

ScanAlert: Electronic Medication Monitor and Reminder to Improve Medication Adherence

Vanessa Sanchez¹, Russell Ro¹, Lauryn Kent¹, Jamie Navas¹, Oluwatosin Diyan¹, Chris Roussel², Shahab Tayeb³

¹AEOP UNITE, ²RET, ³UNLV
Las Vegas, Nevada

Abstract—Lack of medication adherence accounts for billions of dollars lost and immense morbidity in the health industry. ScanAlert was developed to reduce medication non-adherence by reminding and monitoring the accidentally neglectful patients. The integrated system covers three main processes: setup, signal, and scan. In the setup process, a patient will input prescription information, contact e-mail addresses, and network information into the system. ScanAlert will signal the user by activating the buzzer thirty minutes prior to the scheduled time and at the scheduled time of medication intake. The patient is notified to take the prescription and scan the modified RFID tag attached underneath the cap of the prescription bottle to complete the process. If the prescription is not taken within thirty minutes, they receive the scheduled reminder in which they must scan the prescription cap. Any occurrence of the cap not being scanned, ScanAlert will send an e-mail to the designated physician. ScanAlert has the potential to reduce missed prescriptions, notify physicians of patient medication non-adherence, improve patient outcomes, and reduce the financial burden to insurance companies and patients.

Keywords—Adherence, Arduino, Android, electronic medication monitor, integrated system, RFID.

I. INTRODUCTION

Medication adherence refers to the consistency in which a patient takes their prescribed medication as instructed. For example, a patient may be prescribed to take a prescription two times a week: every Monday and Friday morning. However, many patients, whether purposefully or not, are not adhering to their prescribed schedule. Poor medication adherence accounts for 33 to 69 percent of all medical-related hospital admissions in the United States, as well as the loss of \$100 billion annually in increased medical costs, and the annual deaths of approximately 125,000 per year [1-3]. This prevalent issue may be assessed through two methods of categorization: direct or indirect. Osterberg *et. al.* defines direct assessment as the physical, concrete oversight between the physician and patient. This method may include directly observed therapy, measurement of the level of medicine or metabolite in blood, and measurement of the biological marker in blood [4]. Indirect assessment is defined as the opposite. It is the more efficient method but falls in its lack of assurance as it relies on the patient's integrity. For example, patient questionnaires, self-reports, pill counts, rate of prescription refills, assessment of the patient's clinical response, electronic medication monitors, measurement of physiological markers, and patient diaries may be used. "Each

method has its pros and cons, and no method is considered to be gold standard" [8].

A factor that contributes to medication non-adherence comes from erroneous prescription reports such as handwritten notes or printed instructions. Electronic prescribing provides a solution and replaces the need for paper and fax machines. Prescription errors account for 70% of medication errors that could potentially result in adverse effects [5]. Information regarding specific medications is sent to the pharmacy and in most cases, individual patients. This solution reduces the risk of errors in prescribing new medication, such as poor handwriting, creating faults in dose selection, or forgetting specific instructions for taking this medication. Mistakes in prescriptions are rarely fatal, but it can affect the safety and health of the users. The use of electronic prescribing increases chances for eliminating patient biases in indirect methods such as patient self-reports. In the context of both issues, medication adherence and electronic prescription could be accounted for two-fold through electronic medication monitors.

To improve medication adherence, we developed an affordable medication adherence system that will both remind and encourage patients to take their medication as accurately prescribed by their physician. The proposed system is composed of an application that will be downloaded on the users' phone, and a prototype. The Bluetooth application will allow the users or physicians to connect to the Arduino and input the medication name and dosage as a means of electronic prescription. To remind the users to ingest the proper prescription, the device will sound and display which prescription to ingest. The users will be reminded both thirty minutes prior to and at the scheduled time of medication intake. Using a built-in sensor, the users must scan a Radio-Frequency Identification (RFID) tag (attached underneath the cap of the appropriate pill bottle) to turn off the buzzer and to validate ingestion. If the users do not comply within the one hour window, an e-mail will be sent to the physician alerting them of the users' noncompliance.

The purpose of this research is to improve medication adherence resulting in more favorable health outcomes, particularly reductions in morbidity and mortality. Improvement in patient adherence will also result in substantial savings to the health insurance industry. The money saved by the insurance industry will hopefully lead to a reduction of insurance premiums allowing more people to afford better insurance coverage.

