Original Research Article

SIMULATION AND CONSTRUCTION OF WIRELESS HEARTBEAT AND BODY TEMPERATURE MONITORING DEVICE USING MICROCONTROLLER

ABSTRACT

Heart rate and body temperature are important health parameter that need to be monitored especially for the old aged that needs constant medical care. In this study, simulation and construction of wireless body temperature and heartbeat monitoring device was carried out using PIC16F886 microcontroller and RF module. The circuit was simulated using Proteus8.4, while a prototype was constructed on a Vero board. The circuit was tested by measuring temperature and heartbeat of a volunteer during different levels of activities. Result shows that, the transmitter section, reads body temperature and heartbeat using sensors. The signal is then processed by the microcontroller and wirelessly transmitted to the receiver section through RF module at 433MHz, while detail is displayed on the LCD. At the receiver section, the signals are received through RF antenna operating at the same frequency with the transmitting RF module (433MHz). The data processed by the receiver microcontroller is also displayed on LCD. The readings of body temperature and heartbeat can be taken simultaneously by the same device and transmitted wirelessly to the care giver or patient relation. The device recorded a heartbeat rate of 76bpm at normal body temperature of 36.2°C and for every degree increases in body temperature, the heart beats about 10bpm faster. The device is reliable and cost effective to enable it accessible and affordable to the care giver and patient's relative who can monitor the patient remotely.

Keywords: Heartbeat monitoring; temperature monitoring; microcontroller; Proteus design suit; electrocardiography; pulse rate.

1. Introduction

The human health is one of the most important concerns in the world today. For good Medicare, people, government and non – government organization (NGO) spend a lot of resources (money) to ensure a better health condition for all. Scientists and engineers always carry out research to invent modern electrical/electronic and mechanical devices as a means of supporting a sound health system [1, 2]. The advantage of regular medical check-ups is to verify any medical problems as early as possible, so that they can avoid serious medical related troubles in the future [3]. Old age problems are very common these days, as the social structure has evolve into satellite family systems where children after attaining their adulthood no longer live with their parents and the old souls are left to cater for themselves. Typically, aged people live a secluded and reclusive life with multiple problems of memory disorder, depression, falls and unsteadiness, poor nutrition, problems with self-care and other complex chronic medical conditions especially heart problems [4]. Homecare telemedicine could be a solution. The main purpose is to develop a wireless, low-cost and user friendly system, which allows patients to measure their own vital signs and provide the health care professionals with the facility to remotely monitor the patient's vital signs quickly and easily [1, 3]. In this way, they can take care of their health within the comfort of their own home.

According to Sunitha and Prathyusha [5] the primary parameters in defining the health condition of human are heartbeat rate, blood pressure and body temperature which are most vital for saving lives especially for the old aged. The heart condition can be managed effectively and many patients can be cured and saved if early actions are taken [6]. The heart usually beats 60 – 70 times per minute while the breathing rate is one – fifth of 60 – 70 beats which is either 12 or 14 [7]. Both the breathing oscillation and heart oscillation are disturbed by the kinds of noise superimposed by higher brain activity present

UNDER PEER REVIEW

such as in Rapid Eye Movement (REM) sleep. Actually, heart rate is tied to the breathing rate in a phenomenon called Respiratory Sinus Arrythma (RSA) [8]. When the person breathes in the heart increases slightly and then, decreases when the person breathe out. The respiration rate is the number of breaths a person takes per minute. The rate is usually measured when a person is at rest. Respiration rates may increase with fever, illness, and with other medical conditions. Normal respiration rates for an adult person at rest range from 15 to 20 breaths per minute. Respiration rates over 25 breaths per minute or fewer than 12 breaths per minute (when at rest) may be considered abnormal [9, 10]. A long-term study of Electro-Cardiogram (ECG) signal during everyday activity is required to obtain a broad spectrum of heart disease categories based on heart rate changing.

