Research Article

Economical Blood Pressure Monitoring System For Telemedicine Applications

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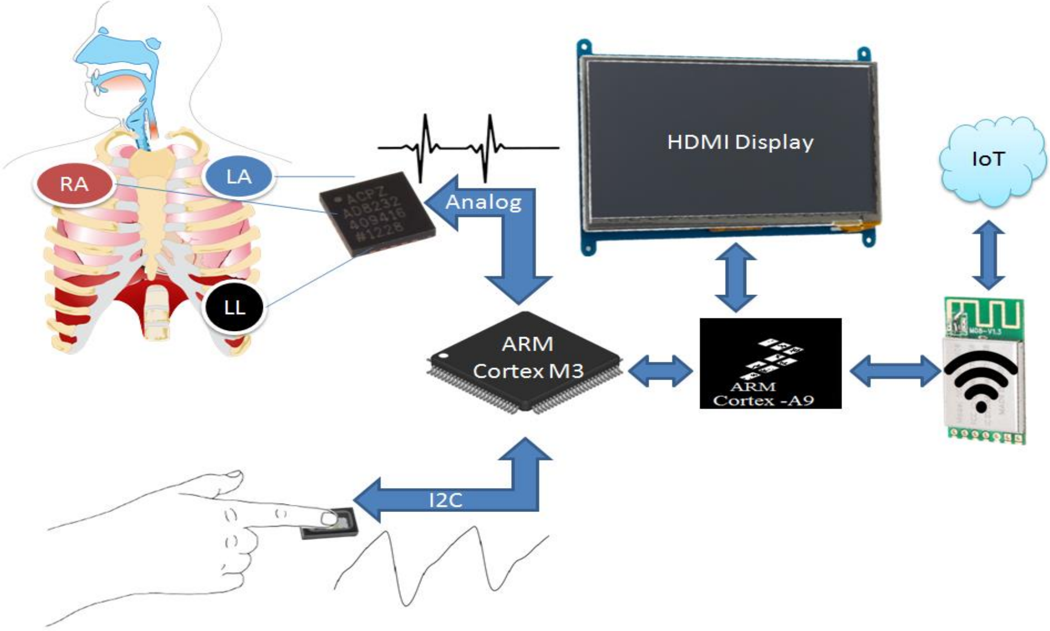
ABSTRACT : Telemedicine and periodic patient monitoring provide medical assistance for people in remote locations. For this hassle free health monitoring systems are required at an affordable cost. In this work, electrocardiogram (EKG) and photoplethysmography (PPG) based blood pressure monitoring device is developed, and the system results are compared with the standard instruments. The EKG of the patients is obtained from the AD8232 sensor, and PPG is captured using the MAX30101. The R peaks of EKG, the peaks, and the valley points of the PPG are used for finding the Pulse Transit Time (PTT). The PTT is calibrated against the standard sphygmomanometers to find the blood pressure. The PPG signal is calibrated to calculate the arterial oxygen saturation levels of the patient and the frequency of the EKG peaks is calculated for obtaining the heart beat rate. The results are displayed on the displaying unit and are stored in the IoT cloud platform for remote access. The accuracy of Heart rate is recorded at ± 2BPM, SaO2 at ± 2.5% Systolic BP at ± 5mmHg and Diastolic BP ± 5mmHg.

Keywords: EKG, PPG, Heart rate, IoT, Telemedicine.

Graphical Abstract



INTRODUCTION

In almost every human's life, medical assistance is very important as humans once in a while tend to get ill and injured. Woefully, not all human beings are equipped with the same medical facilities due to diverse reasons. In most countries, the doctor to population ratio is not up to the minimum standards set by the World Health Organization [1]. People in rural areas find it difficult to reach out to the cities in time for accessing medical facilities. Owing to all these reasons, telemedicine and remote patient monitoring systems became inevitable in today's world.

