ECE 445/ME 470

SENIOR DESIGN LABORATORY

PROPOSAL

Smart Medicine Box

Team #6

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March 17, 2025

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1 Introduction

1.1 Background

1.1.1 Problem Statement

Global population aging poses significant challenges to healthcare systems, particularly with respect to medication management among elderly populations. According to the World Health Organization, the global population of individuals 60 years of age or older is projected to reach nearly 2 billion by 2050 [1]. Currently, data from the National Center for Health Statistics indicate that approximately 69% of US adults aged 40-79 regularly use at least one prescription drug, with 22 4% engaged in polypharmacy, defined as the use of five or more medications simultaneously [2]. Polypharmacy, driven by multiple chronic conditions, amplifies safety risks such as medication mismanagement, incorrect dosages, and timing errors, leading to adverse drug reactions, increased hospitalizations, and elevated morbidity rates. [2]. Therefore, it is urgent to develop an intelligent and reliable smart medical box capable of automatic and precise medication dispensing, real-time inventory monitoring, and consistent medication reminders to effectively address these health risks.

1.1.2 Current Research and Limitations

Although current smart pillbox technologies offer certain functionalities to address medication adherence, significant limitations remain. For example, existing devices that use voice alerts and visual displays are highly dependent on user manual pill selection, potentially causing confusion and dispensing errors, especially in cognitively impaired or elderly individuals [3]. More advanced designs feature automated pill dispensing with biometric verification to improve accuracy; however, these systems still face dispensing precision issues, such as misalignment and incorrect pill sizes leading to incorrect dosages [4]. Furthermore, many current dispensing systems have limited medication storage capacities, which require frequent manual refilling, increasing the risk of human error.
Therefore, there is a significant need for a comprehensive and fully automated solution capable of accurately dispensing diverse medications, autonomously monitoring inventory, and providing consistent and reliable medication reminders to improve medication adherence and patient safety among elderly populations.

1.2 Objectives

1.2.1 Goals

The primary goal of our smart medicine box design is to effectively resolve the prevalent issues related to medication non-adherence, particularly among elderly populations. It addresses challenges such as missed doses, incorrect medication, dosage inaccuracies, and timing errors, which often result in adverse health outcomes. Our solution aims to improve medication adherence, enhance safety, and promote independence among elderly users.

1.2.2 Functions

The proposed smart medicine box performs the following core functions:

- **Automatic Pill Dispensing:** Employs a linkage mechanism driven by an air pump to autonomously pick and accurately dispense medicines into a collection compartment.
- **Rotating Storage Device:** Automatically rotates to align the correct compartment for medication retrieval.
- **Mobile App Integration:** Utilizes multimodal AI-based image recognition and analysis to interpret prescriptions, verify safety, and seamlessly transmit verified data to the pillbox for dispensing.
- **Real-time Prescription Analysis:** Ensures the safety and correctness of prescribed medication using AI-driven real-time analysis to enhance patient safety and medication accuracy.

1.2.3 Benefits

This system offers numerous consumer-centric advantages:

- **Improved Medication Adherence:** Reduces missed doses and errors through automation.
- **Enhanced Safety and Accuracy:** Minimizes human error by automatically verifying prescriptions and dosages.
- **Increased Convenience:** Reduces daily medication preparation burdens for patients and caregivers.
- **Promotion of Independence:** Enables elderly patients to independently manage their medications, thus enhancing autonomy and quality of life.

1.2.4 Features

Key marketable features distinguishing our design include:

- **Precise Grabbing Mechanism:** A high-precision linkage and air pump mechanism minimize pill dispensing errors compared to traditional disk dispensers [4].
- **Flexible Medicine Storage:** Accommodates diverse medication sizes and types with six dedicated compartments.
- **Advanced Multimodal Analysis:** Leverages advanced multimodal large models for highly accurate prescription interpretation and safety verification.

- **User-friendly Interface:** Mobile app equipped with intuitive prescription management, ensuring ease of use and patient-centric design.

1.3 High-Level Requirements List

- The smart medicine box must achieve automatic medication dispensing accuracy, maintaining a rotational positioning error within and a grabbing mechanism precision of to prevent incorrect or missed medication doses.
- The integrated mobile app must correctly interpret and verify prescription images with a minimum accuracy rate of 95%, ensuring safe medication practices through advanced multimodal AI model analysis.
- The medicine box must reliably dispense prescribed medications within 30 seconds after receiving validated prescription data from the mobile app, supporting timely adherence to medication schedules.

