Automatic Medicine Dispenser (Team 26)

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ABSTRACT

Medication non-adherence poses significant challenges in healthcare, leading to severe health consequences, increased hospitalizations, and higher medical costs. This project addresses this issue by developing an IoT-based automatic pill dispenser designed to ensure timely medication intake, prevent over/under-dosing, and enhance medication adherence. The proposed system integrates hardware components, software, and cloud-based communication protocols to create an intelligent, interactive device. It synchronizes with predefined medication schedules, dispenses pills accordingly, and verifies patient identity through NFC technology. Additionally, the system provides real-time updates to caregivers via the Slack app, facilitating remote monitoring and control. By leveraging modern technology, this research aims to offer a reliable and efficient solution for medication management, ultimately improving patient outcomes and reducing the burden on healthcare systems.

1 INTRODUCTION

Medication adherence is a critical component of effective healthcare management, particularly for patients with chronic conditions that require consistent medication intake. Despite the availability of various reminder systems and pill organizers, these tools often fall short in ensuring patients adhere to their prescribed medication schedules. Non-adherence can lead to severe health complications, increased hospitalizations, and escalating medical costs, underscoring the urgent need for more efficient and reliable solutions.

Our project aims to address this challenge by developing an IoT-based automatic pill dispenser. This device is designed to assist patients in taking their medications on time, ensuring accurate dosing, and providing real-time monitoring capabilities. By seamlessly integrating hardware components, software, and cloud-based communication protocols, we aim to create an intelligent and interactive system that can significantly improve medication adherence.

The pill dispenser operates on a straightforward yet effective premise: it synchronizes with a predefined medication schedule and dispenses pills at the appropriate times. It is equipped with an OLED display that notifies patients when it is time to take their medication. To ensure that the medication is administered to the correct individual, patients must verify their identity by scanning a Near Field Communication (NFC) card. This verification process helps prevent medication errors and enhances the system's reliability.

To further improve user interaction and provide real-time status updates, the dispenser incorporates a multi-sensory feedback mechanism. This includes LEDs and buzzers to signal different stages of the process: a green LED and buzzer indicate successful verification, a blue LED activates during the dispensing process, and a red LED along with an audible alert signals a missed dose. These features ensure that the device is both user-friendly and effective in maintaining medication schedules.

A key innovation of our system is its integration with cloud-based communication channels, specifically through the Slack app. This allows caregivers and healthcare providers to receive real-time notifications about medication adherence, enabling them to take timely action if necessary. Moreover, administrators can remotely dispense specific medications via the Slack interface, providing flexibility and control over patient medication management. This remote functionality is particularly valuable in scenarios where immediate caregiver intervention is required, but physical presence is not feasible.

By leveraging modern technology, our research aims to provide a comprehensive solution to the pervasive issue of medication non-adherence. The findings from this study could lead to the widespread adoption of automated medication management systems, improving patient outcomes and reducing the overall burden on healthcare systems. This project not only simplifies medication management for patients but also offers peace of mind for caregivers and healthcare providers, ultimately contributing to better healthcare delivery and patient well-being.

2 RELATED WORK

In this section, we highlight other projects that show some similarities to our project or which idea we want to use and adapt. The following chapters cover three approaches. The first paper covers the idea of time based alerts and notifications to dispense medications to patients. After that, the second paper covers the idea of using fingerprint as a way to authenticate patients. The final paper introduces an IoT based smart pill dispenser that uses real-time monitoring techniques to ensure medicine adherence.

2.1 Smart Medicine Dispenser

Antoun et al. [1] present a Smart Medicine Dispenser (SMD) prototype in this paper. Their reasoning for developing such a device is to help patients with taking their medicine. Their target demographic are mostly seniors and/or persons who tend to forget to take their pills or may over/underdose. By dispensing the correct amount automatically, the SMD reduces user errors in this regard. Additionally, Antoun et al. developed a supporting application for smartphones for this device, which enables the user to create alarms such that they are reminded to take their medicine at a specific time. This touch interface also enables users to remotely manage the SMD, for example by changing the pill schedules It also enables a connection between a patient and its caregiver as the caregiver will be informed if the patients missed their pills.