To practice telemedicine at an affordable cost, a wide range of economic models need to be developed. The monitoring systems are supposed to be non-invasive as the practice of telemedicine is not under the direct monitoring of the medical expert. The common cardiovascular abnormalities can be detected by continuous monitoring of EKG and PPG of the patients [2]. The irregularities in heartbeats and pulse rate are calculated by measuring the frequency, inter-beat interval, and inter-pulse interval of the PPG and EKG signals. The EKG can be practiced with multiple leads placed at various parts of the body and tracking the voltage variations at those sites. EKG, with the higher number of electrodes, the placement and maintenance become difficult for inexperienced people to use them. Hence it is advised to use tri-terminal EKG probes for personal monitoring systems. The three terminals can be easily placed on the body sites for forming an Einthoven's triangle to collect the EKG. Oxygen saturation is also one of the vital signs of the physiological system, which gives information about the risk of diseases like hypoxia. To measure the (arterial oxygen Saturation) SaO2, either invasive or non-invasive techniques can be employed. Despite the limitations of accuracy, the non-invasive techniques provide an indication of hypoxia and can be implemented with medical standards. To record the oxygen saturation, PPG-based pulse oximetry is performed as the technique is non-invasive and inexpensive. Lambert-Beer's law is employed in this technique to compute the SaO2 by using two sources of light with different frequencies [3].

The blood pressure of human beings must be within the prescribed limits for proper metabolism and is needed to be monitored continuously. Mercury-based sphygmomanometers with a cuff are best known for their accuracy in measuring blood pressure with the help of a stethoscope. To measure the BP with this technique, the cuff will be wrapped around the arm. Further, the air valve is operated to increase the pressure around 200 mmHg, and the stethoscope will be placed on the brachial artery. Later, by using the air valve, the pressure will be released slowly, and the practitioner notes down the (Systolic) pressure point from where the Korotkov sound of the brachial artery is started and the (Diastolic) pressure point where the sound ends [4]. To replace this setup, electronic equipment with motors came into existence with relatively good accuracy for personal monitoring of the cuff-based BP monitoring without the need for any stethoscope. The cuff-based sensors are not suitable for continuous monitoring of the BP because they cause discomfort for the users, especially when required to measure at the time of sleep. For addressing these limitations, a novel method using EKG and PPG is being researched all around the world. The time difference between the EKG and PPG signal peaks is termed as pulse transit time, and is used for calculating the cuff-less blood pressure [5].

Storage and transfer of the medical parameters are essential in the current scenario for adequate medical care and telemedicine applications. For this, the Internet of Things technology is efficacious with smart sensors and smart systems. In this study, a smart IoT-based system for measuring non-invasive BP and SaO2 is developed. The results are continuously updated in the online cloud platform for using them at various stages of the treatment.

MATERIALS AND METHODS

The system with the blocks shown in Fig. 1 is designed using a development board named UDOO Quad with an on-board microcontroller and a microprocessor [6]. The on-board ARM Cortex-M3 microcontroller is interfaced with the EKG sensor AD8232 and PPG sensor MAX30101. The 84 MHz ARM controller has 512 KB of Flash memory, 96 KB of SRAM, 16-channel 12-bit ADC, and 12-bit dual-channel DAC. The 144-pin microcontroller, with 103 programmable I/Os, supports various serial communication interfaces such as UART/USART, TWI, and SPI.

