TALLINN UNIVERSITY OF TECHNOLOGY

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL POWER ENGINEERING AND MECHATRONICS

SMART-HANGER HARDWARE, SOFTWARE AND ELECTRONICS DEVELOPMENT THROUGH 3D MODELLING AND PROTOTYPING

Nutikas riidepuu riistvara, tarkvara ja elektroonika arendamine 3D-modelleerimise ja prototüüpide loomise kaudu

MASTER THESIS

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Tallinn 2022

(*On the reverse side of title page*)

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THESIS TASK

Student: Nikoloz Kalandarishvili 194523

Study programme, MAHM Mechatronics MSc

main speciality: Mechatronics

Supervisor: Heigo Mõlder, Engineer, PhD

Thesis topic:

SMART-HANGER HARDWARE, SOFTWARE AND ELECTRONICS DEVELOPMENT THROUGH 3D MODELLING AND PROTOTYPING

NUTIKAS RIIDEPUU RIISTVARA, TARKVARA JA ELEKTROONIKA ARENDAMINE 3D-MODELLEERIMISE JA PROTOTÜÜPIDE LOOMISE KAUDU (in Estonian)

Thesis main objectives:

1. Researching the clothes/coats storage existing services
2. Coming up with several alternavite solutions and choosing one for prototyping
3. Choosing the right components, making the hardware design and prototyping

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Problem idetification and reviwing existing solutions	01.2022
2.	Finding alternative solutins and choosing the best option	02.2022
3.	Picking up the components and creating mechanical 3D model	03.2022
4.	Building the final prototype	03.2022
5.	Designing a real-life prototype	04.2022

Language: Eng **Deadline for submission of thesis:** “…….”………20….a

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PREFACE

First of all, the author of the thesis wants to express massive gratitude towards the supervisor of this work Mr Heigo Mõlder. Who initiated the idea of the Smart hanger and was part of the product development throughout the whole time spent on this project.

In the beginning, the idea of this project was to build a solution to have an automatized version of the coat storage service at Tallinn University of Technology. However, the idea expanded and improved during the building process. This project can be implemented in many establishments, such as operas, theatres, and other public premises where they used to have coat storage service before the pandemic.

The author of this thesis worked as a hardware layout, mechanical design and embedded software engineer whose main task was to create the prototype of the device. The author wants to show great appreciation to Mr Giorgi Okroshidze, who supported the project from the software side, and Mr Vano Saginashvili, who helped with the illustrations in the thesis report.

The author is thankful to Tallinn University of Technology and its staff, especially program manager Professor Anton Rassõlkin, who gave the courage, working environment, tools, and recourses.

Keywords: Mechanical design, 3D model, rapid prototyping, Embedded software, Electronics

List of abbreviations and symbols

3D	3-dimensional
BOM	Bill of Materials
CNC	Computer Numeric Control
CSS	Cascading Style Sheets
FEM	Finitie Elemet Method
GPIO	General-purpose input/output
HPL	High Pressure Laminate
HTML	HyperText Markup Language
I2C	Inter-Integrated Circuit
IoT	Internet of Things
LCD	Liquid Crystal Diode
LED	Light Emitting Diode
MVP	Minimun Viable Product
MySQL	My Structured Query Language
OS	Operating System
PLA	Polylactic Acid
Ral	Reichs-Ausschuß für Lieferbedingungen
RC	Radio Controlled
RFID	Radio-Frequency Identification
SPI	Serial Peripheral Interface
UART	Universal asynchronous receiver-transmitter
UTHM	Universiti Tun Hussein Onn
Amp	Ampere
P	Power

1. INTRODUCTION

In everyday life, people meet situations where they need to find a place to leave their coats when entering an establishment. This service is usually provided at the building entrance, where service personnel take the coat and give back the number. When they decide to leave and want to take the coat back, they give the staff number and get back the coat.

This sort of approach was valid until the Covid outbreak. After Covid became a world threat (a pandemic), these services were stopped in most places, and people started leaving their coats at the same place but without anyone's attendance. Providing this service became dangerous for the service personnel, who had to come in contact with many peoples' coats and personal belongings.

Even without the outbreak, the need to automate such a service was already in demand. However, the covid pandemic boosted the demand, which eventually became very high, and the need became important. If there is a chance to do it yourself without human interaction, people should at least have a choice. There should be an option to leave a coat in a wardrobe and feel safe, that no one will steal or accidentally take your stuff. In northern countries, people tend to not interact with each other as much as in countries with a warmer climate. The automatization of this service benefits the user since no human interaction is needed to leave the coat and personal belongings in a safe place.

One solution to this problem is closed cabinet boxes (lockers). This solution is widely used in water parks, gyms and some venues. Users leave their jackets, clothes, and other personal belongings in the locker and lock the cabinets when entering the establishment. Before leaving, they unlock the lockers and take their stuff. The locker is a good solution; however, it takes too much space. There needs to be a new solution for just coats and jackets, which will be more compact and not take up a massive space, like closed cabinet boxes.

The thesis is about a project that digitalizes the entrance wardrobe service and makes the coat hanger smart by adding IoT (Internet of Things) technology. The hanger hooks are mechanical and can get locked or unlocked by the user. With this approach, the user does not need to interact with anyone else while leaving the coat in a safe place. The thesis will explain the different methods of making this technology. The user interface and working principle will be explained more in detail later in the main body. Similar projects will be discussed, and the hardware and the software algorithm will be illustrated to show the project's working principle and 3D (3-dimensional) model design.

The prototype of the project was built and carefully analyzed. The device's electrical, mechanical, and software sides have been prepared and tested on the prototype. The thesis describes the prototype in detail and gives results. After that, a real-life prototype can be built to integrate this project into some establishments.

2 LITERATURE OVERVIEW/ANALYSIS

2.1 Manual labor for keeping visitors’ coats/jackets in establishments

In many establishments, coat storage services were provided for visitors at the building entrance in the pre-pandemic period. The employees used to take the visitor's coat, and they gave back the number tag. When visitors wanted to get back the coat, they gave the number tag back to the employees and returned the coat/jacket. Tallinn University of Technology also provided this service before the covid outbreak in Estonia. When it became unsafe for the working ladies to interact with many peoples' personal belongings, TalTech stopped this service. As it was researched in the human resources department of TalTech, these employees received the minimum wage salary and 4-5 ladies used to work in the main entrance of the building.

It can be roughly estimated that each employee was responsible for a hundred hanger hooks. So, for hundreds of hanger hooks, approximately 500 euros were spent by the university each month. (The university's human resources department gave this information).

Figure 2.1 An illustration of a lady giving a number tag in exchange to the coat to the establishment visitor

2.2 Smart ways to securely lock clothes

2.2.1 Locker Cabinets

The Smart hanger idea is related to the lockers system by its essence. The locker systems are widely used in gym changing rooms, schools, parks, and water parks, where users can leave their personal belongings in the locker cabinets.

People meet lockers of different sizes or locking systems. The most popular locking system is with the key. For example, every student has a personal locker and a key at school, and the locker is for their personal use. There are other types of locking systems used for locking the safes, such as an RFID-based locking system, where the user needs to put a coin to lock the locker, the one with the combination locks, or the ones which are unlocked using barcoded wristbands. More about different ways of locking systems will be discussed in the following sections of the thesis.

All these types of locker cabinets are there to store users' personal belongings securely. This way to securely lock clothes is a prevalent and widely used method; however, these types of lockers take up a massive space and would not be helpful to be put at the university entrance for just coats/jackets. For that kind of purpose, some other solution needs to be found.

Figure 2.2 Locker cabinets [1]

2.2.2 Locker Security System Using Keypad and RFID

In 2019, in Albyada,Libya two engineers of University of Omar Al-mukhtar developed a project – Locker security system using keypad and RFID [2]. This system is a password and an RFID based access-control system which permits only an authentic person to unlock. The user validates the RFID tag and enters the password, if both are valid, the safe unlocks.

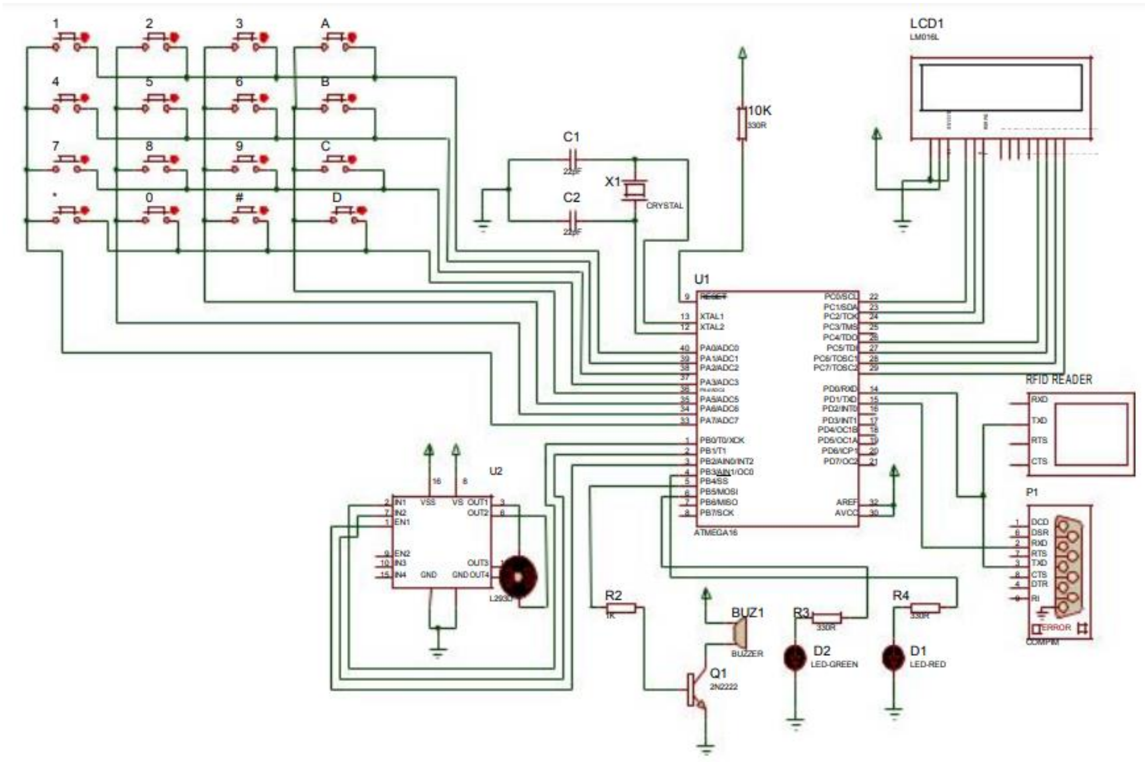

Figure 2.3 Circuit diagram of Locker Security System using Keypad and RFID. [2]

The system consists of Atmega16, keypad, RFID module, LCD screen, LEDs, buzzer, motor driver and a motor. The working principle of the locker is relatively simple. The LCDs - Enter your RFID tag and then, if matched with the tag stored in the database, outputs the following message – Enter 1 to login, Enter 2 to change the password. If pressed 1, the user inputs the password, and if correct, the locker gets unlocked. If pressed 2, the user puts the old password first and, if right, puts the new password and updates it in the database.

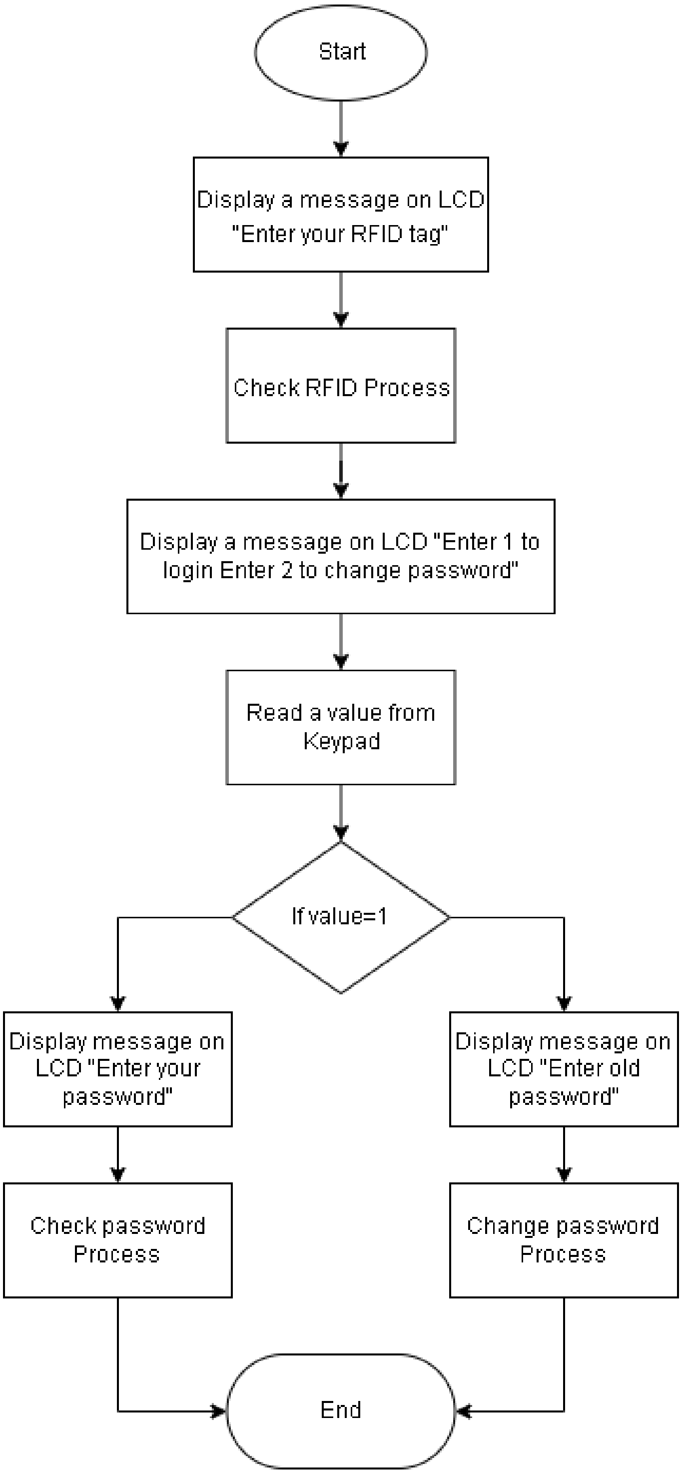

Figure 2.4 Locker Security System using Keypad and RFID working principle

2.2.3 Jialifu gym HPL (High Pressure Laminate) locker

There are tons of lockers with different locking systems in the market, and many companies produce lockers for changing rooms, schools, or other establishments. These companies are:

- Gantner, [3]
- Ricoh, [4]
- Locktec, [5]
- Jialifu, [6]

And many more. However, here will be explained Jialifu gym locker solutions. Jialifu is a Chinese manufacturer producing gym lockers and other products. They use Compact Laminate Panel; it is made of multi-layer cowhide phenolic, double face decorative colour paper immersed in melamine resin, laminated and pressed on a 150°C steel plate at high pressure (1430psi). It is resistant to water and fire, has easy cleaning, reliable quality and durability. Especially suitable for stations, hospitals, shopping malls, schools, airports, office buildings and stadiums. [7] Jialifu offers lockers in different sizes and locking system.

Table 2.1 Jialifu locking systems

RFID lock	**Fingerprint lock**	**Digital lock**
		

Cam lock **Combination lock** **S.S handle**

2.2.4 G-LB lock hanger

G-LB lock hanger is a type of hanger which is used to securely lock clothes with keys on the hanger [8]. This solution is purely mechanical. The user hangs the jacket on the hanger, puts the rope in the jacket's sleeves, and locks the rope. This type of solution would not help hang the coat/jacket at the university entrance or any other such establishment since it is very inconvenient to lock the coat. Moreover, after locking the coat, there is a possibility of losing the key, which can cause trouble.

Figure 2.5 G-LB lock hanger

2.3 Existing patents

For searching the existing patents related to clothes/coats storage systems, the Google patents (https://patents.google.com/) search portal was used. Google Patents portal was chosen because it is the top free patents search engine and offers the ability to search in Google Scholars for non-patent literature.

Several keyword combinations were put in the search bar to search the patents related to intelligent locking systems of personal items. Furthermore, here are keyword combinations and the number of results.

Table 2.2 Search results

Keyword	**Number of results**
Personal items locking smart systems [9]	75
Smart clothes lockers [10]	38
personal items locker systems RFID	159
locker rental system	226
Electronic RFID locker storage	70

It turns out that there are many patents related to smart locking systems for personal items. Out of those patents, three were chosen for further analysis since they were the most related patents to this topic. These patents are:

- Locker system using barcoded wristbands
- Locker rental system using external codes
- Electronic RFID locker to improve the convenience of storage

The correlation to the safe coat hanging system will be shown.

2.3.1 Locker system using barcoded wristbands

Amusement parks, water parks and many establishments offer visitors to rent lockers. They need lockers to store their valuable personal belongings while in the park—for example, towels, shoes or other accessories. [11]

This invention offers a barcoded wristband to open the locked cabinet. The barcode is included on the wristband, and the system of lockers has a barcode reader, which reads the barcode from the wristband, and then the locker is assigned to the user. Later, when the user scans the barcode again, the same locker opens, and the user gets access to his valuables.

This solution is sometimes problematic because the scanner can get damaged, and the user will not be able to get access to personal belongings. Moreover, having wristbands gives additional expenses for the host company. [11]

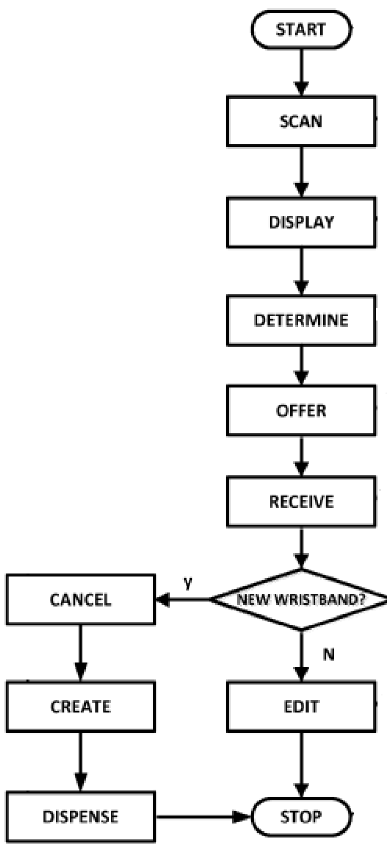

Figure 2.6 User experience of locker system using barcoded wristbands

2.3.2 Locker rental system using external codes

Some venues, such as theme parks, water parks, etc., make lockers available to the guests. Visitors use lockers to store personal possessions while visiting the venue. Those venues mainly issue temporary physical keys, like keycards or wristbands, which adds to the expenses to the host establishment. Using fingerprint scanning on any other biometric is a complex technology and usually has scanning problems which make visitors unable to retrieve stored items. [12]

The patent "Locker rental system using external codes" was patented by the inventor Keith Louis Amdahl, and the idea was developed due to the problems mentioned above. A locker rental system includes electronic lockers centrally managed by a locker manager, and the locker manager is connected to a separate external system. When visiting the venue, the guests usually get an admission ticket or a card for purchasing at the venue. Both have a unique or semi-unique identification code that the locker manager can handle. So, in this way, the external codes are connected to the database that the locker manager controls and the problems mentioned above are solved.

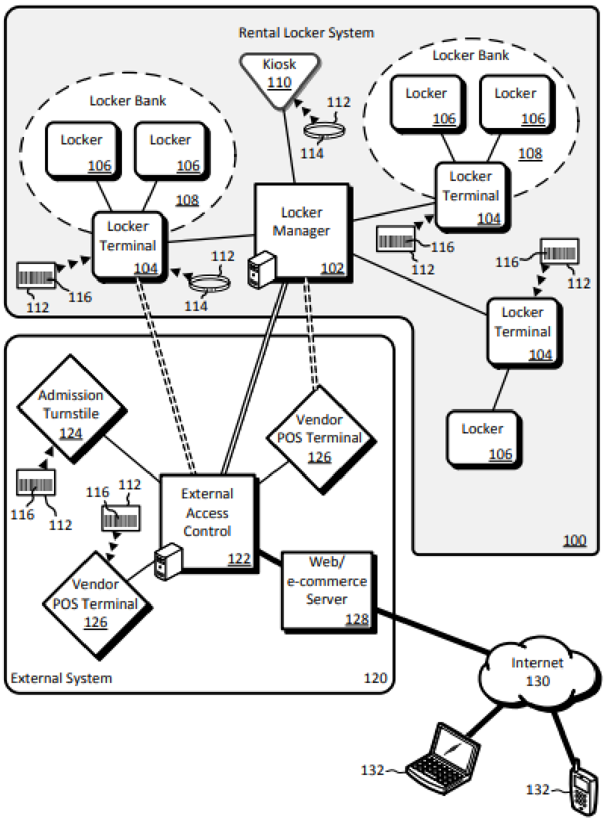

Figure 2.9 Locker rental system using external codes

2.3.3 Electronic RFID locker to improve the convenience of storage

The “Electronic RFID locker to improve the convenience of storage” was patented in South Korea by two local inventors. The patent is about improving the convenience for schools to get storage space for school students. The problem is rather simple but global, which this invention is solving. [13]

In many schools each student gets a personal locker cabinet and a single key particularly for their personal use. However, they get the locker for the certain period of time. Sometimes student change the building, school or they finish their studies and the locker becomes free to use. However, it raises some security concerns. Because, the previous user of the locker can theoretically multiply the key and steal from the current user. Or if the student loses the key, it also creates a threat to the locker in case someone finds it and steals from the locker.

