ECE 445/ME 470

SENIOR DESIGN LABORATORY

FINAL REPORT

Smart Medicine Box

Team #6

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Abstract

This project presents the design and implementation of a smart medicine box aimed at improving medication adherence among elderly users. The system integrates four functional modules: a mobile application for prescription recognition and validation, a secure rotating medicine storage tray, a suction-based pill grabbing and dropping mechanism, and a reminder system with drawer retrieval and audible alerts. Utilizing a multimodal AI model and Bluetooth-enabled communication, the system automates the dispensing process while ensuring safety, accuracy, and user accessibility. Iterative testing and hardware optimization addressed key challenges in mechanical reliability and pill detection. The final prototype demonstrates that low-cost, modular hardware combined with intelligent software can provide a robust and user-friendly solution to a critical healthcare need.

Contents

1 Introduction

1.1 Problem Statement

The rapid growth of the global elderly population is intensifying pressure on healthcare systems, particularly in the area of medication adherence. By 2050, the population aged 60 or above is expected to reach nearly 2 billion worldwide, and studies have shown that over 22% of adults aged 40–79 in the United States are engaged in polypharmacy, the simultaneous use of five or more medications [1]. This increases the likelihood of dosing errors, missed medications, and adverse drug events—risks that are especially dangerous for older adults with cognitive decline or limited independence. While existing smart pillboxes provide basic functionalities such as alarms and storage, they still rely heavily on manual pill organization and often suffer from low capacity, poor accuracy in dispensing, or user-unfriendly interfaces [2][3].

1.2 Solution

1.2.1 Overview

To address these limitations, we propose a novel smart medicine box that integrates mechanical automation and multimodal AI assistance to enhance the safety, accuracy, and independence of elderly users in managing their prescriptions. Our design combines an air-pump-based suction mechanism for automatic pill pick and drop, a rotating multi-compartment storage tray, and a mobile application for remote control, inventory management, and real-time prescription validation via vision-language models. Compared to existing solutions, our system emphasizes precision, modularity, and user convenience. To contextualize our proposed solution, Figure 1 presents a visual overview of the system in use. It illustrates how the smart medicine box interacts with the user and external components, including a mobile application and a cloud-based prescription analysis module. This scenario-based diagram highlights key functionalities such as automatic pill dispensing, remote control via smartphone, and AI-driven prescription verification, demonstrating how our solution fits seamlessly into a typical daily medication routine.

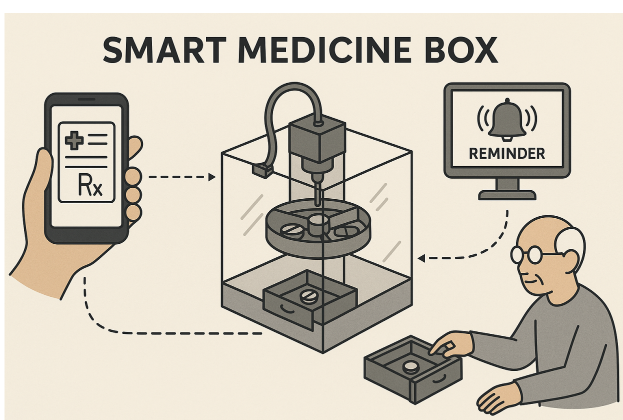


Figure 1: Visual Aid

1.2.2 Block Description

Figure 2 shows how our system works.

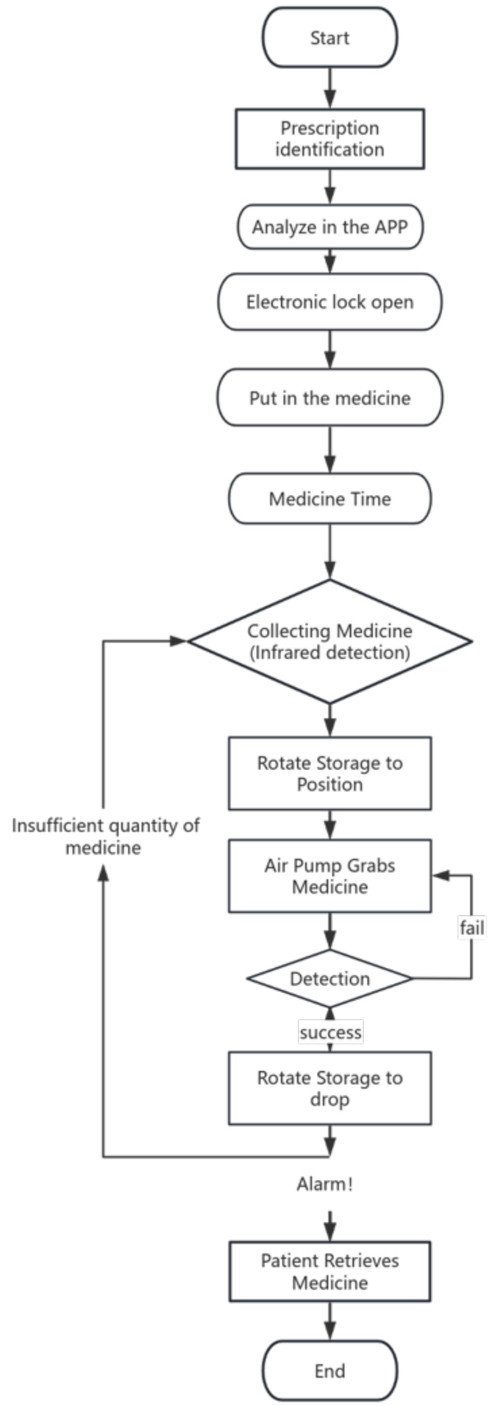


Figure 2: System Workflow

The smart medicine box system begins with the user uploading a prescription. The mobile app identifies the prescription content and analyzes its validity using an AI model. Once the safety of the prescription is confirmed, users can click a button on the app to open the electronic lock on the medicine box. Then, users need to place different types of medicine into the corresponding storage compartments according to the automatically generated list on the app. After that, users should close the door and confirm on the completion of medicine placement on the app. Then, the processed prescription, which contains types, dosage, and administration time of the patient-needed medicines, will be uploaded to the medicine box through bluetooth. At the scheduled administration time, the system will begin to collect pills. The storage tray rotates to a specific degree to align the correct compartment beneath the suction nozzle. The air pump is activated to grab a pill, and a detection sensor verifies whether the pickup is successful. If the attempt fails, the system retries until it is successful. Upon successful pickup, the tray rotates again to position the nozzle above the drop slot, and the pill is released into the collection drawer. The system retries this routine until all the medicines needed to take in that time slot are in the collection drawer. The system triggers an alarm to remind the user. And finally, the patient retrieves the medicine, completing one dispensing cycle.