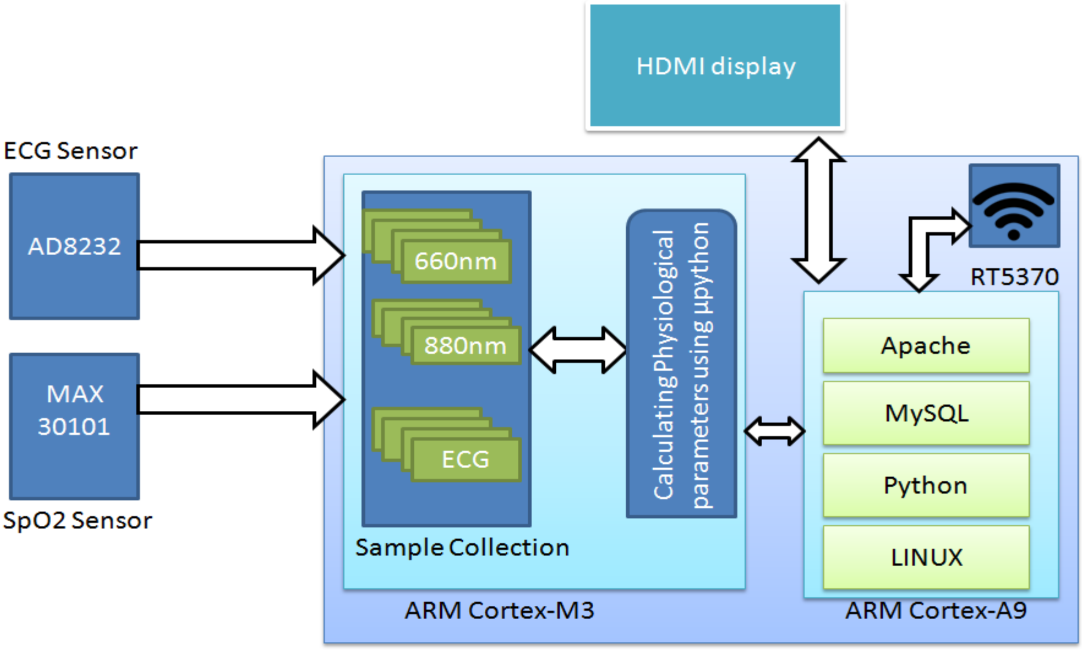


Figure 1 Conceptual Block diagram of the system

The EKG sensor AD8232 of AD Inc. is interfaced to one of the 16-channels of the analog to digital convertor. The integrated circuit is one of the best-suited front ends for wearable EKG devices. It is operated with a 3.3V power supply at a very low current of 170µA. It has a CMRR of 80dB, PSRR of 76dB, a high gain of 100 with dc blocking capabilities, and provides full swing rail-to-rail output. The automatic leads-off sensing and quick restore circuitry of this ECG IC are the additional features. The IC has an instrumental amplifier, an optional rail-to-rail amplifier for additional gain, an amplifier for proving required CMRR, and an amplifier to work as a reference buffer. The EKG sensor is configured in the tri-electrode cardiac monitoring mode, as shown in Fig. 2. For collecting pulse oximetry signals, MAX30101 of MAXIM Integrated is used in dual LED mode [7]. The sensor is interfaced to the Cortex-M3 controller using the two-wire interface protocol. The half-duplex communication protocol utilizes clock and data signals to transfer the data between the sensor and the microcontroller. The 14-pin tiny sensor with a volume of 28.64mm3 is covered with a small glass cover. The two LEDs are alternatively driven by utilizing the LED driver circuit using the TWI protocol [8]. The sensor keeps track of the reflected light detected by converting the analog samples into digital data using an inbuilt 18-bit ADC. Before the data gets digitized, the ambient light noise is eliminated with the help of ambient noise canceling circuit. After digitizing the data, a digital filter in the sensor eliminates any further noise and stores the sample information in the 32-deep FIFO.

The samples of both the sensors are collected simultaneously and are stored in buffers at regular intervals. The data in the buffers is processed for every 8 seconds to obtain the physiological parameters. The ARM Cortex-M3 is programmed with Python for sample collection and data processing. The data of the SaO2 sensor is processed for obtaining the arterial oxygen saturation. The ac root mean square values and dc average values of the LEDs are substituted in equation (1) to obtain the SaO2 ratio. Further, the SaO2 ratio is substituted in equation (2) to obtain the SaO2 value.