Due to these problems mentioned above the inventors patented a new methodology for the South Korean schools. The students get student cards and the particular locker cabinet is assigned to each card digitally. When the student does not need the locker anymore, they just remove the card from the database and assign the locker to some other student.

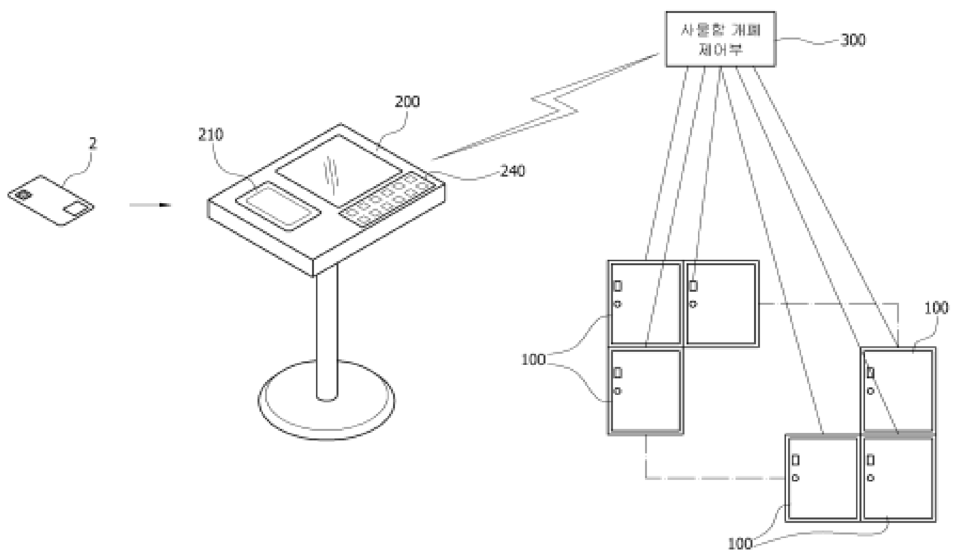

Figure 2.10 Electronic RFID locker to improve the convenience of storage

Here are what numbers indicate on figure 2.10:

2	Student Card
210	RFID reader
200	Display
240	Input keyboard
300	Locker opening/closing control
100	Locker

2.4 Literature overview summary

The literature overview discussed the manual labour method to store coats and jackets in the entrances of the building and lockers used to store personal possessions in a safe place. Also, different patents were discussed regarding the locking systems for the locker cabinets. It can be concluded from the literature review that such a device that can be installed at the entrance of the building to hang the coat safely does not exist in the open-source world. One option would be installing locker cabinets.

The disadvantages to installing locker cabinets in the entrances of the establishment for coat hanging are massive. At first, there is no need to have such enormous wardrobes for just coats, and it would take massive space for a few lockers and would not be enough for the students. Secondly, the price of the lockers is high, and it requires more budget solutions.

The literature overview clearly emphasizes the need for a new solution for coat storage - the new automated coat storage solution – An intelligent hanger. A smart hanger that will use a clever way to lock the coat securely would be easy and convenient for the user to hang and take the coat from the hanger.

3 ANALYSIS OF DIFFERENT SOLUTION IDEAS

3.1 The solution alternatives

As discussed in the literature overview, the market needs a new solution for a Smart hanger. A device that will be installed at the building entrance, and users will be able to hang their coats safely and take them when needed without any human interaction, like lockers [6], but smaller and without cabinets. There are multiple solution alternatives for making the Smart hanger with these requirements. This chapter will discuss all the solution ideas, and the best one will be chosen from the list.

3.1.1 Solution with touchscreen

Since the idea is to create a Smart hanger for Universities, this solution will be considered for university coat hanging areas. However, it can be implemented in other establishments, such as operas, theatres and schools.

The Smart hanger will be installed at the university entrance, in the coat hanging area. A touchscreen will have a default welcoming message – "Please scan your ISIC/ITIC card". After validating the card, the next page shows the available and busy hooks on the hanger. When choosing the correct hook number, the hook releases and opens, and the user will have 45s to hang the coat. After 45s, the hook will close automatically. When leaving the premises, the user validates the card again and presses the unlock button on the touchscreen. The hook opens up for 45s and closes. In the system, it becomes an available hook for the following user.

Figure 3.1 Illustration of the touchscreen solution

3.1.2 Card reader for each hook

This alternative solution does not require a touchscreen. Every hook has a card reader next to the number tag. When the user validates the card, the hook opens for several seconds, and the user hangs the coat, and the hook closes automatically. When the hook is in the “busy” state, no card will open it except the one used to lock it. When the user decides to take the coat/jacket back, he validates the card in the same place again and takes the coat back. The hook returns to its “available” state.

Figure 3.2 Illustration of RFID reader with each hook

3.1.3 Solution with mobile app

This solution does not require the touchscreen but requires mobile app development. There is a barcode sticker attached to the Smart hanger in the coat hanging area when entering the building. When scanning the barcode with the smartphone, it opens a webpage/app with the busy and available hooks on the hanger. The user chooses the hook and presses the open button on his phone. The hook opens, and the user has some time to hang the coat on the hook. The hook locks automatically after several seconds. When the user decides to leave the premice and take the coat/jacket back, he scans the barcode again and unlocks the hook. He takes the coat, and the hook returns to its "available" state.

Figure 3.3 Alternative solution with mobile app

3.1.4 Face recognition solution

The following solution does not require an RFID reader. Instead of RFID, it uses face recognition technology. When a user wants to hang the coat on the hanger, he shows the face to the camera installed on the Smart hanger. The camera reads the face and unlocks the hook for the user. The user puts the coat on the hanger, and in the database, the hanger is connected to the user's face until the user decides to take it from the hanger. Then, the user again shows the face to the camera, unlocks the hook, and the hook returns to its "available" state.

Figure 3.4 Face recogniton solution illustration

3.1.5 Portable hanger

The last alternative solution is a portable model. The mobile model differing from the other solutions requires a battery for the power supply. In the case of the portable version, multiple designs can be modelled, one of which is shown in figure 3.5. When the user hangs the coat on the hanger, two ropes will go through the jacket's sleeves and lock up each other by a magnetic force.

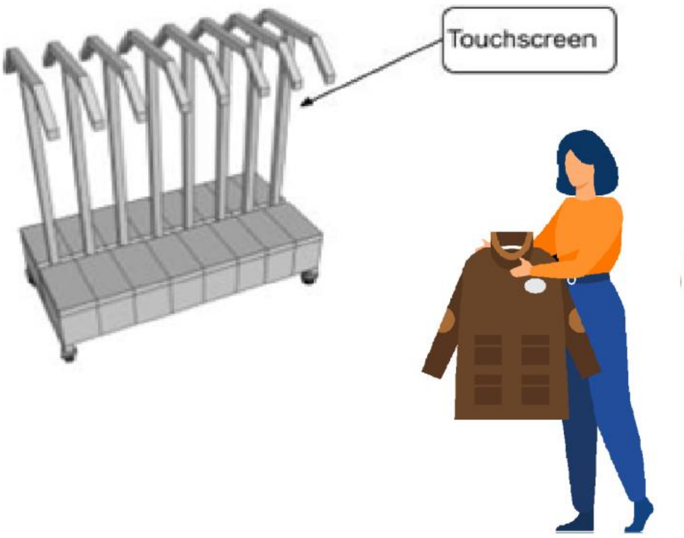

Figure 3.5 Portable Smart hanger solution

3.1.6 Chosen solution for prototyping

Even though all the alternative solutions are valid and can be made, the chosen solution for prototyping is a solution with a touchscreen. The prototype will have a hook, touchscreen and a card reader. This solution requires developing a user interface, database and embedded program for a hook and a card reader. Component selection for this solution will be shown in the next section.

3.2 Component selection

3.2.1 Choosing the right controller for Smart hanger

Nowadays, primarily the control systems are based on special-purpose devices. However, little attention is given to universal microcontrollers that can perform a wide variety of tasks. [14]. The performance growth of microcontrollers has led to their ability to manage complex applications. Raspberry and Arduino are the most widely used microcontrollers [15]. Both of them provide high performance, and they can be used in many challenging automation applications.

As shown in the analysis of past project, they are using Arduino to control similar types of components and here is the comparison between several controllers and explanation which is the best controller to use in Smart hanger. [16]

Table 3.1 Technical comparison between different controllers

Boards			
	Raspberry Pi 4 [17]	**Arduino** [18]	**Netduino** [19]
Price	€144.18[1]	€25[2]	€59.15[3]
Summary	Raspberry Pi is a small single-board computer with programmable GPIO pins and video processing	Signle-board microcontroller with digital and analog pins	Open source microcontroller programmed using the .NET/C programming. Uses an Arduino layout for shield compatibility
OS (Operating System)	Yes	No	No
Processor	ARM Cortex-A72	Atmega 328	ARM Cortex-M 32-bit
Processor Speed	1.5GHz	16MHz	120MHz
Digital Pins	8-Digital/Analog GPIO	14 (6PWM)	22-Digital/Analog GPIO
Analog Pins	8-Digital/Analog GPIO	6	22-Digital/Analog GPIO
Memory	2GB RAM	SRAM 2KB-EEPROM 1KB	Code 192KB-RAM 60KB

In the prototype, the Raspberry Pi 4 will be used as the device's controller. There were multiple reasons why Raspberry Pi was chosen for prototyping. Raspberry Pi is a mini computer with a credit card size, giving the user many possibilities. [20]. Since the touchscreen needs to be connected to the device, Raspberry Pi is the best option for the prototype.

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[1] https://www.amazon.de [Accessed 05.2022]

[2] https://www.oomipood.ee [Accessed 05.2022]

[3] https://www.mouser.ee [Accessed 05.2022]

3.2.2 Choosing the right actuator type for Smart hanger

Choosing the correct type of actuator is a crucial part of the project. The actuator should lift the coat and hold its weight without any problems. [21] The hook must be attached to the actuator, which controls the position of the hooks. The analysis shows which actuator type is the best choice for these particular purposes. These are the purpose requirements for choosing the right actuator for Smart hanger:

- Power source availability
- Required movement
- Precision
- Speed
- Error handling
- Strenght
- Safety

There are 4 main types of actuators: Electro-mechanical, hydraulic, pneumatic, piezoelectric. For the prototype purposes, only electro-mechanical actuators/motors are considered as candidates and table 3.2 shows the comparison between three main electro-mechanical actuators. [22] The main requirements for the actuators are: ability to lift the coat, having high torque, speed is not that important, the controller should be able to get the position of the actuator for the error handling, precision and at the end – safety. Safety in two sences:

- If the finger of the user gets stuck in between the hook and the wall – The hook should not cause any damage to the user
- If the hook is in the locked position, it should not be possible to open it manually and steal the coat.

In the table below, three actuator types comparison table is shown. Servo motor differing from stepper and DC motors is not a type of motor; it is a brushless permanent magnet DC motor with a gearbox and driver. However, the comparison is given to choose the best actuator for the prototype, which is why the comparison table is valid.

Table 3.2 actuator comparison table [23]

Actuators			
	Brushed/brushless DC motor	**Servo motor** **(brushless permanent magnet DC motor with gearbox and driver)**	**Stepper motor**
Summary	Capable of fast, continues rotation	High torque, accurate rotation within limmited angle	Slow precise rotation, able to give feedback
Price	Big range, relatively cheap	Cheaper than stepper, more expensive than DC motor	The most expensive out of these three
Range of rotation	Unlimmited	0-180º	Unlimmited
Requires driver	Yes	No	Yes
Advantages	Cheap, simple, fast	High torque and accurate	Very precise, used in 3D printers and CNC machines
Disadvantages	Not controllable step	No feedback mechanism, range of rotational angle	Expensive and requires driver

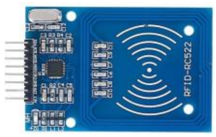
From the table, after careful consideration, the best and the most simple actuator for prototyping is a servo motor. So, for prototyping purposes, the servo motor will be used. However, there are multiple servo motors with different characteristics and, most importantly, different stall torque. [24] *Stall torque* is a torque load that causes the motor to stop rotating. So, the stall torque has to be higher than the torque caused by the weight of the coat. The average weight of the coat is about 1.5kg [25]. There are servo motors with stall torque of 1.2 $kg \cdot cm$, 5 $kg \cdot cm$, 8 $kg \cdot cm$, etc. However, there are servo motors with higher stall torques for heavier loads[1]. A servo motor will be used for the current prototype with 12 $kg \cdot cm$ stall torque.

[1] This information is taken from web page: https://www.oomipood.ee/

3.2.3 Card reader modules comparison

Two solution alternatives out of three requires a card reader. So, the card reader module selection is important. The table 3.3 shows the main differences between two most commonly used chip readers RC522 and PN532. [26] [27]

Table 3.3 Comparison between card reader modules

Card readers		
	RC522 [28]	**PN532** [29]
Description	RC522 is a high-frequency radio frequency chip that supports **the ISO14443A** protocol of the NXP company.	PN532 is a radio frequency chip supporting NFC function and an NXP company.
Price	€8.50[1]	€47.08[1]
Compatible with Arduino and Raspberry Pi	Yes	Yes
Communication/interfaces	SPI (Serial Peripheral Interface)	SPI, I2C (Inter-Integrated Circuit), UART (Universal asynchronous receiver-transmitter)
Communication distance	5-7cm	Upto 10cm
Operation frequency	13.56MHz	13.56MHz
Operation voltage	3.3V DC	3.3V - 5V DC
Summary	if only ISO14443A protocol is needed, then RC522 is a very cost-effective and good option, but if another protocol support is needed, then PN532 solution is the better option	

RC522 can be used for the two solutions discussed above, and since it is a cheaper option, the RC522 RFID reader will be used.

[1] https://www.oomipood.ee [Accessed 05.2022]

3.3 Methods of building each solution

3.3.1 Building each solution methodology

Since all the necessary components are reviewed, and the alternative solutions are discussed, it is possible to have a brief overview of a setup for each solution. Since the first solution requires a touchscreen, the Raspberry Pi has to be used as the controller and figure 3.6 describes the component list for this particular solution. 7'' Raspberry Pi touch display will be used to build this solution. This display connects to Raspberry Pi via an adapter board. It requires only two connections, one to the power and a ribbon cable that connects to the DSI port.

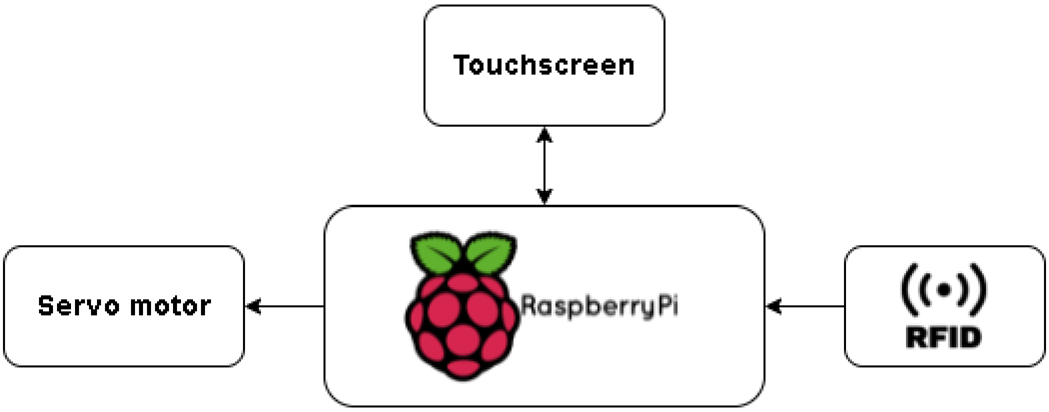


Figure 3.6 Solution with touchscreen

For the solution, when each hook has its own card reader next to the number tag, it does not require a complex module such as Raspberry Pi and needs a cheaper solution like Arduino. However, it would require separate arduinos and card readers for each hanger and it would increase the price of the product.

Figure 3.7 Card reader with each hook

The third alternative solution is the system controlled by mobile app. For this, arduino is enough, however it requires additional module – Wifi. So, that user could controll the hook from the smartphone.

Figure 3.8 Smart hanger controlled from a mobile app

Hanger with face recognition is the most complex software wise, and it requires the face recognition technology to be input into the controller. In this case, Raspberry Pi would not be suitable, and a more powerful controller needs to be used for this matter, such as Jetson Nano. A camera detects the face and the controller turns on the actuator. When the face is recognized a second time, the controller activates precisely the same actuator the second time.

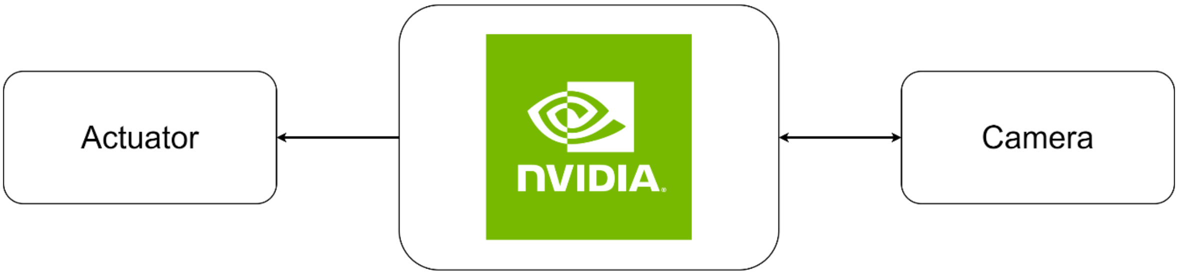


Figure 3.9 Face recognition solution

3.3.2 Chosen principal solution

Each described solution is unique and has its implementation methods depending on the establishment's requirements. Since the project, in the beginning, was intended for the Tallinn University of Technology coat hanging area, the author has decided to choose the first - touchscreen solution. Also, this solution is the cheapest and the most convenient. The solution will be explained in more detail in the following chapters, and the prototype will be shown. However, the idea is not to build an MVP (Minumum Viable Product) but a prototype. The mechanical or electrical designs will be for the prototype and not the MVP. If mobile app or face recognition solutions were chosen for prototyping, the price for the hardware would have been lower than the first solution. However, the software would have been more complex and not as easy to use as the solution with a touchscreen. If the user wore glasses in case of a face recognition solution, the apparatus would no longer be useful, same with face masks.

4 MECHANICAL DESIGN

4.1 The prototype assembly

Before starting the physical building of a prototype, having a mechanical 3D model of the device is essential. Figure 4.1 shows the 3D model of the Smart hanger prototype. It is essential to have a 3D model because it gives all the necessary dimensions and quickly determines where the electrical component would go before purchasing them.

4.1.1 Bill of materials

Table 4.1 BOM (Bill Of Materials)

Item Nr	Description	Quantity	Price
1	Front Panel	1	€17.50[1]
2	100mm Bolt	4	€1-5[1]
3	Nut	4	€0-1[1]
4	Servo motor with hook (sub assembly)	3	€30-40[2]
5	Touchscreen 7’	1	€116.41[2]
5	Raspberry Pi 4	1	€144.18[3]
6	RC522	1	€8.50[2]

The front panel is made with acrylic glass and is painted from the back side with Ral9005 (black paint color) matte paint. The servo motor holders and the hooks attached to the motors were 3D printed. Raspberry Pi is attached to the touchscreen display from the backside.

[1] https://www.k-rauta.ee [Accessed 05.2022]

[2] https://www.oomipood.ee [Accessed 05.2022]

[3] https://www.amazon.de [Accessed 05.2022]

a) b)

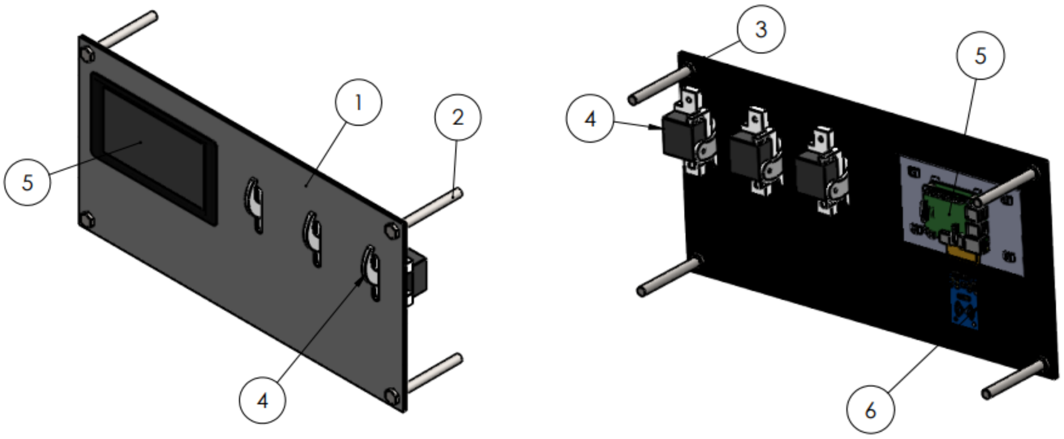


Figure 4.1 Prototype assembly with balloons

Each balloon represents the part or a subassembly number in the bill of materilas, shown above. Figure A shows the front isometric view of the prototype CAD model and figure B shows the back of the assembly.

