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LoRa-based Smart Patient Monitoring System

A.P. Murdan, J.S. Ramphul
Department of Electrical and Electronic Engineering
University of Mauritius
Reduit, Mauritius
a.murdan@uom.ac.mu

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Abstract

Advancements in mobile technologies, internet, cloud computing, digital platforms and social media have significantly contributed to connecting people after the COVID-19 pandemic. With people becoming much more health-conscious, there is a growing demand for innovative ways to monitor health and well-being. This project aims at deploying Internet of Things (IoT) devices for measuring vital medical parameters of patients and securely transmitting the data to caregivers or any authorized persons for timely decisions. Essentially, our proposed system allows patients to move freely within a certain radius, while wearing an IoT kit, consisting of several sensors and communication modules. The project consists of three main parts: transmission, receiving and 'body fall' detection and alert systems. The transmission section records data through sensors and sends it to the receiving section, which then uploads the data to the cloud. The 'body fall' system detects changes in orientation and acceleration, alerting caregiver, in case the patient falls. Implementation and testing were successfully performed, with live data presented to caregivers through the LoRa technology and IoT platforms such as Blynk and Cayenne.

I. INTRODUCTION

The COVID-19 pandemic has placed enormous pressure on healthcare systems worldwide, exposing the vulnerability of the entire industry. In response, governments are reassessing their healthcare plans to promote resilience, sustainability, and thereby strengthening the sector. The pandemic has highlighted the urgent need for policies to improve preparedness addressing issues such as health staff recruitment and retention, capacity management, productivity, facility upgrades, and the expansion of telehealth services and home care for patients.

Telehealth involves using digital information and communication technologies to access health care services remotely [1]. The devices include computers, tablets, or smartphones. It aims to provide healthcare access to individuals with limited mobility, time or transportation, thereby increasing overall access to healthcare. Telemedicine, a subset of telehealth, was formally introduced in the early 1950s, with significant federal funding for research and development projects in Arizona and Alaska during the 1960s and 1970s [2]. These projects demonstrated that robust and secure communication technologies could serve as alternatives for obtaining medical care and specialized care in emergency situations. Today, terms such as e-health, mobile-health, and mHealth are used synonymously with telehealth, encompassing a wide range of communication technologies, including the internet.

During the COVID-19 pandemic e-health gained prominence as in-person primary care was severely affected, leading to a surge in telehealth adoption [3]. In the US, medical claims involving telehealth increased by a staggering 4,347% between March 2019 to March 2020, reflecting an unprecedented expansion of telehealth services [4]. However, despite the fact that telehealth presents numerous benefits, there are also many barriers to the adoption of telehealth as described in [5].

The advent of the Internet of Things (IoT), ubiquitous Internet connectivity, robust sensors, cloud and fog computing infrastructure, Machine Learning (ML) algorithms, as well as IoT platforms have propelled telehealth to new heights. Literature abounds with IoT-based health systems addressing various diseases. Numerous Remote Patient Monitoring (RPM), Smart Healthcare Monitoring (SHM) frameworks, as well as Smart Health Knowledge Systems, primarily based on ML have been developed [6]–[11]. In addition, researchers have utilized low-cost microcontrollers, sensors, and actuators, and IoT platforms to demonstrate proof-of-concept systems that can be easily scaled up for home use and small to medium-sized businesses. An Arduino board and a cardiac sensor were utilized in [12] to monitor and classify individuals' health with respect to cardiac disease, employing the K-Nearest Neighbour (k-NN) algorithm for classification and validation.

In this project, we present the design and implementation of an IoT-based patient monitoring system that leverages LoRa communication technology. This comprehensive system not only provides patient fall detection, but measures, displays, and transmits vital health parameters, including body temperature, heart rate, electrocardiogram, and blood oxygen levels. The successful implementation and testing of this system demonstrates its effectiveness in realt time patient monitoring. By utilizing LoRa technology and IoT platforms, such as Blynk and Cayenne, the system ensures that live health data is readily accessible to caregivers, enhancing patient care and enabling timely intervention when necessary.