We want our pill dispenser to also be able to notify patients when it is time for them to take their pills. We take this idea a bit further by also introducing a time interval within which the medicine is to be taken, else resulting in a missed dose notification. In our project, we also re-use the idea of involving a caregiver in the loop by relaying all notifications of a successful dose take or a missed dose.

2.2 An IoT based Smart Medicine Dispenser Model for Healthcare

Patil et al. [2] present an IOT based Smart Medicine Dispenser (SMD) prototype in this paper. The goal of their proposed system is to assist patients and dependent senior citizens take their pills on time, all the while eliminating the possibility of missing pills. Patil et al. implemented a medicine dispenser where a user is authenticated by means of a fingerprint scanner. Once the device receives a user's fingerprint during alarm buzz, it will stop the alarm and automatically dispense the medicines at the given point of time. Their implementation also enables greater flexibility to add new dosages of medicine, update time slots of existing dosage and delete slots by taking input from the user through a keypad, with each command followed by validation with fingerprint.

Here, we take the idea of differentiating between patients and authenticating patients via NFC technology and integrate this within our project. We conclude that this offers a simple interface especially for old-aged patients who might not be technically proficient with more advanced authentication measures.

2.3 Smart Medication Management: Enhancing Medication Adherence with an IoT-based Pill Dispenser and Smart Cup

V.Peddisetti et al. [3] introduces an in-depth approach, involving a Smart Pill dispenser, a Smart cup, and an Android application for real-time monitoring, notifications, and adherence alerts. This paper aims to provide medical adherence to users by the implementation of the Smart Pill Dispenser System. It also includes the verification of the patient consuming the pill as well as a mechanism to prevent overdosing of the same. The designed architecture of the system ensures an accurate and reliable medical management involving: system initialization, user interface and scheduling, time tracking and schedule management, smart cup position verification, Bluetooth low energy (BLE) communication, pill dispensing mechanism, pill consumption verification, data Logging and user alerts.

This paper provides a basic outline on the type of communication used between the system and the user as well as the fail-safe mechanisms. Our implementation plans to utilize a Slack channel to send notifications to the caregiver and pass commands to the user.

3 USE CASES

In this section, we present three different scenarios that can occur when using our medicine dispenser. Each of these scenarios can differ clearly in at least one point.

3.1 Use Case 1: NFC dispensing

In this scenario, we cover the use case of dispensing medication with the help of a NFC tag.

Gabi is in treatment living at home. She needs to take her medication in a specific timeframe. She possesses an NFC tag and her medication data is saved on the server. Robert the nurse that takes care of Gabi. Scenario:

- The medicine dispenser activates the blue LED and a buzzer sound to inform Gabi that she needs to take her medication.
- Gabi scans the NFC tag on the medicine dispenser.
- The medicine dispenser verifies the NFC card and confirms the patient's identity.
- Upon successful verification, the green LED illuminates, and a buzzer sounds, indicating that the medication is ready for dispensation.
- The blue LED activates, and the medicine dispenser dispenses the correct dosage of medication.
- After dispensing, the system records the event and updates the medication log.
- The system sends a notification to the Slack app, informing Robert that Gabi has taken their medication on time.

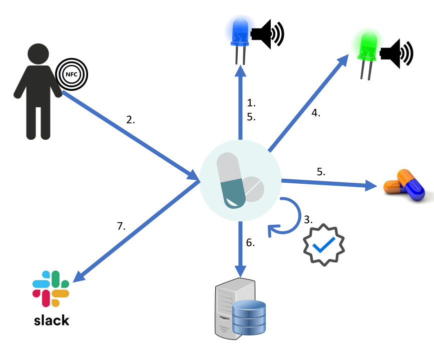

Figure 1: Process of NFC dispensing

Figure 1 demonstrates the control flow of the medicine dispenser during NFC dispensing.