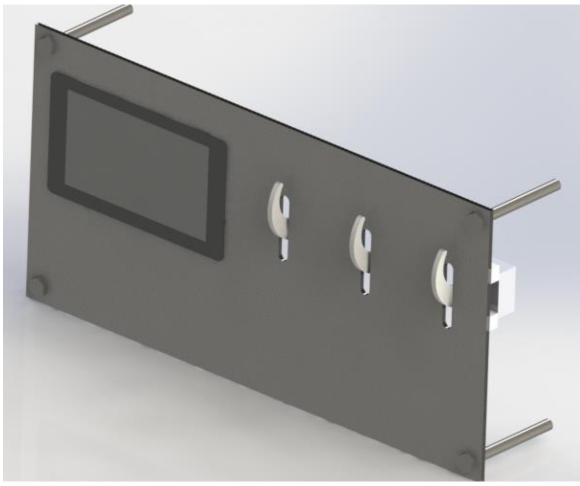


Figure 4.2 Final render of the prototype model

5 EMBEDDED HARDWARE LAYOUT AND ELECTRONICS

5.1 Electrical layout and the connection diagram of the prototype

The final product hardware layout differs from the one used in prototyping, since the final one will be more complex with more functions and features. However, the prototype has the main charachteristics as the final product and reflects all the main funtions.

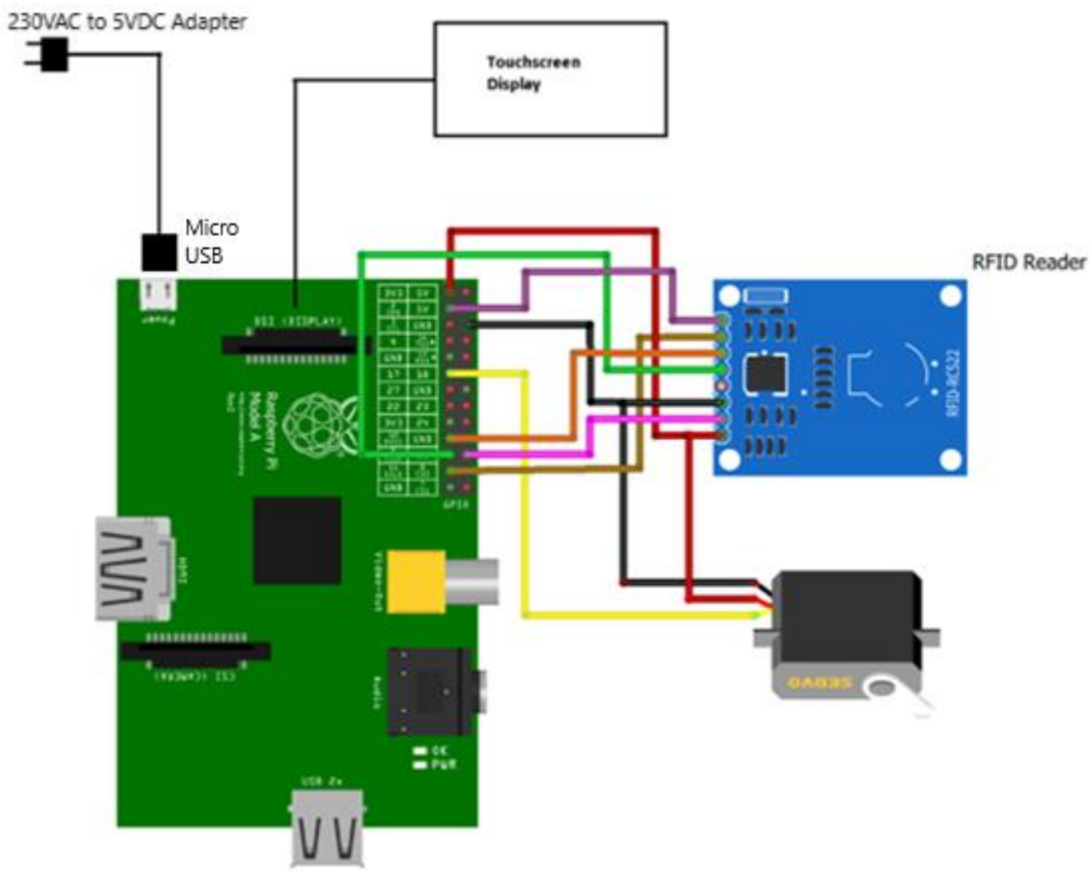


Figure 5.1 Electrical connection diagram of the prototype

The figure above shows the electrical schematic of the prototype. The main brain is Raspbbery Pi with the implemented operating system Raspberry OS. The Raspberry Pi is connected to the RFID reader (RC522) and the servo motor and both components are controlled trough Raspberry Pi.

Table 5.1 Component connection table

Raspberry Pi		
Pin 24	SDA	RC522
Pin 23	SCK	
Pin 19	MOSI	
Pin 21	MISO	
Pin 6	GND	
Pin 22	RST	
Pin 1	3.3V	
Pin 17	3.3V	Servo motor
Pin 39	GND	
Pin 11	Signal	

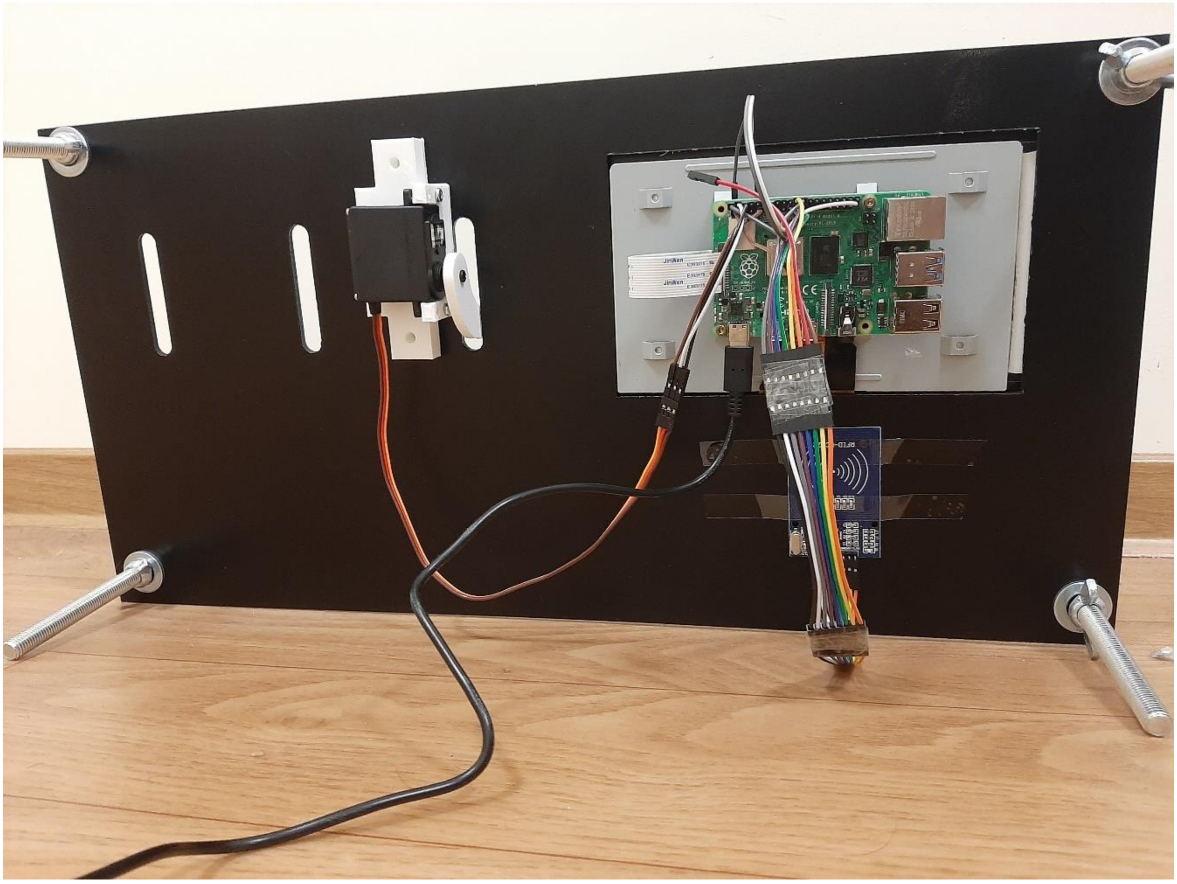


Figure 5.2 Component connections on the prototype

6 SOFTWARE

One of the most complex parts of the project is the software, both embedded and front-end. The software-side consists of three main parts: the application built using the Electron framework, the database that stores hanger status and owner information using MySQL, and the python scripts that handle the electronic components.

The Electron framework uses JavaScript, HTML (HyperText Markup Language), and CSS (Cascading Style Sheets) to build desktop applications. Additional tools used in the program include

- Bootstrap, which was used for frontend styling
- sweetalert2, a frontend tool used for customizable popups
- PythonShell module [30], used for running python child-processes from the JavaScript-based application

As mentioned, the application stores data in a separate database, and MySQL is used for database management. The database includes only one basic table named hangers, which stores the following attributes: id, indx, which stores the index of the specified hook, servoPIN, showing the GPIO (General-purpose input/output) PIN to which the servo signal pin is connected to, occupied, that shows the status of the hook, and student_card_uid, storing the card UID of the temporary owner of the hook (see Appendix 2).

Python scripts are used for controlling electrical components, which include the following imports:

- RPi.GPIO [31] for servo motor rotation
- mfrc522 [32] for reading the RFID chip (see Appendix 3).

6.1 Code working principle

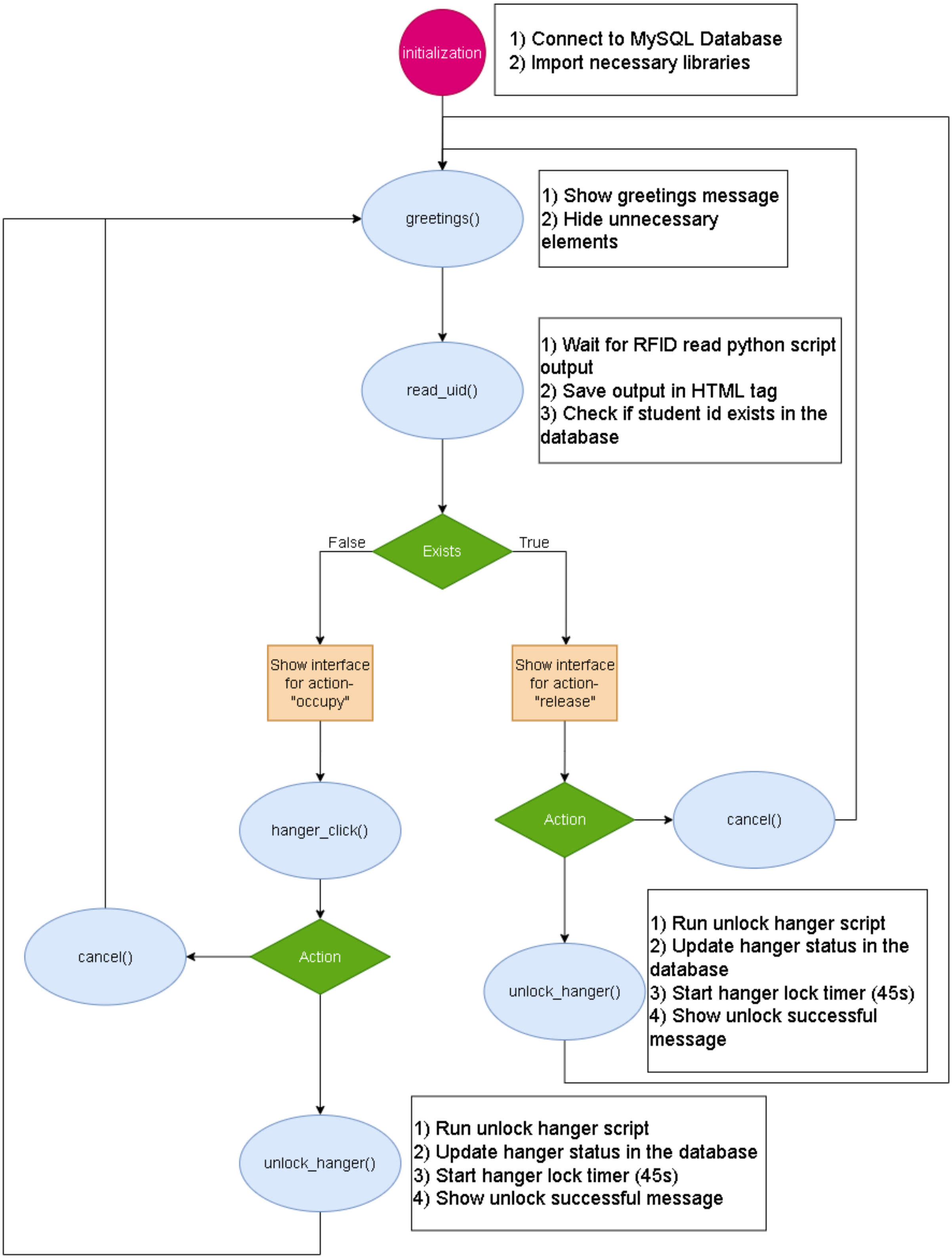


Figure 6.1 Code flowchart describing the working princple

7 WORKING PRINCIPLE OF THE APPARATUS SMART-HANGER

In this chapter the user experience will be explained. What happens when the user starts using the apparatus – Smart hanger? What options does the user have and how to use it.

7.1 User experience

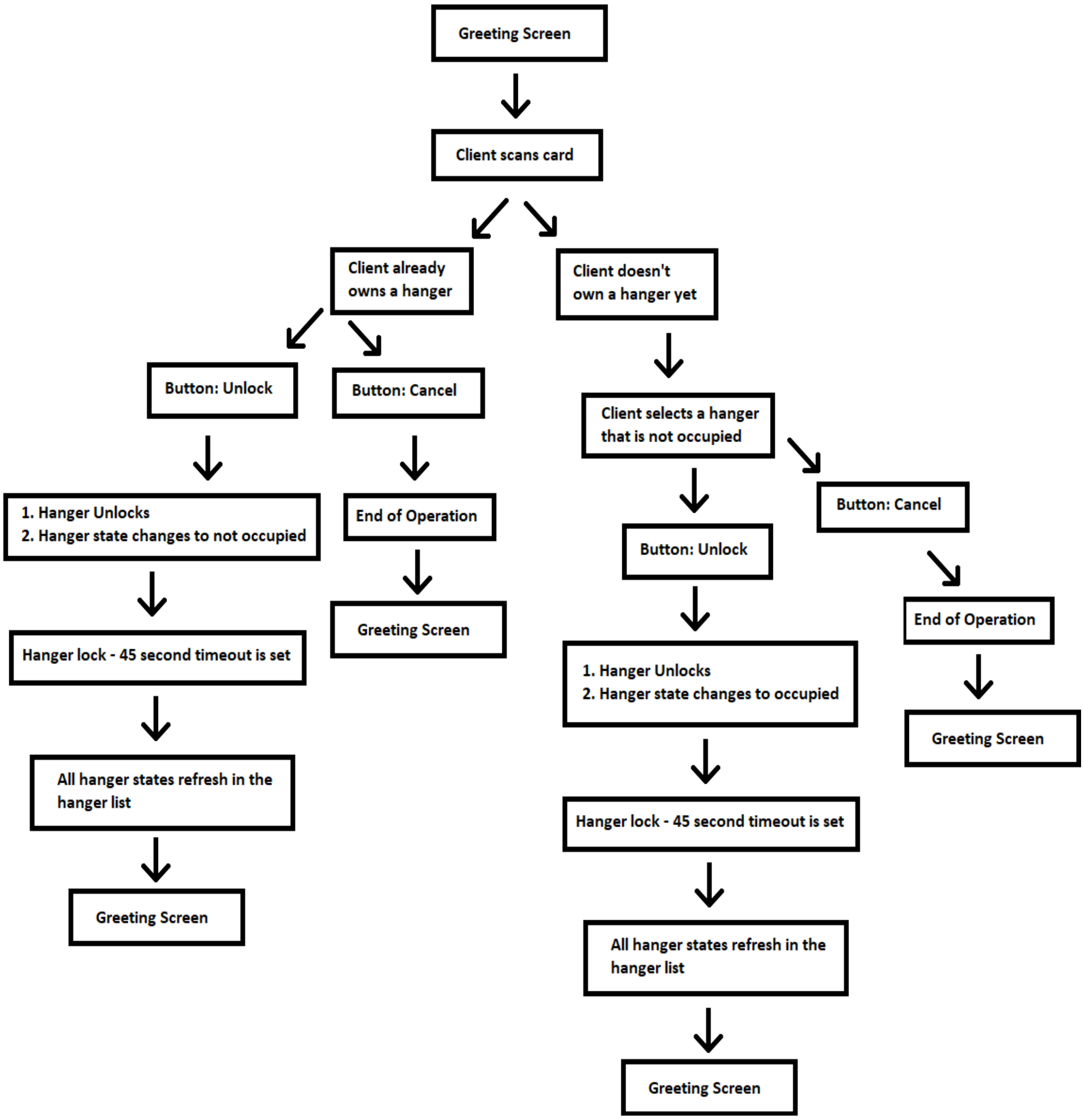


Figure 7.1 User experience flowchart

When the user enters the building (in this case, University) and approaches the garderobe, the Smart hanger is installed. The Smart hanger has a touchscreen, a card reader and numbered locked hooks for coat hanging. By default, there is a greeting message on the screen, both in English and in Estonian, stating - „Please touch your ISIC/ITIC card on the card reader".

Figure 7.2 Greeting message

After scanning the card, open the page with available and occupied hooks. In the prototype, there are only four hooks. However, the number of hooks are easily changeable depending on the requirements.

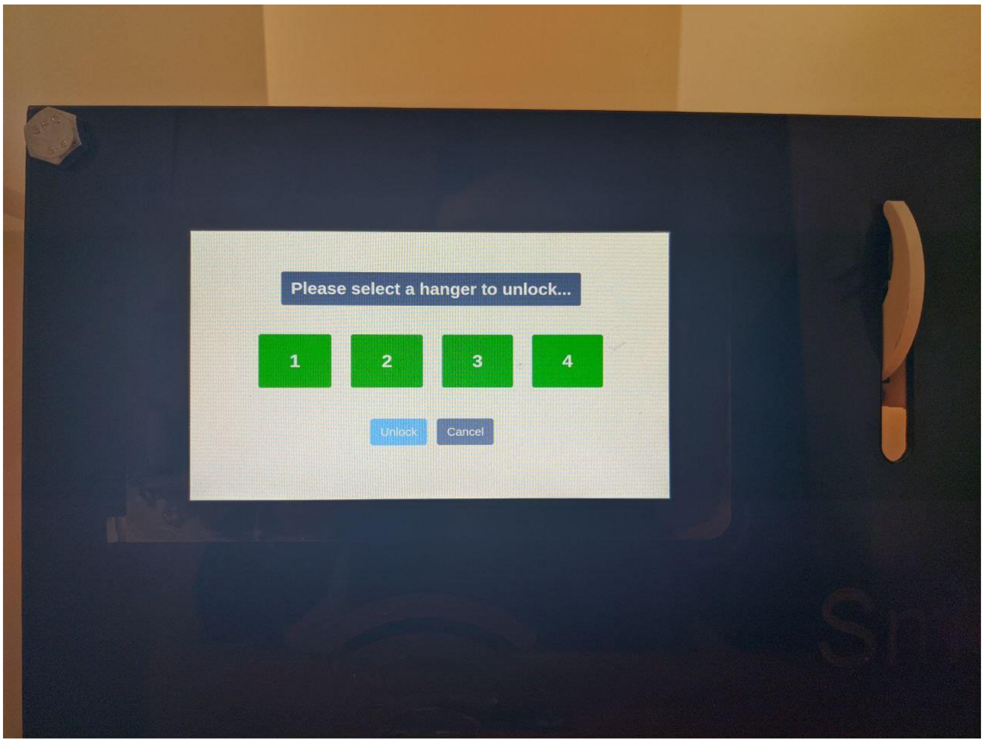


Figure 7.3 Available hanger/hooks on user interface

The user chooses the hook and presses it on the touchscreen. After this operation, the little window pops up with „Cancel" and „Unlock"options. If the user chooses the cancel button, it goes back to the first page(greeting message). If „Unlock" is chosen, the hook opens up for 45s to hang the coat and changes the available state to the occupied one. Then the system shows the greeting message once again.

a) b)

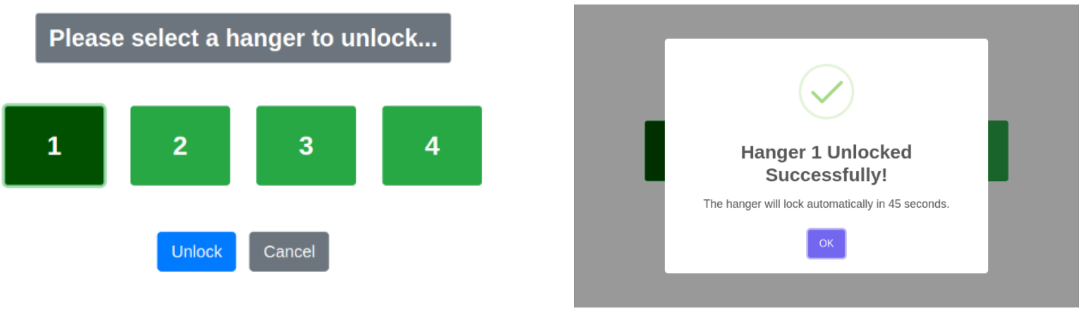


Figure 7.4 a) showing the Selected hook and b) showing the pop-up message after successfuly unlocking the hanger

When the user decides to take the coat back from the hanger, he needs to scan the same card again. The system checks the card number and if the card number is associated with any hook, opens the page with the two options – „Cancel" and „Unlock". If pressed cancel, the hook stays closed, the coat can not be taken from the hanger, and the page goes back to the greeting page. If „Unlock" is pressed, the hook opens, and the user has 45s to take the coat from the hanger.

