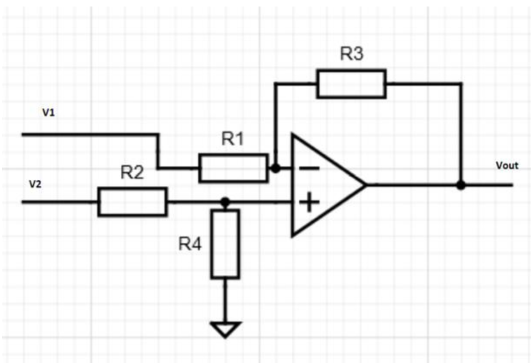


Figure 111: Differential inverting amplifier

The standard differential amplifier with two input signals V1 and V2 can be seen in (Figure 111). The non-inverting part is directed to the ground or connected to a voltage source as seen in (Figure 112). The output equation can be easily reduced to [29]:

$$Vout = -V_1 \cdot \frac{R_3}{R_1} + V_2 \cdot \left(\frac{R_4}{R_4 + R_2}\right) \cdot \left(\frac{R_3 + R_1}{R_1}\right)$$

It is a common practice in amplifier circuits to equal R1 and R2 as well as R3 and R4. Hence, the above equation can be reduced even more:

$$Vout = \frac{R_3}{R_1}(V_2 - V_1)$$

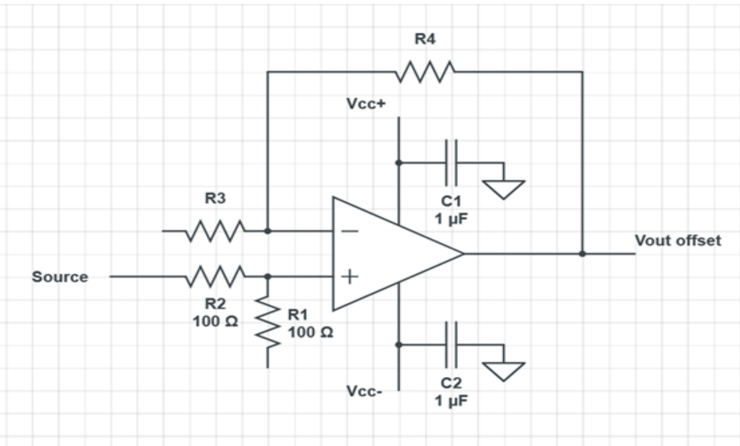


Figure 112: Op amp configuration with an extra source

In the above circuit (Figure 112) R1 and R3 are connected to the differential inputs, which is a demonstration of the offset voltage source on a differential amplifier, after implementing the superposition principle two times on the inputs of amplifier, the following equation is formed [29]:

$$Vout_{offset} = Source \cdot \frac{R1}{R1 + R2} \cdot (\frac{R4}{R3} + 1)$$

Reasons for not implementing the circuit

The above circuit was being built part by part and was an early attempt to feed the sensor's data to the microcontroller. However, the Lm358 and TL081 are prone to noise, and despite decoupling and bypassing efforts, it was rather hard to achieve desired amplification of the signal. Differential amplifiers offer lower CMRR than instrumentation amplifiers [30] [25] [31] and the circuitry required is much greater than the IC of the instrumentation amplifier. What is more, the behavior of the differential amplifiers in the setup had been bizarre at points, where although powered by a dual supply, in a testing with a frequency signal, the negative part of the pulses was being canceled. Last but not least, if powered by 5 volts, the Lm358 can struggle when the output voltage exceeds the 3.5 volt, since it is unable to power it [25]. All in all, the team decided not to proceed with this solution, so the focus was shifted to the Instrumentation amplifier.

Signal Processing Element Design

After receiving a clean voltage out of the circuit, processing must be done to determine a collision. This process is complex given that the behavior of a collision must be clearly differentiated, with a high level of certainty, from any other action on the bed. Machine learning was researched to accomplish this task. Given the amount of time available to the project and the complexity that machine learning implies an experimental approach to this was taken.

Speculations of the form of the data were analyzed, determining that no certain shape of this phenomenon could be concluded without a constructed measurement system. Additionally, it was found, that no way of knowing how other actions on the bed would be represented was possible. In the time of development of the sensing and signal condition elements of the measurement system, a development Graphical User Interface (Figure 113) was built in python to make the process of data gathering and analysis quicker. It was decided to use python because of the extensive machine learning support provided for this programming language [32].

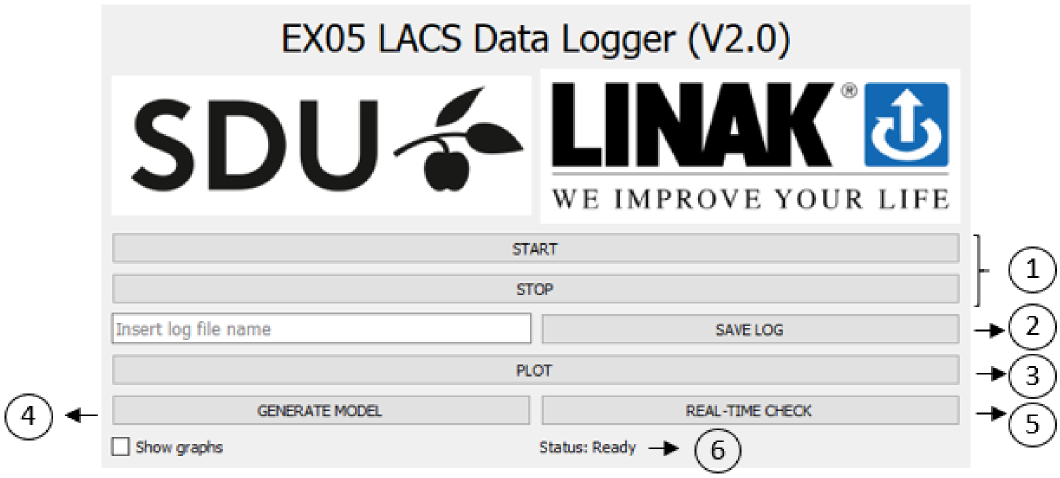


Figure 113: Development GUI of measurement system

Training data is a crucial input for Machine Learning to generate future predictions. The GUI allows for data to be read, logged, saved, and input into a code to generate the Machine Learning algorithm. Said model is then exported as a Python SAV file that can then be input with real time readings and detect collisions. For the training data to be input, an Arduino is used to send the ADC readings through serial to the computer handling the GUI. The Arduino is also responsible of sending a user determined collision or normal operation status during readings (Figure 114).

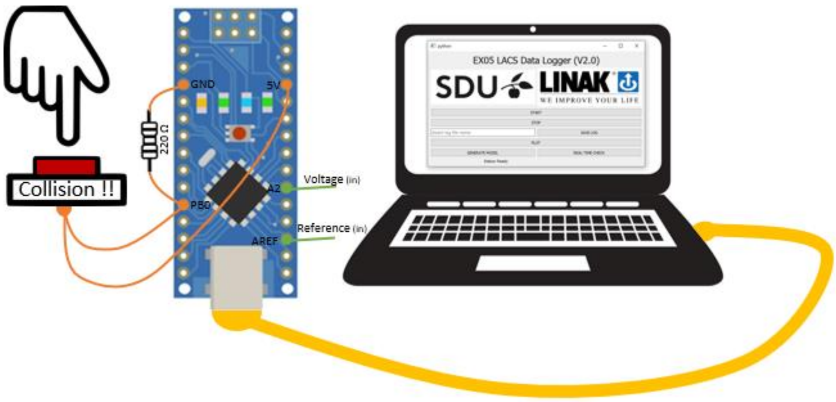


Figure 114: Data collection setup

The Arduino code, in C, can be found in appendix IX. The Arduino's ADC is set to a voltage reference based on the value indicated by the circuit, and two consecutive serial frames are sent with both the resulting value and the status (Figure 115).

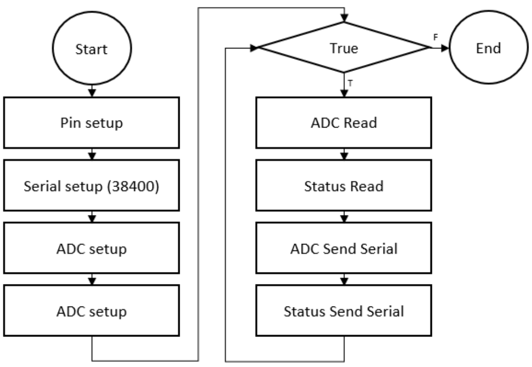


Figure 115: Arduino code flow

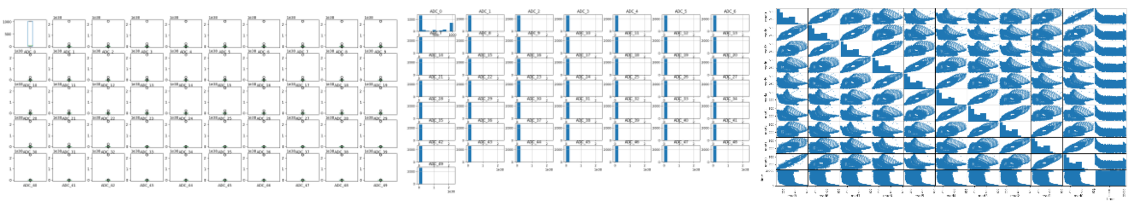
Data logging begins when indicated in the GUI (Figure 113.1). This opens the USB port in which the Arduino is connected and continuously reads serial. Multithreading is used to allow the GUI to run while the operation is being performed (appendix X). This also ensures that the data reading is uninterrupted by other applications. Data logging termination is indicated by the stop button. This stores all the read values into a temporary raw text file with three values per sample; received time, ADC value and status.

The log can be saved if desired by introducing a name in the filename field and pressing the save log button (Figure 113.2). This generates three files; a simple text file with the previously defined values, a two-column text file used for the plotting functionality and an expanded CSV format file which contains the same readings as the original log but is expanded to contain a history of 50 old readings and labels for each column. The CSV file is a standard representation that is portable and ready for predictive modeling learning.

Having an existing log allows to use the plotting functionality (Figure 113.3), which gives a chart of ADC reading with respect to time. This allows to have a visual representation of what the machine learning algorithm is expected to detect and to ignore.

It is at this point that the machine learning model can be built. The Generate Model button starts a sequence of events that takes care of this actions. The dataset (from the CSV file) is loaded, and its dimensions are taken. A peek of the data is displayed on screen to ensure that the data was loaded as expected. Each attribute is statistically analyzed so that the mean, median, standard deviation, among others can be visualized by the developer. This analysis allows for detection of errors prior to the model building. A class distribution is also displayed so that the number of collision and non-collision instances is known.

The button can also optionally display some data visualization aids. Univariate box and whiskers plot (Figure 116a) and histograms (Figure 116b) are first shown to give a clearer idea of the distribution input attributes. Multivariate plots are then shown, which are helpful to spot structures relations between input variables (Figure 116c).



(a) Box and whiskers sample plot *(b) Histogram sample plot* *(c) Multivariate sample plot*

Figure 116: Visualization aids of data

Machine learning contains many algorithms. The algorithms are usually suitable for different kind of data and is selected based on the behavior of the same. As seen in Figure 117, the number of algorithms is big and choosing the right machine learning algorithm without any previous work on the field is challenging.

Figure 117: Mind map of some available machine learning algorithms [33]

Since it is not certain which algorithms would be good for this problem or what configuration to use, a mix of the most common simple linear and nonlinear algorithms was chosen. If real life data had been gathered, the relations of the multivariate plot would have aided in the decision of the algorithm, with a partial linearity being the best scenario for good results. The used models were as follows.

The logistic regression algorithm (LR) [34] is a classic linear method for binary classification. This model is like linear regression with difference in the prediction since the linear regression predicts numerical values rather than two class labels. Given the number of dimensions, a target variable n-dimensional hyperplane to best separate both classes are created. Denoting the input data X with m samples, and the output y with one output for each input, the model is defined in terms of coefficients (β), with one coefficient per input and an additional intercept coefficient (β_0).

The prediction model for a given input, denoted $\hat{y}$

$$\hat{y} = model(X)$$

A given input is predicted as a weighted sum of the inputs

$$\hat{y} = \ \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_m x_m = X * \beta$$

Given the logistic function:

$$f(x) = \frac{1}{1 + e^{-x}}$$

Replacing x with the weighted sum to obtain the model:

$$\hat{y} = \frac{1}{1 + e^{-(X*\beta)}}$$

The Linear Discriminant Analysis algorithm (LDA) [35] looks to maximize the separability among known categories. This is done by creating an axis based on the data, on which the all the data is projected to maximize the separation of the two categories (Figure 118). The axis is created based on a maximization of the means distance and a minimization of the variation (called "scatter" and denoted s^2in LDA). This is a very powerful algorithm as it allows to represent the n-dimensional data collected in a 2-axes that maximize the separation of the two categories. The axis taken are the ones with the most variation in the categories.

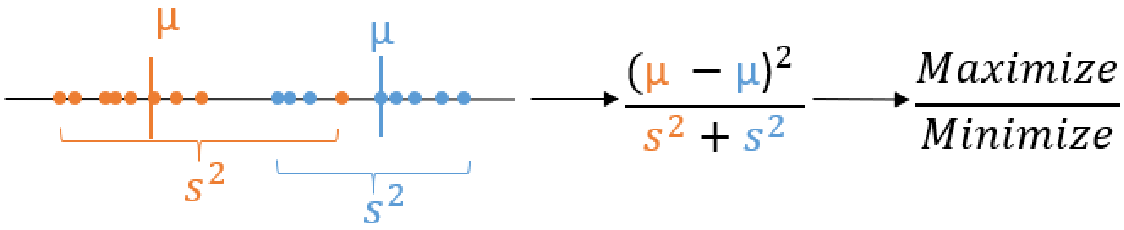


Figure 118: One-dimensional representation of LDA

The K-Nearest Neighbor Algorithm (KNN) [36] is a model that makes predictions using the training dataset directly. The class of a new input is determined by searching through the entire set and identifying the K most similar input in the dataset and assuming the output value of those K inputs (K being the neighbors). To determine which of the K inputs in the dataset is most similar the Euclidian distance is measured (other common distance measurements are Hamming, Manhattan and Makowski distance). Denoting the new input x, the existing input x_i across all inputs j:

$$Euclidean\ Distance(x, x_i) = \sqrt{\sum (x_j - x_{ij})^2}$$

The Classification and Regression Trees (CART) [37] algorithm consists of a Decision Tree. This algorithm is the base for bigger algorithms like bagged decision trees, random forest and boosted decision trees. The CART model is created by selecting split points in the input variables until a suitable tree is constructed. The selection of input variable to use and the specific split is chosen with the greedy algorithm to minimize a cost function. This is a numerical procedure in which all the values aligned and split in different locations, testing with a cost reduction function. The results of all the splits are then compared and the one with best cost is selected. The binary splitting this algorithm undergoes needs to know when to stop splitting. This is commonly done by using a minimum count on the number of training instances assigned to each leaf node.

The Gaussian Naïve Bayes (NB) [38] is an algorithm used for classification of binary problems. The calculation of probability of each instance is calculated to be tractable. It is based on the Bayes Theorem which allows to calculate a posterior probability from a prior probability. The algorithm calculates the probability for different hypothesis and selects the result with the highest probability (known as Maximum a Posteriori). This can be written as:

$$MAP(h) = max\big(P(h|d)\big) = max\left(\frac{P(d|h) * P(h)}{P(d)}\right)$$

Where;

$P(h|d)$ is the probability of hypothesis h given the data d
$P(d|h)$ is the probability of data d given that the hypothesis h was true
$P(h)$ is the probability of hypothesis h being true (regardless of the data)
$P(d)$ is the probability of the data (regardless of the hypothesis)

The Naïve Bayes theorem can then be extended to real-values attributes by assuming Gaussian distribution.

The Support Vector Machines (SVM) [39] algorithm is a model that generates an n-dimensional hyperplane as a Support Vector Classifier which is then used to predict new observations based on their location relative to the hyperplane. This hyperplane is calculated by use of the inner product of two given observations. All the data is then displaced towards the hyperplane generated and reduced one dimension. This algorithm is very powerful as it allows to generate a model even when misclassifications and outliers occur.

The collected data after the logging phase is then split into 80% training sample, and 20% validation sample. All algorithms were set to reiterate their calculations through 100 cycles before testing themselves with the full dataset (appendix XI). The success was measured and returned as a number between 0 and 1 (with 1 being 100% effective). Based on this, the most suitable model is exported into a SAV file that can later be accessed by the real-time operation function.

By testing a wide range of algorithms, it was aimed to determine if a machine learning solution is viable. It is important to mention that for any of these algorithms to work a large sample of quality data is required. It would be needed for real life data to be recorded as normal operation, while hundreds of collisions logged in through the development GUI are also added.

The Real Time Check functionality of the GUI (Figure 113.5) is currently under development. It can now take an existing log and run it through the last saved model created with the Generate Model button.

This results in the model being tested with a completely new dataset, returning its success rate as a number between 0 and 1.

The status of the GUI is given at all moments on the bottom of the window (Figure 113 point 6). It is here that all user instructions, problems, and errors are displayed.

Measurement system results

Working with the different elements of the measurement system, it was found that the strain gauge is a viable way to measure the load. The mechanical element, converting load to strain, provides a good approach to give an input to the strain gauge, but further improvements must be made to ensure that operation can continue in the piece even the normal load is exceeded. A physical mean to directly transfer the excess load to the actuator itself must be implemented to ensure operation under the same load as the actuator itself.

The IC is currently in an operational state with pending manufacturing. Further research to improve the noise present in the signal, as well as increase the voltage range output of the Wheatstone bridge must be conducted to have an even more reliable circuit. Current setup, though sufficient for development, must be improved as a collision detection must be guaranteed before placing in the market and an unreliable signal could easily result in a false trigger even with a machine learning algorithm in place. A frequency signal design also needs to be researched, as the current DC circuit with its low amplitude signal results challenging to work with.

A long path remains in the implementation of a machine learning algorithm capable of detecting a collision. The designed development GUI paves the way to explore the feasibility of a wide range of machine learning algorithms and allows for a broad view of how different data samples behave under very different mathematical models. Real time reading with the constructed model, as well as communication with the actuator is to be implemented to the GUI as to further verify the model's efficiency. A large data sample of real-life non-collision, as well as collision, is essential for proper construction of the model.

Marketing plan

Market research

Looking into the market for adjustable beds, the prices vary and so does the quality. Moreover, the beds come with different features to ease and provide more comfort for the customers. However, the IEC standards [8], soon to be followed by the producers, have stated some requirements to ensure higher safety around among others adjustable beds.

With LINAK's vision of implementing Google Assistant or Alexa, the anti-pinching system will be more important than before [40]. The fact that you are not able to stop the bed once it is moving, makes it dangerous in cases where e.g. a child or a pet has crawled under the bed. Some beds on the market already connect with Google Assistant and Alexa, however they do not include safety features to prevent accidents caused by collisions [41]. Therefore, as stated in the State of the art section, LINAK will need to implement this in the future, making it better than the current solutions on the market.

The Smart Home features on the market are more focused on sleep tracking and adjusting the bed according to several factors [42]. They work with an app and connect to several other Smart Home devices such as heaters, music and curtains. Some of the beds automatically adjusts according to sleep position and if snoring occurs. These beds operate without the usage of the remote with the biased-off switch. Therefore, accidents can happen, especially if children and pets are around during the night.

User research

In order to make a market strategy, a user research is necessary and important to gain an overview of the market and how the users interact with it. This knowledge is useful for the development of a solution to the project. The user research for this project is designed to include qualitative and quantitative research methods. The combination of the two data types can improve the evaluation by ensuring that the limitations of one of them can be balanced by the strengths of the other.

Qualitative research

It was decided to use the qualitative research method and interview the retailers. It allows the interviewer to get an overview of the "heart and mind" of the person selling the product. It is easier for the retailers to express their extensive knowledge about the customers and the safety of adjustable beds if the questions are not data or number driven. The interviews were arranged by contacting the different retailers in town and get an appointment with them. This resulted in two interviews, one with the founder and COO of SengeSpecialisten and another one with the Chief Consultant of Wonderland's Danish department.

The COO Jørgen Staal made it clear that the number of beds with safety features has decreased through the years due to the lack of interest from the customers. Beforehand the beds in the more expensive range would have some sort of anti-pinching system with foam or a lot of sensors. The foam solution is still used, but at the expense of the overall aesthetics. Therefore, these beds are not as popular due to the customers being more interested in comfort, design and price, making safety and Smart Home features less valued. Despite that Jørgen Staal is confident that adding a safety feature like an add-on would be able to sell, especially to engineers and people working with children. Also, the feature with a voice-controlled bed is something that they already have in store, however it is not easy to use if the users do not speak proper English. Hence a solution connecting to Alexa or Google Home would provide an option of being able to control the bed speaking Danish and mispronounced English. Something that the group working with marketing, saw a need for when visiting SengeSpecialisten in Sønderborg. Here the design of the foam solution was checked as well and information gathered from the main salesperson in the shop. Adding to this, Jørgen Staal said that the salespeople at times emphasize the fact that the bed is adjustable through the app, but he is not sure that the customers even use it. Furthermore, features like easy cleaning has proven to be a good function to pitch for the customers, especially the female ones. Here the beds from Auping have implemented the function of the bed moving to the highest level at which is possible for easier access to clean the bed underneath.