II. METHODOLOGY

A. System architecture

The system architecture with the transmitter and the receiver blocks is depicted in Figure 1.

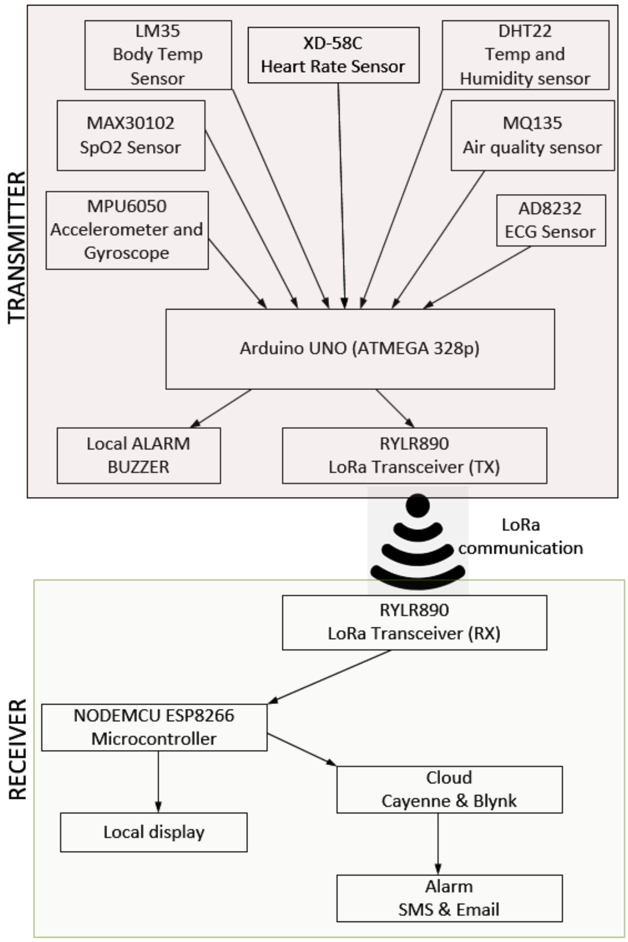

Figure 1. System architecture – Transmitter and receiver

The different sensors employed in this system are connected to the Arduino Uno microcontroller, which sends the collected data to the LoRa transceiver, configured as a transmitter. A local alarm buzzer is designed to signal a patient's body fall, but body fall data is also transmitted to the LoRa module for remote monitoring. In line-of-sight conditions, the communication range between the two LoRa modules can reach up to 10 km. Various tests were carried out to evaluate the system's performance in real world conditions. It was found that even in densely populated areas with many high-rise buildings, the LoRa signal was effectively transmitted across a distance of 3.6 km.

B. Components

1) XD-58C Sensor

The XD-58C is used to measure heart rate through the patient's finger or earlobe. The heart rate sensor operates by a technique called photoplethysmogram[13] which is used to to determine blood volume changes in peripheral circulation. A green light of a wavelength of approximately 550nm is directed at the finger and the resulting reflected light is detected by a photosensor. The received light is then converted into a voltage signal. An RC arrangement filters out noise, and the signal is amplified by an on-board Op-Amp [14].

2) LM-35 temperature Sensor

Monitoring the patient's body temperature is another crucial parameter. For example, the first sign of a COVID-19 infected person is often related to an elevated body temperature. The LM35 is a temperature measuring device that produces an analog output voltage proportional to the temperature [15]. By amplifying this voltage change, a signal directly proportional to temperature is generated.

3) MAX 30102 Pulse Oximeter sensor

The main purpose of a pulse oximetry is to determine the patient's blood oxygenation level. The oximeter sensor measures the level of hemoglobin molecules in the blood being pumped. Oxygenated and deoxygenated hemoglobin exhibit different light absorption characteristics, depending on the applied light wavelength. Deoxygenated hemoglobin is a deep dark red substance, whereas oxygenated hemoglobin is a bright red substance. The sensor contains a pair of LEDs that emit monochromatic red light with a wavelength of 660nm and infrared light with a wavelength of 940nm. The two types of hemoglobin have significantly different absorbance properties at the specified wavelengths. This difference permits the computation of oxygenated hemoglobin and its counterpart. The integrated pair of light detectors detect the amount of each wavelength that has successfully reflected back and translate it into a voltage [16].