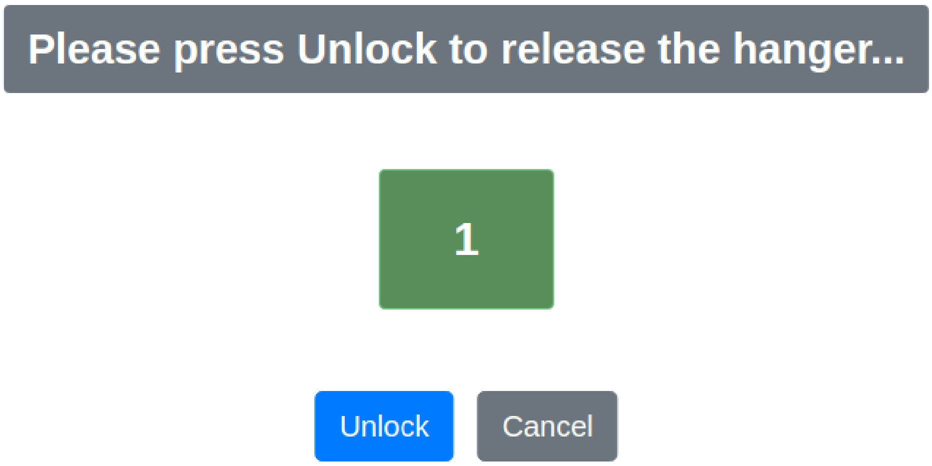


Figure 7.5 Screenshot of the display when the card is validated for unlocking the hanger

If someone else tries to use the Smart hanger, after scanning the card, the already chosen hooks are shown as occupied, and the user can not use it since the particular hooks are assigned, so the unique cards, the ones which were validated beforehand. In this case, the user can only choose the available hooks (numbers in the green box).

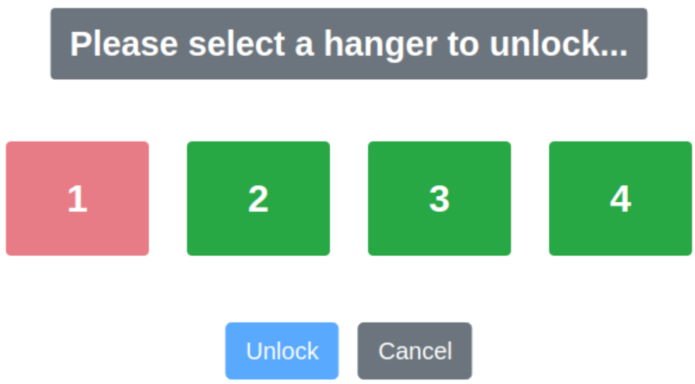


Figure 7.6 The display when second user scans the card (The first hanger is not in the "available" state)

7.2 Existing prototype

The front panel is an acrylic glass, which was milled in CNC (Computer Numeric Control) machine. The hooks and servo holders are 3D printed with white PLA (Polylactic Acid). The text is engraved on the plexi glass and colored with markers.

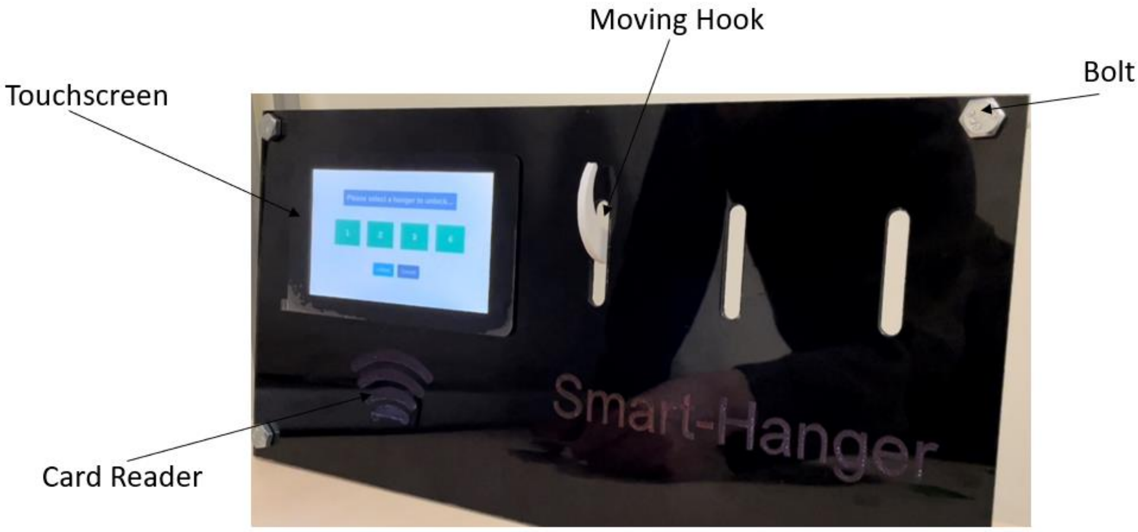


Figure 7.7 The built and ready working prototype

8 STRENGHT ANALYSIS OF THE HOOKS

8.1 Needed torque for servo motor

8.1.1 Torque caused by gravitational force

When such a device is built to perform some task in the world, it is essential to make sure that each hook is strong enough to lift the coat, in this case, servo motor, since this particular actuator type is used in the prototype. So, the motor's torque has to be high enough to be able to lift the desired weight. [33]

The torque is calculated with the following formula:

$$\tau = r \cdot F sin\theta \ , \tag{8.1}$$

where

τ is tourque ($N \cdot m$)

r is the distance from the from the turning point to the point where force is centered (m)

θ is the angle the force vector and the horizontal axis from the turnig point (rad)

F is the scalar quanity of the force vector, in this case gravity. (N)

The maximum stall tourque of the used servo motor is 12 $kg \cdot cm$ [34]which is higher than the averge 2.8 $kg \cdot cm$

8.1.2 Torque caused by the angular acceleration

The torque of the angular acceleration is what make the servo pin to rotate. So,

$$\tau_{total} = \tau_{ang\ acceleration} + \tau_{gravity} \tag{8.2}$$

$$\tau_{ang\ acceleration} = I\alpha \ , \tag{8.3}$$

where

I is the rotational inertia

α is the angular acceleration

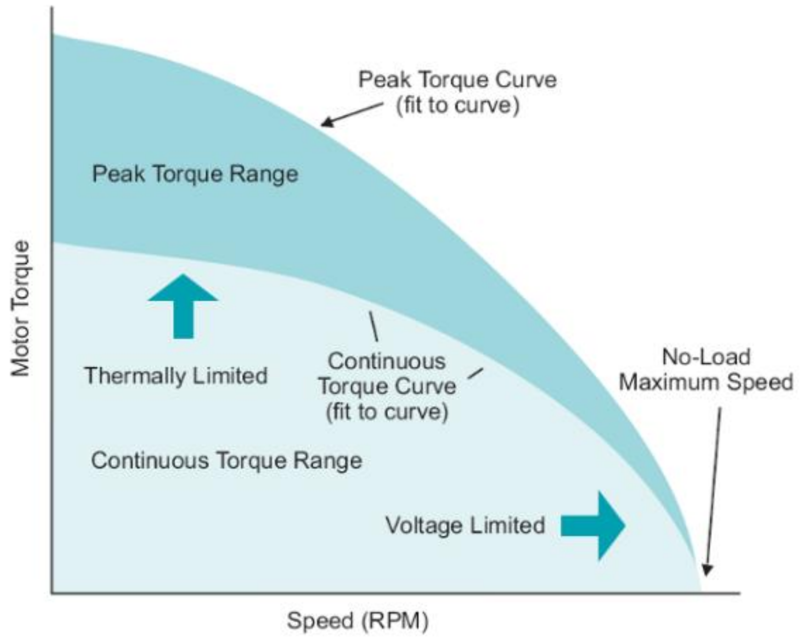


Figure 8.1 Servo motor torque value dependance on its speed [35]

8.2 Calculations

8.2.1 Servo motor specifications

Stall torque	$12\ kg \cdot cm$
Gear type	Metal gear attached with 3D printed hook
Servo weight	55g
Operating speed	0.17 s/60°
Consumption	100mA
Operating voltage	4.8V to 7.2V

8.2.2 Total torque calculation

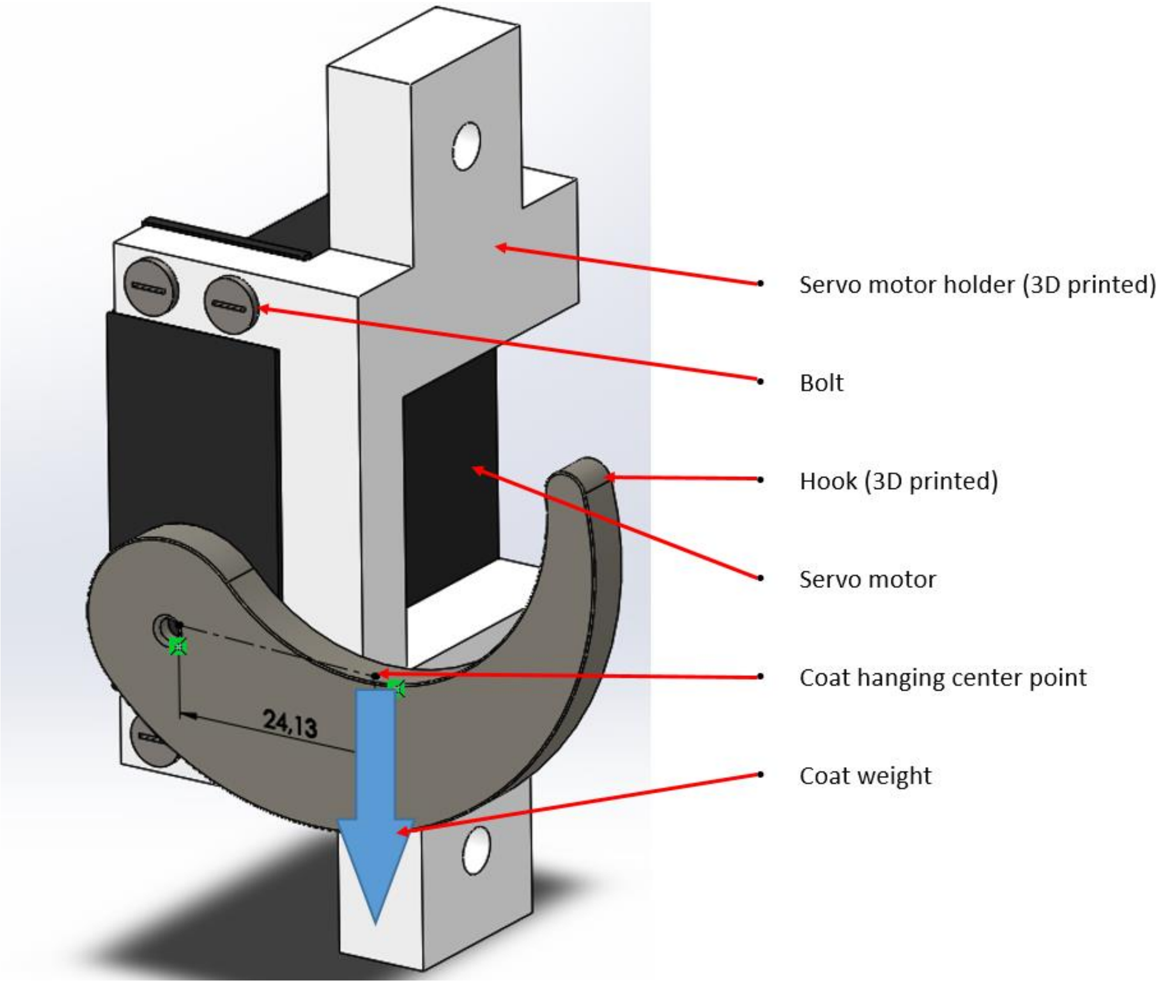


Figure 8.2 Servo motor with hook, assembly

$$\tau_{total} = \tau_{ang\ acceleration} + \tau_{gravity}$$

$$\tau_{gravity} = r \cdot F sin\theta \rightarrow \tau_{gravity} = \frac{24.1}{1000} \cdot F \tag{8.4}$$

The average weight of the coat is 1kg-1.5kg. Let's take two times the highest value for the calculations – 3kg.

$$\tau_{gravity} = \frac{24.1}{1000} \cdot mg \rightarrow \tau_{gravity} = \frac{24.1}{1000} \cdot 3 \cdot 9.8 \rightarrow \tau_{gravity} = 2 \cdot 0.354\ Nm \rightarrow \ \tau_{gravity} = 7.4\ kg \cdot cm$$

$$\tau_{ang\ acceleration} = I\alpha \tag{8.5}$$

Rotational inertia with this type of movement is calculated with this formula:

$$I = \frac{1}{3}mL^2 + ML^2 \ , \tag{8.6}$$

where

m is the mass of the rod (in this case plastic hook)

L is the legth of the rod

M is the mass of the load attached to the rod

Therefore,

$$\tau_{ang\ acceleration} = (\frac{1}{3}mL^2 + ML^2) \cdot \alpha \rightarrow \ \tau_{ang\ acceleration} = 0.5 \cdot 5.76 \cdot 10^{-8} \cdot \alpha \tag{8.7}$$

$\alpha = 2.9 \cdot 10^{-3}\ rad/s^2$ (from the servo spec)

$\tau_{ang\ acceleration}$ is almost zero and can be neglected in the calculations

So, torque needed to lift and hold the coat is upto 8 $kg \cdot cm$ and the servo motor which is used in the prototype can lift and hold more than one coats at the same time. However, it would be easily breakable by a human force, since humans can break the servo and overcome the servo's stall tourque.

8.2.3 Power consumption

In prototype, the servo motors are getting power from Raspberry Pi (5V). The maximum power consumption for Raspberry Pi in idle state is upto 2.7W. The motor that is being used in the prototype consumes 100mA at 5V, which means that power consumed by servo is:

$$P = U \cdot I \rightarrow P = 0.5W \tag{8.8}$$

Since Raspberry Pi can only consume upto 2.7W, it means that it can only feed 5 motors only, if power consumed by touchscreen and other components will be neglected.

8.3 Conclusions

From the calculations, it can be concluded that the servo motor can indeed lift the coat. Therefore, in the prototype servo motor is used as an actuator of the device and practical results also showed the same outcome. However, the servo motor does not allow error handling and is not very precise, so it can not be used in MVP (Minumum Viable Product). The calculations also showed how much minimal torque is needed to lift a coat. These results can be later used in calculations to choose an MVP actuator.

The mechanical design for prototyping works correctly, although the design has to change in the case of a real-life prototype. The hooks are not helpful for coat hanging and are very uncomfortable; plus, the prototype hook is made with PLA, which is not a good material for coat hanging.

The prototype does not provide any security for coats/jackets. If the hook is broken and coat/taken by a stranger, the prototype does not have an alert system to react. So, the security issue needs to be addressed to develop a Smart hanger further. Also, if the raspberry gets overheated, the whole system will break down and stop working. All of these remarks above are taken into account in MVP development.

9 MIMUNIM VIABLE PRODUCT

After building the prototype, creating MVP is an essential and adequate next step. The MVP of the Smart hanger is a working device that can be used in real life. The author of the thesis selected components for MVP accurately, prepared mechanical design, made electrical connection diagrams and performed the strength analysis.

In the case of MVP, differing from the prototype, the “Card reader for each hook” solution was chosen. Each hook is a different module, and only the power source is common for each module. Number tags(stickers) are attached below each hook to help the user memorize the hook where he left the coat. When the user validates the card, the hook opens for several seconds, and the user hangs the coat, and the hook closes automatically. When the hook is in the “busy” state and the red LED is on, no card will open it except the one used to lock it. When the user decides to take the coat/jacket back, he validates the card in the same place again and takes the coat back. The hook returns to its “available” state, and the green LED turns on.

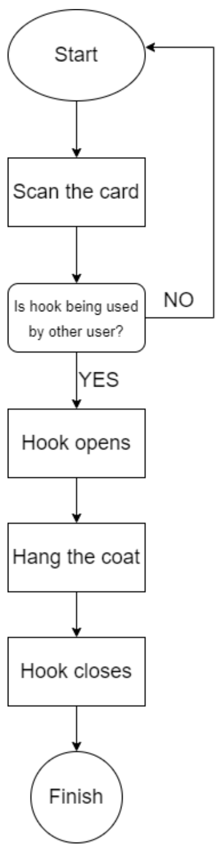


Figure 9.1 MVP user experience

While developing the MVP, safety was also taken into account. The camera is looking at the hanger, and if somebody takes another person's personal belongings, the camera will record it. The camera is not attached to the product, but it is attached to a wall and is observing the coats from that angle. The MVP also has a system to detect if the coat was taken from the hook without opening it. Later in this chapter, the principle will be explained more in detail.

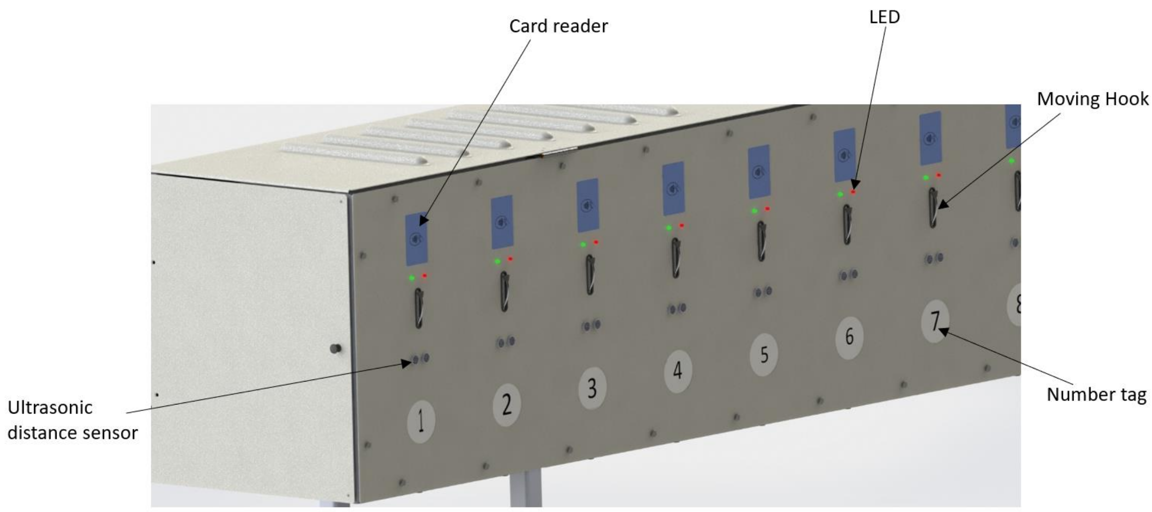


Figure 9.2 Mimimal viable product render (See appendix 4)

Inside the apparatus, a wifi module is connected to each hook separately. This module allows to check the hanger usage and see how many hooks are taken. With this technology, the establishment can roughly estimate how many people visit the building. Wifi module also allows error handling. If the hook acts abnormally, the wifi module can send logs to the maintenance.

9.1 Minimum viable product components

9.1.1 Stepper motor

The Stepper motor was chosen due to a reason. Even though a stepper motor is more expensive than, for example, servo or DC motors, it has some advantages. It is capable of error handling, can lock itself in the OFF position and is more durable.

