MediSuit: Wearable Health Monitoring System for Elders and Bed-ridden Patients

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Abstract— As people get older, the body gets weaker and it starts showing signs and symptoms of chronic diseases like cardiovascular diseases, diabetes, or even conditions of stress and depression. These signs may be increased heart rate, unusually low blood saturation level, or abnormal body temperature. Most of the time these signs go unnoticed and hence the patients are not diagnosed. By the time they become aware of their illness it might be too late. The weakening health, the chances of skin related problems, bed sores etc are becoming critical in case of bed ridden patients. A simple, compact, wearable, and user-friendly electronic device for continuous monitoring of health parameters is the need of the hour. The proposed MediSuit is wearable, unobtrusive clothing with embedded sensors which measure different physiological parameters and transmit them to a central processor which decides whether to raise an alert depending critical nature of these parameters. The central controller uses a GSM modem to communicate with a smartphone application which shows these parameters graphically as plots and graphs. The GSM modem also alerts the caretakers when the parameters cross the predetermined threshold values, by sending a message to their mobile phones.

Index Terms— elder, healthcare, vital parameters, monitor, GSM modem.

I. INTRODUCTION

The extent of medical support required by the elders varies from person to person. For some, special care must be taken in monitoring heart rate and some may have special interest in monitoring their blood pressure but a simultaneous measurement of the health parameters could give a comprehensive understanding of the patient’s health status and could also be used to predict trends in the health status and apply preventive health care. In most serious cases the patient may have to lay bedridden requiring assistance from their kin most of the time. We find that most of the diseases haunting elders at old age are chronic and the detection and cure of these diseases depend on continuous monitoring of the vital health parameters due to their special nature of occurrence. Other major issues affecting elders are bed-sore in case of bed-ridden elders and unintentional fall.

It is not possible for a single person to take care of the elders when it comes to manual monitoring. The caretakers usually have to take shifts and hence a health monitoring system can assist them as it is a record keeper of the health status during all the shifts. The trends in lifestyle and the rising number of dependent elderly is a major problem that many countries are facing now. In this scenario, a constant and reliable assistive technology which can cater the needs of these home bound elders is the need of the hour. Assistive technology devices are helpful products that improve a person’s ability to live and function independently. These types of assistive gadgets can also prove to be a boon to the caregivers, since their workload can be drastically reduced.

II. MOTIVATION

The elderly population is growing at a fast rate in India and by 2050 India will be home to one out of six older persons in the world with only China having larger number of older people, estimates United Nations Population Fund. A report released by this organization along with HelpAge India, says that about 90 million elderly persons lived in India in 2011 and is expected to grow to 173 million by 2026. In such scenario there is going to be huge increase in the medical assistance and healthcare needs for this elderly population. A separate and comprehensive health care to senior citizens would be in much demand sooner than later. Therefore it is very important that the health care system in India must reach a stage to provide affordable and accessible health care to elderly particularly to offer treatment and diagnostic services for the management of chronic diseases.

III. RELATED WORKS

Some of the elder care systems as mentioned in [1] monitor activities of the elders in their home. They embed a video system in the living environment of elders and continuously monitor their activities at home. However, this system doesn’t measure any of the vital parameters of the elderly patient. There are also smart dispensers which help in tracking and providing assistance in consuming medicines which might be helpful for elders as in [6]. Modeling of health care systems for general public are discussed widely by various researchers as in [7] but they lack proper evaluation when it comes to deployment and stop with theoretical analysis and mathematical modeling. Measuring the vital parameters is inevitable if the elder person suffers from any sort of heart ailments, which are very common in individuals aged above 60 [5]. In [2] mobile devices like Caalyx (Complete Ambient Assisted Living Experiment) which can measure vital signs like ECG, pulse, Blood pressure, Movement and Fall detection. However, the design we have proposed can monitor vital parameters and fall detection along with tilt monitoring for the bed-ridden patients to monitor any case of bedsore.
Some devices as in [3] monitor only fall detection for the elderly patients based on the sensor readings from accelerometers and microphones attached to the body of the patients. The system proposed in [4] is applicable to patients and elders for activity monitoring and fall detection and also sports athletes' exercise measurement and pattern analysis. In one of our earlier papers [8] we have discussed about measuring vital health parameters which is useful in elder healthcare services. In another research paper [9] we have discussed in detail about the various ways blood pressure can be measured, particularly in elders.