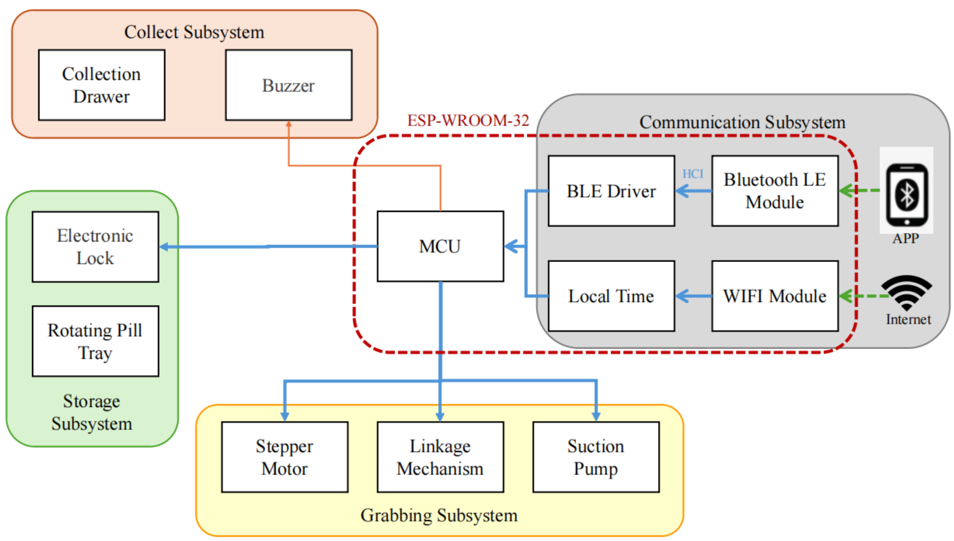


Figure 3: Block Diagram

The smart medicine box integrates four key subsystems, as shown in Figure 3 : the **APP Subsystem**, **Medicine Storage Subsystem**, **Grabbing and Dropping Subsystem**, and **Medicine Collection and Reminder Subsystem**. These subsystems work collaboratively to automate the process from prescription input to pill dispensing. The mobile application plays a central role in the digitization of prescriptions - users can upload a photo of a prescription, which is then analyzed using a multi-modal large model. The system checks for the prescription safety, dosage correctness, and potential interactions before sending the validated data to the hardware unit via Bluetooth. Once received, the smart box record the prescription into its control system memory automatically.

During the development process, we revised our original subsystem definitions to better reflect functional responsibilities and improve system modularity. Initially, our architecture was divided into traditional hardware-based subsystems—such as Power Management, Communication, Mechanism, and Sensor—based on the type of electrical components. However, as the design evolved, we adopted a task-oriented block structure, grouping components into four functional modules: APP subsystem, Medicine Storage subsystem, Grabbing and Testing subsystem, and Medicine Collection and Reminder Subsystem. This new division aligns more closely with the user experience and software-hardware interaction flow, making debugging and testing more efficient.

Additionally, one key component, the pressure transducer used for air pressure-based pill detection, was discarded after empirical testing revealed its unreliable results due to the small air pressure change the picked-up pills caused. Instead, we restructured the Grabbing and Dropping Subsystem to rely entirely on optical detection using infrared sensors, simplifying the subsystem and improving stability.

To meet project requirements, our system must achieve the following:

- Interpret prescription photos with an accuracy rate of at least 80%.
- Maintain synchronization between the rotating storage and air pump grabbing mechanism.
- Ensure dispensing of a single pill per processing cycle, with a success rate of at least 75%.
- Complete dispensing after receiving validated data which shows required medicine is dispensed.
- Issue timely medicine-taken reminders and ensure design security using an electronic lock.

This smart medicine box represents a robust, scalable solution that combines mechanical precision with intelligent software. It supports secure, accurate medication handling while offering users greater autonomy and safety.

2 Design

Figures 4 to 6 illustrate the design evolution of the smart medicine box through three stages of CAD modeling. The first conceptual model (Figure 4) was a rough representation used to communicate the system's basic functionality. At this stage, the tray had no defined bottom geometry, the linkage structure moving with the suction tube was simplistic, and motor placement was not yet considered.
The second version (Figure 5) introduced more defined geometry and preliminary component placement. However, it employed a DC motor to actuate the suction linkage, which, as initial testing showed, delivered insufficient torque and lacked precision—resulting in unstable motion and unreliable pill pickup.
In the updated design (Figure 6), a dual-shaft stepper motor was adopted to enable synchronized and accurate linkage actuation. Structural improvements were also made to the linkage and the suction bracket, reducing mechanical friction and enabling smoother vertical motion. An acrylic protective enclosure was added to enhance system stability, block external interference, and support the placement of a user-accessible pill collection drawer. These refinements improved overall performance, modularity, and robustness.

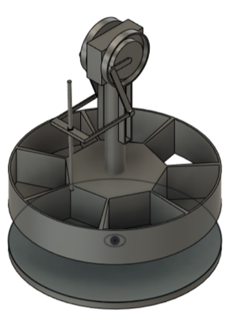


Figure 4: First Conceptual CAD

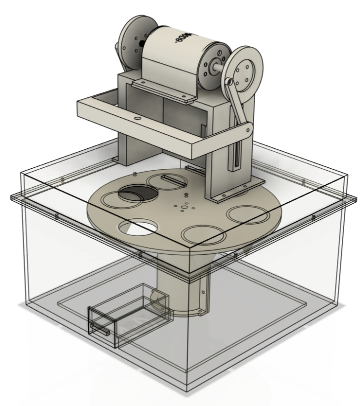


Figure 5: Intermediate CAD Version

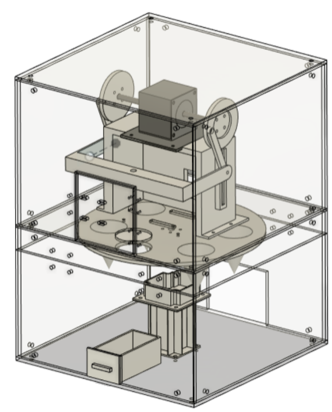


Figure 6: Final Updated CAD Model

In addition to mechanical improvements, the smart medicine box also incorporates electrical circuits for motor and sensor control, a mobile application for user interaction and medication reminders, and sensing-feedback mechanisms for reliable pill delivery. The following sections describe the design rationale and implementation details across mechanical, electrical, and software subsystems. An overview of the assembled prototype is shown in Figure 7, which demonstrates the integration of mechanical structures, sensors, control electronics, and the protective enclosure.