The rest of our paper is organized as follows. Section II analyzes similar works and describes their purposes and their downfalls. Section III details the devices and systems used to collect data. Next, the process of experimentation follows and describes instances of a user's particular responses. Section IV presents the results, Section V discusses the results, its broader world implications, and future work, and Section VI sums up the whole paper.

II. RELATED WORKS

The issue of poor medication adherence has been approached previously using such monitors. For example, Holmes *et. al* [6] presented a method of automatically evaluating inhaler adherence through analysis of inhaler sound. Whenever a patient used an inhaler, an acoustic monitoring device recorded its sound, the date, and time, producing an effective monitoring algorithm. However, problems arose when the device mistook background noise as blisters, inhalations, and exhalations. We derived Holmes' concept of ensuring adherence by employing an RFID-based scanner on our integrated system, similar to the acoustic monitoring device.

Graddage *et. al* [7] introduced a smart drug packaging in which a reusable integrated circuit (IC) detects the rupturing on a circuit printed on a disposable packages' covers. Nonetheless, this device works under the assumption that the drug is consumed when ruptured from the package. This relates to a fundamental issue that arose during the fabrication process of our system. We considered a device that would eliminate the "assumption" of consumption and would rather ensure the ingestion of the prescription. However, we decided on shifting the project's focus by targeting a specific demographic: the accidentally negligent patients. This eliminated the incentive to fix the problem posed in Graddage's research, uncovering a new solution to a new problem. Further justification will be explained in Section III. *B. Justification.*

Wang *et. al* [8] developed a wireless that detects and classifies hand gestures of patients during solid-phase medication intake. Problems arose when the device mistook similar hand gestures to intaking medicine. The issue of misinterpretation prevailed in our project as well. If the patient is purposefully negligent, they may scan the cap without ingesting the medication.

Kirtana [9] developed a "low-cost, long-range, secure, prompt, easy-to-use" monitoring system that analyzes the patient's pulse. This lowers the danger of young and elderly individuals becoming prey to deadly hypertension. Kirtana's purposes of this development were to measure hypertension and notify the health care provider. The Arduino Uno was used as a gateway to connect to the Message Queue Telemetry Transport (MQTT) server from a pulse module. A few problems emerged when the Heart Rate Variability (HRV) analysis system was needed for high-risk, hypertension patients. This meant that the project wasn't able to account for all situations as it needed the HRV system to assess special

cases. We found the use of affordable components a comparable from Kirtana's project to our own.

Abu Sadat [10] developed an in-home diabetic monitoring system. The purpose was to create an easy to use at home personal diabetic monitor. This development immediately assesses the condition of the patient without having them rush to the hospital for unnecessary hospital visits. The Arduino was used to connect to the software and communicate the insertion of a blood strip into the analog-to-digital converter (ADC). Just like our project, Sadat accomplished an electronic medication monitor that serves as a home consultant.

Diaz Justo [11] proposed that the methods for testing allergies were open to many other variables that could result in an inaccurate diagnosis. In an effort to improve diagnosis, Justo introduced a mechatronic system that scans a patient's arm to measure allergic reactions. This scanner works like a big camera that measures the size of the wheals and analyzes their shape compared to a circle. The Arduino was used for managing the stepper motor and communications between the 3D system and the computer. Rather than analyzing Justo's purpose, we derived the concepts presented in the integrated system as it relates to the use of system-on-chip (SOC) management.

Aditi Pushola [12] noticed a decrease in nurses being able to communicate with some patients without someone there to communicate with them 24 hours a day due to them being differently abled. Pushola presented the idea of an affordable, reliable system that would use modern technologies' speed and effectiveness to increase the intelligible communication between nurses and paralytic or differently abled patients. The device on the patient's body or near the patient would link to a receiver close to the nurse and relay the desired message based on a specific movement of the patient. The Arduino Uno was used to turn on the buzzer to notify the nurse of the message from the patient. Similar to Sadat's diabetic monitor, this device provided another take on approaching specific issues under indirect assessment.

Kabigting [13] introduced a compact wearable prototype. "It was designed to assess the functionality and suitability of a customized sensor array to capture waveforms for quantitative TCM pulse diagnosis." The Arduino was used to control the sensor array with USB and Bluetooth data transmission. Both Kabigting's project and our project utilized the same fundamental devices (Android, Arduino, Bluetooth communication, etc.).

This paper will focus on an approach to the challenges provided by indirect assessment utilizing an electronic medication monitor similar to the mentioned.

