Entwicklung eines automatisierten Pillenspenders

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von
Roman Iumatov

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Begutachter:
FH-Prof. Dipl.-Ing. Dr. Robert Merwa

Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Linz, Austria, May 12, 2025

Roman Iumatov

Abstract

English

The goal of this project is to develop a prototype of an automatic pill dispenser, a device that would assist caretakers with scheduling and dispensing pills for people with limited motor capabilites. This document will cover the details of how it was done, the problems that have arisen as well as solutions to them. We will go step-by-step through each stage of development of such device and highlight challenges and solutions to the task.

Deutsch

Ziel dieses Projekts ist die Entwicklung eines Prototyps eines automatischen Pillenspenders, eines Geräts, das Pflegekräfte bei der Einnahme von Tabletten für Menschen mit eingeschränkten motorischen Fähigkeiten unterstützen soll. In diesem Dokument wird detailliert beschrieben, wie das Projekt durchgeführt wurde, welche Probleme aufgetreten sind und welche Lösungen es dafür gibt. Wir gehen Schritt für Schritt durch jede Phase der Entwicklung eines solchen Geräts und zeigen die Herausforderungen und Lösungen für diese Aufgabe auf.

Executive Summary

The end result of the project is a working prototype of the device. The specifications of the device were defined at the beginning of the project and are as follows:

1. **The device contains 21 chambers, 3 for each day of the week.**

   This requirement is a necessary condition for every pill dispenser, not just the automatic ones, because even the simple dispensers (normally) have a separate chamber for each day.

2. **The device contains a pill disposal system.**

   This is a place where unused pills are stored. This location is also divided into sections so that the caregiver is able to investigate which pills have not been taken and when. Meeting this requirement makes it easier for the caregiver to manage the device, as it is easy for them to analyze unused pills and dispose of the remaining pills.

3. **The device has an accompanying app for remote control.**

   This requirement enables the caregiver to control the device remotely. This is useful for the following reasons:

   (a) The device lacks a control panel on the housing. Therefore, the function cannot be interrupted by accidentally pressing a button.

   (b) With a single Android app, the caregiver may be able to connect to and manage multiple devices remotely. This is useful in hospitals or retirement homes, for example, where there may be several such devices in a confined space.

   (c) Alternatively, for use at home, multiple apps can be connected to a single device (not simultaneously) if there are multiple independent caregivers for a single device.

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1 Introduction

1.1 Problem Definition and Motivation

The main goal of this project is to explore the possibilities of developing such a device that can be mass produced in a decentralized way using conventional tools (3D printing) and at the same time be widely available due to the low manufacturing costs. The question is whether such a device can exist at all. While there are already ready-made solutions on the market, they are not cheap and lack certain features that are present in the prototype in question, be it the lack of remote controls, the lack of flexible scheduling or the lack of a pill disposal system.

1.2 Goals and Approach

The aim of this project is to develop a device that makes it easier for people with motor or mental disabilities to access their medication. This is to be achieved through automation, ease of use and ergonomics. A working prototype of this device will be developed as part of this project. Here are the initial requirements for this project:

1. The device should contain 21 chambers, 3 for each day of the week. This would be the default setting, but the schedule could also be configured to dispense pills either twice or once a day. In this case, the 21-chamber system does not correspond exactly to the 1-week dispensing time. The dispensing information would be available to the caregiver

2. The device should include a pill disposal system. The purpose of this system is to store the unused pills for safety reasons, to prevent accidental overdosing on previously unused pills and to enable monitoring of unused pills. Therefore, this system is also divided into 21 functional chambers.

3. The device will have a companion app. This is an Android-based application that the caregiver can use to configure, monitor and adjust the device.

As this project involves the development of a prototype, activities such as marketing, certification and industrial mass production are not part of the project. User testing is also not part of this project, as it requires the production of several devices, the collection of test subjects (i.e. establishing contacts with hospitals, nursing homes, etc.) and the statistical analysis of this data.

All of these are obviously necessary next steps after the development of the prototype, but for this project they are out of the ordinary.

1.3 Structure and Organization of the Work

This project is divided into several major steps:

1. **Design and Development of the Body**

   This is the first task: developing the basic structure. At the end of this step, a complete device should be brought into shape. We will look at the different options for developing the structure, discuss their pros and cons and choose the most suitable one for the next step.

2. **Construction and 3D-Printing of the Design**

   This is the step where our design takes on a physical form. This is the prototyping step where we iteratively develop the device to make sure the design works. This is also the step where the material and mechanical properties of our device are our biggest concern. At the end of this step, the device is functional but not yet configurable. This means that it will be able to rotate one chamber at a time.

3. **Development of the Android APP**

   This step is similar to steps 1 and 2, but for an Android app. We design and develop the template for the app, which can then be filled with functions. In this step, we will also determine which functions the microcontroller on our device must output to the app. At the end of this step, we would have a working device and an app, but they are not yet connected, which brings us to the next step.

4. **Development of the interface between the device and the app** This is the final step where everything comes together. The device will communicate with the Android app. It will be able to send (usage statistics, current time, time until next delivery, etc.) and receive (configuration settings, forced delivery command, etc.) information.

The table contains more detailed and precise steps to be taken during this project. Please note that it has been expanded and therefore includes more steps. This means that several steps from the table below are combined into one step from the list above. More specifically, steps 1.0 and 2.0 belong to the **Design and Development of the Body** section, and steps 3.0 and 4.0 belong to the **Construction and 3D-Printing of the Design** section.

Work Package	Input	Activity	Goal
1.0 Initialization	Definition of the precise project requirements, identification of the target audience, execution of the bureaucratic process, definition of the project scope.	Communication with stakeholders	Clearly formulated objective, structured development plan.
2.0 Physical Requirements	Requirements for the device's physical properties: materials, mechanisms, size, robustness requirements, ergonomics.	Analysis of the target audience and communication with stakeholders.	Definition of the boundaries for the proposed designs.
3.0 3D Printing and Construction of a Functional Prototype	Requirements for the materials used, 3D models of the prototype.	Adapting the models for 3D printing, printing the prototypes.	Physically existing device with all functional features.
4.0 Implementation of the Delivery System	Constraints from the previous step, ideas for implementation, feasibility of different approaches.	Defining and finalizing a 3D model of the delivery system, 3D design, optional 3D printing of a prototype.	Functional delivery mechanism.
5.0 Implementation of the Control System	Requirements for ergonomics and functionality.	Selecting the microcontroller, connecting the microcontroller to the delivery system, creating skeleton functions for the required device features.	Delivery system and control system are interconnected and can be programmed, making the delivery system controllable.
6.0 Programming the Remote App	Requirements for the remote app's functionality.	Programming the app (in a high-level programming language).	Application capable of controlling the device over a wireless network.
7.0 Programming the Control System	Skeleton functions implemented in the previous steps.	Programming the microcontroller.	The device functions correctly.

Table 1: Project planning table

2 Design and development of the Body

The development of a device usually involves several steps, starting with the design phase. In this phase, a decision must first be made as to how the device should look in view of the requirements that are set. The requirement to have 21 chambers is of particular interest in this context, as it significantly restricts the design options. However, this restriction should be viewed positively, as the requirements for the first steps seem to be too low. There are no requirements regarding the physical characteristics of the device, such as size or weight. This opens up a remarkably wide scope for design with regard to the external appearance of the device.

