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Development of a wearable wireless body area network for health monitoring of the elderly and disabled

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Development of a wearable wireless body area network for health monitoring of the elderly and disabled

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Abstract. Novel advancements in systems miniaturization, electronics in health care and communication technologies are enabling the integration of both patients and doctors involvement in health care system. A Wearable Wireless Body Area Network (WWBAN) provides continuous, unobtrusive ambulatory, ubiquitous health monitoring, and provide real time patient's status to the physician without any constraint on their normal daily life activities. In this project we developed a wearable wireless body area network system that continuously monitor the health of the elderly and the disabled and provide them with independent, safe and secure living. The WWBAN system monitors the following parameters; blood oxygen saturation using a pulse oximeter sensor (SpO2), heart rate (HR) pulse sensor, Temperature, hydration, glucose level and fall detection. When the wearable system is put on, the sensor values are processed and analysed. If any of the monitored parameter values falls below or exceeds the normal range, there is trigger of remote alert by which an SMS is send to a doctor or physician via GSM module and network. The developed system offers flexibility and mobility to the user; it is a real time system and has significance in revolutionizing health care system by enabling non-invasive, inexpensive, continuous health monitoring.

1. Introduction
Aging (senescence) increases vulnerability to age-associated diseases e.g. heart problems, stroke, respiratory disorder and dementia. Disability can be as a result of these diseases and other several chronic diseases. Most of the time, the elderly and disabled communities would be alone at home whilst their care givers are at work, this expose them to the risk of falling sick or any of their physiological parameters to become abnormal whilst no one can attend to them. Moreover they also need autonomy and independence while ensuring they are secure. Health care records projects a triple increase of the aging population by 2050, simultaneously, the costs of health care are also increasing and scrambling for hospital infrastructure and resources as well as doctor services [1]. As a result of the increase in demand for healthcare services, wireless communication technology advancements, miniaturization, integrated circuits (ICs) and internet, the development of wearable systems has also increased. Some factors contributing to the emergence of sensor networks generation are wearable as well as wireless communication systems. As a result, there is need for advanced technological solutions to alleviate the problems and wearable wireless monitoring systems will become part of healthcare centers with real-time based monitoring [2].

The emerging Wearable Wireless Body Area Networks technology uses sensors to construct a complete wearable health monitoring system [3]. In this project we develop a wearable wireless body area network that monitors the health of the elderly and the disabled and provide them with a safe and secure living. The WWBAN system monitors the following parameters; blood oxygen saturation using a pulse oximeter sensor (SpO2), heart rate (HR) pulse sensor, Temperature using LM35 sensor, hydration, glucose level using Infrared sensor and fall detection using ultrasonic sensor. When the wearable system is put on, the sensor values are acquired, processed and analysed. When any of the monitored parameter values falls below or exceeds the preset normal range, there is trigger of remote alert by which an SMS is send to a doctor or physician via GSM module and network. The developed system offers flexibility and mobility to the user; it is a real time system and has significance in revolutionizing health care system by enabling, non-invasive, inexpensive, continuous health monitoring. Such a system also offers valuable contributions to improvement of patient healthcare; diagnosis, therapeutics monitoring and early detection and prevention of potential diseases that may occur early or later in people's life [3].

The WWBAN system is made up of an integrated non-invasive ultra-low power, sensor nodes, and microcontroller and GSM modules which continuously monitor the health conditions through physiological parameters. Each node in the WWBAN system is capable of capturing the physiological parameters; blood oxygen saturation using a pulse oximeter sensor (SpO2), heart rate (HR) pulse sensor, Temperature using LM35 sensor, hydration, glucose level using Infrared sensor and fall detection [4]. These systems prove possibility of drastic improvement and expansion of the quality of care in a wide variety of population segments and settings [5]. A comprehensive design and development of a wearable health monitoring system is presented in this paper, the system is designed considering scalability, unobtrusiveness, energy efficiency, security. The system developed consists of low power, light weight, miniature sensing devices, wireless transceivers and management electronics which imply there should be consideration for lightweight, long lasting and environmentally friendly power supplies when the health monitoring systems are built. The normal value ranges of the parameters are shown in Table1 below.