4) AD 8232 ECG sensor

A doctor may analyze the patterns of the electrical activity to diagnose heart-related problems such as heart attacks and heart failures. The signal received from the electrodes is transmitted to the output pin of the module and is then fed to the analog input pin of the Arduino for data processing. The signal can be visualized through the serial monitor. The graphical representation it produces can be examined by assessing the various components of the waveform, which have some biological importance [17].

5) DHT 22 temperature and humidity sensor

The DHT 22 component has two integrated sensors:a thermistor and a capacitive humidity sensor. The humidity sensor has two electrodes, sandwiching a moisture-absorbing layer. When water is absorbed, conductivity increases. This increase in conductivity, which corresponds to a change in resistance, is directly proportional to humidity. High humidity decreases resistance and vice versa. The thermistor (NTC) acts as a variable resistor, as its resistance varies with temperature. An increase in temperature yields a decrease in resistance. This sensor is mainly used to monitor the temperature and humidity in the surroundings of the patient.

6) Air quality sensor

The MQ-135 was chosen specifically for its adaptability to measure air quality. The Air Quality Index (AQI) is the standard typically used to assess air quality. The US Environment Protection Authority (EPA) introduced this index to inform the public about the potential health risks associated with unregulated air quality [18]. Table 1 shows the correlation between the AQI and health levels.

Table 1
AQI index [19]

Air quality index range	Level of health concern
0-50	Good
51-100	Moderate
101-150	Unhealthy for sensitive groups
151-200	Unhealthy
201-300	Very unhealthy
301-500	Hazardous

7) Arduino UNO

The Arduino UNO [20] serves as the transmitter, sending data to the receiver via the LoRa protocol. The microcontroller is based on the 8-bit Atmega 328p chip. It has a clock speed of 16MHz, 32kB program memory, 1kB EEPROM and 2kB RAM.

8) Reyax LoRa (RYLR896)

The chosen transceiver module selected is the RYLR890 [21], which was built on the Semtech SX1276 engine and incorporates LoRa (Long Range) technology. The module includes a highly efficient power amplifier and operates on low current compared to other technologies. It operates in the license-free sub-GHz frequency band. Communication between the embedded processor and microcontroller occurs through UART pins. Notably, the transceiver module supports full-duplex data transmission, enabling simultaneous communication in both directions over a signal carrier. Unlike parallel communication, where multiple bits can be transmitted at once, serial communication sends data bit by bit, requiring fewer input and output lines. The LoRa module operates at 3.3 V; hence a voltage divider network is used to reduce the 5V to 3.4V.

9) NodeMCU ESP8266

The NodeMCU [22] is specifically designed for IoT applications as a convenient gateway due to its on-board Wi-Fi module. In this project, the Reyax LoRa module receives transmitted data and passes it to the NodeMCU. The NodeMCU features 4MB flash memory and 128kB RAM, with a clock speed of up to 160 MHz. It can be powered by a battery or connected to a PC through USB.

10) MPU 6050 3-axis accelerometer and gyroscope

This component houses a 3-axis accelerometer and gyroscope on an integrated chip. It operates at 3.3 V, but also supports 5V due to its voltage regulator. Additionally, it consists of three 16-bit ADC, which samples the 3 axes of movement concurrently [23]. The on-chip 3-axis accelerometer is equipped with MEMs technology, enabling linear acceleration measurement. It can also measure angle tilt along the 3 axes. The falling body system undergoes two cycles before activating the buzzer. The sensor reads acceleration values in all three axes. While at rest (on a table or held in the hand), the z-axis acceleration component is approximately +1*g*, as the sensor senses an upward force resisting its fall. However, the sensor perceives *g* at rest to be approximately 7.8 ms^{-2} due to errors. Theoretically, when a person falls, the acceleration sensed will be in two axes (x-z or y-z), but practically, there will still be a component along the discarded axis. Therefore, a 3*g* threshold was chosen for acceleration magnitude, accounting for sensor errors and relevant axes' acceleration. The movement of the earth was not considered in the programming. Thus, the system triggers a buzzer upon detection of an angular change of more than 90º.