2 Design

2.1 Physical Diagram

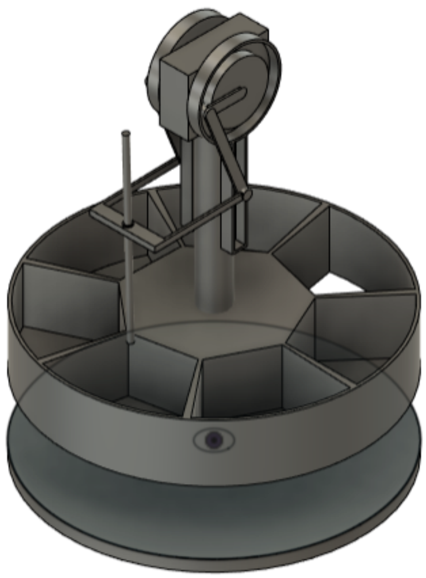

Figure 1: Physical Diagram of Medicine Box

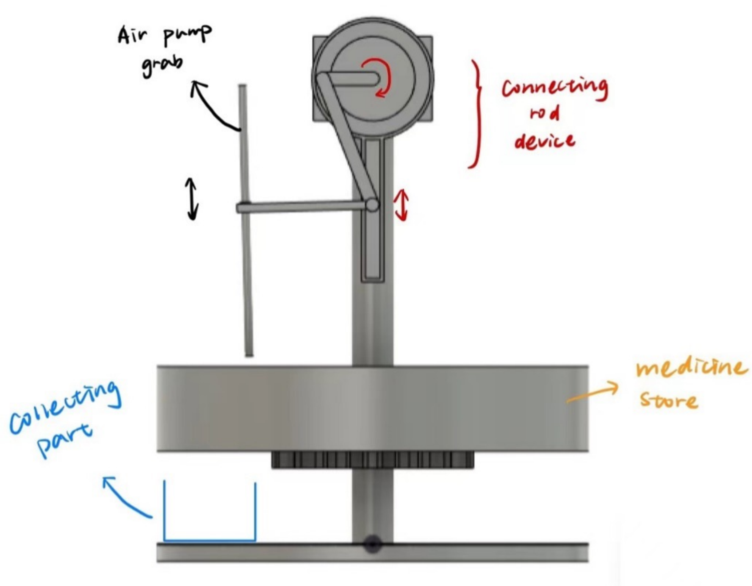

Figure 2: Description of Mechanism

The mechanical design of this smart medicine box includes a linkage mechanism, air pump grabbing mechanism, rotating medicine storage device, and medicine collecting part. The main working principles are as follows:

(a) Medicine Storage

Inside the medicine box, there are six separate storage compartments, with five used for storing different types of medicine and one compartment designed as a passage for dropping medicine into the collecting part.

(b) Medicine Grabbing and Dropping

The linkage mechanism connected to the air pump drives the grabbing device up and down, allowing it to grab the specified medicine and place it into the drop compartment.

(c) Rotating Storage Device

The storage device can rotate automatically to position the correct medicine compartment for the air pump mechanism to grab.

(d) Medicine Collection

Once the medicine drops into the passage compartment, it falls into the collecting part at the bottom, making it easy for the patient to retrieve the medicine.

