Smart Health Monitoring System

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ABSTRACT

Due to the high inpatient population in hospitals, regular monitoring of inpatients' vital signs is currently a practical concern. As a solution, our proposed system manages the continuous analysis of the vital signs of every inpatient in the general wards, and informs medical professionals in any location at any time about their inpatients' current states in real-time to improve inpatients' health. The suggested system consists of the following arrangements; arrangement for acquiring health readings, identifying the on-duty reported doctors in charge of wards, arrangement for health data exhibiting unit, fall detection, and ECG acquisition. In addition to these arrangements, a website, and an android mobile application were designed to publish measured inpatient vital signs. This proposed product is both novel and different from the existent products because, it comprises of collective arrangements, and is developed in order to assess hospital wards' inpatients, whereas other systems are designed for remote health monitoring of patients at home. This paper describes the system that was developed and tested successfully.

KEYWORDS: *Real-time database, Temperature, Heart rate, SpO_2, ECG, Fall detection, Website, Mobile application*

1 INTRODUCTION

At present, the inpatient population is significantly larger than the number of healthcare professionals working in the healthcare sector. According to the World Bank collection of development indicators, the nurse to inpatient ratio in Sri Lanka in 2019 was reported to be 1:156 (Trading Economics, n.d.)., Even though the medical resources and facilities are developing on a daily basis, an effective solution has not been proposed to mitigate the issue. Therefore, to address this problem, the proposed system was implemented.

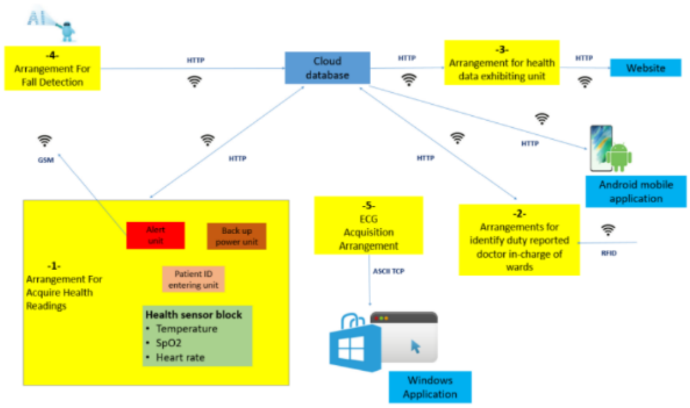

Figure 1. System block diagram

Figure 1 shows five main arrangements and other secondary components required to achieve the intended purpose of the proposed system. The system consists of; arrangement for acquiring health readings, identifying on-duty reported doctors in charge of wards, arrangement for a health data exhibiting unit, fall detection, and ECG acquisition. The main purpose of the health data acquisition arrangement is to measure the health readings such as temperature, heart rate and SpO_2 level of each inpatient using biosensors attached to the inpatient's body. This arrangement also includes a unit that notifies the responsible doctor in charge of the ward via SMS alert if the inpatient is in a critical condition. Further, it also comprises a back-up power unit to supply power to the health reading acquisition arrangement without any interruption. The arrangement for identifying the duty-reported doctors in charge of wards is a support system for the alert unit in the health data acquisition arrangement. The arrangement for health data exhibiting unit is to display the measured inpatient health data to the hospital staff. Next is the arrangement to detect falls, which is basically to identify falls occurring inside hospital premises. The final arrangement is the ECG acquisition arrangement to measure inpatient electrocardiogram signals and detect elementary arrhythmias. In addition to the above mentioned arrangements, an Android mobile application was developed to provide health status of the inpatient to their relatives.

2 RELATED WORKS

Lei Ru and Bin Zhang in (Lei Ru, 2021) have proposed a human health monitoring system that uses wearable sensors to gather vital information about the inpatients. It provides reasonably accurate and consistent testability of human vital symptoms. A team of researchers have proposed a health monitoring system for elders (Sumathy, 2021). Sensors measure vital signs such as the pulse rate, respiratory rate, and temperature. If any significant changes are discovered in an inpatient's condition, the system will be communicate the changes to the doctor and the guardian. The system in (El-Nour, 2019) comprises of an application and wearable devices combined with the global positioning system (GPS) to allow inpatients and healthcare providers to track one another. The system provides highly precise inpatient location information to remote health care service providers. It also sends out alarm messages to inpatients and helps them find nearby healthcare providers.