III. PROPOSED ELECTRONIC MEDICATION MONITOR

A. Devices

The medication adherence monitoring system was assembled using the Arduino Uno, the user's Android device, the Mifare RC522 RF IC Card Sensor Module and key tag, the HC-06 4 Pin Serial Wireless Bluetooth RF Transceiver Module, the ESP8266 ESP-01S Wi-Fi Serial Transceiver

Module, a serial Liquid Crystal Display (LCD) module, and a piezo speaker.

B. Justification

Before delving into the reasons behind our selection of particular devices, background must be supplied as to why this proposed method was adopted. The device was developed for the intended audience of the accidentally negligent patients rather than the purposefully negligent ones. This conclusion stems from the assumption that those that are purposefully negligent will remain negligent or find dishonest methods to bypass indirect assessment. Because of this, we decided on developing an embedded system that seeks to deter accidental medication non-adherence.

Firstly, all the items used for this process were utilized on a budget and thus can help anyone interested in recreating this project. Initially, we debated whether to use a microcontroller, such as an Arduino, or a general-purpose computer, such as a Raspberry Pi. The Arduino was selected due to the system’s software being one-dimensional. From there, the issue of electronic prescribing was approached through direct, electronic input; a user’s Android device, HC-06 4 Pin Serial Wireless Bluetooth RF Transceiver Module, and the *Serial Bluetooth Terminal* Android application were used as platforms for ease of prescription.

Next, the question as to how to verify the user’s adherence posed an issue. We settled on either Near-Field Communication (NFC) stickers or radio-frequency identification (RFID) tags to be scanned by the Mifare RC522 module. The RFID tag was chosen because of its slightly farther range and quick scanning *versus* the NFC stickers. We chose the plastic prescription bottle to stick the tags under (with velcro) as it requires the users to open the bottle in order to scan. This provides an incentive for the users to intake the pills if they are going to open the bottle. The ESP8266 Wi-Fi Module solved the issue of monitoring medication adherence by allowing the device to send an e-mail to the physician if the users do not scan. The serial LCD serves as the hardware’s interface and displays the inputted information (prescription and dosage). Initially, a vibrating disk motor was going to be used as a way of notifying the patient of medication ingestion along with the buzzer, but not enough pins were provided.

TABLE I: DEVICE PRICES

ScanAlert Value	
Component	Price
Mifare RC522 RFIC Module	\$7.98
LCD Screen	\$5.99
HC-06 Bluetooth Module	\$7.39
ESP8266 WiFi Module	\$5.99
Piezo Active Buzzer	\$1.98
Arduino UNO R3 Development Board	\$10.99
Total	\$40.32

C. Radio-Frequency Identification (RFID)

The Mifare RC522 module, which is based on an RFID system, has two main functions: it can read the data that the RFID tag transmits as well as write data onto the tag. The Radio Frequency Identification system consists of a tag, a reader, an antenna, and is based on communication through electromagnetic fields. The tags, which contain an embedded copper coil and chip, can be of two types: active or passive. Passive tags, as opposed to active tags, do not depend on a power source of their own, but instead rely on the energy of the radio waves emitted by the RC522 to transfer data.

To establish connection with the RFID tag, the RC522 sends out radio frequency waves that activate the tag, allowing it to communicate with the RC522 through electromagnetic coupling. Electromagnetic coupling can be subdivided into two types, capacitive and inductive. Inductive coupling relies on a magnetic field to identify objects, while capacitive coupling relies on an electric field for object identification. Because inductive coupling is a type of communication that uses magnetic fields, it is short range, which is the case for most high frequency systems.

The prototype that we developed involves the use of the Mifare RC522 module, which relies on the inductive communication between the reader and the tag. In order to identify a specific tag, the Mifare RC522 will obtain the Unique Identification Numbers (UID) of the scanned RFID tag and compare it to the UID assigned to a certain prescribed medication. The RFID tag that is utilized in the developed monitoring system is a passive RFID key tag with a high frequency of 13.56 MHz. The shape of the RFID key tag was modified to make it possible to be attached onto the inside of the cap of a prescription bottle. The diameter of the tag was modified to 23 mm, and in order to prevent the RFID tag from being scanned without opening the prescription bottle, four sheets of rubber and a sheet of aluminum were attached onto the backside of the RFID tag respectively. Aluminum was