IV. DESIGN AND IMPLEMENTATION

The block diagram of the propose design and interface is shown in the Figure 1. It consists of a vital parameter sensing and measurement block, central controller, a storage space, GSM Modem and a GUI block.

A. Electrocardiogram (ECG)

ECG or electrocardiography is a test to monitor the electrical activity of a patient's heart. The human heart generates minute electrical signals with each heartbeat. This signal is what causes the heart to expand and contract allowing it to pump blood to the rest of the body. ECG records any problems with the heart's rhythm, and the conduction of the heart beat through the heart which may be affected by underlying heart disease. ECG is used by doctors in many cases. It is used to assess if the patient has had a heart attack or also to monitor the effect of any medicines. The block diagram of a typical ECG measurement design is shown in Figure 2.

a) Placement of Electrodes

A 3-Lead ECG has, as name suggests, 3 electrodes. They are usually placed at either left arm and right arm or left chest and right chest and the third one at the right leg. To get the best results place electrodes on the chest wall/either wrists equidistant from the heart.

b) Steps Involved in ECG signal acquisition

1) Amplification

The first stage is differential mode amplification by AD620 instrumentation amplifier using the right leg electrode as right leg drive. In differential mode amplification, the difference between the voltage values of the two arm/chest electrodes is measured and amplified. This third electrode is used to drive the gain resistance of this AD620, thereby increasing its Common Mode Rejection Ratio (CMRR). The gain resistor RG is set using the equation

\[ G = \frac{49.4k\Omega}{R_C} + 1 \]

\[ R_C = \frac{49.4k\Omega}{G-1} \]

where G is the gain required.

2) Filtration
High pass filter removes the signals with frequency lower than the specific value for which the filter is designed for. In usual case of ECG, the higher threshold of frequency was found to be around 40 Hz. The resistors R1 and R2 are of the same value to have unity gain. An active op amp filter was designed for this value using the equation

\[ f_c = \frac{1}{2\pi RC} \text{ Hz}. \]

where R and C are the values of the resistor and the capacitor in the filter.

3) Low Pass Filter

Allows only the signals with frequency lower than a specific value to pass through it and removes the rest. As normal ECG has a lower threshold of 0.5 Hz, we designed a filter for this value using the same equation shown earlier in the case of high pass filter. The resistors R1 and R2 are of the same value to have unity gain.

4) Amplifier

An amplifier is required to compensate for the signal attenuation caused by the low pass filter. A normal op amp amplifier using OP741 is designed and used. The gain of the amplifier is set to be 10.

5) Notch Filter

A notch filter is one that removes all signals with a specified frequency. A twin T notch filter is implemented with the cut-off frequency. The purpose of the notch filter is to eliminate the 50 Hz power supply interference.

6) Clamper

A clamper is kept at the output of the notch filter to restrict amplitude range of the ECG signal to positive axis (greater than zero) by adding a DC offset.

The first stage is differential mode amplification by AD620 instrumentation amplifier using the right leg electrode as right leg drive. Then comes the filtering stage which consist of 3 stages namely high pass, low pass and notch filters. High pass is meant to remove the low frequency noise components, whereas the low pass, the high frequency noise. The purpose of the notch filter is to eliminate the 50 Hz power supply interference. A clamper is kept at the output of the notch filter to restrict amplitude range of the ECG signal to positive axis (greater than zero) by adding a DC offset.

B. Blood Oxygen Saturation Level and Heart Rate : Pulse Oximetry

1) Heart Rate Measurement

A poorly pumping heart is major issue in elderly community. The overall activeness of heart reduces since all the nerves and arteries get weaker. More than 83% of the people who die of heart disease are older than 65 years. So, it is compulsory required to include the heart rate monitoring in gadget. Heart rate is the number of heartbeats recorded per minute typically recorded as Beats per Minute (BPM). In the proposed system, photoplethysmography technique (PPG) mentioned above is used for obtaining the heart rate. Each cardiac cycle appears as a peak. As people get older, the activity of heart reduces. The rate at which oxygenation and deoxygenation occurs decreases. This can create a concern regarding the oxygen content in the blood. So, it is always advised to monitor the oxygen level in the blood also.

