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

Vinay Peddisetti[1]
vinaypeddisetti@csu.fullerton.edu

Pavan Kumar Kandregula[1]
kandregula123@csu.fullerton.edu

Joel Anil John[2]
joel.aniljohn@csu.fullerton.edu

Suseela Poomdla[2]
suseelapoomdla@csu.fullerton.edu

Kiran George[1]
kgeorge@fullerton.edu

Anand Panangadan[2]
apanagadan@fullerton.edu

[1]*Electrical and Computer Engineering Department*
California State University, Fullerton
Fullerton, USA

[2]*Computer Science Department*
California State University, Fullerton
Fullerton, USA

***Abstract*–In today's fast-paced environment, medication errors present a pressing challenge, especially for vulnerable demographics such as the elderly and individuals with mental and cognitive health conditions. To address these critical issues, we present a suite of innovative IoT-based solutions, encompassing the Smart Pill Dispenser, Smart Cup, and an Android Application for real-time notifications. These integrated devices offer a streamlined approach to medication management, ensuring precise and timely intake with a primary focus on pill-based medications. The Smart Pill Dispenser, powered by the Arduino Nano RP2040 microcontroller, is used for precise pill dispensing. The Smart Cup incorporates accelerometers, gyroscopes, and ultrasonic sensors for robust pill consumption verification. Facilitating seamless communication via Bluetooth Low Energy technology, this solution promises to enhance medication adherence significantly, particularly for individuals in need of continuous care, thereby enhancing healthcare quality and patient well-being.**

Keywords–Arduino, pill dispenser, smart cup, BLE, mobile application, healthcare, IoT, accelerometer, gyroscope.

I. Introduction

A major healthcare challenge is poor medication adherence, which is defined as how closely a patient takes their medications as prescribed. Poor medication adherence significantly contributes to the failure of treatment regimens [1]. Bedell *et al*. [2] uncovered a 76% discrepancy between prescribed medications and those consumed by patients. Incorrect timing and dosage further exacerbate morbidity and mortality rates [3]. Researchers have developed several devices for precise medication delivery to address this issue. Such medication adherence solutions are particularly valuable to individuals with physical or cognitive limitations, notably seniors. These automatic pill dispensers have the potential to enhance a user's quality of life by ensuring the timely delivery of prescribed medications.

The far-reaching integration of Internet of Things (IoT) technology has redefined various sectors, with its influence notably ascending in the medical field over the past decade.

However, one important aspect of medication dispensing solutions still needs to be addressed: verifying actual pill consumption by the user after it is dispensed and who to notify if the patient does not take the dispensed medication. Most pill-dispensing products focus on dispensing pills at scheduled intervals and do not verify whether the pill was consumed after it was dispensed. This paper endeavors to offer a comprehensive solution to medication adherence by introducing an IoT-based Smart Pill Dispenser and Smart Cup, coupled with seamless integration with an Android application. This amalgamation facilitates real-time monitoring of pill consumption, notification of users at scheduled times, and alerts for medication refills. Moreover, the paper addresses the issue of potential overdoses by ensuring the dispensing of prescribed medications only once within designated timeframes, thereby contributing to a safer and more effective medication management approach.

II. Related Work

In the field of medication adherence solutions, prior research has explored various avenues, each offering distinctive contributions:

Rajan *et al.* introduced a "Smart Pill Box" with IoT functionality, combining GSM interfaces and Arduino technology [4]. Leveraging the Blynk app, the system delivered timely notifications. It prioritized medication adherence, offering reminders and automated refilling, streamlining medication management.

Al-Mahmud *et al.* introduced an IoT-based Medical Box that delivers medication reminders through email notifications [5]. The system incorporated health sensors, facilitating regular monitoring. With wireless connectivity, it promoted healthcare management and enabled remote communication between patients and healthcare providers.

Hayes *et al*. developed the MedTracker system, emphasizing mobility and in-depth insight into non-adherence and medical errors. However, data transfer requires a Bluetooth-enabled computer, limiting accessibility [6].

