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LoRa driven medical adherence system

Suheib Sherif, Wooi Haw Tan, Chee Pun Ooi, Abubaker Sherif, Sarina Mansor
Faculty of Engineering, Multimedia University, Selangor, Malaysia

Article Info

ABSTRACT

Recent discovered technologies have exposed many new theories and possibilities to improve our standard of living. Medical assistance has been a major research topic in the past, many efforts were put in to simplify the process of following treatment prescriptions. This paper summarizes the work done in developing LoRa driven medical adherence system in order to improve medicine adherence for elderlies. The designed system is composed of two sections; embedded hardware device for the use of patients at home and Web application to manage all patients along with their medicines and keep track of their medicine intake history. LoRa wireless communication technology is used for connecting all embedded devices with a central gateway that manages the network. Hardware and software tests have been conducted and showed great performance in terms of LoRa network range and latency. In short, the proposed system shows promising method of improving medicine adherence.

Corresponding Author:

Suheib Sherif,
Faculty of Engineering,
Multimedia University,
Persiaran Multimedia, 63100 Cyberjaya, Selangor, Malaysia.
Email: suheib.sherif@gmail.com

1. INTRODUCTION

Generally, our lifestyles are always related to what level of technology we are utilizing. Medical and healthcare sector is rapidly changing with respect to new scientific discoveries where many new devices are being designed to simplify the process of recovery for patients. The demographic change in our societies is one of the major challenges that we are facing nowadays as considered by the World Health Organization (WHO). Ageing population is increasing worldwide which will have a great impact on future generations especially on economy and productivity [1]. Recent researches have shown that the number of population of people who are 65 years old and above is increasing and it will reach 29.5% in 2060 compared to 17.4% in 2010 [2]. This increasing population means that the number of dependent elderlies in our societies is almost one third of the society. Those senior citizens, usually, do not prefer to stay at care centers as they do not feel independent and they are put in a controlled environment. The main challenge will be how to take care of these people while they are at the comfort of their homes. Poor medical adherence is considered as one of the major causes of unsatisfactory treatment outcomes as well as being a main contributor for the increasing cost of healthcare in general [3, 4].

According to WHO, treatment adherence to chronic diseases is 50% on average in developed countries whereas in developing countries, it is even lower, which means more than half of the patients do not follow their medication schedule according to their prescriptions [1, 3]. This low rate of treatment adherence results in unpleasant health consequences as well as increasing the time for treatment which will result in increasing the overall cost of treatment course [3]. Even though some care centers offer good care of their residents and make sure that they follow their treatment plans, patients do not feel comfortable living

in these care centers as they tend to feel dependent and lose the level of freedom that they have at their homes. Eventually, they tend to live longer and happier life when they live independently outside those care centers [5].

Some researches focused on monitoring medication intake and reporting unusual drug intake or missing dosage. Others focused on reminding patients to take their medicines at the correct time using different methods. Different technologies were used in developing various solutions for medical adherence, some used pill dispensers along with web applications while others used embedded hardware and mobile applications.

In the past four years, many researches and products were proposed to improve medical adherence. Multiple approaches were followed to deliver different services to patients in the area of medical reminders. Some researches designed embedded hardware to generate medicine reminders alarms, while others proposed pills bottle weight monitoring to check patients medicine intake [6, 7]. Moreover, mobile applications were developed to enhance medical adherence [8]. Some of these solutions only concerned about generating the reminder alarm without taking a step further to call for help or send alerts to third parties such as patient relatives, nurses or doctors which are a huge concern especially in medical applications. User interface is also another major aspect especially when dealing with elderly people whom need a simple yet effective ways to interact with these devices [9, 10]. Some application requires the patient to load the medicine independently and enter the medicine schedule manually which can be inconvenient and not easy to use. Many products were introduced to the market of medical reminders [11, 12].

In short, many efforts were put in order to improve medical adherence in the past. Both researchers and companies have proposed different solutions using different methods to generate medicine reminders and provide feedback on patient's medicine intake [13, 14]. However, some of these solutions do not provide any further assistance if the patient fails to take the medicine after generating the alarm. Others tend to provide insecure systems that have important personal information which is not desirable. User-friendly interface was not taken into count in some of the proposed solutions where the patient must handle complicated processes in order to key in the medicine schedule and get the solution to work [15-17].