Decades ago, diagnosis for heart disease was typically based on tape recording of ECG signal which is then studied and analyzed using a microcomputer. This may be achieved by either correlating the pattern of the ECG signal with a typical healthy signal, characterizing the ECG signal using basic logical decisions, or more complicated algorithms to process in depth the heart disease. The first approach requires complicated mathematical analysis to obtain the required diagnosis, while the second one involves only simple analysis in most cases. Tape systems for recording ECG signals are bulky, heavy and prone to mechanical failure. In addition, these systems need large batteries [11]. Many techniques have been implemented, such as the use of a minicomputer in intensive care to observe patients, or microprocessor-based card in portable system [12]. In this case, the disadvantage is the restriction of patient movement. There are devices in the market which can provide raw measurement data of the patients to the doctors, but the patients may not be able to interpret the medical measurement into a meaningful diagnosis due to their lack of medical background. Today, wireless network provides mobile telemedicine which allows patients to engage their daily routines while they are monitored continuously anytime, anywhere [6, 13]. A wire-free system connected to a hospital minicomputer allows patient mobility within restricted area in the hospital. In healthcare application wireless sensor network, small and lightweight sensors are used to be placed on the patient's body. Benefits of E-health system are used for transmission of blood pressure, heart beat rate, level of oxygen, body temperature from patient to a web server using GPRS [14, 15]. This study shall however, presents the design and implementation of a compact microcontroller-based portable system used for measuring heart rate, temperature and blood pressure in real time. The heartbeat and temperature monitoring device does not impose any hazard to the human health unlike the X– ray machine. In order to reduce the size, weight and power consumption of the system, a single chip Reduced Instruction Set Computer (RISC) architecture microcontroller was chosen. To keep the patient free of movement at home, a data transmission protocol using e-mail is implemented in the system. One of the advantages of this device is that it can be built integrated and standalone device with small size and lightweight.

2. Materials and method

2.1Materials

The materialsand their specification that were used for the design, simulation and construction of the heart beat and body temperature monitoring device includes PIC18F886microcontroller, LM35 temperature sensor, IC7805 voltage regulator, RF transmitter/receiver module,16 x 2 LCD display, windows 10, 500GB, 4GB Ram, Intel N3540 processor laptop, and Proteus 8.4 software.

2.2Methods

The methods for implementation of the microcontroller based automatic heart beat and body temperature monitoring deviceis a stage by stage simulation of the circuit, hardware construction and circuit analysis (testing).

UNDER PEER REVIEW

2.2.1Simulation Method

The simulation of the microcontroller based automatic heart beat and body temperature monitoring device was carried out in two part including the transmitter part and the receiver part according to the block diagrams presented in Figures1 and 2. The circuit was simulated using Proteus ver8.4software and the stages involved includes thepower supply unit,temperature sensor unit, heart beat sensor module, microcontroller unit, Output driver and buzzer unit, LCD unit, RF transmitter/ receiver module.