When it is time for patients to take their medications, the medicine dispenser flashes its blue LED with buzzing. The patient then needs to scan their NFC tag, which contains an id. This id is checked in medicine dispenser to confirm the identity of the person receiving the medicine to prevent unintentional/malicious dispensing of medication. If the person is permitted, the medicine dispenser flashes its green LED with buzzing. The medicine dispenser then flashes its blue led with buzzing and dispenses the medicine. Finally, the dispensing is logged in the back-end server and a notification is sent to the administrator.

3.2 Use Case 2: Missed Dose Alert and Notification

In this scenario, we cover the use case of persons receiving notifications when missing/taking medications.

Herbert is also a patient that undergoes treatment at home currently. He has trouble remembering things or getting so caught up in his magazines that he doesn't hear or see anything else. He also has a NFC tag with his medication data saved on the server. Manuela is the nurse that takes care of Herbert.

Scenario:

- The medicine dispenser activates the blue LED and a buzzer sound to inform Herbert that he needs to take his medication.
- Herbert does not scan the NFC card within the designated time frame.
- The red LED illuminates, and the buzzer is activated to indicate a missed dose.
- The system sends a real-time notification to Manuela via the Slack app, informing her of the missed dose.
- Manuela can contact Herbert to remind him to take their medication or take other appropriate actions.

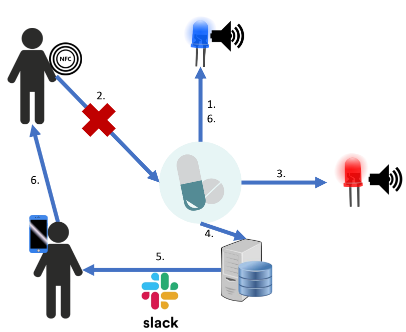

Figure 2: Process of missing a medicine and the administrator receiving a notification

Figure 2 demonstrates the control flow of the medicine dispenser if the patients forgets to take their scheduled medicine.

If the medicine dispenser activated their blue LED with buzzing, but the patient did not scan their NFC card in the necessary time frame, the red LED will flash with a buzzing sound. The medicine dispenser will then send a slack notification to the administrator as soon as the red LED flashes. The message contains the name of the patient, which medicine was missed and the time of the intended dispensing. The administrator can then contact the patient to remind them to take their medicine.

3.3 Use Case 3: Remote Medication Dispensation via Slack

In this scenario, we cover the use case of persons using Slack to dispense medications.

Karin is a nurse that takes care of Werner. Werner contacts Karin and tells her that he has been having strong pains in the last few hours due to a broken limb. He wants to have another dose of his pain medication, as his next one would only be in 6 hours.

Scenario:

- Karin sends a command via the Slack app to dispense a pain medication medicine for Werner.
- The medicine dispenser receives the command and verifies that the patient exists.
- The green LED illuminates, and a buzzer sounds, indicating that the medication is ready for dispensation.
- The blue LED activates, and the medicine dispenser dispenses the correct dosage of medication.
- After dispensing, the system records the event and updates the medication log.
- The system sends a notification to the Slack app, confirming the successful dispensation of the medication.

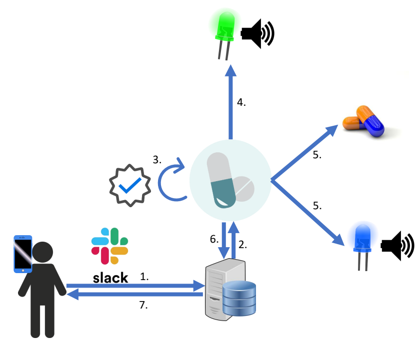

Figure 3: Process of using Slack to dispense medicine

Figure 3 demonstrates the control flow of a Slack command to dispense medicine.

An administrator has the possibility to dispense medicine over the internet with the help of Slack commands. They can choose a patient to receive medicine and send a /dispense command with the id of the chosen patient. The back-end server will verify that the patient id exists. If that is the case, the green LED will flash with buzzing. Afterwards, the blue LED will flash with buzzer sounds and the chosen medicine will be dispensed. Finally, the dispensing is logged in the back-end server and a notification that the dispensing was successful is sent to the administrator.