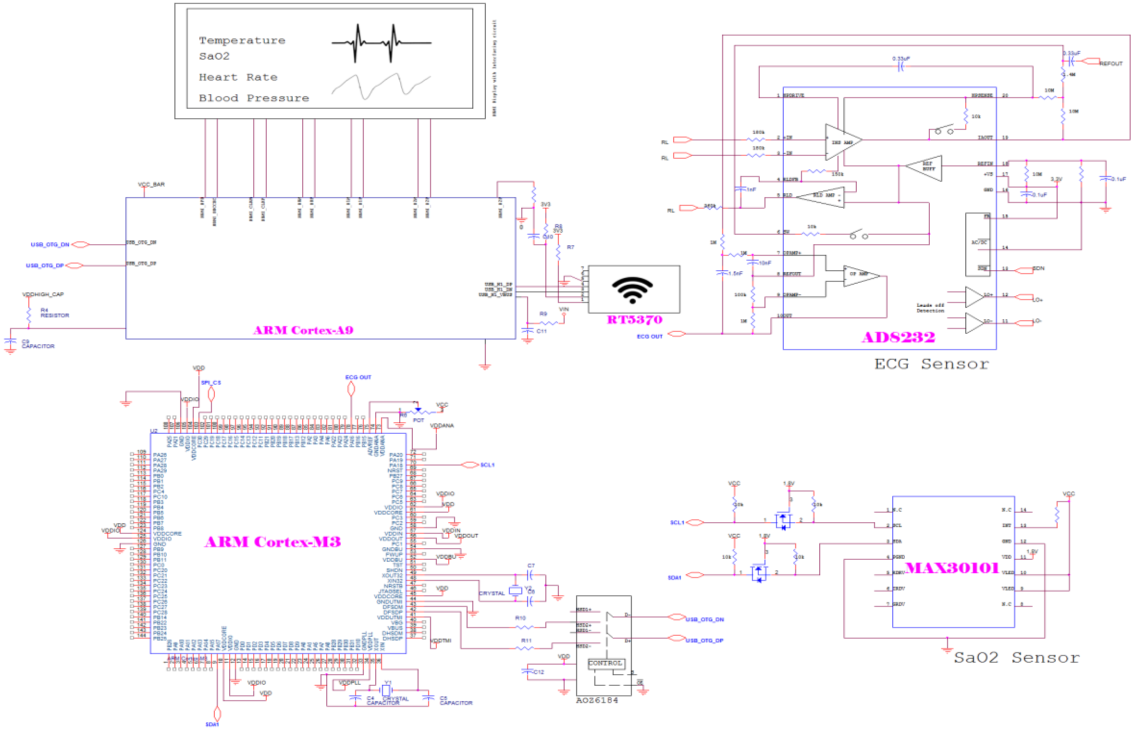


Figure 2 Schematic diagram of the designed system

$$\text{SaO2 ratio} = (\text{AC RMS}_{660nm}/\text{DC Average}_{660nm}) / (\text{AC RMS}_{880nm}/\text{DC Average}_{880nm}) \text{ ---- } (1)$$

$$\text{SaO2} = \alpha\,(\text{SaO}_2\text{ ratio})^{2} + \beta\,(\text{SaO}_2\text{ ratio}) + \lambda \text{ --------------------- } (2)$$

The calibration constants α, β, and l are obtained after calibrating the SaO2 ratio against the SaO2 records of the standard systems.

The AD8232 samples are collected through one of the ADC channels of the microcontroller, and the data is processed every 8 seconds to determine the time domain characteristics such as frequency of the samples, peak to peak interval [9]. The EKG signal is initially processed with a baseline wandering algorithm followed by a notch filter. Later, the peaks finding algorithm is used for locating the R peaks and the distance between the R peaks—the inverse of the average distance between the R peaks in the frequency of the heart beat. The multiplication of the frequency of the beats with the number of seconds in a minute gives the heartbeat of the patient in BPM.

The timed difference between the peaks of SaO2 signal and EKG signals is termed as pulse transit time (PTT). The average PTT measurement is stored in the database and is simultaneously compared against the standard BP machine. The Blood pressure is measured from the PTT by substituting it in equations (3) and (4).

$$\text{Systolic BP} = a + b\,(\log_e(\text{PTT})) + c\,(\text{Heart Rate}) \text{ ------------------- } (3)$$

$$\text{Diastolic BP} = x + y\,(\log_e(\text{PTT})) + z\,(\text{Heart Rate}) \text{ ------------- } (4)$$

The constants a, b, c, x, y, and z are obtained by correlating the PTT while calibrating it with the standard BP machines.

After performing all the calculations, the data from the microcontroller is taken into the microprocessor for visualization and storage of data. The stored signals and the processed values are continuously displayed on the webpage developed with PHP.

RESULTS AND DISCUSSION

The system after calibration is tested against the standard instruments in a medical hospital. The non-invasive system is tested with 30 voluntaries.