This project aims to overcome certain downsides of previous solutions that have been developed. It provides a scalable medical adherence system that can easily be deployed at different clinics and locations without relying on existing infrastructure for internet connection since the communication channel is controlled locally. Apart from this, the ease of use and user friendliness make his proposed system ideal for the use of elderlies since they do not need to worry about the medicine name and dosage time with the use of our color encoded medicine bottles.

2.   RESEARCH METHOD

After going through the product design cycle and developing multiple prototypes for the system, a final system design is proposed in this chapter. The designed solution was developed to overcome any downsides found in the previous solutions as well as implementing technical features to satisfy all requirements and objectives of the project.

2.1. System architecture

The proposed solution system architecture in Figure 1 is shows the main dominant components of the system. Figure 1 illustrates the system architecture of the project. To illustrate the system working principle, the nurse located at the local clinic adds a new patient to the system, through a user-friendly web application, along with the patient information such as address, contact info, medicines, medicine schedule and relatives email addresses. A worker at the main server will keep track of all medicine timing for all patients registered in the system. When the time comes to remind a patient to take medicine, a signal will be sent through LoRa network via MedNotifier Gateway to that specific patient. MedNotifier end device is responsible of receiving LoRa messages and generating visible and audible alarm for patients [18, 19]. An acknowledgment message is then sent by the user, to acknowledge the consumption the medicine, via LoRa network. All medicine records are stored at the server and in case the system does not get an acknowledgment from a particular patient within a specified time, an alarm message will be displayed on clinic dashboard web page so they can take a further action. Relatives can request their family member medicine intake history from the clinic to keep up with their treatment plan as well. The medical report is then generated automatically and sent to specific or all registered relatives.
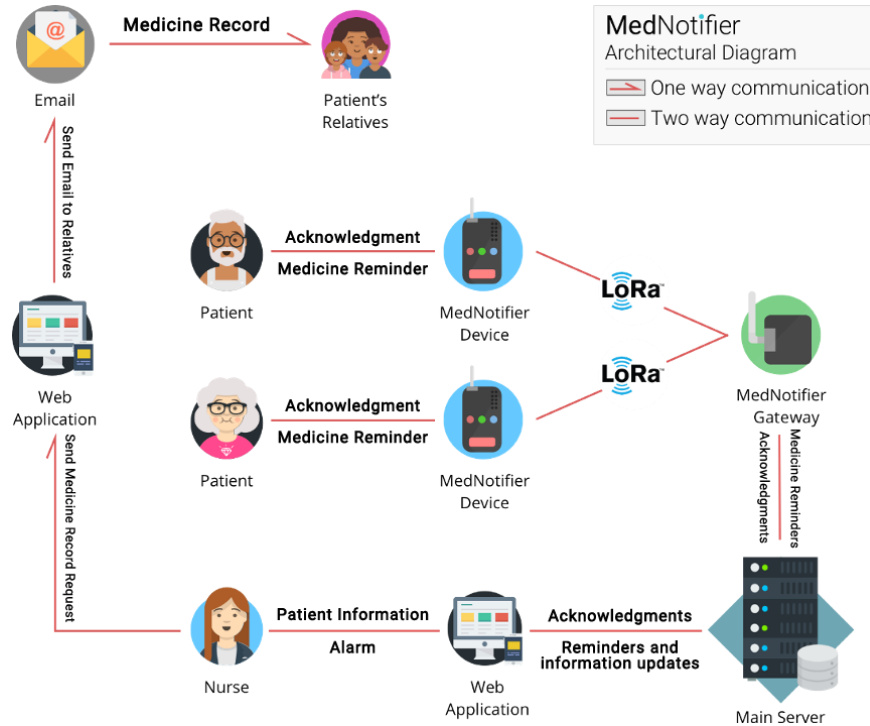
Figure 1. System architecture

2.2. System design

This system utilizes many technologies and algorithms to insure a quick and reliable communication between different components of the system. The main powerful technology that was used in this project is called long range wireless communication (LoRa) [20, 21]. Other technologies and software were used in order to achieve high performance, security and reliability as well as simplifying the user interface for both clinic staff and end users. These technologies are remote dictionary server (Redis), for creating stacks to handle large amount of data requests, advanced encryption standard (AES) to encrypt the data sent from the gateway to the end nodes and vice versa, model view controller (MVC), which is a platform used to simplify making powerful and secure web applications [22-24].

