Design and Development of Physiological Parameter Monitoring System Using Wearable Sensors

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Abstract. Improvement in technology has enriched the popularity of different sectors of society. Healthcare is one of the sectors where people can monitor the physical activity of the body remotely without taking help from a doctor or caretaker. Nowadays, in most of the developing countries, healthcare is much more expensive. Hence it is not affordable by human beings. This paper presents the design and development of a remote health monitoring system using wearable sensors. Hence, we have considered three different wearable sensors like temperature sensor, spo2, and heart rate sensor to sense human vital activity. The acquired raw data has been sent to the data acquisition system and displayed in LCD. Moreover, we have done a comparative study of the human physiological parameters according to different ranges of ages. In our future work, the received data will be sent to the doctor through Wi-Fi for further analysis.

Keywords: Wearable Sensor, Health Monitoring System, ESP32 Microcontroller.

1 Introduction

Wearable technology is a tremendous creation in the healthcare industry. Nowadays, in the healthcare center, diagnosis of diseases and recognizing abnormalities in the human body is the most challenging task because of certain factors like lack of health service, absence of doctors and nurses etc. [1]. In parallel to this, the cost of healthcare becomes increasing day by day. Health is the primary part of every aspect of human life. For a healthy life, it is essential to monitor human vital signals regularly [2]. Health is a parameter which is varied with time. Sudden changes in the environment, having unhygienic food, stress and workload are some factors that affect human health [3].

Vital signs are the measurement of the most crucial functions of living organisms [3] There are five main vital signs i.e. body temperature, blood pressure, heart rate, respiratory rate and spo2(oxygen saturation level). In our study, we have focused on temperature, heart rate and spo2.

There are various sensors used in medical applications. Table 1 shows the normal range of temperature, spo2 and heart rate according to the range of ages [4] [5] [6].

Parameter	**Age**	**Levels**
Body Temperature	Baby and children	97.9°F– 99°F
	Adults	97°F-99°F
	Adults over 65	Below 98.6°F
Spo2	Adults and children	95%-100%
	Adults over 70	Closer to 95%
Heart rate	Newborn(0-12 months)	100-160 BPM
	Children(1-12 years)	70-150 BPM
	Adult(12-18 years) and over	60-100 BPM

Table 1. Normal body temperature, spo2 and heart rate of a person according to different ranges of ages.

The novelties of our work is that it is easy to use. It is an integrated system and as inbuilt storage. Moreover the system is ready to transmit data over Wi-Fi communication and cost is less.

1.1 Background study

In recent years, various health monitoring systems were developed using various techniques. A. A. Patil et al. have mentioned about the use of both Raspberry Pi and PIC/Arduino controller to process patient's physiological data along with various wireless body area sensors to monitor their health condition. Hence, complexity increases in developing the system. Moreover, the system only processes the collected data from sensors, but it doesn't diagnose the data [7]. W. T. Sung et al. have described about the use of both wired and wireless communication systems to process data. Hence, power consumption is high. Moreover, the system is costly and complexity also increases [8]. N. S. Hadis et al. detects and analyzed two vital signs of the human body i.e. body temperature and respiratory rate according to the range of age to test if any abnormality occurs in health conditions [9]. G. Rathi et al. have used a 12-bit ADC myRIO microcontroller which is not popular as well as not available in the local market. In addition, it doesn't have in build Wi-Fi and Bluetooth connectivity [10] .

1.2 Material and study

Pulse and heart rate sensor: We have used an integrated 7 pin MAX30100 pulse oximetry and heart-rate monitor sensor to measure blood oxygen and heart rate based on the I2C protocol [11]. Blood oxygen concentration is measured in terms of percentage and heart rate is calculated in terms of BPM. It consists of two LED's, a photo detector, optimized optics, and low noise analog signal processing to identify pulse and heart-rate signals [12]. It requires a 1.8V to 3.3 V power supply [12].

Temperature sensor: Ds18b20 is an 8bit digital thermometer having one wired data bus for communication. It measures temperature in the range of -55°C to +125°C and -67°F to +257°F [13]. It can operate in parasite power mode i.e. it allows to work without an external power [14]. It can take power from the data line directly.

Microcontroller: ESP32 is a 30 pin low cost and low power system microcontroller having inbuilt Wi-Fi and Bluetooth connectivity [15]. It is used in health care applications, smart agriculture, industrial automation, smart building, home automation, wearable electronics, speech recognition, image recognition etc. It can be programmed using different programming languages such as c, c++, Micro Python and Lua etc. Moreover, it is easily available in the market.