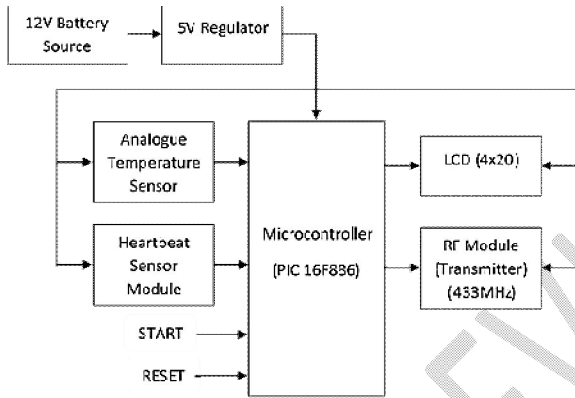


Fig. 1: Block diagram of the transmitter

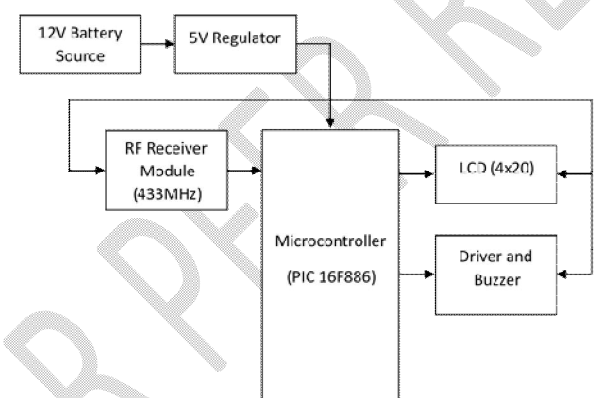


Fig. 2: Block diagram of the receiver

2.2.1.1 The Transmitter

On the transmitter side, power supply from a 12V battery is regulated to 5V and feeds all the blocks at the same time. Transducers connected to pins configured as input on the microcontroller are read. The signals are read by different sensors – body temperature and heartbeat. These two parameters are processed by the microcontroller and wirelessly sent to the receiver section through RF module transmitting at 433MHz while the body temperature and heart beat readings are displayed on the LCD. The transmitter module specifications include 20 – 200m launch distance, 3.5V – 12V operating voltage, AM operating mode, 4kb/s transfer rate,10MW transmitting power, and 25cm external antenna. The transmitterunit is shown in Figure 3.

UNDER PEER REVIEW

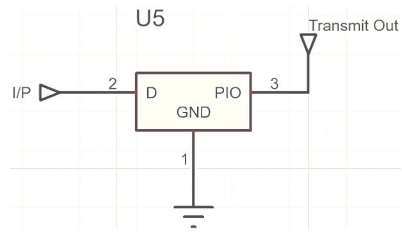


Fig. 3: Circuit diagram of the transmitter

2.2.1.2 The Receiver

The receiver section is connected to the RF module antenna operating at 433.92MHZ. The data is processed by the receiver microcontroller and appropriate action is taken. The serial data received consists of body temperature and heart beat sensor values. The specifications of the receiver include 5V operating voltage, 4mA quiescent current, 433MHz receiving frequency, 105dB receiver sensitivity, 32cm and external antenna.The receiverunit is shown in Figure 4.

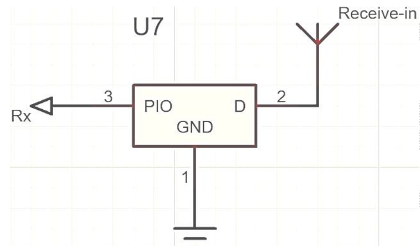


Fig. 4: Circuit diagram of the receiver

2.2.1.3 The Analogue Temperature Sensor Unit

This LM35 analog temperature sensor consists of two independent, high gain, internally frequency-compensated operational amplifiers designed specifically to operate from a single power supply over a wide range of voltages. It is calibrated directly in Celsius (Centigrade), with −55°C to 150°C range and suitable for remote applications. Features include a linear +10mV/°C scale factor, 0.5°C accuracy (at 25°C), operates from 4V to 30V, and <60µA current drain. It is also low cost due to wafer-level trimming, low self-heating (0.08°C) in still air, and low-impedance output (0.1Ω for 1mA load). The LM35 is sued in this study because the low power supply current drain is independent of the magnitude of the power supply voltage and non-linearity is only ±¼°C typical[16]. The circuit diagram of the LM35 is shown in Figure 4.

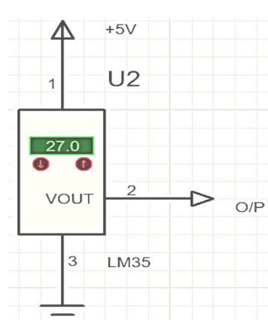


Fig. 5: LM35analogue temperature sensor unit

2.2.1.4 The Heartbeat Sensor Unit

The GP2D12 is a distance measuring sensor (IR Range Sensor) with integrated signal processing and analog voltage output. It has 10 to 80cm effective range, 32ms LED pulse cycle duration and 38ms

UNDER PEER REVIEW

response time. It also has 44ms start up delay, 4.5V ~ 5.5V voltage – supply, 33mA average current consumption, and 80cm: 6cm detection area diameter [17]. The circuit diagram of the GP2D12 is shown in Figure 4.