III. IMPLEMENTATION AND TESTING

All sensors used were individually tested according to the tests recommended in their respective datasheets. The following section describes the testing of the main components.

A. ECG sensor testing

The three electrodes of the sensor were placed on a healthy patient's chest, following [24], while the AD8232 board was connected to the Arduino as shown in Table 2.

The results on the serial monitor are as shown in Figure 2. An ECG typically measures some important parameters of the heart. As can be observed in Figure 2, the ECG signal consists of different waveforms that physicians can use to diagnose cardiac diseases and irregularities. An in-depth study of the ECG is beyond the scope of this paper, but readers interested in more information on ECG can refer to [25].

The waveform in Figure 2 is similar to a standard ECG plot from a medical ECG device. The midpoint value shown on the serial plotter is around 338. In general, the Arduino's default reference voltage for analog input is 5V. The ECG sensor operates at 3.3 V. Therefore, the output will not exceed 3.3V. The midpoint is 3.3/2=1.65 V. The 10-bit ADC incorporated into the Arduino board decodes the 1.65 V to 338, as shown in Equation 1.

$$\frac{ADC\ Resolution}{Voltage_{system}} = \frac{Reading\ of\ ADC}{Analog\ voltage\ measured}$$

$$\frac{1023}{5\ V} = \frac{Reading\ of\ ADC}{1.65\ V} \tag{1}$$

$$Reading\ of\ ADC = 338$$

Table 2
Interfacing AD8232 ECG sensor with Arduino Uno [26]

Board Label	Pin function	Arduino Uno Connection
GND	Ground	GND
3.3V	3.3V power input	3V3
OUTPUT	Analog output of the sensor	A0
LO-	Leads-Off Detect-	D8
LO+	Leads-Off Detect+	D9
$\overline{SDN}$	Shutdown	Optional

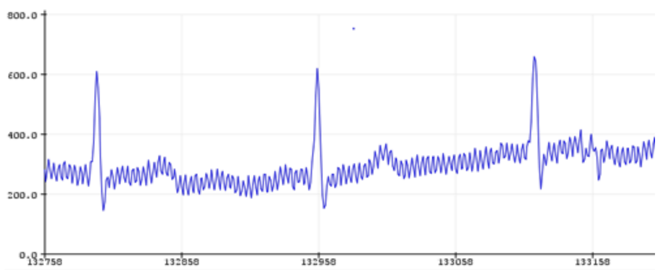

Figure 2. ECG sensor results

B. Body temperature sensor testing

Many automatic hand sanitizer dispensers utilize LM-35 temperature sensor. In this project, the sensor was used to measure the patient's body temperature. Factors such as the individual's age, activity level, and time of day can cause slight variations in normal body temperature. Generally, a normal body temperature is considered to be 98.6°F (37°C). The "normal" range for body temperature is between 97°F (36.1°C) and 99°F (37.2°C). Figure 3 depicts the results obtained on the serial monitor.

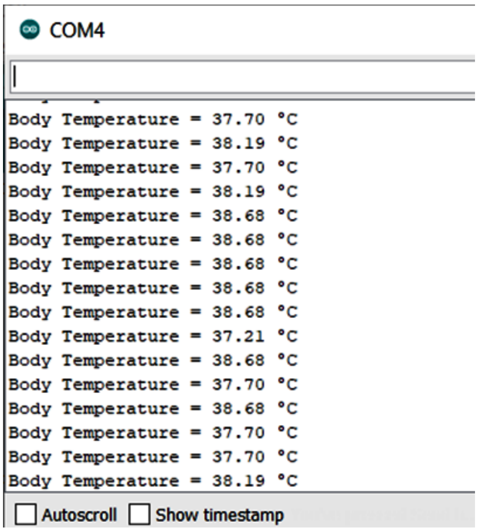

Figure 3. Body temperature of patient

C. Heart rate sensor testing

The pulse sensor was carefully attached to a finger to measure and display the heart rate on the serial monitor. Proper attachment ensured that the sensor did not pick up noise from the environment. A normal person's resting heart rate typically ranges from 60 to 100 beats per minute (BPM). This can increase to 130-150 BPM during exercise. An individual who exercises regularly and is in good health may have a resting heart rate of 60 BPM, which is not considered slow. However, for someone with cholesterol or other health issues, who is not an athlete, a resting heart rate of 60 BPM may be regarded as slow. Figure 4 shows the heart rate readings of the patient.