Based only on the information we have at hand, there are already some initial ideas about what the device might look like, each with its own advantages and disadvantages. Here is a brief overview of the possible designs we have come up with.

2.1 Early Ideas

2.1.1 Pill Dispense System

When thinking about how the pills should be dispensed, a number of ideas inspired by the environment emerged. Below you will find brief descriptions of the systems and also an image 1 of what they would look like. Please note that we are not going into too much detail here as they were the result of a brainstorming session and after all that, only one idea would be developed moving forward, albeit with certain inspirations from ideas that were dismissed.

- The **Revolver** system was the simplest, and it didn't take long to come up with this idea, because such devices had already been developed[1]. Its advantages are the simplicity of the mechanism, the robustness and the low price, while a disadvantage is its size and it requires a motor to drive a fairly large wheel.

- The second design is that of the **Carousel**. The main idea is that it is much smaller and uses space more efficiently than the revolver system. The smaller wheels would rotate at a lower speed than the main arm that holds them, as they are attached to the main axle with a reduction gear and a belt. Although it is slightly more space efficient than a revolver system, it is much more complex and still requires a motor to control the entire structure.

- The third design is that of the **Conveyor Belt**. On the image 1 you can see that it is round, but it could theoretically also be designed elliptically or with other, more complex curves. The principle is as follows: An output chamber is attached to the belt, which moves a series of these chambers along a specific path. It is similar to the revolver system, but the chambers would be removable and the conveyor belt would allow some flexibility in the design of the device. The main disadvantages are the need for a motor, the need for a chamber management system and the overall complexity of the device.

- The fourth design is inspired by **Vending Machines**. It would have 21 chambers, each with an electromagnet attached. Each time a pill is to be dispensed, the electromagnet is activated, causing the chamber to move and the pills to fall onto the dispensing area. In this design, the stepper motor becomes redundant, but simplicity is lost as a logical circuit is required to connect 21 chambers in parallel. Theoretically, a parallel circuit would be advantageous, but this is not the case for us, as we cannot leverage this advantage sensibly.

2.1.2 Pill Disposal System

The idea for the Disposal system at the time was that it would mirror the dispensing system, either by being positioned directly underneath it or in such a way that the tablets would first fall onto a ramp, which after a certain time would be transported into the return mechanism by another action. It is not difficult to see that the choice of disposal system is highly dependent on the dispensing system we develop, so a more detailed description will be given later when we look in more detail at the chosen dispense system.

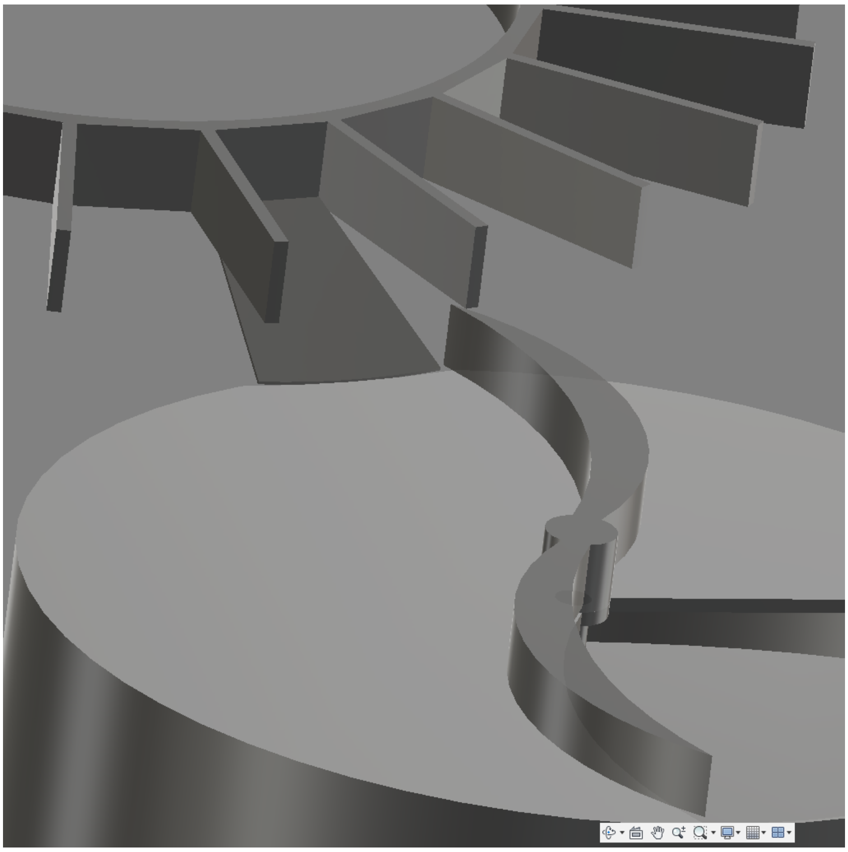

Figure 1: Initial ideas on how the main structure (dispenser) of the device should look. 1. Revolver system. 2. carousel system. 3. conveyor system (running sushi). 4 Vending machine system

2.2 Selection of the Design

Of all the proposed designs, the revolver system seemed to be the most sensible choice, but it required some improvements in the design. A brief market research (e.g. [1] [2]) showed that there is not really such a system that would meet the above requirements of having a built-in disposal mechanism. For this reason, the design would have to be improved.

2.2.1 Improvements to the Revolver system

Now that we have chosen the main mechanism, we need to work out the details. The design philosophy was to make it as simple as possible, with as few moving details as possible. The first ideas were not very successful in this respect. In the picture 2 you can see what the earlier ideas would look like. In such a design, each chamber would have its own door, under that door would be a notch for the lever to fall into to open it. The pills would then fall into the disposal tray. After a certain amount of time (15 minutes), the S-shaped arm would rotate and drop the pills further down the ramp into the disposal storage. This solution had numerous disadvantages:

1. **Too many moving parts**

   Each chamber has 21 doors. The doors need a lever to open (22), this lever needs to be translationally engaged and disengaged in the notch (23), the revolver mechanism needs to rotate (24), the disposal arm also needs to rotate (25, but the idea was to synchronize it with the main axis using belts), the disposal chambers would also need to rotate (26). Although this was a solution, it was not optimal given the number of moving parts. Although the dispensing chambers, the disposal chambers and the disposal arm would rotate around the same axis, the rotation and translation of the lever for an opening would require a complex mechanism that would further increase the effort.

2. **Requires a large dispenser bowl**

   The disposal mechanism itself is already quite large (a diameter of 300 mm was measured for this prototype). If another horizontal surface were added next to this surface, even if it were only half the size (a reduction in size would make it difficult for people with motor disorders to remove the pills safely), the entire system would become extremely large.

3. **Contains several small objects**

   This is not an obvious disadvantage, but each trapdoor must rotate around a specific axis. This axis must consist of either a small metal rod inserted into the openings of the door or 3D printed teeth on the design of the door itself. The first solution requires a daring and precise assembly of 21 doors, the second requires a high level of 3D printing precision that cannot be achieved by conventional means.