According to (D.Shiva Rama Krishnan, 2018) and (Sudhindra F, 2016) the LM35 contact base thermal sensor arrangement was used to measure human body temperature. This sensor can output sensor readings with a precision of around 0.5 Celsius and it can operate in a range of -55 to +150 Celsius. The MAX30205 which is used in (Bakar, 2020) and (Hasan, 2020) is a contact base thermostat temperature that delivers a clinical-level precise analytic body temperature of 0.1 Celsius in the range of 35 Celsius to 39 Celsius. With a resolution of 16 Bits, the MAX30205 converts measurements into digital readings using an analog to digital converter.

When taking readings of heartbeat, in (Sumathy, 2021) the sensor is attached to the inpatient's finger to monitor his/her heartbeat. These readings are sent to the Cloud where they can be monitored by a doctor and the inpatient's guardian. If values are below 60 BPM or above 100 BPM, the person needs medical advice. The device designed by (Andika, 2019) was portable so that users can conduct monitoring at any time and from any location. The data obtained from the MAX30102 sensor was displayed on the TFT LCD screen after it entered the I2C pin. The MAX30102 sensor can give both BPM and SpO2 values. The results of ten respondents were taken the same as BPM measured, and compared with standard measuring instruments. This produced an error value of 0.82% which was then used to calibrate the device.

An ECG reading of a healthy person is provided by monitoring their electrical heartbeat (ECG) using sensors attached to their skin. The sensor that was used to measure ECG in (Martin Clinton Tosima Manullang, 2019) is, AD8232 ECG module. The data is sent to the IoT Cloud via an ESP8266 Wi-Fi module for further analysis and visualization on a web interface. A system consisting of an AD8232 sensor and Arduino Uno was proposed by Matin Clinton and two other researchers in (Vaneeta Bhardwaj, 2022) to obtain and classify ECG signals. This system can be connected to a personal computer for ECG plot visualization. This system comprises an algorithm to calculate the duration of the R peak of the ECG signal. As a result, the authors were able to identify abnormalities in the ECG signal. This system was tested on ten people and the results were compared with medical standard 10 leads ECG cardiac device.

In fall detection several approaches were recognized and among them two approaches were mainly considered: threshold-based approach and machine learning-based approach. Threshold-based approaches use a single or many threshold values to classify occurrences. The system compares real-time sensor data to predefined threshold values, and if these are exceeded, the system signals a fall. In (Rakhman, 2014) accelerometer and gyroscope sensors were used to detect falls. Huynh et al (Huynh, 2015) used three threshold values lower acceleration, upper acceleration, and lower angular velocity to determine whether the person has fallen. Examples for machine learning algorithms are Hidden Markov Model (HMM), Support Vector Machine (SVM), and Decision Tree. A low-cost fall prevention and detection system based on HMM and tri-axial was developed by Tong et al (Bourke, 2008) and the study found that falls could be accurately predicted 200-400ms before an accident and distinguished from other routine activities. Based on an accelerometer sensor inserted into the device, Aguiar et al (Aguiar, 2022) developed a Smartphone-based detection method and tested three algorithms for machine learning: Decision Tree, K-NN, and Naive Bayes. A support vector machine (SVM)-based fall detection method with accelerometer and gyroscope sensors was created by Pierleoni et al (Pierleoni, 2015). The above research findings were referred and analyzed in order to develop a high quality health monitoring system.