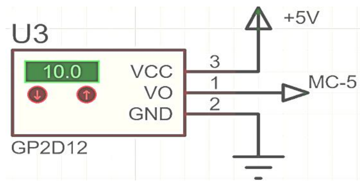


Fig. 6: GP2D12 unit

2.2.1.5 The LCD Unit

The LCD (Liquid Crystal Display) used is a 16x2 LCD display which displays 16 characters per line and there are 2 such lines. Each character is displayed in 5x7 pixel matrix and is capable of displaying 224 different characters and symbols [18]. The LCD is used in this study to displays the state of the heartbeat and body temperature. Figure 5 shows the 16x2 LCD unit.

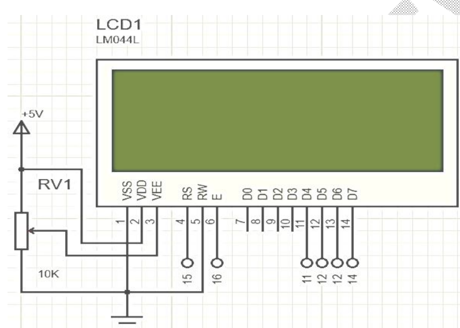
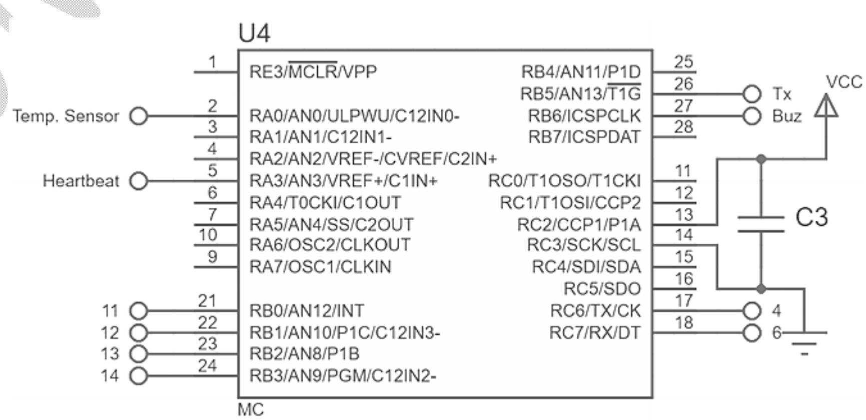


Fig. 7: LCD1 LMO16L Unit

2.2.1.6 The Microcontroller Circuit

The PIC16F886 is a microcontroller from ‘PIC16F’ family made by microchip technology. It is an 8-Bit CMOS Microcontroller with Nano-Watt Technology. It is a 28 pin IC and each pin can perform multiple functions. With 24 programmable Input/output pins developed to handle 20mA current (direct LED driving capability), the system can interface many peripherals easily. Also, with watchdog timer to reset under error automatically, the controller can be used to develop applications of permanent installation [19].The PIC16F886 microcontroller was used in this study because it has high flash memory rewrite cycle of 16Kbytes,which is good for experimenting and developing applications. Figure 6 shows the circuit diagram of the microcontroller unit.