Our proposed solution builds upon these works by introducing a comprehensive IoT-based approach, encompassing a Smart Pill Dispenser, Smart Cup, and an Android application for real-time monitoring, notifications, and adherence alerts. Mainly the pill consumption verification and adopting the fail-safe mechanism to prevent overdosing of pills. This addresses the critical limitations of existing solutions.

III. SYSTEM DESIGN

The system described in this paper encompasses three primary components, as shown in Fig.1: the Pill Dispenser, the Smart Cup, and the Android Application, which collectively form a comprehensive solution for medication management. The cohesive integration of these three components comprises a sophisticated system for effective medication management, ensuring adherence to prescribed schedules and promoting patient well-being.

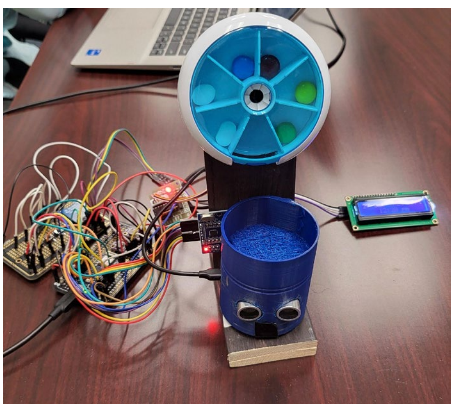

Fig.1. Smart Pill Dispenser and Smart Cup Intended Placement in Completed Design.

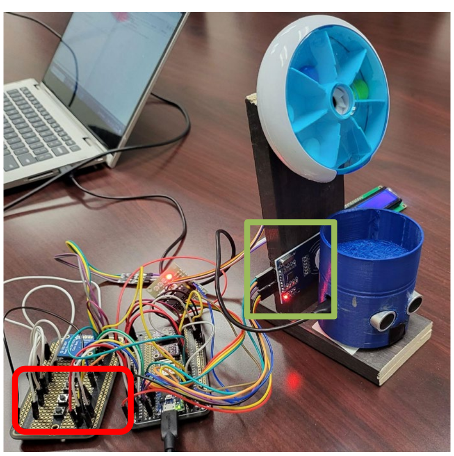

Fig. 2. Smart Pill Dispenser and Smart Cup with the buttons highlighted in red for scheduling and the RFID in green.

The integral component of the system, the Pill Dispenser, is shown in Fig.1. serves the fundamental role of precisely dispensing medications at their prescribed times. It facilitates user input for setting the designated medication schedule, ensuring time tracking for adherence to these schedules. Additionally, the Pill Dispenser is pivotal in notifying the user by signaling the associated Android application during scheduled medication times. It forms the core of the medication management system, orchestrating the timely and accurate delivery of medication doses, thus enhancing the overall healthcare experience.

The Smart Cup is a critical element in the system's architecture, an essential link between the Pill Dispenser and the user. It is precisely engineered to validate whether the user has effectively consumed the dispensed pills. This verification process is paramount in ensuring the system fulfills its primary objective—medication adherence. To maintain user-friendliness and convenience, the Smart Cup has wireless charging capabilities, a feature designed to accommodate elderly users who may encounter difficulties with frequent battery replacements. This innovation aligns to enhance healthcare quality by facilitating seamless and efficient pill consumption verification.

The system features an Android Application designed to track and manage medication habits. It acts as an interface for the user, connecting with the Pill Dispenser to receive notifications during scheduled medication windows. In case of a missed dose, the Pill Dispenser notifies the user through the Android Application, serving as a timely reminder. Furthermore, it sends the refill notifications to the application when the pills in the dispenser are about to finish. Android application, currently in the development phase, is an extensible one, indicating that the same application can connect to multiple IoT devices and display processed information.

Moreover, the Android Application serves as a data repository, functioning as a server to store comprehensive logs of pill consumption. Users can also utilize the application to review their medication history, fostering better medication management. By seamlessly integrating with the other system components, the Android Application plays a crucial role in enhancing medication adherence and simplifying the user experience.