3 METHODOLOGY

3.1 Model of the system

The arrangement to collect health sensor readings is the main arrangement in the whole system, and it mainly contributes to achieving the main goal which is to monitor the health readings of each inpatient. Each bed inside hospital wards should consist of a health data acquisition arrangement. As a result of that, vital signs of each inpatient can be obtained, and that data will be transferred to a central Cloud server set up which was designed for the entire hospital. Further, a patient recognizing unit was used to allocate relevant inpatients inside the wards, to develop health data acquisition arrangements. The health data obtained from sensor modules such as temperature, heart rate, and blood oxygen level attached on health data acquisition arrangements will be displayed on a website where the healthcare workers can easily monitor health details on a single display. In addition, this arrangement comprises a unit to send an alert message to the on-duty doctor if an abnormal condition is identified by the nurse. Besides, each ward will comprise an arrangement to identify the duty-reported doctor at a particular time. This helps to identify which doctor is allocated to a particular ward when a nurse manually gives the command to send an SMS during an emergency. The ECG unit is a separate arrangement which transfers results to a desktop application that runs on Windows OS. This arrangement works independently, and it is a portable device that can be carried to any place inside the hospital. Next, the fall detection arrangement in the proposed system is a wireless device attached to the inpatient's body. This is designed considering acceleration and orientation of the inpatient’s body. In addition, the Android mobile application was included in the whole system to assist inpatient’s guardians when they are unable to visit the inpatient at the hospital.

3.2 Anatomy of the system

1. Arrangement to acquire health sensor readings

Acquisition of heart rate and SpO2 readings

The MAX30102 sensor to measure the heart rate and blood oxygen level was connected to the ESP32 controller with serial communication which is I2C. This sensor collects health readings from the respective inpatient and sends those readings to the Cloud database. MAX30102 sensor emits IR light towards the body and measures the amount of light reflected using the photodetector. These IR readings were filtered, and two consecutive beats were discovered. Then the heart rate was calculated by measuring the time gap between the two acquired consecutive heartbeats. Then the SpO2 was measured by measuring the ratio of IR and RED light received by the photodetector. In order to obtain an accurate reading, 100 samples were taken and averaged. This sensor module is proposed to be attached to the finger tip of the inpatient.

Acquisition of Temperature readings

The MAX30205 sensor was utilized to measure the temperature of the inpatients. It was connected to the ESP32 controller via I2C port. This sensor collects health readings from the respective inpatient and sends those readings to the Cloud database. With reference to human body temperature, there are two types which are peripheral, and core body temperature. Peripheral temperature is subjected to greater fluctuations due to its closer proximity to the environment, but core body temperature is not subjected to significant deviations., Even though the core body temperature method gives accurate readings, it is impractical to continuously take measurements from an inpatient using that method. Therefore, the temperature module was designed to be attached between two fingers which provides the peripheral temperature. In addition, to minimize the deviations, a rectifying technique was implemented considering the standard deviation of the errors.

Backup power unit

The introduced backup power system facilitates the health reading acquisition arrangement, by supplying power without any interruption to its operation. Accordingly, the backup power unit was designed in such a way that the backup battery takes control of the power supply automatically when the main power supply is not available. To introduce an automatic power takeover, P-channel MOSFET was utilized for the backup battery in the circuit. Since the circuit should be capable of supplying power uninterruptedly, switching elements need to have a high switching speed. This was the main reason for choosing MOSFET as a switching device to develop this backup power unit. When it comes to the backup battery in the unit, it charges as long as the main power supply is available and, the moment the main power is unavailable, the battery will stop its charging process and act as the power source for the load. Further, BMS (Battery Management System) was used to prevent the backup battery from getting overcharged and, as backup batteries, li-ion rechargeable batteries were utilized.

Inpatient ID entering unit

This unit is mainly comprised of hardware and firmware layers to control the workflow of the unit. The hardware layer, has a 4 by 4 matrix keypad, and a 16 by 2 LCD module. The firmware of this unit expects inpatient registration number prior to proceeding with acquiring biosensor readings from inpatients. Then the entered ID number will be transferred to the Cloud database via HTTP application layer protocol and 802.11 datalink layer protocol. Basically, this unit is for the health data isolation of each inpatient in the Cloud database.

Alert unit

GSM SIM900A module was used to send messages to the on-duty doctor in charge of the wards. The software was developed to construct the message with necessary details which are; ward number, bed number, inpatient ID, temperature, heart rate, and $SpO_{2.}$ To send messages to the on-duty doctor, AT commands were used. The message will be sent to the number given with the AT+CMGS command while the AT+CMGF command is used to select the operating mode of the GSM modem. Here, 0 is SMS PDU mode while 1 is SMS text mode. In PDU mode, all SMS messages are represented as binary strings encoded in hexadecimal characters and in text mode, SMS messages are represented as readable text. As we need to send a readable text to the doctor, SMS text mode was chosen.