Taking this information attained from the interview with Jørgen Staal it was possible to liken it to the interview with the Chief Consultant at Wonderland Jesper Nielsen. He made it clear that their customers at times ask for safety, but they are more interested to know if they will be shocked due to the actuators being connected to a power outlet. Also, he made it clear that the sensor solutions they had before was not reliable and the number of cables scared people away. However, he confirmed that the market for adjustable beds in Denmark is rising as people realize the practical benefit of having an adjustable bed. For that, Jesper mentions that their customers use the bed as a furniture for work, eat, relax and nursing. In addition to that, he adds that the customers are more interested in alarm functions and memory for bed settings. Consequently, he concludes that the generation for these Smart Home features are not buying adjustable beds yet. But, if it is possible to brand the solution as an add-on, and people can buy it if needed, then it will be easier to sell. Moreover, an important part of a safety feature would be that it should not be too sensitive, and it should be possible to overrule the safety feature by pressing two buttons at a time. Concluding that the user friendliness and reliability is essential and crucial for them not to risk getting any complaints.

Quantitative research

In order to get information about a potential end-user of the anti-pinching system included in the adjustable bed, the quantitative research method was used. It gives the opportunity to identify the attitude of the potential target groups about this product by using the numbers of the results to create tendencies of the questionnaire participants. For designing the questionnaire, the model seen in Figure 119 was used. This approach shows the different possibilities for primary research and helped to create a structured survey. As contact method the Internet was used in form of links and QR codes to the survey website. This was needed to achieve our below calculated sample size.

Figure 119: Primary data collection research design

The objective of this survey is to identify a marketing strategy for adjustable beds with an anti-pinching solution. This will be achieved by presenting different selling points of such a solution and analyzing which age group prefers which feature and is willing to pay more for it. Therefore, the target group of the questionnaire is limited to people which are above 19 years old. The sample size was calculated by taking the population of Denmark (above 19 years) as the "target group" of about 4.500.000 people [43], a confidence level of 95% and a confidence interval of 10. By use of the Cochran's formula the sample size is 96. Everything above this number will give an even better overview of the population's desire but exceeds the survey resources for this project and is not deemed necessary.

The survey participants are divided in different age groups in order to find age related tendencies like younger people preferring the Smart Home feature or parents preferring the anti-pinching feature. The age groups are not structured by the official generation outline because this doesn't fit the approach of the questionnaire but by experience of how interests in technical or safety features are distributed. The following age group structure seen in Figure 120 is used in order to create the analysis of the survey answers:

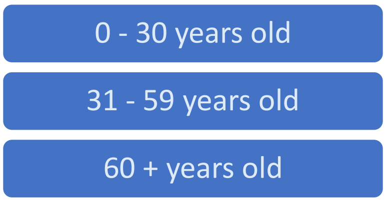


Figure 120: Age group variables

The survey was accomplished by use of "SurveyXact" which offers analysis tools and a final statistical report of the combined analysis for the English, Danish and German survey version. The questionnaire is created in several languages due to the international environment in Sønderborg. Before the analysis of the survey, hypotheses were created. They were also the guideline while creating the survey. As mentioned above the surveys' purpose is to find out if people are aware of the problem of pinching or accidents with adjustable beds at home and to identify customer groups. It is expected that the 0-30 years old age group will prefer the Smart Home feature due to a better understanding and higher need of technology. Parents with children at home are mainly represented in the age group from 31 – 59 so therefore the preference of an anti-pinching feature for more safety in their everyday-life is predicted. Housewives might also see a big use in the feature for a simpler cleaning. This choice of feature is also projected for the oldest age group since the physical ability decreases with increasing age. In addition to that, it is expected that pet owners and people with children at home see a bigger use in an anti-pinching feature than people without.

The analysis of the survey is structured so that above mentioned hypotheses can be either proved right or wrong. The first questions, if people are aware of the problem with pinching was answered by following graph, seen in Figure 121.

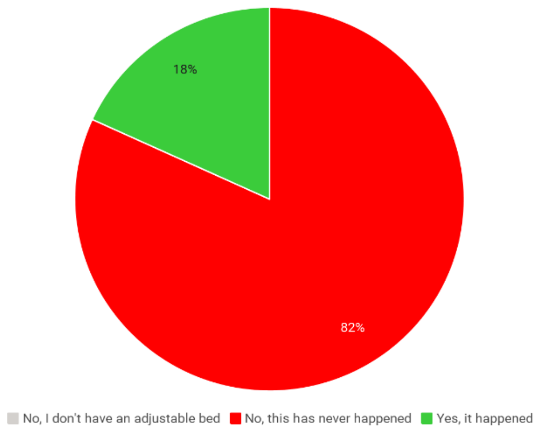


Figure 121: Experiences with accidents with children and pets for people with adjustable beds

Looking at the people with an adjustable bed, it shows that 18% of them have experienced pinching or an accident with pets or children at the adjustable bed. This is an unexpected answer, since it was assumed that people are not aware of this problem.

The most surprising result can be seen in Figure 122. It shows that not many respondents are interested in a Smart Home feature which enables voice control for your bed. Especially the age group 0-30 was expected to have a need for this feature, but the oldest age group has the highest percentage of seeing a need for Voice control. This number is not as reliable as the others since only 7 respondents were in that age group.

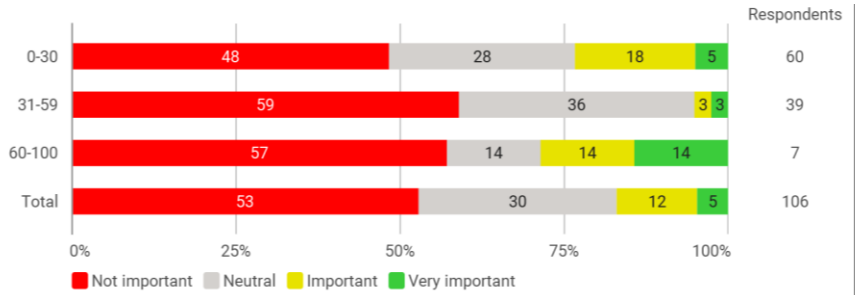


Figure 122: Importance of a Smart Home feature for different age groups

The result of the survey also showed that almost 50% of the middle-aged group (the ones who are most likely to have children or pets at home) are either likely or very likely to pay for a safety feature in the bed as shown in Figure 123. This supports the hypotheses constructed in the beginning.

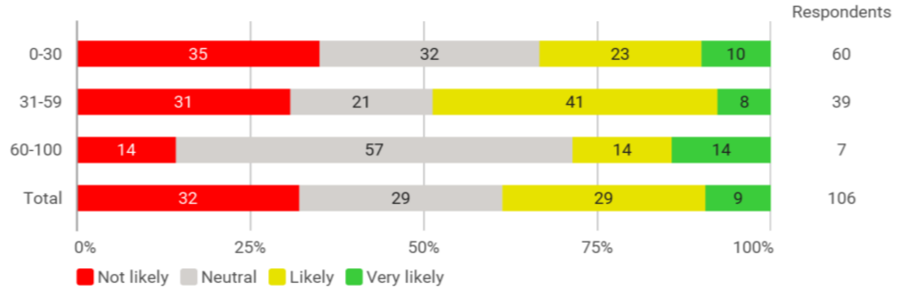


Figure 123: Likeliness of paying for an anti-pinching feature

To identify the attitude of parents towards the safety feature, a graph was created which shows the difference between parents or people without children regarding the importance of an anti-pinching feature and the willingness to pay for it. In Figure 124 people with children see a slightly bigger importance in a safety feature for their bed.

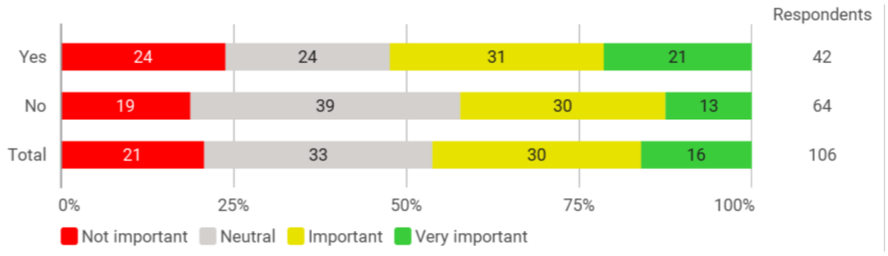


Figure 124: Importance of an anti-pinching feature crossed with "Do you have children?"

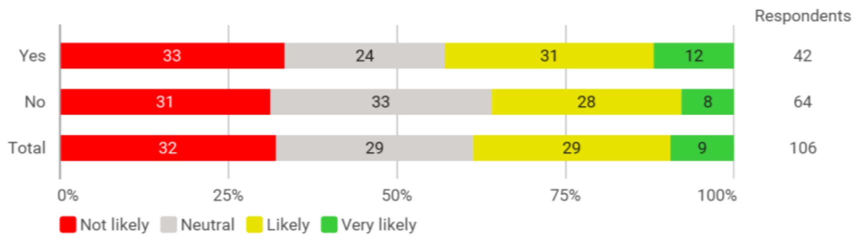


Figure 125: Likeliness to pay for an anti-pinching feature crossed with "Do you have children?"

Figure 125 shows that parents not only see a need in such a feature but almost 50% of them are willing to pay an extra cost for it. This can be a good starting point for a marketing strategy since the safety feature could then be an order winner. This will lead to more customers for LINAK.

Another approach to the marketing strategy is by marketing the anti-pinching feature with another selling point which is added by one of the anti-pinching solutions developed in this project. The simplified cleaning function is expected to be most important for the older age group and for housewives/husbands, so the middle-aged group. Figure 126 shows that almost 75% of the survey respondents in the age group from 60-100 see a big need in a feature that simplifies the cleaning of the bed. An unexpected result is that more than 50% of all the respondents, including the youngest age group is interested in such a feature.

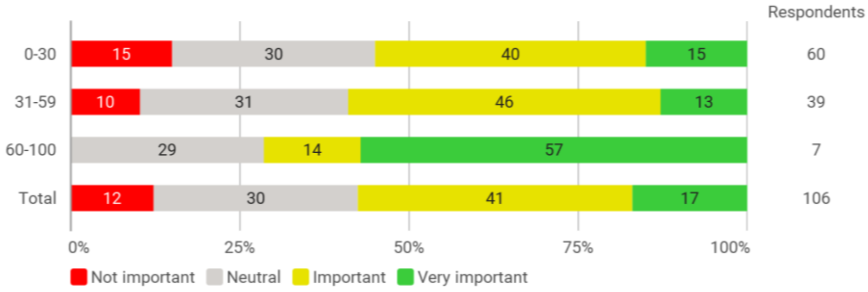


Figure 126: Importance of a feature which simplifies cleaning of the bed

The full analysis of the survey results can be seen in appendix XII.

Value proposition canvas

As a part of the marketing plan it is important to be clear and specific to what value the company creates and provides the customers. Hence the Value Proposition Canvas tool, also described as VPC, is used as it helps to ensure that the product is with the customers and retailers values and needs in mind. With the canvas, seen in Figure 127, consisting of two building blocks – customer profile and a company value proposition, the model is useful when refining an existing product/service or developing a new product or service [44].

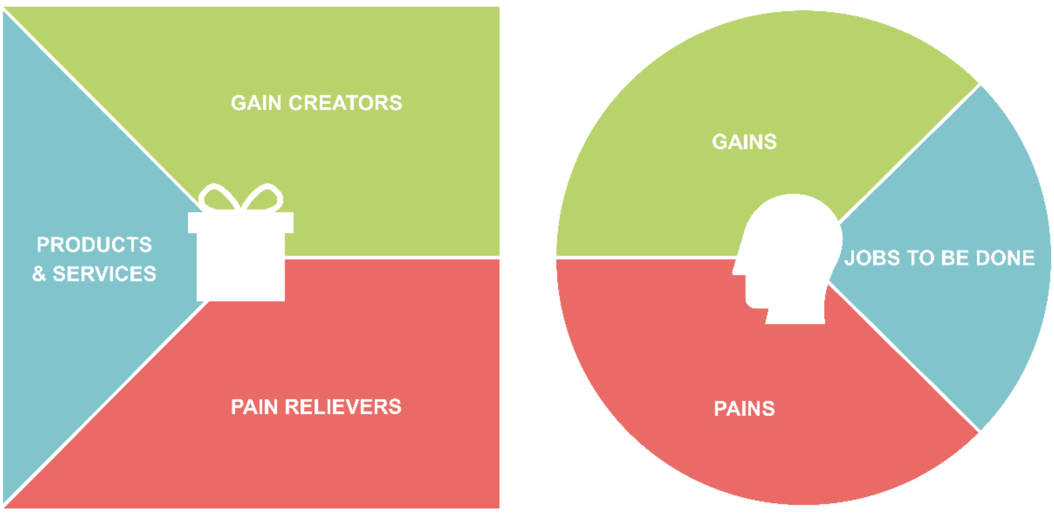


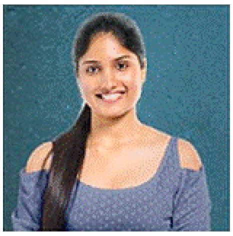
Figure 127: Value Proposition Canvas

In collaboration with LINAK, who use the VPC in practice whenever they develop a product, the need for different VPCs was identified. Therefore, the focus was to define the different personas that would give a representative insight on users/buyers and retailers in the market for adjustable beds. This led to the creation of eight different personas, two retailers and six users/buyers in different age groups. Thus, small descriptions of these personas were made, making it possible to empathize with their needs and problems.

The personas were created and the descriptions together with the VPCs for them can be seen in appendix XIII. Below are pictures [45] of the eight different personas.


Jesper (Retailer)


Thomas (Retailer)


Petra


Brian


Gertrud


John


Sarah


Lena

Due to LINAK selling to retailers and not directly to users, the focus will be on the retailer side. However, it is still important to have the users/buyers in mind, as the retailers are only interested in what the end customer wants. Therefore, most of the personas' created are users/buyers, and all age groups, which could be customers, are represented.

The VPC for a retailer could for example be the one with Jesper Nielsen, the chief consultant at Wonderland. He is a mid-age man with children, worked for Wonderland several years and is their danish representative. It is important to know his values and needs for LINAK to keep up producing actuators made for the beds Wonderland sells to their customers. The VPC created for Jesper Nielsen can be seen in Figure 128, and is explained further in detail down below.

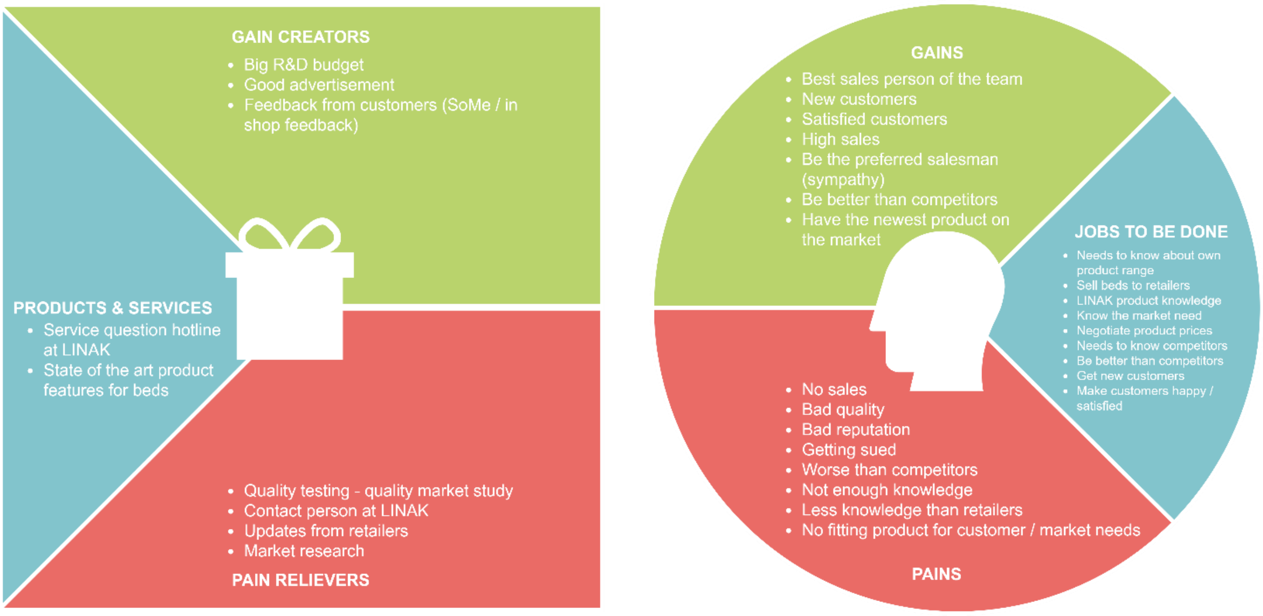


Figure 128: Value Proposition Canvas for Jesper Nielsen

Jobs to be done

The functional, social and emotional tasks the retailer is trying to achieve is, in this case, mainly to sell beds to customers and small retailers. Therefore, he wants to be better than the competitors, which requires he has knowledge about the competitors and has a good understanding of the bed market. Moreover, Jesper wants to get new customers, make them satisfied and happy, whilst still being able to negotiate the price with them and the suppliers e.g., LINAK. For him to negotiate he will need a lot of knowledge about the products from the suppliers and Wonderland's product range.

Pains

For the pains, no sales affect Jesper Nielsen as well as a bad reputation that could make Wonderland worse than the competitors. Adding to this, bad quality or getting sued would be annoying for Jesper when selling beds or after sales. Moreover, it could be frustrating for him not to have enough knowledge about the products he sells combined with the fact that the retailers he sells to would know more about the product than himself. Ultimately, he aims to have a bed for everybody and therefore, no fitting product for the customer or market need could be an obstacle for him achieving his job.

Gains

For it to be a good day for Jesper it would involve getting new customers and satisfied customers, together with being the preferred salesman and the best in the team. Moreover, he wants to be better than the competitors, high sales and to be able to show the newest product on the market.

Pain relievers

The pain relivers in Jesper's case would be that the products are quality tested and a study is made to clarify the best quality on the market. Moreover, allowing him to call specialists at the Supplier would make it easier for him to get the right product knowledge. Also, updates from the retailers would ensure that he knows the need from the market together with newly updated market research.

Gain creators

For the gains to happen, a bigger R&D budget would increase the likelihood of having the newest product on the market. Additionally, commercials and advertisements could enhance sales together with feedback and interaction with customers which would make him closer to the customers and retailers.

Products and services

Concluding to this would be that LINAK should have a service question hotline to take care of questions from the retailers. This would ensure that the information and market feedback is coming directly from the source and to the relevant people. Moreover, having the newest products on the market combined with the state-of-the-art features could be a way to sell more.

To sum up on the VPC for Jesper Nielsen, it shows that the change of information between retailers and suppliers is essential and would create value for both parties. Also, despite the comfort and design still being the main selling points and order qualifiers, the special features not seen before would be the order winners making the sale happen. Looking at the other VPC's in appendix XIII the market research is backed up stating that different age groups would value features differently and some might not see the safety-feature as an order winner but would prefer the technological voice control feature over safety.

Marketing strategy

Looking at LINAKs competitors none of them focusses on a safety feature such as the one explored in this project. This gives LINAK a competitive advantage to be the first mover to market. In order to make this move successful a clear marketing strategy is needed.

The marketing strategy will be based on the concluding results of the market research and the value proposition canvases for the different customer types. It will also take the current market position of LINAK into account and compare them to their competitors. The goal of the marketing strategy is to increase the market size and get new customers by advertising new, state of the art features for the adjustable beds. The strategy will not only focus on the end-customer as the user of the bed but mainly on the bed retailers. With the value proposition canvas for the different personas, it was possible to identify the needs of the customers and how the anti-pinching solution can create more value and decrease the pains in their everyday life.

The research analysis described above showed that the end-user sees a need for an anti-pinching feature but marketed it as a safety feature, which prevents any kind of pinching, could pose a risk for LINAK. As seen in some cases before, customers tend to challenge the promises of a marketing strategy from a company. A well-known example for that is the Red Bull case where people expected the slogan “Gives you wings” to be true and sued the company because they did not fulfil their promises [46]. To prevent this from happening it was decided to only market the anti-pinching feature to the retailers as an additional safety feature. The salespersons in the stores can then market it as a state-of-the-art feature which can be an important selling points for most of the customers. It also gives the retailer the opportunity to offer a safer bed to families or pet owners without making any promises.
Another problem of marketed such a feature is, that it might give the impression that all other adjustable beds are not safe. This is a challenge for the bed retailers and might lead to a decision against LINAKs actuators to be able to sell other non-safe beds as well. This challenge can be overcome by having laws or standards which prescribe a safety feature to prevent pinching. It is a political and legal influence which LINAK cannot control in any way.