Due to these disadvantages, the system was discarded and never further improved. However, one important lesson was learned: if we want to have the simplest design, we have to utilize the power of gravity.

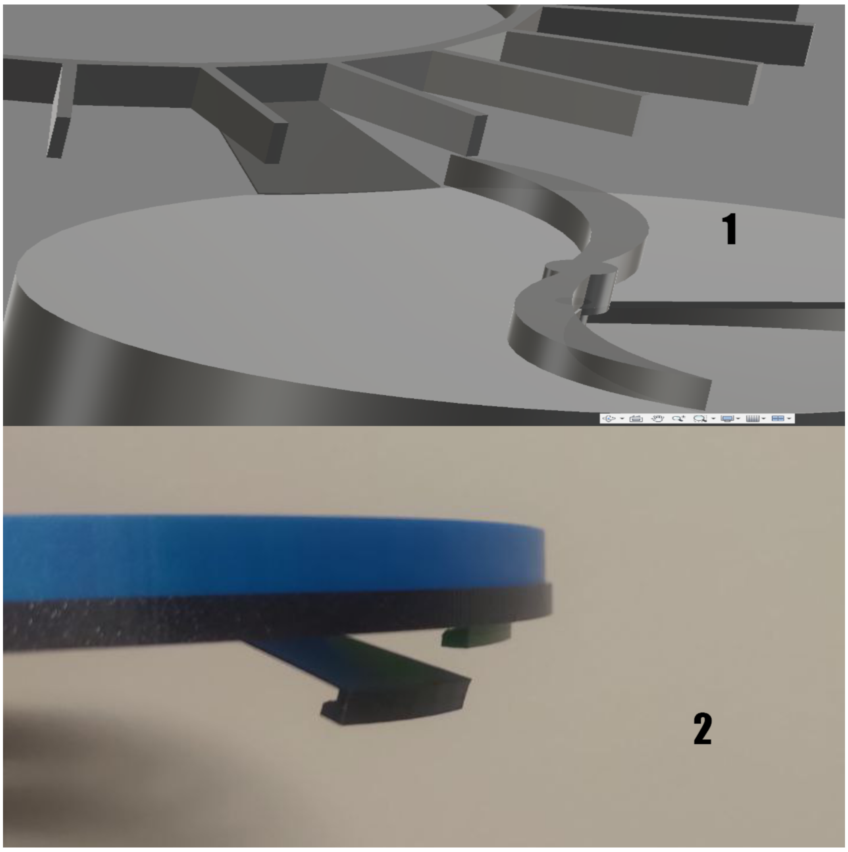

Figure 2: First revolver prototype. Here you can see that initial idea was to have a trapdoor in each chamber which will release the pills onto the disposal dish by opening it.

2.2.2 Redesigning the Revolver system. A new approach

Having realized that we need to get rid of the extra space that the separate body at the side of the main body takes, the new approach was required. This time, the disposal chambers would be directly underneath the dispensing chambers and we would use the power of gravity to move from one chamber to another, as you can see in the image 3. This would drastically reduce the amount of space the pill dispenser takes, significantly reduce complexity, setting all the rotating objects onto a single axis.

Because this system doesn't have a separate mechanism for removing unused pills, another new method would have to be developed for this too. In the image 4 you can see how the chambers of the disposal system look like. The cover of the disposal system has an opening (part 2 of the same image) that is shut when the pills have to be taken. When the upper mechanism rotates to dispose new pills, the lower mechanism rotates to send pills into disposal chamber simultaneously. Ridges are added to the cover of disposal system to prevent pills from accidentally rolling away.

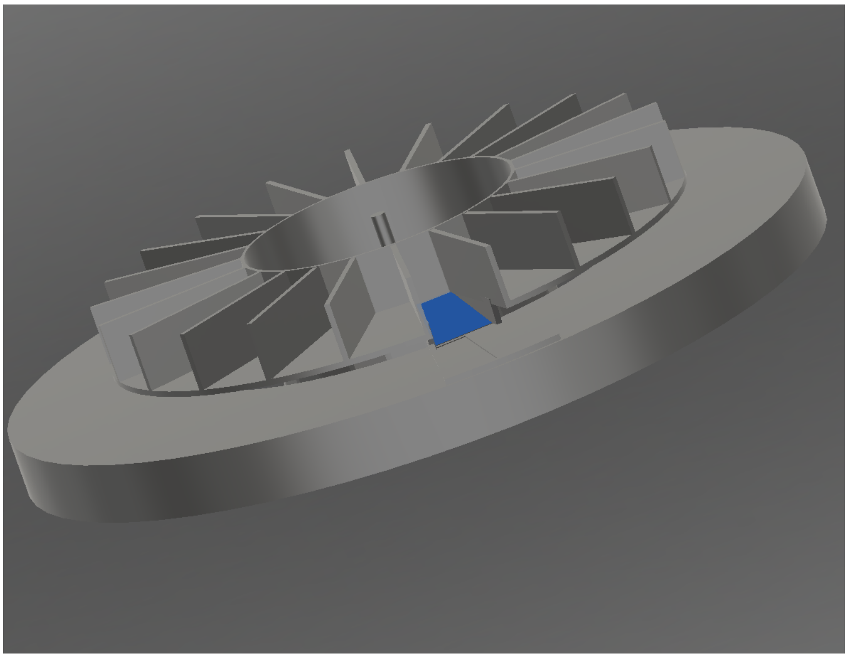

Figure 3: Second variant of the pill dispenser.

However, there are still ways to improve this approach. While much better than the previous one, this one also have some disadvantages:

1. **Chambers of the upper mechanism are smaller.** The chambers of pill storage are significantly smaller. We can calculate chamber volume using the following formulas:
$$A = \pi r_1^2 - \pi r_0^2, \quad V = A \cdot h$$
For the upper chamber: $r_1 = 100\,\mathrm{mm}$,$r_0 = 47.5\,\mathrm{mm}$, $h = 18\,\mathrm{mm}$, the result is:
$$V = 437.90\,\mathrm{cm}^3$$
For the lower chamber: $r_1 = 135\,\mathrm{mm}$, $r_0 = 80\,\mathrm{mm}$, $h = 18\,\mathrm{mm}$, the result is:
$$V = 668.69\,\mathrm{cm}^3$$
As we can see, the lower chambers are almost 1.5 bigger than the upper ones, which is a waste that we might want to get rid of.

2. **Synchronous movement of both chambers** This approach makes future development less flexible. independence of the chambers is a degree of freedom that we might want to keep somehow. The biggest problem with current approach is that it might lead to situations where some pills might fall too fast from the top to fall directly into an opening in time.

3. **Reliance on a ramp for pills to fall down.** This can introduce an undesired behavior where some sticky pills might stick to the ramp and not fall down. This can lead to very dangerous scenario where a pill, not properly dispenced in time, would fall down with the next batch which would then lead to overdose.

As mentioned earlier, this design is already what we would like to see as a final result, but we can improve it further, by redesigning it a bit and adressing the disadvantages we mentioned above.