2. Arrangement to identify duty reported doctor in charge of wards

This arrangement was implemented to acquire the telephone number of the duty-reported doctor in charge of the ward. Initially, RFID cards should be issued to every doctor in the hospital after their telephone number is ciphered to the card. This is a separate system that will be fixed at every ward entrance. When a doctor reports for duty, he/she should swipe their card through the relevant RFID reader at a particular ward entrance. Then each doctor's telephone number will be transferred to the Cloud database via HTTP and 802.11 datalink layer protocol. ESP8266 controller was used to accomplish tasks related to this arrangement.

3. Arrangement for health data exhibiting unit

A static website was designed with a single page and this webpage runs on a controller that is attached to a display unit. This arrangement allows hospital staff to examine each inpatient of a particular ward from a single location without checking inpatients' conditions individually. Raspberry Pi was chosen as the controller for this health data exhibiting arrangement as it can connect to the internet via a Wi-Fi connection. It also has a built-in web browser that opens in a browser when the controller is booted up. The hospital webpage has been designed in a way that it will fit into the viewport of a standard screen-sized display which is 22 inches diagonally. These standard-size displays should be placed in every ward of the hospital. Regarding the webpage, the front end of the webpage was implemented utilizing technologies such as HTML, CSS, and JavaScript. Further, to upgrade our project to a next-level health monitoring system, an additional webpage was developed and incorporated into the above-mentioned webpage. This new webpage lists every ward in the hospital and doctors can browse the relevant ward dashboard and examine their inpatients remotely.

4. Cloud database

To implement the Cloud database in the proposed system, Google's firebase was used. The reasons to choose firebase are, that it provides a real-time database that automatically syncs with our frontend application and, it also provides SDKs for almost every platform such as JavaScript, iOS, Android and etc., to manage our front-end application by bypassing the back end. To achieve expected functionality from the proposed system, the database was constructed as we can separate each ward in the hospital and each inpatient bed in the ward.

5. ECG acquisition arrangement

As the main controller for this arrangement, ESP32 was chosen and to acquire ECG signal values, AD8232 3-lead ECG module was utilized. To display the ECG signal, an application was developed in the .net framework and any device which runs on the Windows platform is compatible with this application. When collecting ECG signal data, sampling frequency is a key area that should be considered. The maximum frequency component of the ECG signal can be 150Hz. Therefore, according to the Nyquist theorem, sampling rate should be at least 300Hz (2 X 150Hz). Therefore, as the sampling frequency for this case, 1000Hz was chosen. To send collected data over to the windows device, UART communication was used. Further, to develop the Windows application, Microsoft Visual Studio was used as the development environment with c sharp language and, .net framework was used as the software development kit. The software layout of the desktop application will follow the procedure shown in the figure given below to achieve the output of the arrangement.

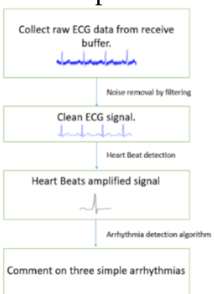

Figure 2. Backend functionalities in desktop application

There are three main types of artifacts that can introduce noise into the ECG signals, which are baseline wander, power line interference, and lead electrode problems. Noise from motion artifacts can be minimized by reducing muscle movements while taking the data. Further, a low pass filter and a high pass filter were implemented to eliminate the baseline wander. Addition to that, a band pass filter was used to remove power-line interference. All these filters were implemented as FIR filters with Kaiser Windowing. In addition to this ECG signal plotting procedure, a method to detect the heart rate and three simple arrhythmias such as sinus bradycardia, sinus tachycardia and, sinus arrhythmia in the heart was designed. In order to do this, a heartbeat detection algorithm was implemented. The goal of the heartbeat detection algorithm is to locate the heartbeats to calculate the heart rate and R peak intervals of the ECG signal. The key method to locate heartbeats is detecting R peaks of the ECG signal. To detect R peaks, another signal processing technique called teager-kaiser energy operator (TKEO) was utilized and it suppresses the noises contaminating inside a signal and it attenuates signal components that have the value range from zero to one. Therefore, R peaks will be more noticeable.