Table 1: The normal physiological parameter ranges

Measurement Variable	Normal Range
Temperature	37 – 37 Degrees Celsius
Heart Rate	60-100 beats per minute
Oxygen Saturation	94-99%
Blood glucose	4-6mmol/dL(72-108mmol/dL)
Hydration level	90-100%
Fall Detection	0-20cm

2. System architecture

The system consists of inexpensive, small sized, light weight and miniature sensors which provides the physiological signals and data, a microcontroller unit (Arduino) and a GSM/ GPRS module which enables cloud storage and GSM network communication. The individual physiological sensor has capability to measure a single or more physiological parameters for example temperature, oxygen saturation, blood glucose, hydration, detect fall and heart rate. The sensors are placed strategically on the person's body or can be integrated to make user's clothing as tiny patches to allow ubiquitous monitoring of health in the subjects' native environment for extended periods [6]. As a result the patient is capable of moving freely and has an improved life quality. The system offers ambulatory monitoring of health parameters status without hindering daily activities. Implying that it allows all time health monitoring at any location. When the continuously monitored parameter values of subject cross the normal range or threshold values, a message is sent to the doctor's mobile phone. Health care services can then be provided by the physician to the patient when out of range values of the physiological parameters are communicated through GSM wireless communication. The architecture of the WWBAN is shown in figure 1 below. Through examination of the sent information, the physician is able to initiate assistive action immediately. In addition the system is connected a cloud server, the sensor data is continuously send to the server and the physician can log in to the server to monitor the patients' health status.

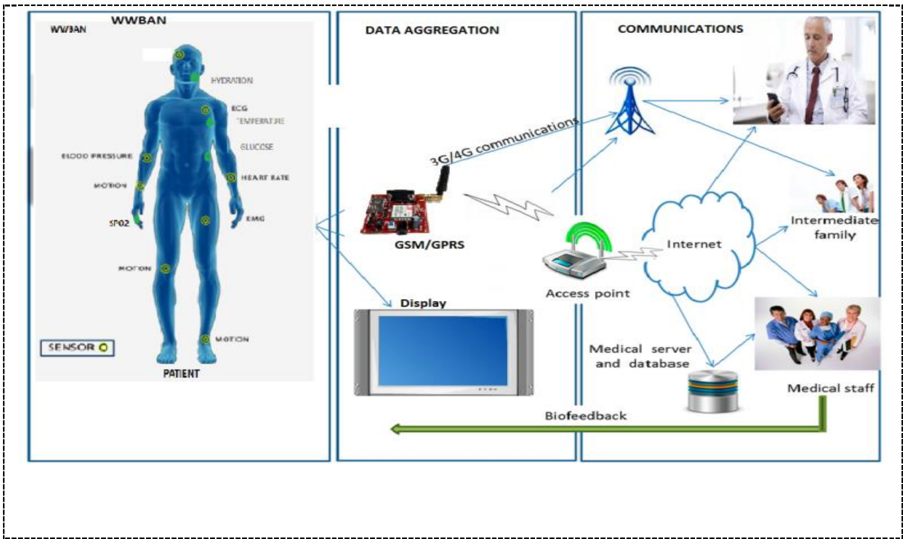

Figure 1. System architecture

3. System hardware description

Figure 2 shows the hardware components of the WWBAN; Arduino microcontroller, sensors, LCD display and GSM modem. For collecting the health signals, the sensors are placed on the human body strategically. The sensors are the LM35 temperature sensor, the pulse sensor for SpO2 and heart rate measurement, hydration sensor and ultrasonic sensor for fall detection. The sensors are connected to the microcontroller for collecting the parameters values; heart rate, oxygen saturation, blood glucose level, body temperature, hydration and fall detection. Between sensors and microcontroller unit, the communication is a wired transmission. LCD display is used by the microcontroller to display the measurement results. Data regarding physiological parameters is transmitted to the physician's mobile phone if any of the values exceed or fall below range using GSM module via GSM network, at the same time the data is continuously send to the cloud server for storage through internet connection.