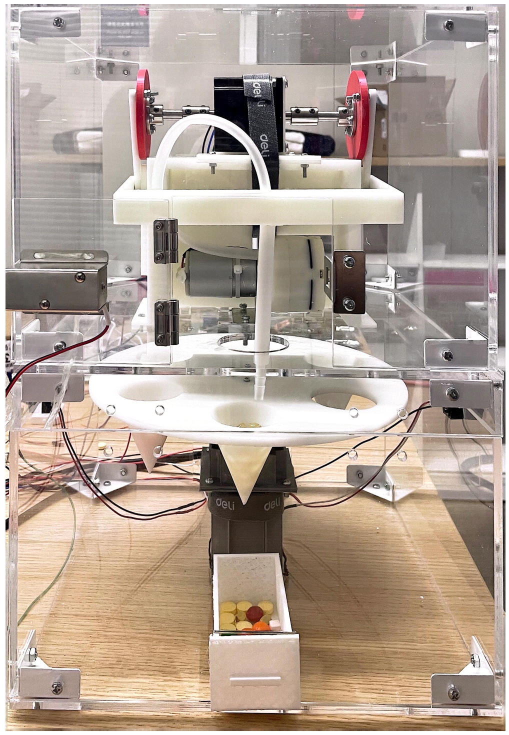


Figure 7: Prototype Overview

2.1 APP Subsystem

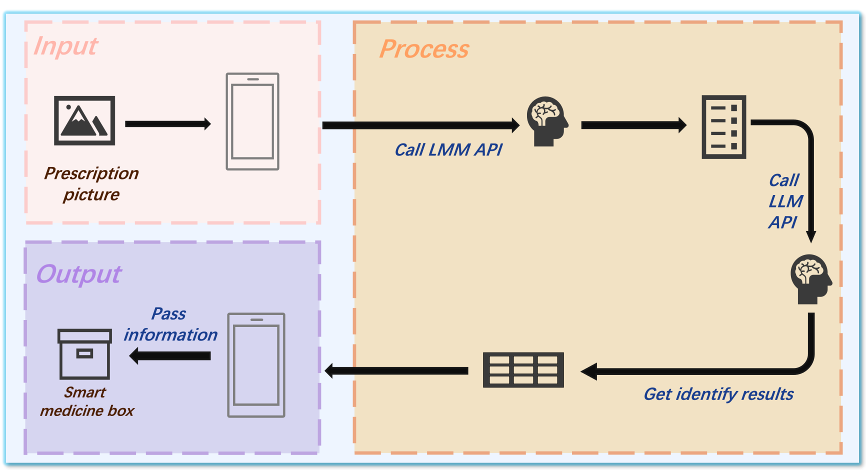


Figure 8: App Subsystem

2.1.1 Design Procedure

The App Subsystem is the module used by the smart medicine box to identify and process prescriptions. The production is mainly accomplished by using the Python language. Specifically, library functions such as kivy, kivymd, and Bluetooth are employed to implement the functions of analysis and transmission. The general subsystem is shown in

8, Users can select the prescription they want to take. After uploading the prescription photo to the app and connecting it to the medicine box, they can send the corresponding information to the medicine box.

2.1.2 Design details

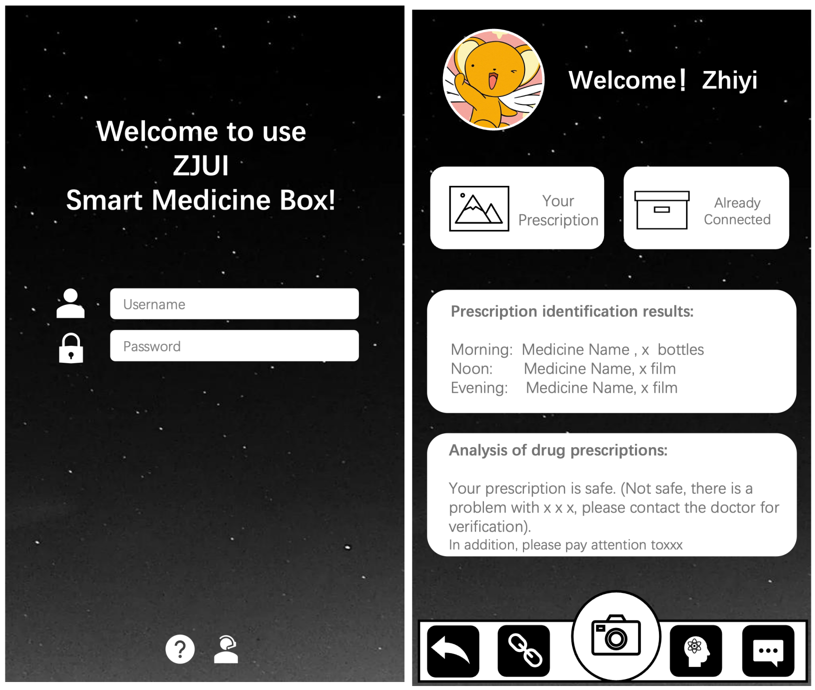
```
screen_helper = """
ScreenManager:
    LoginScreen:
    WorkScreen:

<LoginScreen>:
    name: 'login'

    FloatLayout:
        canvas.before:
            Color:
                rgba: 0,0,0,1
            Rectangle:
                pos:self.pos
                size:self.size
        # Image:
        #     #source: "background.jpeg"  # Changed to welcome.png as background
        #     allow_stretch: True
        #     keep_ratio: False
        #     size_hint: 1, 1
        #     pos_hint: {'center_x': 0.5, 'center_y': 0.5}

        BoxLayout:
            orientation: 'vertical'
            size_hint: 0.8, 0.5
            pos_hint: {'center_x': 0.5, 'center_y': 0.5}
            spacing: '20dp'
            padding: ['20dp', '40dp', '20dp', '20dp']
```

Layout code



Login interface

Work interface

Figure 9: App Layout

Layout The App mainly consists of two pages (shown in figure 9): one is the login interface, and the other is a feature-rich working interface. The construction of the page is mainly composed of components such as Layout and MDLabel. On the login interface, after entering the username and password and clicking "Login", you can be redirected to the working interface to proceed to the next step. The logged-in user information is displayed at the top of the working page, and there are multiple buttons at the bottom. Click the camera button in the middle to select the prescription photo from the device. After clicking the think button, the large model will be called to process the prescription image. After clicking the link button, the user will be asked to connect to the Bluetooth device. After clicking the transfer button, the prescription information will be sent to the smart medicine box after the user finishes dispensing the medicine.

Process The App mainly processes images and extracts data by calling multiple large models. Once the user wants to perform prescription recognition, the function call_api will be called. The figure 10 show call_api code. Internally, the function call_api will first call the "glm-4v-flash" model to extract all the contents in the image, and then call

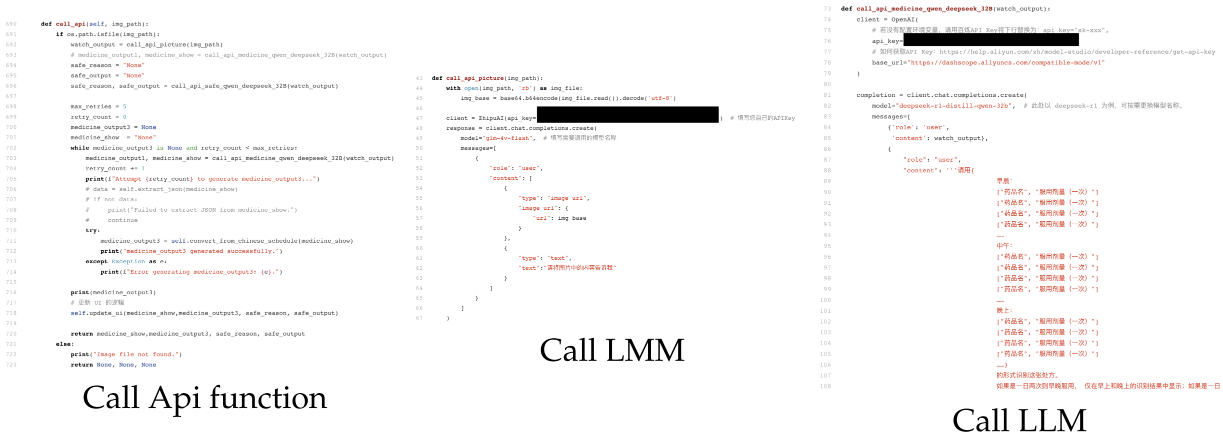


Figure 10: Process perscription

deepseek-r1-distill-qwen-32b twice. Process the prescription into a fixed format, and finally use deepseek-r1-distill-qwen-32b to conduct a security analysis of the extracted content. We found that the glm-4v-flash model performed well in handling the task of image-to-text conversion, but often performed poorly in dealing with logical and text problems. Therefore, the deepseek-r1-distill-qwen-32b model was selected. This model has logical reasoning ability and can well complete the task of extracting text prescriptions.