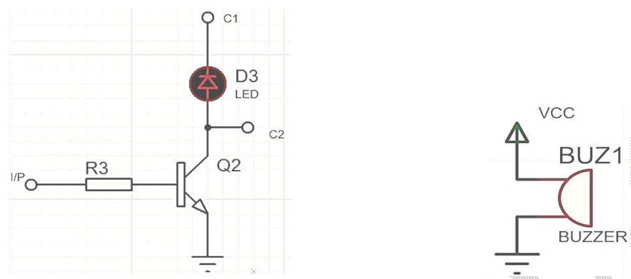


UNDER PEER REVIEW

Fig. 8: The PIC16F886 Microcontroller unit

2.2.1.7 The Relay/Buzzer Output Driver Unit

A relay is an electrical driver capable of controlling the output circuit of higher power from a low power input circuit. It is an electrical shift or switch that opens and closes below the control of added electrical circuit. In the original form, the shift is operated by an electromagnet to open or close one or many arrays of contacts [20].The relay is used to provide enough current to the buzzer at the receiver. The circuit diagram of the relay output driver and buzzer is shown in Figure 7.



a) Relay driver b) Buzzer unit

Fig. 9: The relay output driver and buzzer unit

2.2.1.8 The Power Supply Circuit

A regulated power supply is very much essential for several electronics devices due to the semiconductor materials employed in them as they have a fixed current rate as well as voltage.The power supply supplies the dc voltage to operate the circuit. A step-down transformeris used to obtain 12V AC from 220V mains, which can be rectified to 12V DC using a rectifier. The result of the rectifier still comprises of some distortions despite that it is a DC signal and as such, it is called as fluctuating DC. The ripples will be removed to realize a smoothened signal using DC power filter circuit. 12V is used to power the relay/buzzer unit, while regulated 5V is used to power the microcontroller. The Power Supply unit is shown in Figure 10.

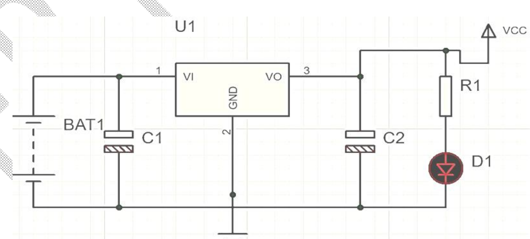


Fig. 10: Regulated power supply unit

The 12V DC voltage can be further stepped down to 5V DC voltage using a DC step – down converter named as voltage regulator IC7805. The first two digits "78' of IC7805 voltage regulator represent positive series voltage regulator and the last two digits '05' represents the output voltage of the regulator.Voltage regulator ICs are available with fixed (5, 12, and 15V) or variable output voltages. IC regulators are mainly used in this circuit to maintain the exact voltage which is followed by the power supply. A regulator is mainly employed with capacitors connected in parallel to the input and output terminals. For checking the gigantic alterations in the input and output, filter capacitors are used, while bypass capacitors mainly of small values are used to check the small period spikes or pulse on the input and output levelsand bypass them straight to the earth. The circuit diagram of the regulator IC is shown in Fig. 11.

UNDER PEER REVIEW

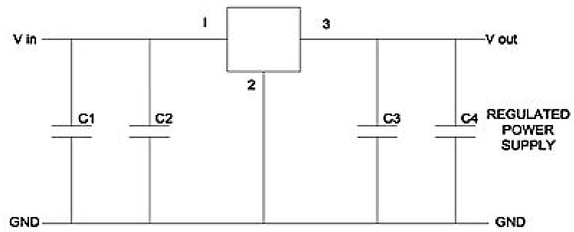


Fig. 11: IC7805 voltage regulator

Since the input voltage rating ranges 7V to 35V, current rating Ic = 1A, output voltage Vmax = 5V and Vmin = 4.8V, the LED protection resistance can be calculated as:

$$R_d = \frac{Vcc - Vd}{1(mA)} \quad (1)$$

Where R_d is the LED protection resistance, V_{cc} is the supply voltage, V_d is the voltage drop across the diode, and I is the current.

2.2.2 The Flow Chart

The flow chart for the microcontroller based automatic heart beat and body temperature monitoring system is shown in Figure 12.

