A Pocket-Sized Interactive Pillbox Device: Design and Development of a Microcontroller-Based System for Medicine Intake Adherence

Marie Luvett I. Goh
College of Computer Studies
FEU Institute of Technology
Manila, Philippines
migoh@feutech.edu.ph

Manuel B. Garcia
College of Computer Studies
FEU Institute of Technology
Manila, Philippines
mbgarcia@feutech.edu.ph

Jay-ar P. Lalata
College of Computer Studies
FEU Institute of Technology
Manila, Philippines
jplalata@feutech.edu.ph

Ace C. Lagman
College of Computer Studies
FEU Institute of Technology
Manila, Philippines
aclagman@feutech.edu.ph

Heintjie N.Vicente
College of Computer Studies
FEU Institute of Technology
Manila, Philippines
hnvicente@feutech.edu.ph

Roman M. De Angel
College of Computer Studies
FEU Institute of Technology
Manila, Philippines
rmdeangel@feutech.edu.ph

***Abstract*— Medicine intake, as prescribed by physicians and health care providers, is important not only for minimizing the risk of relapse but also to treating conditions and improving one's overall well-being. However, adherence to a medication routine seems to be a problem for some people which is usually affected by a variety of factors such as hectic day-to-day activity schedules, poor prescription instruction, concurrent intake of multiple medications, and forgetfulness. Medication adherence has been then considered as one of the major medical problems globally. In such cases, a medical device that could alert and remind patients in taking their medicines on time will come in handy. Consequently, this study aimed to design and develop a pocket-sized electronic pillbox device using TFT LCD display, Arduino microcontroller, Piezo Buzzer (for sound notification), Eccentric Rotating Mass (for vibration notification), Lithium Ion battery as power source, and plastic organizer as the main body. The said pillbox device will act as a countermeasure for medication non-adherence particularly by patients under the case of polypharmacy. Thus, this study focused on the design and development of the prototype, hardware testing and system qualification only. Furthermore, this paper is part of a future study where the assessment and measure of device behavior and adherence will be conducted to compare whether the utilization of pillbox device has an impact to the people who are using it.**

Keywords—Microcontroller, Portable Medical Equipment, Personal Portable Device, Medicine Intake, Arduino

I. Introduction

In primary care, one of the most common treatment forms is pharmaceutical drug intake which ensures patients to have the best possible result with regards to their health problems. Furthermore, medicine intake, as prescribed by physicians and health care providers, is important not only for minimizing the risk of relapse but also to treating conditions and improving one's overall well-being. The prescribed medications are more likely to be effective if one follows doctor's or pharmacists' exact instructions properly on when and how to take them. Adherence to a medication regimen, however, seems to be a problem for many people, which is typically affected by a variety of factors, either intended or unintended [1], such as hectic day-to-day activity and work schedules, forgetfulness, simultaneous intake of multiple medications (polypharmacy), and poor prescription instruction and writing, to name a few. As a consequence of non-adherence to medication, patients escalate their disease, waste pharmaceuticals, unintentionally increase the use of medical resources, and receive a lower quality of life [2]. Doctors and healthcare providers are also affected by this action, or lack thereof, because they are the medical foot soldiers of establishing the value of medication and preventable hospitalizations of people [3].

The health sector has seen a remarkable growth in portable medical equipment and personal portable device [4] that aims to cover comfort and convenience, which people consider as an important aspect of health [5], and enables provision for clinical monitoring outside a hospital institution [6] making it ubiquitous. It is for this reason why portability is considered an important element for this project. It is also important to note that this is not the first time this kind of project will be developed but most of the previous prototypes didn't consider portability. McCall, Maynes, Zou and Zhang [7] developed RMAIS (RFID-based Medication Adherence Intelligence System) where the main focus is on built-in scale of the device for dosage measurement. Mukund and Srinath [8], on the other hand, used hardware modules that are almost similar to this project such as microcontroller, light-emitting diode, and motor controller. Both of these prototypes, however, didn't include portability as a factor when developing the electronic medicine organizers. For people with medicine maintenance, a medicine dispenser device that can practically positioned in one's pocket may encourage people to bring the device with them anywhere they go. Moreover, this is advantageous to a typical alarm set in a mobile phone since the pillbox device is specifically designed to be medically-oriented in terms of its features, design, and how it operates as a medical device.