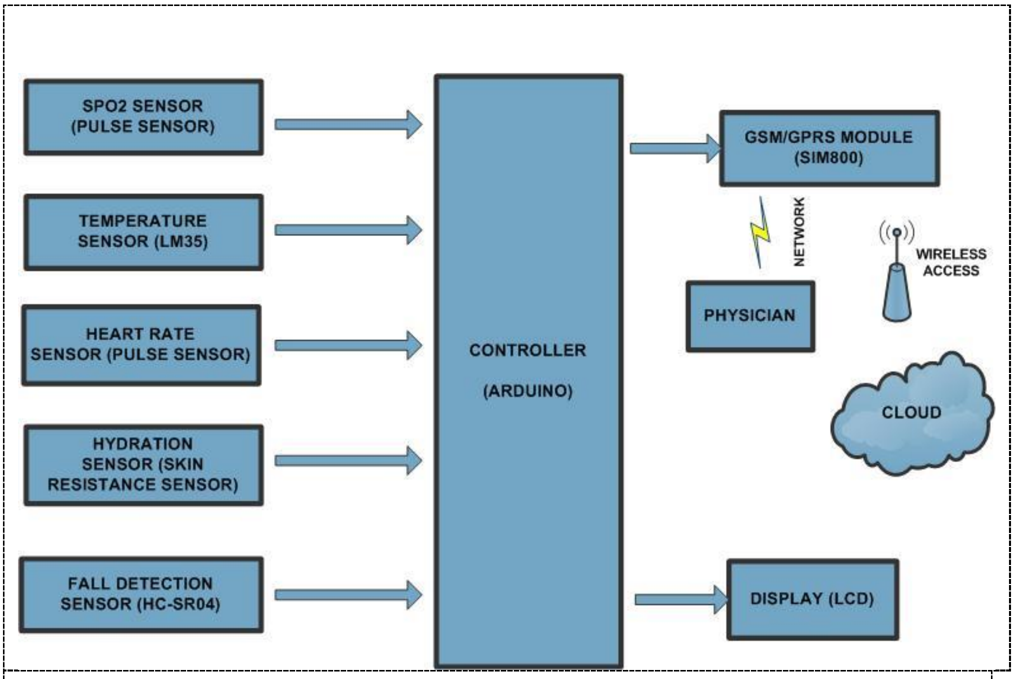

Figure 2. Block diagram for the WWBAN

3.1. Temperature Sensor

The temperature sensor that has been used for body temperature measurement is the LM35 sensor. LM35 temperature devices are a series of precision integrated-circuit devices with output which is linearly proportional to °C (Centigrade temperature). For this reason LM35 presents advantage over the linear temperature sensors calibrated in Kelvins since user needs to do voltage subtraction. The full temperature range for LM35 is −55°C to 150°C. For easy interfacing to readout or control circuitry; linear output, precise calibration and low-output impedance the LM35 device are made [7-8]. The LM35 sensor IC has a 3 pin configuration as shown in figure 3. LM35 offers better and higher output voltage relative to thermocouples, thus they do not need an amplifier. The data that is sensed by the LM35 temperature sensor is transmitted to the Arduino controller for conversion and processing. The normal range for human body temperature is about 35- 37 degree Celsius [8].

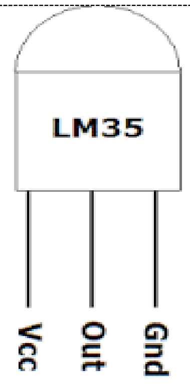

Figure 3. Pin configuration of the LM35 temperature sensor

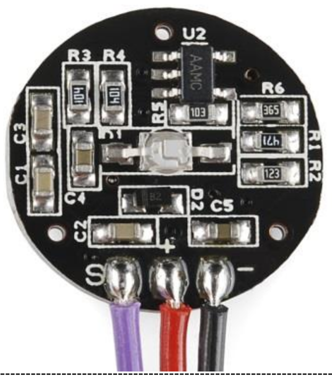

Figure 4. The Pulse sensor

3.2. The heart rate sensor (Pulse sensor)

Heartbeat is defined as the sound caused by the expanding or contracting of valves of the heart when blood is forced to flow from one region of the heart to the other. The number beats per minute (BPM) is the Heart rate. Pulse refers to the beats of the heart that are felt in an artery which lies near to the skin [9]. In this project, we measure the pulse caused by the change of blood amount flowing through the finger blood vessels. The pulse sensor shown in figure 4 is based on the principle that it combines optical heart rate sensor which has got noise cancellation and amplification circuitry, therefore making it easy and fast to obtain reliable and accurate readings. In addition it draws powers with only 4mA current at 5V; therefore it's suitable for many mobile applications.