6. Android mobile application

The android application was developed in Android Studio. In Android Studio, Java was used as the language to develop the code, and as SDK, Android SDK platform 33 was chosen, Firebase real-time database is used at the backend. Here two activities were created in order to enter inpatient registration number and to view health readings of the inpatient. In both activities, the real-time database of firebase was used to acquire details of the inpatient by connecting firebase to the Android Studio project. Android Studio, possesses an inbuilt tool to access firebase functions. With the help of this tool, it can access Firebase data with single functions without hard coding. In this case, it is only required to read data from the database, as we only need to retrieve the health readings and telephone number of the duty-reported doctor in charge of wards to the mobile application. To retrieve this data, a path should be created in our code to access each node in the database. When the functions are called, they will synchronize real-time data without any delay. To test the application, an emulator was utilized. Considering the content of the mobile application, the first layout possesses an inpatient ID entering layout which gives access to the health readings of the inpatient for which the ID is entered. Then in the next layout, it gives the inpatient's ward number, bed number, and the ID. Further, it gives health readings of the relevant inpatient. As an added advantage, the mobile application will also provide the ability for inpatients' relatives to call the duty-reported doctor in charge of wards to acquire additional information about their patients.

7. Fall detection arrangement

The final arrangement in the proposed system is to detect falls, which should turn off manually when the inpatient is resting on a bed, and needs to be turned on manually, when they are using sanitary services. Since changes of body position and sudden change in acceleration are involved in falls, the change of plane of the body is detected by a gyro sensor and for acceleration, an accelerometer was used. Therefore, MPU6050 sensor module is used, as it consists of both gyro and acceleration measuring capability.

Threshold based algorithm

The total sum acceleration vector Acc, which contains both dynamic and static acceleration components, is calculated from sampled data using the following equation.

$$Acc = \sqrt{(Ax)^2 + (Ay)^2 + (Az)^2} \tag{1}$$

where Ax, Ay, Az are the acceleration in the x, y, z axes, respectively.
Similarly, to acceleration, the angular velocity is calculated from sampled data as indicated in the following equation.

$$w = \sqrt{(Wx)^2 + (Wy)^2 + (Wz)^2} \tag{2}$$

where Wx, Wy, Wz are the acceleration in the x, y, z axes, respectively. The acceleration and angular velocity are used to determine the upper and lower fall thresholds. The outcomes of each recorded activity's negative peaks are represented by the lower peak values of the signal. The higher peak values of the signal are the positive peaks for each recorded activity's recorded signals.

Machine learning algorithm

Based on the requirements of the application, data collection is the first step of the ML based fall detection. The ML engine requires two components: a dataset with labeled data containing different movements, each indicating whether it is a fall or an ADL, and a model trained from these data. To train the ML model, a dataset distinguishing between data corresponding to a fall and data corresponding to an ADL must be created. To accomplish this, a set of exercises consisting of falls and ADLs are defined and performed by different subjects in a controlled environment. As the next step in developing the algorithm for ML, the best training method was chosen. According to the results of the data study, SVM was selected as the best method.

Design architecture

The system design consists of two main parts: a sensor that will track the user's movements and a device that will gather and analyze all the data to determine if a movement is an ADL or a fall. The device will be responsible for notifying that situation when a movement is classified as a fall.

4 RESULTS

4.1 Hardware and software models

1. Arrangement to acquire health sensor readings

As mentioned above, to obtain the heart rate and SpO_2 levels, a sensor was attached to the fingertip, and to obtain temperature readings the sensor was attached in-between the fingers of the inpatient. The figures below show the hardware architecture of the arrangement used to acquire health sensor readings.