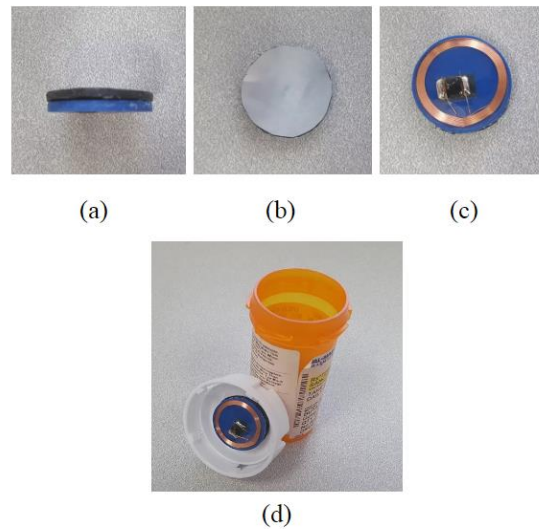


Figure 1. (a) Layered tag assembled with (b) aluminum and four sheets of rubber on top of a (c) RFID tag all attached under a (d) pill bottle cap.

used because, unless specially designed metal RFID tags are used, it is an RFID resistant material [14].

D. User Interface and Communication with Physician

Another component used to complete this prototype was the HC-06 Bluetooth Module for the Arduino. The HC-06 Bluetooth module operates using serial communication, which can be defined as a type of communication in which data is sent one bit at a time, as opposed to parallel communication in which bits are sent simultaneously. Serial communication operates using the Universal Asynchronous Receiver/Transmitter (UART) protocol. The protocol involves a UART, that can either be a microchip on a microcontroller or a standalone integrated circuit (IC). This block of circuitry allows for serial communication through the serial ports of two devices. On the Arduino, the serial ports are the Receiver (RX) and Transmitter (TX) lines, which are located on digital pins 0 and 1 respectively. During serial communication, the Transmission line (TX pin) from one device transmits data to the Reception line (RX pin) from the second device, while the Reception line from the first device receives data from the Transmission line of the second device.

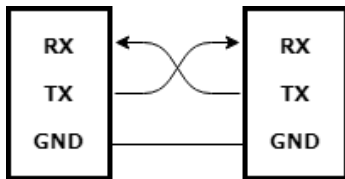


Figure 2. Communication through Serial Ports

In the UART protocol, data is transmitted asynchronously, which indicates that the transmission of bits from the transmitting UART and the processing of bits by the receiving UART are not coordinated by a digital clock signal. A digital clock signal, which is produced by a clock generator, functions as a metronome. To sync the actions of two devices, a clock signal oscillates from a low voltage (0) to a high voltage (1), both of which are determined by the requirements of the circuit. The idle state, the state in which no data is being transmitted, is always held at high voltage. In place of a clock signal, start and stop bits are appended to the UART data frame by the transmitting UART. The attached start bit allows the receiving UART to detect incoming data and prepare for processing, while the stop bits signal an end to the transmitted UART data frame. At the detection of a start bit, the receiving UART begins processing the data at a certain baud rate. *Baud rate* refers to the frequency at which data is being transferred. To maintain synchronized timing between two devices, the baud rates of the devices must not exceed a 10% differential [15]. During data transmission, the transmitting UART receives data in parallel form from a data bus, which contains data from another device. Having received the data from the data bus, the transmitting UART appends one start bit, an optional parity bit, and one or two stop bits to the UART data frame, which contains five to nine bits of data. A parity bit may be added by the transmitting UART to determine if data bits

were altered during data transmission. The produced UART data frame is then serially transmitted to the receiving UART. Once received by the receiving UART, the data is converted back into parallel form and transferred onto the receiving data bus [16-18].

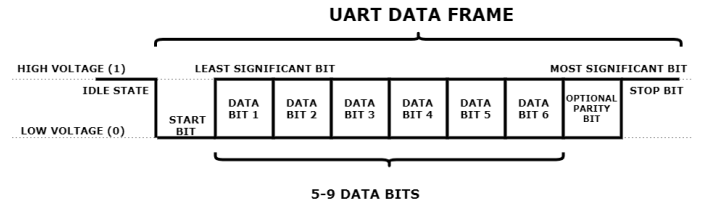
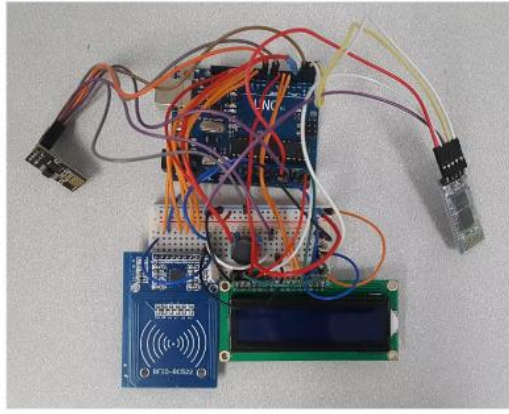