The sensor consists of a transmitter and a receiver through which a pulse is generated when the flow of blood is monitored by placing the sensor on a fingertip. This pulse sensor has also been used to provide SpO2 by using a mathematical relation of SpO2 and pulse sensor. The normal range of heart rate for a human being at resting state is from 60-100 bpm. For an adult man the average pulse at rest is 72 per minute. For athletes the pulse per minute is lower than for people who are less active. The heart rate for children is higher (approx. 90 beats per minute. The key to SpO2 calculation is the modulation ratio between red and infrared LED signals. The modulation ratio is calculated by:

$$R = (ACrms\_Red / DC\_Red) / (ACrms\_IR / DC\_IR) \quad (1)$$

Where "DC_Red" and "DC_IR" mean: "Average value overtime".

And "ACrms" means: alternating amount within the signal values overtime.

$$\% \, SpO2 = 110 - 25 \times R \quad (2)$$

Pulse Rate Calculation is achieved through the following algorithm:

- Read pulse signal.
- Record and monitor the time.
- Find peak and trough of pulse wave.
- Keep track of the lowest point in the pulse wave.
- Set a threshold to avoid noise signal.
- Measure the time between beats

3.3. Ultrasonic sensor

Figure 5. The HC-SR04 (ultrasonic sensor)

The fall detection sensor used is the Ultrasonic ranging module HC - SR04 shown in figure 5. A non-contact type measurement of 2cm - 400cm is provided by the sensor with range of accuracy approximately reaching to 3mm. The sensor module is made up of a receiver, transmitters and a control circuit. The sensor is based on the principle that; an IO trigger is used for at least 10us high level signal, and then it sends eight 40 kHz signals automatically and detects any reflected pulse. IF there is reflected signal via high level, the high output IO duration is equivalent to time from sending to time of returning of the ultrasonic signal.
That is;

$$\text{Test distance} = (\text{high level time} \times \text{sound velocity}) \quad (340\text{M/S}) / 2, \tag{3}$$

$$\tan\emptyset_{xyz} = \left(\frac{G_{py}}{G_{pz}}\right) \tag{4}$$

$$\tan\theta_{xyz} = \left(\frac{-G_{px}}{\sqrt{G_{py}^2 + G_{pz}^2}}\right) \tag{5}$$

3.4. GSM/GPRS modem
The GSM/GPRS modem that had been utilized is the SIM300; it is a digital global mobile communication technology, which has the widest coverage with high reliability. GSM uses SMS (Short Message Service) message service in which a text message is transmitted. The GPRS is used to

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provide internet for global data transmission. The wireless Global Systems for Mobile (GSM) modem works with GSM wireless network for transmission. When any one of the monitored physiological parameter values cross the preset normal range or threshold value, an SMS is sent automatically to the medical personnel such as physician's mobile phone on a real time basis.

3.5. Arduino board

The controller used is the Arduino microcontroller also known as Genuino Uno. It is based on the ATmega328P. It is made up of 14 digital I/O pins whereby the 6 pins can be configured as PWM outputs. 6 analog pins, USB connection, a power jack, 16 MHz crystal, ICSP header and reset button. The board contains all the peripherals needed to support the microcontroller. A USB cable which is connected to a computer or an AC to DC adaptor can be used for powering up the microcontroller.

4. Software architecture

The hardware and software was implemented at the patient's side. Software was built in Arduino IDE software using C programming language. The software flow diagram and operation flow of the system are shown in figure 6. After starting, the initialization procedure whereby the physiological parameters; temperature, Spo2, heart rate, glucose, hydration and fall detection are set. The controller then gets the ADC values from the performed ADC operation. After that the values are calculated and compared with the set values. If the calculated value falls within the preset range, the result is displayed on the Display and no alert is generated or sent. If the value obtained from the monitored parameters is more than (exceeding) or if the value falls below the preset range, an alert is generated and SMS is sent to the medical personnel, for example the physician or the doctor. The doctor in response also sends SMS to instruct the patient's immediate care givers and can take further action to call the ambulance. The detection of an abnormal parameter value and generation of alert in real time based. The cloud storage and medical server is created at the Physician's side. The server was implemented on the Things Speak platform. A unique ID is given to each patient and continuous medical data is presented in graphical form. A feature for locating the correct location of the patient has been incorporated that uses location coordinates send by the system and shows the exact location on the map. The Physician is able to log in to the server to monitor access the patient's health record by observing the graphical parameter levels.