2.2 Block Diagram

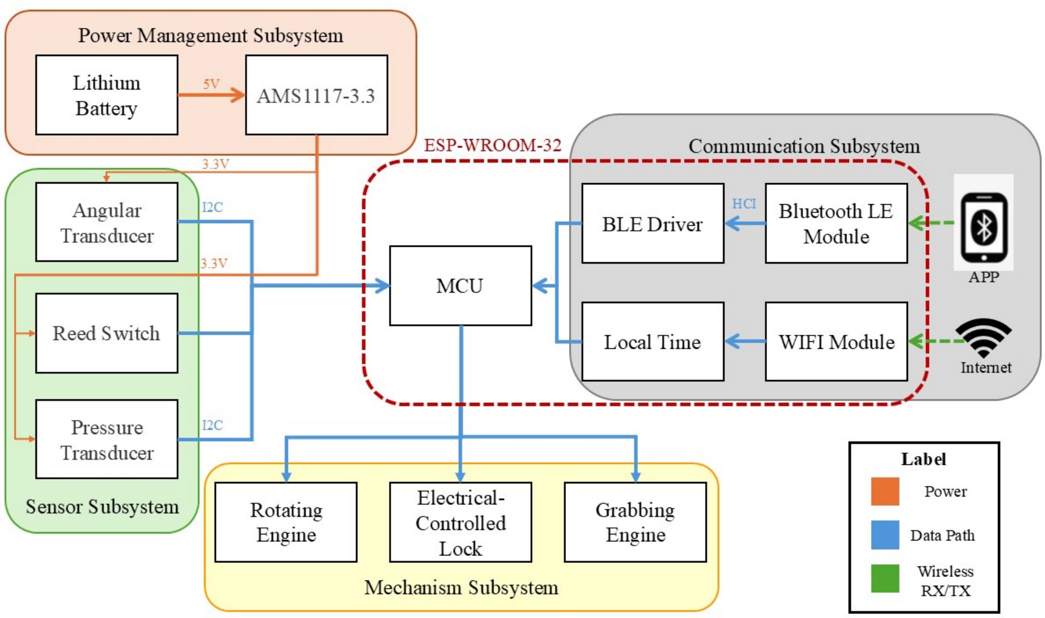

Figure 3: Block Diagram

2.3 System Working Flow Chart

2.3.1 Overall Workflow

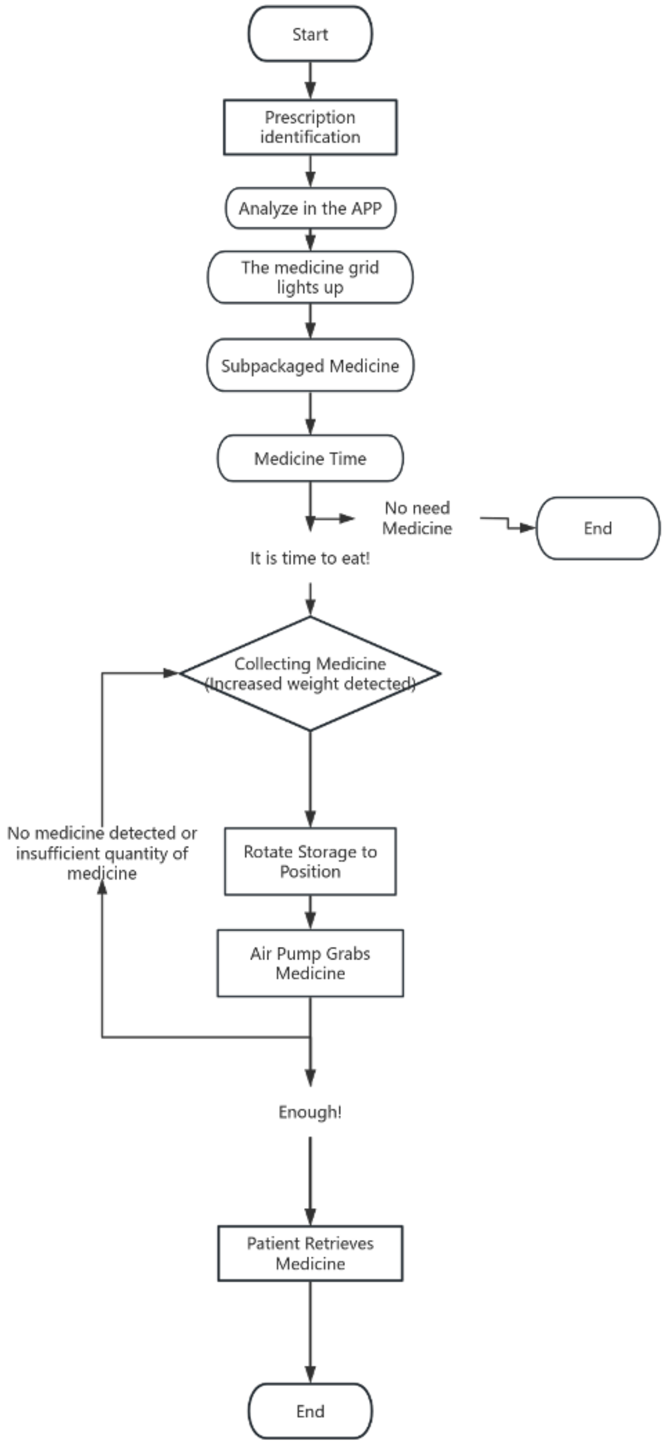

Figure 4: Smart Medicine Box Workflow

2.3.2 App Workflow

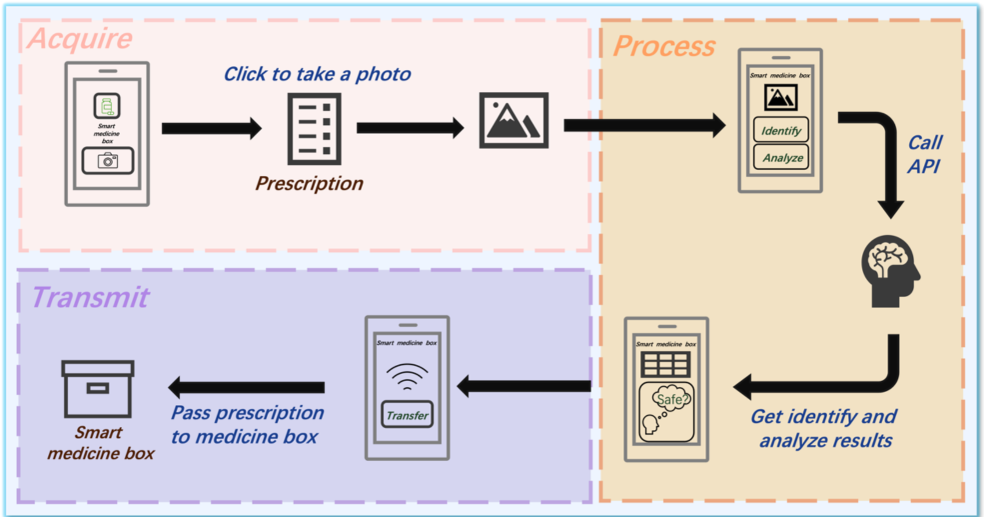

Figure 5: App workflow

2.4 Blocks Description

2.4.1 App Subsystem Description

We will use a mobile app to assist in obtaining prescriptions and transmitting the prescription content to the smart medicine box. The following is an introduction to the process of this app:

This app provides users with a convenient and intelligent prescription management process. First, users only need to click the photo button on the app interface to easily capture pictures of the prescriptions.

Then, the app will use the advanced image recognition technology of the multimodal large model through API to accurately identify the pictures taken and to confirm the types and dosages of the prescription drugs.

After the identification is completed, the app will send the identified prescription drug information again to the large language model for further analysis. This process ensures the accuracy and legality of the prescription, providing users with a safer medication guarantee. During the analysis process, the app will check whether the prescription drugs are safe and make corresponding judgments based on the analysis results. At the same time, the large language model can give patients advice on matters to pay attention to when taking the medicine and health-related suggestions such as diet and exercise based on the prescription.

If the prescription drugs are safe and correct, the app will proceed to the next step, which is to transfer the prescription information to the smart medicine box. The smart medicine box can automatically distribute the corresponding drugs to patients based on the prescription information. After transmitting the prescription information, the medicine box distributes the drugs and ensures that patients can take the required drugs on time and