Voltage regulator: LM2596 (buck converter) is a monolithic integrated circuit used to regulate voltage and provide high current to the circuit. It can drive a maximum 3A load with excellent line and load regulation and can take a maximum input voltage of 40V [16]. Moreover, fixed output voltages of 3.3V, 5V, 12V, and an adjustable output version are available in this device. It requires only 4 external components. It has high efficiency [16]. The circuit can operate at 150 kHz switching frequency.

Serial to parallel converter: PCF8574 is an 8-bit silicon CMOS circuit [17]. It is used as a remote I/O expander for most of the microcontroller families through two-line bidirectional bus based on I2C protocol [17]. If we have a limited number of input-output pins in the microcontroller and we want to increase the I/O pins so that the microcontroller can be connected to several I/O devices. It requires supply voltage ranging from 2.5V to 6V and maximum current consumption is 10 μA. It is compatible with most of the microcontrollers.

Liquid crystal display (LCD): It is an electronic flat panel display device [18]. It can operate by changing the electric voltage to a layer of liquid crystal. It can be used in electronic games, flat-panel televisions, computer monitors, video projection systems, digital watches, etc. [19]. It can operate from 4.7V to 5.3V power supply. In our work, we are using a 20x4 LCD. It displays two rows where each row can display maximum of 20 characters in each row.

1.3. Block diagram

Fig.1. represents the block diagram of the health monitoring system using a temperature sensor and heart rate/Spo2 sensor. The figure consists of six blocks namely buck converter, LCD, temperature sensor, HBT/spo2 sensor, serial to parallel converter and control unit. Buck converter is used to provide proper voltage and high current to the circuit. Temperature sensor DS18b20 transmits data to the microcontroller only when microcontroller send request to the sensor. The control unit ESP32 is used to monitor the entire process of the system. HBT/spo2 i.e. MAX30100 is an integrated sensor used to measure oxygen level in the blood and heart rate of human body. Serial to parallel converter block is used as I/O expander if limited number of input-output pin is available in the microcontroller. We have used one LCD to display sensors values.

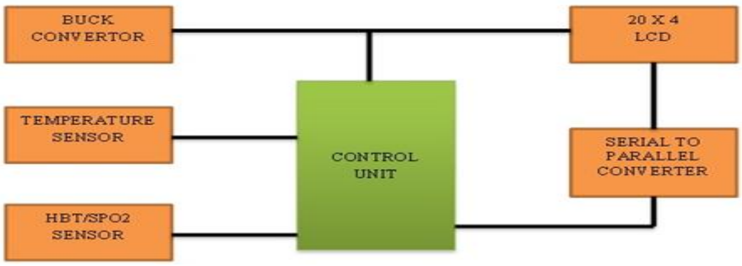

Fig. 1 Diagrammatic representation of the health monitoring system.

1.4. Flowchart

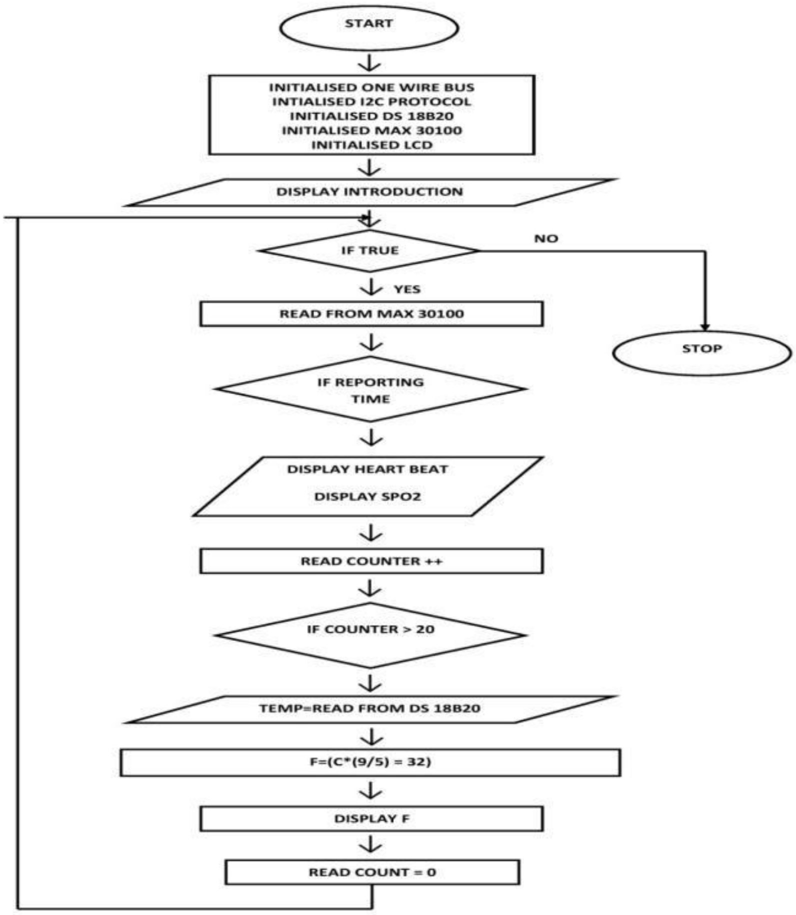

Fig. 2 Flowchart of the designed system.