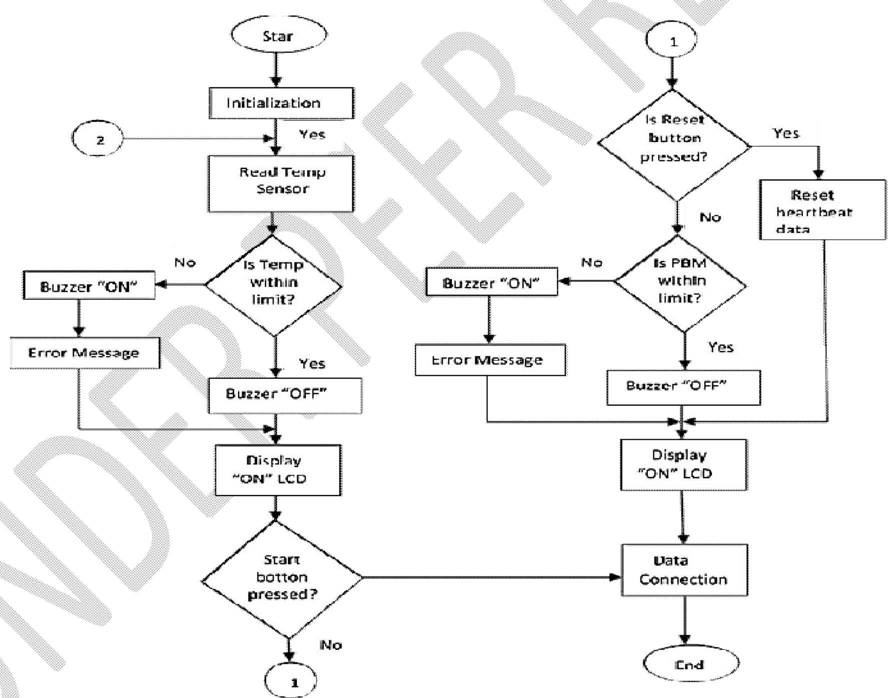


Fig. 12: Flowchart for the proposed plant water sprinkler with weather monitoring system

2.2.3The Algorithm

The algorithm that explains the flowchart for the microcontroller based automatic heart beat and body temperature monitoring system is presented as follows:

I. Press START,

System initialized

UNDER PEER REVIEW

2. Temperature sensor reads

3. Is Temperature within limits?

4. If ‘YES’ Buzzer turns‘OFF’ and displayed temperature on LCD.

5. If‘NO’, BUZZER turns ‘ON’ and display ERROR MESSAGE on LCD.

6. Press START again

7. Heartbeat sensor reads.

8. If ‘YES’, data conversion in RF and TEXT format displays on LCD

9. If ‘NO’, moves to 1

10. RESET button pressed?

11. If ‘YES’, reset heartbeat data reading and display on LCD.

12.If ‘NO’, another question is asked;

13. Is BPM within limits?

14. If ‘YES’, Buzzer turns ‘OFF’ and normal Heart beat reading displayed on LCD.

15. If ‘NO’, Buzzer turns ‘ON’ and ERROR MESSAGEdisplay on LCD.

16. Data Conversion in RF and TEXT format displayed.

17. Go back to 3 to take another temperature reading, or

18. END.

2.2.4 Choice of Programming Language

The basic software application program was written in MPLAB IDE for Windows OS using the ‘C’ language and was compiled for error elimination. The choice of C language programming was because it is more compatible and very simple. For a successful compilation, IDE application generated HEX file for the written program. The programming device was chosen (usually ‘PIC kit 3’ or ‘PIC kit 2’) which establishes communication between PC and PIC16F886.

2.2.5Hardware Construction Method

The circuit construction was carried out following the block diagram in Figure 1. Components were first assembled on electronics breadboard to ensure proper functionality of the system. Then transferred on to a Vero boardfor permanent soldering using the soldering iron and MBO 1mm wire lead solder, +183°C melting point.