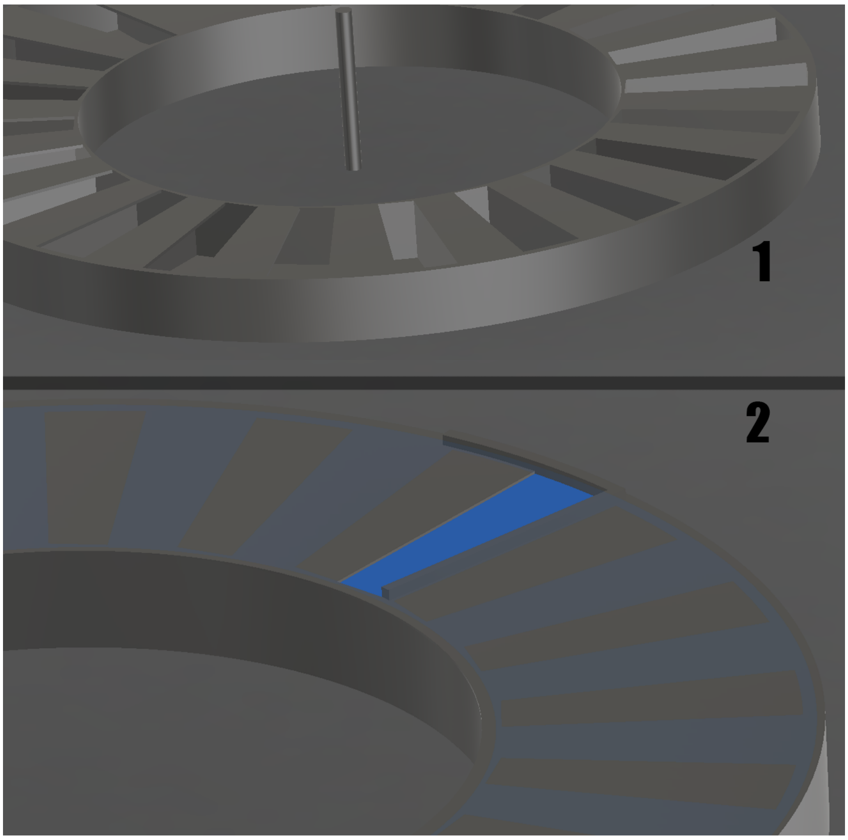

Figure 4: Disposal system of 2nd revolver system

2.2.3 The final Redesign. Improving on what's good.

A few thoughts come to mind as a potential approach to the redesign. Using gravity is obviously good, we need to continue doing, however we might change how we use it. Having 2 systems one above another is also a great idea, what if we can make the chambers the same size? We could reposition the holes. Regarding synchronous movement, we have 2 types of direction of pill movement: From dispense to patient (intended behavior) and from dispense to disposal (backup behavior). The intended behavior implies human interaction, we can make some simple movement to deliver pills that would remove the need for synchronicity from our system. All these ideas are implemented in the final design, however it is worth mentioning that there has also been the intermediary step, where the dispense mechanism was rotated 90 degrees (see image 5), so that it is completely vertical. It is worth giving a short overview of why this idea wasn't chosen as final:

- **Too tall** the wheel with diameter of 100mm would be vertically positioned which takes a lot of space.
- **Requires more torque** A motor would have to directly resist the force of gravity to lift the pills up a mill
- **Doesn't fix synchronicity** The mechanisms are still locked together, this issue remains unresolved.

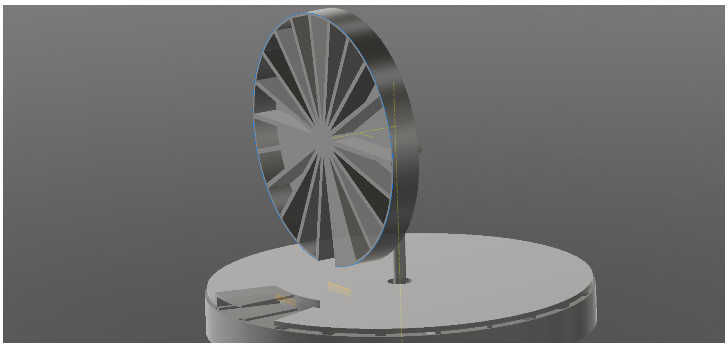

Figure 5: Pill dispenser with dispense system rotated vertically.

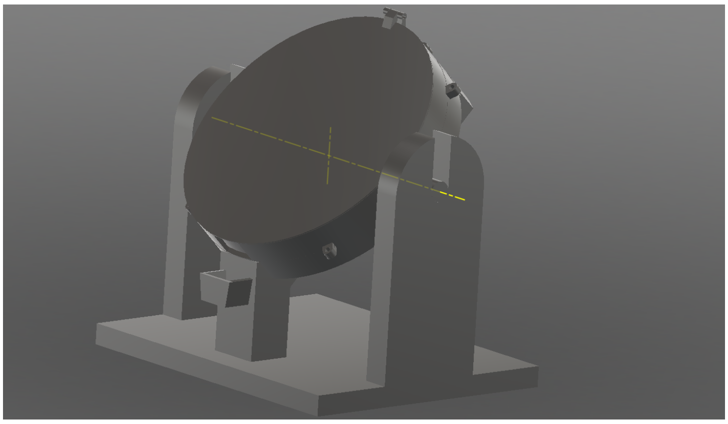

Figure 6: The final design of the Pill Dispenser.

For the final design, the following steps have been taken to address the issue:

1. **Resize the chambers** Chambers size were changed so that they match. The result is device now has a cylindrical form where the chamber mechanisms are located directly on top of each other, maximising the space used

2. **Remove the ramp, change disposal mechanism** The disposal mechanism was also changed. It works in tandem with dispense mechanism, which was also changed. The pills are now dispensed by the same movement by which they are made available, namely by rotation of the dispense mill.

3. **Introduce a separate axis of rotation to dispense pills** We will use tilting movement of the whole device for dispense of the pills into a cup or a hand of a patient, but for that we would have the whole construction elevated.

4. **Expand the device to include the stand** As mentioned above, it needs to be elevated. The stand will provide not only the elevation, but also another axis of rotation, therefore decoupling the disposal and dispense mechanisms from one another.

In the image 6 you can see the final design. It has all the features mentioned above already covered. In the next chapter we will go step by step into the details of the design and see how the proposed solutions were implemented.

3 Construction and 3D-Print of Design

The final design differs significantly from the prototypes. It has seen many iterative improvements and thus deserves its' own chapter to cover all the changes to each component of the design. The final design consists of the following bodies:

1. **Stand** Is the stand upon which the device resides. Needed for introduction an another axis of rotation and decoupling dispense and disposal mechanisms

2. **UpperBody** Consists of a walls and a floor of a dispense mechanism with a cutout for dispense and disposal paths as well as connection mechanisms.