There are 28 hooks; therefore 28 stepper motors inside the product. The mechanical hooks are connected to the stepper motor, and the module is attached to the wall of the product from inside. Here is the hook connected to the stepper motor—front view of the hook module (See appendix 5).

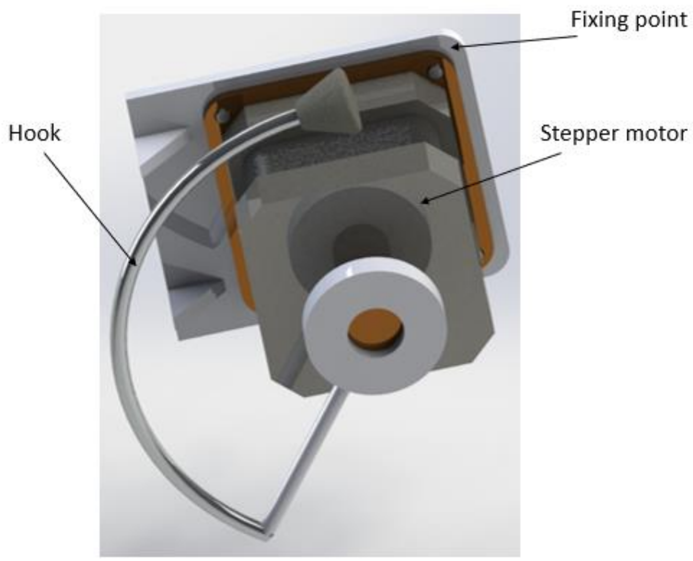


Figure 9.3 The hook assembly with stepper motor

Choosing of stepper motor is depended on the force load on the hook caused by the weight of the coat. The average weight of the coat is about 1.5kg [25]. But for calculation purposes, it is important to consider the maximum load. For that purpose 3kg will be used in calculations. Also, to simplify the 3 dimensional sketch, it can look like this.

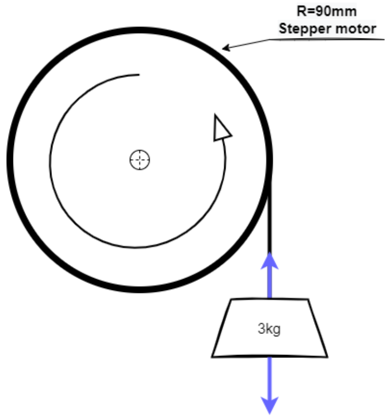


Figure 9.4 Stepper motor and load simplified representation

The torque created by the 3kg load is:

$$\tau = F \cdot d \rightarrow \tau = 3 \cdot 0.9 \rightarrow \tau = 2.7\, kg \cdot cm \qquad (9.1)$$

So, the stepper motor, which can be used in MVP, must have a holding torque greater than 2.7 $kg \cdot cm$. Such motor is NEMA17 stepper motor [36]. It can hold upto 3.2 $kg \cdot cm$, which is indeed greaten than 2.7 and is a perfect option. This stepper motor is generally used in Printers, CNC machines and Laser Cutters. Each phase draws 1.58 A at 12 V, allowing for a holding torque of 3.2 $kg \cdot cm$. [37]

9.1.2 Safety

One of the critical factors of a Smart hanger is safety. The user knows that someone will not take the coat he left on the hook. Because of that, two extra measures have been taken to ensure that coats will not be stolen. The camera needs to be installed so that it is not on the hanger. Furthermore, the distance measuring sensor (Ultrasonic distance sensor) is installed below the hook, and if the coat is taken off the place for more than 5 seconds, the buzzer activates and starts an alarm. (See Appendix A4.2)

Figure 9.5 Smart hanger section view render

9.2 Minimum viable product electronics

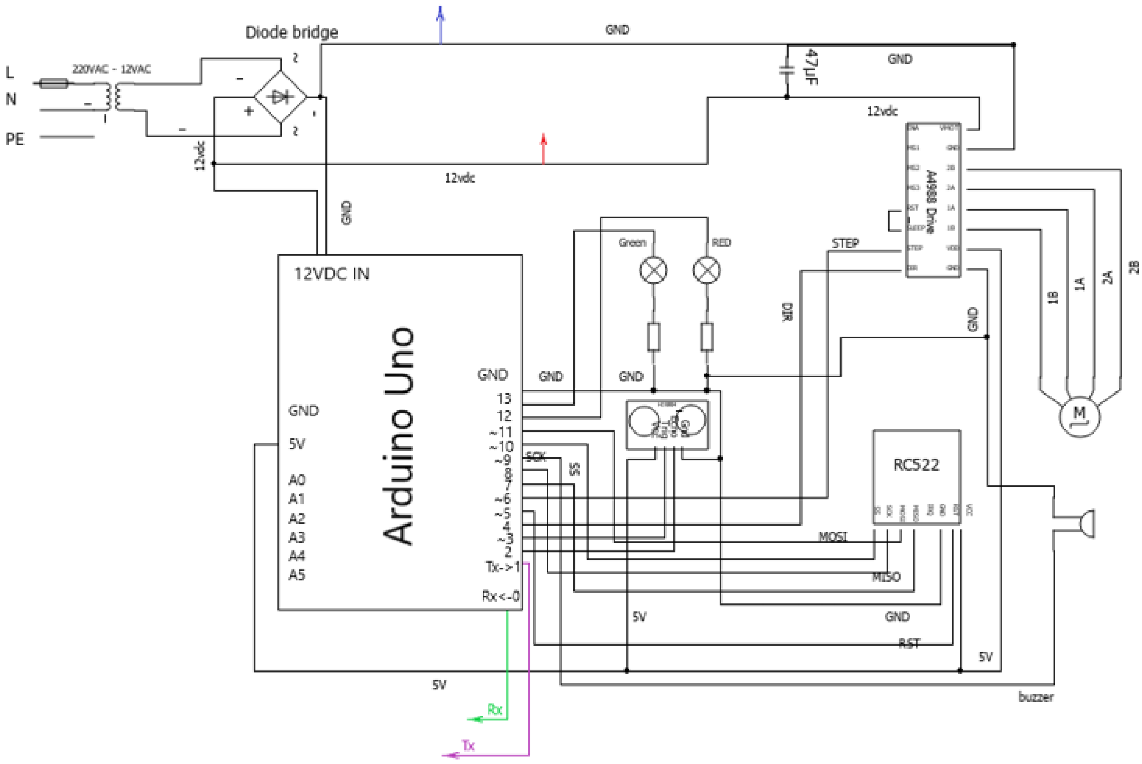


Figure 9.6 Electric diagram of MVP one module

In figure 9.6 the electic diagram of the MVP one module is shown. At first the alternating current of 220V is converted to 12VAC. After that through diode bridge the alternating current is converted to the direct current, which powers up arduino and stepper motor. Other components are powered up through arduino (5VDC). These components are:

- RC522 – RFID reader
- HC-SR04 – Ultrasonic distance sensor
- LEDs
- Buzzer

However, this diagram only shows one module electrical connections, but there are 28. These 28 modules are connected to one power supply. In order to calculate what kind of transfor is needed to power up the whole device, the power consumption of one module needs to be calculated and multiplied by 28. After knowing the necessary power needed for the device, then adequate trafo box can be found accordingly.

The most power is consumed by stepper motors. In this project Nema17 stepper motor is being used. The rated current of one stepper motor is 1.58Amp [38]. If it is assumed that 5 motors are activated at the same time (which is practically the maximum amount of people who can hang their coats at the same time), then power:

$$P = U \cdot I \qquad (9.2)$$

Where, U is voltage and I is current drawn by stepper motor (so it needs to be multiplied by 5).

$$P = 12 \cdot 1.58 * 5 \rightarrow \ P \approx 95\ W \qquad (9.3)$$

So, to be on the safe side, 120W transformer can be a good choice.

Transformer LED 12VDC 120W/10A IP25 will be installed in the MVP.[1]

The coloured wires with arrows on the diagram show connections to other modules. The red and blue wires show the connection of other modules to the power supply in parallel.

---

[1] https://greenice.com/en/transformers [Accessed 03 2022]

The Tx and Rx connection connect each module to the one Arduino with the Wifi shield. That Arduino controls that no more than five hooks will be activated simultaneously. Plus, it connects the device to the internet, making it possible to maintain such issues online.

9.3 Minimum viable product mechanical design

The mechanical design has been prepared for the MVP of Smart hanger. The drawing of the assembly was made as well as the drawings of each designed parts. The skeleton of the MVP is built using 40X40 square profile aluminuim shafts, which are welded together (See appendix 6). The side parts are 1.5mm aluminium sheet metals, on which non-conductive coating has to be performed.

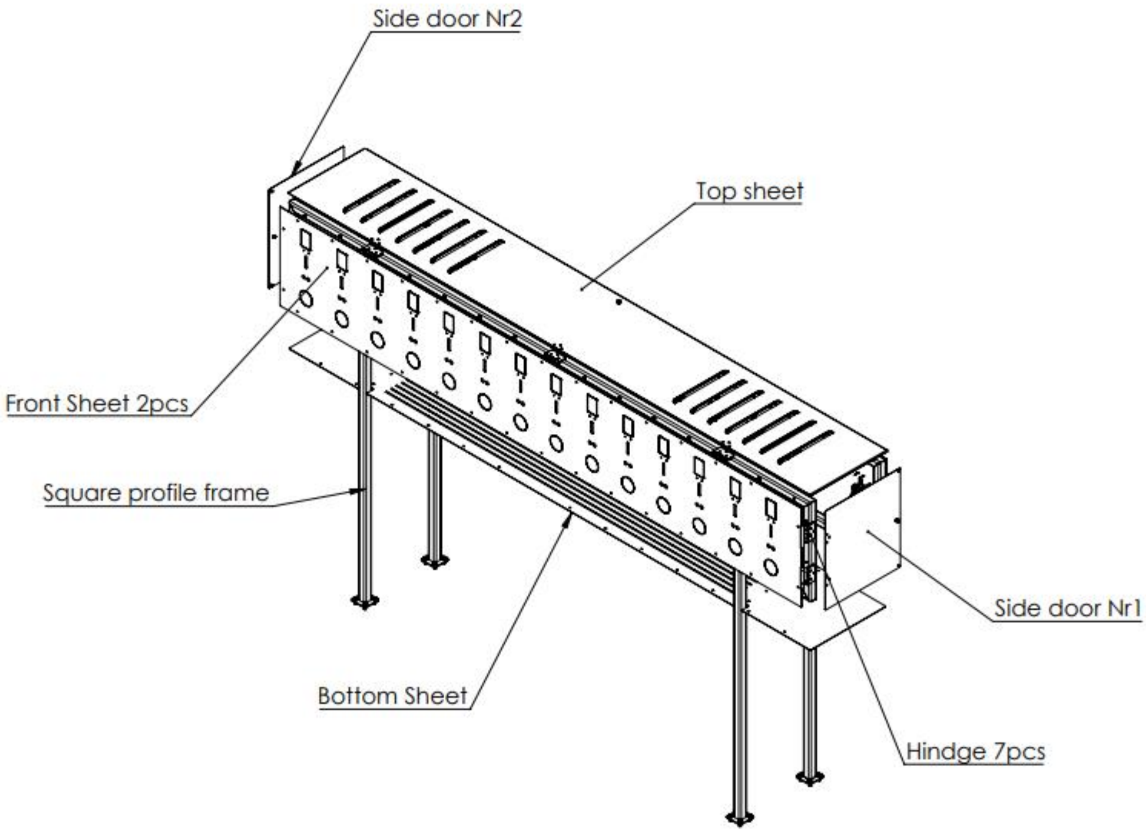


Figure 9.7 MVP assembly exploded view

In figure 9.7 the assembly exploded view is shown. However not all the parts are presented on this figure. Here is the more detailed drawings of the final assembly (See appendix 7).

Table 9.1 BOM of MVP

ITEM NO.	PART	DESCRIPTION	QTY.
1	Skeleton-frame square profile	See Drawing: Skeleton	1
2	Front sheet	See Drawing: Front Sheet	2
3	Hex cap screw, M6 x 1.0		99
4	rubber_gasket	See Drawing Nr3	28
5	LED Green	Regular 5mm diameter color-green LED	28
6	LED RED	Regular 5mm diameter color-red LED	28
7	Ultrasonic_sensor	Ultrasonic Distance Sensor - HC-SR04	28
8	Hindge	See Drawing: Hinge	7
9	side_door	See Drawing: Side Door	2
10	Formed hex screw, M10x1.5 X20		16
11	Top door	See Drawing: Top sheet	1
12	Scan card sticker		28
13	Number tag (sticker)		1
14	Hook_assembly	(See Appendix 5)	28
15	Bottom_plate	See Drawing: Bottom plate	1
16	Arduino Uno		29
17	Transformer	Transformer LED 12VDC 120W/10A IP25	1
18	Arduino wifi shield		1

9.3.1 Maintanance

The idea behind making these doors on the sides and top of the assembly is to make maintenance easy. Also, since each module is connected in parallel, others will continue to work correctly if one module gets damaged. The red LED will turn on if damaged without the coat hanging on the hook. In addition, the stepper motors allow error handling and maintenance is more manageable than other types of actuators.

One extra Arduino is connected to every Arduino through the Tx-Rx serial port. The Wifi shield is mounted on this Arduino, allowing the maintenance to receive feedback online so that some types of problems can be solved without physical presence.

9.4 Program algorithm

Since the MVP is not built yet, the program does not exist. However, here is the algorithm for how the program needs to work on the actual life prototype. So, when the user scans the card on the card reader, Arduino reads the user ID. Then, it checks if the hook is busy or not. If it is in "available state", then opens the hanger, saves the user ID in the local storage (EEPROM), changes the internal status to "busy", turns off the red LED and flashes a green LED for 15 seconds and closes the hook. During these 15 seconds, the user should hang the coat on the hook.

If the initial state is "busy", then there are two options: it is taken by the user who put the hook in the "busy" state, or it is taken by someone else. In both cases, the red LED is on. After scanning the card, it compares the saved ID with the scanned one. If it is different, the red LED flashes multiple times and leaves the hook closed. If these IDs are identical, then the hook opens for 15s; during this duration, the user takes the coat, the green LED starts flashing, and the module returns to the "available state".

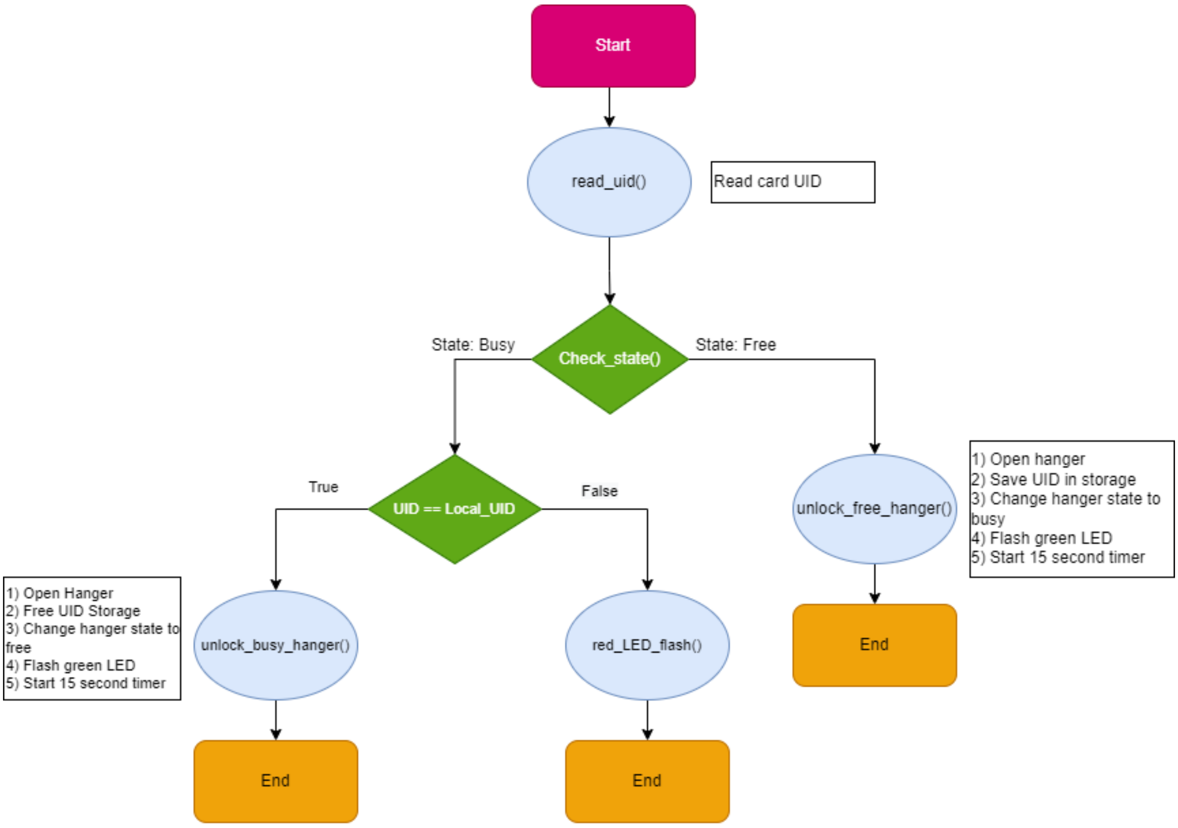


Figure 9.8 MVP program algorithm flowchart

9.4.1 Safety measurements and maintenance SW

As described previously, the MVP has some safety measures. For example, if the coat hanging loop was cut and the coat was taken off the place when the hook was not realeased, it has some alerting system. The distance sensor detects that the coat has been taken, turns on the buzzer and sends the info to the maintenance. In case if any funtion provided in figure 9.8 outputs error, the logs are sent to the maintenance through the wifi module installed on the extra Arduino in the device. This program runns independently from the main thread.

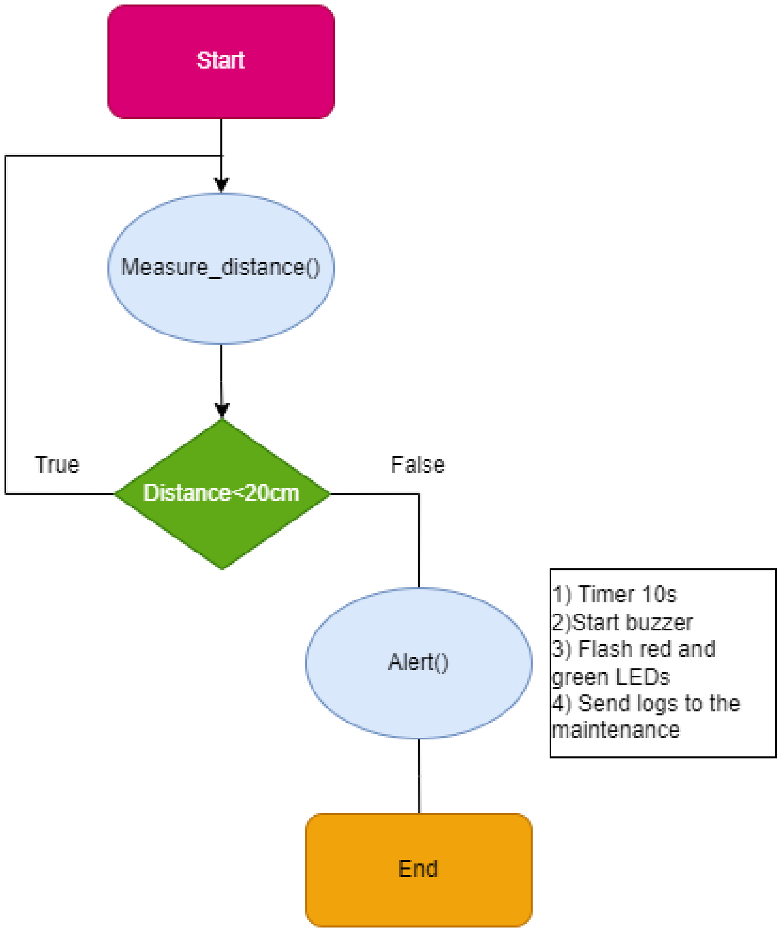


Figure 9.9 Ultrasonic distance sensor working algorithm

10 SUMMARY

The aim of this graduation thesis - Smart hanger hardware, software and electronics development through 3D modelling and prototyping was to develop a prototype and 3D model of an automatized version of a coat hanging service in universities and other establishments. The prototype, 3D model, electronics and software have been successfully built through careful planning and preparation.

In the beginning, this thesis is introductory; it describes how coat hanging services functioned in the pre-pandemic period, shows the need for automatization of such service, and emphasizes the cost-effectiveness and handiness of replacing manual labour with a computerized version. In addition, the interview was conducted with the head of the human recourses office at TalTech to determine the cost of manual labour, which the university used to pay a few years ago. Also, the thesis introduction outlines the problem statement and the absolute necessity of implementing IoT technology in this field.