in the correct amount.
In summary, this app combines technologies such as photo recognition, API invocation of the multimodal large model, and Bluetooth transmission to provide users with a comprehensive and intelligent prescription management process. It not only improves the accuracy and safety of medication but also brings users a more convenient and efficient medication experience.

2.4.2 Power Management Subsystem

- **Description**
  The Power Management Subsystem provides regulated power to all components. It uses a lithium battery as the primary source, which is stepped down to 5V and further regulated to 3.3V via the AMS1117-3.3 LDO. This subsystem connects to every other subsystem (e.g., Communication, Sensor, Mechanism) by supplying stable voltage rails.
- **Components**
  - **Lithium Battery**
    - **Function**: Primary power source (3.7V nominal, 2.5V–4.2V range).
    - **Requirements**:
      - Must deliver $\geq$ 2A peak current.
      - Requires protection circuit to prevent over-discharge (< 2.5V).
  - **5V Rail**
    - **Function**: Distributes 5V power to high-current components.
    - **Requirements**:
      - Voltage stability: 5V $\pm$ 0.1V under 1A load.
  - **AMS1117-3.3**
    - **Function**: Regulates 5V to 3.3V for low-voltage components.
    - **Requirements**:
      - Output current ≥ 800mA.
      - Thermal derating $< 20\%$ at full load.

2.4.3 Communication Subsystem

- **Description**
  This subsystem handles the data exchange with the App and the Internet. The ESP-WROOM-32 MCU acts as the central hub, interfacing with the Bluetooth LE Module

(via HCI) for BLE communication to the APP and the Wi-Fi Module for internet connectivity. It connects to the MCU in the ESP-WROOM-32.