3. **UpperMill** Is a mechanisms that divides the whole dispense system into 21 functional + 1 service chamber (22 in total). Inner side contains a gear and teeth for connecting upper mill with the lower mill (synchronicity between them is still retained)

4. **LowerMill** Is a mechanisms that divides the whole disposal system into 22 chambers. Unlike dispense system, they are all the same, since chambers need to be of the same size as dispense system, but there is no need for the service chamber. it also contains grooves to reduce the surface contact with lower body and thus friction

5. **LowerBody** is a very complex detail. Firstly, it contains cutouts for the stepper motor, driver and the deck that holds further electronics. Secondly, it has "ears" that define the axis of rotation for the dispense pathway. Thirdly, it contains grooves for the lower mill to travel on rotationally, to optimize power spent on overcoming friction.

6. **LowerDeck** Is a cover for all the electronics inside. It contains grooves on the sides for it to slide into electronics chamber.

7. **Electronics** is the housing for microcontroller, battery and charger. it also contains cutout for the deck to slide into so that electronics is covered from the outside.

8. **Holder** is a mechanism of additional mechanical fixation of the electronics. Although the Electronics compartment was designed so, that all the components are fixed in place, it might come to the situations where excess movement (e.g. during transportation) might cause electronics to fall out. this mechanism prevents it.

9. **UpperDeck** Is an upper cover of the device.

Moving forward, we will go step-by-step into the design of each of those components and also will cover the nuances of 3D-printing them all. For now, however, we will compare the final design with the goals set and why this design was chosen in the end. The goals can be divided into 2 types: Initial requirements and the problems arisen during previous designs. Initial requirements are:

1. **The device contains 21 chambers, 3 for each day of the week.** This requirement is satisfied. The final design has 22 chambers, 21 of which can contain pills.

2. **The device contains a pill disposal system.** This requirement is also satisfied.

3. **The device has an accompanying app for remote control.** This is not implemented yet. Alternatively, this requirement tells us, that an user interface on the body of device itself is not required. The electronics of this device are chosen so that this requirement can be implemented later on.

The problems that arisen during the design are solved:

1. From first prototype:
   (a) **Too many moving parts** Final design only has 2 mills that are moving simultaneosly on the same axis and nothing else. This is significant improvement over the first design
   (b) **Requires a large dispenser bowl** the disposal system of the final design is located directly underneath the dispensing system and they have the same spatial dimensions.
   (c) **Contains several small objects** The only small object is the holder, all the other ones are big and static, which reduces the amount of potential failure points.
2. From first prototype:
   (a) **Chambers of the upper mechanism are smaller** Since the dispense and disposal mechanisms are of the same size, this is not the problem
   (b) **Synchronous movement of both chambers** While both mechanisms still move synchronically, the pathways of dispense and disposal were decoupled, therefore their synchronous movement is not a problem anymore.
   (c) **Reliance on a ramp for pills to fall down.** The final design doesn't have a ramp. the pills would fall directly down in the disposal pathway. In dispense pathway, the device would be tilted 45 degrees which makes certain that the pills would fall down.
3. From third prototype:
   (a) **Too tall** The device will never be completely vertical. Although the device is now at an elevation it is still shorter as when having to have one wheel aways be vertical.
   (b) **Requires more Rotational momentum** since both mills are now horizontal, there is no extra power spent to battle gravity. the mills will only normally rotate in horizontal position.

3.1 Components of the final design

3.1.1 UpperBody

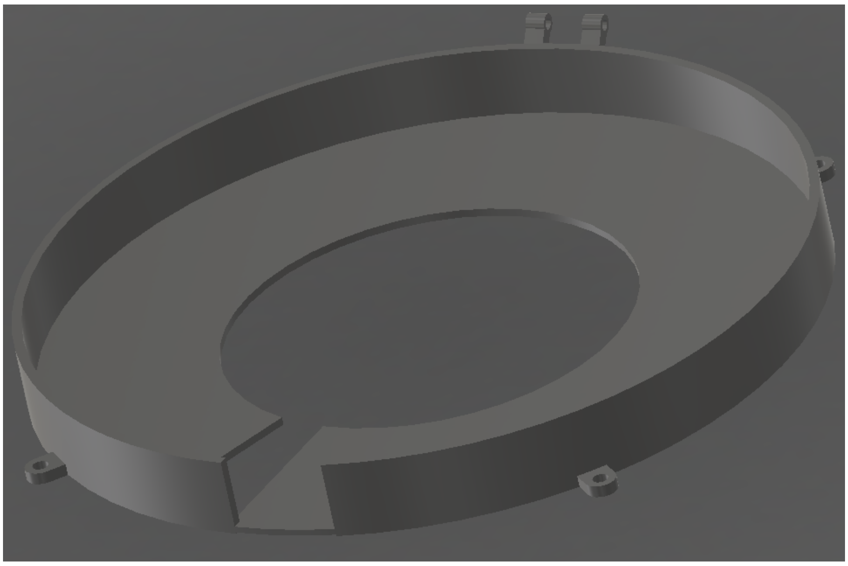

Figure 7: Upper Body

Upper body is a simple design consisting of a cylindrical shape with multiple cutouts. First one is on the floor, through this hole the pills that have not been taken would fall. The other cutout is in the wall, through this cutout the pills that will have to be taken would fall. In the middle there is a circular hole for housing the mill. under the cutout for the dispense pathway, there is a notch to prevent accidental rotation

The measurements are:

- outer radius = 100mm
- inner radius = 52 mm
- height = 20 mm
- thickness of floor = 2 mm
- thickness of wall = 2.5 mm
- notch depth = 0.4 mm

3.1.2 UpperMill

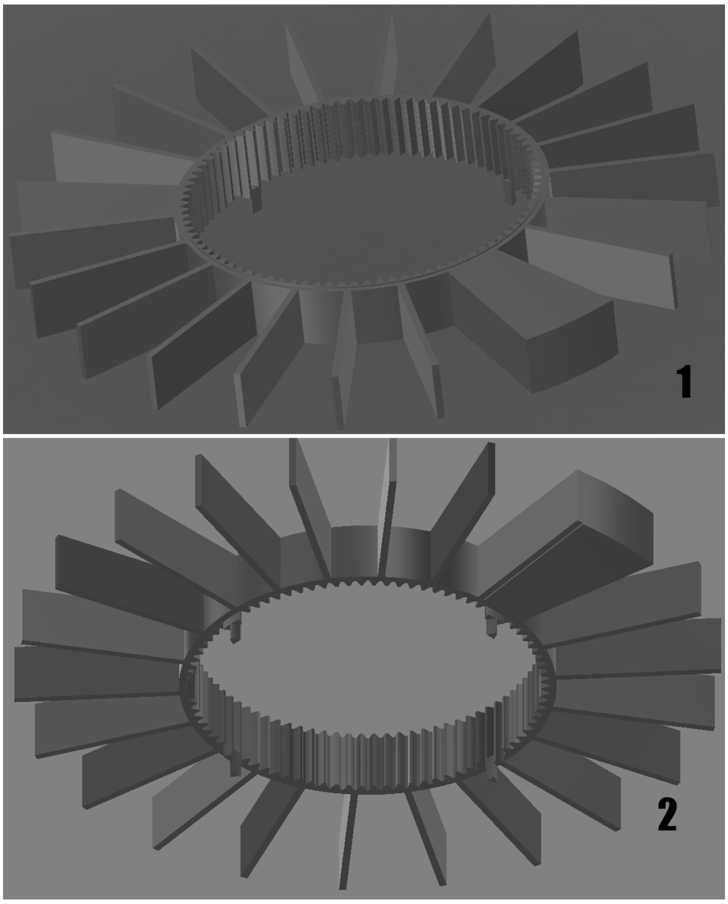

Figure 8: Upper Mill. 1 View from above. 2 view from below

Upper mill consists of 21 functional chambers and one service chamber. the service chamber is needed to cover the hole in the upper body, so that at any time, 21 chambers are available. Inner rim is designed as a cogwheel. It has 88 teeth, it will be important later for the stepper motor movement calculation. The gear was designed using a free tool called DXF and SVG GEAR DXF GENERATOR [3]. These parameters were chosen to match the size of the cog and amount of teeth needed:

- Gear 1 Tooth Count: -88 (internal gear)
- Gear 2 Tooth Count: 22
- Module: 1.11 (mm)
- Pressure Angle: 20°
- Clearance: 0.15 mm
- Gear 1 Center Hole Diameter: 0 mm (no hole)
- Gear 2 Center Hole Diameter: 0 mm (no hole)

The lower side contains 4 teeth to connect the upper mill to the lower mill. This implementation makes sure that the two mills will move at the same time, removing need for a separate stepper motor for each of them or a connection directly to the upper mill.

There are certain design decisions that have been taken to reduce friction. Firstly, on the upper side the ring is offset by 0.4 mm so that the upper deck will not touch the whole mechanism, but only this ring. At the bottom side, the teeth are complex shaped. the upper part of the tooth has a length of 2.4 mm, which is 0.4 mm taller than the thickness of the floor of the upper body. The idea behind it is that the wings of the mill will not touch the floor directly, leaving 0.2 mm opening between the floor and the upper mill.

The measurements of the upper mill are:

- chamber height = 17 mm
- chamber length = 45.05 mm
- inner ring diameter = 100 mm
- outer ring diameter = 193 mm
- gear tooth depth 2.7 mm
- connecting tooth length = 2.4 mm + 5 mm

3.1.3 LowerMill

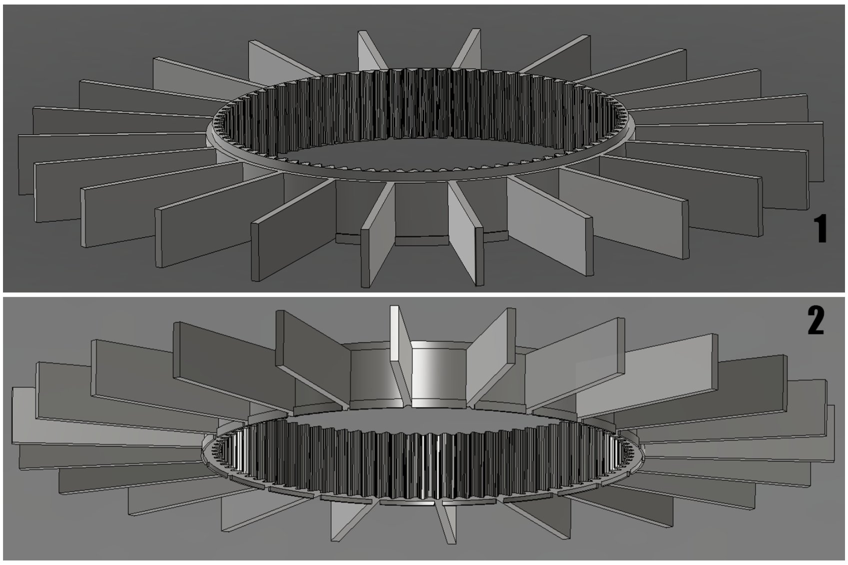

Figure 9: Lower mill. 1 view from above. 2 view from below

Lower mill consists of 22 chambers which are the same. This is done to make sure that the sizes of upper and lower mill chambers are the same. Just as with the upper mill, inner ring is also a cogwheel, designed the same way and with the same parameters as upper mill. Unlike the upper mill, lower mill doesn't have teeth to connect. The teeth of upper mill are inserted into teeth of cogwheel of the lower mill.

The upper part also contains a ring that is 2 mm above the rest of the construction. This ring exists to eliminate the friction between the ceiling (which is a floor of the upper mill) and the chambers.

The lower part is also made in such a way as to reduce friction. it contains rims that would travel rotationally along the ring located on the lower body. they are rather tall, measured at 1 mm to make sure that they don't accidentally fall out during movement.

The measurements of lower mill are:

- chamber height = 13.6 mm
- chamber length = 45.05 mm
- inner ring diameter = 100 mm
- outer ring diameter = 193 mm
- gear tooth depth 2.7 mm

3.1.4 LowerBody

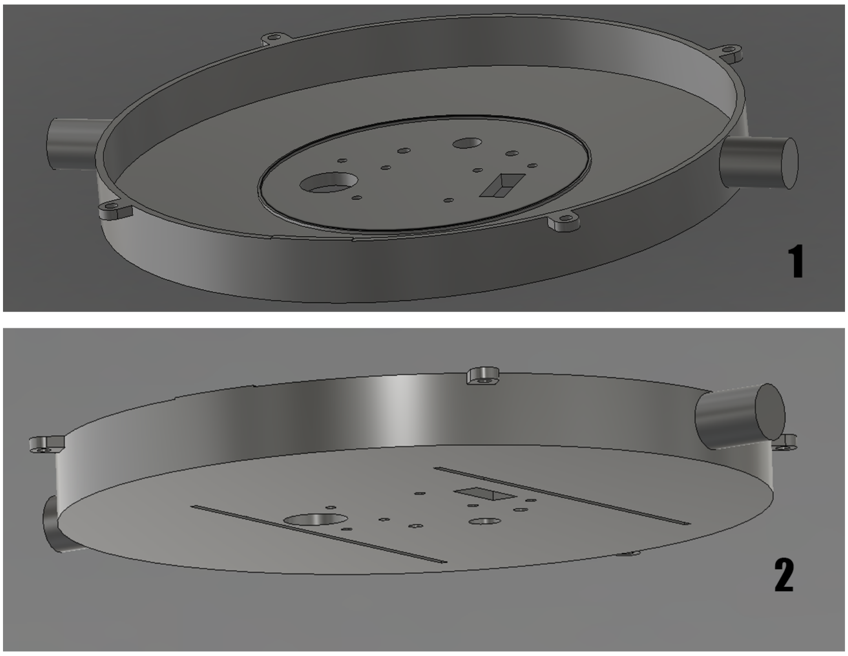

Figure 10: Lower Body. 1 view from above. 2 view from below

Lower body is a bit more complex than the upper one. It is designed to connect multiple electronic components, Stepper motor, motor driver - directly, charger and microcontroller - indirectly, through the lower deck.

On the inner side there is a ring around which the lower mill rotates. This ring also separates the chamber area and electronics area. inside this ring there are cutouts for stepper motor, driver and wires.

On the outer side, there are "ears" upon which the whole device would be positioned on a stand. These ears define the axis of rotation for the dispense pathway. Outer rim contains a ridge to fix the the upper body and prevent accidental rotation.