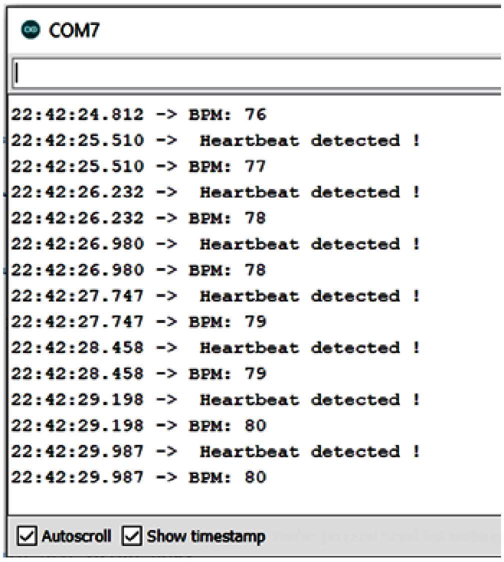

Figure 4. Heart rate readings

D. Oximeter sensor testing

The amount of oxygen inhaled and the amount successfully flows through red blood cells can differ. The blood saturation level, also known as SpO2 level for a healthy person typically ranges from 95-100% [27]. Generally, levels below 95% are considered abnormal, except for older individuals. Figure 5 shows the results from the pulse oximeter sensor

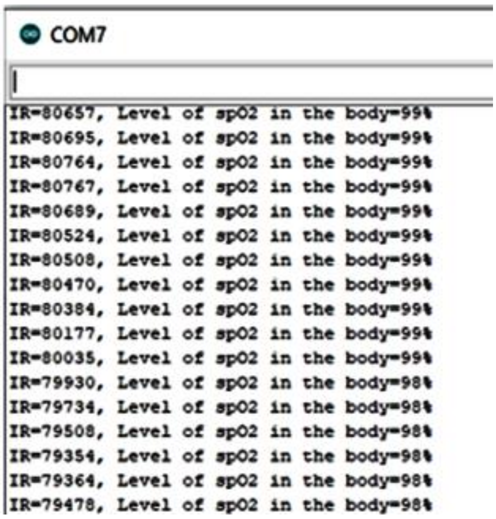

Figure 5. Oximeter sensor testing

E. Reyax LoRa (RYLR896) testing

The AT Command set was used to send a few commands to the serial monitor to obtain responses that demonstrate the proper functioning of the Reyax LoRa module:

1. The first line indicates that the module can respond to commands.
2. The +IPR indicates the baud rate, which in this case is 115200 (default). Both Reyax modules should have matching baud rate for successful communication.
3. The +PARAMETER indicates the spreading factor, bandwidth, coding rate and programmed preamble, respectively.
    - A larger spreading factor results in better sensitivity, but adversely increases transmission time.
    - To achieve a faster coding rate, the value is set to 1.
    - A larger preamble code reduces the likelihood of data loss.
4. The +BAND indicates the RF frequency at which the LoRa module communicates. In this case, it was set at 915 MHz. Both receiver and the transmitter Reyax LoRa modules should have the same frequency for successful communication.
5. The +ADDRESS represents the address ID of the module.
6. The +NETWORKID shows the network ID.
7. The +SEND displays the data sent to the specified address, which is 50 in this case, via Command mode.