Heart rate calculation is done using peak detection and adaptive thresholding in one of the PPG signals. The peaks in the PPG correspond to the systolic contraction of the heart. The time interval between two peaks (heart beats) is the Inter-beat interval. It can be measured by finding the time elapsed between two peaks in the PPG. The instantaneous heart rate can be calculated by dividing one minute by the Inter-beat interval. The average heart beat is estimated using the time for 5-10 heart beats or more.

Initially the PPG signals were sampled at 500Hz. When the sample value crosses the threshold a peak is detected. When a peak is detected, for a short period of time the algorithm does not search for the peak to avoid detecting the dicortic notch and other noise components near the peak. The time of between present and past peak is found by using a counter that increment by two (500Hz = 2ms) every time a sample is taken. The sampling frequency was increased to 4Hz and the counter incremented by 0.25 (4 kHz = 0.25ms) every time a sample is taken to accommodate the control signaling for the Nellcore DS100 probe for PPG Acquisition.

The threshold is updated as the middle value between the maximum and minimum amplitude of the PPG waveform in a period of the PPG signal after one cycle of the signal is completed. This adaptive variation of the threshold helps to find the Inter-beat interval even if the PPG signal amplitude varies to some extent. This is a desired feature for finding the heart rate from PPG because the amplitude of the signal will vary from person to person due to differences in the thickness of the finger of the subjects or due to other factors.

Heart Rate (Beats per minute)

\[ \frac{60000 \text{ ms}}{\text{Average Inter – beat – Interval (ms)}} \]

Where, Average Inter – beat – Interval is given by

\[ \text{Average Inter – beat – Interval} = \frac{1}{n} \sum_{n=1}^{n} (IBI) \]

2) SPO2 calculation

Oxygen saturation level can be achieved by employing a photo detector. Red and near-IR light emitting diodes (LED’s) to measure the light that scatters through blood perfused tissue. Oxygen is transported in the blood by haemoglobin, and depending on whether haemoglobin is bound to oxygen or not, it absorbs light at different wavelengths. This effect is taken advantage of in oximetry by using two LEDs with different wavelengths (typically 660 and 940 nm) and shining them through the tissue. The ratio of absorption at the two wavelengths is used to determine the fraction of saturated haemoglobin. Previous research had indicated that oxy and deoxy haemoglobin has different optical attenuation characteristics. For best result the wavelengths are to be selected such that at one wavelength, the attenuation by Hb and HbO are different as possible and at the second wavelength they are nearly the same. The
available pulse oxymeter uses the light at 660nm (R) and 940nm (IR.). Based upon the ratio of changing absorbance of the red and infrared light caused by the difference in colour between oxygen-bound (bright red) and oxygen unbound (dark red or blue, in severe cases) blood haemoglobin, a measure of oxygenation (the per cent of haemoglobin molecules bound with oxygen molecules) can be made as in

$$\text{SpO}_2 = \frac{\text{HbO}_2}{\text{HbO}_2 + \text{Hb}} \times 100$$

Pulse oxymeter utilizes Beer-Lambert’s law, which states that concentration of an absorbing substance in a solution can be determined from the intensity of light, transmitted through the solution. Here the light intensity of transmitted light ($I_0$) is given by

$$I_0 = I_N e^{-\varepsilon c L}$$

where $\varepsilon$ is the wavelength dependent extinction coefficient, $c$ is the concentration of the absorber and $L$ is the optical path length (cm). The light is absorbed while passing through the solution is expressed in terms of absorbance is given by

$$A = \ln \left(\frac{I_0}{I_R}\right) = \varepsilon c L$$

where $A$ is the absorbance, a dimensionless quantity, normally termed the optical density (OD). Hence Beer's Lambert's law allow us to determine the unknown concentration if the absorbance of light is measured and extinction coefficient at the wavelength and optical path length are known. The DC values and AC amplitudes of the cardiac synchronous pulsatile portions in red and infrared PPG signals, DCR and ACIR and ACR and CIR respectively are extracted. Then a normalized red to IR absorption ratio R is obtained as

$$R = \frac{AC_R/DC_R}{AC_{CR}/DC_{CR}}$$

Once the R value is calculated from the two PPG signals, SpO2 values are determined from R by using Where K is proportionality constant, which can be considered by calibration results.