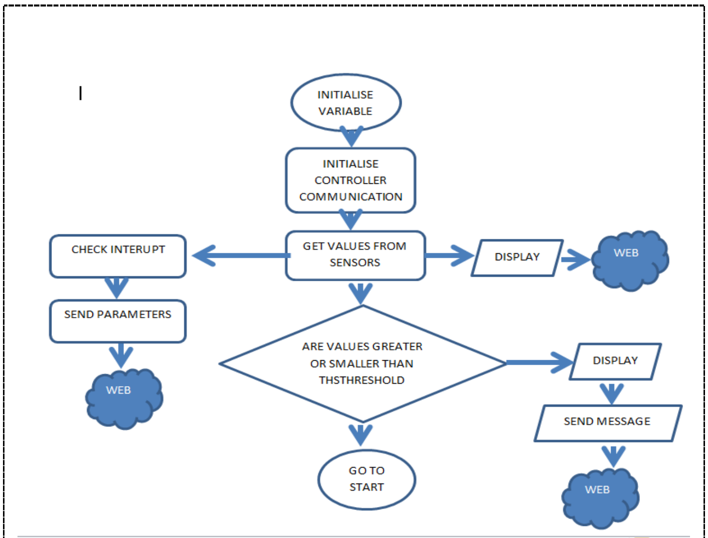

Figure 6. The flow chart for software and system

5. Results and discussion

Acquisition of data from the physiological parameters monitored was simulated in the Arduino IDE software. The monitor showed each parameter being acquired and the resulting values at various intervals. Figure 7 shows the sensors connection. Figure 8-15 shows the results from the WWBAN. Through the GSM/GPRS patient's data is continuously send to the web server and SMS is sent to the Physician is if threshold level is exceeded.

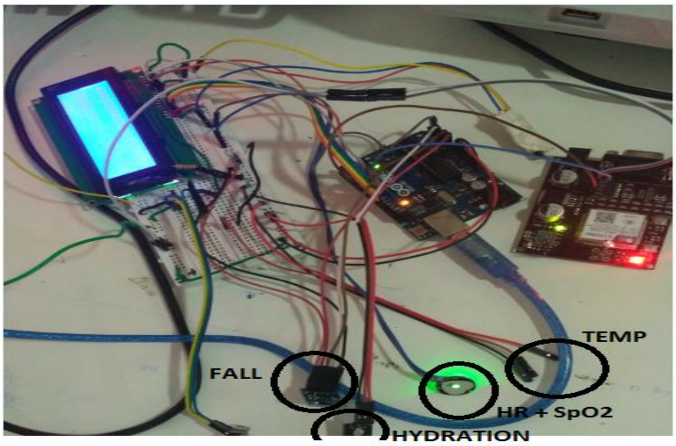

Figure 7. Hardware connection for sensors and GSM and Arduino.

Figure 8. 78 BPM from a normal adult.

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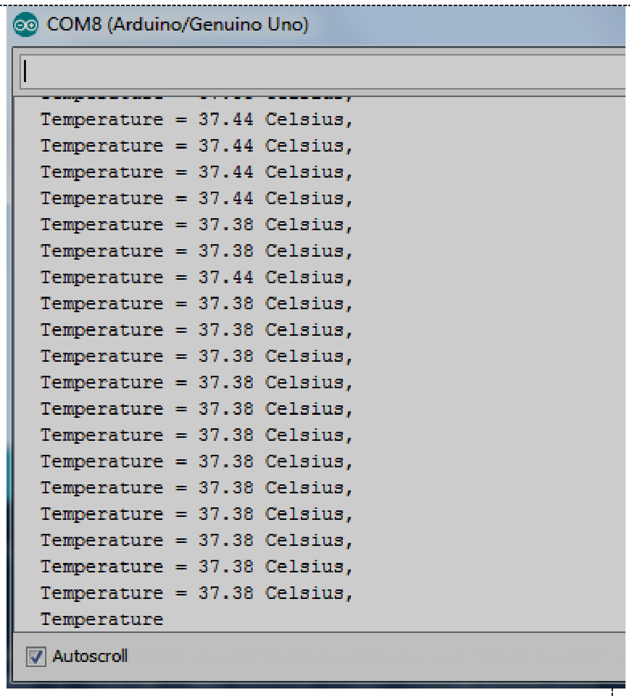