Figure 3. Serial Communication

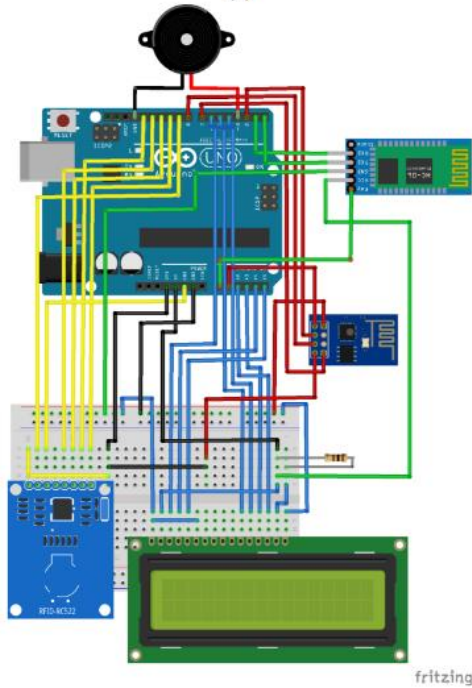
The ESP8266 Wi-Fi Module was integrated into the developed monitoring system to grant the Arduino access to any Wi-Fi network (if given the network name and password). Once the network connection is established, the prototype will have the ability to send an e-mail at the command of the Arduino. Like the HC-06, RFID RC522, and Arduino, the ESP8266 Wi-Fi module also uses the UART protocol. Furthermore, the alarm system of the developed prototype is composed of the serial LCD display module and a piezo speaker. The LCD module will be used to display information that will facilitate the process of ingesting the correct prescription; while the piezo speaker will activate to alert the user when it is time to take the prescribed medication.

Prior to downloading the Android application, *Serial Bluetooth Terminal* by Kai Morich, the user must make an AOL e-mail, because unlike Gmail, AOL offers unencrypted authenticated access. After creating an e-mail with their name in the username, the user will have to download the Arduino IDE. Having downloaded the IDE, the user will be able to access the code for the prototype by visiting <https://sites.google.com/view/scanalert/home>. Once inside the Arduino sketch, the user will be guided through a series of steps to set up the monitoring system. The user will be asked to input their network name, network password, AOL e-mail, AOL Email password, base64 encoded AOL e-mail, base64 encoded AOL Email password, and their physician's e-mail. After properly inputting the required information into the sketch, the user must connect the prototype to the computer using the blue USB cable. Before uploading the sketch, the user will be required to disconnect digital pins 0 and 1.

After the sketch is successfully uploaded, the user will have to plug the two wires into their respective pins. After this, the user must activate their Bluetooth and enter either "1234" or "0000" as the password. Access will be granted to the prototype, which will appear under the name "HC-06." To finish the customizing of the alarm system, a series of question will be asked regarding the user's prescribed medication.



(a)



(b)

Figure 4. (a) Hardware of integrated system and its (b) Fritzing.

The serial data received by the HC-06 Bluetooth module will be transmitted onto the Arduino and stored inside variables. Once all the questions have been answered, the user will be able to deactivate their Bluetooth. In order for the developed monitoring system to be fully functional, the user must attach one of the modified RFID tags onto the inside of the cap of the prescription bottle that the user entered into the application. The prototype will then remain passive until the scheduled time for medication intake approaches. Thirty minutes prior to the scheduled time of medication ingestion, the buzzer will activate for thirty seconds to notify the user that the one hour window set to take the indicated medication has commenced. Throughout the one hour window, the LCD module will display the medication information until the RFID tag is scanned. After the thirty seconds in which the prototype

is active, the user will be able to scan the proper RFID tag by placing it upon the RC522 until “scanned” is displayed on the LCD, indicating that the correct UID was received. The scanning of the RFID tag will deactivate the buzzer and validate ingestion. If the tag has not been held up to the RC522 reader to be scanned by the half hour mark, the buzzer will activate a second time. However, this time the prototype will buzz for ten minutes to alert the user that the scheduled time for medication intake has been reached. After the beginning of the second reminder, thirty minutes will remain for the user to scan the tag and validate ingestion.

If these conditions are not met, an e-mail will be sent to the user’s physician, notifying them of the user’s noncompliance. A one-hour window is set for the user to ingest the proper medication because to achieve enhanced results, medication must be ingested thirty minutes prior to or after the scheduled time [19].