The user research showed that there is an interest in a Smart Home feature, but it is not big enough to use this as something customers would pay more money for. With the anti-pinching feature, it would be possible to market it as a safer Smart Home application compared to other beds. The combination of these two things will be an order winner and create the most value for all end user types.

One of the solutions offers a complete weightless feeling of the bed which enables the user to move it into any desired position without any effort. It is not only a feature not seen before on the market but also offers a new marketing opportunity to create a new market for simplified cleaning of the bed. This feature does not necessarily need to be marketed as a safety feature since it offers a new and independent value for adjustable bed users.

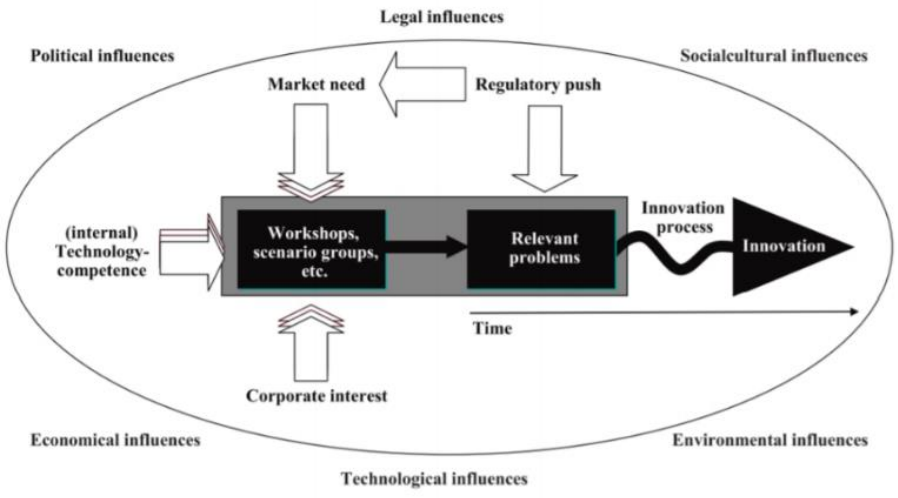


Figure 129: Innovation Model

The Innovation Model shown in Figure 129 presents the complexity of an innovation process. It sums up the whole innovation process of this project from ideation until marketing strategy. For this project especially the legal influences, as regards to the new standard for motorized furniture coming up was a motivator for the innovation process. Also, social cultural influences, with state-of-the-art technology as status symbol, and technological development were the push and guideline for achieving the goal of the project.

Risk Management

Risk Management of a device is used in the project to keep track of possible risks in the final products. In this project the risk analysis has only been performed at the end of the project, but ideally with an assigned risk manager, the process could have been done during the development process, to see which risks and counter measures might arise. Also, as this project is the development of a safety device, the risks are expected to be reasonable, due to the expected severity.

Tables for risk analysis

The following tables are used to assess the risk involved in the mechanical device and the capacitive sensor. The three risk levels shown in Table 10 are; broadly acceptable, as low as reasonably possible (ALARP) and intolerable.

Table 6: Probability of Occurrence (Po)

Probability of Occurrence levels (Po)					
	geom. ave. value	min limit	max limit	Class	Example
1			1,00E-06%	Incredible	Residual Risk
2	3E-06	1,00E-06	1,00E-05%	Very improbable	Redundant systems
3	3E-05	1,00E-05	1,00E-04%	Improbable	Robust Mechanical or Electronic Parts
4	3E-04	0,0001	0,001%	Remote	Mechanical or Electronics Devices
5	0,32%	0,1%	1%	Occasional	Sensitive Components
6	3,2%	1%	10%	Probable	Human Errors (Some attention)
7	32%	10%	100%	Frequent	Human Errors (Little or no Attention)

The probability of occurrence is in this analysis used as the probability of a given user situation combined with the probability of a failure mode occurs. The percentage chance of user situations is set to be between 1 and 10 %, (Probability level 6, see Table 1). This probability is based loosely on the findings of the market research see Figure 121. It is also based on the fact, that some human errors will at some point occur.

This probability is then multiplied with the probability of a corresponding failure mode, which gives the final probability of occurrence (Po). The probability of a failure mode greatly depends on the components in the device that is being analyzed. Mechanical and electronical devices are deemed much safer than coding, and coding will therefore be defined as having 100% probability of failing. Furthermore, if there are redundant systems, such that the device must have multiple failures at ones in order to pose any danger.

Table 7: Probability of Detection (Pd)

Probability of detection levels (Pd)					
	geom. ave. value	min limit	max limit		
1	99,997%	99,990%	99,999%	Automated, validated det.	Validated Automatic Detection/Prevention
2	99,97%	99,90%	99,99%	Very high level of detection	In Line Test and Procedures in Production
3	99,7%	99,0%	99,9%	High level of detection	Trained, Alert Human Detection (Of Alarm)
4	97,0%	90,0%	99,0%	probable detection	Informed Human Detection (Of Situation)
5	70,0%	0,0%	90,0%	Occasional detection	Non-Informed, Non-Alert Human Detection

The probability of detection (Table 7) is used as the probability of a situation occurring and being noticed, whether it be by a sensor or a human. Ideally a detection would lead to the failure mode being nullified, such that no harm can happen.

Table 8: Sum of Probability (Po) and (Pd)

Likelihood of Harm (Lh)			
Po+Pd		Pmax(harm)	
2-6	1	1,00E-06	Incredible
7	2	1,00E-05	Very Improbable
8	3	1,00E-04	Improbable
9	4	1,00E-03	Remote
10	5	1,00E-02	Occasional
11	6	1,00E-01	Probable
12	7	1,00E+00	Frequent

Likelihood of harm is the combined score of probability of detection and occurrence:

$$Lh = Po + Pd$$

This score is used in the final risk assessment.

The score ranges from frequent, which happens almost all the time to incredible, which happens in less than one millionth of uses.

Table 9: Levels of Severity (S)

	Severity of Incident levels (S)	
		Possible occurrence
5	Life threatening	Death
4	Severe. Permanent injury.	Permanent significant disability
3	Transient disability	Transient but significant disability; permanent minor disability
2	Transient or minor disability.	Transient minor disability
1	Inconvenience. No physical harm.	No disability or physical complaints anticipated. Annoying complaints

In Table 9 the levels of severity (S) can be seen. These levels represent the seriousness of a given situation. It encompasses everything from no harm to life threatening.

Table 10: The risk levels

	Inconvenience. No physical harm	Transient or minor disability	Transient Disability	Severe. Permanent Injury	Life Threatening
Lh	1	2	3	4	5
2-6	Broadly Acc	Broadly Acc	Broadly Acc	Broadly Acc	ALARP
7	Broadly Acc	Broadly Acc	Broadly Acc	ALARP	Intolerable
8	Broadly Acc	Broadly Acc	Broadly Acc	ALARP	Intolerable
9	Broadly Acc	Broadly Acc	ALARP	Intolerable	Intolerable
10	Broadly Acc	ALARP	Intolerable	Intolerable	Intolerable
11	Broadly Acc	ALARP	Intolerable	Intolerable	Intolerable
12	ALARP	Intolerable	Intolerable	Intolerable	Intolerable

In Table 10 the likelihood of harm is combined with the severity levels to give the final score to determine the risk of each situation. The risk levels are Broadly acceptable (green), as low as reasonably possible (Yellow) and Intolerable (Red). Based on the likelihood of harm, the severity can cause either of these assessments.

Risk Analysis of solutions

In the following analysis user events are assumed to be probable, thus happening 1-10% of the time, which gives a Po = 6. However, this should be multiplied with the probability of occurrence of a given failure mode cause. This multiplication makes any given situation more improbable. In another way, the probability of a given failure mode is a level lower than inherent to the device.

To avoid trivial cases of risk, the analysis is only as comprehensive as practicable in scope.

Risks linked with the mechanical solution

The mechanical device has many different components, giving each user event many possible failure modes. For example, the springs can feasibly wear out and snap, making the device void, and a user situation unsafe. Here is a part of the complete risk analysis table for the mechanical device, to show the procedure for determining risk.

Table 11: User Situation and failure modes

User situation	User Event	Failure Mode	Failure Mode Cause
Bed moves	Hand pinches in bedframe	Spring failure	Wear and Tear
			Missuse
		Software failure	Sofware failure
		Motor Failure	Electrics failure
		Sensor Failure	Dirty Lense
			Shorted circuit
			Obstructed view
		Lever failure	Wear and Tear
		Talks in sleep	False recognition

For all the failure modes and their associated risks, probability of occurrence, detection and severity are determined, as specified by the above tables.

Table 12: Mechanical Risk Analysis

	Inconvenience. No physical harm	Transient or minor disability	Transient Disability	Severe. Permanent Injury	Life Threatening
Po+Pd	1	2	3	4	5
2-6	0	0	13	8	0
7	0	0	1	6	0
8	0	1	0	0	0
9	0	0	0	0	0

The results from the risk analysis might seem trivial, but as the device is itself a safety device, it is not surprising that it is such. This is also the reason, for there being no other counter measures other than that of the user manual.

Risk linked with the capacitive sensor solution

As the capacitive solution only consists of a small circuit and as it is a passive sensor, there are very few failure modes for the sensor. The possibility of misuse from the user is also diminished by the fact that the circuit is inside of the actuator, thereby being relatively inaccessible.

As the whole device works with pure electronics it is not prone to software failures, as is the case with the mechanical device. For this reason, there are very few risks involved

Table 13: Capacitive Risk Analysis

	Inconvenience. No physical harm	Transient or minor disability	Transient Disability	Severe. Permanent Injury	Life Threatening
Po+Pd	1	2	3	4	5
2-6	0	0	1	2	1
7	1	0	2	1	0
8	0	0	0	0	0
9	0	0	0	0	0

Risk evaluation

There has not been a risk analysis related to the embedded solution the project, as there is no tangible device to relate the analysis to, although there is a preliminary prototype. However, the risk analysis would greatly depend on the machine learning, currently not concluded.

From the analysis on the capacitive sensor and the mechanical device, if implemented correctly, as currently designed, they would be safe for use. However, it is not known to what degree they make the adjustable beds safer.

Risk analysis of the project

The likelihood for the project to have an outcome of a well-functioning product have been analyzed beforehand. Combining the knowledge about previous projects together with the knowledge gained throughout the project, it has been concluded that the risk of failure is high but still possible as shown throughout the R&D of this project. Taking the history of failed products from big international companies into account, the current solutions on the market is not design aesthetically appealing and fully functional. Based on this, and the fact that the market is not looking for an anti-pinching solution, it will be difficult to make a product and to push it into the market.

Discussion

With the project originally being presented as a task to find a reliable solution that could prevent collision, the team was in the early phase skeptical and in lack of motivation. However, the more developed the prototypes became, and the fact that the aim of the project was changed to focus on exploring potential solutions, the team got inspired and motivated to keep exploring and not only focus on the deadline for a finished product. Moreover, the communication and collaboration with LINAK showed that they were more curious to see the progress and the result of the exploratory process compared to having a single half-finished product. As a result of this it was decided together with the supervisors to continue the project with the purpose of exploring potential solutions. Also, this decision was influenced by a risk analysis made and therefore based on the market analysis and state of the art section.

Furthermore, LINAK's resources became valuable when components were needed due to the wide range of sub suppliers. Also, due to technical issues ordering through University proved to take weeks and therefore LINAK provided us with components and equipment if they had them in stock or were able to order it.

As a result of the exploring phase, three different potential solutions have been described in this report. The three solutions can be combined but also used separately as they focus on different aspects of how to prevent pinching and collision. These ideas and the research made, demonstrates potential solutions on how to be prepared for the new standard [8] and regulations on the market for furniture with electrically motorized parts. The ideas are based on the requirements stated aim to fulfill all requirements from the standard and LINAK when fully developed.

First idea is the mechanical solution which is simulated and should be functional, however additional tests should be made to check its functionality. Furthermore, it is an expensive solution due to the price for springs and material being high. Therefore, it cannot meet the requirements set for this project, as the final version would have a higher price than the actuator. However, the solution proved to show potential as not only an anti-collision system but could create new market opportunities by changing the way you operate the bed to e.g., ease cleaning.

Second idea is the capacitive sensor solution which shows the potential of the capacitive effect making it a relatively cheap solution compared to the others as there are no external developed sensors needed. Moreover, the capacitive sensor stripes can be added wherever needed, making the device able to detect touch where added. This however can be hard to implement due to all the places where pinching can occur shall be covered for full functionality. Also, both the time-based measurement method and the voltage drop solution were not sensitive enough to detect covered skin, since detection requires a certain capacitance. The time-based measurement system only reacted with some fabric types, but in general it would not be reliable enough to guarantee it to detect covered skin or for that matter furred animals. It should be possible to attain a high enough sensitivity to overcome these issues, however the current solution is only able to ensure detection of skin, like hands and fingers. Despite reaching the requirement of detecting animals as well as covered skin, the solution is already functional with the TD5 actuator and an integrated LIN bus signal transmission to stop the actuator immediately. Then it only requires LINAK to read the signal and change the code to make the actuator move in the opposite direction. Furthermore, it will require a modification in the way the bed producers make the frames as these might need to implement stripes of anodized aluminum or any other electric conducting material in the frame or fabric.

Third idea is the embedded sensor implemented in the actuator. The idea of having a sensor implemented in the actuator at the point of connection between bed frame and actuator proved to be challenging due to the high forces and porous sensors. Despite order delays and lack of knowledge the measurement system works in a development state, with only the manufacturing time of the mechanical element obstructing tests to be performed. This is due to the load at the point being higher than informed and simulated, resulting in a mechanical failure. Also, the signal sensing element of the measurement system requires further improvements in the noise level and the voltage range as to provide better data with a wider range of values for the machine learning algorithm to build a model on. With the idea of using machine learning, a machine learning GUI was created as part of the development of the solution to aid with the recollection of data, as well as the decision of which machine learning algorithm to use. Furthermore, a large data collection is required to prove if any machine learning algorithm is feasible.

The market analysis showed some interesting results by among other things clarifying that some have experienced pinching. Moreover, it became clear that the interest for a safety feature is, as expected, high for people with children. Additionally, more people than expected were interested in the idea of making the adjustable bed easier to clean by use of the mechanical solution. Nevertheless, the results backed up the hypothesis that the younger generation would be the biggest supporter of the voice-controlled feature only surprisingly being followed by the oldest generation. However, with the information received from the quantitative and qualitative research it became clear that it is not possible to brand the safety feature, but it should be marketed towards the retailers and shown in the shop without any guarantees given.

The project management part proved to be of great use, with the Belbin tests showing that the final stage would be of focus. Combined with the circumstances of COVID-19, the last part of the project was mostly online, and the group therefore followed the plan to use in case of closedown due to COVID. For that reason, the project managers kept a close contact to the team leaders to ensure everything were completed in time as the SWOT analysis showed to be of importance. Interestingly the Belbin roles were more indicating than anticipated, looking back at the groups and their workflow.

Conclusion

The project proved to be far more extensive than first anticipated, however it has been an interesting learning experience to combine different educations, work methods and ideas to come together and form a team for four months. To develop an anti-collision system for adjustable beds was challenging and all team members participation and knowledge sharing were important to reach this stage. The outcome of the project is three different solutions, yet to be developed for final implementation at LINAK. Moreover, the goal for the team and this project were to explore and investigate the potential of the ideas that LINAK found to be interesting. The ideas are close to functional prototypes and with the solutions proposed it will open for new market opportunities if used in the right way. Therefore, the market research came to be of great use proving that the solutions could be of interest for the market and uncovered that there have been cases with accidents in the past, contrary to initial thoughts.

Future improvements

The potential solutions do not yet live up to the requirements set. However, they aim to fulfill as many requirements as possible at the final stage of product development.

- The mechanical solution would require more development for the springs to fit and be implementable under an adjustable bed.
- The capacitive sensor strip design requires and solution to the design of the beds made. It requires a conductive material in stripes which is difficult to ensure with frames covered in fabric.
- The embedded solutions will require more development to reach the stage of testing and to implement the machine learning algorithm to detect collisions.

References

[1] T. Schmall, "New York Post," 21 March 2019. [Online]. Available: https://nypost.com/2019/03/21/we-spend-nearly-half-of-our-lifetime-lying-around-in-bed/. [Accessed 30 November 2020].

[2] "Dreams.co.uk," [Online]. Available: https://www.dreams.co.uk/sleep-matters-club/your-life-in-numbers-infographic/. [Accessed 17 09 2020].

[3] "National Heart, Lung, and Blood Institute," [Online]. Available: https://www.nhlbi.nih.gov/health-topics/sleep-deprivation-and-deficiency. [Accessed 21 09 2020].

[4] "Tuck," [Online]. Available: https://www.tuck.com/adjustable-bed-reviews/ . [Accessed 21 09 2020].

[5] "IBISWorld," [Online]. Available: https://www.ibisworld.com/industry-statistics/market-size/adjustable-bed-mattress-manufacturing-united-states/. [Accessed 22 09 2020].

[6] "Statista," 11 2019. [Online]. Available: https://www.statista.com/statistics/1069616/smart-furniture-market-size-worldwide/. [Accessed 28 09 2020].

[7] "BEA," [Online]. Available: https://eu.beasensors.com/en/product/lzr-flatscan-rev-pz/. [Accessed 28 09 2020].

[8] "IEC 60335-2-116:2019," in *Household and similar electrical appliances - Safety - Part 2-116: Particular requirements for furniture with electrically motorized parts*, International Standard, 2019, p. 14.

[9] "Gemba," [Online]. Available: http://gemba.dk/stage-gate/. [Accessed 28 09 2020].

[10] A. &. V. Brem, "Technovation," in *Integration of market pull and technology push in the corporate front end and innovation management—Insights from the German software industry.*, K.-I., 2009, p. 351–367.

[11] J. Moultrie, "IfM," University of Cambridge, [Online]. Available: https://www.ifm.eng.cam.ac.uk/research/dmg/tools-and-techniques/belbins-team-roles/. [Accessed 03 11 2020].

[12] B. Moga, "ActiveCollab," [Online]. Available: https://activecollab.com/blog/collaboration/belbin-team-roles-theory-practice. [Accessed 08 11 2020].

[13] "Advantages of worm gears," [Online]. Available: https://gearmotions.com/advantages-of-worm-gears/. [Accessed 30 11 2020].

[14] "Wikipedia - Lever," [Online]. Available: https://en.wikipedia.org/wiki/Lever. [Accessed 30 11 2020].

[15] "Sparkfun," [Online]. Available: https://www.sparkfun.com/products/15569. [Accessed 06 12 2020].

[16] "Arduinotech," [Online]. Available: https://arduinotech.dk/shop/3-axis-gyroscopeaccelerometer-6dof-gy-521/. [Accessed 06 12 2020].

[17] "RS-online," [Online]. Available: https://dk.rs-online.com/web/p/reflektive-optiske-sensorer/6666568/. [Accessed 07 12 2020].

[18] "RS-online," [Online]. Available: https://dk.rs-online.com/web/p/potentiometre/7377792/. [Accessed 07 12 2020].

[19] "Wikipedia - Hook´s Law," [Online]. Available: https://en.wikipedia.org/wiki/Hooke%27s_law¨. [Accessed 4 12 2020].

[20] "fjedre," [Online]. Available: https://www.fjedre.dk/14110. [Accessed 19 12 2020].

[21] "Arduino.cc," 23 04 2020. [Online]. Available: https://www.arduino.cc/reference/de/language/variables/constants/constants/. [Accessed 24 11 2020].

[22] "Arduino.cc," 16 04 2020. [Online]. Available: https://www.arduino.cc/reference/de/language/functions/external-interrupts/attachinterrupt/. [Accessed 24 11 2020].

[23] Texas Instruments Incorporated, "www.ti.com," 02 2000. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm555.pdf. [Accessed 30 11 2020].

[24] J. P. Netly, Principles of Measurement Systems, Harlow: Pearson Education, 2005.

[25] "TS358 Single Supply Dual Operational Amplifiers," [Online]. Available: https://www.mouser.com/datasheet/2/395/TS358_A09-248541.pdf. [Accessed 20 11 2020].

[26] "Datasheet, RS PRO Foil Strain Gauges," [Online]. Available: https://docs.rs-online.com/3160/0900766b816d3523.pdf. [Accessed 20 11 2020].