The next subject of the study was previously made intelligent hangers and what made them smart. Also, lockers were deeply examined, and more than fifteen locker companies' products were investigated in detail to see what technologies they used to achieve a similar purpose. It was concluded that such a device that can be installed at the building entrance to hang the coat safely did not exist in the open-source world. In addition, the existing patents were researched and examined deeply, and the three closest patents were carefully chosen from the list and analyzed in a precise manner.

Three solution alternatives of Smart hangers were analyzed, and each of them was looked into detail step-by-step. One of these solutions was selected, and the electrical components for that particular solution were carefully chosen. After component selection, the 3D mechanical design with these components was modelled, and for a better illustration of the final prototype, the renders were generated. Since the components were already selected, thus the electrical connection diagram was prepared.

The next chapter was focused on the software part of the Smart hanger. It explains how the program works and what frameworks, imports and scripts were used to achieve the satisfactory result. The working principle was shown, and the user experience was explained. Next, the strength analysis of the hooks was performed and total torque, caused by the coat weight, was calculated and compared with the stall torque of the servo motor. Finally, the prototype was assembled successfully and tested multiple times.

After testing the prototype, the test results were analyzed, and conclusions were made. Next, the MVP was modelled according to the results received after testing the prototype, and everything was taken into account while developing the MVP. The different electrical diagram was generated for MVP, and 3D models and drawings were prepared. Afterwards, the algorithms for the embedded program and code for security purposes were created.

It can be concluded that the main objective has been achieved. The solution was developed, which takes much less space than the lockers; moreover, it is cheaper. The size of the Smart hanger and the amount of hooks is not final and strictly limited, and in that sense, the MVP is flexible. It would depend on the requirements given by the client establishment.

During working on this topic, a massive amount of knowledge was acquired. Plus, it required many background skills and expertise in multiple fields, such as electrical engineering, mechanical engineering, embedded software development and prototyping. After defending a thesis, the author plans to build the MVP and further develop the idea under a supervision of a current supervisor. In conclusion, the result was achieved by careful planning and preparation. The prototype is ready, and after this thesis, building MVP of Smart hanger can be started with a strong background. The thesis provided a 3D model, electronics layout, and software for a novel product – Smart hanger.

11 KOKKUVÕTE

Käesoleva lõputöö eesmärk - nutika riidepuu riistvara, tarkvara ja elektroonika arendamine läbi 3D modelleerimise. Loodi lihtne laual toimiv riietehoiu prototüüp ja joonised järgmisele elusuuruses MVP prototüübile, mis võimaldaks ülikoolides ja muudes asutustes riietehoidu automatiseerida. Reaal elulise MVP prototüübi, 3D-mudel, elektroonika ja tarkvara sai lõputöö raames kavandatud ja ettevalmistatud.

Sissejuhatuses kirjeldatakse, kuidas riietehoiu teenused pandeemiaeelsel perioodil toimisid, näidatakse vajadust sellise teenuse automatiseerimiseks ning rõhutatakse käsitsitöö robot-versiooniga asendamise kuluefektiivsust ja käepärasust. Lisaks tehti intervjuu TalTechi personalibüroo juhatajaga, et selgitada välja käsitsitöö maksumus, mida ülikool paar aastat tagasi riidhoiu teenuse eest maksis. Samuti tuuakse lõputöö sissejuhatuses välja probleemipüstitus ja IoT tehnoloogia rakendamise absoluutne vajadus selles valdkonnas.

Järgmiseks teemaks oli maailmas varem tehtud intelligentsed riidepuud ja uuriti lahendused, mis kuidas need on targaks tehtud. Samuti uuriti põhjalikult ca 15 ettevõtte lahendust, et näha, milliseid tehnoloogiaid riiete lukustamiseks kasutatakse ja kas neid oleks mõistlik ka meie lahenduses kasutada. Jõuti järeldusele, et otseselt sellist seadet, mille saab paigaldada hoone sissepääsu juurde, et mantel ohutult automaatselt riputada ja lukustada, ei eksisteeri. Samuti puudub avatud lähtekood ja joonised olemas olevatele lahendustele. Lisaks uuriti olemasolevaid patente ning valiti välja kolm lähimat patenti ning analüüsiti neid detailsemalt.

Ideena analüüsiti kolme nutikate riidepuude lahendusvarianti, millest igaüks vaadati samm-sammult läbi. Üks neist lahendustest otsustati ehitada riistvaja/tarkvara arendustöö tulemusena prototüübiks. Pärast komponentide valimist modelleeriti nende komponentidega 3D mehaaniline disain ja lõpliku prototüübi paremaks illustreerimiseks genereeriti renderdus. Koostati ka elektriühenduse skeem ja tarkvara arhitektuur.

Järgmine peatükk keskendus nutika riidepuu tarkvaralisele osale. Selgitatakse, kuidas tarkvara on üles ehitatud, milliseid raamistikke kasutatakse. Näidatakse tööpõhimõtet ja püütakse arvesse võtta kasutaja kogemust. Järgmisena viidi läbi konksude tugevusanalüüs ja arvutati riiete (mantli) massist põhjustatud jõumoment ning võrreldi seda servomootori poolt arendatava jõumomendiga. Lõpuks pandi kokku töötav prototüüp mida testiti korduvalt.

Pärast esimese prototüübi testimist analüüsiti tulemusi ja tehti järeldused. Järgmise sammuna modelleeriti elusuuruse MVP prototüüb, milles võeti arvesse esimese prototüübi tegemisel tekkinud puudused. MVP jaoks koostati uus elektriskeem ning koostati 3D mudelid ja joonised. Seejärel loodi tarkvara programm.

Tehtud tööst võib järeldada, et põhieesmärk sai saavutatud. Töötati välja lahendus, mis võtab palju vähem ruumi kui olemas olevad metall kapid, pealegi on loodud lahendus odavam inimtööjõust. Nutika riidepuu suurus ja konksude hulk ei ole piiratud ja seda võid pikendada vastavalt vajadusele. Loomulikult tuleks peale MVP valmisehitamist koguda kokku veel kliendtide tagasiside ja arendada toodet edasi.

Selle teemaga tegeledes omandati tohutul hulgal uusi teadmisi. Lisaks nõudis arendustöö palju tausta-oskusi ja eriteadmisi mitmes valdkonnas, nagu elektrotehnika, masinaehitus, tarkvara arendus ja prototüüpimine. Pärast lõputöö kaitsmist plaanib lõputöö autor ehitada järgmise MVP ja ideed edasi arendada võimalusel koos juhendajaga.

Kokkuvõtteks võib öelda, et tulemused saavutati, prototüüp on valmis ja peale seda lõputööd saab tugeva tausta-teadmistega alustada uue generatsiooni nutika riidepu ehitamist. Lõputöös esitati uudse toote ideed – nutikas riidepuu – selle 3D-mudel, elektroonika ja tarkvara.

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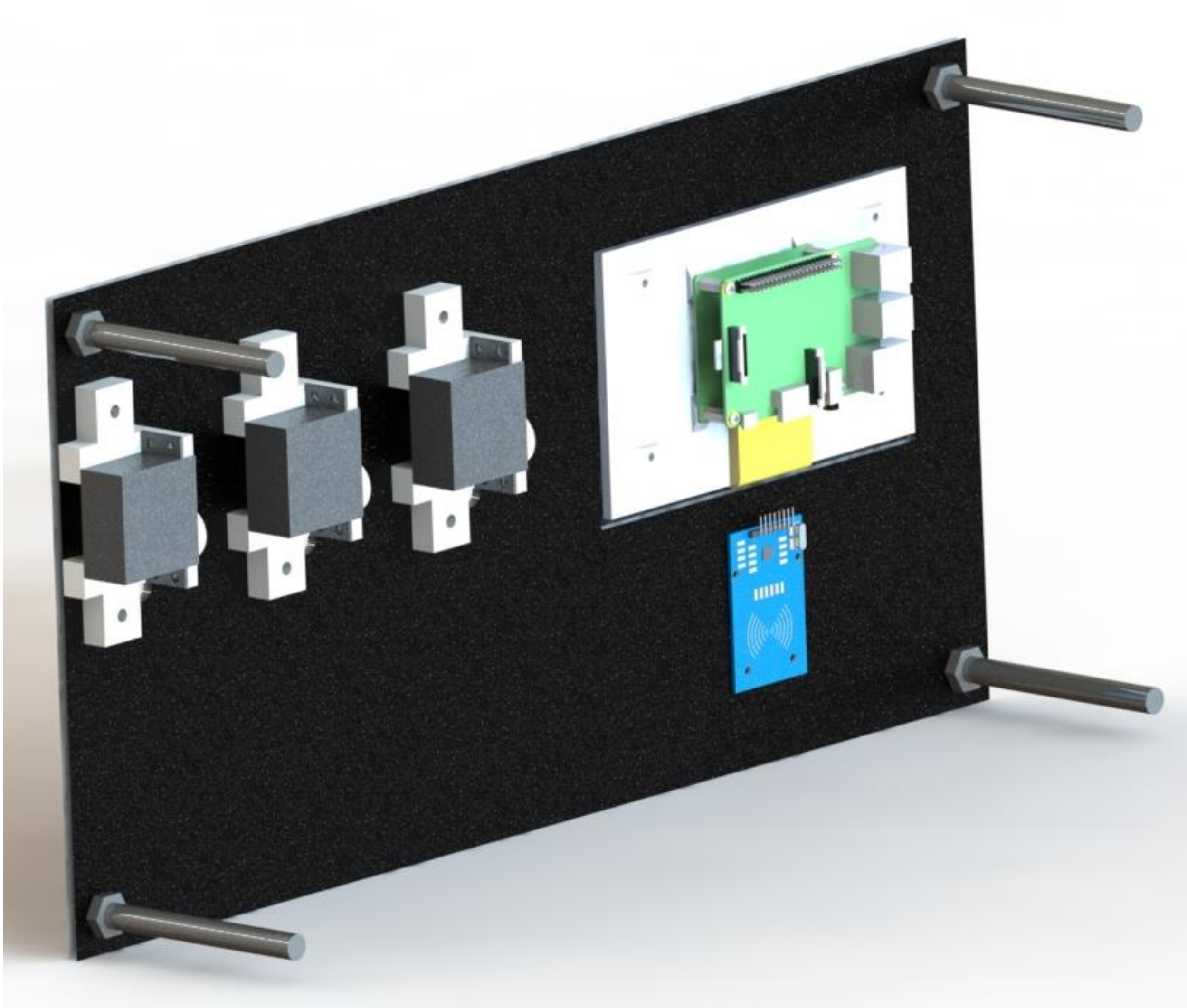
APPENDICES

Appendix 1 – Render of the prototype backside



Appendix 2 - Database tables

A2.1 Table description

```
mysql> describe hangers;
+------------------+---------------------+------+-----+---------+----------------+
| Field            | Type                | Null | Key | Default | Extra          |
+------------------+---------------------+------+-----+---------+----------------+
| id               | int(6) unsigned     | NO   | PRI | NULL    | auto_increment |
| indx             | int(6) unsigned     | NO   | UNI | NULL    |                |
| servoPIN         | int(2) unsigned     | NO   | UNI | NULL    |                |
| occupied         | tinyint(1) unsigned | NO   |     | 0       |                |
| student_card_uid | varchar(10)         | YES  | UNI | NULL    |                |
+------------------+---------------------+------+-----+---------+----------------+
5 rows in set (0.01 sec)
```

A2.2 Table contents

```
mysql> select * from hangers;
+----+------+----------+----------+------------------+
| id | indx | servoPIN | occupied | student_card_uid |
+----+------+----------+----------+------------------+
|  1 |    1 |       17 |        0 | NULL             |
|  3 |    2 |       19 |        0 | NULL             |
|  4 |    3 |       21 |        0 | NULL             |
|  5 |    4 |       23 |        0 | NULL             |
+----+------+----------+----------+------------------+
4 rows in set (0.00 sec)
```

Appendix 3 – Python scripts

A3.1 Hanger unlock code

```python
import RPi.GPIO as GPIO
import time
import sys

servoPIN = sys.argv[1]
GPIO.setmode(GPIO.BCM)
GPIO.setup(servoPIN, GPIO.OUT)

p = GPIO.PWM(servoPIN, 50) # GPIO 17 for PWM with 50Hz
p.start(2.5) # Initialization

p.ChangeDutyCycle(7.5)
time.sleep(0.5)

p.stop()
GPIO.cleanup()
```

A3.2 Hanger lock code

```python
import RPi.GPIO as GPIO
import time
import sys

servoPIN = sys.argv[1]
GPIO.setmode(GPIO.BCM)
GPIO.setup(servoPIN, GPIO.OUT)

p = GPIO.PWM(servoPIN, 50) # GPIO 17 for PWM with 50Hz
p.start(7.5) # Initialization

p.ChangeDutyCycle(2.5)
time.sleep(0.5)

p.stop()
GPIO.cleanup()
```

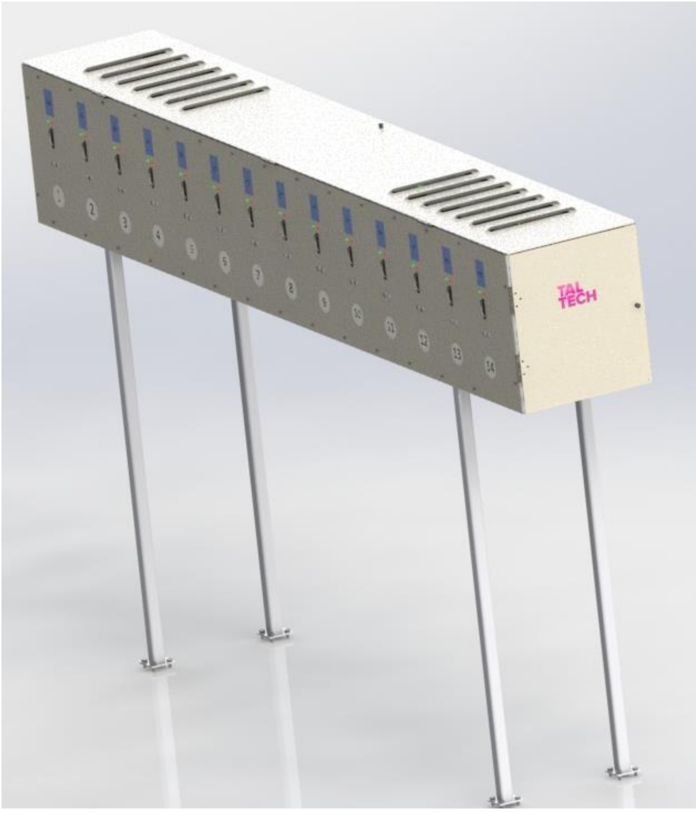
Appendix 3 – Python scripts

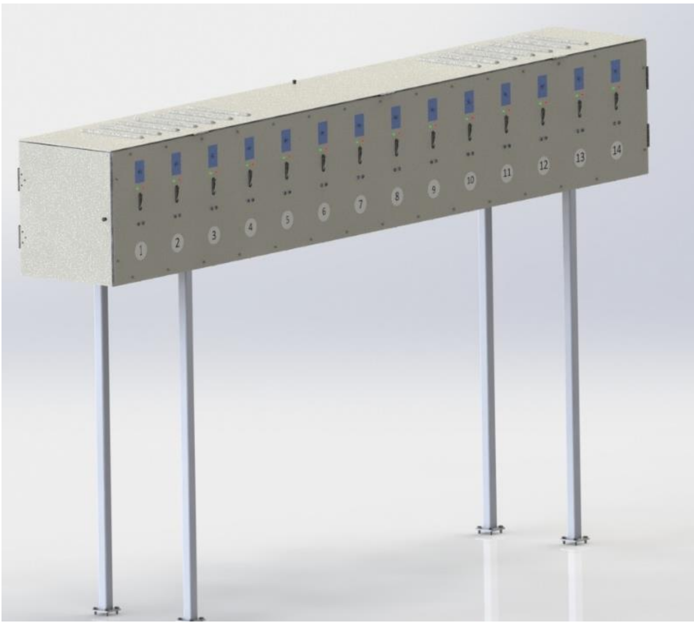
A3.3 RFID read input

```
#!/usr/bin/env python

import RPi.GPIO as GPIO
from mfrc522 import SimpleMFRC522

reader = SimpleMFRC522()

try:
        id, text = reader.read()
        print(id)
finally:
        GPIO.cleanup()