4 IMPLEMENTATION

In this section, we discuss the steps involved in implementing the NFC-based automatic medicine dispenser. It consists of two main parts: the first is the hardware design and coding, and the second is the back-end implementation, which handles the slack control. This section is split into hardware specifications, which explains the required hardware. It is then followed by the design that describes how the hardware comes together to form the prototype and the way the components are programmed via the ESP8266 to function such that it satisfies the objectives.

4.1 Hardware Specifications

To get our automatic medicine dispenser up and running, we require a few sensors and actuators. In this subsection we list out the hardware components used in the prototype.

- **Buzzer**: The piezo or the buzzer is used to achieve the auditory alert. It operates at both 3.3V and 5V with a sound output of 85 decibels.
- **RGB LED**: The RGB LED is used to achieve the visual indication. It has the capability to switch between red, blue and green color without the need to have different LEDs for each color due to the presence of three different color emitting diodes.
- **Servo motor**: We require to servo motors-micro servo 9G, to run the automatic medicine dispenser. One to run the dispenser and the other one to control the opening.
- **OLED**: The Organic Light-Emitting Diode displays the particular patient's data with name, age, medicine prescribed as well as the angle to which the motor is set for that patient.
- **NFC-reader module**: The Adafruit NFC shield uses the PN532 chip-set. The main purpose of the NFC module is to scan the patient's card where the scanned data is used to control the other parts of the prototype.
- **ESP8266 WiFi module**: The central controller for the entire automatic dispenser. All the components are connected to the ESP8266 via jumper wires and breadboard. Specifically, Wemos D1 mini lite is used for the application.
- **Resistors**: The RGB LED is connected via three of 230 ohms resistors to prevent the damage of the LED.

4.2 Design Process and Working

The design of the prototype can be classified into scanning phase and controlling phase. The automatic medicine dispenser consists of different slots which are assigned based on the angles 0, 45, 90, 135, 180 degrees. Each patient is assigned a particular angle which over the course is defined as the slot. The slots are fed with medicines provided by health care workers. Lets dive into the first phase, which is the scanning. The ESP8266, using the Adafruit library compatible for PN532 NFC module is integrated such that the UID of each of the available cards are extracted. The extracted UID is then leveraged on to assign patient data. The patient data includes: name of the patient, name and dosage of the medicine, the rotation angle of the servo motor. The RGB LED, buzzer and the OLED are interrelated to the scanning phase. A visual representation is provided in Figure 4. Please note this is just a representation.

Lets consider a patient who is under treatment living at home possessing a NFC tag. The pill dispenser activates the blue LED and a buzzer sound to inform them that they need to take the medication which will be displayed on the OLED as well. The patient then scans the NFC tag against the NFC reader attached to the pill dispenser. The pill dispenser verifies the NFC card and confirms the patient's identity. Upon successful verification, the green LED illuminates, and a buzzer sounds, indicating that the medication is ready for dispensation. After dispensing, the system records the event and updates the medication log. The system sends a notification to the Slack app, informing the caregiver that the patient has taken their medication on time. The prototype is programmed in such a way that it follows a specific order of patients who will all receive turns to have their medications dispensed. The dispenser waits for the patient whose turn it is for a pre-defined time interval. If the patient misses to scan the NFC card within time, then the patient has to wait until their turn arrives again.