As Jimmy and Jose advised [3] for medication adherence, various techniques like improving aids can help patients to stick with their therapeutic regimen. In line with this, a device that can alert and remind patients in taking their medicines on time will come in handy. Therefore, this paper was initiated to develop an electronic pillbox device using TFT LCD display, Arduino microcontroller, Piezo Buzzer, Eccentric Rotating Mass (for vibration notification), Lithium Ion battery as power source, and plastic organizer as the main body that is pocket-sized. The device aims to monitor the medication schedule of patients particularly elders, people with chronic diseases, and those who have a lifetime medication. Medicine such as syrup, liquefied and non-encapsulated medicine, however, cannot be placed or stored inside the compartment of the organizer.

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

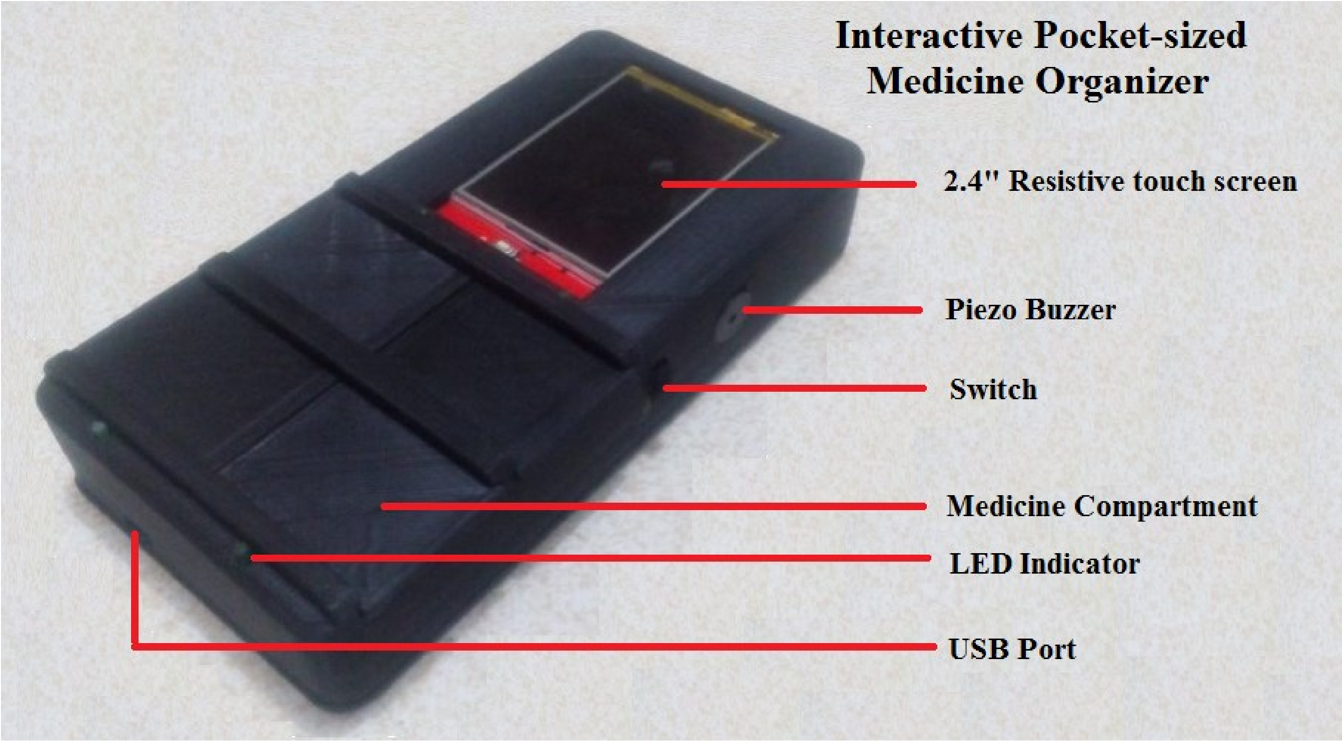

Fig. 1. Working Prototype of the Pocket-sized Electronic Pillbox Device

II. Methodology

A. Project Methodology

Fig. 2 illustrates the Prototyping Methodology which was utilized in the project development. This kind of methodology is appropriate for research and development projects like this pillbox device that does require a built prototype with minimal need for programming. In general, this kind of methodology addresses issues with through iterative process like building prototypes that start with small and then grow in complexity, e.g., combining hardware modules one by one.

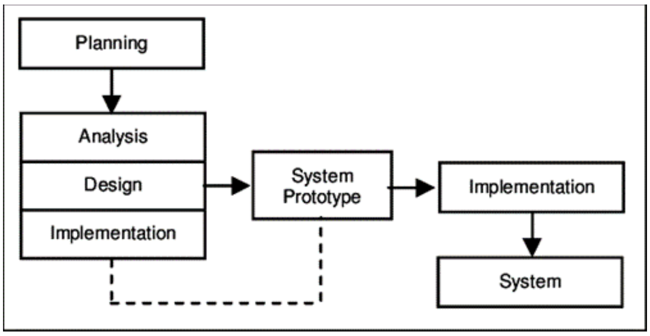

Fig. 2. Prototyping Methodology

1) Planning Phase

Relevant information regarding medicine non-adherence and its effects was gathered by conducting an informal interview with several doctors, nurses, and pharmacists during the planning phase. Topics revolve around medical points such as the minimum time a patient could skip a single dose of medicine, what skipping a dose of medicine means, and how it would affect a certain person. The project was also briefly introduced and the responders where asked about their opinions on a portable or pocket-sized medicine storage that can alert patients when it is time to take their medicine. Since the response is positive, the researchers pushed through with this project. Other hardware-related factors that were taken into consideration while planning the research project are the portability and battery life, as well as the modules itself.

