SMART PILL HUB

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Abstract

The Smart Pill Hub is a medication management system designed to improve compliance among elderly users with cognitive impairments. This device stores, dispenses, and manages multiple types of medications through a user-friendly interface connected to a mobile application. The system features precise dispensing mechanisms and environmental sensors to ensure that the correct doses are delivered under optimal conditions. Our findings indicate that the Smart Pill Hub significantly reduces medication errors and enhances user compliance with prescription regimens. Testing has confirmed the reliability and effectiveness of the system, with an error rate in pill dispensing far below acceptable thresholds. This report details the design process, functional testing, and system integration results, highlighting the practical benefits and technical reliability of the Smart Pill Hub.

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1. Introduction

As the global population ages, the challenge of managing chronic diseases and medication regimens for the elderly becomes increasingly common. This is especially true for those with cognitive impairments, such as Alzheimer's disease and Parkinson's disease, where adhering to a prescribed medication schedule can be both confusing and daunting. Existing solutions on the market are often expensive and lack the necessary features to fully meet the specific needs of this demographic, exacerbating the challenge. The Smart Pill Hub, developed by Team #65 for the ECE 445 senior design course, aims to address these critical issues by providing an automated, user-friendly medication management system. This device is designed to alleviate the burden on individuals and caregivers by ensuring accurate and timely medication dispensing, thereby enhancing compliance and overall health outcomes.

Problem Statement

Many elderly individuals struggle with the complexity of managing multiple medications, which can lead to dosage and timing errors, potentially resulting in severe health impacts. Current market solutions, such as basic pill organizers and reminders, fail to provide the comprehensive support needed for individuals with severe cognitive decline. Additionally, the high cost of advanced systems makes them unaffordable for many who would benefit most.

Motivation for the Smart Pill Hub

The motivation behind the Smart Pill Hub is to create a cost-effective, comprehensive medication management system that enhances the independence and well-being of elderly users. By integrating cutting-edge technology in a user-friendly format, the Smart Pill Hub aims to fill the gaps left by existing products.

Project Objectives

- Enhance Medication Compliance: Utilize automated dispensing and smart reminders to ensure medications are taken at the correct times and doses.

- User-Friendly Interface: Develop a simple, intuitive interface for a mobile application, enabling users and caregivers to easily manage medication schedules.

- Cost-Effective: Offer a more affordable solution compared to existing smart pillboxes, making advanced medication management accessible to a broader audience.

- Safe and Reliable: Incorporate features such as real-time environmental monitoring to ensure medications are stored under optimal conditions and integrate sensors to verify the correct dispensing of pills.

By achieving these objectives, the Smart Pill Hub is expected to significantly impact the quality of life for its users, providing a reliable and simple solution for effectively managing their medication needs. This report will detail the design process from conceptualization to validation, highlighting the innovative approaches taken to meet the needs of the vulnerable populations.

2. Design and Implementation

The development of the Smart Pill Hub is aimed at providing a comprehensive solution for medication management, particularly for elderly individuals with diseases such as Alzheimer's and Parkinson's. This design combines advanced technology with a user-friendly interface to simplify the medication process, ensuring accuracy and timeliness in drug administration.

Technical Overview of the Smart Pill Hub

The Smart Pill Hub utilizes a sophisticated array of components including microcontrollers, motors, sensors, and a mobile application to provide an integrated medication management solution. This system ensures precise control and monitoring of medication schedules. Here is a overview from top level and concise technical breakdown of each subsystem:

Top-level design

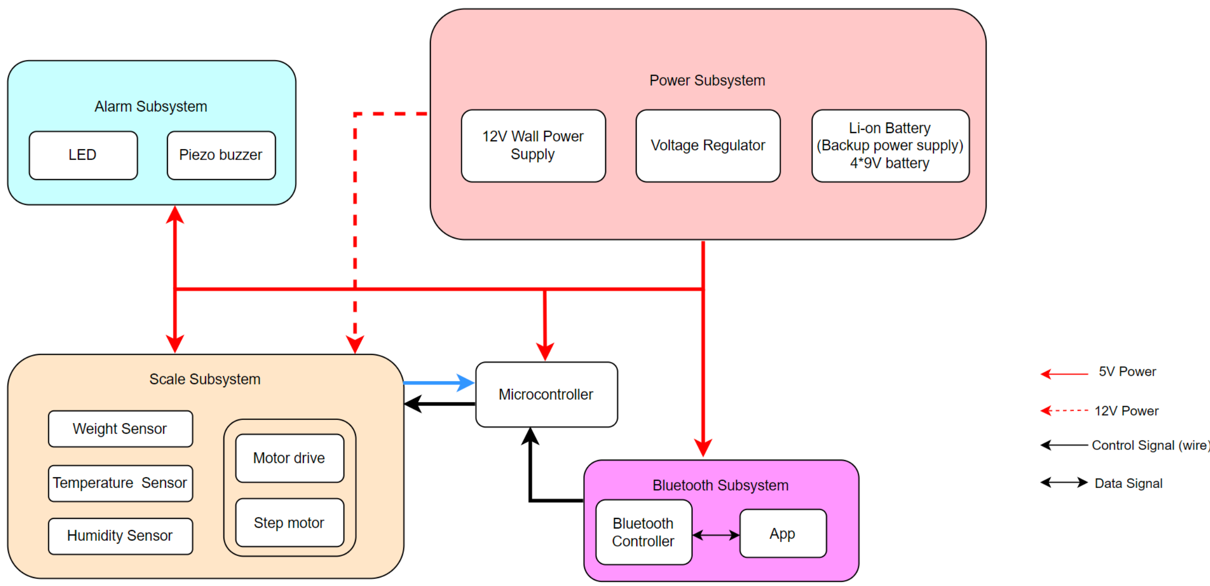

Figure 1: Block Diagram

The hardware design of the Smart Pill Hub centers around robustness and reliability, which are essential for handling the critical task of medication management.

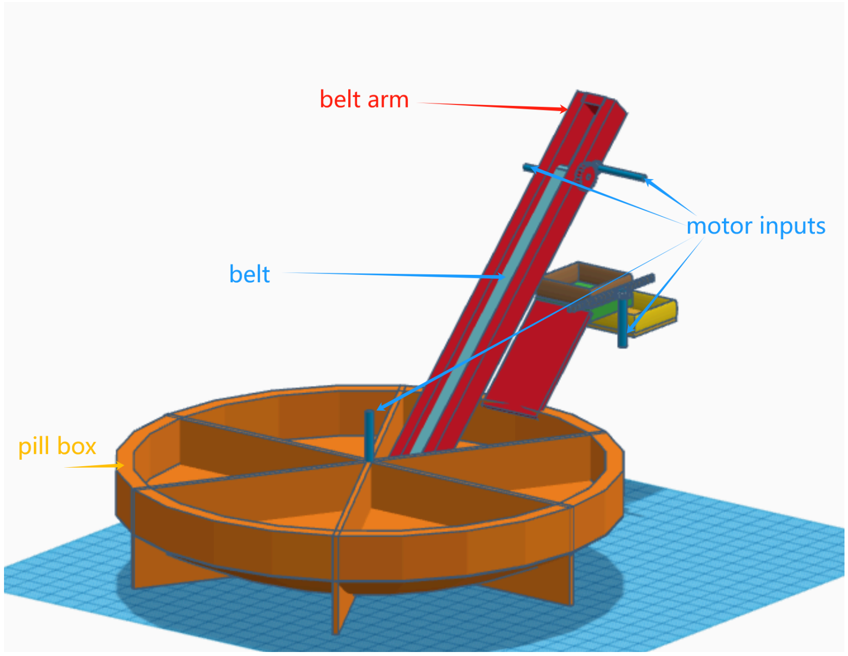

Figure 2: Physical Design (Side View)

The picture above shows the mechanical part of our design, and we will be utilizing 3D printing technology to complete our design. We will be modeling more accurately as well as having a more logical layout. Also to increase the overall portability of the pillbox, we will be using a method that uses battery power.

Subsystem 1: Control and Mobile Application with Bluetooth Connectivity

We chose the ESP32 microcontroller for its high performance, Bluetooth capabilities, and low power consumption, making it an ideal choice for managing various functions of the Smart Pill Hub. We built an Android app and used opcode and text to communicate with ESP32 via Bluetooth.

Below are our schematics and Android app screenshots for the system illustrated above.