The communication between all three system components is facilitated through Bluetooth Low Energy. BLE has been selected as the communication protocol due to its established track record in developing efficient IoT systems, particularly for short-range communications. Energy efficiency is of paramount importance in the design of our system, which is tailored to the needs of elderly individuals. Maintaining synchronization and continuous communication between the Pill Dispenser and Smart Cup and Pill Dispenser and Android application is imperative for the system's functionality. In this context, BLE proves to be a reasonable choice due to its remarkable energy efficiency compared to alternatives like classic Bluetooth or Zigbee, and its widespread integration in smartphones distinguishes it from other low-power wireless technologies such as ZigBee or Thread [7].

Furthermore, BLE's capabilities extend beyond energy efficiency. It possesses the potential to support voice transmission and bidirectional data exchange, thereby positioning the system for future expansion and advanced functionality. This choice aligns with the long-term vision of the project, ensuring its adaptability and readiness for forthcoming enhancements.

Hardware Design

A) Pill Dispenser:

The Pill Dispenser is built around the Arduino Nano RP 2040 Connect microcontroller. This microcontroller is equipped with an integrated Bluetooth Low Energy (BLE) module, simplifying the establishment of Internet of Things (IoT) connectivity. An external Adafruit DS3231 Precision RTC module is employed for precise time tracking, ensuring adherence to medication schedules. The Dispenser is designed with an array of user interface elements shown in Fig.2, including buttons and an LCD with an I2C serial interface, which enables users to program and manage their medication schedules. At its core, a 28BYJ-48 stepper motor, coupled with the ULN2003 driver board, powers a pill container with seven slots, facilitating the automated dispensing of pills at predetermined times. The BLE module allows seamless communication between the Pill Dispenser, the Smart Cup, and the Android Application.

To enhance the safety and accuracy of the system, an RFID RC522 Module receiver is integrated, ensuring that the Smart Cup is correctly positioned before pills are dispensed. It communicates to the microcontroller with SPI protocol. This feature serves as a fail-safe mechanism for the risk of dispensing pills outside the cup.

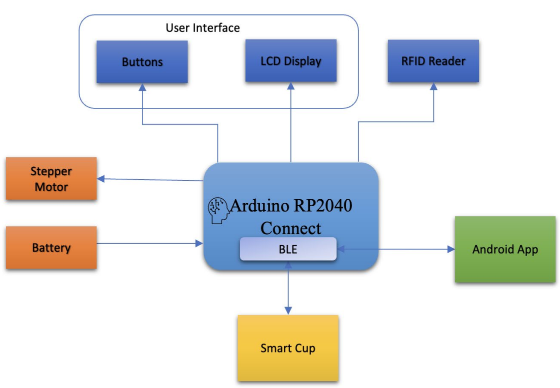

Fig.3. Block diagram of Pill Dispenser.

B) Smart Cup:

The Smart Cup, another integral system component, utilizes the same Arduino Nano RP 2040 Connect microcontroller used for the Pill Dispenser. It leverages BLE technology to connect and synchronize with the Pill Dispenser, ensuring that pills are dispensed into the cup at the scheduled time. Moreover, it is powered by wireless charging since elderly people may face difficulty changing the battery. To monitor the consumption of dispensed pills, the Smart Cup is equipped with an LSM6DSOX Inertial Measurement Unit (IMU), encompassing an accelerometer and gyroscope to detect the motion and angular momentum of the cup. Additionally, an ultrasonic sensorHC-SR04 is employed to find the user's proximity after dispensing pills, verifying that the user has consumed the pills [8]. This not only promotes medication adherence but also enhances data accuracy for the Android Application.

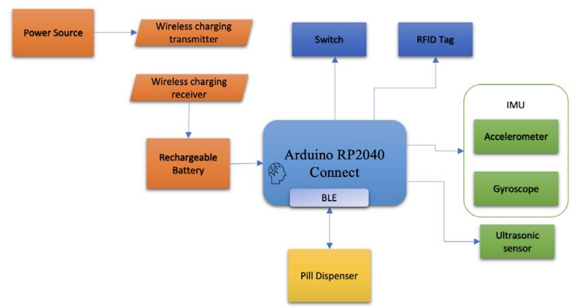

Fig.4. Block diagram of Smart Cup

Android Application Implementation

The connection between the pill dispenser and the Android app is established through BLE. The Android application presents the user with two pages, one for connectivity and the other for interacting with the device. These tabs are called "Home" and "Notification" respectively, and these are separated by a tab layout where the user can swipe either left or right on the screen to get to either one.