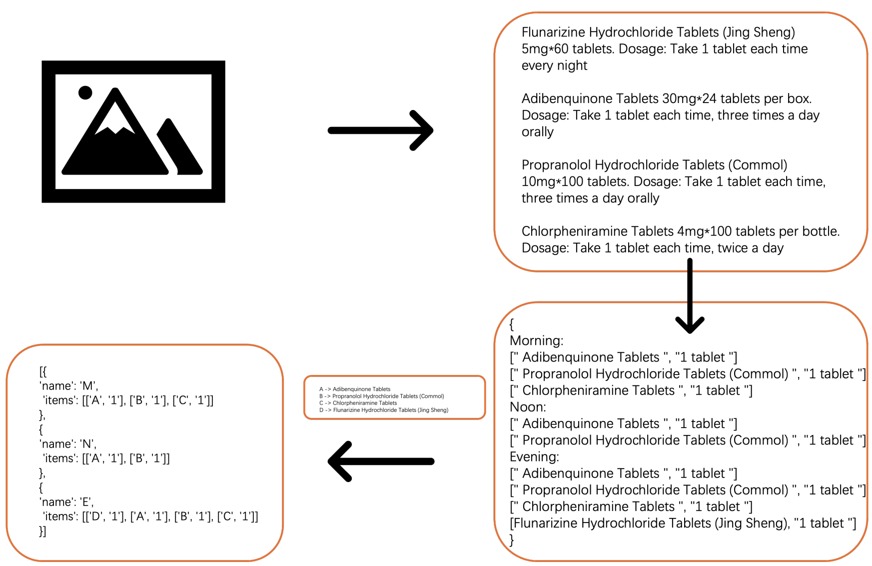


Figure 11: App transmit to smart medicine box

Transmit During the Bluetooth pairing and transmission section, to facilitate the processing of the medicine box, we will match the drug names with their numbers and convert the transmitted content into an array. For example, in figure 11, the output will be an array according to the prescription.

2.2 Medicine Storage Subsystem

2.2.1 Design Procedure

The Medicine Storage Subsystem was designed to ensure accurate pill storage, reliable positioning, and structural protection while maintaining compatibility with the system's electronic and software modules. The design process emphasized fabrication simplicity, mechanical reliability, and modular integration. Key mechanical components—including the rotating pill tray, stepper motor mounting assembly, and acrylic protective enclosure—were developed iteratively to balance functional performance with manufacturability. Key electrical components-the stepper motor and its controller are then determined to match the torque needed by the mechanical system.

2.2.2 Design details

Rotating Pill Tray The pill tray adopts a circular disk with six compartments (five storage slots and one dispensing slot) to facilitate indexed rotation for sequential dispensing. To optimize pill centering and suction efficiency, four different compartment base geometries were prototyped and evaluated: hemispherical (bowl-shaped), pyramidal, conical, and flat-bottomed cylindrical.

As shown in Figure 12, these geometries were fabricated using 3D printing and experimentally tested for suction pickup reliability. Among them, the conical base demonstrated the best overall performance—providing consistent pill centering, minimizing jamming, and significantly improving suction success rate. Therefore, the conical design was selected for final implementation in the tray. Figure 13 shows the CAD rendering of the finalized rotating pill tray, including the overall compartment layout and dimensions.

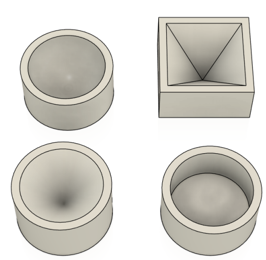


Figure 12: Shape Testing of Pill Tray Compartments

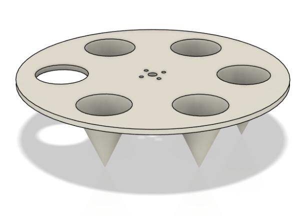


Figure 13: CAD of the Rotating Pill Tray

Stepper Motor Mounting and Flange Coupling To drive the tray rotation, a stepper motor mounting assembly was designed, consisting of a reinforced support frame and upper housing for motor fixation. The motor mount ensures rigid alignment with the pill tray's axis of rotation, with vertical ribs enhancing structural stability.

The tray connects to the stepper motor shaft through a flange coupling. Specifically,

the tray is fastened to the flange using four countersunk screws. The flange itself is secured onto the motor shaft with set screws, providing accurate torque transmission and maintaining concentric alignment. This coupling design minimizes rotational backlash, thereby improving dispensing precision.
Figure 14 shows the CAD rendering of the stepper motor mounting assembly, showing support structure and interface with tray.

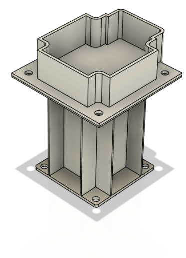


Figure 14: CAD of Stepper Motor Mounting Assembly

Figure 15 and Figure 16 are the real photos of the tray-flange connection highlighting the four-screw mounting, and the assembled tray-flange-motor system displaying overall integration, respectively.

Figure 15: Connection Between Tray and Flange

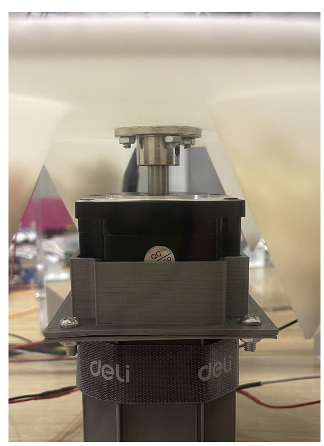


Figure 16: Flange Coupling to Stepper Motor Shaft

Stepper Motor and its controller To drive the pill tray to rotate freely, we decide to use the stepper motor because it can realize 360 degrees rotation and 360 degrees angle control. We fill the pill tray with pills and then weigh the whole mechanism to get the maximum operating weight. Then we use this value and other mechanism parameters to calculate the holding torque we need to rotate the pill tray. After that, we decide to use the 57-41 stepper motor which has a holding torque of 0.64Nm and working current 2.4A. The TB6600 stepper motor controller then is chosen cause it can provide a current of 0.5A-4.0A to the stepper motor.

Acrylic Protective Enclosure with Hinged Cover The enclosure is constructed from laser-cut acrylic panels, forming a rectangular housing to protect internal mechanisms from dust and physical interference. Panels are joined using angle brackets at the corners where three panels meet. This configuration enhances the mechanical rigidity of the enclosure while simplifying fabrication and assembly.

A rectangular slot opening is reserved on the front panel of the enclosure to accommodate a removable pill collection drawer. This opening allows the drawer to slide in and out smoothly, providing a designated area for collecting dispensed pills while maintaining the enclosure's protective function. The slot's dimensions are designed to ensure alignment with the pill dropping outlet above.