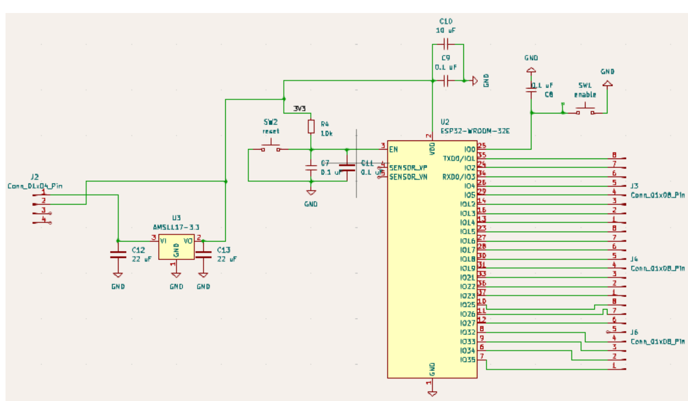

Figure 3: Microcontroller Schematic

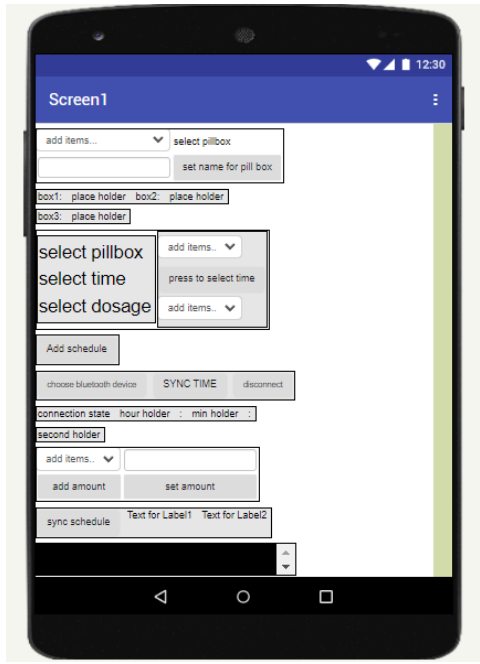

Figure 4: Android App Screenshot

When setting up the smart pill box, users need to pair the device to Bluetooth in the settings of their phone. Then, they will pick the device from a list of paired devices. The user will need to sync time between the phone and the microcontroller. After this, users can add/set the pill amount in each pillbox and set the schedule(pillbox,time, dosage) as well.

Our microcontroller, which is the core of our control, receives and stores those commands. It will then use the command and data from the sensor as input to control multiple motors to execute the dose schedule.