C. Tilt Detection

In many families elders are left alone in home during day time. Due to this, many incidents have been reported in the case of elders who are prone to bed sores, as they are left with no one to help them to shift their orientation in bed. We are devising a system to detect tilt using 3-axis accelerometer ADXL 335.

a) Tilt Detection Sensor - Tri-Axis Accelerometer

ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tillsensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. ADXL335 is 3v3 compatible device, it's powered by a 3.3v source and also generates 3.3v peak outputs. It has three outputs for each axis i.e. X, Y & Z. These are analog outputs and thus require an ADC in a micro-controller.

D. Body Temperature Measurement

Normal core body temperature is around 37°C (98.6°F). This is an average of normal body temperatures. Your temperature may be 1°F (0.6°C) or more above or below 98.6°F (37°C). But this is in the case of core body temperature. Temperature measured at the skin is comparatively lesser lying in the range 30°C-32°C. The human body temperature can also vary depending on how active you are at that moment. An abnormally low temperature (hypothermia) can be serious, even life-threatening. This can occur due to cold exposure, shock, alcohol or drug use or certain metabolic disorders such as diabetes or hypothyroidism. A low body temperature may also be a sign of an infection as in the case of sepsis, which causes an abnormally low body temperature. Heatstroke occurs when body fails to regulate its own temperature and body temperature continues to rise. Heat related illnesses produce a high body temperature because the body cannot transfer heat effectively or because external heat gain is excessive.

The body temperature is measured using DS 1620 IC from Maxim Industries. It is a digital thermometer and thermostat. It supports two modes: Stand-alone mode and 3-Wire Interface mode. The latter is used when the DS 1620 is used in combination with a micro-controller or micro-processor to allow synchronous serial data transfer whereas the former is used in absence of any such component and when it acts as a thermostat. Here the temperature is read as 9-bit values through the 3-wire serial interface. The algorithm inside the microcontroller reads the output from the sensor and converts it to Celsius and Fahrenheit values.

E. The Central Controller

The central controller in the MediSuit system is Arduino Mega 2560 microcontroller board which is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The central controller does all the control, timing functions of the system. It also handles some amount of signal processing. It controls the GSM module, SD card module, RTC (Real Time Clock) Module. It initializes all the modules to proper settings required by the system. It generates and sends the alert messages with the help of the GSM module. It stored the health parameters namely temperature, heart rate, blood saturation content in the SD card. It reads the SD card to find the critical values of the health parameters of the patient entered by the doctor through the computer application. It keeps track of the time in terms of date, hours, minutes and seconds with the help of RTC module. It then uses this time to time stamp the data stored in SD card. It also uses this for some of its internal working. It does signal processing on temperature sensor (DS1620) output to calculate the temperature. It also processes the PPG signals from the RED and IR channel to find the blood oxygen saturation. The calculation of heart rate from PPG signal is also a major function of the central controller.
A Dual Band GSM/GPRS engine, SIM900, which works on frequencies 900/1800 MHz is used as the interface with the central controller which does the purpose of alerting caretakers in case of emergency. The modem can be directly interfaced with microcontroller using two voltage levels, either 5V or 3.3V and do not require any voltage conversion chips. The baud rate is configurable from 9600-115200 through AT command. The GSM/GPRS Modem has the internal TCP/IP stack which enables it to connect with internet via GPRS. It is suitable for SMS, voice as well as data transfer application.

The GPRS Modem and the Arduino communicate serially. Arduino sends AT Commands to the GPRS modem and it executes the command and replies the status back. The Table 1 shows some of the AT Commands that are used in the working of the GSM modules for sending a message.