In the updated design, an upper acrylic cover is added to complete the enclosure, forming a fully enclosed box structure. The cover is connected to the main housing via metal hinges, allowing it to open upward like a lid. This hinged cover design provides easy access for pill refilling, motor maintenance, and internal inspection, while maintaining protection during regular operation.

M4 screws and hex nuts are used to fasten the panels to the brackets via pre-drilled holes. This method allows for easy disassembly and maintenance, avoiding the need for adhesive bonding or complex fixtures. Figure 17 shows the CAD model of the acrylic protective enclosure, highlighting panel layout, mounting holes, hinge connection points, and access openings.

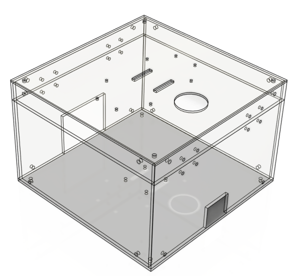


Figure 17: CAD model of the lower acrylic protective enclosure

Figure 18 and Figure 19 illustrate the fastening mechanisms used at different parts of the enclosure: metal brackets for structural frame joints and hinges for lid mobility.

Figure 18: Angle Bracket Fixing between Acrylic Panels

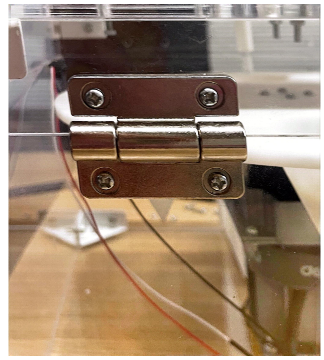


Figure 19: Hinge Connection between Lid and Enclosure

2.3 Medicine Grabbing and Dropping Subsystem

2.3.1 Design Procedure

The Medicine Grabbing and Dropping Subsystem was designed to accurately pickup and put down individual pills from the storage tray to the collection drawer. The mechanism utilizes a suction-based grabbing method, driven by an air pump, combined with a linkage-actuated vertical motion system.
Initially, mechanical grippers and vibration-assisted feeders were considered, but were rejected due to complexity, potential pill damage, and space constraints. A suction nozzle driven by an air pump was ultimately chosen for its compactness, high accuracy, and simplicity.
To actuate the nozzle's vertical motion, a linkage-crank mechanism was developed, driven by a dual-shaft stepper motor. This solution offers precise control over movement while minimizing mechanical complexity. The motor selection process initially considered DC motors, but due to its unstable speed and unreliable open loop control mechanism the design was upgraded to a stepper motor for improved performance. The 57-51 type of the stepper motor is then chosen based on some calculation for the torque needed to rotate the whole mechanism as well as its controller TB6600 which can provide a sufficient current of 3.5A to the step motor.
Throughout development, iterative improvements were made to enhance mechanical reliability, ensure smooth motion, and guarantee accurate pill grabbing and dropping. Feedback control using optical sensors was integrated to verify pill pickup success before initiating the dropping sequence.

2.3.2 Design details

Overall Structure Overview The overall structure of the Medicine Grabbing and Dropping Subsystem is shown in Figure 20. The system consists of a dual-shaft stepper motor, rotating crank disks, linkages with sliding guides, a suction hose bracket, and an air pump mounted below the motor support. This mechanism achieves precise vertical motion for pill grabbing, reliable pill release, and seamless integration with the storage module's collection drawer.

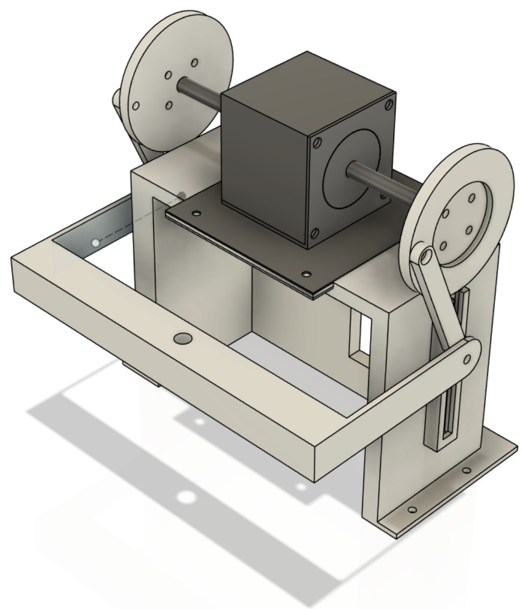


Figure 20: Overall CAD of Medicine Grabbing and Dropping Subsystem

Dual-Shaft Motor and Flange-Driven Rotation At the core of the mechanism is a dual-shaft stepper motor, mounted securely on top of the support structure. The motor is fastened to the frame through dedicated mounting holes, ensuring rigid installation and minimizing vibration during operation.

Each shaft end of the motor is connected to a rotating disk (crank wheel) via a flange coupling. The flanges are fixed to the motor shaft using set screws and are bolted to the crank disks through multiple screw holes. This rigid connection guarantees precise torque transmission, maintaining synchronized bilateral rotation without backlash, which is critical for the smooth vertical actuation of the linkages.

Figure 21 shows the mounting of the stepper motor on the support structure, as well as the flange coupling connection between the motor shaft and the crank disks.

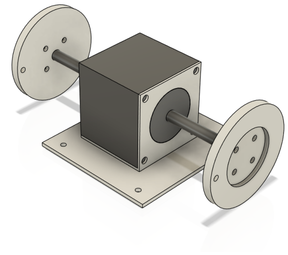


Figure 21: Stepper Motor Mounting and Flange Coupling to Crank Disks

Linkage-Driven Vertical Actuation The rotating disks are connected to a pair of linkages, which convert rotational motion into vertical reciprocating movement. The details could be found in Appendix C. The tail ends of these linkages feature cylindrical protrusions that slide within vertical guide slots on the sides of the motor support housing. This configuration constrains the motion path, ensuring smooth and controlled vertical actuation.

Linkage-to-Bracket Connection with Dowel Pin Initially, the linkages were connected to the suction hose support bracket using self-tapping screws. However, this method resulted in instability and wear during repetitive operation. To address this, the design was revised to use cylindrical dowel pins, inserted through precisely machined holes in both the linkage tails and the bracket. This connection ensures smooth rotation of the bracket with minimal play, significantly enhancing mechanical stability. Figure 22 illustrates the CAD model of the linkage-to-bracket dowel pin connection.

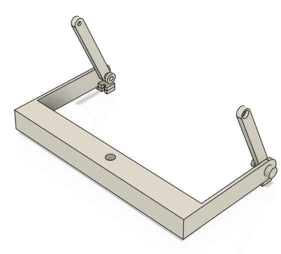


Figure 22: CAD of the Linkage-to-Bracket Dowel Pin Connection

H-Shaped Support Reinforcement To maintain horizontal alignment of the suction hose support bracket during vertical motion, an H-shaped reinforcement structure was added beneath the bracket. One end of the H-shaped support connects to the bracket, while the other slides within the guide slots. This reinforcement prevents tilting or angular deviation, ensuring the suction nozzle remains correctly oriented throughout its movement. Figure 23 shows the real-world implementation of the H-shaped support structure, demonstrating its effectiveness in maintaining bracket horizontality.