Subsystem 2: Pill Storage and Dispensing Mechanism

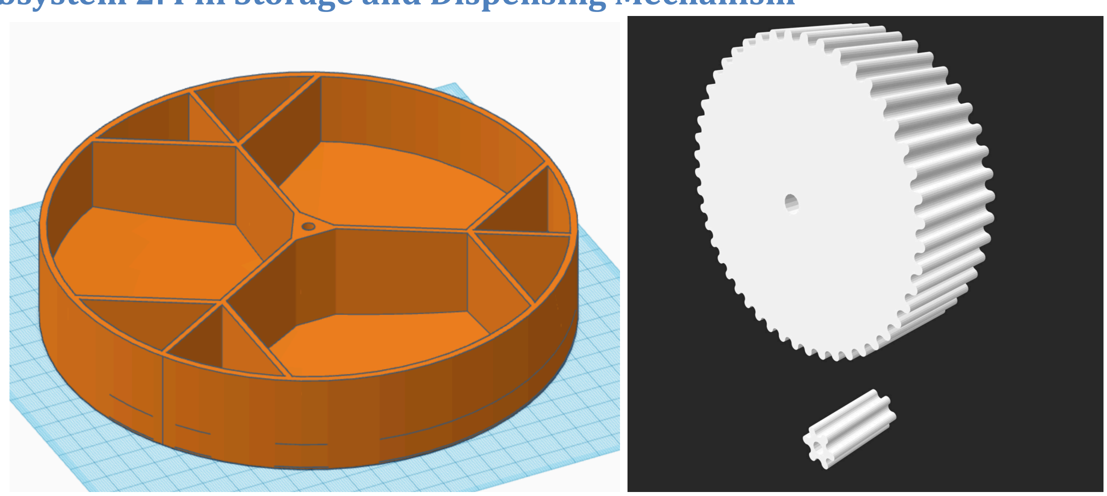

Figure 5: 3D print pillbox and Gear Sets

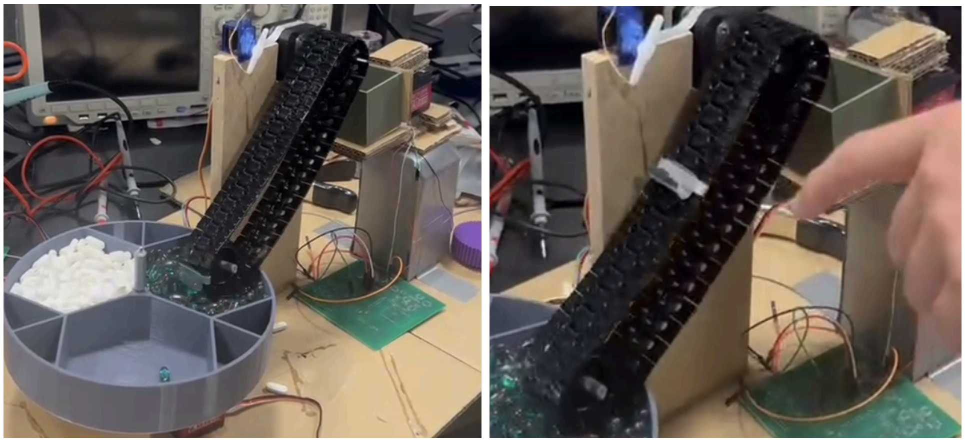

Figure 6: pill getting picked up and transporting

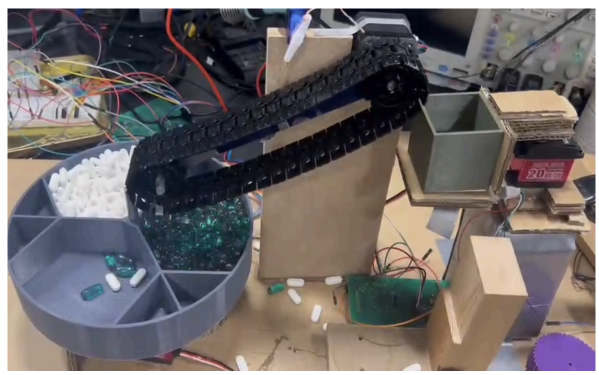

Figure 7: Pill being Released *Figure 8:* Arm being Pulled Up

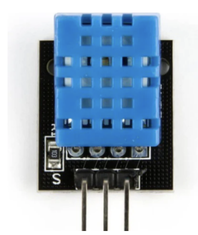

Figure 9: dht11

For pill storage, our design features a 3D printed round box that has 3 different compartments. It is intended that each compartment only stores one kind of pill. For the dispensing mechanism, we have a belt system mounted on an arm. We have a step motor to rotate the belt, which can hook pills into the hook, and then the belt will transport it to the destination to release it. We have a servo motor, which we pair with a set of gears to control which pillbox the arm interacts with. The reason we chose this setup instead of a step motor here is for easier control. To effectively hook the pill up when the pills aren't completely full, the arm has to dip into the pillbox, and when we want to change the pillbox, the edge of the pillbox will block it. To solve this, we add another small servo to lift the arm up when changing the pillbox. After release, the pill will end up in a small compartment where there will be further action by the verification subsystem. We have a temp and humidity sensor in there as well, it will monitor the condition of the storage and will update the user if the app is connected.