2.3. System hardware implementation
2.3.1. Home medicine reminder device

Hardware device was designed for patients to have at their homes. Each device is hardcoded with a unique ID, this ID should be registered at the clinic system to the respective patient. This device, shown in Figure 2, is responsible of generating audible and visible alarms for patients to remind them to take their medicines. The device is controlled by Atmega328p microcontroller, it is designed to receive LoRa packets via SX1276 LoRa transceiver module. Red-Green-Blue LED is used to specify which medicine to take at that specific alarm according to the bottle sticker, as shown in Figure 3, along with a loud alarm sound. It is also equipped with a push button to acknowledge the reception of the alarm and taking the medicine respectively.
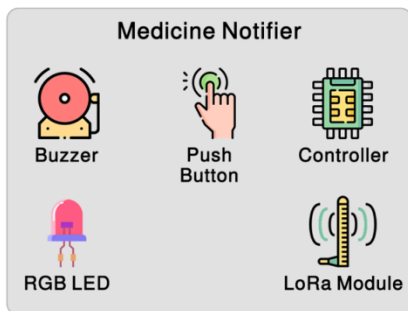

Figure 2. Home gateway hardware design

Figure 3. Medicine container stickers

2.3.2. Security gateway
        At the clinic, a LoRa gateway is placed. The gateway is responsible of sending and receiving LoRa packets from and to MedNotifier devices. The gateway is made using two connected devices which are Raspberry Pi zero W connected serially to Arduino Nano as shown in Figure 4. The Arduino microcontroller is connected to LoRa module and it acts as a transceiver for LoRa packets. It also handles the encryption and decryption for the messages using advanced encryption standard (AES). The Raspberry Pi is used to provide stable wireless connection to the server either locally or through internet. It also handles some data processing.
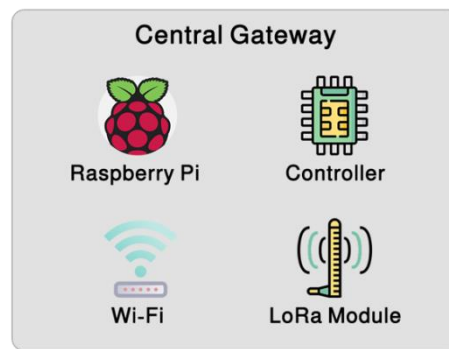

Figure 4. Clinic gateway

2.4. Software implementation
        The web application is designed specifically for nurses. Many factors were taken in order to develop a user-friendly interface for the ease of use by nurses. In terms of backend development, the web application is directly accessed by the nurse where the initial stage is to register a new user as shown in Figure 5. At later stage, patient information can be modified in case of any changes in the address or contact information. The nurse can also assign one or more relatives to that particular patient so they can easily be contacted in case of emergency. After successfully registering a patient, the nurse can then assign one or more medicine to the patient along with their intake time and sticker color. The notification worker will read all patients medicine schedule and it will initiate a medicine notification to the user in case the medicine time is due. The alarm worker will keep scanning in case the notification sent does not receive an acknowledgment within a time limit, it will send an alarm event along with the patient ID to the web page that the nurse is monitoring. When the patient receives the medicine reminder notification and acknowledges the reception, it will send a taken event to the web application and it will be stored in the patient record for future reference.
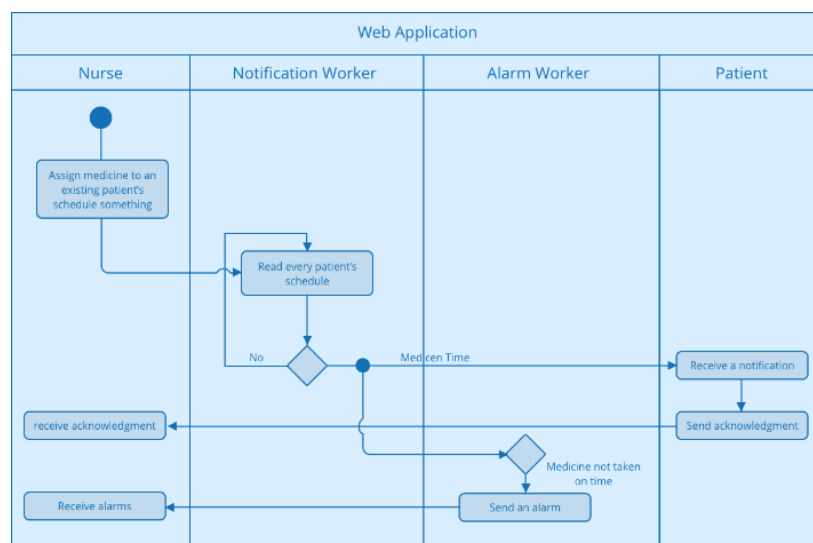

Figure 5. Web application

The alarm worker is divided into three main processes that are timeout catch process, acknowledgment watcher, and notifier.