[27] "TL431/ TL432PrecisionProgrammableReference," [Online]. Available: https://www.ti.com/lit/ds/symlink/tl431.pdf?ts=1607534771124&ref_url=https%253A%252F%252Fwww.ti.com%252Fstore%252Fti%252Fen%252Fp%252Fproduct%252F%253Fp%253DTL431ACDR. [Accessed 23 11 2020].

[28] Cdn.sparkfun.com. 2020. HX711 Datasheet. [online] Available at: <http://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/hx711_english.pdf> [Accessed 21 December 2020]..

[29] B. Carter, Op Amps For Everyone, 2013.

[30] Anonymous, "TL081 Datasheet," Ti.com, [Online]. Available: https://www.ti.com/lit/ds/symlink/tl081.pdf?ts=1608537131176&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FTL081%253Futm_source%253Dgoogle%2526utm_medium%253Dcpc%2526utm_campaign%253Dasc-null. [Accessed 13 11 2020].

[31] "Low-Noise, Low-Distortion INSTRUMENTATION AMPLIFIER," [Online]. Available: https://www.ti.com/lit/ds/symlink/ina163.pdf?ts=1608539406524&ref_url=https%253A%252F%252Fwww.google.com%252F. [Accessed 25 11 2020].

[32] J. Brownlee, "Machine Learning Mastery," [Online]. Available: https://machinelearningmastery.com/machine-learning-in-python-step-by-step/. [Accessed 18 10 2020].

[33] V. Sridharan, "Machine Learning Algorithms Mindmap," Jixta, [Online]. Available: https://jixta.wordpress.com/2015/07/17/machine-learning-algorithms-mindmap/. [Accessed 15 10 2020].

[34] J. Brownlee, "A Gentle Introduction to Logistic Regression With Maximum Likelihood Estimation," Machine Learning Mastery, [Online]. Available: https://machinelearningmastery.com/logistic-regression-with-maximum-likelihood-estimation/. [Accessed 10 10 2020].

[35] J. Brownlee, "Linear Discriminant Analysis for Machine Learning," Machine Learning Mastery, [Online]. Available: https://machinelearningmastery.com/linear-discriminant-analysis-for-machine-learning/. [Accessed 29 10 2020].

[36] J. Brownlee, "Machine Learning Mastery: K-Nearest Neighbors for Machine Learning," [Online]. Available: https://machinelearningmastery.com/k-nearest-neighbors-for-machine-learning/. [Accessed 18 10 2020].

[37] J. Brownlee, "Classification And Regression Trees for Machine Learning," Machine Learning Mastery, [Online]. Available: https://machinelearningmastery.com/classification-and-regression-trees-for-machine-learning/. [Accessed 4 11 2020].

[38] J. Brownlee, "Machine Learning Mastery," [Online]. Available: https://machinelearningmastery.com/naive-bayes-for-machine-learning/. [Accessed 26 10 2020].

[39] J. Brownlee, "Support Vector Machines for Machine Learning," Machine Learning Mastery, [Online]. Available: https://machinelearningmastery.com/support-vector-machines-for-machine-learning/. [Accessed 22 11 2020].

[40] "LINAK," LINAK, [Online]. Available: https://www.linak.com/segments/homeline/tech-trends/time-to-connect-bedrooms-to-the-smart-home/. [Accessed 15 10 2020].

[41] L. Tucker, "iotTechTrends," 18 12 2019. [Online]. Available: https://www.iottechtrends.com/smart-adjustable-bed-great-nights-sleep/. [Accessed 15 10 2020].

[42] "Sleep Gadgets," [Online]. Available: https://sleepgadgets.io/smart-mattress-smart-bed/. [Accessed 15 10 2020].

[43] "Statista," 02 2020. [Online]. Available: https://www.statista.com/statistics/570654/total-population-in-denmark-by-age/. [Accessed 09 11 2020].

[44] "B2B International," [Online]. Available: https://www.b2binternational.com/research/methods/faq/what-is-the-value-proposition-canvas/. [Accessed 10 11 2020].

[45] "Rawpixel," [Online]. Available: https://www.rawpixel.com/image/96403/premium-photo-image-collage-people-african-collage-face . [Accessed 17 12 2020].

[46] O. Duggan, "The Telegraph," 11 10 2014. [Online]. Available: https://www.telegraph.co.uk/news/worldnews/northamerica/usa/11155731/13m-lawsuit-proves-Red-Bull-doesnt-give-you-wings.html. [Accessed 17 12 2020].

[47] D. Nield, "the ambient," 27 10 2020. [Online]. Available: https://www.the-ambient.com/guides/smart-home-ecosystems-152. [Accessed 23 11 2020].

[48] Anonymous, "Chegg Study," [Online]. Available: https://www.chegg.com/homework-help/questions-and-answers/problem-4-bridge-circuit-strain-gauge-connected-instrumentation-amplifier-ideal-filter-gai-q27133114?fbclid=IwAR08UHGxbNifm2IwWx-AgNN5-nP-2UeBNcIFiDIEzk8ZK6u_V1rnpxvffQQ. [Accessed 20 11 2020].

Appendix

Table of contents

I Belbin team roles

An overview of the different roles presented in the group and their orientation according to the Belbin theory. The percentages given for each role and member in the group.

	Nicklas	Horia	Mohammed	Maria	Maram	Dennis	Magnus	Pablo	Ioannis	Erik	Esben	Anina
Shaper	17	8	14	8	14	14	14	17	17	11	11	8
Implementer	3	17	8	14	11	14	8	19	3	6	19	11
Completer finisher	6	3	8	14	8	6	6	8	6	6	6	8
Coordinator	11	11	11	8	17	14	8	11	8	19	6	11
Team worker	14	14	17	14	17	2	11	6	17	11	6	17
Resource Investigator	8	19	14	2	8	14	14	8	14	8	11	17
Plant	17	8	8	14	6	17	17	8	19	14	17	8
Monitor-Evaluator	8	8	14	11	8	8	6	11	11	11	19	11
Specialist	17	11	6	14	11	11	17	11	6	14	6	8

Figure 1 - Belbin Team Roles

A table with an overview of the different roles assigned in the test made in Project Management[1]. These roles are compared to the well-recognized roles from the official Belbin test. Moreover, the weaknesses and orientation in a team is described by use of theory about these team roles[2].

Orientation	Belbin general role	Belbin roles from test	Contribution	Weaknesses
Action Oriented Roles	Shaper	Driver	Challenging, dynamic, thrives on pressure. Has the drive and courage to overcome obstacles.	Prone to provocation. Offends people's feelings.
	Implementer	Executive	Practical, reliable, efficient. Turns ideas into actions and organizes work that needs to be done.	Somewhat inflexible. Slow to respond to new possibilities.
	Completer Finisher	Completer	Painstaking, conscientious, anxious. Searches out errors. Polishes and perfects.	Inclined to worry unduly. Reluctant to delegate.
People Oriented Roles	Coordinator	Chairman	Mature, confident, identifies talent. Clarifies goals. Delegates effectively.	Can be seen as manipulative. Offloads own share of the work.
	Team Worker	Team player	Co-operative, perceptive and diplomatic. Listens and averts friction.	Indecisive in crunch situations. Avoids confrontation.
	Resource Investigator	Explorer	Outgoing, enthusiastic, communicative. Explores opportunities and develops contacts.	Over-optimistic. Loses interest once initial enthusiasm has passed.

[1] https://www.123test.com/team-roles-test/ (18-09-2020)
[2] https://www.mindtools.com/pages/article/newLDR_83.htm (08-11-2020)
https://developerexperience.io/practices/team-roles-definition (08-11-2020)

Thought Oriented Roles	Plant	Innovator	Creative, imaginative, free-thinking. Generates ideas and solves difficult problems.	Ignores incidentals. Too preoccupied to communicate effectively.
	Monitor-Evaluator	Analyst	Sober, strategic, and discerning. Sees all options and judges accurately.	Lacks drive and ability to inspire others. Can be overly critical.
	Specialist	Expert	Single-minded, self-starting, dedicated. Provides knowledge and skill in rare supply.	Contributes only on a narrow front. Dwells on technicalities.

Figure 2 - Roles from Belbin test

The distribution of the Belbin roles for each group:

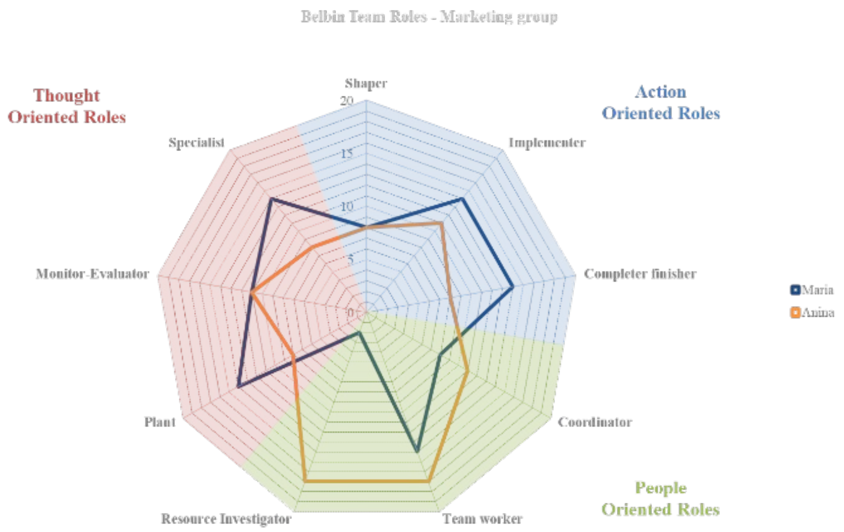


Figure 3 - Marketing group

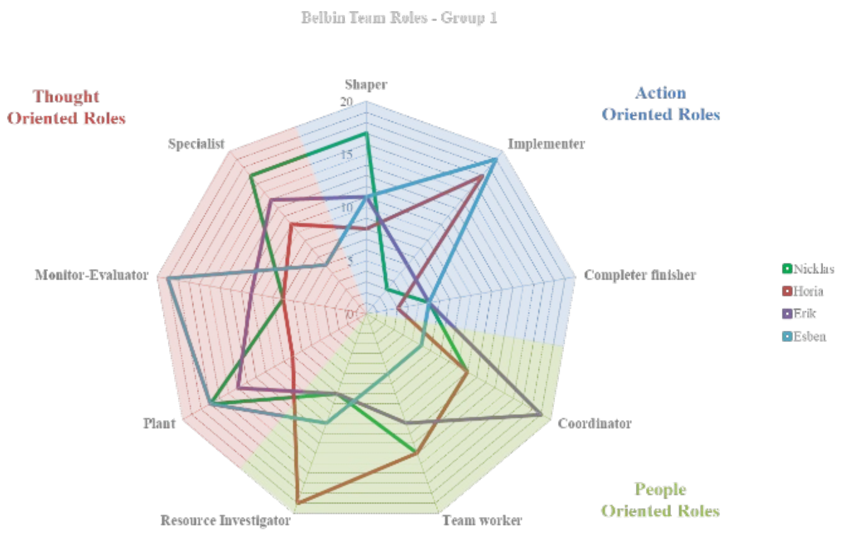


Figure 4 - Group 1

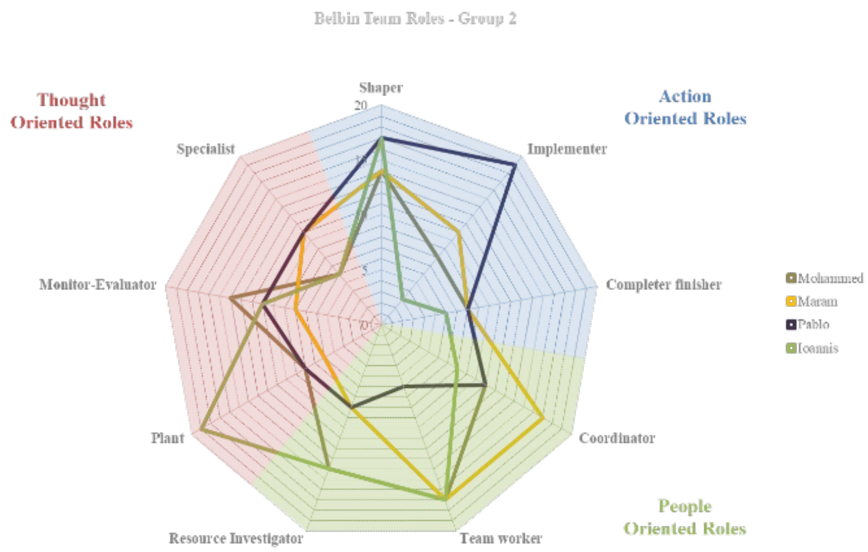


Figure 5 - Group 2

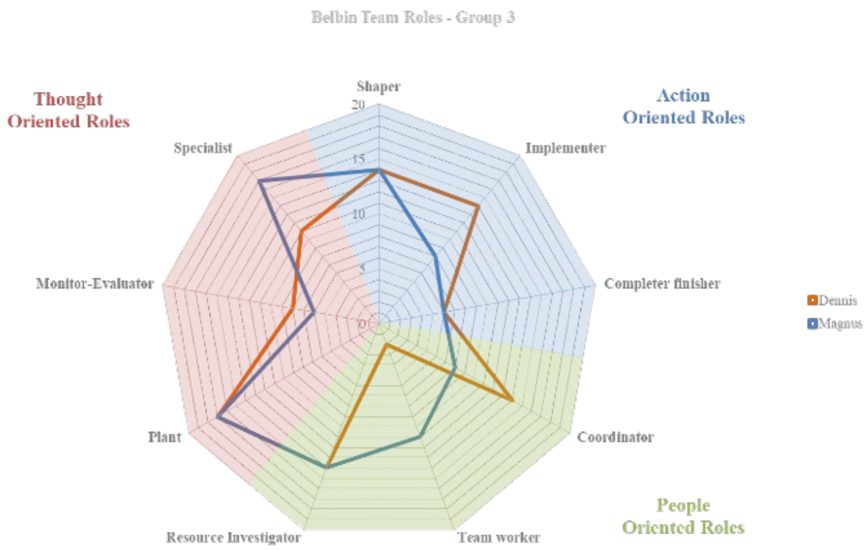


Figure 6 - Group 3

II Idea selection and grouping

Flexibility Easily implemented in other frames Size, Shape and material	1
Reliability Ease of circumvention (to go around our solution) How idiot proof is it? How accurate is it?	2
Complexity How hard is it to execute?How much do we know about it?	3
Looks Is the product attractive? Does the product make you feel something?	4
Durability Dust proof (IPXX) Water resistant Shock resistant	5
Cost Is the cost reasonable? Is the cost significantly reduced if mass produced?	6
Production How easy is it to scale up? Can it be mass produced?	7
Usability Are there any additional complications for the user?Is it intuitive to use? How easy is it to install?	8

Grading from 1-5 with 5 being the best!

Criteria weight determination	Value
1. Flexibility	2
2. Reliability	2,5
3. Complexity	2,5
4. Looks	1,5
5. Durability	1,8
6. Cost	3
7. Production	1
8. Usability	1,5

			Team Member																							
			1								2								3							
Key	Name	Description	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
A	Camera	Using visual recognition to set a perimeter and look for objects	5	1	3	2	3	\	1	1	5	2	5	4	2	1	5	3	4	3	1	4	5	1	4	5
B	Capacitive touch strips	Strip on frame to measure voltage that varies when pressed	5	4	3	4	4	2	4	4	5	4	3	2	1	5	3	4	3	2	3	2	2	4	3	2
C	Cat whiskers	Small senstive wires to detect objects that touch	1	1	1	2	2	2	1	3	1	1	2	1	2	2	3	1	3	2	3	2	2	3	3	2
D	Flexible smart sensor	Sensor used in other semeter project	3	3	2	3	2	3	4	5	5	3	3	3	3	4	5	2	2	3	2	2	3	2	3	2
E	Current motor sensor	Monitor current on motor for load changes	5	3	2	5	5	2	4	3	5	3	2	5	5	5	5	5	4	3	2	4	4	3	4	3
F	Infrared light bridge	Use of IR sensors to create a curtain of light	2	4	3	3	2	2	2	1	3	4	2	3	1	4	5	2	4	3	2	3	3	3	3	2
G	Resistive touch strips	Similar to capacitive strips but with resistance	5	4	3	4	4	2	4	4	5	5	4	1	2	5	5	2	3	2	3	2	2	4	4	2
H	Pressure sensor	Use of touch pressure sensor to analyze load	3	3	2	3	3	2	2	2	3	2	3	1	1	3	5	3	4	2	3	4	3	3	4	2
I	Machine learning on load	Analysis of load patterns to determine particula behaviour	5	3	1	5	5	3	4	5	5	3	1	5	5	5	3	5	4	2	1	4	3	3	4	3
J	Air pressure sensor	Tube filled with air and used to measure the difference in the air	2	2	2	3	3	4	3	2	2	3	4	5	3	3	3	2	3	3	3	2	5	4	4	2
K	Magnetic/electric field	Look for disturbances in magnetic or electric fields to detect objects	2	3	1	3	4	1	1	1	2	3	1	5	1	1	1	1	3	3	2	3	4	4	4	3
L	Ultrasonic sensors	Use of ultrasonic sensor for detecting object under bed	4	1	2	3	1	1	1	2	3	1	1	1	1	5	5	1	2	2	2	3	2	3	4	1
M	Sensitive skin	Use of sensitive skin as in robotic arms	4	5	1	3	4	1	1	1	5	5	1	2	2	1	1	1	2	3	1	2	2	1	3	1
N	Electric frame	Applied current on frame to detect human and animal touch	4	5	2	3	4	2	1	1	5	5	2	5	4	2	2	1	3	4	3	4	5	4	5	5
O	Damper to remove load	Use of damper and spinrg to remove most of load in the actuactor	1	2	1	4	3	1	1	2	1	1	1	1	3	1	1	1	4	3	3	3	4	3	3	1
P	BEA sensor	Smart infrared sensor (revolving door)	5	4	1	3	4	1	1	2	5	4	1	2	2	1	1	2	3	4	2	3	3	2	4	2
Q	Piezo sensor cable	Use of piezo senstive cable to mount on all edges of bed	3	3	1	2	3	1	1	1	4	3	1	1	2	3	1	1	2	2	3	2	3	2	4	2
R	Piezo sensor on actuator	Piezo sensor inhoused in the actuator to analyze the load	5	4	2	5	5	1	1	5	5	5	2	5	5	3	5	1	3	3	2	3	5	3	4	1
S	Edge safety sensor	Tube that sends signal when squeezed	3	4	1	2	4	1	1	3	3	3	2	1	3	1	1		3	3	3	2	5	4	4	2

	Team Member																							
	4								5								6							
Key	1	2	3	4	5	6	7	8	1	2	3	4	5	6	8	8	1	2	3	4	5	6	7	8
A	2	2	3	3	1	1	2	1	3	2	1	4	5	2	3	3	5	2	1	3	4	1	3	2
B	4	4	3	5	4	2	3	4	5	4	3	2	5	5	3	3	5	3	2	3	1	3	4	4
C	2	1	2	3	2	1	3	2	2	1	3	1	2	3	3	3	1	2	2	1	3	3	3	4
D	3	3	2	2	2	3	2	2	2	3	2	3	2	3	2	2	5	3	4	4	4	2	4	4
E	4	3	3	5	4	3	3	3	5	3	2	5	5	4	3	3	5	3	2	5	5	3	5	5
F	4	3	2	4	4	2	3	1	3	4	2	3	3	3	3	3	4	3	3	3	3	4	3	3
G	5	4	4	4	3	3	4	4	4	5	3	1	3	4	3	3	5	2	2	3	2	3	4	4
H	3	3	2	3	3	3	2	1	3	2	3	1	2	3	3	3	4	3	3	2	3	4	4	3
I	3	2	1	3	3	2	4	3	5	3	1	5	5	5	4	4	5	3	1	5	5	3	5	5
J	2	2	1	3	3	2	1	1	3	3	3	5	2	3	3	3	5	3	3	3	3	4	3	4
K	2	3	2	2	1	2	1	1	3	3	2	5	3	3	3	3	4	4	2	5	3	3	5	3
L	3	2	3	2	2	3	3	2	2	1	2	1	5	3	2	2	3	2	1	1	2	2	3	1
M	3	4	2	3	3	2	1	2	4	5	1	2	3	3	3	3	4	3	1	4	3	1	3	3
N	4	4	1	3	5	1	2	2	3	5	3	5	5	5	4	4	4	3	1	5	3	3	4	4
O	2	2	3	4	3	1	2	2	2	1	3	1	2	2	3	3	4	4	3	4	5	4	3	3
P	4	4	2	3	3	2	2	1	3	4	2	2	3	3	3	3	3	4	3	3	3	3	2	2
Q	2	3	2	4	3	2	2	1	2	3	3	1	3	3	2	2	3	4	4	3	3	4	3	3
R	3	3	2	5	4	2	2	4	3	5	2	5	3	3	4	4	3	3	4	3	3	4	3	3
S	4	3	2	2	3	1	1	2	4	3	3	1	3	3	3	3	4	4	2	2	4	3	2	3