The "Home" tab is shown in Fig.5. consists of three buttons the user must click to connect to their device successfully. The "Enable Bluetooth" button will be first visible to the user upon entry to the app. Once this button is clicked, the application will check to ensure that the user has enabled Bluetooth in the settings of their device. If they have not, the application will display an alert asking the user's permission to enable Bluetooth. If the user accepts, the application will enable Bluetooth to proceed in the connection process. Next, the application prompts the user with the "Scan for Bluetooth Devices" button. Pressing this button will trigger a scan of all the Bluetooth devices in the area that are active. Before it does so, to use security measures that Android 12 has in place, the app must first request permission from the user. Once the user accepts, then the scan will truly start. The last and final button that then unveils to the user is the "Start" button.

Once clicked, this button will list out all the Bluetooth devices in the area that are currently advertising, as shown in Fig.6. The user will then click on the name of the device that they want to connect to. This will trigger a connection, and if successful, the app will connect to the device and display a toast (message on the bottom center of the screen) informing the user that the Android device has successfully connected to the pill dispenser.

Fig.5. Images of the Home page, List of Bluetooth devices, and Notifications page

The notification tab is shown in Fig.7. and consists of a text field area and a button titled “Send Acknowledgement.” Once the patient has consumed a pill, the pill dispenser will send a message over to the application. If not consumed, the pill dispenser will wait until the end of the buffer period to send a message stating that the pill hasn’t been consumed. This message states whether the pill has been consumed and the exact time and date when it was or was not consumed. This message is received by the application and then displayed in the notification tab. Once received, the app sends an acknowledgment back to the device, letting it know that the message was received by the application and correctly displayed to the user.

IV. Methodology

Development of the proposed system is characterized by robust fail-safety mechanisms, seamless synchronization, and user-friendly operation. The system architecture is designed to ensure accurate and reliable medication management, encompassing the following key steps:

A. System Initialization:

Upon system power-up, the RP2040 microcontroller reads and retrieves the last dispensed and last pill consumption time stored in the flash memory. This safeguard is vital to prevent the inadvertent dispensing of pills multiple times, contributing to the fail-safe mechanism. It initializes the BLE communication with the Smart Cup and Android application. Smart Cup remains on standby until pills are dispensed, enhancing safety and minimizing user interaction.

B. User Interface and Scheduling:

Users can efficiently program medication schedules using the user-friendly interface, which includes physical buttons and an LCD. These features facilitate schedule programming and enable users to review previously scheduled timings when the system is powered on.

C. Time Tracking and Schedule Management:

Leveraging the integrated RTC module within the Pill Dispenser, the system calculates the next scheduled medication time accurately. The Android Application receives a notification from the Pill Dispenser, providing a 5-minute advance alert to the user, thereby ensuring timely medication adherence.

D. Smart Cup Position Verification:

To enhance safety and accuracy, the system activates the RFID RC522 Module receiver. It verifies the correct positioning of the Smart Cup using the tag attached to it. This step ensures the cup is in place to receive the dispensed pills.

E. Bluetooth Low Energy (BLE) Communication:

The Smart Pill Dispenser and the Android application establish a BLE connection to enable communication. This connection is initiated through the pairing process, ensuring a secure and reliable link between the two devices. To maintain the Bluetooth connection, an auto-scanning feature is implemented in the Android application. This feature continually scans for the presence of the Smart Pill Dispenser, re-establishing the link if it is interrupted due to unforeseen circumstances.

Once the Bluetooth connection is established, both devices engage in regular message exchanges at predefined time intervals. This proactive communication strategy is designed to preserve the connection's stability and reliability. It ensures that the Smart Pill Dispenser and the Android application remain synchronized, allowing real-time data exchange.

Furthermore, the Pill Dispenser, functioning as a BLE peripheral, initiates BLE packet advertising 5 minutes before the scheduled time to the Smart Cup, designed as the BLE Central device. When the current time approaches the scheduled time, it cross-checks the previous pill consumption time to prevent potential over-dispensing during the scheduled interval. Simultaneously, the Pill Dispenser communicates with the Android Application. The user is notified 5 minutes before the scheduled medication time to ensure readiness.