Figure 9. Display Temperature results

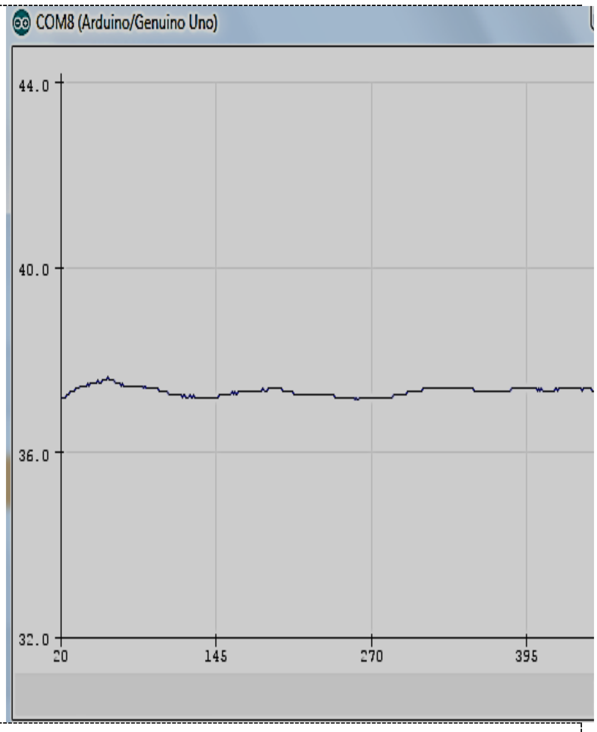

Figure 10. Temperature in real time

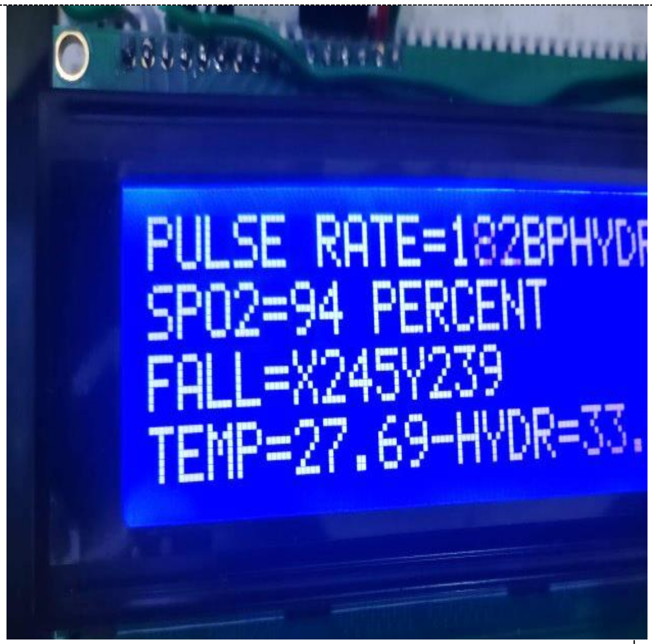

Figure 11. LCD Display

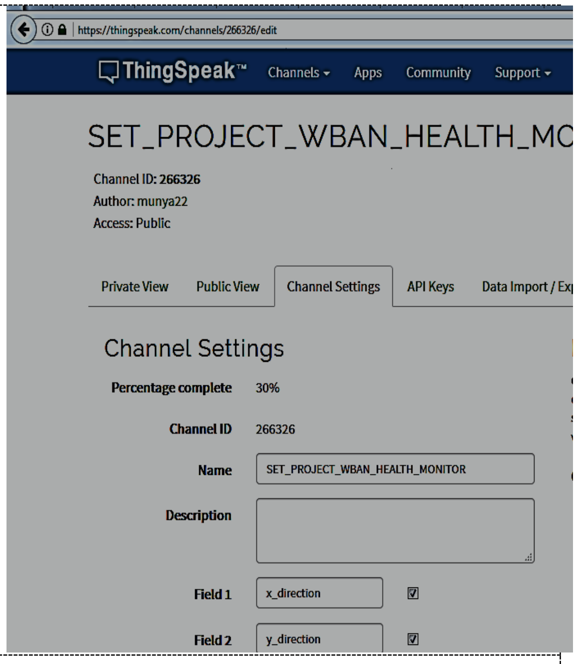