<table>
<thead>
<tr>
<th>SI. No.</th>
<th>AT Command</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AT</td>
<td>Check if modem is responding</td>
</tr>
<tr>
<td>2</td>
<td>AT+CMGF=1</td>
<td>Set SMS mode as Text mode</td>
</tr>
<tr>
<td>3</td>
<td>AT+CSMS=&quot;GSM&quot;</td>
<td>Selection of GSM character set</td>
</tr>
<tr>
<td>4</td>
<td>AT+CSMS=&quot;GSM&quot;</td>
<td>Set SMS Text Mode Parameters</td>
</tr>
<tr>
<td>5</td>
<td>AT+CSMP=17.167.0.240</td>
<td>Specification of mobile number and command to send message</td>
</tr>
<tr>
<td>6</td>
<td>AT+CMGS=&quot;9999999999&quot;</td>
<td>Makes a voice call</td>
</tr>
</tbody>
</table>

G. Windows Application
This application will be responsible for the communication between the Control unit and the mobile in ABM model. The application uses Bluetooth facility of the mobile for communication. The user is provided with various customizable options like critical heart rate, oxygen content, temperature value and timing arrangement for turning the elder in order to avoid skin related problems etc. This will also display the current status of the elder giving the current physical parameter values. The Android application module will provide options for setting critical values for health parameters. The monitored data is stored into the mobile phone database system and whenever the user requests to display the details, the Data Display option will display the whole parameter data along with graphical representation of value variations till that point of time. For reliable security needs, this area will provide the system, a password based access to all of its management and database access. Figure 3 shows the GUI Application that was developed for Windows OS.

The MediSuit tests are carried out with various subjects whose age range is from 55 years to 85 years. ECG, heart rate, SPO2 and temperature measurements are recorded. The sample measurement of the ECG waveform is shown in Figure 4.

The PPG waveform is given in Figure 5 as measured using MediSuit.

<table>
<thead>
<tr>
<th>Test Subjects</th>
<th>MediSuit Reading</th>
<th>Pulse Oximeter Reading</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>98.5</td>
<td>98</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>98</td>
<td>99</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>97</td>
<td>97.5</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>96</td>
<td>99</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>98</td>
<td>2</td>
</tr>
</tbody>
</table>
### TABLE III. HEART RATE READING

<table>
<thead>
<tr>
<th>Test Subjects</th>
<th>Medisuit Reading</th>
<th>Pulse Oximeter Reading</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>78</td>
<td>75</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>92</td>
<td>95</td>
<td>3.15</td>
</tr>
<tr>
<td>3</td>
<td>72</td>
<td>72</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>86</td>
<td>84</td>
<td>2.38</td>
</tr>
<tr>
<td>5</td>
<td>103</td>
<td>110</td>
<td>6.36</td>
</tr>
</tbody>
</table>

### TABLE IV. BODY TEMPERATURE READING (°C)

<table>
<thead>
<tr>
<th>Test Subjects</th>
<th>Medisuit Reading</th>
<th>Thermometer Reading</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34.5</td>
<td>34.2</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>33</td>
<td>3.15</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>37.5</td>
<td>1.33</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>37</td>
<td>2.7</td>
</tr>
<tr>
<td>5</td>
<td>36.5</td>
<td>36</td>
<td>1.38</td>
</tr>
</tbody>
</table>

Tables 2, 3 and 4 show SPO2, heart rate and temperature measurements with the MediSuit and also standard measurements using Pulse Oximeter and Thermometer respectively. The error % for each of these parameters is provided in the last column of these tables. As we can observe, there is a maximum of 6% error in case of heart rate measurements which is a tolerable one. As we continue with our testing for more and more number of test subjects we are sure that we would be able to achieve a MediSuit which will be perfect for the aged people in developing nations like India.

### VI. CONCLUSION

Lack of quality and timely health care for elderly population is a growing concern in both developed and developing nations. Majority of them suffer from chronic illnesses like BP or Diabetes. Moreover, the lonely living conditions of many enhance the risk of fatal emergencies, thus stressing the need for a real-time monitoring system. This system will be able to effectively measure five health parameters namely Heart rate, Blood oxygen saturation, temperature, ECG and tilt of the patient and if needed alert the caretaker which can help to prevent unexpected fatal medical conditions.

**ACKNOWLEDGEMENT**

We wish to thank Almighty God who gave us the opportunity to successfully complete this venture. The authors wish to thank Amrita Vishwa Vidyapeetham and the Humanitarian Technology Lab of ECE Dept., for aiding us in this endeavor.

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