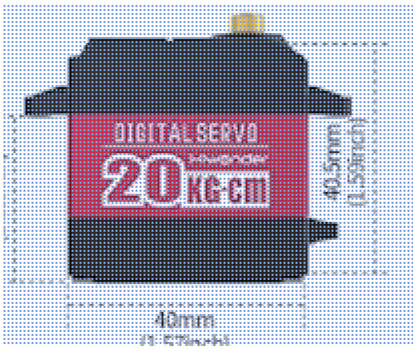

Figure 10: Servo

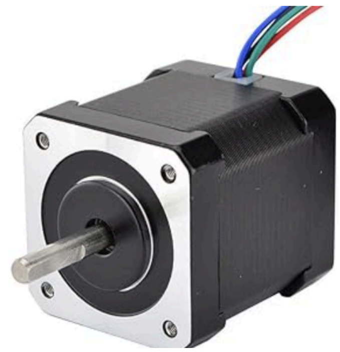

Figure 11: step motor

Figure 12: small servo

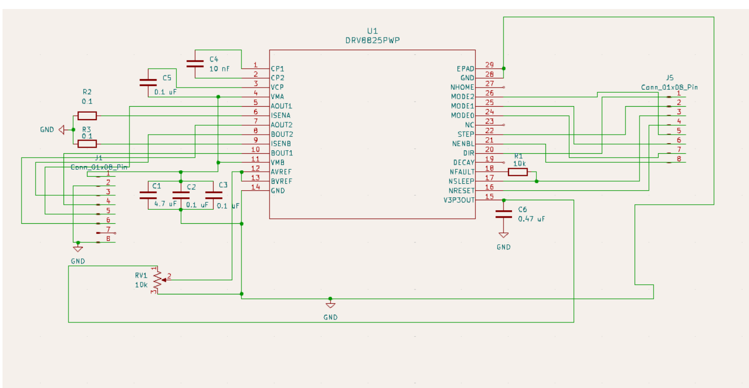

Figure 13: drv8825 schematics

Subsystem 3: Integrated Digital Scales Verification

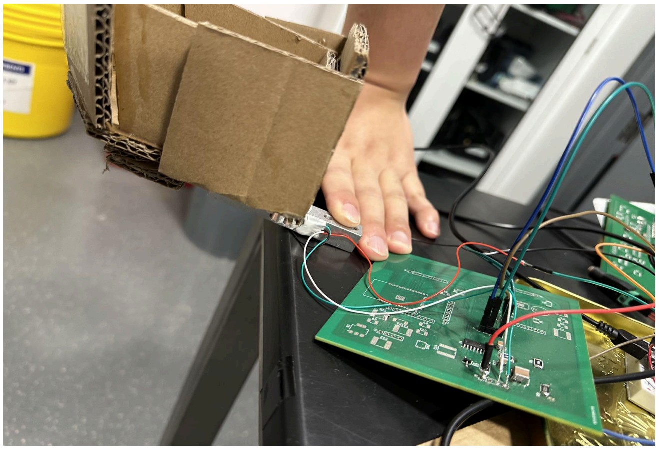

Figure 14: scale1 weighting system

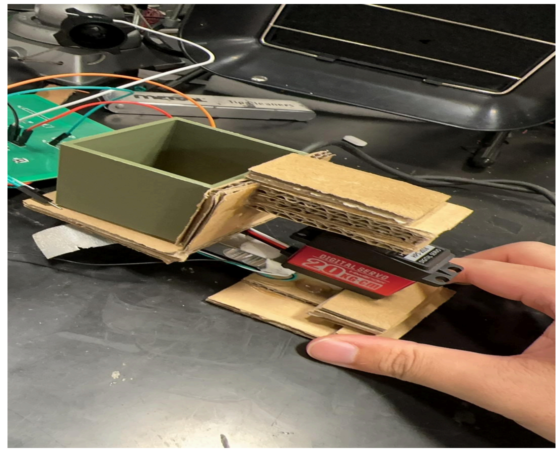

Figure 15: scale 2 verification system

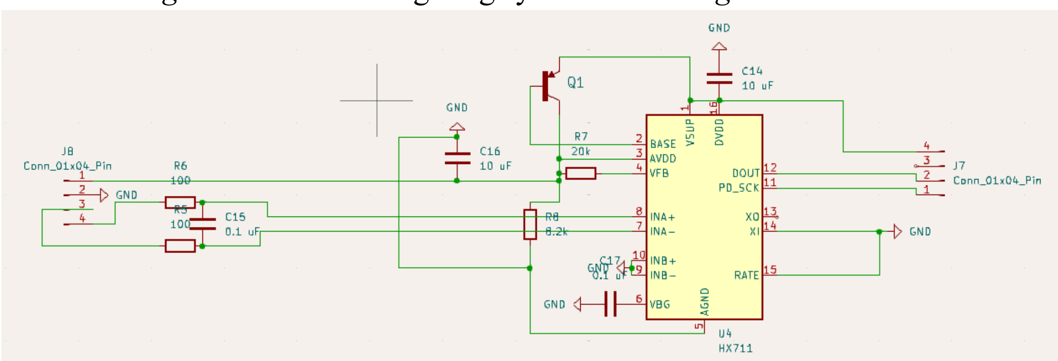

Figure 16: Hx711 Schematics

Figure 17: Pills Got Send Back

For our scale system, we have two scales, which each paired with an hx711, to convert the signal to a digital signal for our microcontroller. The user can use the first scale to count pills by recording the weight of a single pill and an unknown amount of pills. As in the previous subsystem, when the pill is released from the belt, the second scale will weigh it, and compare the weight of a single pill of that kind recorded by scale 1 to make sure only one pill is hooked up to avoid a release of the wrong amount of pills. It will be sent back by a slide and motion of servo mounted on the scale. Otherwise it will swing the other way, and the pills will end up in a compartment waiting for the user to collect. Note this system has a servo as well.

Subsystem 4: Alert System

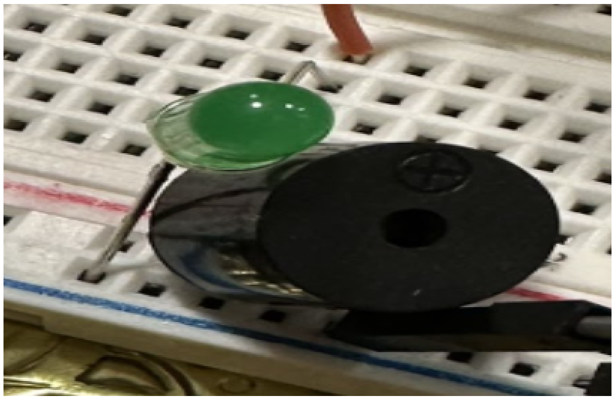

Figure 18: LED and Buzzer

Our alert system is simple, at the setted time, the LED and buzzer will alert the user to take the pill. The app will also send user notifications.

Subsystem 5: Backup battery system

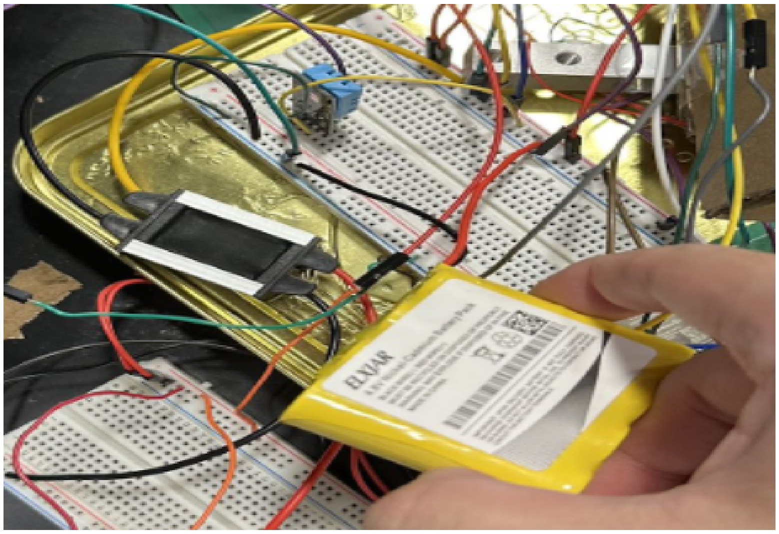

Figure 19: converter and 4.8v lithium battery

Our battery system is simple as well, it features a power supply that converts 110v AC from the wall to 12V DC. We will use the 12V to power our step motor. We have a buck converter to convert it to 5V. The 5V will power our PCB, servo, and keep our battery charged. Once the wall power is out, the battery will keep only the microcontroller and alert system running, it will notify the user it is time to take the pill and that the power is out. We used a mosfet for the control signal in this part.