IV. RESULTS

A. Power Consumption

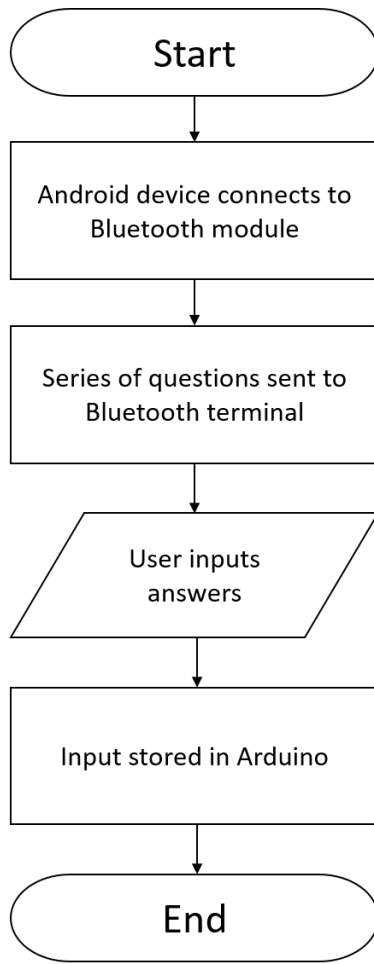
To calculate how long ScanAlert lasts on a 9V battery, we looked at datasheets of each component and added up the total wattage. Assuming the 9V battery has 500 mAh capacity, the device will last about 3.6 hours if it is always on standby or 1.28 hours if it is always active (using the formula $\text{hour} = \text{mAh}/\text{mA}$). Since the device is only active during the scheduled prescription time, it can be assumed that the device will last for approximately 3 hours on a 9V battery.

TABLE II: SCANALERT POWER CONSUMPTION

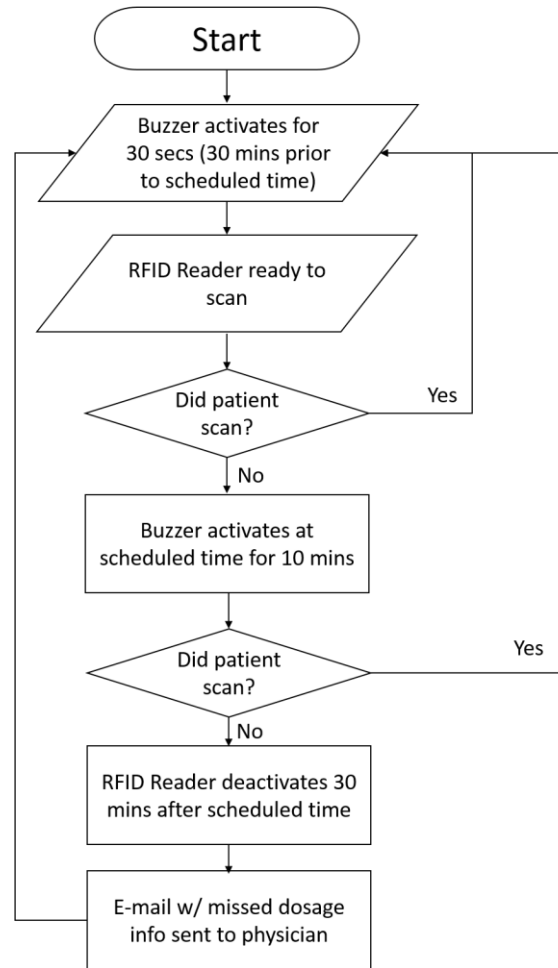
ScanAlert Power Consumption		
Component	Standby	Working
Mifare RC522 RFID Module	33 mW - 42.9mW	33mW - 85.8mW
HC-06 Bluetooth Module	10mW - 40mW	150mW - 200mW
ESP8266 ESP-01S WiFi Serial Transceiver Module	0 mW	0.86mW - 215mW
LCD Module	0mW	5mW
Passive Buzzer	0mW	9.9mW
Arduino Uno R3	734mW	734mW
Total	777 mW - 816.9 mW	932.76 mW - 1249.7 mW

B. RFID Read Range

The modified RFID tag is composed of layered plastic and aluminum. The tag can be scanned by hovering the interior of the cap over the Mifare RC522 module. The aluminum disrupts the signals sent from both the tag and module making the range shorter than it is without the modification. We tested the RFID tag twenty times without the modification and twenty times with the modification. The trials indicate success in achieving our purpose for modifying the RFID tag: encouraging the user to open the bottle and consume prescriptions. The decreased range of the modified tag is a byproduct towards ensuring that it cannot be scanned from the top of the cap. It must be opened. Without modification, the scanner detected the tag at 2.2325 centimeters away on average. With modification, the scanner detected the tag 1.4225 centimeters away on average.