2) Analysis Phase

In line with interviews with health care professionals, the analysis phase produced various concepts of creating a portable medicine organizer that can fit inside the pocket and notify the user to take the medicine on time. The objective of the researchers is to prevent user from missing the medicine on time wherever they are. An alarm system is integrated such as the piezo buzzer and eccentric rotating mass that would inform the user to take their medicine. The purpose is to attract the attention of its user. The TFT LCD display shows which medicine to be taken and the time when it should be taken. The portable pillbox device has four compartments that would save patients from overdose and confusion on which medicine is needed to be taken. This project is feasible since there are already existing devices that is related to this study, thus this study intended to develop a project that had more improved features of a portable medicine organizer.

3) Design Phase

During the design phase, the researchers decided to develop a project which concerns the portability and functionalities of IPSMO. The prototype is a device that can be used by anybody who could read and were familiar with smartphones. The device is small and could fit inside the pocket. The system allowed the user to specify the medicine information, dosage frequency and required time input. The system can also display the battery level meter to inform users. Every time the device alarms and vibrates, it indicates that it is time to take the medicine and the compartment that must be opened. The project design was based on its functions

4) Implementation Phase

The integration of hardware components and prototype construction were lastly conducted during the implementation phase. It was decided that the physical appearance of the device was developed based on the features and functionalities as outlined in this research study. The prototype was tested to ensure it performs the way it was designed most especially with the integration of several hardware modules such as TFT LCD display, Arduino microcontroller, Piezo Buzzer (for sound notification), Eccentric Rotating Mass (for vibration notification), and Lithium Ion battery as power source.