Design modification

We changed from Atmega328p plus HC-05 to ESP32 for simpler control and higher processing capability. We changed the PCB design of the step motor driver and whether to use servo or step motor in various places due to soldering, PCB/component ordering. We changed from a weekly dose schedule to daily schedule since most of the medication is taken daily. Other designs remain mostly untouched, with some having minor compromises due to multiple reasons.

Testing and Debugging Strategies

Each component and subsystem undergoes rigorous testing to verify its functionality and reliability. The design verification process includes functional testing to ensure these mechanisms dispense the correct amount of pills at the correct times, and system-wide integration testing to verify that all subsystems work consistently to perform the intended tasks.

3. Design Verification

Design verification is a crucial stage in the development of the Smart Pill Hub, ensuring the system meets all technical requirements and is user-friendly for the target audience. This section details the systematic approach used to test and verify each component of the Smart Pill Hub, with a focus on functionality, usability, and fault tolerance.

3.1 System Testing

- 3.1.1 Functional Testing

- Objective: Verify that all functions of the Smart Pill Hub operate as expected under various conditions.

- Method:

- Automated Dispensing Test: This test checks the accuracy and reliability of the dispensing mechanism by commanding the device to dispense a set number of pills under controlled conditions. The test is repeated with different types of medications to ensure versatility.

- Sensor Accuracy Testing: Temperature, humidity, and weight sensors are tested against certified reference instruments to verify their accuracy and responsiveness to changes in environmental conditions.

- Connectivity Test: The Bluetooth connection between the Smart Pill Hub and the mobile application undergoes stability and range tests to ensure reliable command and alert transmission even at the edges of the specified range.

- Results: All system functions operate as prescribed, with a pill count accuracy rate of 95% for the dispensing mechanisms, and all sensors operating within acceptable error thresholds. The bluetooth is functional up to 25 meters in open space. The sensors are calibrated with a thermometer, a hygrometer, and known weight.

- 3.1.2 Usability Testing - Objective: Ensure that the Smart Pill Hub and its accompanying software are intuitive and easy to use for elderly users, including those with limited tech proficiency.

- Method:

  - User Interaction Test: A group of elderly volunteers is asked to interact with the Smart Pill Hub through its mobile application. Tasks include setting medication schedules, retrieving medications, and responding to reminders and alerts.

  - Feedback Collection: Participants provide feedback on their experience, focusing on ease of use, interface intuitiveness, and overall satisfaction.

  - Observational Study: Researchers observe user interactions with the system to identify any potential usability issues, such as buttons being too small to use comfortably or instructions being confusing.

- Results: Most users find the mobile application simple and easy to navigate. Suggestions for improving certain interface elements are noted for future updates.

- 3.1.3 Error and Tolerance Testing

- Objective: Assess the robustness of the system by determining its ability to handle errors and operate within tolerable limits under adverse conditions.

- Method:

  - Error Handling Test: Errors such as incorrect pill loading and blockages in the dispensing path are deliberately introduced to see how effectively the system detects and handles these events.

  - Environmental Stress Testing: The Smart Pill Hub is exposed to extreme levels of temperature and humidity to ensure it can continue to operate effectively under less than ideal environmental conditions.

  - Power Fluctuation Testing: The backup battery system and power management are tested under intermittent power supply conditions to assess the system's response to power fluctuations.

- Results: The Smart Pill Hub successfully identifies and alerts users to all simulated errors, and continues to operate within operational parameters during environmental and power tests. Error recovery protocols are highly effective, allowing the system to quickly resume normal operation after resolving issues.

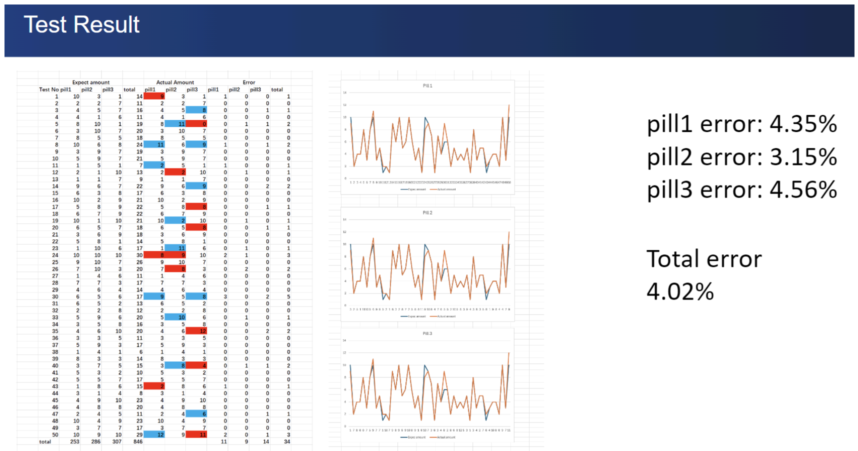

Figure 20: tolerance test result

- 3.1.4 Summary

The design verification process demonstrates that the Smart Pill Hub meets all necessary functionality, usability, and reliability standards, confirming that it is ready for real-world deployment. These tests not only highlight the system's effectiveness and robustness but also provide valuable insights into areas needing improvement, ensuring that the final product truly meets user needs. The detailed test result of each subsystem can be find in appendix A at the end.