```

Appendix 4 – MVP

A4.1 MVP renders



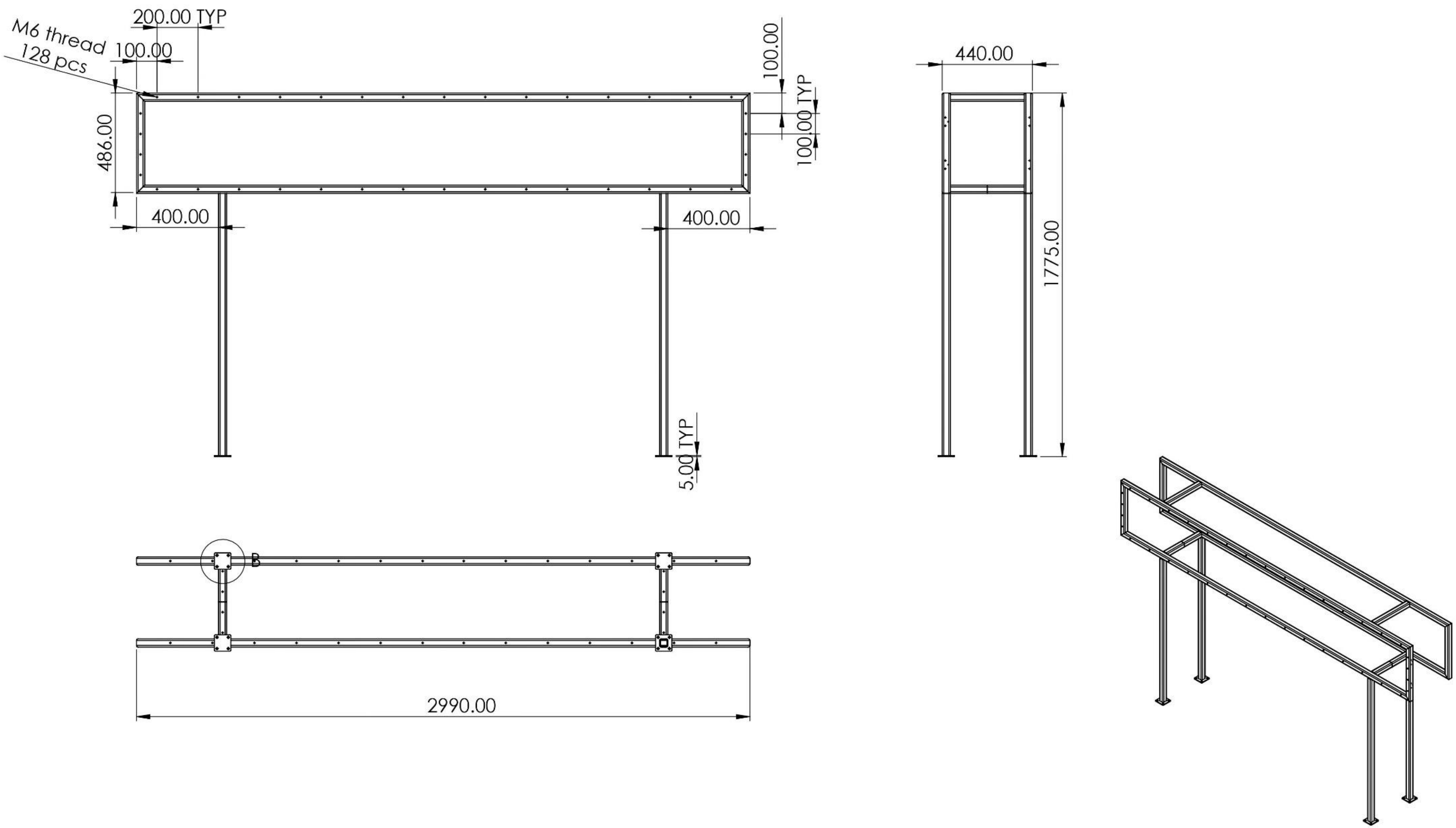


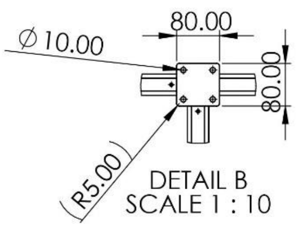
Appendix 4 – MVP

A4.2 Ultrasonic Distance sensor on Smart hanger

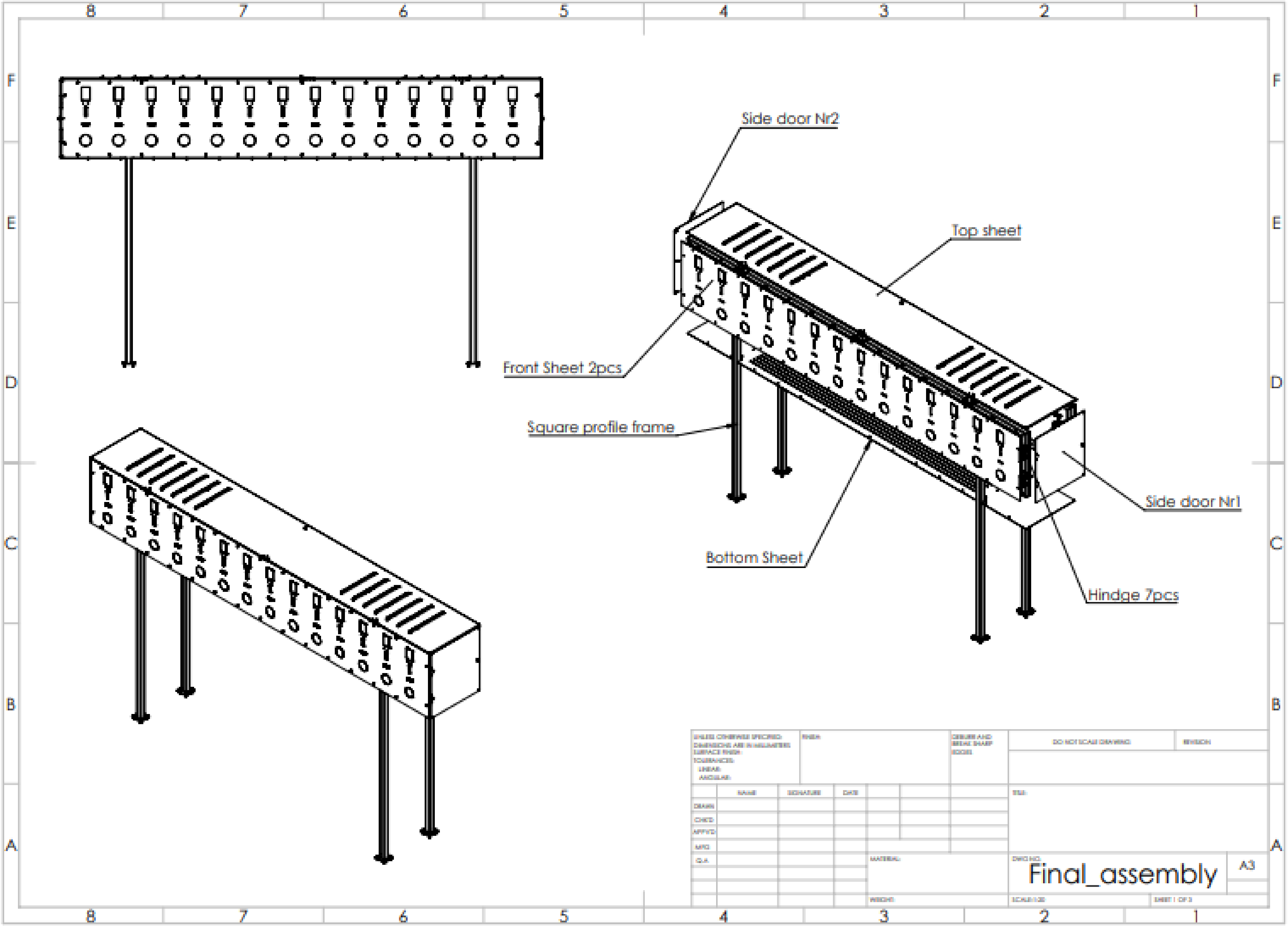
Appendix 5 – Hook module front view

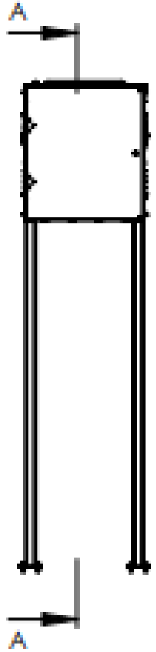
GRAPHICAL MATERIAL

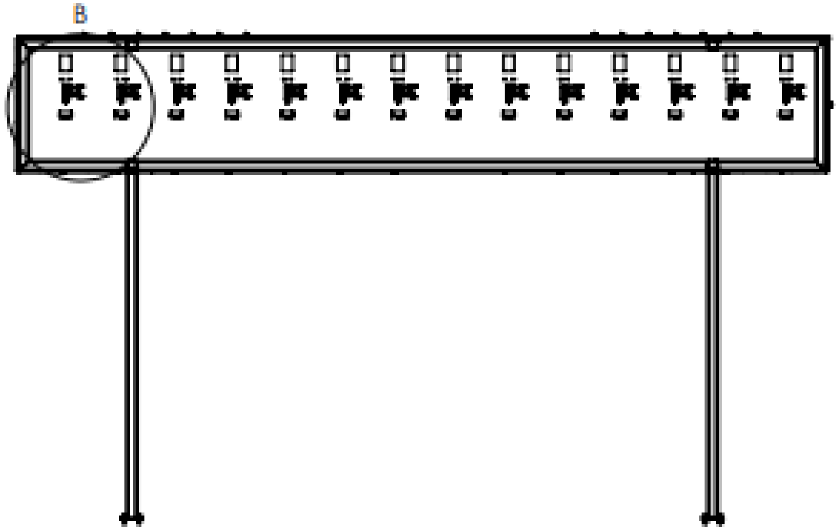




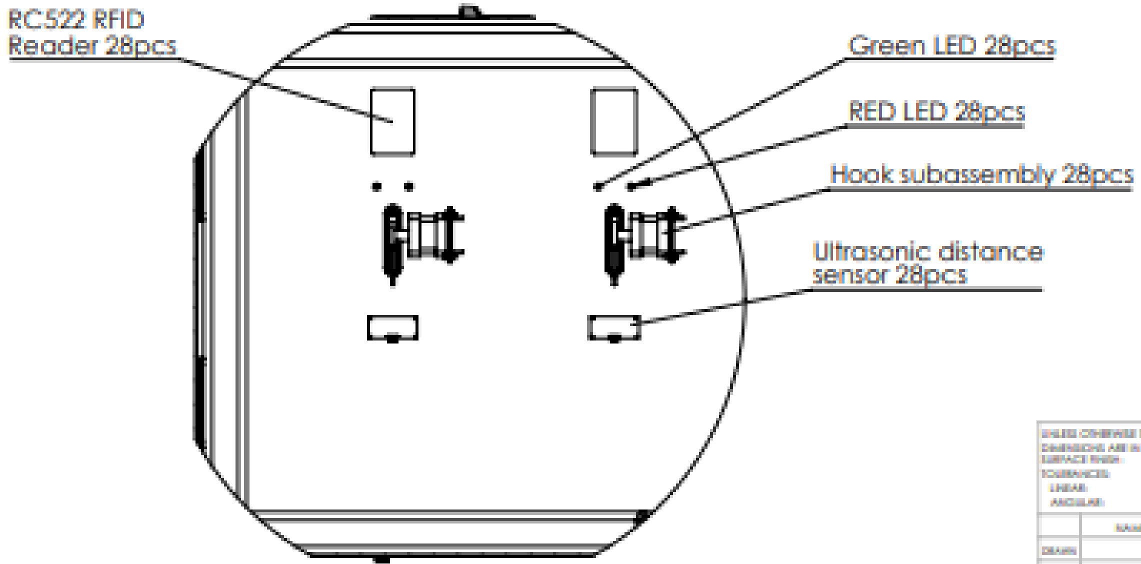
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN				Square profile frame	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL:	DWG NO. skeleton	A3
			WEIGHT:	SCALE:1:20	SHEET 1 OF 1


Side door Nr2
Top sheet
Front Sheet 2pcs
Square profile frame
Side door Nr1
Bottom Sheet
Hindge 7pcs
Final_assembly
A3





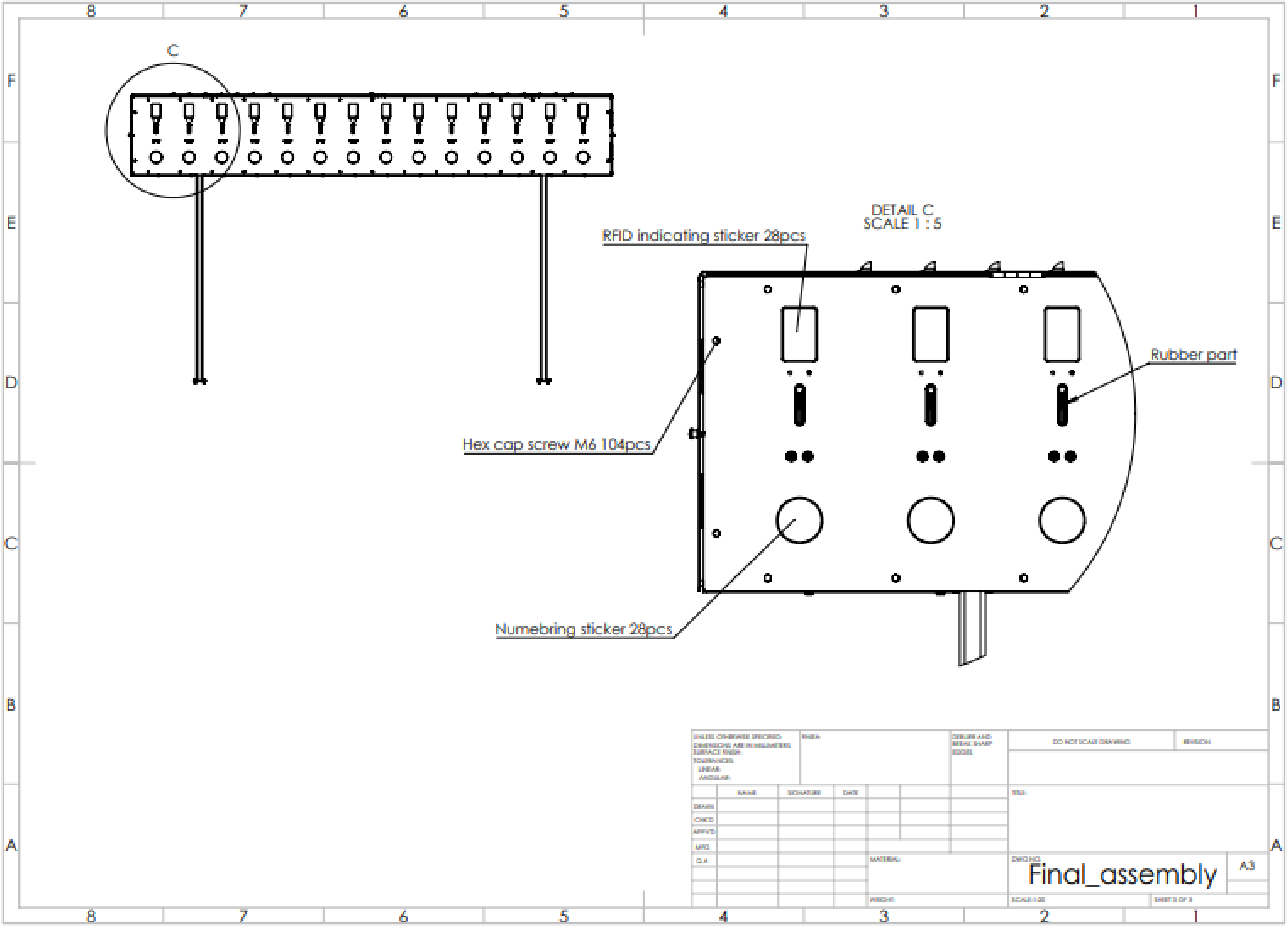
SECTION A-A



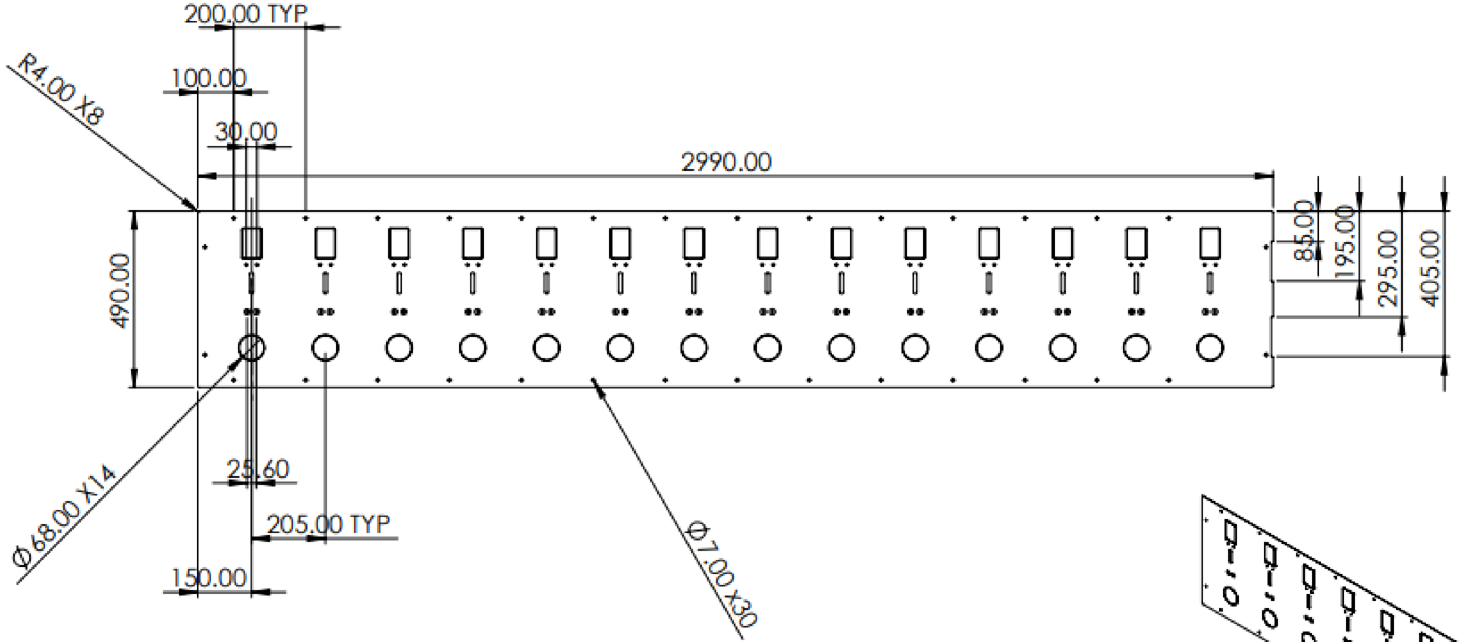
DETAIL B
SCALE 1 : 5

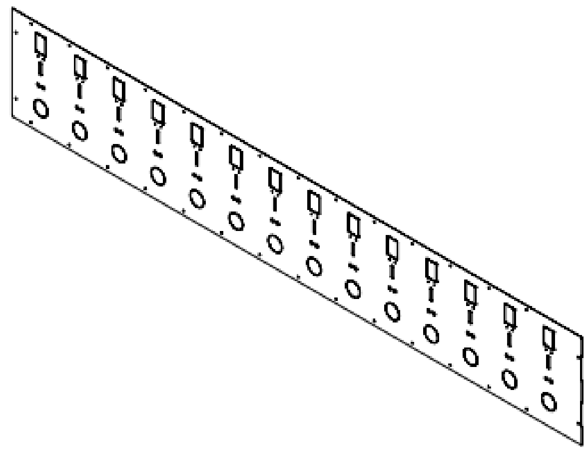
Final_assembly

A3

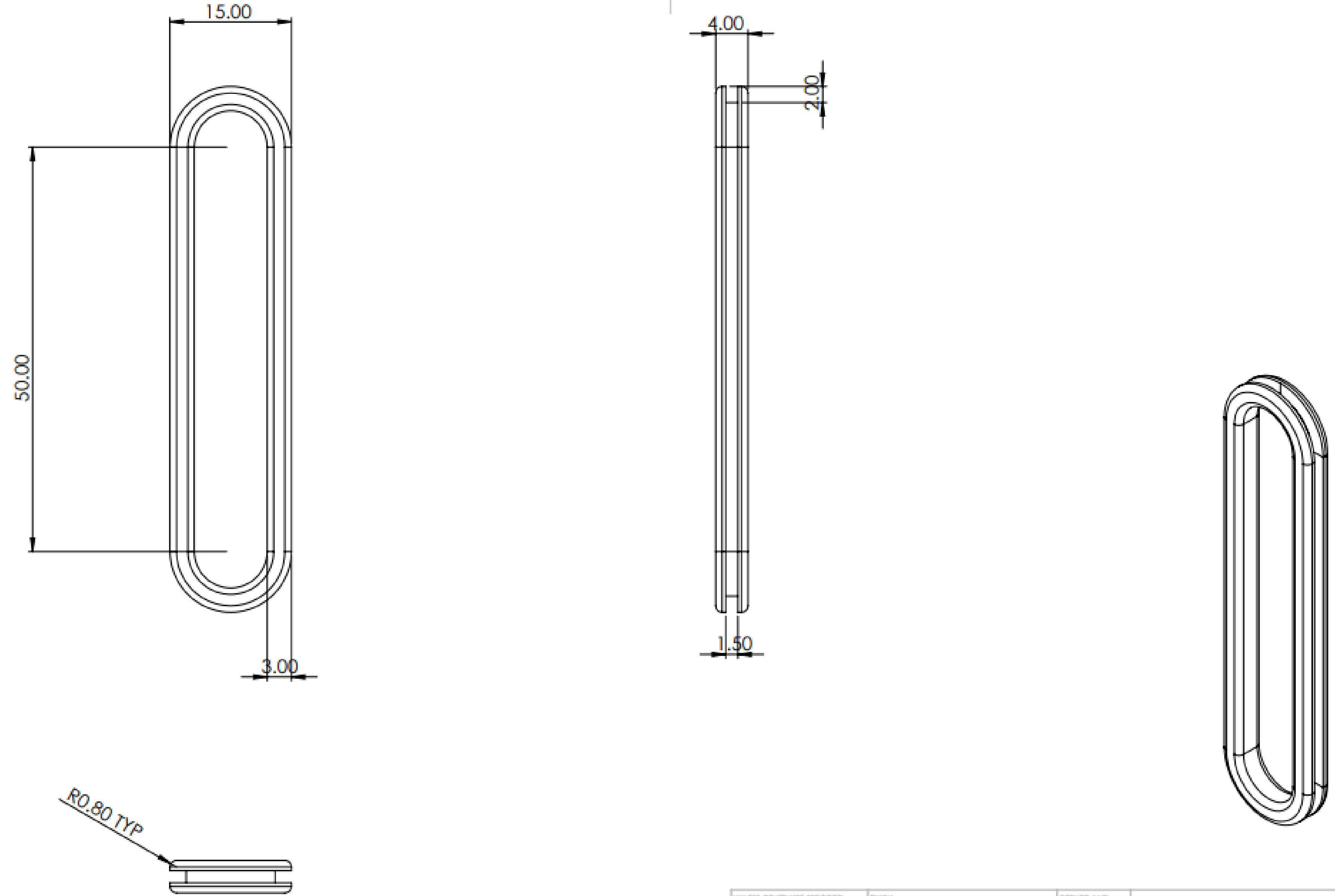

C
DETAIL C
SCALE 1 : 5
RFID indicating sticker 28pcs
Rubber part
Hex cap screw M6 104pcs
Numebring sticker 28pcs
Final_assembly
A3

Thickness: 1.5mm





UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE	TITLE:	Front Sheet
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL:	DWG NO.	Front_sheet
					A3
			WEIGHT:	SCALE:1:20	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

Rubber Gasket

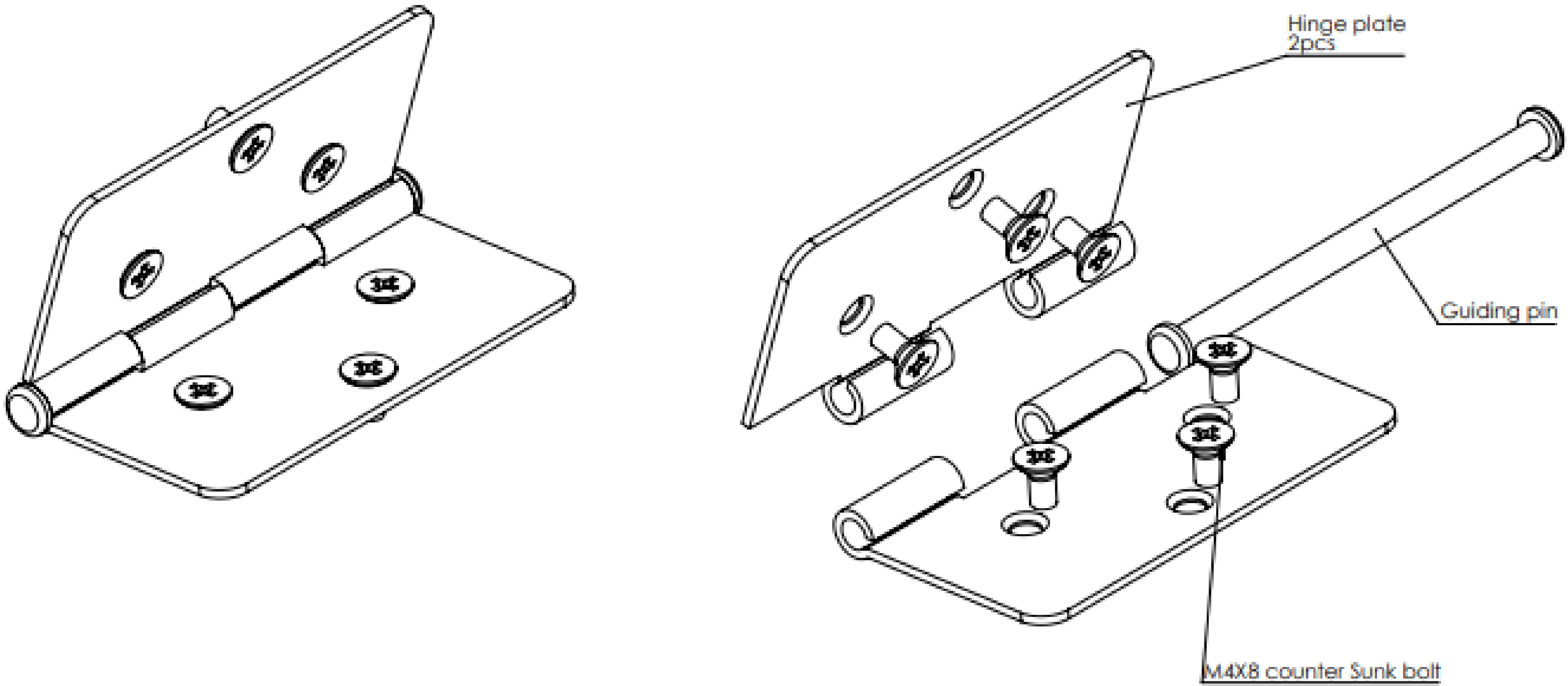
DWG NO.