B. Project Design

Fig. 3 shows the hardware modules of the prototype which comprised of display, audio, light, motor, and switch modules.

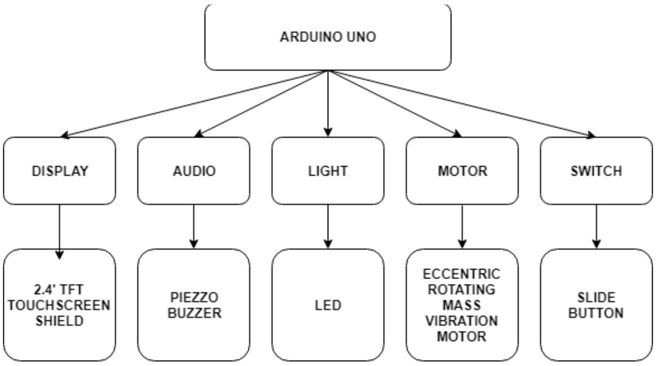

Fig. 3. Decomposition of Hardware Modules

1) Arduino Uno

The Arduino Uno was used to control all the hardware components connected to it with the aid of a program. The Arduino Uno is a microcontroller serving as a control center where it receives and sends signals to the modules so that they could perform their specific functions. These components are 2.4" TFT (thin film transistor) touchscreen shield, Piezo buzzer, LED (light emitting diode), eccentric rotating mass vibration motor, and slice button.

2) TFT Touchscreen Shield

2.4" TFT (thin film transistor) touchscreen shield serves as the input and output module which displays important data and receives instruction to and from the user. This type of touchscreen shield is compatible to Arduino Uno. As an output module, TFT touchscreen shield provides a graphical user interface to user so that they could easily interact with the prototype. As an input module, the prototype receives signals when user touches the screen of the TFT touchscreen shield which will store data and interpreted by Arduino Uno.

3) Piezo Buzzer

A Piezo buzzer, short term for "piezoelectric" buzzer, was used in the alarm system of the device that can emit sounds when triggered. It acts as an audio device in the alarm system to catch the attention of the user when it was time to take the medicine. It was triggered when the real time meets the time that the user set. The sound of the buzzer is high-pitched tone which was enough for the user to be alerted especially when they are asleep or far from the device.

4) LED

A Light-Emitting Diode (LED) was mounted to each medicine compartment of the device. It serves as an indicator for user on which medicine would be taken when the alarm is triggered. This prevents the patients from taking the wrong medicine especially if they have multiple ones available.

5) Eccentric Rotating Mass Vibration Motor

Eccentric rotating mass vibration motor (ERM), also known as pager motor, is a DC motor with an offset (non-symmetric) mass attached to the shaft. This motor can be operated without the use of a motor driver; hence, it could be directly connected to the Arduino Uno. The offset mass is in direct contact to the body case of the project which produced vibration when triggered which will only happen when the current time (based from the world clock) meets the time and schedule of medicine intake set by the user.

6) Slide Button

Slide button, a popular input component used in devices, is a simple switch mechanism used to control the device or process. This was used to send signal to the Arduino Uno that will determine if the user wants to turn the device into sleep mode to save battery. In a typical slide switch, two positions are available while one of the switches is thrown on one side which outputs a GDN at rest and a VDD when pressed. Obviously, when user throw the momentary contact button into the pre-specified side, the device will trigger a signal to be received and interpreted as sleep mode by Arduino Uno.

Fig. 4. Arduino and 2.4 TFT Touchscreen Shield

C. Project Construction

Fig. 4 illustrates the 2.4 TFT touchscreen shield mounted on top of the Arduino Uno. Intentionally, the touchscreen shield is perfectly fitted to the Arduino Uno. They have the same pin numbers and the length and width of both modules are the same. In addition, the Arduino Uno also recognized the driver of the touchscreen shield.