- **Components**
  - **ESP-WROOM-32 (MCU)**
    - **Function**: Central processing unit for data handling and protocol management.
    - **Requirements**:
      - Must support dual-core operation for real-time task scheduling.
      - GPIO pins must tolerate 5V logic for motor control.
  - **BLE Driver (HCI)**
    - **Function**: Manages Bluetooth Low Energy
    - **Requirements**:
      - RSSI > -80dBm for stable connection.
      - Latency < 50ms for command transmission.
  - **Wi-Fi Module**
    - **Function**: Connects to the internet for data upload (e.g., sensor logs).
    - **Requirements**:
      - IEEE 802.11 b/g/n compliance.
      - Minimum throughput: 1Mbps.

2.4.4 Sensor Subsystem

- **Description**
  This subsystem collects mechanical status data via Pressure Transducer, Angular Transducer (both I2C), and Reed Switch (digital input), which is important for MCU to control the Mechanism subsystem and make sure it work as our wanted. The Data collected by this subsystem is sent to the ESP32 via I2C or GPIOs.
- **Components**
  - **Pressure Transducer**
    - **Function**: Measures environmental pressure (0–100kPa).
    - **Requirements**:
      - Accuracy $\pm 0.5\%$ FS.
      - Operating voltage: 3.3V $\pm\ 5\%$.

- **Angular Transducer**
  - **Function**: Tracks rotational angle (e.g., motor shaft position).
  - **Requirements**:
    - 12-bit resolution (0.087° per LSB).
    - Sampling rate ≥ 100Hz.
- **Reed Switch**
  - **Function**: Detects door/closure state via magnetic contact.
  - **Requirements**:
    - Debounce time < 10ms.
    - Contact resistance $< 100\text{m}\Omega$.

2.4.5 Mechanism Subsystem

- **Overview**
  This subsystem executes physical actions of the medicine box through a Rotating Engine (motor), a Electrical-Controlled Lock, and a Grabbing Engine. It receives control signals from the ESP32 (via GPIO/PWM) and is powered by the 5V rail. Feedback from sensors (e.g., angular position) ensures precise operation.
- **Components**
  - **Rotating Engine (Motor)**
    - **Function**: Drives mechanical motion (e.g., robotic arm rotation).
    - **Requirements**:
      - Stall current ≤ 1.2A at 5V.
      - Back-EMF protection required.
  - **Electrical-Controlled Lock**
    - **Function**: Secures mechanism in position (e.g., door lock).
    - **Requirements**:
      - Engage/disengage time < 200ms.
      - Hold current ≤ 500mA.
  - **Grabbing Engine**
    - **Function**: Performs object grasping/releasing actions.
    - **Requirements**:
      - Force feedback accuracy $\pm 5\%$.

· Operating voltage: $5\text{V} \pm 0.2\text{V}$.

2.5 Risk Analysis

2.5.1 App Making

When confronted with the task of making an app to do prescription recognition and analysis, we are faced with two core challenges. The following is a detailed elaboration and supplementation of these difficulties:
Risk One: Select an appropriate multimodal large model to accurately perform prescription recognition and analysis.
Prescription recognition and analysis is a complex and meticulous process, which requires the selected multimodal large model to not only possess strong image recognition capabilities (to parse the text, symbols, and graphic information on the prescription) but also have natural language processing (NLP) technology to understand and analyze the semantic content of the prescription. Currently, there are numerous models on the market, each excelling in different fields and application scenarios. How to select a multimodal model that can not only efficiently handle image data but also deeply understand textual information has become an urgent problem to be solved. Additionally, the model's accuracy, generalization ability, and processing speed are also key factors in evaluating its applicability.
Risk Two: Building an efficient and precise prompt to guide the model to output the expected recognition and analysis results and format.
When using multimodal large models for prescription analysis, how to construct a prompt word to do analysis and ensure the output meets specific requirements is another major challenge. This requires the prompt not only to accurately reflect the core tasks of prescription recognition, such as identifying drug names, dosages, and usage methods but also to consider the format requirements of the output to ensure that the results can be directly applied to the processing of medicine boxes.

2.5.2 System Construction

Identified Risk: Thermal Management of AMS1117-3.3 LDO
The AMS1117-3.3 linear regulator is critical for providing stable 3.3V power to the MCU, sensors, and wireless modules. However, its thermal performance poses a significant risk due to high power dissipation under load.