			Team Member																							
			7								8								9							
Key	Name	Description	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
A	Camera	Using visual recognition to set a perimeter and look for objects	3	2	4	3	4	3	4	3	5	3	2	4	3	1	3	3	4	2	3	1	2	3	2	2
B	Capacitive touch strips	Strip on frame to measure voltage that varies when pressed	3	4	3	2	3	2	3	3	2	4	4	4	2	4	4	3	4	3	4	4	4	3	4	4
C	Cat whiskers	Small senstive wires to detect objects that touch	2	1	2	1	2	2	2	3	1	1	1	1	3	1	2	2	3	2	1	3	3	2	3	2
D	Flexible smart sensor	Sensor used in other semeter project	3	3	2	2	3	2	3	2	4	3	2	3	4	1	1	3	3	1	2	3	3	2	4	5
E	Current motor sensor	Monitor current on motor for load changes	5	5	3	5	4	2	4	3	5	4	2	5	4	2	3	3	5	3	3	4	4	3	4	3
F	Infrared light bridge	Use of IR sensors to create a curtain of light	3	3	3	3	3	3	3	3	2	2	2	3	3	3	4	2	3	4	3	3	1	2	2	2
G	Resistive touch strips	Similar to capacitive strips but with resistance	3	3	3	2	2	3	3	3	4	4	3	3	3	2	3	3	4	4	3	4	4	2	3	4
H	Pressure sensor	Use of touch pressure sensor to analyze load	4	4	3	2	3	2	4	3	4	4	3	3	3	3	4	3	3	2	3	3	3	2	2	2
I	Machine learning on load	Analysis of load patterns to determine particula behaviour	5	4	2	5	5	4	3	4	5	3	1	5	5	3	2	4	4	4	1	5	5	2	4	5
J	Air pressure sensor	Tube filled with air and used to measure the difference in the air	4	3	1	2	2	3	2	3	4	3	2	3	2	3	3	3	1	1	3	3	2	4	3	2
K	Magnetic/electric field	Look for disturbances in magnetic or electric fields to detect objects	4	2	1	3	2	2	3	3	4	2	2	3	2	3	3	3	1	3	1	3	3	1	2	1
L	Ultrasonic sensors	Use of ultrasonic sensor for detecting object under bed	2	3	2	2	2	3	3	2	4	3	3	3	3	2	3	3	5	2	3	2	1	1	2	2
M	Sensitive skin	Use of sensitive skin as in robotic arms	2	4	2	4	3	1	2	3	4	5	3	4	3	1	2	3	3	4	1	3	5	3	2	2
N	Electric frame	Applied current on frame to detect human and animal touch	4	4	4	5	5	4	4	4	2	4	4	5	5	5	4	4	4	5	3	3	4	3	1	2
O	Damper to remove load	Use of damper and spinrg to remove most of load in the actuactor	3	3	3	4	3	2	2	3	4	3	3	3	3	2	2	2	1	3	2	3	3	1	2	3
P	BEA sensor	Smart infrared sensor (revolving door)	4	4	2	3	3	2	3	3	5	5	3	4	3	2	3	3	5	4	1	3	3	2	1	2
Q	Piezo sensor cable	Use of piezo senstive cable to mount on all edges of bed	3	4	3	2	3	2	3	2	3	4	3	2	3	4	4	3	3	4	2	3	4	2	2	1
R	Piezo sensor on actuator	Piezo sensor inhoused in the actuator to analyze the load	5	4	3	5	5	3	3	4	5	3	3	5	5	4	3	4	5	3	2	4	4	1	1	4
S	Edge safety sensor	Tube that sends signal when squeezed	3	2	3	3	3	2	3	3	3	2	2	3	3	3	3	3	3	3	2	2	4	1	2	3

	Team Member																							
	10								11								12							
Key	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
A	4	3	1	5	4	2	5	2	3	3	2	3	4	4	4	3	3	2	3	3	3	4	5	2
B	5	3	4	3	5	3	5	3	3	4	3	2	2	3	3	2	5	3	3	4	4	5	4	4
C	5	1	3	2	5	2	4	2	2	1	1	1	3	1	1	1	4	1	4	3	3	5	3	1
D	3	3	2	2	4	2	4	3	4	2	3	2	3	4	2	3	4	3	3	3	5	4	4	3
E	5	2	2	5	5	5	5	5	3	3	2	2	3	3	5	3	4	4	3	5	5	2	3	4
F	3	2	5	5	5	4	3	2	3	4	3	2	2	2	3	3	2	4	3	3	4	3	3	4
G	5	4	5	4	5	5	5	2	5	4	4	2	3	4	3	3	4	3	4	4	5	2	4	3
H	3	2	4	4	5	5	5	4	4	3	2	2	4	3	2	3	3	3	2	4	5	4	4	3
I	5	2	1	5	5	5	5	5	4	3	1	3	4	4	4	4	4	4	1	5	5	4	5	4
J	4	3	3	2	5	3	3	1	2	2	2	1	2	3	2	1	3	2	2	3	2	4	2	2
K	5	5	4	5	5	3	5	3	4	4	3	4	3	4	4	2	3	2	3	2	4	3	3	2
L	2	2	2	5	4	3	4	2	1	1	2	1	1	2	2	1	2	1	1	1	2	5	1	1
M	5	5	2	5	4	1	5	5	3	4	2	3	4	1	2	2	4	5	5	3	4	1	2	5
N	2	2	5	5	2	5	5	5	4	4	3	2	3	3	2	4	4	4	4	5	5	3	3	4
O	4	5	3	2	5	2	2	3	5	4	3	5	4	5	5	5	3	4	3	3	3	3	5	4
P	5	4	3	5	5	2	4	4	3	2	3	3	4	1	2	3	3	3	2	4	2	1	3	3
Q	4	4	4	4	5	3	5	3	3	3	2	1	3	1	3	3	4	3	3	4	4	2	3	3
R	5	3	2	5	5	5	5	4	3	3	2	4	3	3	3	3	5	3	3	5	4	2	3	3
S	4	4	4	4	5	3	5	3	3	2	2	1	3	2	2	2	3	2	3	3	3	3	2	2

				Criteria Total										
	Key	Name	Description	1	2	3	4	5	6	7	8	T	PT	WF
1	A	Camera	Using visual recognition to set a perimeter and look for objects	4	2	2	3	3	2	3	3	5,57	2,88	2,69
2	B	Capacitive touch strips	Strip on frame to measure voltage that varies when pressed	4	4	3	3	3	3	4	3	6,60	3,41	3,19
X	C	Cat whiskers	Small senstive wires to detect objects that touch	2	1	2	2	3	2	3	2	4,08	2,13	1,95
2	D	Flexible smart sensor	Sensor used in other semeter project	3	3	2	3	3	3	3	3	5,61	2,91	2,70
3	E	Current motor sensor	Monitor current on motor for load changes	5	3	2	5	4	3	4	4	7,07	3,73	3,34
4	F	Infrared light bridge	Use of IR sensors to create a curtain of light	3	3	3	3	3	3	3	2	5,74	2,93	2,82
2	G	Resistive touch strips	Similar to capacitive strips but with resistance	4	4	3	3	3	3	4	3	6,75	3,44	3,31
3	H	Pressure sensor	Use of touch pressure sensor to analyze load	3	3	3	3	3	3	3	3	5,76	2,99	2,77
3	I	Machine learning on load	Analysis of load patterns to determine particula behaviour	5	3	1	5	5	4	4	4	6,60	3,69	2,91
2	J	Air pressure sensor	Tube filled with air and used to measure the difference in the air	3	3	2	3	3	3	3	2	5,26	2,72	2,54
6	K	Magnetic/electric field	Look for disturbances in magnetic or electric fields to detect objects	3	3	2	4	3	3	3	2	5,35	2,78	2,57
X	L	Ultrasonic sensors	Use of ultrasonic sensor for detecting object under bed	3	2	2	2	2	3	3	2	4,17	2,24	1,93
X	M	Sensitive skin	Use of sensitive skin as in robotic arms	4	4	2	3	3	1	2	3	5,79	2,81	2,98
2	N	Electric frame	Applied current on frame to detect human and animal touch	4	4	3	4	4	3	3	3	7,17	3,58	3,59
5	O	Damper to remove load	Use of damper and spinrg to remove most of load in the actuactor	3	3	3	3	3	2	3	3	5,67	2,79	2,88
4	P	BEA sensor	Smart infrared sensor (revolving door)	4	4	2	3	3	2	2	3	5,84	2,88	2,96
2	Q	Piezo sensor cable	Use of piezo senstive cable to mount on all edges of bed	3	3	3	2	3	2	3	2	5,54	2,73	2,81
3	R	Piezo sensor on actuator	Piezo sensor inhoused in the actuator to analyze the load	4	4	2	5	4	3	3	3	6,93	3,51	3,42
2	S	Edge safety sensor	Tube that sends signal when squeezed	3	3	2	2	4	2	2	2	5,52	2,69	2,83

Group 1	Visual recognition
Camera	

Group 2	Stripe like ideas
Capacitive touch strips	
Flexible smart sensor	
Resistive touch strips	
Air pressure sesor	
Electric frame	
Piezo sensor cable	
Edge safety sensor	

Group 3	Load sensing and algorithm
Current motor sensing	
Pressure sensor	
Machine learning on load	
Piezo sensor on actuator	

Group 4	Light sensing
BEA sensor	
Infrared light bridge	

Group 5	Mechanical approach
Dampner to remove load	

Group 6	Experimental tech
Magnetic/electric field	

		G1	G2	G3	G4	G5	G6
Mohammed	1	0	2	3	0	1	0
Pablo	2	0	2	3	0	1	0
Anina	*3*	*0*	*3*	*2*	*1*	*0*	*0*
Nick	4	2	3	1	0	0	0
Horia	5	0	3	2	1	0	0
Maria	*6*	*0*	*3*	*2*	*1*	*0*	*0*
Magnus	7	0	3	2	1	0	0
Erik	8	0	2	0	1	0	3
Dennis	9	0	2	1	0	3	0
Maram	10	0	2	3	1	0	0
Ioannis	11	0	2	3	0	1	0
Esben	12	0	3	2	0	1	0
	T	0,2	2,5	2,0	0,5	0,6	0,3

III Test for human capacitance

Date: 12.10.2020

Objective

The objective of the test is to determine actual body capacitance values, when using the two-stripe sensor developed by this team.

Hypothesis

The expected body capacitance values range from 300pF to 4nF.

Test equipment

- Oscilloscope - Rohde & Schwarz Model RTB2004 2.5 GSa/s.
- Function generator - Gwinstek model AFG-2125.
- Potentiometer - 0 - 10k.
- Breadboard.
- Wires for connection.
- Multimeter - Tenma model 72-7765A

Test procedure

The idea of the test was to make a voltage divider circuit using a potentiometer as R1 and a humans capacitor as Z2.

A sine wave signal would then be generated with an 8 volt amplitude, and the potentiometer can be adjusted until

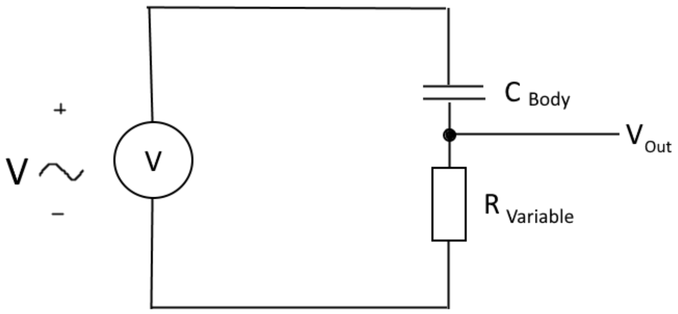
$$V_{out} = \frac{V_{in}}{2}$$

A known signal frequency would be used (100kHz). Once the criteria in equation above was met, the capacitance can be found as such:

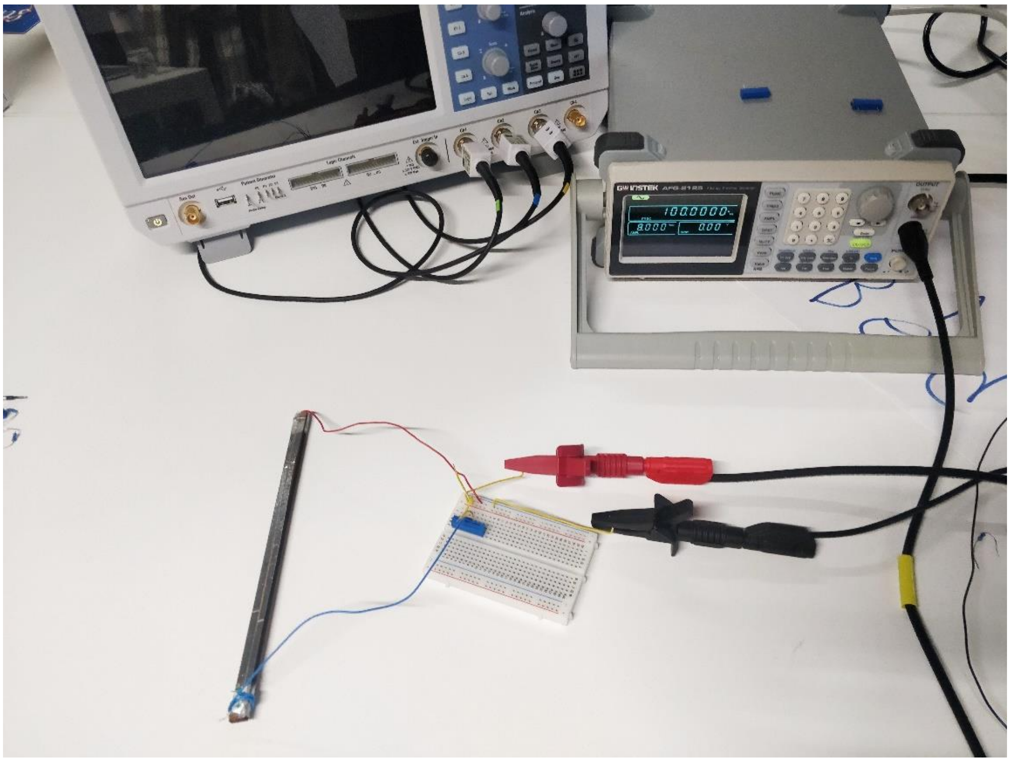
$$C = \frac{1}{2 \cdot pi \cdot f \cdot X_c}$$

This assumes the body has no ESR and inductance. In order to verify this, the body resistance was measured using the sensor and was found to be $R_{finger} > 5M\Omega$. This means the resistive effect will be negligible.

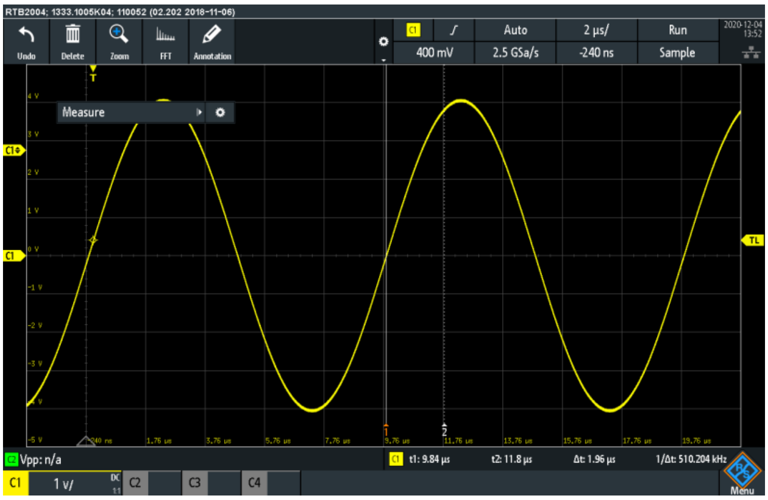
A circuit describing the test set-up can be seen as such:

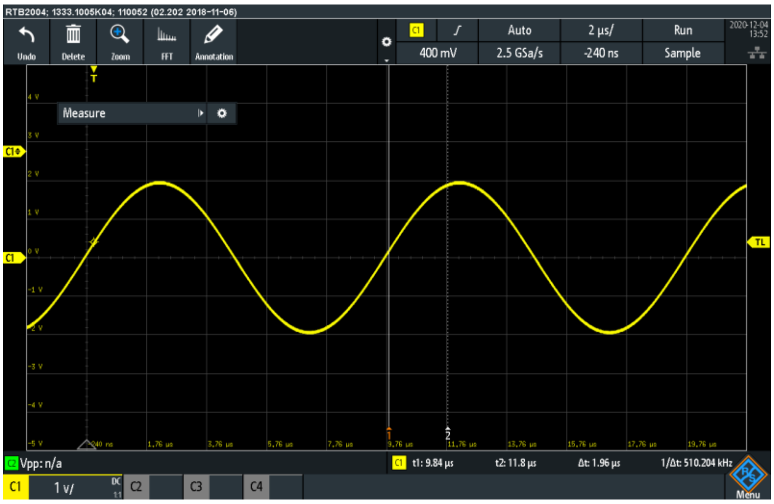


Picture of set-up



Test results





As can be seen in the pictures the signal V_{out} collapses to $\frac{V_{in}}{2}$ when the resistance was 1078 ohms.

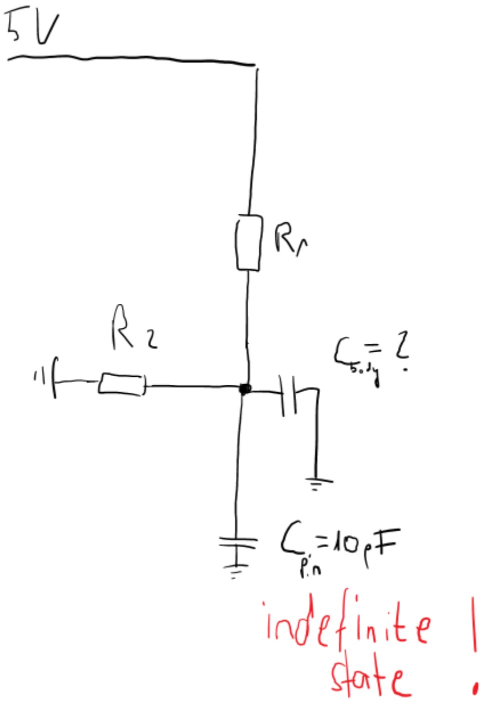
These equations result in a human capacitance of:

$$C = \frac{1}{2 \cdot pi \cdot f \cdot X_c} = \frac{1}{2 \cdot 3.1416 \cdot 100000 \cdot 1078} = 1{,}476387 \cdot 10^{-9} \approx 1.48nF$$

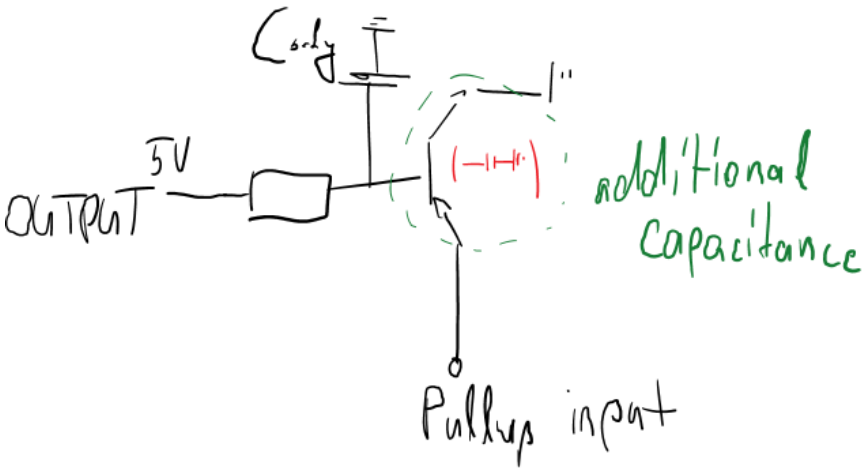
Conclusion

It can be concluded that the human capacitance is approximately 1.48nF for a “normal finger touch”. This was within our expected range. It can also be concluded that the human body resistance is $> 5M\Omega$ when using our sensor.