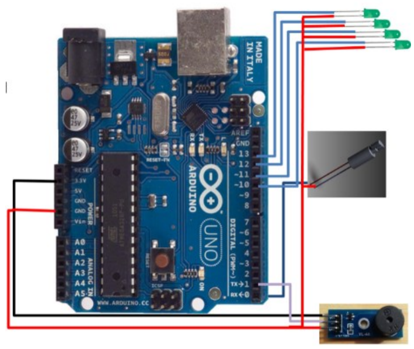

Fig. 5. Alarm System, LED, and Compartment Indicator Components

Fig. 5 shows the pin connection of Alarm and LED in Arduino UNO where components were connected via wires inside the casing. VCC pin of piezo buzzer was connected to the 3.3 V. The I/O pin which was in the middle was connected to digital pin 1. The GND pin was connected to GND of Arduino Uno. The ERM vibration motor pins were connected to digital pin 0 and GND. Its pin had no polarity so either pins can be connected to digital pin and gnd. The four (4) LED indicators were connected to the digital pins 10, 11, 12 and 13. Each connection was soldered under the Arduino board.

D. *Testing and Evaluation*

Integration test was conducted to verify the operation of the integrated system behavior. It is conducted after the components needed for the device is successfully tested. Actual test results were noted during the functionality testing of the device to provide basis for further improvements.

III. Results and Discussion

A. *The Developed System*

The developed pocket-sized interactive pillbox device is an Arduino-based medical device that can organize and store medicines and notify users of the time of medicine intake. The device is made up of plastic with a dimension of 5.8 inches in length, 3.0 inches in width, and 0.8 inches in thickness. The prototype has four medicine compartments which can contain a maximum of four (4) pieces of capsules, tablets, or caplets per compartment. When user calibrates the device, the alarm and LED of each medicine compartment will be activated if the set time is met. To calibrate each compartment, user will use the Home Screen Interface as shown in Fig. 6. The screen has also access with compartments, and the home button.

Fig. 6. Home Screen Interface

Fig. 7 shows the Pillbox Keypad Interface. This interface will be displayed when the user clicked on the Medicine Name. Through this interface, it allows user to input names of medicines stored to each compartment.

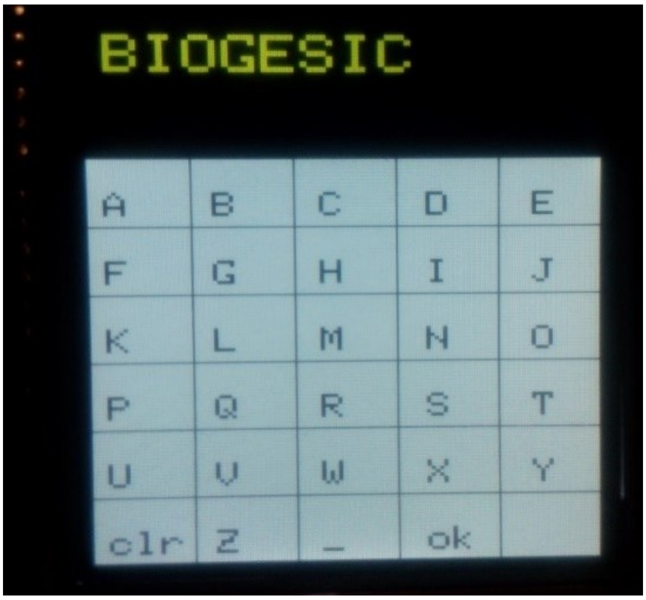

Fig. 7. Pillbox Keypad Interface

Fig. 8 shows the interface that allows user to set system time of the device under the Edit Time option. The interface layout for Edit Time is the same with Set Alarm Time.

Fig. 8. Medicine Intake Frequency Interface

Fig. 9 shows the interface to configure each compartment. Through this interface, user will input the medicine name, in-take frequency and alarm time of each medicine compartment.