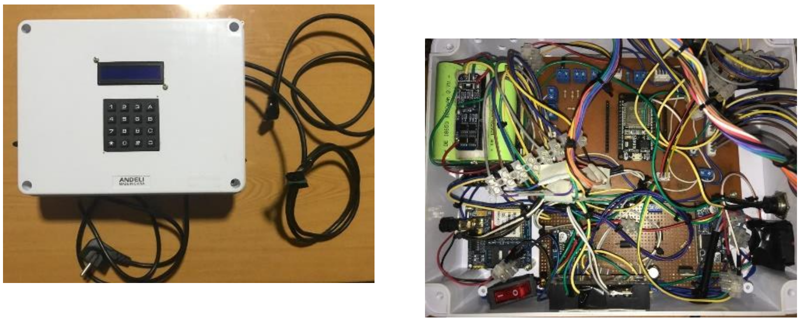

Figure 3. External and internal view of the arrangement used to acquire health sensor readings

Figure 4 shows the inpatient ID entering unit that comprises a 4x4 matrix keypad and an LCD unit. When an ID with 8 characters is entered to the system it will be stored in the database.

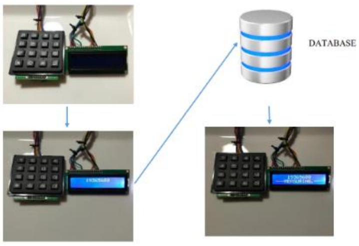

Figure 4. Inpatient registration process

According to the format explained in the methodology section, the message will appear on the doctor's mobile. The figure below shows a snapshot captured after a message was sent to the doctor's mobile from the GSM module.

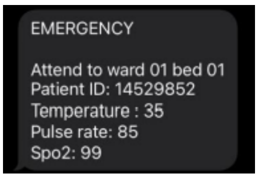

Figure 5. Snapshot of the message that was sent to the mobile from the GSM module

2. Arrangement to identify the duty reported doctor in charge of wards

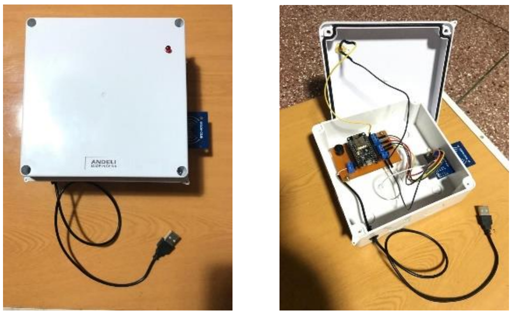

Figure 6. Internal and external view of the arrangement to identify the duty reported doctor in charge of wards

3. Arrangement for health data exhibiting unit

This task was accomplished using a website as mentioned in the methodology section. The designed website is utilized for remote health monitoring, which allows hospital staff to log into the website using various devices.

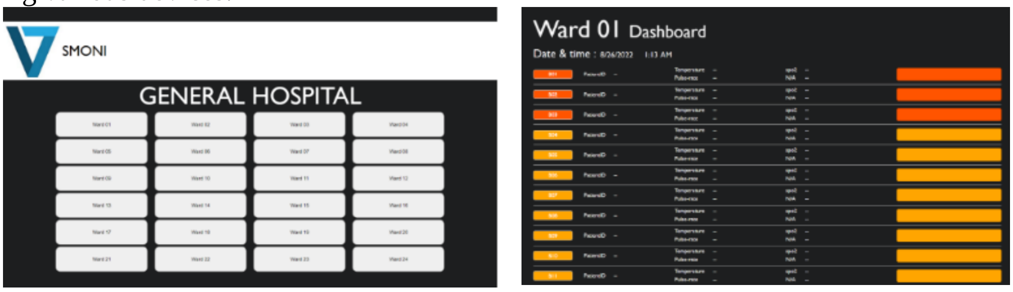

Figure 7. Ward selection web page and ward's health measurement exhibit website

4. ECG acquisition arrangement

When starting the “SMONI ECG-KIT” application, on a Windows device, it will open the start-up interface of the application and it is shown in the figure below.

Figure 8. Start-up interface of the ECG desktop application

5. Android mobile application

The mobile application was tested on a range of devices that are widely accessible. The design is compatible with each device and supports both portrait and landscape data viewing.