On the inner side there is also grooves to append lower deck, these grooves are needed to remove the possibility of attaching the lower deck the wrong way. Grooves are 125 mm long, 2 mm wide and 2 mm deep.

The measurements of lower body are:

- radius = 100mm
- ring inner radius = 50.5 mm
- ring inner radius = 51.4 mm
- ring height = 1 mm
- body height = 20 mm
- thickness of floor = 4 mm
- thickness of wall = 2.5 mm
- notch depth = 0.4 mm

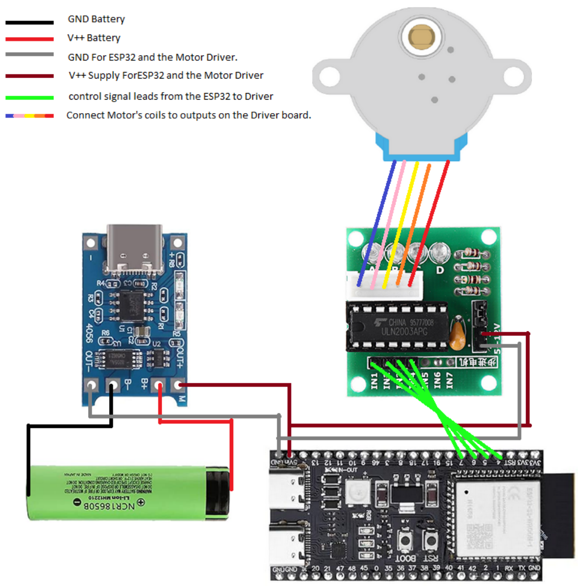

Figure 11: Connection schema of electronic components. Components from top to bottom: 1)28BYJ Stepper motor 2) Left: Charger Module 3)Right: ULN2003 Motor Driver 4)Left:Panasonic NCR18650B Battery 5)Right ESP32 S3 DevKitC-1 N16R8 S3 Microcontroller

3.1.5 Electronics

The device needs a microcontroller and a stepper motor for control. There are many options from which to choose, therefore we need to know what we need for our electronics to filter out possible choices. Microcontroller needs to be able to control a stepper motor and also to have a network interface, Wi-Fi or Bluetooth, so that we can host an user interface somewhere else. Stepper motor needs to have enough torque to rotate 2 mills and a load. We don't need a high performance stepper motor, since our rotational speed is not that important. also it should be noticed that there is a gear reduction of 4:1 on the gears which results in 4 times higher torque for 4 times lower speed. From the measurements above we know that the diameter of mill is 200 mm, the weight is hard to calculate, but we can access the calculation used by the slicer software. The results are 44 g for Lower mill, and 61 g for Upper mill for 105g in total. The extra weight from pills would be around 100g for 205g in total. While there has been no calculation involved, the setup was tested with the coins to serve as a load, however it was tested only with the lower mill attached. We will come back to discuss the results in the later part of the document. Considering also that the one of the goals of the project was to develop the device for as cheap as possible, a 28BYJ [4] stepper motor was chosen, together with the ULN2003[5] Motor driver.

For the microcontroller, an ESP32 S3 DevKitC-1 N16R8 ESP32 S3 was selected [6]. it is a common choice to pair this microcontroller and stepper motor and it has the network interface (both Wi-Fi and Bluetooth). For us a Bluetooth Low Energy (BLE) is of particular interest. It allows us to save battery, since we don't need a constant stream of data exchange between a smartphone and device.

Another addition to the electronics is inclusion of battery. While not a requirement, battery-powered device is much more convenient to use as it makes it independent from being located near a socket. For this, Panasonic NCR18650B [7] Battery was selected.

3.1.6 Lower Deck(Electronics compartment)

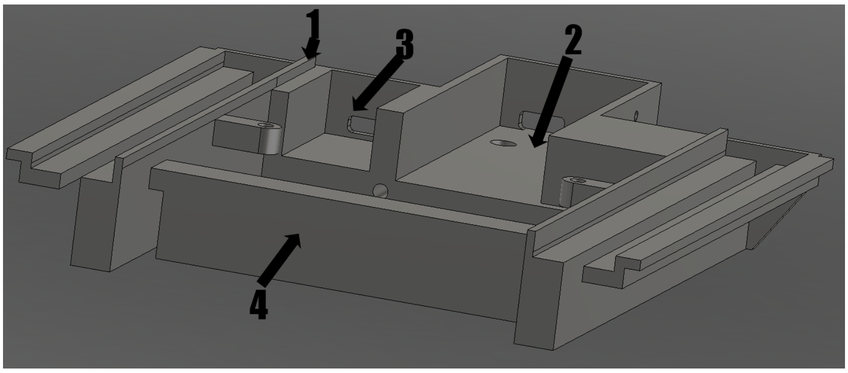

Figure 12: Lower Deck and its' features: 1)Ridge 2)Microcontroller housing 3)Charger Module housing 4)Battery Wall

The lower deck houses three electronic components: Microcontroller, battery charger and battery. It also serves as a cover for the stepper motor, whereas the driver would be located on the opposite side of the lower body, inside the ring. The shape of the lower deck is quite more complex than that of the previous bodies, therefore it makes sense to divide the description of it into multiple parts. on the image 12 you can see the lower deck and a numbers that point to the parts of components. Here is a description of all the components of this body:

1. **Ridge** Lower body has 2 parallel grooves on its lower part. These grooves will house these ridges on the lower deck. The ridges are designed to actually be a tiny bit smaller (1.6 mm vs 2 mm) than the notches of the lower body, we will discuss why in the later chapter. Ridges are 125mm long, 1.6 mm thick and 2 mm deep.

2. **ISP32 Microcontroller housing** This is where the microcontroller would be placed. We know the dimensions of the microcontroller (63.5 mm x 28 mm) and this opening is made to be around the same size to fit it (67.6 mm x 28 mm). It has cutouts on the body for 2 USB ports present on a microcontroller, as well as a LED.

3. **Charger Module housing** In this part the charger circuit will be nested. The cutout matches exactly the dimensions of the charging module (28 mm x 17.5 mm). This compartment contains also the cutout on the body for the USB port.

4. **Battery Wall** Battery holder is attached to this wall. at the sides one can notice that the connection to the side walls does not go all the way. The reason is that wires will go from the battery holder through these openings.

Lower deck also features a long hole for a slide-in lid which you can see to the sides from the Ridges that connect Deck to the lower body.