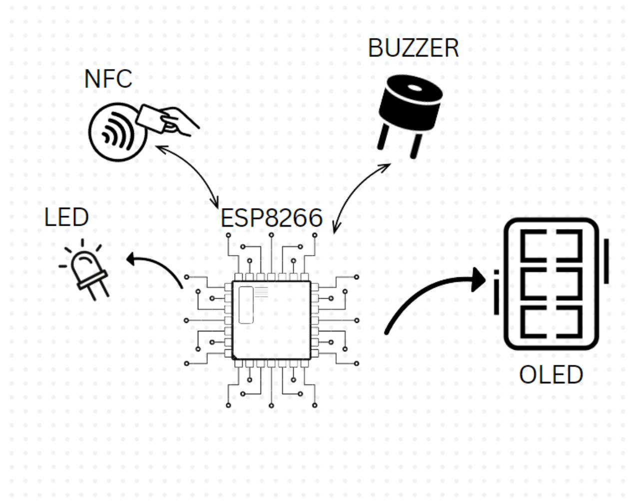

Figure 4: Scanning Phase

Moving onto the control phase, we use two servo motors. One motor is to control the rotation of the slots and the other one is to control the opening and closing of the gap for the medicine to get dispensed through. As mentioned earlier, the NFC cards are associated with specific unique rotation angles. The data obtained from the scanned card is directly sent to one of the motors controlling the rotation of the slots. Once the dispenser rotates to the specific angle, after a certain time delay the second motor rotates to open the gap for the medicine to fall through such that it can be picked up. It has to also be noted that the second motor controlling the opening and closing of the gap only opens on successful scanning of the NFC card within the time interval. The design of the control phase is represented in Figure 5.

The automatic medicine dispenser also interacts with the patient via a slack channel. Initially, the patient is notified via the slack channel with a notification that he/she has to take their dosage of medicine. It basically acts as a reminder to the patient. On successfully scanning the correct patient card, another message is sent onto the slack channel to notify that the intended patient has scanned the card and the medicine is now being dispensed. A notification is also sent, when the intended patient has not turned up to scan their card and has eventually missed the dose. Each time a medication is dispensed, this process is saved in a database on the back-end server with the time and patient that took the medicine.

The slack integration was done in Python, as it is easy to use, has a library for slack and the slower speed does not matter in this case. It is running on a back-end server to support better scalability. We used *flask* to run a socket on the back-end server, which transmits

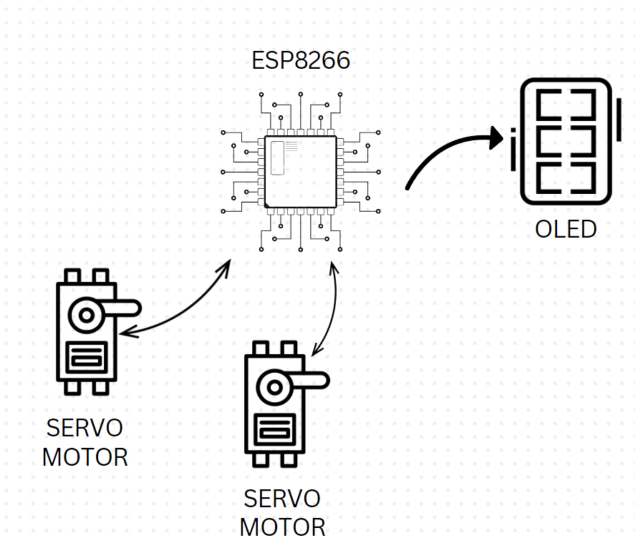

Figure 5: Controlling Phase

the data to the command handler or receives HTTP requests from the medicine dispenser. If the command has the parameter of the patient id, a HTTP request is sent to the medicine dispenser with the patient id as an additional argument. The medicine dispenser then tries to dispense it and return the code 200 if it was successful. In this case, an entry in the database is created and a successful dispensation message is sent to the slack channel. If the dispensation was unsuccessful, an error message that the medicine could not be dispensed will be sent to the slack channel. If a patient uses their NFC card or misses their dose, the medicine dispenser will send a HTTP request to the back-end server with *success* or *fail* and the name of the patient that took or forgot the medicine as an argument. The back-end server will then send a message to the slack channel that the medicine for the patients name has been dispensed or that the patient missed their dose.

4.3 Deployment Issues / Resolutions

During the implementation we faced several issues. The first one was with the servo motor rotation angle. The motor initially was rotating at most 90 degrees instead of a range of 180 degrees. Having the motor rotating 180 degrees was essential for our system to function in the way it is required to. Thus, we altered the values affecting the pulse-width modulation of the servo motor thereby helping us achieve a whole 180 degree rotation of the motor.