- Timeout catch process: When a notification is sent to a patient. Timeout catch process is kept waiting around fifteen minutes then check if any acknowledgement received from the patient. If the patient does not send an acknowledgement within that time, it means that it is most probably that the patient did not take the medicine on time. The event information then will be pushed to a queue called timeout events to be handled by another process.
- Acknowledgment watcher process: The acknowledgment watcher processes is listening to any acknowledgments sent from patients. When any acknowledgment is received, the event will be added to the queue of received events which means that the patients have already taken the medicine.
- Notifier process: The Notifier process is dequeuing from both timeout events queue and received events queue. This process is responsible to send notification to the nurses when a patient does not take the medicine or register acknowledgments that are sent from patients to the database to be recorded in the patient's medicines logs.

2.4. System implementation

In a practical implementation of the system has been designed in a way that the MedNotifier Gateway is placed at a clinical center inside a residential area. Nurses at the clinic have the access to the web application so that they can add, modify or delete any patient or medicine. A list of all medicines available in the clinic pharmacy or taken by the community residents is saved on the website along with their information. A nurse can then assign any patient with a medicine by registering it in the patient profile. The nurse shall select a sticker color to be put on the medicine package and registered on the system accordingly. The patient can take the MedNotifier Device back home and wait for the reminders without worrying about messing treatment anymore. In case the clinic does not receive a medicine reception acknowledgment within 15 minutes, the web application will generate an alarm for nurses to follow up with that particular patient and make sure the medicine is taken

For prototyping proposes and budget constraints, some practical components such as high gain antennas were replaced with small 3dbi antenna to develop a functioning prototype. The cloud server that was highlighted in the system design was hosted on Digital Ocean cloud services provider and multiple services were installed on the same server such as LAMP software bundle which includes Linux, Apache, MySQL and PHP. Linux is the operating system of the virtual server while Apache is a web server software that is developed and maintained by open-source community. MySQL is a relational structured query language database that is developed and maintained by open-source community as well while PHP is a well-known programming language for web server applications and it was managed using MVC framework called Laravel. Laravel was another open-source component that was used efficiently in developing the web application.

3. RESULTS AND DISCUSSION

This section summarizes the tests and evaluations done on both hardware and software components of the system to ensure that the system behaves as designed initially. A complete functionality test was carried out as well and every component of the system was verified. LoRa network was examined as well for range, latency and power consumption.

3.1. LoRa network range test

In order to evaluate LoRa network connection, a drive test was carried out by sending LoRa packets from different distances with different obstacles between the transmitter and the receiver. LoRa gateway was installed at a high place in order to maximize coverage. The height was 50 meters and the test points were from 200 to 3500 meters at different angles as shown in Figure 6.

To evaluate the signal strength, received signal strength indicator (RSSI) was measured at the receiver end for each packet and recorded accordingly. RSSI determines the signal quality from transmitter to receiver, by relying on this reading a decision can be made whether the connection is suitable for transmission or not. RSSI is usually measured in dBm which means the smaller negative values have better performance compared to higher negative values which represents weak signals. To decide which spreading factor shall be used for modulation and which data rate is to be used in this application, the drive test conducted using two different data rates and spreading factors. In theory, higher spreading factor with lower data rate provides better signal performance [24, 25].
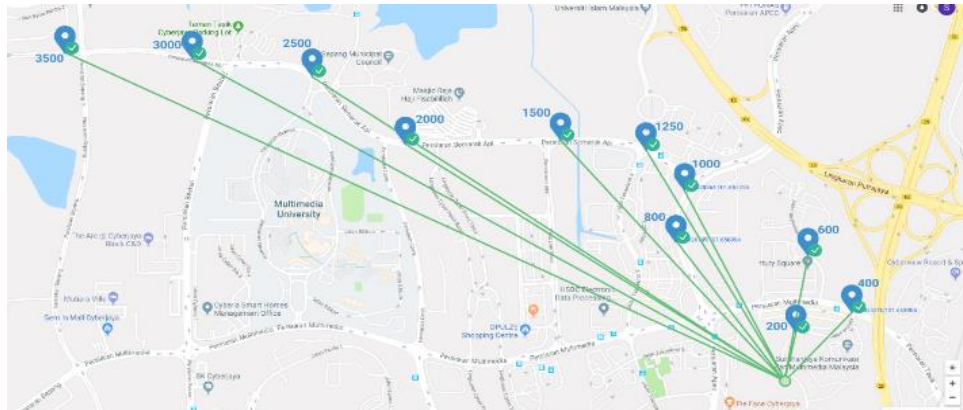
Figure 6. LoRa range test