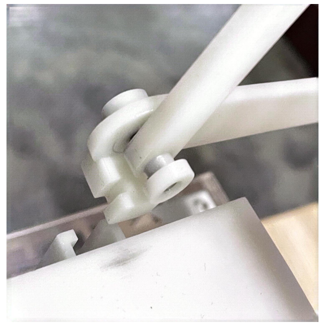


Figure 23: H-shaped Support Structure

Air Pump Suction Mechanism An air pump is mounted beneath the motor support frame, making efficient use of the hollow space. The pump generates negative pressure through a flexible hose connected to the nozzle bracket. When the nozzle reaches its lowest position above the designated pill compartment, suction is applied to grab a pill from the tray. Figure 24 shows the air pump mounting and hose connection interface.

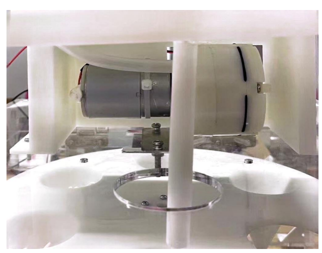


Figure 24: Air Pump

Fiber-Optic Sensor Feedback Control A fiber-optic sensor is positioned along the nozzle's vertical path. During upward motion, the sensor detects whether a pill has been successfully picked up. If pill presence is confirmed, the system proceeds to the dropping phase. Otherwise, the suction action is repeated until the successful pickup is verified, ensuring accuracy of the dispensing.

Pill Dropping and Collection Drawer Interface Once a pill is successfully picked up, the storage tray rotates to align the suction nozzle above a designated dropping slot—an open cavity without a bottom. The air pump then shuts off, releasing the pill. The pill falls directly into the collection drawer, which is housed in the enclosure slot of the medicine storage subsystem. This design provides a clear, user-accessible retrieval point for the dispensed medication. Figure 25 presents the pill collection drawer and its interface with the enclosure opening.

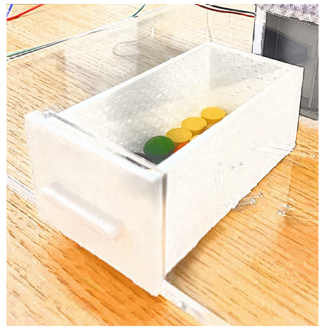


Figure 25: Pill Collection Drawer

Upper Protective Enclosure and Electromagnetic Locking Door To safeguard the motion components and air pump located in the grabbing mechanism, an upper acrylic protective enclosure was added above the rotating disk and linkage system. This enclosure prevents accidental contact with moving parts during operation while maintaining visibility for inspection and maintenance.

A hinged acrylic door was integrated into one side of the enclosure and designed to be controlled via an electromagnetic locking mechanism. The original intention was to use this door as a refill port for adding pills directly into the rotating tray compartments. However, due to the current positioning of the air pump and its suction hose, the available clearance was insufficient to accommodate the neck of a standard pill bottle.

As a result, the door currently serves only as a maintenance access point. For future iterations, repositioning the pump assembly or rerouting the suction hose could restore the intended refill functionality of this access door. Figures 26 and 27 show the CAD design and real-world implementation of the electromagnetic locking door.

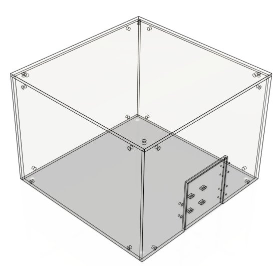


Figure 26: CAD Model of Upper Enclosure and Electromagnetic Locking Door

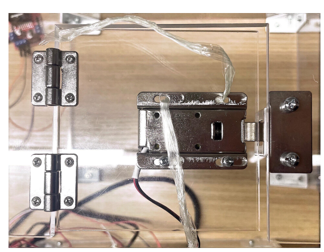


Figure 27: Real Implementation of the Electromagnetic Locking Door

2.4 Medicine Collection and Reminder Subsystem

2.4.1 Design Procedure

The collection and reminder module is responsible for receiving dispensed pills and facilitating user access to medication. In the mechanical subsystem, this function is realized through a small pill drawer integrated into the lower section of the protective acrylic enclosure. The design ensures that pills released by the suction mechanism are reliably delivered to an accessible collection area.

The overall logic is triggered after successful pill pickup is verified by the sensor module. Once a pill is confirmed to be attached to the suction nozzle, the system rotates the storage tray to align the nozzle with a designated open-bottom dispensing slot. At this point, the air pump is shut off, allowing the pill to drop naturally by gravity into the collection drawer.

The reminder function is managed the local controller, ESP32, of the smart medicine box. It will be triggered when the required types and dosage of medicines is successfully placed into the pill collection drawer. And when it is triggered, the speaker module automatically plays a pre-recorded voice. This enables real-time, audible alerts to prompt the user to retrieve their medication. Further implementation details will be described in later sections.

2.4.2 Design details

The pill collection drawer is positioned behind a rectangular slot in the front face of the acrylic enclosure. Its dimensions are sized to fit snugly within the enclosure opening, enabling smooth sliding in and out while preventing unintended displacement. The drawer itself is shallow to reduce pill bouncing and is mechanically decoupled from the suction system for modularity.

This mechanical interface completes the dispensing cycle by physically isolating the released medication from the internal mechanism, making it easy for users to retrieve pills without disrupting internal components. Figure 25 shows the drawer design and its integration with the enclosure.

3 Verification

We summarized the key requirements and whether each was met in the Requirement & Verification Table (see Appendix B).
The **APP block** successfully met all functional requirements, as shown in Figure 11. Prescription images were captured and transmitted via Bluetooth to the ESP32. The AI model was able to correctly interpret medication names and dosages with a classification accuracy exceeding 80%.

For the **Medicine Storage Block**, we verified the functionality of the rotating pill tray and the electronic lock mechanism. The stepper motor accurately rotated the tray to the intended compartment within a 5° error margin across multiple cycles. The electronic lock was tested over 50 trials and demonstrated a **90% success rate** in securely opening and locking upon receiving commands from the controller. These results indicate that the storage system offers both functional accuracy and secure medication access control.

The **Grabbing and Dropping Block** was subjected to extensive testing, particularly in suction performance and pill detection. We tested multiple suction head geometries and found that a **4 mm diameter Silicone nozzle** achieved the highest pickup success rate across various pill sizes and shapes. The result is shown in Figure 28.

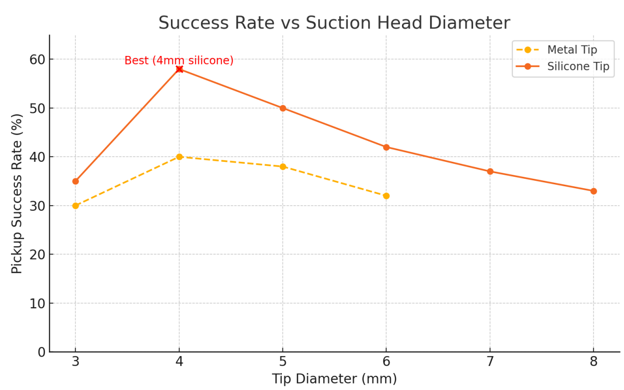


Figure 28: Success Rate Vs. Suction Head

For pills weighing over 0.2 g, the system achieved a **grab success rate of 59%** in 20 trials.