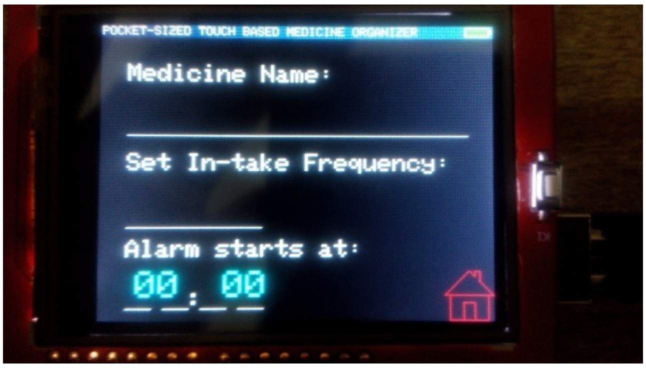

Fig. 9. Medicine Compartment Settings

To set the in-take frequency of the medicine the user must click the Set In-take frequency as shown in Fig. 10. Then the user must choose between the four (4) options. Then press OK. Each number denotes the medicine in-take frequency.

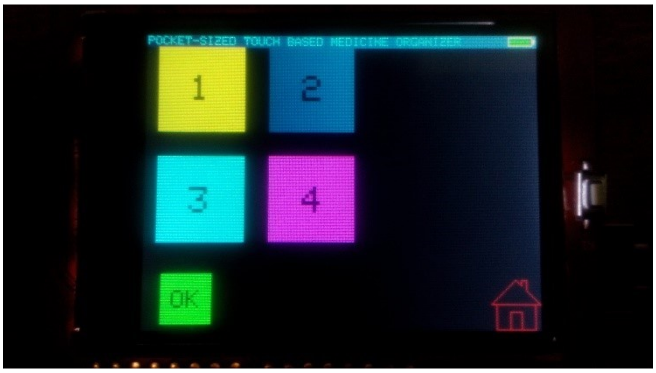

Fig. 10. Medicine Intake Frequency Intake for Compartments

Fig. 11, on the other hand, shows the alarm screen of the device. It only pops up when the real time matches one of the alarm time of the compartments. There are two options: OK and SNOOZE. By pressing OK, the alarm system will stop. SNOOZE button will let user to delay the intake of medicine by 5 to 15 minutes depending on user's preference.

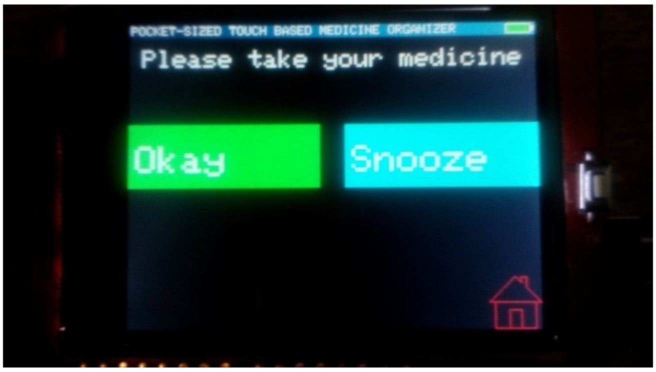

Fig. 11. Alarm Screen

The prototype is a rechargeable device equipped with a battery control system which reminds the user to charge the device. To notify the carrier of the portable medicine organizer, an alarm system together with a vibration and Light Emitting Diode (LED) were utilized. The device will then notify the patient or user if it's time and which medicine to take. The programming language used in this project is C++ through Arduino and was composed of different hardware modules that were connected and working as one. A thin film transistor touchscreen acted as the medium for interaction between the organizer and user. With the use of a stylus, the user could accurately press a button on the TFT touchscreen. For alarm system, the hardware modules used were eccentric rotating mass vibration motor and piezo buzzer which are embedded to the case so that the user can feel the vibration when the alarm happens. The piezo buzzer is a component that produced sound so that the user could hear the alarm. To indicate what compartment to open, a LED was placed to the side of each compartment designed to keep several medicines and it would light up when the alarm happens.