3.1.7 Stand

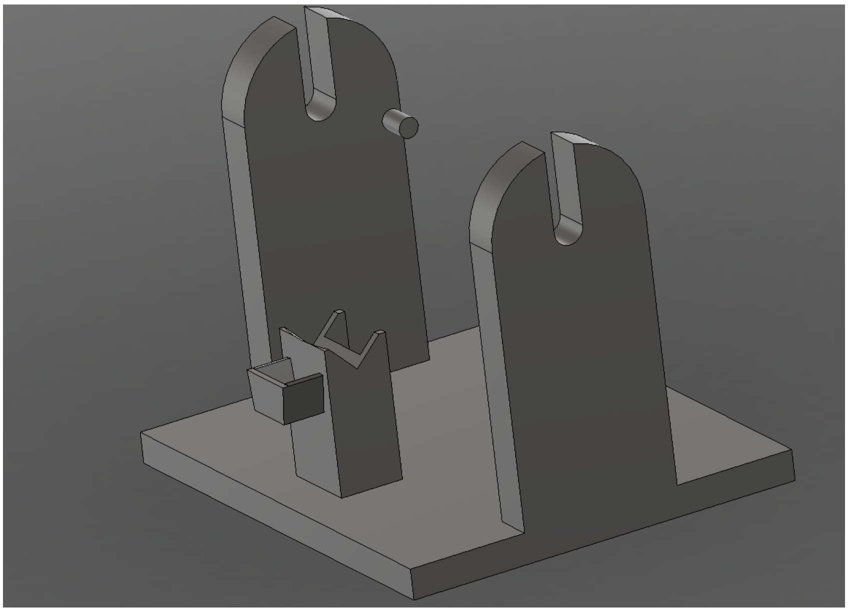

Figure 13: Stand

Stand is a simple design that features 2 distinct components: Pillars to the sides to hold the device and a dispensing dock in the front and center of it. The pillars have a cutout to slide down the device into it and notches to prevent the device from tilting backwards. The dispensing dock is designed to match the shape of the device so that it can easily be tilted into it at a 45 degree angle. The dimensions are:

- Stand height from bottom to the peak of stand: 190 mm
- Stand Width: 240 mm
- Stand Length: 200 mm
- Stand floor thickness: 15 mm
- Pillar thickness: 20 mm

It should be noted, however, that although this Stand is the default solution for the sake of completeness of the project, ideally, it would be manufactured not with a plastic, but rather with metal. The purpose of the stand (besides providing pathway for dispense of the pills) is also to provide stability of the construction so that people suffering from tremors would be able to lean firmly onto it and stabilize their hand. In this case, plastic might not be the optimal solution.

3.2 3D printing specifics

As mentioned earlier, one of the goals of the project is to make the device buildable with consumer-grade devices, among them 3D-Printers. This requirement introduces first physical limitations for the device, as 3D-Printers have a limited printing space. For this project as a reference printer, a Prusa MK4S 3D-Printer [8] was selected. From the Specification we can see that the build volume is 250 x 210 x 220 mm, putting a limitation on how large our device can be. Theoretically, of course, we could circumvent this limitation by designing the components in such a way that they would consist of multiple parts interlocking with themselves, however this adds unnecessary complexity to an already extensive project. The dimensions of each component mentioned in previous section conform to this limitation.

As for material selection, Prusa MK4S (and many other printers) support printing with Polylactic Acid (PLA) plastic. This material has many advantages: it is biodegradable (it is a polymer of lactic acid), lightweight, sterile [9], doesn't produce as much fumes(but still dues) as standard Acrylonitrile–Butadiene–Styrene (ABS) plastic [10], due to lower printing temperature and is easy to print with. However, certain disadvantages should be mentioned: Heat deflection at around 55-60 degrees [11] means it cannot be washed with boiling water as it would warp the body. Pure PLA is food safe [12], however the pigments might not be, so any wear might introduce microparticles that might not be as safe to consume if colored PLA is chosen.

4 Development of a Remote-APP

4.1 General Outlook

4.2 Device Connection

4.3 Device Configuration

5 Microcontroller Programming

Before going into the details of how the backend part of programming the device is structured, an overview of the general plan for the backend development is worth looking at. Before starting the implementation, the plan was drafted that would outline important functions that would be needed for the app to communicate properly with the device.

Writable

- `Set_Device_Time` — synchronize the ESP32 clock.
- `Set_Dispense_Schedule` — add, edit, or delete schedule entries.
- `Trigger_Manual_Dispense` — manually trigger a dispense (logged for traceability).

Readable

- `Get_Device_Time` — read the current device time.
- `Get_Dispense_Schedule` — retrieve the stored schedule.
- `Get_Last_Dispense_Info` — timestamp + status of the last event.
- `Get_Time_Until_Next_Dispense` — countdown to the next dose.
- `Get_Dispense_Log` — full dispense history.

Notify/Indicate

- `Notify_Dispense_Event` — real-time success/failure updates with timestamps.
- `Notify_Schedule_Change_Confirmation` (optional) — acknowledgement of schedule edits.

5.1 Important Functions

5.2 Backend-Frontend Integration

6 Results Analysis and Discussion

The project was very extensive and diverse in types of tasks one person had to do.I would consider the end result to be rather **Unsuccessful**. In this chapter I will reflect and discuss on the process and provide my **personal** feedback on what went well, could've been done better, and what would be needed to be done next. It is worth going through the problems first, so that it provides the context for the final result of the project.

6.1 Problems

The problems that have occurred can be divided into 2 big categories. First is the problems of **Organization and Project Management** These are the issues of the structure. Unfortunately, I have never had any experience before in managing a successful **Project**. Although I have work experience, my tasks were primarily immanent ones, those that either don't last long or don't require deep planning. It might have actually negatively affected my outcome for this project as I worked under a rather arrogant assumption that my experience would be of use here also, but it was actually the opposite. My work experience made me somewhat negligent of the due process of dividing this (quite extensive) task into the smaller pieces and tackle them one by one. This is what I would call structure and this my project lacked.

The other problem with organization of the project is ambiguity of the roles that the participants would play. I came to the project management with somewhat **Agile** paradigm in mind. Which meant that there would be a second player from whom I would receive constant feedback, but the issue was that while there was an agile mindset, there was no agile project management and there was also no such person that would provide actionable, useful feedback. This state hindered the speed of development in an already quite extensive project somewhat. Adding to that, because there was no clear division of tasks and this was what felt like to be my personal project, receiving whatever feedback I would get felt awkward and hard to act upon, even if that feedback was good. Another problem of doing everything personally was the issue of **divided attention** where everything would have to be kept in mind by one person and jumping from one task to the other felt very disorienting. On the other hand, this experience has shed the light on importance of proper documentation of different areas of development in the project: it allows different teams/departments/organizations to communicate better with each other by laying down definitions and overview of the structure.

Yet another problem with Project Management was inadequate assessment of effort. While 3D-design and 3D-printing were a relatively easy and straightforwards processes, which have also been quite insightful in and of itself, they also took quite some time to finish. The next steps, namely Frontend and Backend programming were not such. Android development requires a set of knowledge that is not normally practiced in the field such as Object-Oriented Programming (OOP) paradigm for the GUI development, knowledge of either Kotlin or Java **programming languages (syntax)** and the **specifics** of these languages (as they are not the same language family as either C, Python or Matlab, so they handle data types, memory management, compiler and runtime errors differently), as well as **Platform specifics** (Android API, Packaging toolchain, App Components, device compatibility and so on). The microcontroller programming part requires extra research into BLE, microcontroller specifics (which is made relatively easy, but still time-consuming, by existence of documentation and data sheets). Since all of this was done by a single person it felt so daunting (I will also cover the meaning of this in the later part, where I will discuss my personal pitfalls).

Project management Task was too big Everything done by one person (with the assumption that there would be team work) Personal Reluctance to engage deeper Lack of motivation general state of disorganization

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