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Smart Medical Pill Dispenser

ECE 445

Project Proposal

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Introduction

Problem:

According to Census, the growth of the 65+ population is rapidly increasing seeing a 9.4% increase from 2020 to 2023. With people living longer lives, there are a few growing pains; largely medical troubles. With 54% of 65+ year olds taking four or more prescription drugs (KFF) and 50% forgetting to take them on time, or at all, (NIH) we believe the way towards a healthier future for the growing post-retirement population, lies in automated medicine. Not only will this lead to healthier outcomes, but also major cost savings as the average 65+ year old spends around $800 per year (HPI Georgetown University). Currently, there are a few options in the market to automate taking and preparing the concoctions of medications a patient must take per week but they range from largely useless to extremely expensive. Pill organizers play the role of "meal prepping" for medication, however, not only do they become a chore but also depend on the user placing the right medication into the right compartment the right amount of times. Notice the number of "rights" needed for a pill organizer to work and consider the error rate of a pharmacist, a professional, being 1.6% (NIH), it slowly becomes obvious that automated pill dispensers are a necessity. However, this leads to the second leg of the problem, automated pill dispensers like Hero cost $540 per year and only work with 2.4 GHz WiFi. With 10.9% of 65+ year olds living in poverty (Census) and pills needing to be dispensed even during WiFi outages, it becomes clear that a solution that does not require internet and is cost-effective is a necessity.

Solution:

To solve the problem/s listed above we propose a simple solution. A cost-effective ($250) automated pill dispenser that takes in 4 types of pills, needs to be connected to the internet only during calibration and any updates made by the user, and requires a far more cost-effective monthly server charge ($5/month). Our smart medical pill dispenser will take in user's pills from the top in a funnel, one bottle at a time, and place them into their own compartments. After all (max 4 types) pills have been placed into the dispenser the user will navigate through a setup process that will ask them for the time, quantity, and type of pill they must take on any given day. The user will then be alerted via a web app (when connected by Bluetooth) and an LED as to when they must take their pills. Users will also be alerted of refills needed and if they forgot to take their medication. Lastly, the system will have an internal battery along with a charging brick to withstand power outages and will be allowed to update timing based on Bluetooth. The system automatically sorts pills into correct daily doses and dispenses them at the scheduled time, put simply.

Visual Aid:

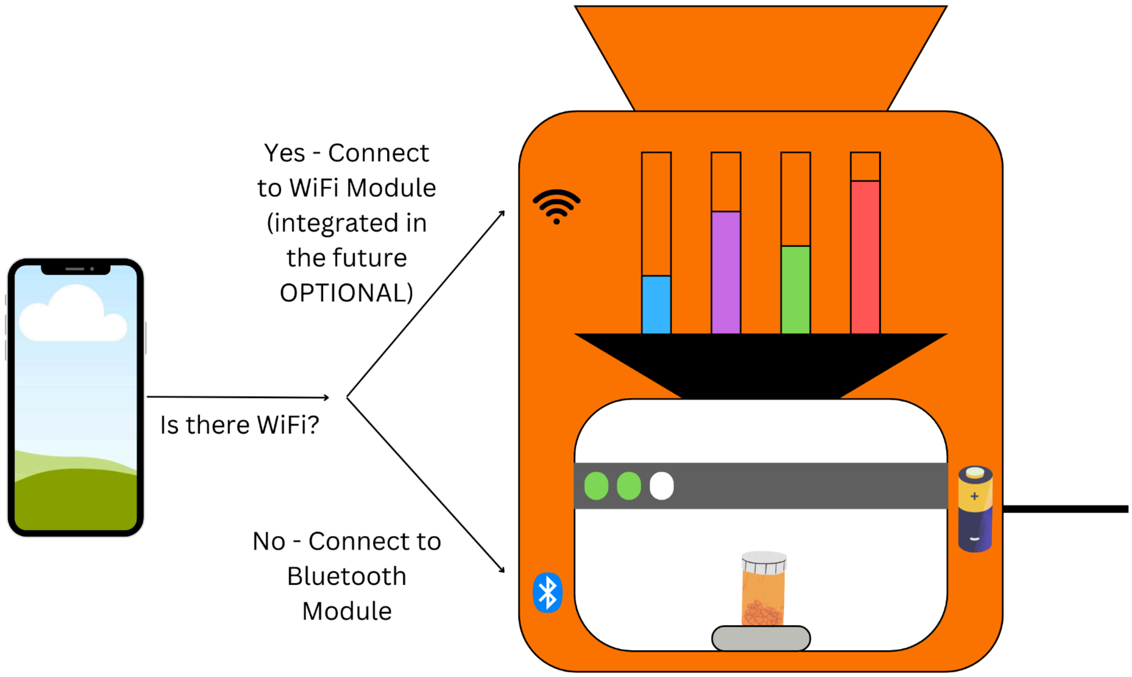

Figure 1: Visual Aid

As shown in Figure 1, the smart medical pill dispenser (SMPD) has a funnel at the top to compartmentalize different pills and a funnel at the bottom to dispense them all at once into the container of choice. Additionally, there is a plug for the tool, however, it is backed up with a battery to ensure proper dispensing even during outages. The phone is the main interface with which the user can customize their SMPD, with the program interface changing depending on whether the user is accessing the device through the internet or Bluetooth. Lastly, there are 3 LEDs on the device, one to indicate refills needed, another to indicate active dispensing, and last to indicate when a user has forgotten to take their pills. The PCB inside the SMPD will determine which pills are supposed to be dispensed based on the user-set configuration.

High-Level Requirements:

Our project will be a success under the following constraints as mentioned in the RFA:

- 98.4% Pill Dispensing Accuracy
- The SMPD alerts the user within 5 seconds of the scheduled times
- Refill alerts are sent out when the compartment is left with ~10% of pills

Design

Block Diagram:

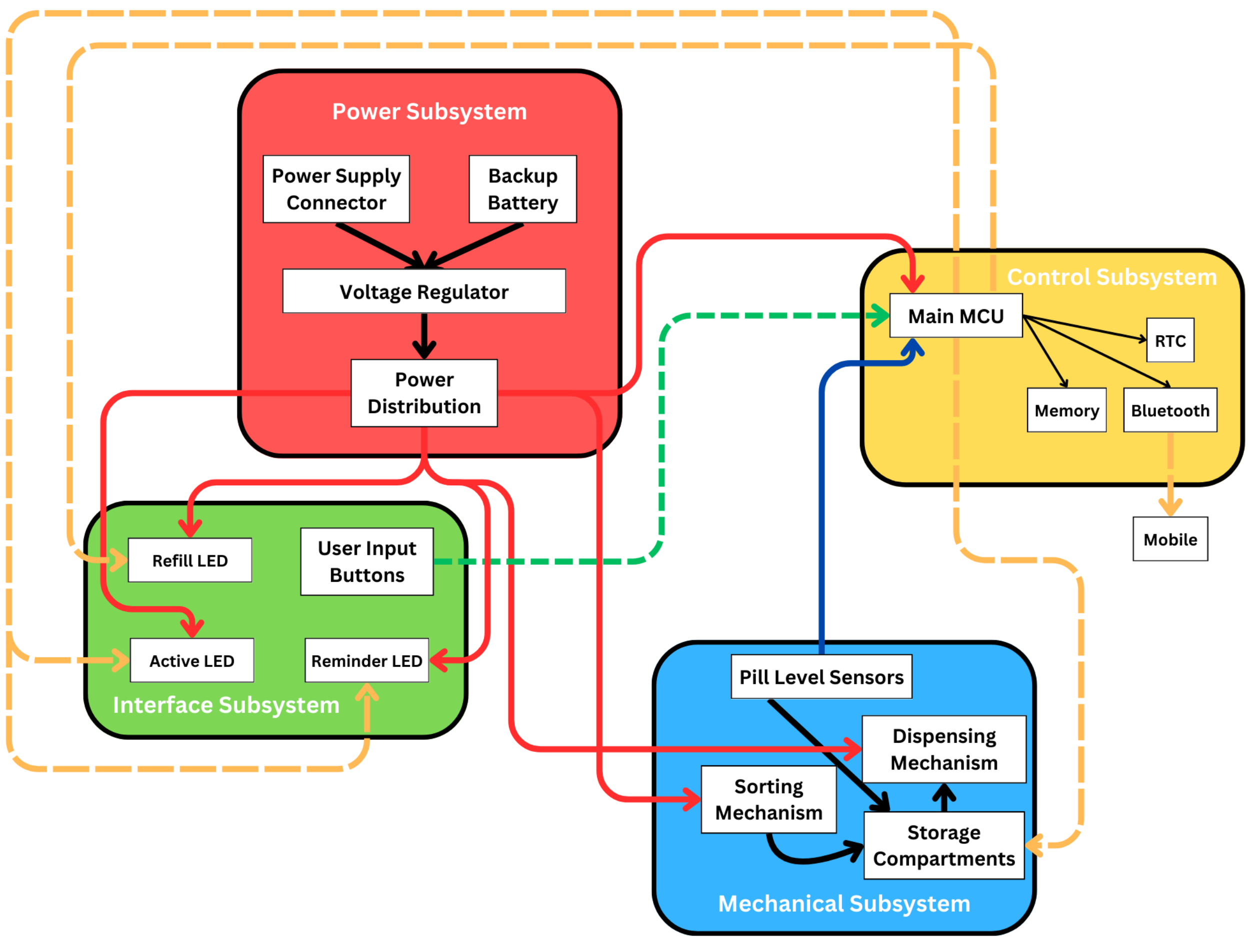

Figure 2: Block Diagram

Subsystem Overview:

Power Subsystem

This system will be using a **7812 voltage regulator** to ensure a stable **12V DC output**. The regulator will step down an input voltage of **14V DC to 12V DC,** possible since a 7812 has a 2V dropout voltage, ensuring consistent power distribution for the microcontroller and all other components. A **rechargeable 12V battery** will serve as a **backup power source**, ensuring at least **24 hours of operation** in case of a power failure. Essentially we are creating a voltage regulator that switches from an electrical outlet to a battery pack when the power goes out. These specifics are subject to change as we create the system, as this would be our first time creating such a circuit.

The **charging circuit** will include:

- **Diode D1 (1N4007)** to prevent reverse voltage flow into the regulator.
- **Resistor R2 (100Ω)** to limit the charging current to the battery.
- **Diode D2 (1N4007)** to avoid battery discharge back into the system.
- **R1 (1kΩ) and an LED** to indicate the power status of the system

Control Subsystem

The **microcontroller (MCU)** will execute **pill dispensing operations** and ensure that the pills are dispensed at the right time. This subsystem will include a **Real-Time Clock (RTC) component** to work with the MCU so that the SMPD dispenses at the right time, with a **maximum drift of ~1 minute per month**. The MCU will also process user input from the **web app** through a Bluetooth connection and control the **stepper motors** responsible for pill dispensing. To ensure reliability, the power subsystem will **automatically** switch from electrical outlet to battery.

It works with:

- **The mechanical subsystem** to trigger pill sorting and dispensing.
- **The interface subsystem** for user notifications and inputs.
- **The power subsystem** for stable operation.

Mechanical subsystem

The **pill sorting system** will use a **stepper motor-driven rotating disk** to align pill compartments with the **dispensing and intake funnels**. This mechanism is designed to achieve a **sorting accuracy of 98.4%**, which is equivalent to a pharmacist.

To dispense pills, **motor-controlled gates** at the bottom will release the **precise number of pills per dose**, as scheduled by the user. **Load sensors** will track pill levels, triggering **refill alerts** when the compartments reach **~10% capacity (+/- 0.9%)**.

This subsystem is essential for meeting the accuracy requirements and ensuring timely dispensing.

It works with:

- **The control subsystem** for activation and dose scheduling.
- **The interface subsystem** for user alerts and notifications.

Interface subsystem

The **user interface** will consist of a **Bluetooth connected web app**, allowing users to **configure their pill schedules** and **receive notifications**. Additionally, the physical **user input button** will be included for basic interactions such as **setup mode and manual dispensing, changing functionality based on which mode it is in**.

- The system will use **LED indicators** to provide real-time status updates:
    - **Refill Needed (Yellow LED):** Alerts the user when pill levels drop below **~10%**.
    - **Active Dispensing (Green LED):** Indicates when a scheduled dose is being dispensed.
    - **Missed Dose Alert (Red LED):** Notifies the user **within 5 seconds** of a missed scheduled dose.
- The **LED brightness** must be **visible in daylight at a distance of 1 meter** for accessibility.

This subsystem works with:

- **The control subsystem** for status updates and notifications.
- **The power subsystem** for reliable operation.

Sorting Mechanism

Objective:

The system must correctly separate and store **up to four pill types**, ensuring at least **98.4% sorting accuracy** while minimizing user input.

How the Sorting Mechanism Works

1. Pill Loading Process (Manual but Guided)

- The **top section of the device has one funnel.** As the user rotates through their pill bottles the compartments for the pills rotate under the funnel.
- The user loads **one pill bottle at a time** into **Compartment 1** and presses the main button which constitutes "Next" during configuration mode**.**
- The system then **rotates a mechanical disk** (via a stepper motor) to align the next empty compartment under the intake funnel.
- The process repeats for up to **four different pills**.