B. *Integration Testing*

Table 1 shows and discusses the hardware testing based from the research objectives of the prototype, and the results of those testing in accordance with the goal of the device. Based from the results of the hardware testing, all objectives were met and the actual results were "Passed". This signifies that the final prototype is working and is doing what it intends to accomplish. However, this result does not guarantee that patients will 100% take their medicine all the time. It is yet to be identify the behavior of the patients when using this pillbox device. As such, it is the next goal of the study, in its second installment, to identify the usage behavior of patients.

TABLE I. HARDWARE TESTING BASED FROM THE RESEARCH OBJECTIVES

Objective	Actual Result	Comment	Findings
To develop a pocket-sized medicine organizer that can be tucked in a briefcase or in the pocket of the user.	The body case of the prototype was a 3D printed material made of Lego. Black is the color of the body with a dimension of 3x6x1 inches. It has 4 compartments which can store 4 medicines at most.	There was a little defect on the printing of the casing. The side of the case shrunk a little due to intense heat during the printing process, thus, the thickness of the casing was decreased by few millimetres. For the compartments, four pieces of pre-cut sealed medicines can be stored.	Passed
To develop a rechargeable Arduino-based interactive medicine organizer with a battery that could last for at least eight (8) hours.	The Arduino was connected to a power booster that amplified a 3.7V, 2000mah Li-Ion battery. The power booster device had a USB port that serves as the charging port of the device. When the user tested the battery life, the battery happened to last up to 24 hours.	Do not let the battery be fully drained. The touchscreen will not power up even the device is connected on a charger.	Passed
To provide a touch-based interface to input data such as medicine name, medicine intake frequency, clock, and alarm system to each compartment of the device.	2.4" TFT Touchscreen Shield was used in the prototype which was resistive. It is mounted above the Arduino Uno. The Alarm Notification System is made through programming. Interfaces display the name of the medicine, medicine intake frequency, clock and alarm system for each compartment.	Using fingertips on the TFT Touchscreen was allowed but it is advisable to use the stylus pen to get precise screen navigation. The TFT touchscreen was properly placed which allows user to use the organizer using only one hand. Some problems were encountered due to resistive touch however, it was tolerable. Characters in the interfaces are all readable.	Passed
To provide battery level meter in the prototype.	The battery level meter used a battery icon and was displayed at the upper part of Home Screen. 3 colors were used for battery level indicator. Green color means that the load was high or full. Red means the battery was low or drained. The meter indicator gradually decreased during the usage of the prototype and increased when charging the battery.	If the battery was fully charged, the indicator displays a green color on full level state, but when the battery was low, the indicator displays a red color on low level state.	Passed

IV. Conclusion and Future Works

As established on the introductory section of the paper, medication non-adherence is considered a global problem [9] and one way to assist people in sticking with their therapeutic regimen is to give them the necessary improving aids and tools [3] like schedule monitoring and medicine alarm. As asserted by doctors and healthcare professionals, a patient-centered approach could make more progress in combatting medication non-adherence [10], which is unswervingly supported by the Patient-Centered Outcomes Research Institute [11]. This is the motivating force behind this research project aside from the opportunity of giving a technology-based solution in aiding people to alleviate their problems, and contributing a helping hand to the health sector through information technology.

For the conclusion part, this paper entails to present two major findings in the development of the pillbox device which includes the testing of the application and the integration of the components to develop a Pocket-Sized Interactive Pillbox Device for Medicine Intake Adherence. The testing results of the hardware prototype works accurately based on prescribed design of the researchers. The listed objectives and hardware components (TFT LCD display, Arduino microcontroller, Eccentric Rotating Mass for vibration, Piezo Buzzer for audio, and Lithium Ion battery) are properly designed and integrated to one another. Nevertheless, developers are still warned about using a multitude of hardware components especially with the necessary specifications that allow the needed integration.