Fig. 2 shows how the system works in order to display sensors data on LCD. First of all, we have initialized the temperature sensor, heart rate/ spo2 sensor and LCD. Then the system will read data from the heart-rate/ spo2 sensor and display it on LCD. The system cannot read data from the temperature sensor and heart rate/ spo2 together at the same time. Hence, we have set a counter. The counter will count to 20 seconds. After 20 seconds, the system will read temperature from the temperature sensor. As the human temperature is measured in terms of Fahrenheit, we convert it from Celsius using mathematical formula and display it on LCD.

1.5. Circuit diagram

Fig. 3 shows the circuit description of health monitoring system. The circuit is based on most popular ESP32 based development board which is having in built Bluetooth and Wi-Fi communication. In our work, we have used multiple sensors. Primarily digital temperature sensor DS18B20 and HBT/spo2 sensor i.e. MAX30100 is used in the circuit. DS18B20 is one of the most reliable and stable digital temperature sensors. It communicates with host system using one wired protocol. In our circuit diagram, the DQ pin of DS18B20 is connected to D4 I/O pin. According to data set of DS18B20, the DQ pin is open drain and we must have to use external pull up. Hence, a 4.7K resistance is connected from DQ to 3.3 V power supply. DS18B20 communicated with microcontroller through predefined set of commends primarily classify into ROM commend like 0XF0, 0X33, 0X55 and function commends like 0X44, 0X4E etc. Table 3 and table 4 shows description of each command used by the temperature sensor.

Table 3 ROM commands

ROM command	**Description**
SEARCH ROM [F0h]	When a system is initially powered up, the master must identify the ROM codes of all slave devices on the bus, which allows the master to determine the number of slaves and their device types.
READ ROM [33h]	This command can only be used when there is one slave on the bus. It allows the bus master to read the slave's 64-bit ROM code without using the Search ROM procedure.
MATCH ROM [55h]	It allows the bus master to address a specific slave device on a multi drop or single-drop bus.

SKIP ROM [CCh]	The master can use this command to address all devices on the bus simultaneously without sending out any ROM code information.
ALARM SEARCH [ECh]	This command allows the master device to determine if any DS18B20s experienced an alarm condition during the most recent temperature conversion.

Table 4 Function commands

Function command	**Description**
Convert T	It Initiates temperature conversion.
Read Scratchpad	It Reads the entire scratchpad including the CRC byte.
Write Scratchpad	It writes 3 bytes of data to the DS18B20's scratchpad. The first data byte is written into the TH register (byte 2 of the scratchpad), the second byte is written into the TL register (byte 3), and the third byte is written into the configuration register (byte 4)
Copy Scratchpad	Copies TH, TL, and configuration register data from the scratchpad to EEPROM
Recall E2	Recalls TH, TL, and configuration register data from EEPROM to the scratchpad.
Read Power Supply	Signals DS18B20 power supply mode to the master.

HBT/Spo2 sensor i.e. MAX30100 is used in the circuit. This sensor communicates with the host through I2C protocol. i.e. SCL and SDA pin are used to provide serial clock and transfer serial data. The SCL and SDA pin are connected to corresponding SCL and SDA pin of ESP32 development board. To display the parameters i.e. temperature and HBT/spo2, a 20x 4 LCD module is used. To consume least number of I/O pin of ESP32 board in our circuit, an I2C driver is used to communicate with LCD module. Hence, we have used PCF8574 as I2C driver. We have used a buck converter to provide power supply to the circuit so that circuit gets proper voltage and current. We have used LM2596 based buck converter in the circuit.

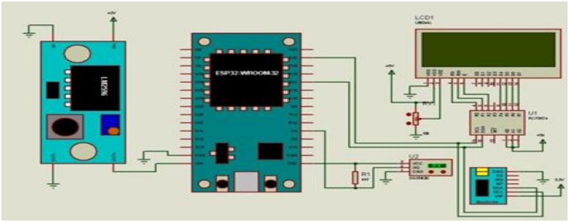

Fig. 3 Circuit Diagram

1.6 Testing

Fig. 4 Displaying body temperature, heart rate and Spo2 in LCD of different persons.