4. Costs

A detailed cost analysis is crucial in the development of the Smart Pill Hub to ensure the solution is accessible to the target market while maintaining high quality standards. This section outlines the cost breakdown related to parts, labor, and overall expenditures necessary for prototype development and potential mass production.

4.1 Parts

Following is a starter table for parts costs. Add cell contents as well as rows and, if necessary, columns. Update the table number according to your sequence. Note that columns 1 and 2 are set up for centered text (words) and columns 3-5 (numbers) are set up for right-alignment so that decimal points align.

	Quantity	**Price per ($)**	**Total Cost ($)**
Nema17	1	18	18
SG90 9G	1	3	3
20KG RC Servo	2	15	30
DHT11	1	3	3

LED	1	0.5	0.5
3D pillbox	1	60	60
Buzzer	1	0.5	0.5
3D Gears sets	1	15	15
ESP32	1	3	3
PCB	10	5	50
DRV8825	1	6	6
HX711	1	5	5
Capacitors/Resistor	20	0.3 on average	6
Cardboard/Glue	3	9	27
Other tools	1	15	15

Table 1- Parts Costs

Total parts cost is 242$.

4.2 Labor

Labor costs include the time spent on design, engineering, and assembly. The team invested approximately 120 hours in this project, with each team member contributing about the same. Detailed as follows:

Design and Testing: 70 hours

Engineering Development: 25 hours

Assembly and Quality Control: 25 hours

Assuming an average engineering rate of $30 per hour, the total labor cost for the development stage is estimated to be $3600. This figure is for the prototype phase and does not include labor efficiencies gained in a full production setup.

	Jerry Ning	Eric Cheng	Jinpeng Liu
Week of 2/26	Start PCB design	Secure parts of testing such as stepper motors, sensors	Create a debugging setup to simulate the inputs to the board and LEDs.
Week of 3/4	Ensure all parts we	Assost om testing on	Assist in the creation

	need are ordered	breadboard	of PCB schematic
Week of 3/11	PCB ordering	Check the PCB design	Check the physical design
Week of 3/18	Program the control system	Testing the physical design	Testing the code on the present PCB
Week of 3/25	Test the backup power	Connect the PCB with the mechanical component	Assist with the connection of PCB and mechanical component
Week of 4/1	Programming the Bluetooth on PCB.	Looking for possible weaknesses with the current PCB design	Make sure the PCB performs the same way the Arduino performed
Week of 4/8	Testing possible bugs	Testing all functionality	Check the tolerance
Week of 4/15	Testing the Bluetooth to be ready for demo	Testing Software App to be ready for demo	Polishing the overall product
Week of 4/22	Final demo mock presentation	Final demo mock presentation	Final demo mock presentation
Week of 4/29	Final presentation Final paper	Final presentation Final paper	Final presentation Final paper

Tble 2- Work done by week.

The total cost for the project is 242+3600, equals to 3842$.

5. Conclusion

The Smart Pill Hub project successfully addressed significant challenges in the field of elderly care by developing a reliable and user-friendly automated medication management system. This conclusion summarizes the project's achievements, discusses uncertainties and limitations, explores ethical considerations, and outlines potential future work.

5.1 Accomplishments

Enhanced Medication Compliance:

Through automated dispensing and smart reminders, the system ensures medications are taken at the correct time and dosage, significantly improving compliance.

User-Friendly Design:

The intuitive mobile application allows easy management of medication schedules, enabling elderly users (including those with limited technical skills) to use the system.

Cost-Effectiveness:

Strategic component sourcing and efficient design practices made the development of the system affordable, which is critical for widespread adoption.

Reliability and Safety:

Comprehensive testing has confirmed that the device operates reliably under various conditions and meets all safety standards required for medical devices.

5.2 Uncertainties

Scalability:

While prototype testing showed promising results, scaling up production to meet large-scale demands presents logistical and financial challenges.

Long-term Durability:

Further long-term studies are needed to ensure the device's durability and consistent performance.

Adaptability:

As medication regimens and technologies evolve, the system needs to be continuously updated to accommodate new drugs and integrate with other healthcare technologies.

5.3 Ethical Considerations

The development of the Smart Pill Hub requires careful consideration of ethical issues:

Data Privacy:

Given the sensitivity of health information, ensuring the privacy and security of user data is crucial. All data transmitted and stored by the system is encrypted and complies with HIPAA regulations.

User Consent:

It is crucial that users (or their caregivers) provide informed consent, understanding how the device operates and how their data will be used.

Accessibility:

We strive to ensure that the people who need the device most (not just those who can afford the latest technology) can afford and use it.

5.4 Future Work

Looking ahead, further development can take several directions:

Integration with Artificial Intelligence:

Adopting artificial intelligence to analyze user behavior and predict future medication patterns could enhance the effectiveness of the Smart Pill Hub.