Gasket

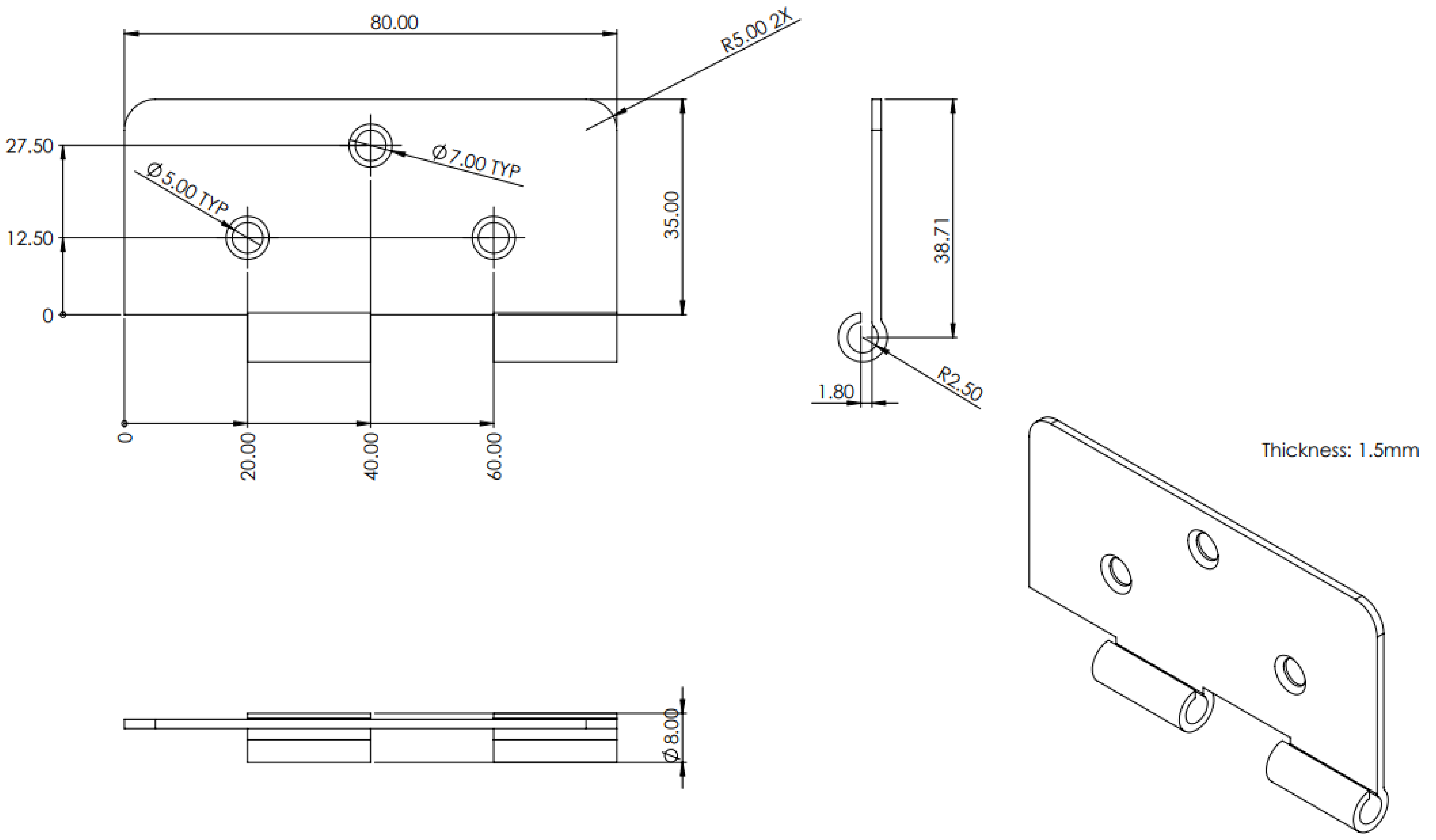
A3

SCALE:2:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE: Hinge assembly
DRAWN				
CHK'D				
APPV'D				
MFG				
Q.A			MATERIAL:	DWG NO. Hindge — A3
			WEIGHT:	SCALE:1:1 — SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

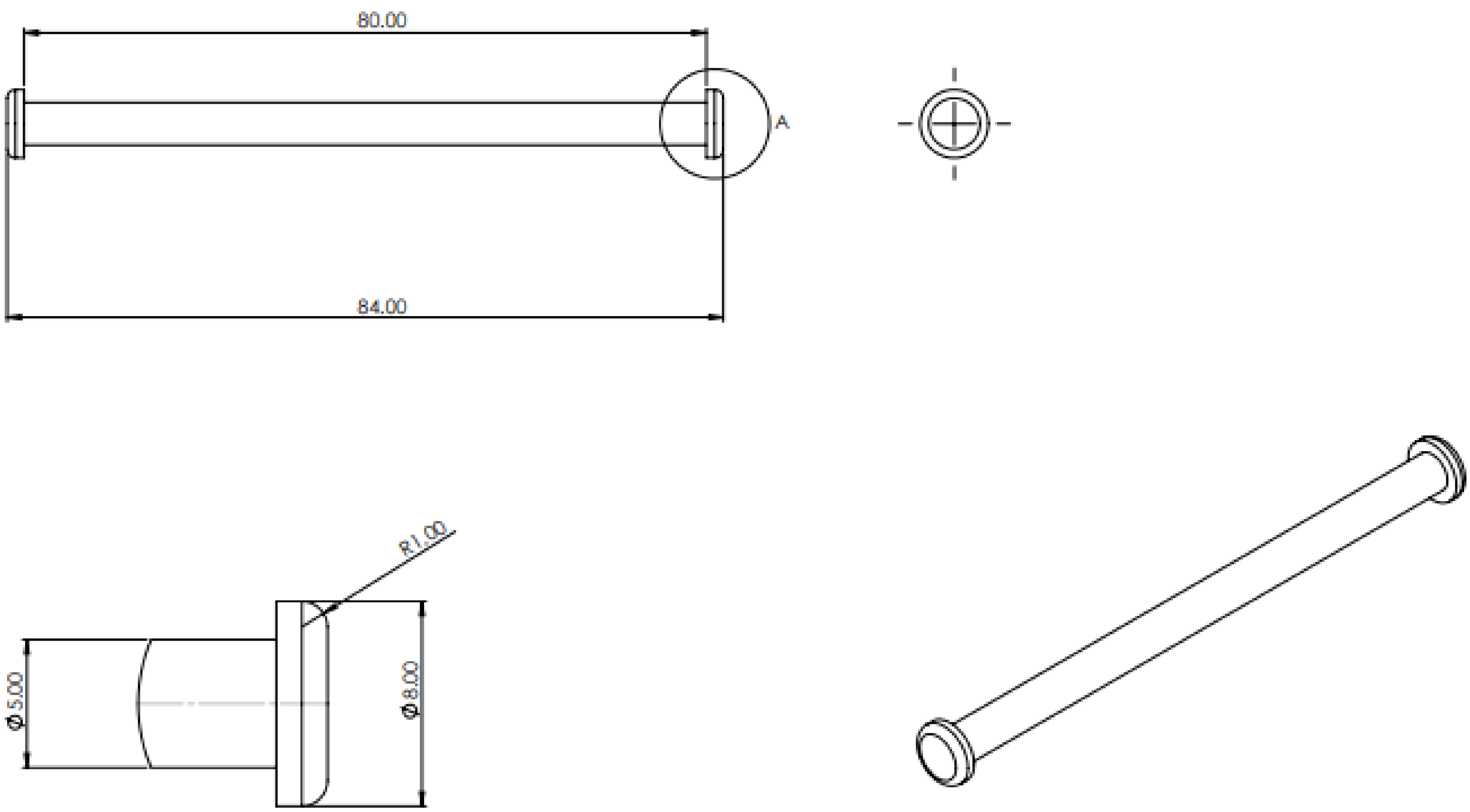
TITLE: Hinge Plate

DWG NO. Hindge

A3

SCALE:1.5:1

SHEET 2 OF 3



DETAIL A
SCALE 6 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	
DRAWN				
CHK'D				
APPV'D				
MFG				
Q.A			MATERIAL:	
			WEIGHT:	

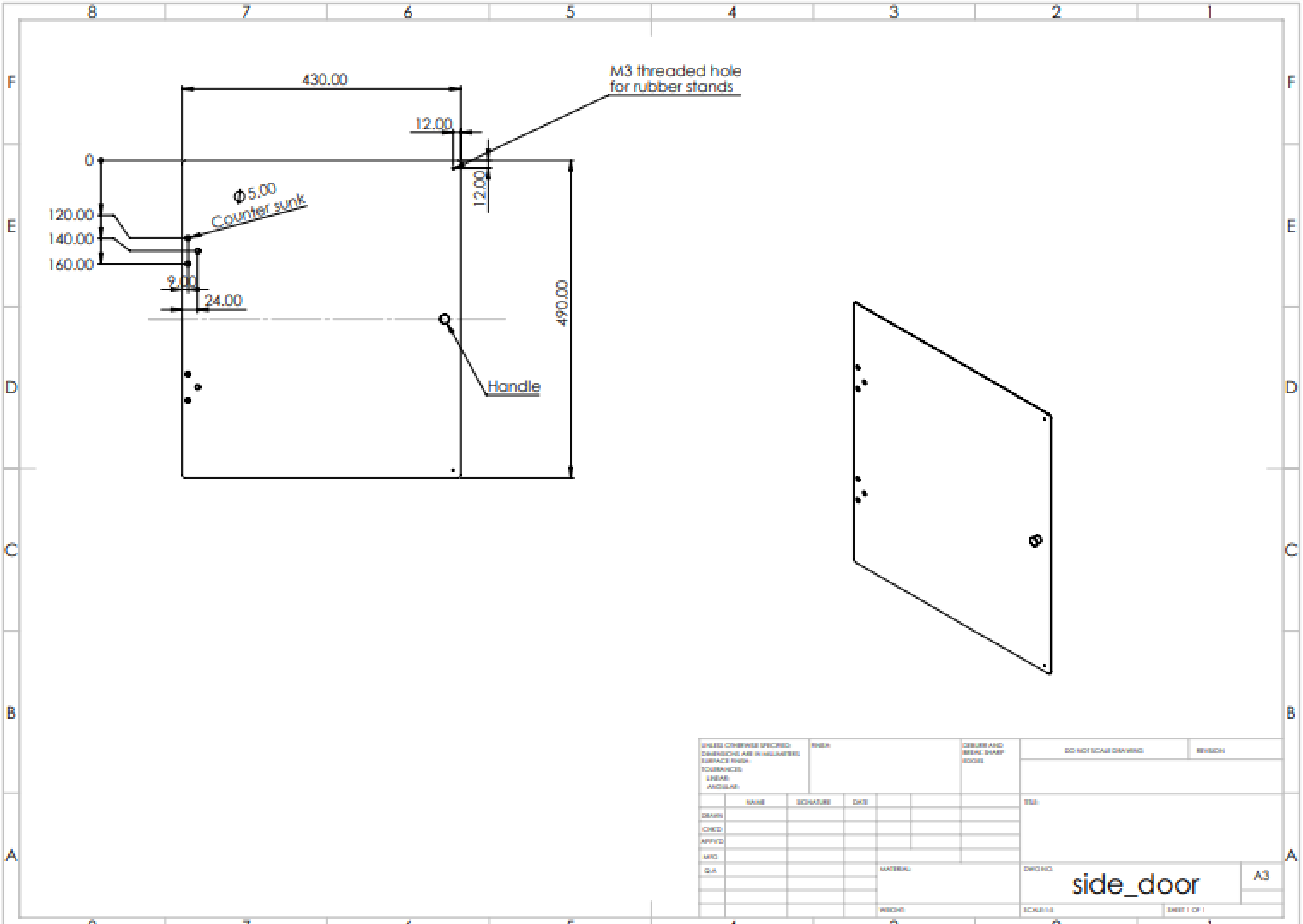
TITLE: **Guiding Pin**

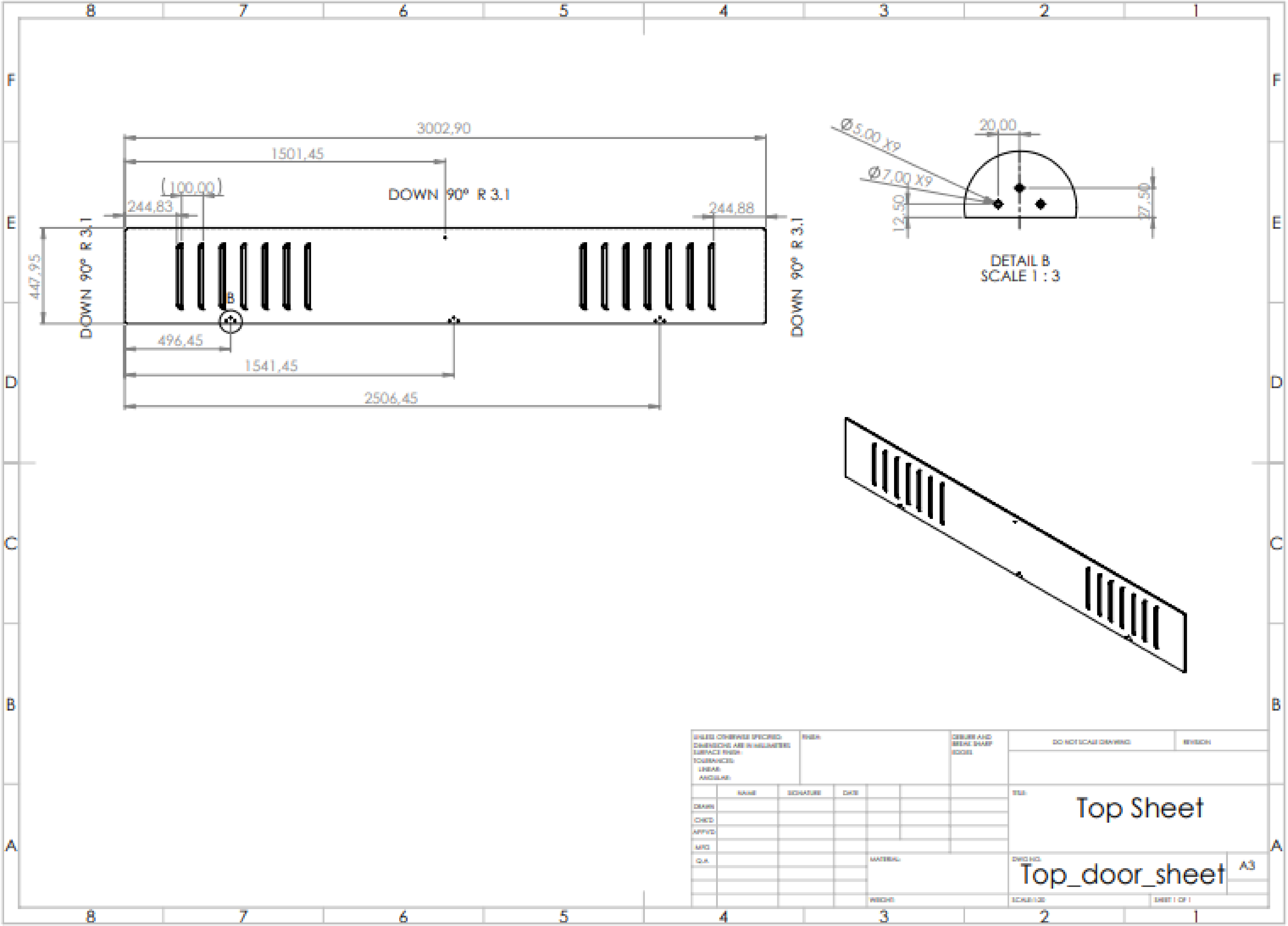
DWG NO. **Hindge**

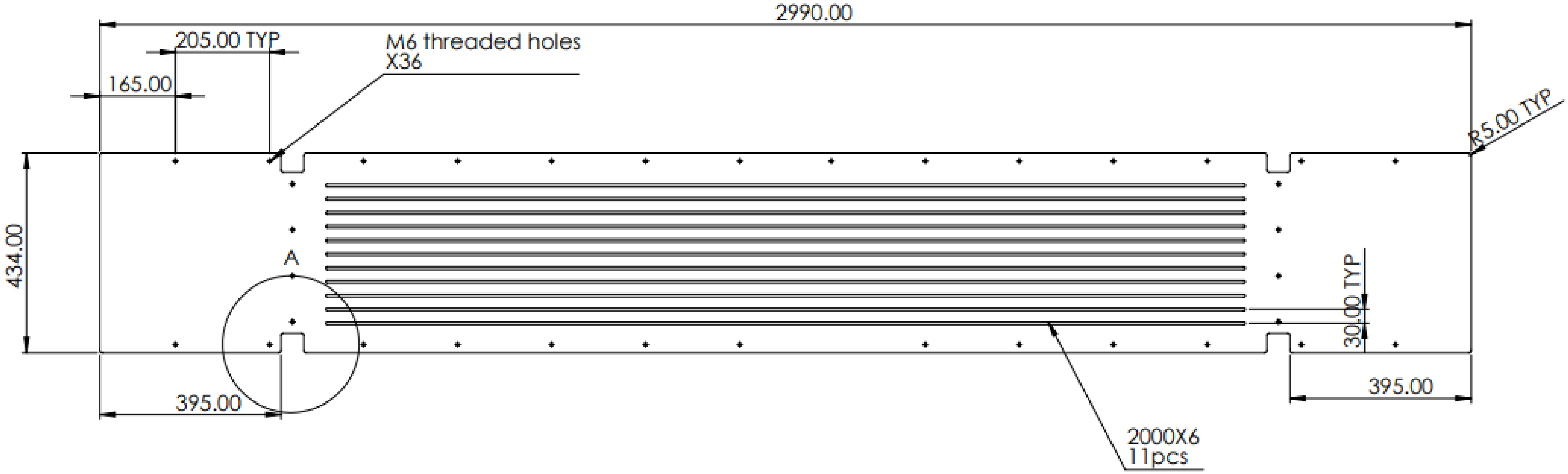
A3

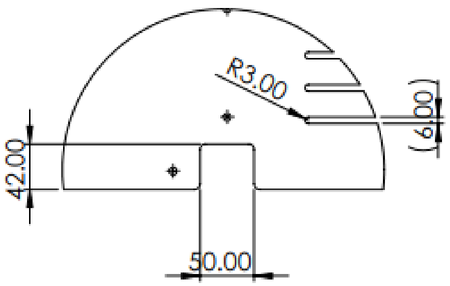
SCALE 2:1

SHEET 3 OF 3


430.00
M3 threaded hole
for rubber stands
12.00
0
12.00
Φ5.00
Counter sunk
120.00
140.00
160.00
9.00
24.00
490.00
Handle
DO NOT SCALE DRAWING
REVISION
side_door
A3


3002,90
1501,45
(100,00)
244,83
DOWN 90° R 3.1
244,88
447,95
DOWN 90° R 3.1
DOWN 90° R 3.1
B
496,45
1541,45
2506,45
Ø5,00 X9
Ø7,00 X9
20,00
12,50
27,50
DETAIL B
SCALE 1 : 3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Top Sheet
DWG NO.
Top_door_sheet
A3
SHEET 1 OF 1





DETAIL A
SCALE 1 : 5

Thickness: 1.5mm

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE: Bottom plate

DWG NO. Bottom plate

A3

SCALE:1:10

SHEET 1 OF 1