We have tested the considered sensors by holding the end of sensors for four to five minutes. The readings of the sensors will be displayed on LCD within few minutes as shown in figure 4. To obtain the accuracy of the sensors, we have considered digital device and compare data obtained from both in the form of error rate. The LCD is used in our work which has displayed heartbeat and Spo2 in the first row and body temperature in the second row.

1.7 Data Retrieval

Retrieval of Heartbeat data

Table 5 Real data collection from subjects of different age group to measure heartbeat .

Sl No	Subjects Name	Date	MAX30100 Sensor		Digital Heartbeat		Error (%)
			Time Frame	Measurment (Bpm)	Time Frame	Measurment (Bpm)	
1.	A	20.12.2022	10.10AM	105	10.15AM	102	3
2.	B	21.12.2022	10.25AM	104	10.30AM	103	1
3.	C	22.12.2022	10.20AM	102	10.25AM	105	3
4.	D	23.12.2022	11.10AM	68	11.15AM	69	1
5.	E	24.12.2022	11.10AM	86	11.15AM	88	2
6.	F	25.12.2022	10.10AM	72	10.15AM	74	2
Average Error							**2**

We have retrieved heartbeat data from six person’s successfully to see the condition's of a person’s heart whether it is healthy or not. We have collected the samples repeatedly thrice from each person within 60 seconds each to find the average value generated by the sensor. The digital measurement is done to determine the error rate of the designed sensor device. The data obtained shows that the heartbeat sensors between 72-105 bpm. The measured heartbeat condition is categorized as normal with a limit of 60-100 bpm for ages 30-80 years. The heartbeat MAX30100 sensor is worked well with an average error rate of 2%. The results of heartbeat data retrieval is shown in table 5.

Retrieval of Body temperature data

Table 6 Real data collection from subjects of different age group to measure body temperature .

Sl No	Subjects Name	Date	Ds18b20 sensor		Digital Thermometer		Error (%)
			Time Frame	Measurment (°F)	Time Frame	Measurment (°F)	
1	A	20.12.2022	10.00AM	98°F	10.04AM	98.5°F	.5
2	B	21.12.2022	10.15AM	99°F	10.20AM	99.6°F	.6
3	C	22.12.2022	10.10AM	97°F	10.15AM	97.5°F	.5
4	D	23.12.2022	11.00AM	96°F	11.05AM	96.6°F	.6
5	E	24.12.2022	11.05AM	96°F	11.10AM	96.8°F	.8
6	F	25.12.2022	10.02AM	97°F	10.07AM	97.4°F	.4
Average Error							**.56**

The results of data retrieval indicates that the sensor DS18b20 measured between 96^0F- 99^0F. Measurable body temperature conditions considered as normal within a limit of 96^0F- 99^0F for ages 19 to 75 years. The body temperature sensor used works well with an average error rate of .56%. The results of body temperature data capture can see in table 6.

Retrieval of Oxygen saturation level data

Table 7 Real data collection from subjects of different age group to measure oxygen saturation level.

Sl No	Subjects Name	Date	MAX30100 sensor		Digital Pulse Oximeter		Error (%)
			Time Frame	Measurment (%)	Time Frame	Measurment (%)	

1	A	20.12.2022	10.10AM	98	10.15AM	98	0
2	B	21.12.2022	10.25AM	99	10.30AM	99	0
3	C	22.12.2022	10.20AM	98	10.25AM	99	1
4	D	23.12.2022	11.10AM	97	11.15AM	98	1
5	E	24.12.2022	11.10AM	98	11.15AM	99	1
6	F	25.12.2022	10.10AM	97	10.15AM	98	1
Average Error							**.66**

Data retrieved from MAX30100 sensor is in between 96-98 % which is considered as normal within a limit of 96-98% for ages 19-80 years. Oxygen saturation level sensor works successfully with an average error rate of .66%. The results of oxygen saturation level is shown in table 7.

3. Conclusion

In our work, we have successfully developed a health monitoring system to acquire vital signals accurately from the human body and display it on a 20x4 LCD. We have considered three physiological parameters i.e. body temperature, spo2 and heart rate. In future work, we will consider more parameters to measure more human vital signs such as blood pressure, electromyography (EMG) and electrocardiography (ECG). Moreover, we will communicate with doctors or caretaker through Wi-Fi. On the other hand, in our study, we have considered only adults of ages from 20 to 80 years. In future study, we will consider children below 20 years to collect their physiological data.

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