Another issue we faced was difficulty with sending HTTP POST requests to slack. We then realized that we were trying to connect to a slack webhook url that uses HTTPS, while using a HTTPClient to send the request. Due to this reason, we decided to use a method on wifiClient that does not validate certificate chains. Although this is insecure generally, this helped us to set up the slack interface for our pill dispenser for the purpose of our implementation.

We also encountered problems with the slack integration, as the *delay()* operation is blocking, thus HTTP requests were dropped if the code was blocked for too long. As the ESP8266 does not support multiple threads, we needed to find a different solution. We remedied this by removing some *delay()* operations by checking the time with *millis()* and continuing with the code once the time interval between patients was reached.

Lastly, we also faced some difficulty with setting up a time interval during which the patient is supposed to scan their NFC card for pill dispensation. It turned out that the method we initially used to detect if a NFC card is scanned or not was a blocking call. This meant that once execution reached this point within the loop that checks if the time-interval has elapsed or not, the execution refuses to exit the aforementioned loop until the NFC card is scanned. Such behaviour would not have helped us in implementing our defined use-cases. To avoid this, we later switched to a non-blocking passive method of the NFC class for NFC card detection.

4.4 Firmware

To ensure smooth operation and precise medication dispensing, the firmware of the automatic medicine dispenser is essential in managing both the scanning and regulating phases. NFC scanning, servo motor control, LED indications, buzzer alarms, OLED display updates, and communication with other systems like the Slack app are just a few of the important features that are integrated by the firmware.

5 PSEUDO-EVALUATION AND RESULTS

This section covers the evaluation of our automatic pill dispenser with regards to its technical strengths and limitations. We also realized a small case study and discuss the results in this section.

First, we evaluate the technical strengths and limitations. One of our goals was to tackle the problem of medication adherence among patients by reducing the possibility that patients forget to take their pills. By interfacing our device with Slack, where a care-giver can receive notifications of a missed dose, we believe this creates the possibility of real accountability. This means that this allows a care-giver to follow up with the patient, possibly remind the patient to take the medication or come up with a plan of action to avoid such misses in the future. We believe such accountability, if followed through, can really reinforce positive behavior on the part of patients. We also believe that using NFC technology helps with quick interaction between the patient and our pill dispenser, because it allows for quick identification such as tapping a card to a reader. Tapping a card to a reader makes our device easy to use, with a simple and straightforward way to dispense medicines to the correct patient.

However, there are also some disadvantages that need to be stated as well. One limitation is the number of patients that our device can serve. At the moment, we plan on only accommodating at most 4 or 5 patients due to limited resources such as NFC cards. Another limitation is the ability of the servo motor to rotate just over 180 degrees. As we leverage on the rotation angle of the servo motor to dispense the medicine for each patient, we would not be able to rotate the dispenser entirely for 360 degrees unlike the stepper motor. This limits the rotation angles resulting in limited slots assigned for each patient with their particular medications in the respective slots.

In the following, we cover a small case study. First, we state the design of our study. Then, we will present the results of the case study.

5.1 Study Design

The idea of the case study is to get an intuition on whether the design regarding generating audio and visual alerts to alert a patient, who then would need to scan their NFC card to receive their prescribed dose is suitable in a normal environment (daily life). The key point of our approach is the scanning of the NFC card within the predefined time interval. To test the feasibility of our pill dispenser, we designed 3 different tasks. Each task represents a different scenario regarding the usage of our pill dispenser. The tasks are specified in the following:

Task 1 : Simulating a correct response to dose time

A dose time is defined as the time when the pill dispenser notifies the patient to take their pills with auditory and visual alerts. The patient then approaches the device with their preconfigured NFC card and scans it against the NFC card reader to have their pill dispensed. It has to be also noted that a correct response involves approaching and scanning the card within the acceptable time interval currently configured to 5 seconds. The device responds to a correct response with further auditory and visual alerts, followed by finally dispensing the pill.

To test whether executing this task in the real world is simple enough, we asked the participants to wait around the device. On hearing the auditory and visual alerts, they are then advised to approach the device, and confirm that it is their turn by looking at the information displayed on the OLED. If it is their turn, we asked the particpants to scan their NFC card within the 5 second limit, and receive the medication prescribed to them. With this seemingly simple task, we also wanted to check the general comfort that users have when using our project.