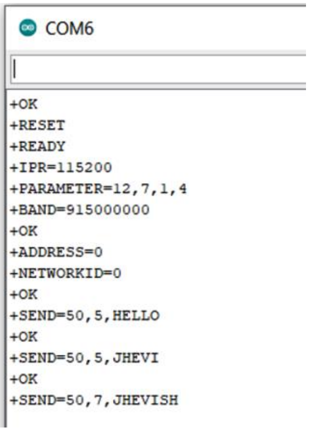

Figure 6. Reyax Test

F. LoRa Transmission distance testing

The system was tested at various locations to analyze how the Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR) varied with distance. In the first scenario, the ability of the device to receive data in all four directions was evaluated. The system was connected to a mobile hotspot and placed approximately 560 metres away. Data was collected, as shown in Figure 7, with live location support and Google Map verification. The same steps were carried out for different distances to further assess the performance of the system.

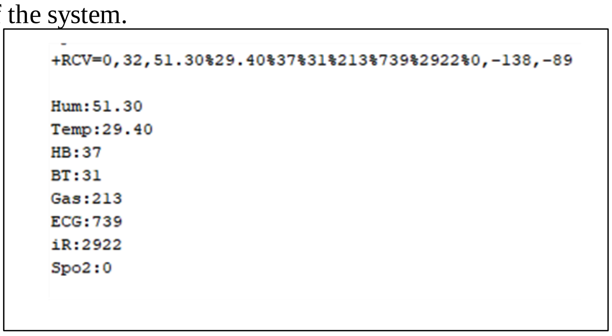

Figure 7. Data collected at a distance of 560 m

Similar tests were carried out at distances of 1700m and 3650m. It was found that the Reyax LoRa module transmitted all parameters without errors. Initially, we planned to take measurements at 0.5km, 1.5 and 3.5km. However, due to the presence of private residential buildings at these distances, we opted to slightly increase the distance. The results obtained were highly conclusive.

IV. RESULTS AND DISCUSSION

A. Final design

A prototype of the system was designed using 3D Tinkercad [28]. The box was drawn with a larger dimensions than the original version to enhance visibility. A battery was connected to power the microcontroller. It was designed to be worn around the wrist (similar to a watch), using leather straps. This design allows patients to roam around freely while still providing health parameters to the caretakers. Figure 8 shows the final design of the prototype.

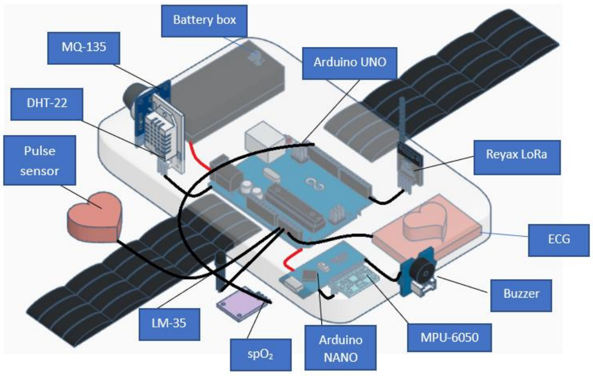

Figure 8. Final design of transmitter side and fall detection

B. Monitoring of data on IoT platforms

Two IoT platforms, namely Cayenne [29] and Blynk [30], were tested, and data were sent simultaneously to both. According to its website, Cayenne is “the world’s first drag and drop IoT project builder that empowers developers, designers and engineers to quickly prototype and share their connected device projects. Cayenne was designed to help users create Internet of Things prototypes and then bring them to production.” In contrast, Blynk markets itself as “a full suite of software required to prototype, deploy, and remotely manage connected electronic devices at any scale: from personal IoT projects to millions of commercial connected products.” Both IoT platforms offer free trial for exploration and early prototyping. For this project, both platforms have been tested. They provided a wide array of features, an intuitive dashboard, and similar performance. Figure 9 shows the Cayenne dashboard, while Figure 10 depicts the Blynk dashboard.