The original design included a pressure sensor to confirm pickup success; however, empirical tests revealed that it failed to detect zero-pressure states during large pill pickups and exhibited negligible variation for small pills. Therefore, the pressure transducer was removed and replaced with an improved **infrared sensor** with a wider field and longer range. This sensor achieved consistently high accuracy but struggled with transparent or very small pills. To address this, we upgraded to a model with a broader detection beam, which improved detection reliability.

The **Medicine Collection and Reminder Block** was verified through drawer retrieval and alert timing tests. Pills dropped into the drawer were accessible without obstruction in all tests. The buzzer reminder system was evaluated across 20 cycles and activated successfully in 20 out of 20 cases, demonstrating full reliability.

4 Costs

Our fixed development costs are estimated to be 100¥/h, 10 hours/week for four people. We consider the approximate cost of our final design this semester (16 weeks), neglecting the central server, mesh network optimization, and partnerships with NGOs:

$$100/h \cdot people \times 10h/week \times 16weeks \times 4people = 64000$$

Our parts and manufacturing prototype costs are estimated to be 929.82 ¥ each, as shown in Appendix A:

Since we will only build one smart medicine box, this yields a total development cost of 64929.82¥.

5 Conclusion

5.1 Summary

This project successfully delivered a functional smart medicine box system integrating mobile prescription management, mechanical pill dispensing, and user alert features. The system comprises four key modules—APP interface, medicine storage, grabbing and dropping, and collection/reminder—which were designed to operate in coordination for a smooth, automated user experience. Throughout the design process, we overcame several practical challenges such as unstable detection methods, inconsistent suction, and mechanical misalignment. Iterative testing and redesign led to substantial performance improvements across all blocks. While some limitations remain—such as detection difficulties with small transparent pills or occasional unlocking errors—the overall system meets its design intent and demonstrates promising real-world applicability.

5.2 Ethics and Safety

Our design adheres to the IEEE Code of Ethics [4] by ensuring safe, responsible, and transparent system behavior. Sensitive medical information processed by the app is transmitted securely and used only for functional execution without long-term storage. We explicitly ensure that the AI prescription analysis tool supports, rather than replaces, human judgment. Additionally, system feedback mechanisms are designed to prevent harm from failed pill pickup or incorrect dispensing, reflecting our commitment to user health and safety.

5.3 Broader Impact

This smart medicine box addresses urgent global needs in elderly healthcare, particularly in supporting medication adherence. Its low-cost, modular architecture promotes affordability and accessibility in both individual households and under-resourced clinical settings. By empowering users with limited mobility or cognitive decline to manage their medication schedules independently, the system enhances quality of life and reduces dependency on external care. Furthermore, its sustainable design—featuring reusable components and reduced waste—aligns with broader environmental goals, making it a socially and globally conscious engineering solution.

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Appendix A Bill of Materials

Item	Quantity	Cost
Rigid Flange Coupling	4	15.31
Right Angle Bracket	20	9.2
Medium Damping Hinge	4	25.16
Brass Reducer Barb Tube	3	5.04
Acrylic Bottom Shell	10	75
3D Printing	8	368
Extra Small Damping Hinge	2	6.79
Screw and Nut Set	1	10.31
Acrylic Top Shell	5	60
Velcro Tape	1	4.01
PP Hose Connector	1	6.5
Rigid Reducer Coupling	2	9.29
Dowel Pin	2	3.12
Suction Cup	1	1.2
Acrylic Adhesive	1	23.84
24V Air Pump	1	44.53
Latch Strip	1	11.42
Single-axis Stepper Motor	1	40
Stepper Motor Controller	1	30
ESP32	1	24.8
Water Drop Sensor	1	29.6
Electromagnetic Lock	1	23.9
Dual-axis Stepper Motor	1	103

Appendix B Requirement and Verification Table

Requirement	Verification
The app can take photos of the prescription.	Given a prescription, the user can take the photo and see the picture on the App Interface.
For the prescription photos that have been taken, the App can realize the function of calling a large model for identification and analysis.	For the prescription photos that have been taken, the user can see the identification and analysis results on the interface.
The app can connect to the esp32 and pass the output of the large model to the esp32 via Bluetooth.	Esp32 When connected to the app, can get the information from the app.

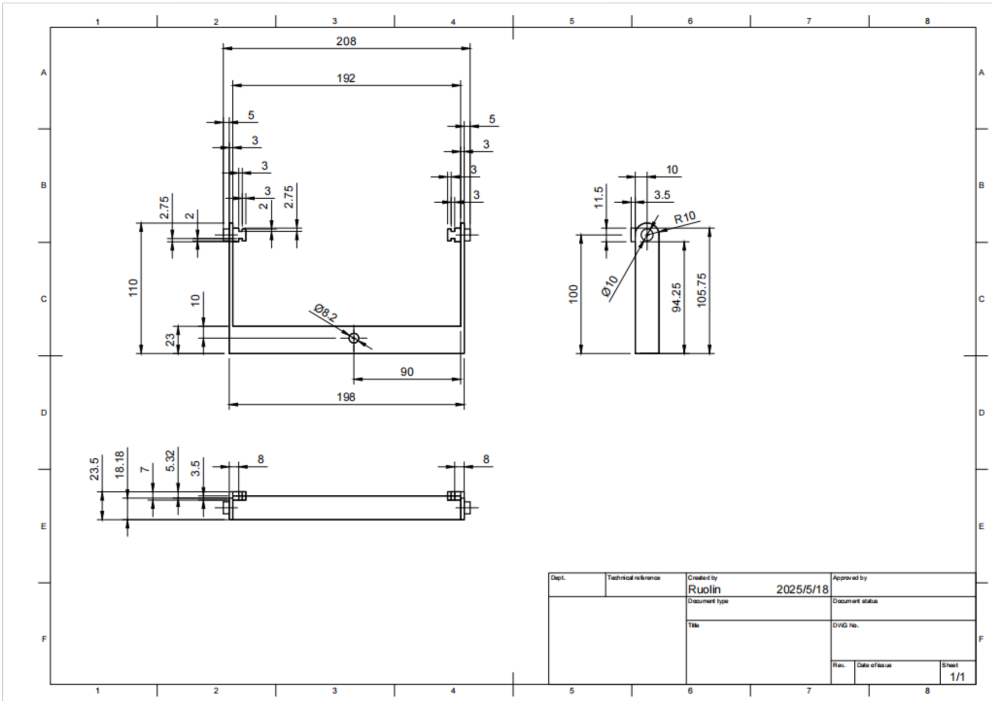
Requirement	Verification
A $3.3\text{V} \pm 0.1\text{V}$ power is provided to the STM32. Noise should be $\leq 50\text{mV}$.	Use the oscilloscope to test the STM32 power voltage from the power management subsystem. The result should be a voltage of $3.3\text{V} \pm 0.1\text{V}$ with noise should be $\leq 50\text{mV}$.
A $12\text{V} \pm 0.5\%$ power is provided to the step model and double-ended motor. The maximum current should be 10A.	Use the oscilloscope to test the step model and double-ended motor power voltage from the power management subsystem. The result should be a voltage of $12\text{V} \pm 0.5\%$ with maximum current 10A.
A $24\text{V} \pm 3\%$ power is provided to the suction engine with a maximum current 8A.	Use the oscilloscope to test suction engine power voltage from the power management subsystem. The result should be a voltage of $24\text{V} \pm 3\%$ with maximum current 8A.