Broader Compatibility:

Expanding the device's compatibility to work with a wider range of medications and other medical devices.

Market Expansion:

Exploring partnerships with healthcare providers and insurance companies to broaden the market reach and ensure the device is included in healthcare plans.

Improve Safety:

On the hardware side, using medical-grade materials to make the design safer. On the software side, continued development of the app to make it easier to operate, with a focus on user privacy and personal information security.

References

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Appendix A Requirement and Verification Table

An appendix is a good place for the Requirement and Verification Table from your design review. Below is a starter table. Including these details here will help to avoid lengthy and tedious narrative descriptions in the main text, which may not be of immediate interest to your imagined audience of company managers and professionals. Any requirement that is not verified should be explained either in the main text or the appendix. Note that both the pagination and the numbering of figures, tables, and equations continues from main text to appendices.

Table 3 *System Requirements and Verifications*

Subsystem	Requirement	Verification	Verification status (Y or N)
Subsystem 1: Control and Mobile Application with Bluetooth Connectivity	Must be able to pair seamlessly with a designated app on a smartphone or tablet to allow wireless transmission of distribution commands. The device should provide operational status feedback through the application interface, including successful dispensing, errors, or warnings of insufficient pill stock as well as the schedule and does of dispensing.	Verify the ability of the device to pair with apps on different devices (phones and tablets) and operating systems. Test the range and stability of Bluetooth connections to ensure commands are received without loss. Tests the ability of the system to provide feedback to the application about its status, including successful operations, errors (e.g., lag, empty storage), and warnings (e.g., low inventory). Tests the ability of the system to provide feedback to the application about its status, including successful operations, errors (e.g., lag, empty storage), and warnings (e.g., low inventory)	Y Y
Subsystem 2: Pill Storage and Dispensing Mechanism	The mechanisms should be available that can accommodate different types of pills without causing contamination or damage. The designed mechanism can dispense the pills associated with the command request received by the paired device.	Evaluate storage compartments for compatibility with different pill sizes and shapes to ensure no damage or contamination occurs. Test the mechanism's ability to prevent moisture or other environmental factors from affecting the pills.	Y

		Conduct tests using pills of various sizes to ensure the design can accommodate multiple sizes of pills. Perform multiple tests to eliminate randomness.	N
Subsystem 3: Integrated Digital Scales Verification	The weight sensor detects the weight of the pills remaining in the pill box, as well as detecting the weight of the dispensed pills to evaluate the exact number of pills.Temperature, humidity and pressure sensors test the temperature, humidity and pressure in the pill box and display the data to the application.The motor can be rotated by a corresponding angle according to the received signal.	Ensure through testing that the weight sensor can detect the required weight changes. Conduct multiple tests to avoid randomness in the results. Ensure that the correct signals are received from the control subsystem and the correct commands are accomplished based on those signals. Tested to ensure that the temperature humidity and pressure sensors can accurately detect the temperature humidity and pressure in the pill box. Ensure that this data can be transferred to the application via Bluetooth signal. Test to make sure the motor can turn at the desired angle. Test to ensure that the motor is receiving signals and can fulfill the correct commands.	Y Y Y
Subsystem 4: Alert System	Alarm device exist Adjustable alarm strength Ability to work independently Ability to integrate work	Perform a physical check to confirm that the LEDs and buzzers are properly installed in the system, and verify their operating status with a simple circuit test (e.g., activation with a test power supply). Using a PWM signal generator, provide "high" and "low" PWM signals to the switching transistors controlling the LED and buzzer, respectively. Observe and record the change in brightness of the LED and the change in volume of the buzzer to verify the ability to	Y

		adjust the intensity of the alarm. Verify that the LEDs and buzzers can operate independently based on the input signal by controlling the alarm subsystem directly (not through the main control system). This can be tested by manually supplying a voltage or by sending a PWM signal using a simple controller. Integrate the alarm subsystem with the main control unit to simulate an actual use scenario (e.g., setting specific warning conditions) and verify the response of the alarm subsystem in the integrated environment. This can be accomplished by controlling the main control unit with software that triggers the alarm subsystem under predetermined conditions.	Y Y
Subsystem 5: Backup battery system	Non-disruptive switching capability Long-term backup power supply capacity Power supply fluctuation adaptability	Test the system's ability to immediately and seamlessly switch to the backup power supply by simulating a mains power failure. This can be achieved by disconnecting the mains power supply and immediately monitoring whether the system continues to operate without any functional interruption. Focus on how quickly the system switches to the alternate power supply and whether there are any operational interruptions. Test the durability and reliability of the backup power supply by running the system continuously for a certain period of time (e.g., a few hours to a day) while it is	Y Y

		powered by the backup power supply. This will verify that the system can maintain normal operation and its endurance in the absence of primary power. Simulate power fluctuations, such as short-term voltage drops or instability, and test whether the system can continue to operate stably or automatically switch to a backup power source when the main power source is unstable. Observe the system's response to power fluctuations to ensure that system operation is not affected during fluctuations.	Y