Risk Justification

- **High Power Dissipation**:

$$
\begin{aligned}
P_{\text{dissipated}} &= (V_{\text{in}} - V_{\text{out}}) \times I_{\text{load}} \\
&= (5V - 3.3V) \times 0.8A \\
&= 1.36W
\end{aligned}
$$

- **Thermal Analysis**:

$$\begin{aligned}\Delta T &= P_{\text{dissipated}} \times R_{\theta(\text{JA})} \\ &= 1.36W \times 90/W \\ &= 122.4\end{aligned}$$

Junction temperature at 25 ambient:

$$T_j = 25 + 122.4 = 147.4 \text{ (Exceeds 125 limit)}$$

Acceptable Tolerances

Table 1: Tolerance Requirements

Parameter	Value
Maximum junction temperature	125
Maximum allowable power dissipation	1.11W
Maximum safe load current	0.65A

Mitigation Strategies

1. **Switch to Buck Converter**:

$$P_{\text{dissipated}} = P_{\text{in}} \times (1 - \eta) = (5V \times 0.8A) \times 0.1 = 0.4W$$

2. **Add Heatsink**:

$$\begin{aligned}R_{\theta(\text{total})} &= R_{\theta(\text{JA})} + R_{\theta(\text{heatsink})} \\ &= 90/W + 20/W \\ &= 110/W\end{aligned}$$

3. **Load Current Reduction**:

$$I_{\text{max}} = \frac{P_{\text{max}}}{V_{\text{in}} - V_{\text{out}}} = \frac{1.11W}{1.7V} = 0.65A$$

Conclusion
To meet high-level requirements:

- Replace LDO with switching regulator (e.g., MP1584)
- If retaining LDO:
  - Limit load current to 0.65A
  - Add heatsink with $R_\theta \leq 20/W$

2.5.3 Smart Box Construction

The interface between the air pump grabbing mechanism and the rotating medicine storage system poses the greatest difficulty in implementation due to the following reasons:

- **High Precision Requirements:** The air pump must accurately grab the correct medicine, or it may result in incorrect dispensing.
- **Synchronization of Rotation and Grabbing:** The rotation of the storage system must be precisely aligned with the air pump's grabbing motion to prevent misalignment.
- **Compatibility with Different Medicine Sizes:** The air pump needs to accommodate variations in medicine size and shape to ensure successful gripping.

To ensure functionality, the following tolerances should be maintained:

- **Rotation Positioning Error:** $\pm 1^\circ$ (Ensuring that the medicine compartment aligns with the grabbing position).
- **Air Pump Grabbing Position Error:** ± 0.5 mm (To ensure stable gripping of the medicine).
- **Air Pump Force Control:** The suction power should be adjustable based on the weight and fragility of the medicine to prevent damage or failed grabs.

3 Ethic and Safety

3.1 Ethics

The smart medicine box handles sensitive medical information and directly impacts patient health, so ethical considerations are crucial.

- **Privacy and Data Security**: The system must ensure that prescription data is securely stored and transmitted to prevent unauthorized access. Encryption and strict access control should be implemented.
- **Accuracy and Reliability**: Prescription recognition and medication dispensing must be highly accurate to avoid errors that could lead to incorrect dosages or missed medications. A manual verification step can be integrated to enhance safety.
- **User Trust and Transparency**: Patients and caregivers must be fully informed about how the system works and its limitations. Clear instructions and feedback mechanisms should be provided to users.

Since this project does not involve direct human or animal testing, IRB or IACUC approval is not required. However, ethical best practices must still be followed in handling prescription data and ensuring patient safety.

3.2 Safety

The smart medicine box includes several mechanical and electrical components, requiring safety measures in both design and operation.

- **Electrical Safety**: All wiring and power connections must be insulated properly to prevent short circuits and electrical hazards. The system should be designed to shut down safely in case of power failure.
- **Mechanical Safety**: The rotating storage and air pump mechanisms should be designed with proper tolerances to prevent jamming or accidental medication spillage. Safety guards may be added where necessary.
- **End-User Safety**: The device should be user-friendly to prevent misoperation. If a malfunction occurs, the system should provide an alert rather than dispensing incorrect medication.
- **Compliance with Safety Standards**: The design should follow medical device safety guidelines to ensure reliability and minimize risks.

If hazardous materials or high-voltage components are introduced in future iterations, proper safety training and documentation (such as a Lab Safety Manual) will be required.

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