Signals transmitted with spreading factor of 9 with data rate of 1760bps showed weaker performance in comparison with the signal transmitted with spreading factor of 10 with data rate of 980bps as expected from the theory stated above. However, more conditions can affect the signal strength such as the antenna gain and power used in the transmission, the propagation path and link loss. To keep the tests in similar conditions, both signals were transmitted from the exact same location. As a result, SF10 was used in this system since data rate is not a critical measure in this system so it can be sacrificed in order to obtain a stable link connection. The antennas used in this test were both 3dbi which is good enough for making a demo of the system but in industrial applications higher gain antennas are used at the gateway to achieve even larger range.

3.2. Latency test

There is a slight delay between the alarm time and the reception of the alarm due to the delay added to the worker in case there is no scheduled alarm which is 5 seconds. As expected the delay is roughly between 1 and 5 seconds which is acceptable for this application. Another latency test was carried out to measure the delay between acknowledging the reception of the alarm through the push button to the reception of the notification and recording the acknowledgment. The time was measured using a stop watch and the transmitter and receiver were tested at two different locations to ensure realistic measurements. The average latency from a distance is around 1.5 seconds which is good for the designed system requirements.

3.3. Web and mobile applications results

Figure 7 shows the monitoring dashboard for nurses where they receive all alarm notifications for untaken medicines. After registering a patient, nurses can then assign medicine to them as shown in Figure 8, where they can choose medicines from the provided list and register the medicine time along with the sticker colour that is fixed on the pill container.
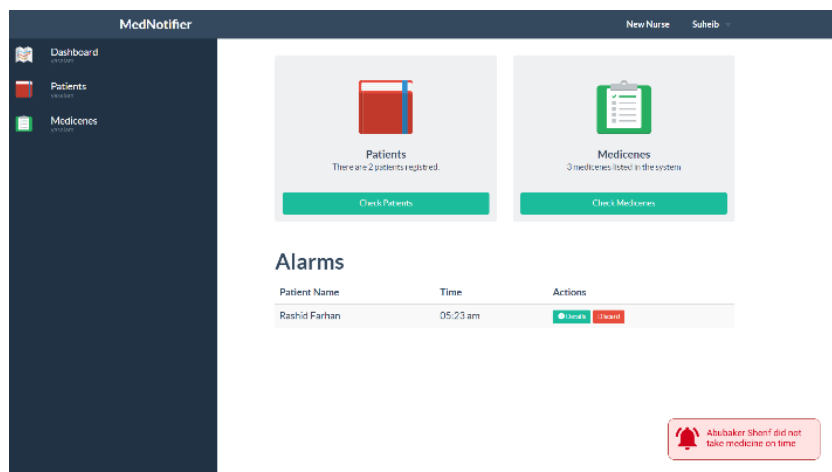

Figure 7. Web application-clinic home page

Figure 8. Clinic web application-medicine assignment

4. CONCLUSION

This paper summarized the work done in developing LoRa driven medical adherence system, starting by researching about existing solutions and products. The previous solutions were compared to each other in terms of their strengths and weaknesses which was helpful in designing the proposed system. System architecture was then explained and each component was discussed. The overall system was tested for functionality and it showed positive results in solving the stated problem.

After developing, implementing and testing each system component, the system was found stable and can be scaled without affecting the performance. In order to make further improvement on the existing solution, data analysis can be integrated to analyze the patients' medication habits and whether or not doctors should adjust their medication time. Medicine detection is also a great feature to add to the system where the system automatically knows whether the patient consumed the medicine or not without human interaction

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