Figure 12. Web Configuration

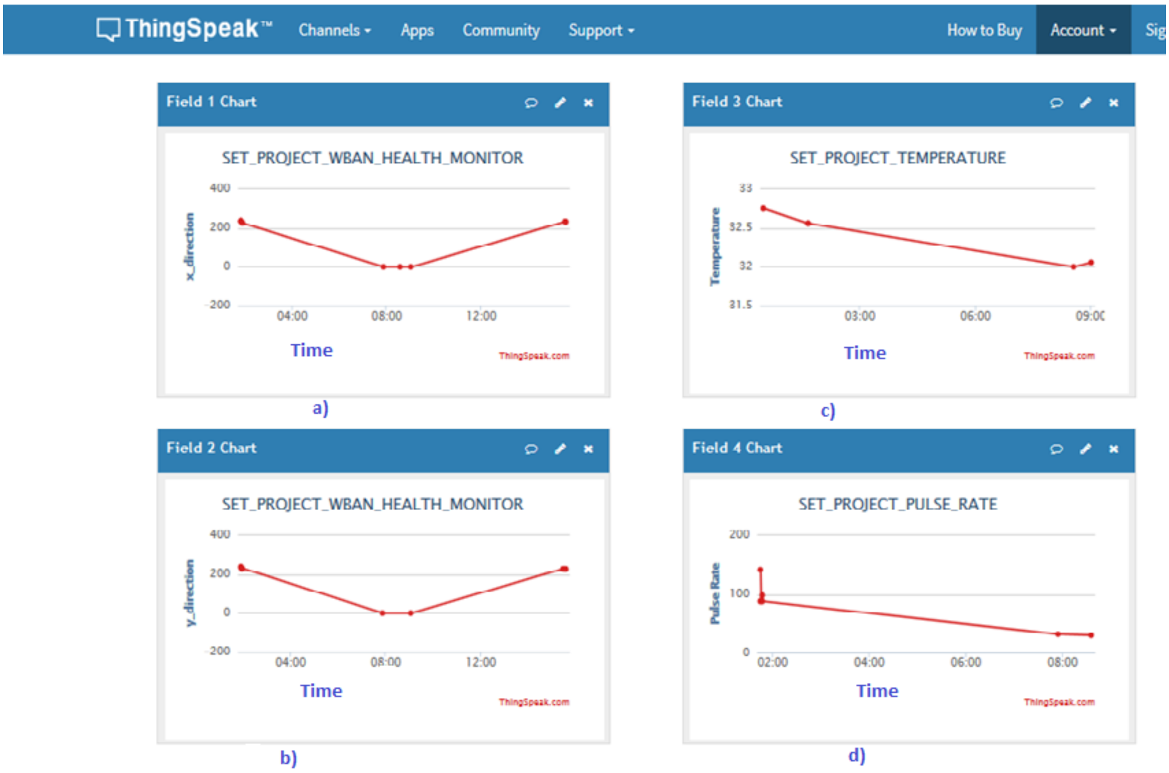

Figure 13. Cloud health data

a,b) fall detection (x and y direction respectively), b) Temperature vs Time d) Pulse Rate vs Time