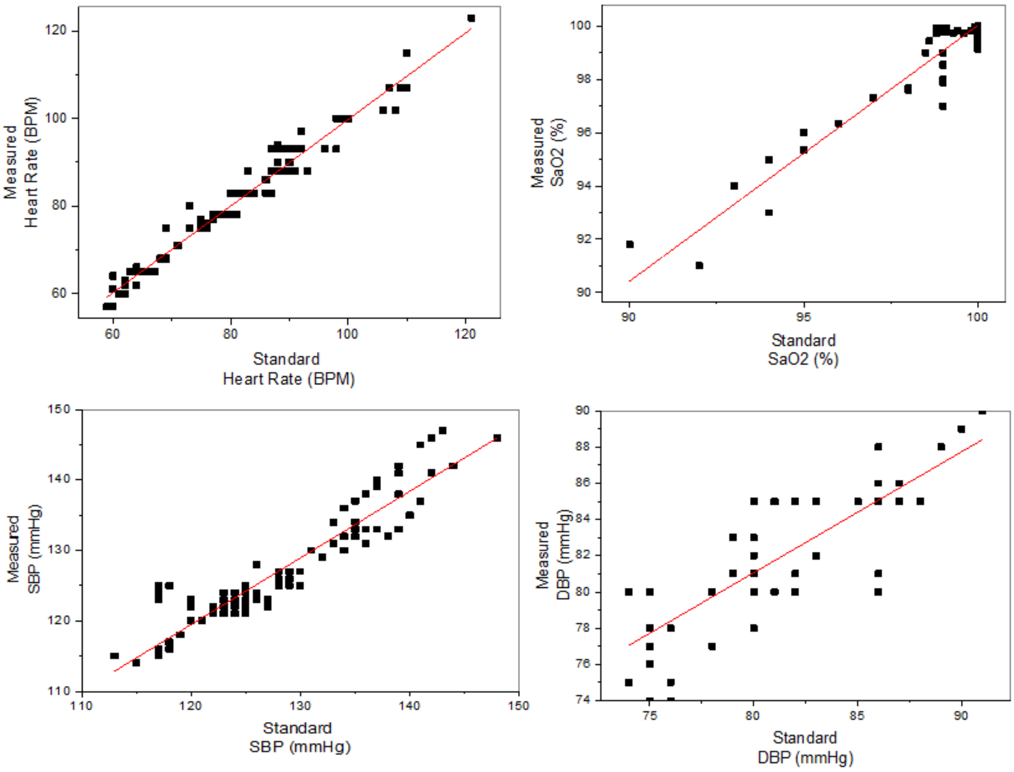


Figure 3 The physiological measurements of standard system Vs the designed System

The ECG probes are connected in the Einthoven triangle, and the finger is placed on the SaO2 probe of the designed system. The SaO2 probe of the standard system is connected to the adjacent finger to the finger where the developed system's probe is connected. The cuff-based standard BP machine is connected to the other hand. The measurement starts with entering the name of the person on the webpage. The values of the standard systems are recorded manually, and the values of the designed system are automatically stored in the database. The data, EKG, and PPG signals are visualized in the webpage of the system. The data on the displaying page gets updated every 10 seconds. The outputs of the designed and standard systems are depicted in Fig. 3.

The SaO2 of the patients is recorded at an average of 99.64 with an accuracy of ±2.5%. The heart rate recordings are averaged about 83 with an accuracy of ± 2BPM. The blood pressure recordings are monitored as 126mmHg Systolic with accuracy ± 5mmHg of and 84mmHg diastolic at an accuracy of ± 5mmHg. The results are displayed in both the local system as well as the other IoT-connected devices with the help of a web browser. The past database is also accessible for the authorized people with a user name and a passcode.

CONCLUSIONS

An economic prototype for measuring the different parameters of the human body is developed, and the data is stored and transferred to the IoT-connected remote locations for telemedicine applications. The measured records are in good agreement with the standard instruments used in the medical hospital. As an extension of this work, the authors are trying to provide a multimedia interface between the local and remote stations along with these physiological parameters for holistic telemedicine practice.

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