(a)



(b)

Figure 5. Flowcharts of (a) initial setup in the Bluetooth terminal and (b) the passive and active process of ScanAlert.

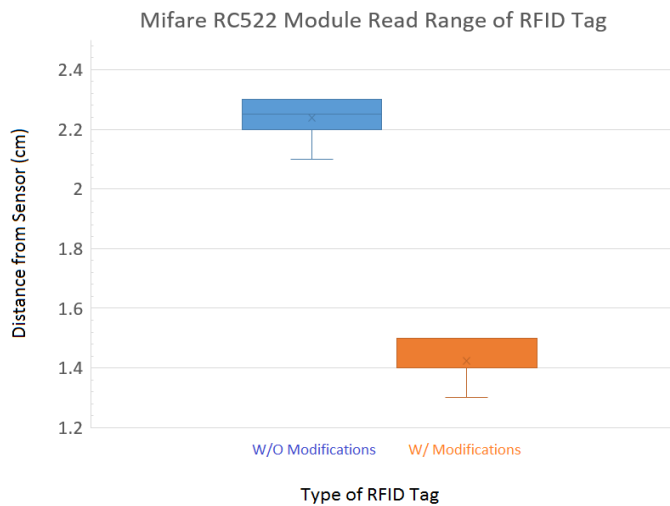


Figure 8. Read range of RFID tag.

C. Application Setup and Use

To configure the device for the user's specifications, the user must follow these instructions:

- 1) Hardcode network and e-mail information and upload the code.
- 2) Install the *Serial Bluetooth Terminal* application onto an Android device.
- 3) Power ScanAlert through a 5V adapter or 9V battery and make sure that the HC-06 module's LED is blinking, which indicates disconnection or the searching for devices.
- 4) Turn on Bluetooth and pair to a device named "HC-06."
- 5) A dialog box will appear; enter "1234" or "0000" as the password.
- 6) Open the application, and in the menu, open "Bluetooth Devices."
- 7) Under "BLUETOOTH CLASSIC", a green bar should indicate that the phone and ScanAlert are paired; if not, click on it until the bar lights green.

- 8) Return to the menu and open “Terminal.” The connection will complete, and a series of questions will appear in the terminal.
- 9) Answer the questions and unpair the Android device once the terminal says to.
- 10) The ScanAlert setup is now complete.

V. DISCUSSION

The globe faces an immense loss of funds and lives due to medication non-adherence. We presented a solution through ScanAlert, a reminding, electronic medication monitor. Similar to a nurse, the device serves as an electronic assistant in incentivizing users to properly take their medications. It also serves as a monitor that reports uncooperative behavior if the patient neglects their prescriptions. Provided to the right audience (the accidentally neglectful), ScanAlert has the capability to save lives and health industries substantial funds.

The goal of this project was to provide virtual assistance that would eliminate the need for a human to provide supervision for the patients’ prescription compliance. To accomplish this, an integrated system was developed. We created this project with regard to the setting and audience. Generally, middle-aged and elderly people take prescriptions in a home environment. ScanAlert would blend in as it would most likely situate on a table or counter plugged into an

electrical socket, by an adapter with an output of 5V, ideally near prescriptions. Also, the system acts similarly to an alarm clock or home security system. When it buzzes, the user is incentivized to approach the area of the device and complete the process. ScanAlert’s fabrication was completed to appeal to its anticipated consumers.

In further research, ScanAlert has the capability to be embedded in today’s prevalent smart device. Ideally, the prototype was created to be built into a wearable (such as an Apple watch) that has the user’s specifications, an alarm, and a built-in scanner. We considered its use embedded into a smartphone, but we settled on the potential use of a wearable because wearables are ubiquitous (a phone can be separated from the user or have settings to turn off the application easily).