For future iterations of the pillbox device prototype, other programmable LCD touchscreens may be integrated as an input/output device per compartment, dosage frequency, snooze and sound in order to improve the interface of the system. Sending message to other devices such as smartphone and email can also add another layer of reminders for the users. A medicine counting algorithm [7] will also make the device smarter especially if it can determine on its own the depletion of the medicine inside each compartment. The success of the integration of the components can be a basis to develop a smaller size of Pocket-Sized Interactive Pillbox Device that can be more convenient to users in terms of portability criterion. Also, the researchers aim to integrate a mobile platform that will store historical data of the medicine intake of the users as basis for medicine adherence. The use of mobile application has been proven to be a successful platform when dealing with medical-related tasks (e.g., integrating the game elements for a speech therapy [12]).

Lastly, as repeatedly mentioned on the paper, this project is just a beginning of a much larger research study. After the construction of the prototype, the researchers will test it out and use in the field to determine if it could combat medication non-adherence. Since the device can tailor the schedule of each specific user, which is contrary to usual interventions aimed for the general population, it is expected to bring promising results when deployed. A more in-depth analysis is also warranted to learn more about the impact of the device on users' behavior, and above all, their medication adherence.

References

[1] E. Lehane and G. McCarthy, "Intentional and unintentional medication non-adherence: A comprehensive framework for clinical research and practice? A discussion paper," *International Journal of Nursing Studies,* vol. 44, pp. 1468-1477, 2007/11/01/ 2007.

[2] S. Sullivan, D. Kreling, and T. Hazlet, "Noncompliance with medication regimens and subsequent hospitalizations: A literature analysis and cost of hospitalization estimate," *Journal of Research in Pharmaceutical Economics,* vol. 2, pp. 19-33, 1990.

[3] B. Jimmy and J. Jose, "Patient Medication Adherence: Measures in Daily Practice," *Oman Medical Journal,* vol. 3, 2011.

[4] M. B. Garcia and N. U. Pilueta, "The VISIMP Portable Communications Device for Visually Impaired Individuals – Development and Feasibility Study of an Assistive Technology," *Journal of Advanced Manufacturing Technology,* 2019.

[5] P. Pharow, B. Blobel, P. Ruotsalainen, F. Petersen, and A. Hovsto, "Portable Devices, Sensors and Networks: Wireless Personalized eHealth Services," *European Federation for Medical Informatic,* 2009.

[6] D. I. Fotiadis, C. Glaros, and A. Likas, "Wearable Medical Devices," *University of Ioannina*.

[7] C. McCall, B. Maynes, C. C. Zou, and N. J. Zhang, "An Automatic Medication Self-Management and Monitoring System for Independently Living Patients," *Medical and Engineering Physics,* vol. 35, pp. 505-514, 2013.

[8] S. Mukund and N. K. Srinath, "Design of Automatic Medication Dispenser," in *International Conference of Advanced Computer Science & Information Technology*, 2012.

[9] O. L. and B. T., "Adherence to medication," *The New England Journal of Medicine* vol. 353, 2005.

[10] Z. A. Marcum, M. A. Sevick, and S. M. Handler, "Medication nonadherence: a diagnosable and treatable medical condition," *JAMA,* vol. 309, pp. 2105-2106, 2013.

[11] J. V. Selby, A. C. Beal, and L. Frank, "The Patient-Centered Outcomes Research Institute (PCORI) national priorities for research and initial research agenda," *JAMA,* vol. 307, 2012.

[12] M. B. Garcia, "A Speech Therapy Game Application for Aphasia Patient Neurorehabilitation – A Pilot Study of an mHealth App," *International Journal of Simulation: Systems, Science & Technology,* 2019.