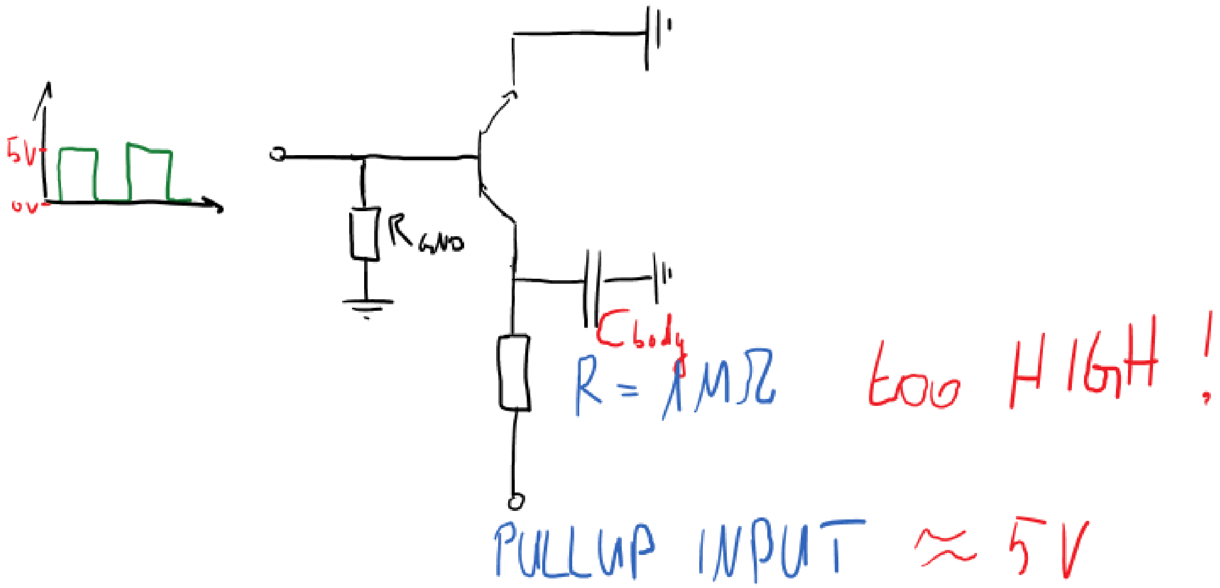
IV Circuit development: Time



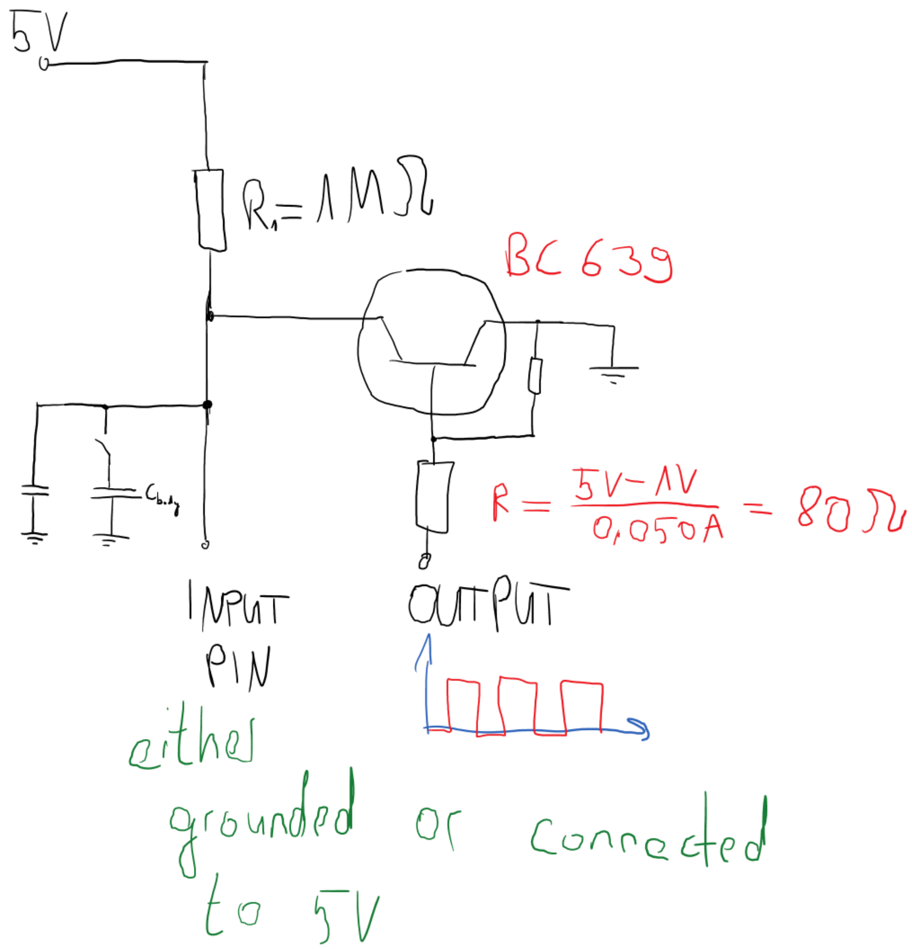
first draft



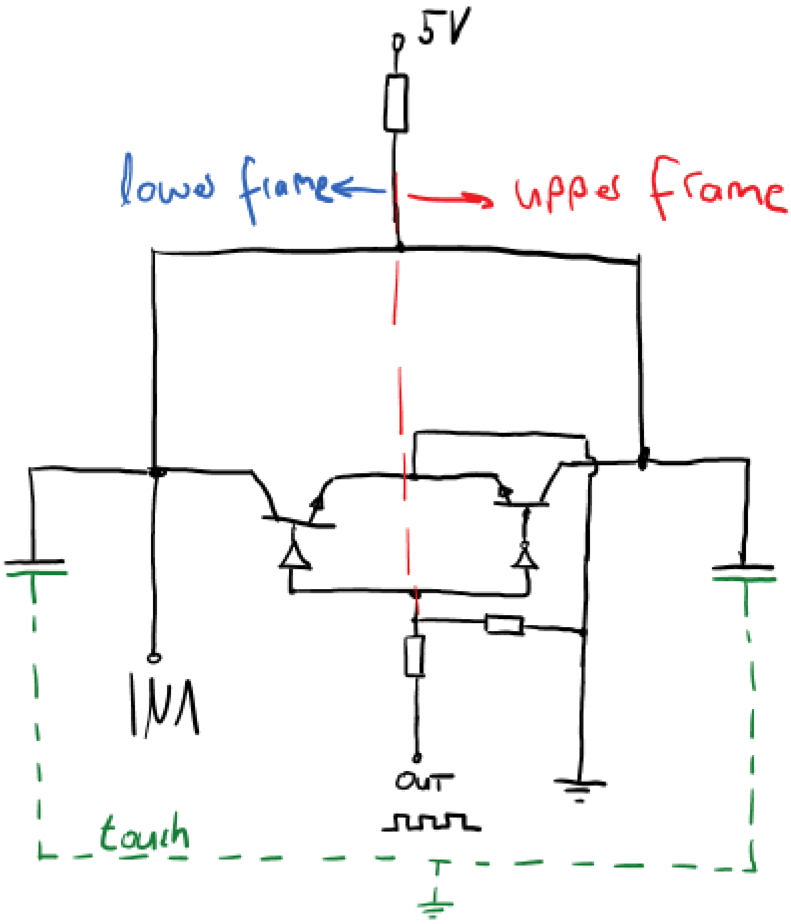
second draft



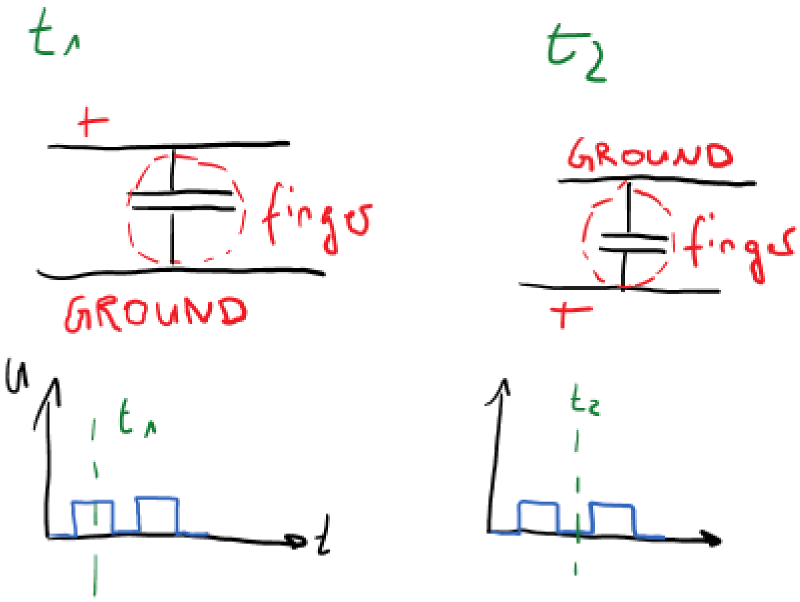
third draft



fourth draft



final circuit



sensing and ground in once

V Arduino: first program for time

```
int received_change();              //interrupt function, enables pin toggling, sets recent state of the pin, calls time printing
void print_time();                  //prints timestamp through serial communication
void toggle_pin(int pin1,int pin2); //toggles pin2


unsigned long send_time;            //global declaration for time

bool state=false;                   //state of the toggled pin
int counter=0;                      //semaphore, either 1 or 0
int mode=1;


void setup() {
  // put your setup code here, to run once:
pinMode(10,OUTPUT);            //OUTPUT Sensor 1
pinMode(11,OUTPUT);             //OUTPUT Sensor 1 (inverted OUTPUT 10)
pinMode(6,OUTPUT);
pinMode(7,OUTPUT);
digitalWrite(10,LOW);
digitalWrite(11,HIGH);




pinMode(2,INPUT);
pinMode(3,INPUT);
pinMode(LED_BUILTIN, OUTPUT);

attachInterrupt(digitalPinToInterrupt(2), received_change,RISING);
attachInterrupt(digitalPinToInterrupt(3), received_change,RISING);

Serial.begin(9600);

send_time=millis();
}


void loop()
{

  if (mode==1)                    //external information, starts checking as soon as actuator starts
    {
      if(counter==0)
      {
        send_time=millis();
        counter=1;                    //disables toggling after leaving if statement
        toggle_pin(10,11);          //changes state of pin 10 and 11;
      }
    }

}



int received_change()
{
  counter=0;         //enables state change in main
  print_time();     //print time dalay, reset sendtime
  return 0;
}


void toggle_pin(int pin1,int pin2)
{
    digitalWrite(pin1,(state)? LOW:HIGH);
    digitalWrite(pin2,(state)? HIGH:LOW);
     digitalWrite(LED_BUILTIN,(state)? LOW:HIGH);
  state= !state;
}


void print_time()
{
   int    timedif=millis()-send_time;

   if(timedif-1)
  {


      Serial.print(timedif);
      Serial.print("\n");


  }




}
```

VI Arduino: final program for time

```
/*Capacitive touch sensing
 * author: Erik Winkler
 * date:10.12.2020
 * Notes:
 * internal 16-bit timers of ATmega2560 TIM4 and TIM5 are used in Input Cature Mode
 * output signals are provided by pin 4 (for ICP4) and pin 5 (for ICP5)
 *
 */
 /*possible prescaler settings
  * CSn2   CSn1   CSn0     presc           t_ovf[ms]
  *  0      0      1       no prescaling    4
  *  0      1      0       8                33
  *  0      1      1       64               262
  *  1      0      0       256              1050
  *  1      0      1       1024             4198
  *   t_ovf=2^16*presc/(16MHz)
  */
#include <avr/interrupt.h>
void toggle_pin();

//private variables
bool state=0;              //current HIGH or LOW state of pin4 (output)
bool mode=1;               //external information, enables measurement cycle
bool toggle_enabled=1;     //prevents toggling before signal was received

ISR(TIMER4_CAPT_vect)
{
   unsigned int timer_value;
   timer_value=ICR4;     //save timer value
  TCNT4=0;               //reset timer
  TIMSK4=0;              //diable interrupts

   toggle_enabled=1;     //enables toggling in main

   Serial.print(timer_value);      //print to Console for debugging purposes
    Serial.print("\n");
}

// timer overflows (every 65536 counts), automatic timer reset
ISR(TIMER4_OVF_vect)
{
   Serial.print("Overflow4\n");     //signal delayed Touch detect
  TIMSK4=0;              //diable interrupts
    toggle_enabled=1;
}


ISR(TIMER5_CAPT_vect)
{
   unsigned int timer_value;
   timer_value=ICR5;     //save timer value
  TCNT5=0;               //reset timer
  TIMSK5=0;              //diable interrupts

    toggle_enabled=1;

   Serial.print(timer_value);      //print to Console for debugging purposes
    Serial.print("\n");
}

// timer overflows (every 65536 counts), automatic timer reset
ISR(TIMER5_OVF_vect)
{
   Serial.print("Overflow5\n");     //signal delayed Touch detect
  TIMSK5=0;              //diable interrupts
    toggle_enabled=1;
}
void set_interrupt()
{
   //disable global interrupt
   cli();
/*timer 4 settings */
  // reset timer 4
   TCCR4A=0;
   TCCR4B=0;
   // clear flags by setting registers to 1
   TIFR4 |= (1<<ICF4) |(1<<TOV4);
   //set timer count to 0
   TCNT4 = 0;
   //disable timer4 interrupts
   TIMSK4=0;
   //edge select ->falling
   TCCR4B &=~(1<<ICES4);
   //prescaler setting
    TCCR4B|=(1<<CS41)|(1<<CS40);  //64
   //initialize ICR4
   ICR4=0;

/*timer 5 settings*/
  // reset timer 5
   TCCR5A=0;
   TCCR5B=0;
   //disable timer 5 interrupts
   TIMSK5=0;
   // clear flags by setting registers to 1
   TIFR5 |= (1<<ICF5) |(1<<TOV5);
   //set timer count to 0
```

```
   TCNT5 = 0;
    //edge select ->falling
    TCCR5B  &=~(1<<ICES5);
    //prescaler setting
     TCCR5B|=(1<<CS51)|(1<<CS50);   //64
    //initialize ICR5
    ICR5=0;

    //enable global interrupt
    sei();

}




void setup() {
   //set pin 4 and 5 to output
    DDRG|= (1<<DDG5); //pin 4
    DDRE|= (1<<DDE3); //pin 5

//set LED_BUILTIN as output
DDRB|=  (1<<DDB7);


//initialize output pins
PORTG&=~ (1<<PORTG5);    //pin 4
PORTE|=  (1<<PORTE3);    //pin 5
PORTB|=    (1<<PORTB7);

//set  BAUDRATE
Serial.begin(9600);

//configurate timers
set_interrupt();

}


void  loop()
{

   if (mode==1)
   {
        if(toggle_enabled==1)
      {
         toggle_enabled=0; //no toggle possible until an interrupt occurs

         if(state==0)    //pin4 is currently 0 --> toggling results in ground connection --> falling edge at ICP4
       {
          TCNT4=0; //set timer 4 to 0;
             TIMSK4|=(1<<TOIE4)|(1<<ICIE4); //enable timer 4 interrupts: Overflow|Input Capture

          delay(10);
        }else             //pin5 is currently 0 --> toggling results in ground connection --> falling edge at ICP5
         {
          TCNT5=0; //set timer 5 to 0;
             TIMSK5|=(1<<TOIE5)|(1<<ICIE5); //enable timer 5 interrupts: Overflow|Input Capture

          delay(10);
         }

        toggle_pin();        //change both output states

      }
   }

}




void  toggle_pin()
{
   //pin4:
    if(state)
   {
     PORTG&=~(1<<PORTG5);
   }else
    {
       PORTG|=(1<<PORTG5);
    }
   //pin5:
    if(state)
   {
     PORTE|=(1<<PORTE3);
   }else
   {
       PORTE&=~(1<<PORTE3);
   }

   state= !state;
}
```

VII Excel sheet for 555 timer setup calculation

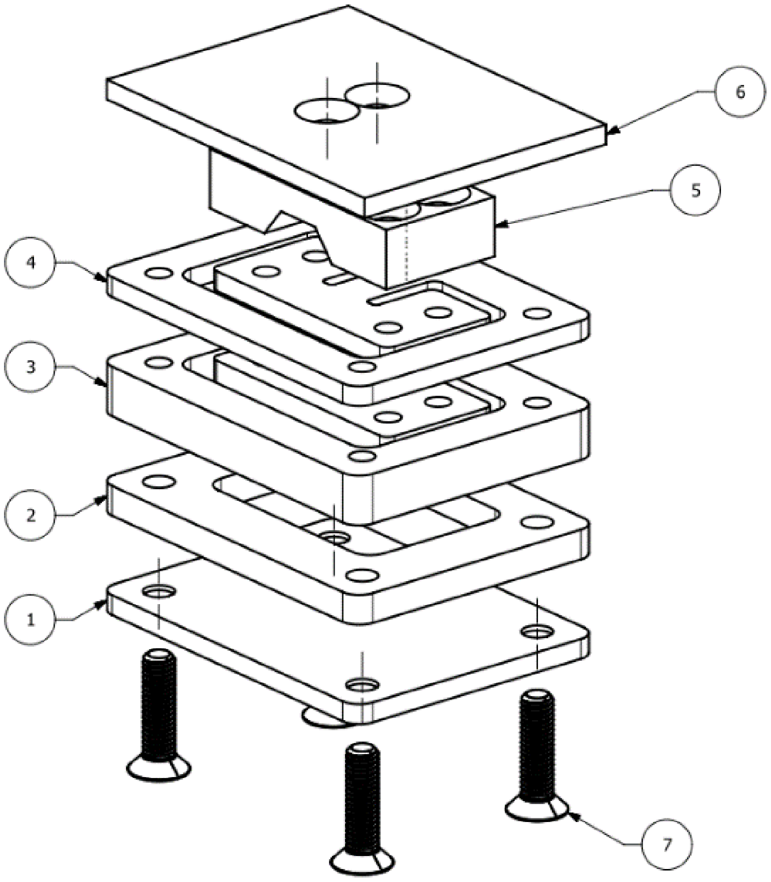
		frequency	50000	100000	150000	200000	250000	300000	350000	400000	450000	500000
Chuman [nF]		Cbed [nF]	Z0									
0,5		0,05	59851,7	30849	20779,7	15666,2	12572,3	10498,9	9012,6	7894,92	7023,87	6325,93
		0,1	30849,033	15666,2	10498,9	7894,92	6325,93	5277,17	4526,7	3963,1	3524,31	3173
		0,15	20779,7	10498,9	7023,87	5277,17	4226,2	3524,31	3022,36	2645,56	2352,3	2117,57
		0,2	15666,16	7894,92	5277,17	3963,1	3173	2645,56	2268,48	1985,49	1765,27	1589,02
U		0,25	12572,32	6325,93	4226,2	3173	2540,01	2117,57	1815,61	1589,02	1412,71	1271,62
10		0,3	10498,932	5277,17	3524,31	2645,56	2117,57	1765,27	1513,47	1324,53	1177,54	1059,91
		0,35	9012,6024	4526,7	3022,36	2268,48	1815,61	1513,47	1297,54	1135,53	1009,49	908,63
		0,4	7894,9214	3963,1	2645,56	1985,49	1589,02	1324,53	1135,53	993,73	883,413	795,142
R1		0,45	7023,8693	3524,31	2352,3	1765,27	1412,71	1177,54	1009,49	883,413	785,333	706,855
10000		0,5	6325,9256	3173	2117,57	1589,02	1271,62	1059,91	908,63	795,142	706,855	636,215
R2			Z1									
100000		0,05	5754,1506	2885,38	1925,44	1444,77	1156,15	963,646	826,096	722,909	642,637	578,41
		0,1	5277,1685	2645,56	1765,27	1324,53	1059,91	883,413	757,307	662,706	589,115	530,235
		0,15	4873,2107	2442,56	1629,7	1222,77	978,457	815,514	699,093	611,76	543,824	489,468
		0,2	4526,6999	2268,48	1513,47	1135,53	908,63	757,307	649,19	568,088	504,999	454,522
		0,25	4226,1953	2117,57	1412,71	1059,91	848,106	706,855	605,937	530,235	471,348	424,233
		0,3	3963,1049	1985,49	1324,53	993,73	795,142	662,706	568,088	497,112	441,902	397,729
		0,35	3730,8508	1868,91	1246,72	935,33	748,404	623,748	534,689	467,884	415,918	374,342
		0,4	3524,3118	1765,27	1177,54	883,413	706,855	589,115	504,999	441,902	392,821	353,553
		0,45	3339,4411	1672,51	1115,63	836,957	669,677	558,127	478,432	418,653	372,154	334,951
		0,5	3172,9989	1589,02	1059,91	795,142	636,215	530,235	454,522	397,729	353,553	318,209
			Delta									
		0,05	0,9038599	0,90647	0,90734	0,90778	0,90804	0,90821	0,90834	0,90843	0,90851	0,90857
		0,1	0,8289357	0,83113	0,83186	0,83223	0,83245	0,8326	0,8327	0,83278	0,83284	0,83289
		0,15	0,7654821	0,76735	0,76798	0,76829	0,76848	0,7686	0,76869	0,76876	0,76881	0,76885
		0,2	0,7110524	0,71267	0,7132	0,71347	0,71364	0,71374	0,71382	0,71388	0,71393	0,71396
		0,25	0,6638492	0,66525	0,66572	0,66596	0,6661	0,6662	0,66626	0,66631	0,66635	0,66638
		0,3	0,6225231	0,62376	0,62417	0,62438	0,6245	0,62459	0,62464	0,62469	0,62472	0,62475
		0,35	0,5860407	0,58714	0,5875	0,58769	0,5878	0,58787	0,58792	0,58796	0,58799	0,58802
		0,4	0,5535976	0,55457	0,5549	0,55506	0,55516	0,55523	0,55528	0,55531	0,55534	0,55536
		0,45	0,5245582	0,52544	0,52573	0,52588	0,52596	0,52602	0,52606	0,5261	0,52612	0,52614
		0,5	0,4984135	0,49921	0,49947	0,4996	0,49968	0,49973	0,49977	0,4998	0,49982	0,49984