Also, ScanAlert may be modified to include different, more accessible features. One user suggested that rather than an RFID tag, it can scan through a Quick Response (QR) code which may be printed on paper or a sticker (ScanAlert would have to include a barcode reader device rather than an RFID scanner). The difficulty of crafting modified RFID tags would be eliminated as this would only require a printer and an adhesive. Another user suggested advancing the electronic prescription so that a physician may directly input the user’s prescription information rather than the user inputting it

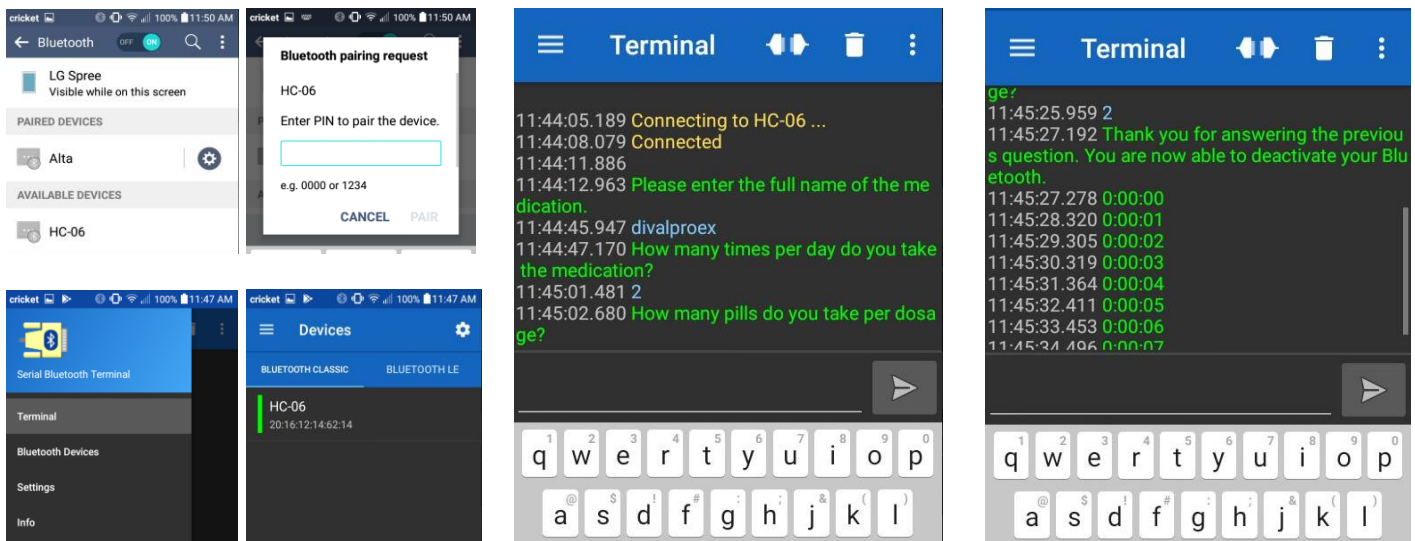


Figure 9. Reference images to application setup.

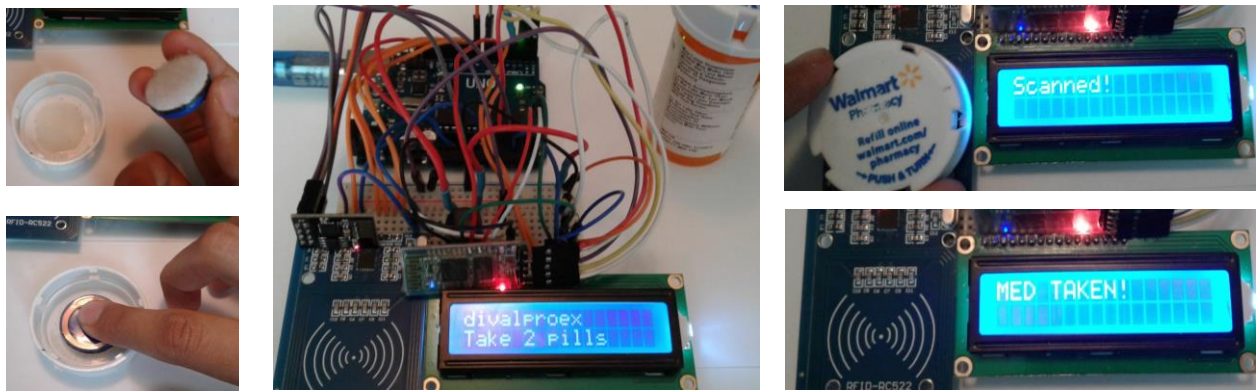


Figure 10. Reference images to device use.

themselves. This would eliminate the need for a tedious questionnaire at the beginning of every boot up.

VI. CONCLUSION

An integrated system was developed that reminds patients to take their medication and monitors their prescription intake through an RFID-scanner-based Arduino circuit. ScanAlert acts as a virtual assistant that communicates with both the patient and physician to encourage higher medication adherence rates. With an affordable answer to a prevalent problem, ScanAlert promotes prescription intake without being intrusive on the user's everyday life.

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