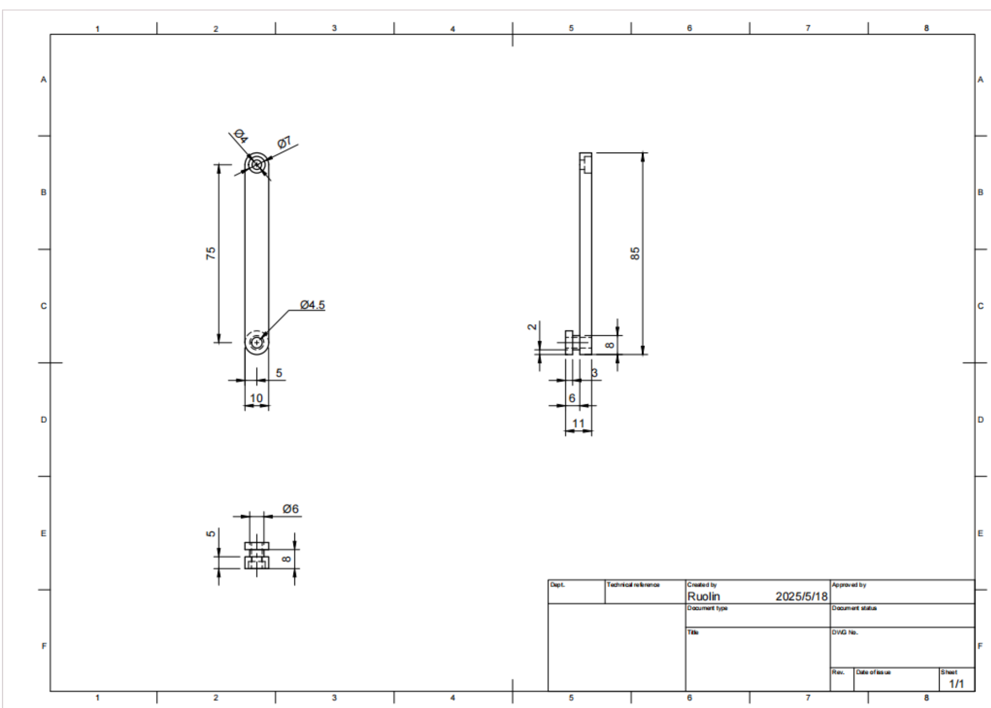
Requirement	Verification
The bluetooth of the STM32 can successfully connect to the APP with a connection time $\leq$ 5s and maximum working distance $\geq$ 10m. Packet loss rate should be $\leq 0.1\%$.	Connect the APP to our smart medicine box and measure the connection time. Repeat for some times and the average time should be $\leq$ 5s. Send 100 instructions to medicine box within a distance of 10m. Caculate the packet loss rate and it should be $\leq 0.1\%$.
The WIFI module should have the ability to connect to the WIFI signal when the RSSI ≥ -70dBm.	Try to connect the STM32 to WIFI signal with -90dBm $\leq$ RSSI $\leq$ -60dBm and test its success rate.
The STM32 should get a time $\leq$ $\pm$1sec within the local time so that we can remind users to take pills at accurate time.	Connect the STM32 to the WIFI and then calibrate the module time by NTP. Measure the difference between the module time and standard local time. The difference should be within $\pm$1sec.

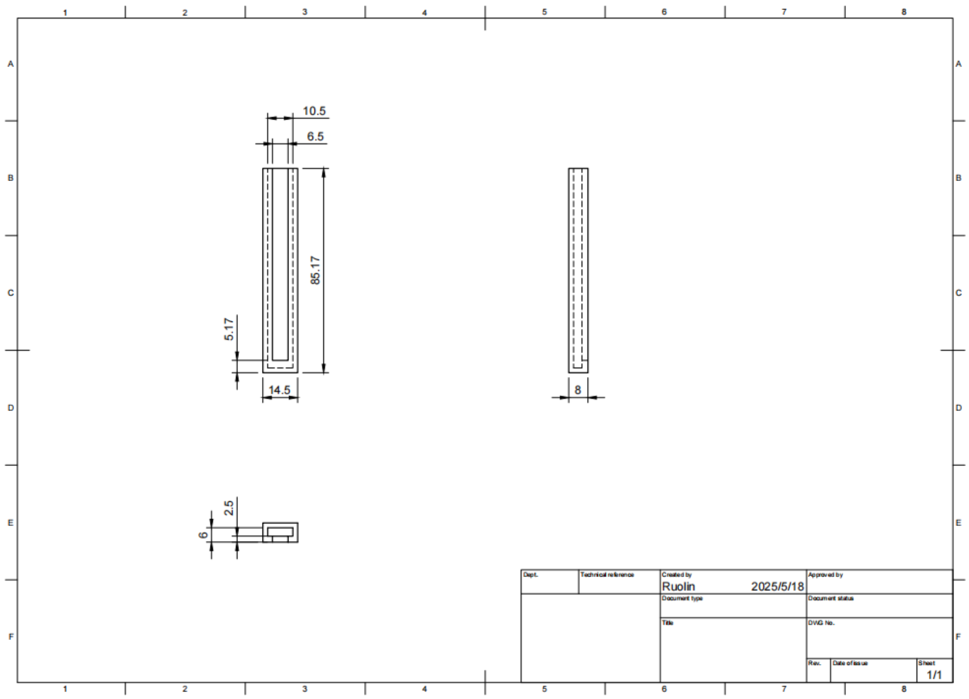
Requirement	Verification
By editing the parameters in the STM32, the pressure transducer should successfully report the suction action at an accuracy greater than 80%	Open the suction pump and connect the pressure transducer to the air-out. Connect the output of the pressure transducer to the STM32, and then the output of STM32 to a LED test circuit. Try to suck one pill onto the straw. The LED should be light on with a probability of 80% .
After programs compiling, the Infrared sensor should have the ability to report the tablet drop at a accuracy greater than 80%	After installation, try to drop pills into the collection compartment at the same height as the straw does. Connect STM32 processed version of the sensor output to the oscillator, then observe and count its success rate.

Requirement	Verification
Rotate the storage in specific angle.	Use STM32 to specify a rotation Angle between 0 and 360, the system can be rotated to and error in 5 degrees.
The suction mechanism must successfully grab pills weighing ≥ 0.2g with a success rate of at least 60% across 20 trials.	Conduct 20 consecutive trials using pills (≥ 0.2g each). Log the number of successful grabs. A successful grab means the pill is fully lifted and transferred to the output compartment. Success rate = (successful trials ÷ total trials) × 100%.
The system must be able to dispense exactly one pill per activation cycle, with an accuracy of at least 60%.	Trigger 20 grab cycles, each intended to dispense a single pill. Use an optical or weight sensor to count the number of pills actually dispensed each time. The system should dispense exactly one pill in at least 12 out of 20 trials. Record results in a table.

Appendix C Design Drawings



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8
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Technical reference
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