	R1									
	1000									
frequenc	50000	100000	150000	200000	250000	300000	350000	400000	450000	500000
	potential									
	9,83567	9,68602	9,54086	9,39998	9,26321	9,13035	9,00126	8,87576	8,75372	8,63498
	9,68602	9,39998	9,13035	8,87576	8,63498	8,40693	8,1906	7,98513	7,78972	7,60364
	9,54086	9,13035	8,75372	8,40693	8,08656	7,78972	7,5139	7,25694	7,01698	6,79238
	9,39998	8,87576	8,40693	7,98513	7,60364	7,25694	6,94048	6,65046	6,38371	6,13754
	9,26321	8,63498	8,08656	7,60364	7,17515	6,79238	6,44837	6,13754	5,85529	5,59786
	9,13035	8,40693	7,78972	7,25694	6,79238	6,38371	6,02143	5,69806	5,40766	5,14542
	9,00126	8,1906	7,5139	6,94048	6,44837	6,02143	5,64752	5,31732	5,02361	4,76064
	8,87576	7,98513	7,25694	6,65046	6,13754	5,69806	5,31732	4,98428	4,69049	4,42941
	8,75372	7,78972	7,01698	6,38371	5,85529	5,40766	5,02361	4,69049	4,3988	4,14127
	8,63498	7,60364	6,79238	6,13754	5,59786	5,14542	4,76064	4,42941	4,14127	3,88833
	8,51943	7,42625	6,58171	5,90964	5,36211	4,90743	4,52384	4,19586	3,91223	3,66451
	8,40693	7,25694	6,38371	5,69806	5,14542	4,69049	4,30947	3,98571	3,70719	3,46506
	8,29735	7,09518	6,19728	5,50111	4,94556	4,49192	4,11451	3,7956	3,52258	3,28619
	8,1906	6,94048	6,02143	5,31732	4,76064	4,30947	3,93642	3,62281	3,35548	3,12489
	8,08656	6,79238	5,85529	5,14542	4,58906	4,14127	3,77311	3,46506	3,20351	2,97868
	7,98513	6,65046	5,69806	4,98428	4,42941	3,98571	3,62281	3,32047	3,06471	2,84554
	7,88622	6,51436	5,54906	4,83292	4,2805	3,84141	3,48402	3,18747	2,93745	2,72379
	7,78972	6,38371	5,40766	4,69049	4,14127	3,70719	3,35548	3,06471	2,82033	2,61203
	7,69556	6,2582	5,27328	4,55621	4,01082	3,58204	3,23608	2,95106	2,71219	2,50909
	7,60364	6,13754	5,14542	4,42941	3,88833	3,46506	3,12489	2,84554	2,61203	2,41395
	1,31624	2,25977	2,95915	3,49034	3,9011	4,22292	4,47742	4,6799	4,84149	4,97047
	1,27909	2,14304	2,74664	3,1777	3,48957	3,71643	3,88113	3,99942	4,08253	4,13859
	1,2435	2,03517	2,55644	2,90581	3,14101	3,2978	3,39939	3,46134	3,4944	3,50618
	1,20938	1,93529	2,38549	2,66781	2,843	2,94747	3,00406	3,02766	3,02824	3,01265
	1,17664	1,84261	2,23128	2,45823	2,58609	2,6511	2,67527	2,67248	2,65178	2,61918
	1,14522	1,75646	2,09166	2,27267	2,36297	2,398	2,39863	2,37759	2,34294	2,29988
	1,11504	1,67624	1,96483	2,10756	2,16788	2,18002	2,1635	2,12985	2,08616	2,03685
	1,08604	1,60142	1,84928	1,95997	1,99626	1,99087	1,96185	1,91956	1,87016	1,81738
	1,05816	1,53152	1,7437	1,8275	1,84447	1,82562	1,78753	1,73943	1,68662	1,63219
	1,03134	1,46611	1,64696	1,70813	1,70952	1,68036	1,63575	1,58387	1,52924	1,47439

R1									
1500									
50000	100000	150000	200000	250000	300000	350000	400000	450000	500000
potential									
9,75551	9,53631	9,32674	9,12619	8,93408	8,74989	8,57314	8,40339	8,24024	8,08329
9,53631	9,12619	8,74989	8,40339	8,08329	7,78669	7,51108	7,25431	7,01452	6,79007
9,32674	8,74989	8,24024	7,78669	7,38046	7,01452	6,68315	6,38168	6,10623	5,85357
9,12619	8,40339	7,78669	7,25431	6,79007	6,38168	6,01962	5,69644	5,40619	5,14409
8,93408	8,08329	7,38046	6,79007	6,28714	5,85357	5,47595	5,14409	4,85016	4,588
8,74989	7,78669	7,01452	6,38168	5,85357	5,40619	5,02235	4,68939	4,39784	4,14042
8,57314	7,51108	6,68315	6,01962	5,47595	5,02235	4,63814	4,30855	4,02268	3,77239
8,40339	7,25431	6,38168	5,69644	5,14409	4,68939	4,30855	3,98491	3,7065	3,46446
8,24024	7,01452	6,10623	5,40619	4,85016	4,39784	4,02268	3,7065	3,43641	3,203
8,08329	6,79007	5,85357	5,14409	4,588	4,14042	3,77239	3,46446	3,203	2,97823
7,93222	6,57954	5,621	4,90623	4,35273	3,91146	3,55143	3,25208	2,99928	2,78295
7,78669	6,38168	5,40619	4,68939	4,14042	3,7065	3,35491	3,06424	2,81993	2,61169
7,6464	6,19536	5,20721	4,49091	3,94785	3,52196	3,17901	2,89692	2,66081	2,4603
7,51108	6,01962	5,02235	4,30855	3,77239	3,35491	3,02063	2,74692	2,5187	2,32549
7,38046	5,85357	4,85016	4,14042	3,61187	3,203	2,87728	2,61169	2,39099	2,20469
7,25431	5,69644	4,68939	3,98491	3,46446	3,06424	2,74692	2,48915	2,27561	2,09582
7,1324	5,54752	4,53894	3,84067	3,3286	2,93701	2,62786	2,3776	2,17086	1,99719
7,01452	5,40619	4,39784	3,7065	3,203	2,81993	2,5187	2,27561	2,07532	1,90743
6,90047	5,27189	4,26525	3,5814	3,08653	2,71182	2,41824	2,18202	1,98784	1,82539
6,79007	5,14409	4,14042	3,46446	2,97823	2,61169	2,32549	2,09582	1,90743	1,75012
1,82329	2,95677	3,70575	4,21996	4,58134	4,83843	5,02171	5,15131	5,24095	5,30035
1,74962	2,74451	3,34369	3,714	3,94288	4,08018	4,15616	4,19006	4,19459	4,17838
1,68034	2,55453	3,03303	3,29578	3,43261	3,49256	3,50414	3,48476	3,44541	3,39328
1,61511	2,38377	2,76434	2,94576	3,01768	3,02676	2,99899	2,94952	2,8875	2,8186
1,55362	2,22972	2,5303	2,64965	2,67526	2,65057	2,59867	2,5324	2,45917	2,38332
1,49558	2,09025	2,32513	2,39676	2,38912	2,34195	2,27542	2,20024	2,12222	2,0446
1,44074	1,96355	2,14421	2,17895	2,14735	2,08533	2,01028	1,93095	1,85183	1,7752
1,38888	1,84811	1,98384	1,98994	1,94109	1,86946	1,78985	1,7093	1,63118	1,55702
1,33977	1,74263	1,84098	1,8248	1,76363	1,68602	1,60444	1,52449	1,44857	1,3776
1,29322	1,64598	1,71316	1,67964	1,60977	1,52872	1,44691	1,36864	1,29557	1,22811

R1									
2000									
50000	100000	150000	200000	250000	300000	350000	400000	450000	500000
potential									
9,67665	9,39115	9,12203	8,86789	8,62753	8,39986	8,1839	7,97876	7,78366	7,59786
9,39115	8,86789	8,39986	7,97876	7,59786	7,25168	6,93566	6,64604	6,37964	6,13377
9,12203	8,39986	7,78366	7,25168	6,78777	6,37964	6,01781	5,69482	5,40473	5,14277
8,86789	7,97876	7,25168	6,64604	6,13377	5,69482	5,3145	4,98179	4,68829	4,42745
8,62753	7,59786	6,78777	6,13377	5,59472	5,14277	4,75838	4,42745	4,13956	3,88682
8,39986	7,25168	6,37964	5,69482	5,14277	4,68829	4,30762	3,98412	3,70582	3,46386
8,1839	6,93566	6,01781	5,3145	4,75838	4,30762	3,93487	3,62149	3,35435	3,12391
7,97876	6,64604	5,69482	4,98179	4,42745	3,98412	3,62149	3,31937	3,06378	2,84473
7,78366	6,37964	5,40473	4,68829	4,13956	3,70582	3,35435	3,06378	2,81953	2,61135
7,59786	6,13377	5,14277	4,42745	3,88682	3,46386	3,12391	2,84473	2,61135	2,41336
7,42074	5,90615	4,90503	4,1941	3,66317	3,25156	2,9231	2,65491	2,4318	2,24328
7,25168	5,69482	4,68829	3,98412	3,46386	3,06378	2,74655	2,48884	2,27535	2,0956
7,09015	5,49809	4,4899	3,79416	3,28511	2,8965	2,5901	2,34233	2,13782	1,96615
6,93566	5,3145	4,30762	3,62149	3,12391	2,74655	2,45052	2,2121	2,01596	1,85177
6,78777	5,14277	4,13956	3,46386	2,97779	2,61135	2,32522	2,0956	1,90725	1,74997
6,64604	4,98179	3,98412	3,31937	2,84473	2,48884	2,2121	1,99075	1,80966	1,65877
6,51012	4,83059	3,83993	3,18646	2,72305	2,37732	2,10948	1,89589	1,72157	1,57661
6,37964	4,68829	3,70582	3,06378	2,61135	2,27535	2,01596	1,80966	1,64166	1,50221
6,25429	4,55414	3,58075	2,95019	2,50846	2,18178	1,93038	1,73094	1,56884	1,43451
6,13377	4,42745	3,46386	2,84473	2,41336	2,0956	1,85177	1,65877	1,50221	1,37265
2,25591	3,485	4,217	4,67379	4,96436	5,14831	5,2608	5,32385	5,35185	5,35458
2,13948	3,17307	3,71157	3,99464	4,13401	4,1879	4,18912	4,1572	4,10429	4,03817
2,03187	2,90178	3,29376	3,45752	3,50265	3,48314	3,4277	3,35249	3,26691	3,17661
1,93223	2,66427	2,94406	3,02455	3,00986	2,94827	2,86397	2,76969	2,67233	2,57568
1,83977	2,4551	2,64821	2,66991	2,61693	2,53142	2,43316	2,33185	2,23231	2,13685
1,75382	2,26989	2,39552	2,37545	2,29804	2,19945	2,09551	1,99337	1,89616	1,80508
1,67378	2,10508	2,17788	2,12804	2,03533	1,9303	1,82539	1,7256	1,63278	1,5473
1,59912	1,95775	1,989	1,91802	1,8161	1,70877	1,60553	1,50971	1,42211	1,34252
1,52937	1,8255	1,82398	1,7381	1,6311	1,52404	1,42397	1,33284	1,25069	1,17684
1,46409	1,70632	1,67891	1,58272	1,47346	1,36826	1,27214	1,18595	1,10914	1,04072

VIII Exploded view and part list of mechanical elements



7	M3_10	4	[Steel]
6	EX5LACS004-SGPLATE	1	[Aluminium]
5	EX5LACS003-SGEXTENDER	1	[Steel]
4	EX5LACS006-SGFLEXER2	1	[Steel]
3	EX5LACS002-SGFLEXER	1	[Steel]
2	EX5LACS005-SGSPACER	1	[Aluminium]
1	EX5LACS001-SGBASE	1	[Steel]
PC NO	PART NAME	QTY	Material

IX Arduino nano code: electrical solution

```
#include <avr/io.h>
#include <stdio.h>
#include <stdint.h>
#include <util/delay.h>

#define BAUD 38400
#define BPRE (((F_CPU / (BAUD * 16UL))) - 1)

#define VREF 5000
#define RESOLUTION 1024.0

void USART_init(void);
unsigned char USART_receive(void);
void USART_send(unsigned char data);

uint16_t adc_read(uint8_t adc_channel);
void uart_init(void);

int main(void){
 USART_init();
 DDRC = 0xF0;
 PORTC = 0x3F;

 PORTC = 0b00111111;

 static uint16_t adc_result;
 static float voltage;
 static uint8_t adcLow;
 static uint8_t adcHigh;

 ADMUX = (1<<REFS0);
 ADCSRA = (1<<ADPS2)|(1<<ADPS1)|(1<<ADPS0)|(1<<ADEN);

 while(1){
  adc_result = adc_read(2);
  USART_send(adc_result);
 }
}

uint16_t adc_read(uint8_t adc_channel){
 ADMUX &= 0xf0;
 ADMUX |= adc_channel;
 ADCSRA |= (1<<ADSC);
 while ( (ADCSRA & (1<<ADSC)) );
 return ADC;
}


void USART_init(void)
{
 UBRR0H = (uint8_t)(BPRE>>8);
 UBRR0L = (uint8_t)(BPRE);
 UCSR0B = (1<<RXEN0)|(1<<TXEN0);
 UCSR0C = ((1<<UCSZ00)|(1<<UCSZ01));
}

void USART_send (unsigned char data) {
while(!(UCSR0A & (1<<UDRE0)));
UDR0 = data;
}
```

X GUI python code

```
from PySide2.QtGui import *
from PySide2.QtWidgets import *
from PySide2.QtCore import *
import Loggert as logger
import Plotter
import os
from datetime import datetime as dt
from datetime import date as dat
import Simplifier as simp
import Modeler as mod
class MainWindow(QMainWindow):

    def __init__(self, *args, **kwargs):
        super(MainWindow, self).__init__(*args, **kwargs)

        self.counter = 0
        self.currentLog = 0
        self.slog = []
        self.check = True
        self.fileName = ''
        self.showGraphs = True

        layout = QGridLayout()
        font1 = QFont("Fantasy", 20)

        self.l = QLabel("EX05 LACS Data Logger (V2.0)")
        self.l.setFont(font1)
        self.label = QLabel("", self)

        check = QCheckBox("Show graphs", self)
        check.stateChanged.connect(self.checkBoxChange)
        check.toggle()

        b = QPushButton("START")
        b.pressed.connect(self.oh_no)

        a = QPushButton("STOP")
        a.pressed.connect(self.oh_yes)

        c = QPushButton("SAVE LOG")
        c.pressed.connect(self.saveLog)

        d = QPushButton("PLOT")
        d.pressed.connect(self.plott)

        e = QPushButton("GENERATE MODEL")
        e.pressed.connect(self.handleMach)

        f = QPushButton("REAL-TIME CHECK")
        f.pressed.connect(self.handleRT)

        self.slog0 = QLabel("Status: Ready")

        picture = QPixmap("C:/Users/Pablo
        Paniagua/Desktop/S05/EX05-SW/Development/SDU_Small.jpg")
        label = QLabel()
        label.setPixmap(picture)
        label.setAlignment(Qt.AlignCenter)
        picture2 = QPixmap("C:/Users/Pablo
        Paniagua/Desktop/S05/EX05-SW/Development/LINAK_Big.png")
        label2 = QLabel()
        label2.setPixmap(picture2)
        label2.setAlignment(Qt.AlignCenter)
```

```
        font2 = QFont("Fantasy", 10)
        self.ti = QLineEdit()
        self.ti.setFont(font2)
        self.ti.setPlaceholderText("Insert log file name")

        layout.addWidget(self.l, 0, 0, 1, 4, Qt.AlignHCenter)
        layout.addWidget(label, 1, 0, 1, 2)
        layout.addWidget(label2, 1, 2, 1, 2)
        layout.addWidget(b, 2, 0, 1, 4)
        layout.addWidget(a, 3, 0, 1, 4)
        layout.addWidget(self.ti, 4, 0, 1, 2)
        layout.addWidget(c, 4, 2, 1, 2)
        layout.addWidget(d, 5, 0, 1, 4)
        layout.addWidget(e, 6, 0, 1, 2)
        layout.addWidget(f, 6, 2, 1, 2)
        layout.addWidget(check, 7, 0, 1, 2)
        layout.addWidget(self.slog0, 7, 2, 1, 2)

        w = QWidget()
        w.setLayout(layout)

        self.setCentralWidget(w)

        self.show()

        self.threadpool = QThreadPool()
        #print("Multithreading with maximum %d threads" %
        self.threadpool.maxThreadCount())

    def oh_no(self):
        worker = Worker(self.executeLog)
        self.threadpool.start(worker)
        self.slog0.setText("Status: Reading")

    def oh_yes(self):
        self.check = False
        self.slog0.setText("Status: Reading stopped --> Save data to avoid log losses")

    def saveLog(self):
        str_name =str(self.ti.text())
        day = str(dat.today())
        str_clean = str_name.replace(" ", "_")
        day_clean = day.replace(" ", "_")
        self.fileName = str(day_clean) + "-" + "Log_" + str(str_clean) + ".csv"
        os.system("LogSave.bat " + self.fileName)
        self.ti.setText("")
        self.slog0.setText("Status: Reading stopped --> Log saved")

    def plott(self):
        if self.fileName == '':
            self.slog0.setText("Status: Save file before plotting")
        else:
            self.slog0.setText("Status: Plotting")
            this = "C:/Users/Pablo Paniagua/Desktop/S05/EX05-SW/Logs/" + self.fileName
            simp.clenData(this)
            Plotter.dataGraph()


    def executeLog(self):
        self.check = True
        print("Thread running")
        log = logger.logger()
        log.startLog()
        while self.check:
            self.currentLog = log.runLog()
        log.stopLog()
        print("Thread complete")
```

```
    def exec_kill(self):
        self.check = False

    def handleLog(self):
        while self.check:
            self.slog1.setText(str(self.currentLog))

    def handleMach(self):
        if self.showGraphs == True:
            self.handleRT()
        else:
            worker = Worker(self.handleRT)
            self.threadpool.start(worker)

    def handleRT(self):
        if self.fileName == '':
            self.slog0.setText("Status: Save file before modeling")
        else:
            self.slog0.setText("Status: Generating Model")
            self.model = mod.magic("C:/Users/Pablo Paniagua/Desktop/S05/EX05-SW/Logs/" + self.fileName, self.showGraphs)
            self.model.statistics()
            self.model.blackFuckery()

    def checkBoxChange(self, state):
        if state == Qt.Checked:
            self.showGraphs = True

        else:
            self.showGraphs = False

    #def recurring_timer(self):
        #self.counter +=1
        #self.l.setText("Counter: %d" % self.counter)

class Worker(QRunnable):
    '''
    Worker thread

    Inherits from QRunnable to handler worker thread setup, signals and wrap-up.

    :param callback: The function callback to run on this worker thread. Supplied args and
                     kwargs will be passed through to the runner.
    :type callback: function
    :param args: Arguments to pass to the callback function
    :param kwargs: Keywords to pass to the callback function

    '''
    def __init__(self, fn, *args, **kwargs):
        super(Worker, self).__init__()
        # Store constructor arguments (re-used for processing)
        self.fn = fn
        self.args = args
        self.kwargs = kwargs

    @Slot()  # QtCore.Slot
    def run(self):
        '''
        Initialise the runner function with passed args, kwargs.
        '''
        self.fn(*self.args, **self.kwargs)

app = QApplication([])
window = MainWindow()
app.exec_()
```