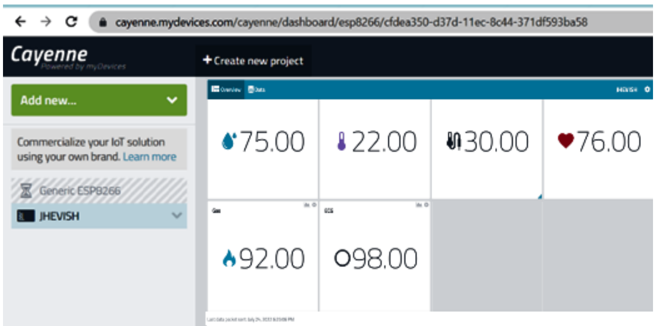

Figure 9. Cayenne Dashboard display

The first four readings on the dashboard in the Figure 9 are real-time values of ambient percentage humidity, ambient temperature, and peripheral body temperature and pulse rate. On the second row, the readings represent the air quality index in parts per million, and the blood saturation level. Similar values are shown in the Blynk dashboard in Figure 10.

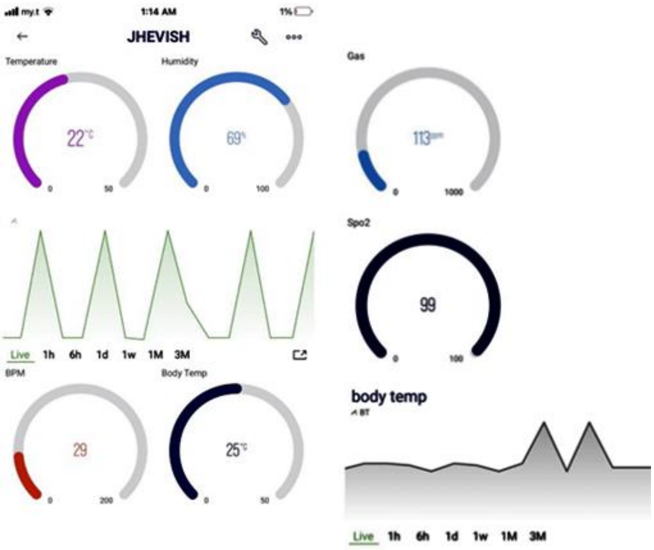

Figure 10 Blynk Dashboard display

C. Power source for transmitter side

The current drawn from the transmitter side was measured using a multimeter. It was found that the circuit required 140mA to function. The battery pack capacity used had a 2700 mAh capacity. The lifetime of the battery connected to the system was calculated using Equation (2).

$$\text{Battery life in hours} = \frac{(\text{Battery charge})}{\text{Drawn current of transmitter side}} = 19.3 \quad hours \qquad (2)$$

D. Fall detection

The system was tested by simulating a fall on a table, which triggered the buzzer for a period of time.

V. DISCUSSION

In this project, seven sensors, one actuator (buzzer) and one LoRa transmitter was connected to an Arduino UNO. Each of these components were initially tested individually before the final implementation. On the receiving end, a LoRa receiver was connected to a NODEMCU microcontroller, which pushed the sensor data to the cloud platforms. Connecting all these components to make the system was a challenging task. However, after several hardware iterations and revisions of codes for the microcontrollers, the system was gradually built and tested. The tests were conclusive, with all the components functioning as expected. Since a healthy person tested the system, all his medical parameters were normal, as depicted in Figure 9 and Figure 10, and this was confirmed by a physician.

VI. CONCLUSION

This paper presented the design, implementation and testing of an IoT-based system that utilize LoRa communication technology to transmit crucial medical parameters of patients to authorized caregivers. Two IoT platforms, Cayenne and Blynk, were tested, and both delivered highly satisfactory performance. The body sensors were tested extensively, and and their outputs were validated with medical equipment operated by qualified medical personnel. After implementation, integrated testing was performed. Several updates and upgrades were made based on feedback from patients and medical personnel involved in the project.

Range testing confirmed that the device, equipped with a Reyax LoRa module, successfully transmitted a series of data packets, without errors up toa distance of 3.6 km in a densely populated region with high-rise buildings. For further work, a scenario with multiple transmitters and a single receiver could be envisaged, using a time-sharing approach. Additional features could be incorporated into the device and data received could be stored for further detailed investigations. Machine learning techniques could also be utilized to detect potential hidden health issues.

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