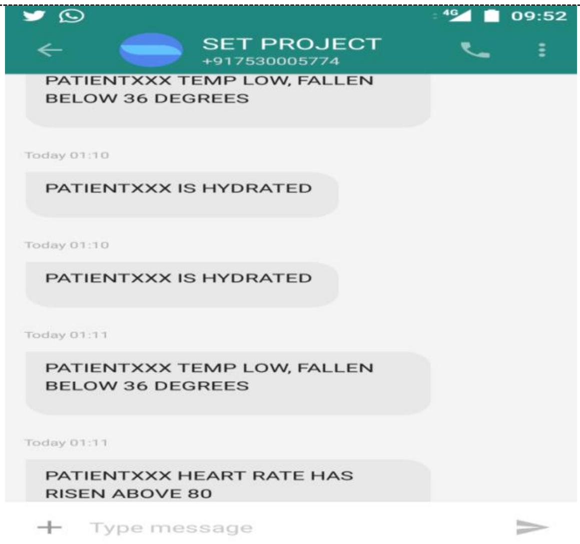

Figure 14. SMS received by doctor

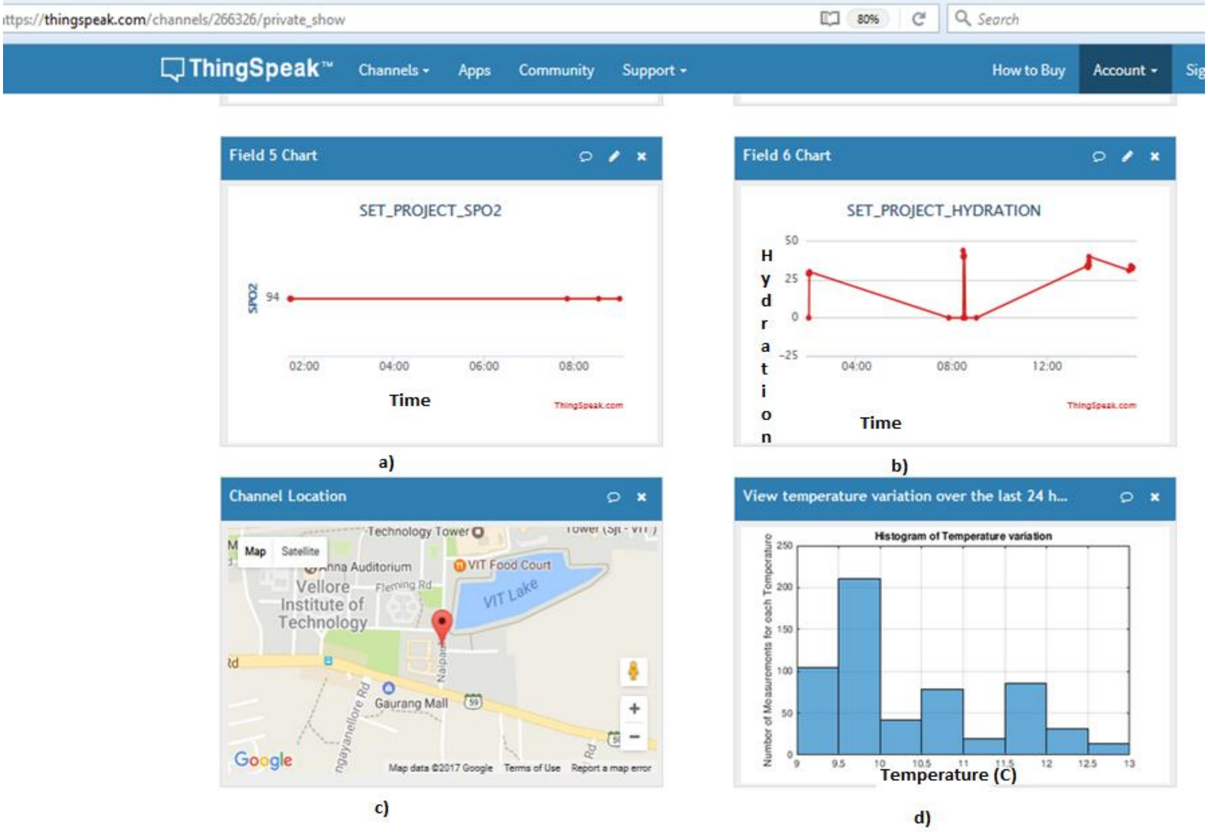

Figure 15. Cloud data display

a) SPO2 b) Hydration c) Patient location d) Temperature

6. Conclusion and future work

6.1. Conclusion

In this era of miniature and wearable devices, wireless health monitoring of the elderly and disabled physiological parameters with medical warning is essential. In the event of the monitored parameters exceeding or falling below the set normal ranges, an SMS has been successfully sent to the physician. The system managed to continuously send the parameters data to the cloud server. A relatively low cost system has been successfully implemented to help the disabled and elderly so that they may be independent and secure while continuously monitored in the comfort of their residential places.

6.2. Future Work

More physiological parameters can be incorporated for making the system a standalone and independent health care system. The system could be built in such a way as to be able to dispense medication automatically according to the doctor's prescription so that one can be fully independent without the need for care giver personnel but rather the aid of the system only. More patients could be monitored under the control of one controller. A feedback platform could be incorporated whereby the stored data can be analyzed and send to the patient to alert them on how their health has improved or deteriorated.

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