*E*xpected Results : We expected the participants to scan their NFC card on their turn and within the 5 second limit. By doing so, the pill dispenser would be expected to dispense the medication, accompanied with flashing the green LED and further buzzer sounds.

Task 2 : Simulating an incorrect response to dose time

In this task, we asked the participants to not respond correctly to dose time as stated in Task 1. During dose time, we asked the participants to approach the device and not scan their NFC card if it is their turn until the 5 second time interval elapses. The device responds to such an incorrect response with further auditory and visual alerts, without dispensing any pill.

*E*xpected Results : The goal of this task is partly to inform the participants of how the device responds when they miss dose time, and therefore to reinforce positive behaviour in the long term. By following through on our advised actions for this task, the pill dispenser would be expected to not dispense any medication, accompanied with flashing the red LED and further buzzer sounds.

Task 3 : Simulating remote pill dispensation via Slack

With the final task, we asked our participants to role-play as caregivers to remotely send commands to the pill dispenser to dispense medication for a particular patient through Slack. Every patient is uniquely identified by a patient identification number, which we provide as a list to the participants along with patient names. To simplify the task, we also setup individual Slack accounts for our participants along with access to the Slack channel that is being used.

*E*xpected Results : Once the user enters the command for a particular patient and confirms the action, the pill dispenser would be expected to dispense the medication, accompanied with flashing the green LED and further buzzer sounds.

5.2 Results

We asked 5 people in total to participate in this case study, and in this section we inspect the results of each task separately.

*T*ask 1 : The results of this task were as expected. Initially, some users needed guidance to locate the NFC card reader on the device, but once that was clear, all the participants successfully executed the task, demonstrating the simplicity of using our device. Users found it easy to understand and interact with the system, which shows a positive user experience.

*T*ask 2 : The results of this task were also as expected. Since this task didn't need much involvement from the users, except that they were observant to how the device responded to their inaction, all participants successfully completed this task. A few participants also stated that they found the visual and auditory cues to be helpful.

*T*ask 3 : Considering that the task was greatly simplified for the users, all they had to do was choose a valid patient identification number and enter the command in the slack channel. It is to be noted that the users were also provided with the syntax of the command, which further simplified the task at hand. On entering the command, the results were as expected with the functioning of the pill dispenser. One of the participants of this task was really impressed with this functionality, and remarked to us that they would love to have such a device with this capability, as they currently have elderly parents living at home, who would benefit with such a device.

6 CONCLUSION

To conclude, the proposed system aims at addressing the issue of medication non-adherence which leads to severe health implications resulting in increased medical costs.

We introduce the IoT-based automatic pill dispenser, which proves to be a promising solution to medication non-adherence. Our system tries to address the issue and tackles it by ensuring timely medication intake, preventing dosing errors, and enhancing adherence. The above features are achieved by integrating simple hardware, firmware, and communication protocols over the device. Moreover, this integration brings along some more features such as NFC patient verification and real-time updates to caregivers via Slack. The utilization of the Slack app brings along secure and reliable remote monitoring and control of the medical system.

The main objective of developing such a system is in the vision of providing a reliable and efficient medication management system that improves patient interaction outcomes as well as decreasing the healthcare workers' burden.

Future work could explore improving the functionality for a larger number of users. Thus focusing on scalability, as well as compatibility with various medications. It could also look into the scope of smartly measuring the dosage of the medicine being dispensed by integrating the weight scanner hardware onto the prototype. This could prevent over-dosage and thus reduce the physical monitoring of dose dispensing.

7 CONTRIBUTIONS

Shraman Jain : Report contributions for Milestone 1,2,3 and hardware/firmware and device construction support.

Vignesh Sriram : Report contributions for Milestone 1,2,3 and hardware/firmware and device construction support.

Dan Jose : Report contributions for Milestone 1,2,3 and hardware/firmware support with poster creation.

Timon Dörzapf : Report contributions for Milestone 1,2,3 and hardware/firmware support along with slack implementation and final video presentation.

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