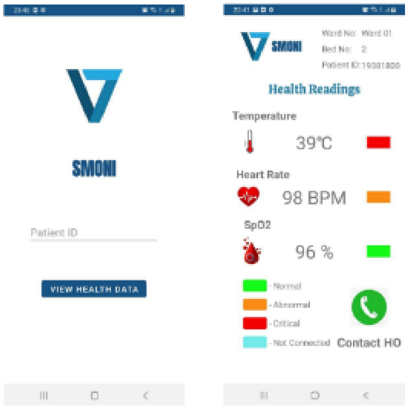

Figure 9. First and second layouts of mobile application in portrait mode

6. Fall detection arrangement

Two MPU6050 sensors are used and to achieve better outcomes, data was gathered from each sensor and the average value was taken. Threshold values for both sensors were set, and when compared to one another, the microcontroller receives the information. The microcontroller is programmed to detect the fall and generate immediate outputs. The figure below shows a fall happening when a person walks.

Figure 10. Before and after a fall

Using this threshold-based approach, a dataset distinguishing between data corresponding to a fall and data corresponding to an ADL was created to train the machine learning model. To accomplish this, a set of exercises consisting of falls and ADLs is defined and performed in a controlled environment by various subjects. Separate data sets were collected for each category, such as downSit, freeFall, runFall, runSit, walkFall, and walkSit. As the collected data is noisy, preprocessing was done to eliminate irrelevant and noisy signals from the data. From feature extraction, the result is taken out of the pre-processed data. A machine learning model was created to identify irregular postures, falls, or ADLs using the SVM algorithm. Then, the data was separated into testing and training. The classifier's performance is evaluated using the test data after it has been trained. Consequently, with the help of this machine learning model, it was able to determine whether the movement was a fall or a normal move.

4.2 Analysis of collected data

1. Arrangement to acquire health sensor readings

After connecting the MAX30102 sensor to the inpatient's fingertip, readings of 10 randomly chosen people were taken from different age groups. These readings were taken from the proposed system, as well as from a heart rate measuring device and a SpO_2 level measuring device available in the market to compare both values. After that, those values were compared by calculating the error percentage for each sample using the equation below.

$$Error\ Percentage = \frac{Measured\ value - True\ value}{True\ value} \times 100 \tag{3}$$

Table 1. Comparison of heart rate measurements

Number of samples	Sensor Value (bps)	Device value (bps)	Error percentage (%)
Sample 1	78	81	3.70
Sample 2	76	73	4.11
Sample 3	76	72	5.56
Sample 4	59	59	0.00
Sample 5	61	64	4.69
Sample 6	78	79	1.27
Sample 7	77	79	2.53
Sample 8	72	72	0.00
Sample 9	76	73	4.11
Sample 10	69	69	0.00

Table 2. Comparison of SpO_2 level measurements

Number of samples	Sensor Value (%)	Device value (%)	Error percentage (%)
Sample 1	96	95	1.05
Sample 2	99	96	3.13
Sample 3	97	97	0.00
Sample 4	99	98	1.02
Sample 5	98	97	1.03
Sample 6	98	98	0.00
Sample 7	99	97	2.06
Sample 8	97	97	0.00
Sample 9	97	95	2.11
Sample 10	98	97	1.03

Similarly, temperature measurements of 10 different samples were taken from the developed model and the generic thermometer and the errors were calculated.

Table 3. The comparison of body temperature measurements

Number of samples	Room temperature measured	Body temperature observed by developed model	Actual body temperature observed by generic thermometer	Error
Sample 1	29 °C	35.15	36.27	1.12
Sample 2	29 °C	35.30	36.77	1.47
Sample 3	29 °C	36.57	36.77	1.20
Sample 4	29 °C	34.8	36	1.15
Sample 5	30 °C	35.67	36.61	0.94
Sample 6	30 °C	35.07	36.34	1.27
Sample 7	30 °C	35.22	36.18	0.96
Sample 8	29 °C	35.01	36.59	1.17
Sample 9	29 °C	35.12	36.42	1.3
Sample 10	29 °C	35.84	36.83	0.99

When five attempts were taken from the GSM module, all attempts were successful as the result, which means when the button is pressed the message was delivered to the allocated mobile number. From this we can conclude that the module works accurately.

Table 4. Test attempts of GSM module

Attempt	Result
Attempt 1	Successful
Attempt 2	Successful
Attempt 3	Successful
Attempt 4	Successful
Attempt 5	Successful

2. Cloud database

The performance of database data communication was analyzed by transferring ten sample garbage data to the database from IP-enabled devices utilized in the proposed system. Testing results are depicted in the table below.