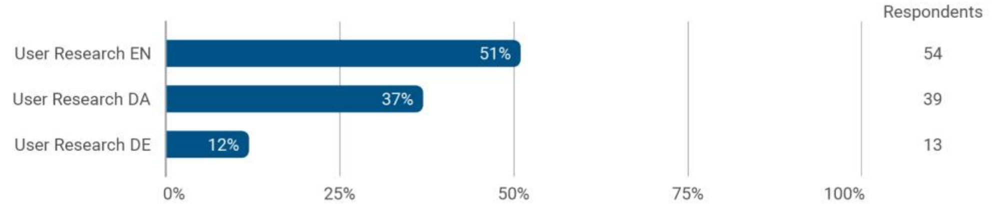
XI Machine learning algorithms python code

```python
# Load libraries
from pandas import read_csv
from pandas.plotting import scatter_matrix
from matplotlib import pyplot
from sklearn.model_selection import train_test_split
from sklearn.model_selection import cross_val_score
from sklearn.model_selection import StratifiedKFold
from sklearn.metrics import classification_report
from sklearn.metrics import confusion_matrix
from sklearn.metrics import accuracy_score
from sklearn.linear_model import LogisticRegression
from sklearn.tree import DecisionTreeClassifier
from sklearn.neighbors import KNeighborsClassifier
from sklearn.discriminant_analysis import LinearDiscriminantAnalysis
from sklearn.naive_bayes import GaussianNB
from sklearn.svm import SVC
from sklearn import model_selection
import pickle


class magic:
    def __init__(self, fileName, runAnalysis):
        self.ShowGraphs = runAnalysis
        self.file = fileName
        self.dataset = read_csv(self.file)


    def statistics(self):
        # shape
        print(self.dataset.shape)
        # head
        print(self.dataset.head(20))
        # descriptions
        print(self.dataset.describe())
        # class distribution
        print(self.dataset.groupby('status').size())

        if self.ShowGraphs:
            # ------------------------------------------------------------------------------------------------------------------
            # Start with some univariate plots of each individual variable
            # 1. Box and whiskers plot
            # 2. Histogram plot

            # box and whisker plots
            self.dataset.plot(kind='box', subplots=True, layout=(6,10), sharex=False, sharey=False)
            pyplot.show()

            # histograms
            self.dataset.hist()
            pyplot.show()

            # ------------------------------------------------------------------------------------------------------------------
            # Plots to see interactions between pairs of attributes

            # scatter plot matrix
            scatter_matrix(self.dataset)
            pyplot.show()

    def runModels(self):
        # ------------------------------------------------------------------------------------------------------------------
```

```
        # Evaluate some algorithms
        array = self.dataset.values
        X = array[:,0:50]
        y = array[:,50]
        self.X_train, self.X_validation, self.Y_train, self.Y_validation = train_test_split(X, y, test_size=0.20, random_state=1)

        # Spot Check Algorithms
        models = []
        models.append(('LR', LogisticRegression(solver='liblinear', multi_class='ovr')))
        models.append(('LDA', LinearDiscriminantAnalysis()))
        models.append(('KNN', KNeighborsClassifier()))
        models.append(('CART', DecisionTreeClassifier()))
        models.append(('NB', GaussianNB()))
        models.append(('SVM', SVC(gamma='auto')))

        # evaluate each model in turn
        results = []
        names = []
        bestModel = ''
        score = 0
        for name, model in models:
            kfold = StratifiedKFold(n_splits=10, random_state=1, shuffle=True)
            cv_results = cross_val_score(model, self.X_train, self.Y_train, cv=kfold, scoring='accuracy')
            results.append(cv_results)
            names.append(name)
            print('%s: %f (%f)' % (name, cv_results.mean(), cv_results.std()))
            if score > cv_results.mean():
                score = cv_results.mean()
                bestModel = model

        if self.ShowGraphs:
            # Compare Algorithms
            pyplot.boxplot(results, labels=names)
            pyplot.title('Algorithm Comparison')
            pyplot.show()

        self.filename = 'final_model.sav'
        pickle.dump(bestModel, open(self.filename, 'wb'))

    def predict (self):
        loaded_model = pickle.load(open(self.filename, 'rb'))
        result = loaded_model.score(self.X_validation, self.Y_validation)
        print(result)
        # --------------------------------------------------------------------------------------------------------------------
        # Make predictions on validation dataset
        predictions = loaded_model.predict(self.X_validation)

        # Evaluate predictions
        print(accuracy_score(self.Y_validation, predictions))
        print(confusion_matrix(self.Y_validation, predictions))
        print(classification_report(self.Y_validation, predictions))
```

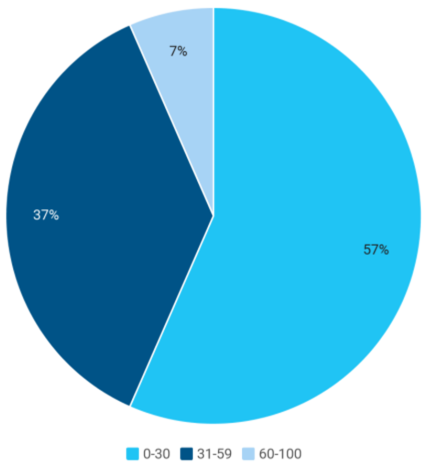
XII Survey Analysis

Survey languages

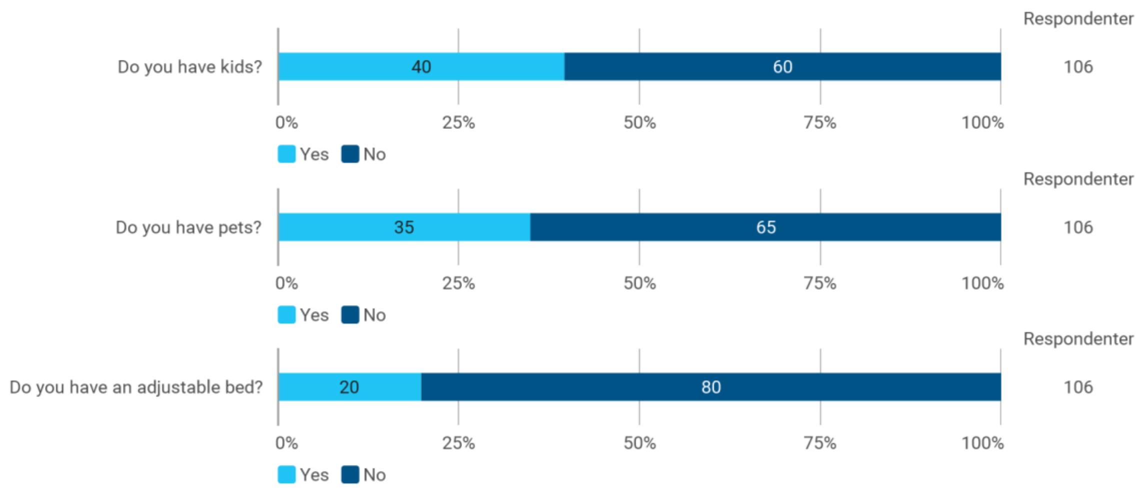


Average age of survey respondents

Age Group - Filter

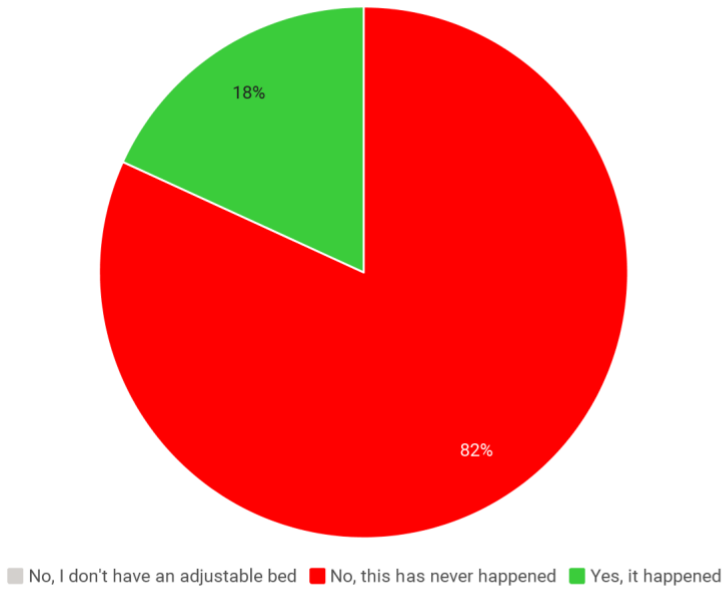


General questions



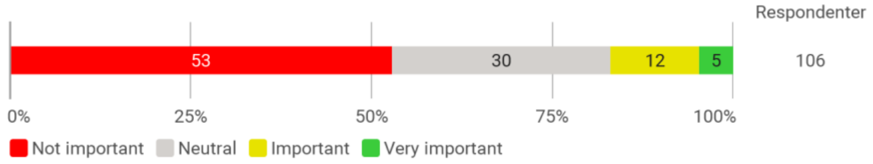
Have you experienced any kind of pinching or accidents with kids or pets?

Filter: Do you have an adjustable bed? = [Yes]



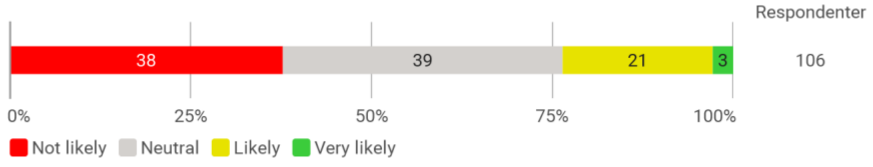
How important is a Smart Home feature to you when buying an adjustable bed?

Crossed with: Age Group



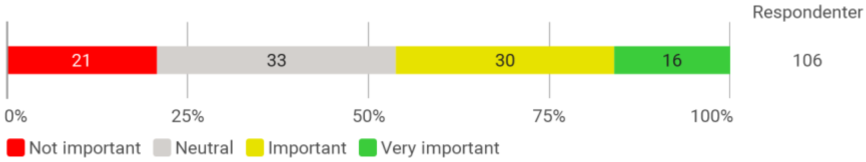
How likely is it that you would spend more money on a smart home feature?

Crossed with: Age Group



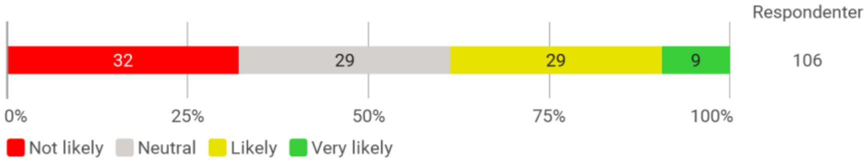
How important is an anti-pinching feature to you when buying an adjustable bed?

Crossed with: Age Group



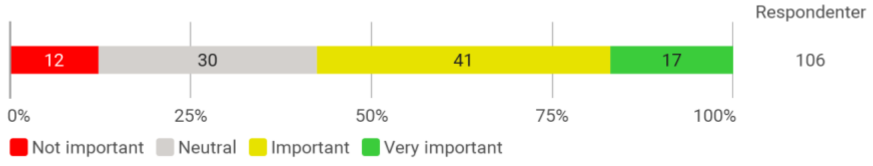
How likely is it that you would spend more money on an anti-pinching feature?

Crossed with: Age Group



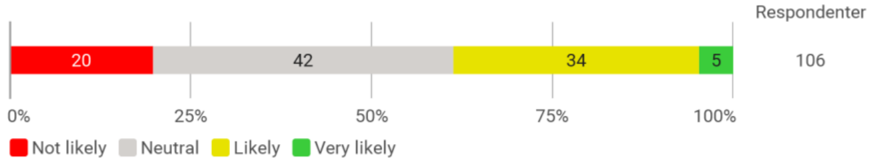
How important is a feature which simplifies cleaning of the adjustable bed?

Crossed with: Age Group



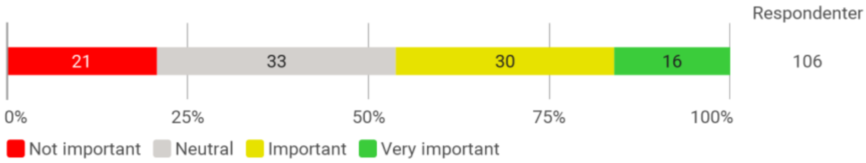
How likely is it that you would spend more money on a cleaning feature?

Crossed with: Age Group



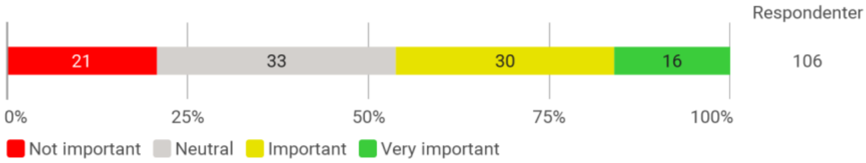
How important is an anti-pinching feature to you when buying an adjustable bed?

Crossed with: Do you have kids?



How important is an anti-pinching feature to you when buying an adjustable bed?

Crossed with: Do you have pets?

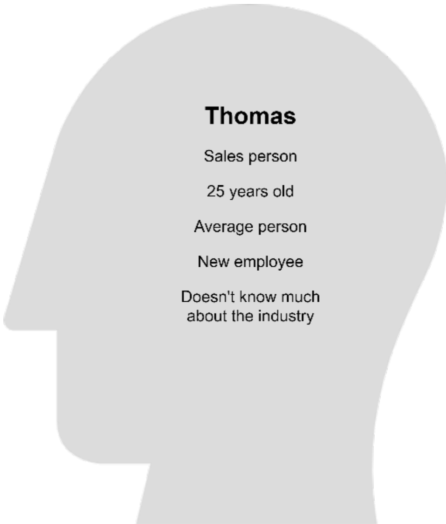


XIII Value Proposition Canvas

Personas:

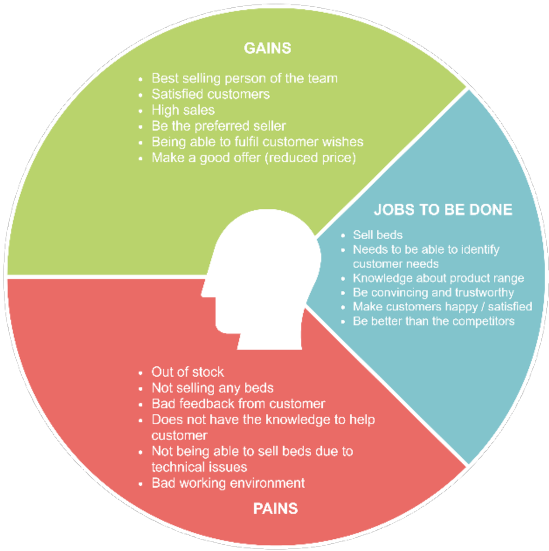
Jesper – 43 years old – Retailer

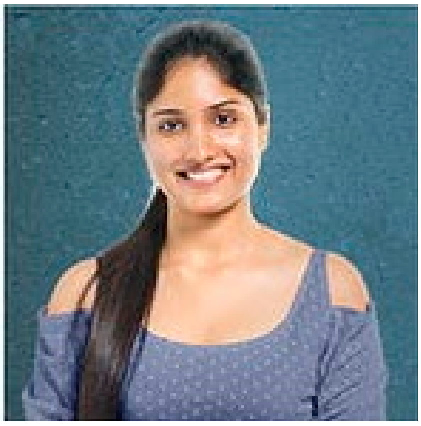
Consultant at Wonderland



Thomas – 25 years old – Retailer

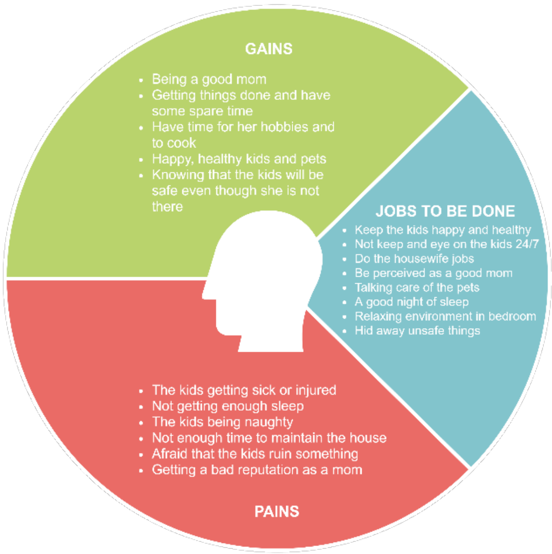
Salesperson, new employee, no prior experience





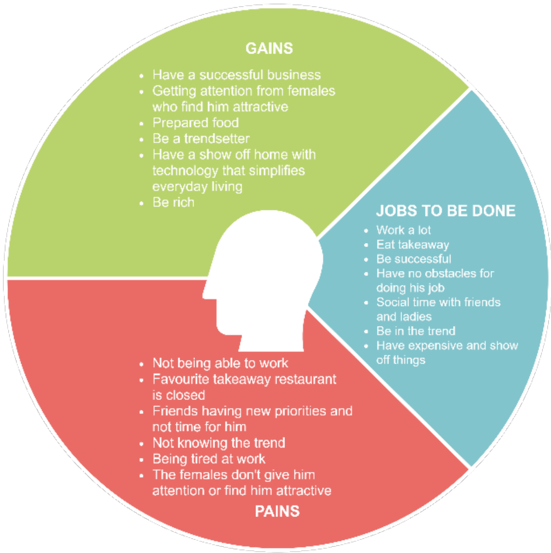
Petra – 40 years old

Mother of two boys, has one dog and cat, busy husband, likes to cook



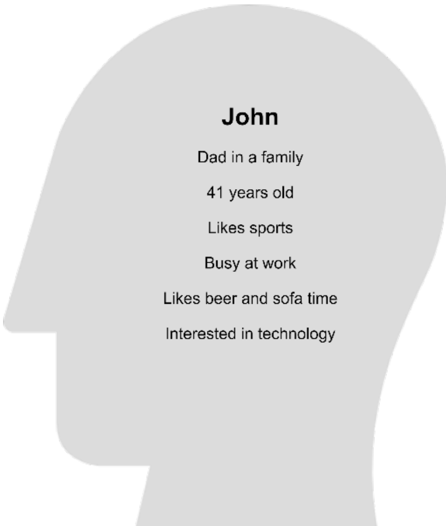
Brian – 29 years old

Single without kids, successful own business, barely home only for sleeping



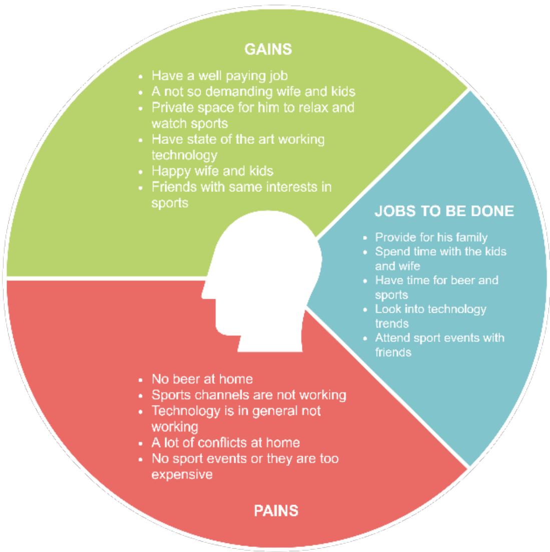
Gertrud – 65 years old

Has a cat, loves baking, not a frequent user of internet, likes to spend time with her five grandchildren



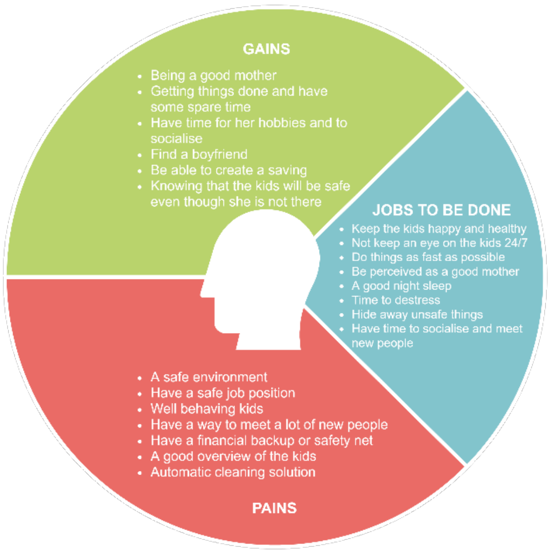
John – 41 years old

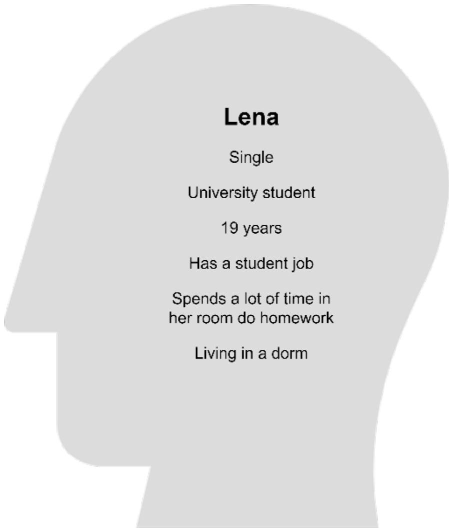
Dad, married, likes to watch sports, busy at work, enjoy afterwork beer in sofa, into technology



Sarah – 28 years old

Single mother has two kids, working in bank, super busy and stressed





Lena – 19 years old

Single, student at university, has a student job, do homework in her room, lives in a dorm