F. Pill Dispensing Mechanism:

Upon successful BLE connection between the Cup and Dispenser, a "Push to dispense" message is displayed on the LCD, instructing the user to push the button to dispense the pills into the Cup. The Dispenser then orchestrates the rotation of the pill container to facilitate pill dispensing and sends corresponding BLE characteristics to the Cup, confirming pill delivery.

G. Pill Consumption Verification:

The Smart Cup awakens from standby mode and activates the Inertial Measurement Unit (IMU), incorporating Accelerometer and Gyroscope sensors. These sensors monitor the cup's movements, providing valuable data for pill consumption verification. Additionally, an Ultrasonic sensor is employed further to enhance the accuracy of the pill consumption assessment. Smart Cup analyzes the sensor data, evaluates the movements, and verifies pill consumption. It sends back the signal indicating the pill consumption verification.

H. Data Logging and User Alerts:

The Pill Dispenser sends the consumption status and timestamps to the Android application, ensuring a comprehensive history of pill consumption. In the event of a missed medication dose, the Android Application is triggered to alert the user promptly. If the pills are about to finish, Pill Dispenser will send a refill notification to the App.

This methodology, characterized by fail-safety measures, meticulous synchronization, and effective user interaction, forms the foundation of the proposed system's functionality, enhancing medication adherence and patient well-being.

V. Evaluation And Results

The evaluation of the system predominantly centers around four critical aspects, each contributing to the overall assessment of its functionality and reliability:

A. *Accurate Stepper Motor Rotation*

Accurate rotation of the stepper motor is a pivotal aspect of the evaluation. This entails ensuring that the motor operates flawlessly, precisely positioning each slot for pill dispensing into the cup. The system must consistently achieve this, as accuracy is paramount in medication management. In the context of the system's hardware, choosing the 28BYJ-48 stepper motor operating at 5V is essential. This selection was motivated by the motor's compact size and energy efficiency. To enable precise control over the stepper motor's operation, it is coupled with the ULN2003 driver board, which grants comprehensive control over aspects such as direction, speed, and acceleration.

To further evaluate the system's hardware performance, a series of tests were conducted. The stepper motor underwent testing with five different acceleration settings and four different speed settings for each acceleration. These tests assessed the system's ability to rotate accurately to each slot, a vital factor in the reliable dispensing of pills. For each speed configuration, the completion time for rotating to the next slot was measured. This measurement gauged how efficiently the system moved between slots. Furthermore, each rotation was evaluated for its appropriateness to allow pill dispensing.

Tables 1 through 5 [7] include the recorded total time taken for the pill dispenser to rotate to the designated slot, dispense the pills, alert the Smart Cup to monitor cup movements, and facilitate two-way communication between the Smart Cup and the Smart Pill Dispenser. In total, this rigorous experiment comprised two hundred measurements, ensuring a thorough assessment of the system's hardware performance and its ability to facilitate accurate pill dispensing.

Table 1: Average time to rotate and total task time for an Acceleration value of 50 based on 4 set speeds.

Acceleration	Speed	AVG Time to rotate (s)	AVG Total Time for Task (s)	Success Rate of Delivery
50	250	4.57	18.61	100%
	500	4.47	18.86	100%
	750	4.26	18.86	100%
	1000	4.38	18.86	100%

Table 2: Average time to rotate and total task time for an Acceleration value of 100 based on 4 set speeds.

Acceleration	Speed	AVG Time to rotate (s)	AVG Total Time for Task (s)	Success Rate of Delivery
100	250	2.61	17.31	100%
	500	2.76	17.63	100%
	750	2.50	17.44	100%
	1000	2.90	17.40	100%

Table 3: Average time to rotate and total task time for an Acceleration value of 200 based on 4 set speeds.

Acceleration	Speed	AVG Time to rotate (s)	AVG Total Time for Task (s)	Success Rate of Delivery
200	250	1.92	16..45	100%
	500	1.95	16.45	100%
	750	1.93	16.41	100%
	1000	1.95	16.47	100%

Table 4: Average time to rotate and total task time for an Acceleration value of 400 based on 4 set speeds.