2. Compartmentalization and Storage

- Each funnel **leads to a separate storage chamber** inside the dispenser.
- Once the loading process is complete, each pill type is stored in its respective compartment.
- The device then switches to **dispensing mode**, where pills are released as per the user's scheduled dosages.

Pill Dispensing Process

1. Scheduled Dispensing

- When it's time to take the medication, the microcontroller **activates stepper motors** to release pills from the correct compartments.
- Each compartment has a **gate-controlled release mechanism**, ensuring that only the exact **prescribed number of pills** is dispensed.
- Pills drop through a final **bottom-funnel** into a small container for collection.

2. Tracking Pill Usage & Refill Alerts

- A **weight sensor (load cell + HX711 amplifier)** tracks the remaining pills.
- When the stock falls below a threshold, the system **activates an LED alert** and notifies the user via the **web app** to refill the specific compartment.

Sorting Accuracy & Testing

Requirement:

Sorting accuracy must be **≥ 98.4%**

Testing Approach:

- Run trials with **100 pills** (10 times) of varying sizes and weights.
- Track how many are **correctly sorted** into their compartments.
- If 984+ pills are correctly placed, the system meets the requirement.

Error Handling:

- To account for misidentification the SMPD will ask the user to confirm the correct pills were dispensed.
- If **pills jam**, the stepper motor reverses briefly and attempts to retry sorting.

Failure Considerations & Backup Mechanism

1. The sorting system halts safely since an **RTC module maintains timing**.
2. A **backup battery** ensures that the sorting function resumes when power returns.
3. The RTC also ensures that the pills continue to be dispensed at the right time.
4. The Bluetooth component will allow connection even if the power is out.

Why This Approach?

Cost-Effective:

Using weight sensors instead of cameras reduces costs. Using 3d printing significantly reduces the costs of the chassis.

Compact & Scalable:

The rotating disk allows for a **small form factor** while enabling pill expansion in future iterations.

Minimal User Effort:

Users only need to pour pills; no manual sorting is required.

Tolerance Analysis:

1. Pill Recognition Accuracy
    a. The sorting system must achieve an accuracy of at least 98.4% as stated before
    b. We will be conducting 10 trials with 100 pills each taking into consideration different sizes and weights ensuring that 984/1000 pills are sorted correctly
    c. Potential sources of error include jamming or misalignment in the rotating disk, which will be solved by stepper motor reversal logic.
2. Power Consumption Calculations
    a. Power consumption breakdown
        i. Microcontroller ~ 50mW
        ii. Stepper Motors ~ 1 W
        iii. Sensors and LEDs ~ 50mW
        iv. Bluetooth module ~ 300mW
    b. A 12 V rechargeable battery will sustain operation for at least a full day in standby mode.
3. Timing Precision Requirements
    a. The RTC must maintain an accuracy of less than 1-minute drift per month
    b. The pill dispenser should notify the user within 5 seconds of the scheduled time
    c. Bluetooth latency should remain below 1 seconds to ensure real-time connectivity.
4. Storage Capacity Requirements
    a. Each compartment holds up to 100 pills
    b. Total storage: 400 pills (4 compartments)
    c. Minimum threshold for refill alert: 10 pills per compartment
5. Error Rate in the Dispensing Mechanism
    a. Stepper motors (NEMA 14) ensure precise movement
    b. Load cell (HX711) tracks exact pill count
    c. Error mitigation:
        i. Pill jamming detection using load variance
        ii. Motor reversal logic for clearing jams
        iii. User confirmation for wrongly dispensed pills

Ethics and Safety

As for ethics and safety, our team is going to ensure the product is safe to use and HIPAA compliant. This will require that the device be made with food-safe PLA or PETG filament as we plan to 3d print it. Additionally, the cloud infrastructure we build will need to remain HIPAA compliant by only using GCP/AWS/Azure's HIPAA-focused services. We will continuously document our development process to ensure any 3rd party can verify our statements. Additionally, we are guided by the ethical guidelines as written in the IEEE Code of Ethics and ACM Code of Ethics. Our entire team has also completed the University's Division of Research Safety's safety training. We have also read through the safe battery usage and safe current limits guidelines. We will treat everyone with respect and kindness, showcasing empathy and understanding. Our team will ensure that our project is built to strict networking safety guidelines, to ensure no user data can be stolen, and comply with any relevant licensing terms for all the software we use. Lastly, we will ensure that any training needed in the future is taken immediately and with the utmost focus.