Table 5. Performance evaluation of data communication in database

Data samples	operation	Description
Data 1	Post	succeed
Data 2	Post	failed
Data 3	Post	succeed
Data 4	Post	succeed
Data 5	Post	succeed
Data 6	Get	succeed
Data 7	Get	succeed
Data 8	Get	succeed
Data 9	Get	succeed
Data 10	Get	succeed

3. ECG acquisition arrangement

We performed the ECG acquisition on three different people to verify the accuracy of the results. The following figure illustrates an ECG signal of a person who is aged 24. Further, in this presented result, in the comment section, system outputs; "NO ANY ABNORMALITY IS DETECTED". Accordingly, our arrangement looks for abnormal conditions with respect to the sinus bradycardia, sinus tachycardia and, sinus arrhythmia on ECG signals by analyzing the signal and, if any abnormal condition is detected, it will be displayed in the comment section of the interface.

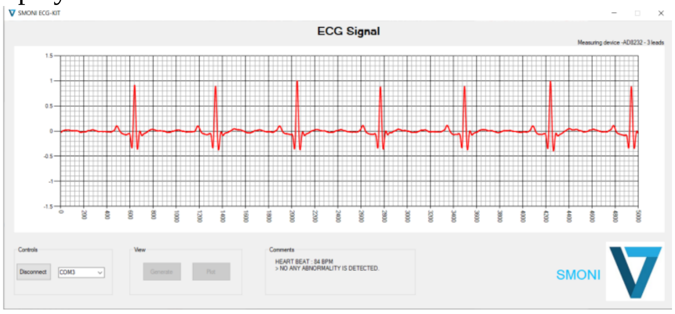

Figure 11. ECG signal of a person

4.3 Performance Evaluation

1. Arrangement to acquire health sensor readings

After the above analysis, error percentages of the heart rate and the blood oxygen level measurements were obtained. The average error percentage of heart rate was calculated utilizing each error percentage calculated from 10 samples.

$$Average\ error\ Percentage = \frac{25.97}{10} = 2.597\% \tag{4}$$

Similarly, the average error percentage of the blood oxygen level was calculated using each error percentage calculated from 10 samples.

$$Average\ error\ percentage = \frac{11.43}{10} = 1.143\% \tag{5}$$

When considering temperature measurements, figures below depict characteristics such as the Mean, Median of the relative errors and, error variation of samples we obtained from the third approach by placing the sensor between two fingers.

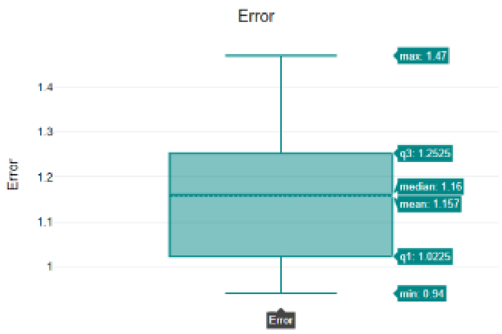

Figure 12. Characteristics of error distribution

2. ECG acquisition arrangement

We performed ECG acquisitioning on three different people to verify the accuracy of the results generated from the developed ECG acquisition arrangement. However, since we were unable to compare the output results with a clinical level 12 leads ECG machine, we sought support from a medical practitioner to confirm the accuracy of PQRST point determination. She has approved two output results out of three results.

5 CONCLUSION

When compared to the existing remote health monitoring devices available in the market, we have developed this device to assist healthcare professionals in general hospitals. Considering the large number of inpatient population, and busy work schedules in hospitals, this proposed system aids healthcare workers to perform their day-to-day activities effectively. In addition, it will be time-efficient for doctors as well as nurses and provides extra security to inpatients while they are taking treatments in the hospital. Further research of this proposed product can lead to more developments such as, using machine learning techniques in ECG anomaly detection, making mobile application compatible to both Android and iOS platforms to increase user-friendliness, improving functionalities of the fall detection system, and developing the device in order to acquire other vital signs such as blood glucose levels and blood pressure levels. In conclusion, we can say that research findings are technical, cost effective and user friendly in every aspect where the proposed system manifests the novelty of the product.

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