Acceleration	Speed	AVG Time to rotate (s)	AVG Total Time for Task (s)	Success Rate of Delivery
400	250	1.57	16.27	100%
	500	1.58	16.26	100%
	750	1.55	16.25	100%
	1000	1.58	16.25	100%

Table 5: Average time to rotate and total task time for an Acceleration value of 800 based on 4 set speeds.

Acceleration	Speed	AVG Time to rotate (s)	AVG Total Time for Task (s)	Success Rate of Delivery
800	250	1.00	15.37	100%
	500	0.97	15.50	100%
	750	0.94	15.43	100%
	1000	0.94	15.32	100%

B. *Validation of Fail-Safe Mechanism*

The evaluation rigorously assesses the system's fail-safe mechanisms, engineered to avert the risk of over-dispensing medications during prescribed schedules. The fail-safe mechanism underwent comprehensive validation in the following three scenarios, each designed to scrutinize its effectiveness and reliability.

i) In the initial scenario, pills were dispensed at the scheduled time, and pill consumption occurred in a single continuous event. This test verified the system's ability to facilitate accurate stepper motor rotation and successful pill dispensing into the Smart Cup. Consequently, pill consumption was positively validated as the pills were visibly consumed, demonstrating the system's accuracy.

ii) The second scenario involved the dispensing of pills at the designated time, followed by a system reset before Smart Cup could validate pill consumption. This test was instrumental in determining the system's resilience in preventing potential overdoses. As anticipated, the dispenser effectively safeguarded against over-dispensing, even in cases where the dispense button was pressed multiple times after pills were already dispensed. The system seamlessly resumed the pill verification with the pills initially dispensed before the reset.

iii) In the third scenario, a comprehensive cycle of pill dispensing and consumption occurred within the five-minute window of the scheduled time. An attempt to dispense pills again within the same scheduled window was made. In line with expectations, the Pill Dispenser efficiently prevented double dispensing for a scheduled time, reinforcing the system's robust fail-safe measures.

These meticulous evaluations of the fail-safe mechanism underscore its reliability in mitigating the risk of medication errors, reinforcing the system's adherence to safe medication dispensing practices. These tests validate the fail-safe mechanisms' effectiveness and their pivotal role in the system's overall performance.

Table 6: Results of the fail-safe mechanism evaluations.

Scenario	Test Description	Outcome
i)	Dispensing and consumption occurred in a single continuous event	Successful pill dispensing and consumption verification
ii)	Dispensing followed by system reset before consumption validation	Prevention of over-dispensing, successful pill verification after reset
iii)	Dispensing and consumption within the five-minute window, followed by an attempt to dispense again	Efficient prevention of double dispensing

C. *Verification of Pill Consumption*

The validation of pill consumption tracking represents a critical facet of our evaluation. It is necessary for the system to accurately detect and confirm the act of pill consumption, primarily relying on the Smart Cup's sensors, including the Inertial Measurement Unit (IMU) and Ultrasonic sensor. The precision of this verification is paramount for monitoring medication adherence. To this end, experiments were meticulously conducted to assess the system's performance in discerning three specific pill consumption scenarios discussed below.

Test 1 - Ideal Pill Consumption: In this scenario, the user's pill consumption process proceeded as intended.

Test 2 - False Positive: This scenario was deliberately constructed to simulate situations where the user initiates and does not complete the pill consumption action, yet the system erroneously identified it as a completed action.

Test 3 - Non-Initiation of Pill Consumption: Here, we evaluated cases where the user did not initiate the pill consumption action.

To evaluate the above scenarios, we closely observed specific movements critical to the proper consumption of pills, which are:

1) Lifting the Cup - Utilizing the Z-axis readings of the accelerometer.

2) Tilting the Cup - Determining the angular movement of the cup using the gyroscope.

3) Sequential Movements - Assessing both lifting and tilting actions performed in sequence.

These movements were executed in the three scenarios, aiming to challenge the system and assess its capability to discern and differentiate between valid pill consumption and potential false positives. Each test was conducted thrice for each movement, resulting in a comprehensive set of 27 measurements.

Accuracy Achieved:

As shown in Table 7 [9], the outcome of these evaluations was a remarkable 100% accuracy in detecting the pill consumption status, as depicted in Table 1. This high level of accuracy underscores the system's capability to track pill consumption reliably and effectively, enhancing its role in monitoring medication adherence.

Table 7: Results of Pill consumption verification.

Number of true positives			
Measurement	**Test 1**	**Test 2**	**Test 3**
Movement 1	3	3	3
Movement 2	3	3	3
Movement 3	3	3	3
Accuracy	100%	100%	100%

These results demonstrate the system's exceptional proficiency in monitoring and verifying pill consumption, bolstering its value in promoting adherence and patient well-being.

D. *Testing BLE Communication:*

Verifying the Bluetooth Low Energy (BLE) communication with the Android Application is crucial in the Smart Pill Dispenser and Smart Cup IoT-based system. Three primary tests were conducted to assess the system's BLE communication capabilities:

1. BLE Pairing and Connection Establishment:

The initial assessment focused on the pairing and connection establishment between the Smart Pill Dispenser, Smart Cup, and the Android Application. This test ensured the system's proficiency in establishing and maintaining stable BLE connections.

2. Data Transmission Reliability:

A critical facet of BLE communication is the reliable transmission of data. Multiple data types, including medication schedules, dispensed pill information, and user alerts, were transmitted between system components and the Android Application. The goal was to validate the system's ability to transmit data accurately, ensuring timely delivery of medication reminders and adherence alerts.

3. Synchronization Testing:

To confirm synchronization accuracy, the system underwent various scheduling scenarios, including concurrent and rescheduled medication times. This test ensured that the Android Application accurately received and synchronized medication schedules and adherence data, reflecting real-time changes made through the Pill Dispenser's user interface.

These three fundamental tests encompass BLE communication validation and are pivotal in evaluating the system's robustness in facilitating seamless IoT-based medication management. These assessments provide valuable insights into the system's efficacy and reliability in maintaining BLE connections and accurate data exchange with the Android Application.

VI. Future Work And System Expansion

The exciting prospects for further development within the system involve extending the pill dispenser's capability from the current 7 slots to a 28 slots system, thereby enabling greater flexibility in medication management. To increase the efficiency of pill consumption verification, future iterations will incorporate a weight sensor within the Smart Cup. This addition will further refine the system's ability to accurately confirm pill consumption, ensuring heightened precision in medication adherence monitoring.

The ongoing development of the Android application includes implementing an auto-connection feature. This feature will streamline the user experience by enabling the application to initiate a connection with the pill dispenser as soon as it commences advertising. This eliminates the need for manual connection setup by the user, enhancing the overall usability and convenience of the application. Also, a user-friendly interface will be added, which allows individuals to configure their prescribed medication schedules seamlessly. It will be equipped with the capability to connect to multiple IoT devices. This extended compatibility ensures that users can manage various aspects of their healthcare through a unified platform, offering a holistic approach to IoT-based healthcare solutions.

To improve the application's security, future work will focus on regular GPS location updates and the implementation of robust authentication and authorization mechanisms. These measures will ensure the integrity and confidentiality of user data, enhancing the overall safety of the application. It also includes local data storage and seamless synchronization with cloud services, such as AWS. This integration will enable users to access and manage their medication consumption history from any location, leveraging the advanced capabilities and scalability cloud platforms offer.

The application will require user authentication and account creation to access its services, elevating security standards and ensuring user accountability for utilizing the app's features. Logs detailing consumption history will be securely stored in cloud services like AWS, offering users the convenience of accessing their historical medication data at any time.

These future enhancements and expansions signify a comprehensive commitment to advancing the system's capabilities, user experience, and overall effectiveness in medication management and adherence.

VII. Limitations

1. The findings may not be as broadly applicable to a larger population because this study’s participants are from a particular demographic group.
2. A controlled setting and simulated circumstances were used for the system evaluation. This controlled environment may not accurately represent the variety of dynamic variables that users may experience in their daily lives, which could influence the system's efficacy in the real world.
3. Users' persistent usage of the Smart Cup and Smart Pill Dispenser as intended is necessary for the system to function well. This is dependent on their compliance with the technology. The overall performance of the system could be impacted by any departure from the typical user behavior.
4. The system's scalability isn't fully tested with respect to the pill dispenser's capacity. For upcoming deployments, scalability-related issues must be recognized and resolved.
5.Reliance on Bluetooth Low Energy (BLE) technology can result in restrictions over connectivity and device compatibility. It is possible that some consumers won't have BLE-capable devices, which could limit how widely the system is used.

VIII. Conclusion

This paper introduces the designed Pill dispenser and Smart cup, in conjunction with the Android Application, which will address the critical issue of maintaining medication adherence. The pill dispenser handles the scheduling of pills for each day and time. The Smart cup is responsible for the verification of pill consumption. Android application is developed to notify the user during the scheduled time and alert the user in case of missed dosage. The communication between these components is established using BLE technology. Through rigorous evaluations and experimentation, the fail-safe mechanisms within the system have demonstrated their reliability in preventing over-dispensing, reinforcing the commitment to patient safety. Verifying pill consumption has showcased the system's precision and ability to ensure adherence. Looking to the future, system expansion plans include increasing the pill dispenser's capacity and enhancing the Android application's usability, security, and data management. These innovations promise a more user-centric and flexible medication management experience.

ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation under Grant No. 2125654.

REFERENCES

[1].T. L. Hayes, J. M. Hunt, A. Adami and J. A. Kaye, "An Electronic Pillbox for Continuous Monitoring of Medication Adherence," 2006 International Conference of the IEEE Engineering in Medicine and Biology Society, New York, NY, USA, 2006, pp. 6400-6403, doi: 10.1109/IEMBS.2006.260367.

[2].S. E. Bedell, S. Jabbour, R. Goldberg, H. Glaser, S. Gobble, Y. Young-Xu, T. B. Graboys, and S. Ravid, "Discrepancies in the use of medications: their extent and predictors in an outpatient practice," Arch Intern Med, vol. 160, pp. 2129-34, 2000.

[3].Dhawan I, Tewari A, Sehgal S, Sinha AC. Medication errors in anesthesia: unacceptable or unavoidable? Braz J Anesthesiol. 2017 Mar-Apr;67(2):184-192.

[4]. B. P. T. Rajan et al., "Smart Pill Box With Reminder To Consume And Auto-Filling Process Using IOT," 2021 Fifth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), Palladam, India, 2021, pp. 40-44, doi: 10.1109/I-SMAC52330.2021.9641043.

[5].O. Al-Mahmud, K. Khan, R. Roy and F. Mashuque Alamgir, "Internet of Things (IoT) Based Smart Health Care Medical Box for Elderly People," 2020 International Conference for Emerging Technology (INCET), Belgaum, India, 2020, pp. 1-6, doi: 10.1109/INCET49848.2020.9153994.

[6].T. L. Hayes, J. M. Hunt, A. Adami and J. A. Kaye, "An Electronic Pillbox for Continuous Monitoring of Medication Adherence," 2006 International Conference of the IEEE Engineering in Medicine and Biology Society, New York, NY, USA, 2006, pp. 6400-6403, doi: 10.1109/IEMBS.2006.260367.

[7]. S. R. Minera, A. Nuerbiya, A. Espinoza, K. George and A. Panangadan, "Smart Pill Dispenser with Smart Cup," 2023 IEEE World AI IoT Congress (AIIoT), Seattle, WA, USA, 2023, pp. 0598-0604, doi: 10.1109/AIIoT58121.2023.10174536.

[8]. J. Fürst, K. Chen, H. -S. Kim and P. Bonnet, "Evaluating Bluetooth Low Energy for IoT," 2018 IEEE Workshop on Benchmarking Cyber-Physical Networks and Systems (CPSBench), Porto, Portugal, 2018, pp. 1-6, doi: 10.1109/CPSBench.2018.00007.

[9]. S. R. Minera, A. Nuerbiya, A. Espinoza, K. George and A. Panangadan, "Smart Cup for a Smart Pill Dispenser for Verification of Pill Consumption," 2023 IEEE 13th Annual Computing and Communication Workshop and Conference (CCWC), Las Vegas, NV, USA, 2023, pp. 0994-0998, doi: 10.1109/CCWC57344.2023.10099363.