2.2.6Circuit Testing Method

Components testing was carried out before fixing them on the Veroboard. Also Continuity test and Power ON test were carried out during construction. This was to ensure proper functioning of the circuit, to ensure that no components in the circuit undergo heating when the device is in use, tofind any electrical open paths,and free flow of current. Test were also carried outto ascertain the circuit voltage for each state, toensure nostage loading and impedance mismatches.The multi-meter was used to carry out these tests in this study.

UNDER PEER REVIEW

2.2.7 Performance Evaluation Test

The performance evaluation was carried out to ascertain the functionality of the constructed device. This was carried out to test theworking condition of the output for various body temperature and heartbeat for different levels of activity.

3. Results

3.1Simulation Results

The simulation was carried out in stages according to the block diagram in Figure 1 and the results are presented in Figures13 to 17.

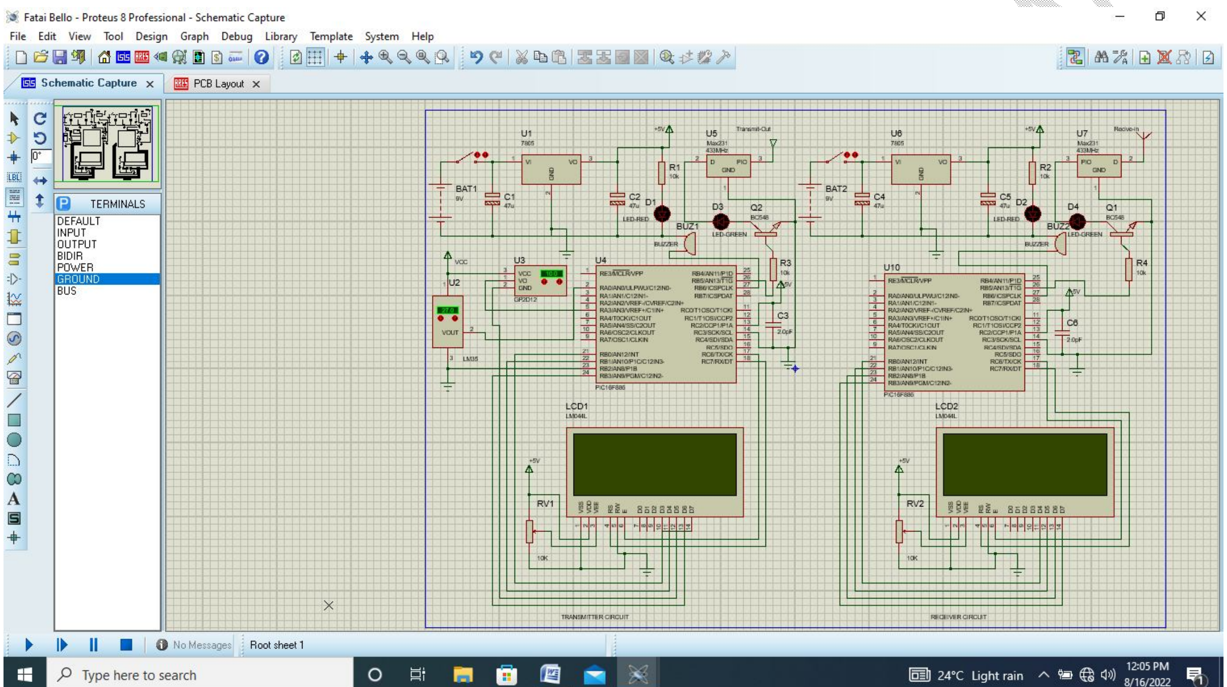


Fig. 13: Simulated general circuitidle state

The general circuit diagram of wireless heartbeat and body temperature monitoring system as can be seen in the simulation window showing both the transmitter and receiver units, each having the power supply, output driver, microcontroller and LCD units. The temperature sensor, heartbeat sensor and transmitter module are added to the transmitter unit, while only receiver module is added to the receiver unit. At this stage the circuit is in the idle state without being powered.

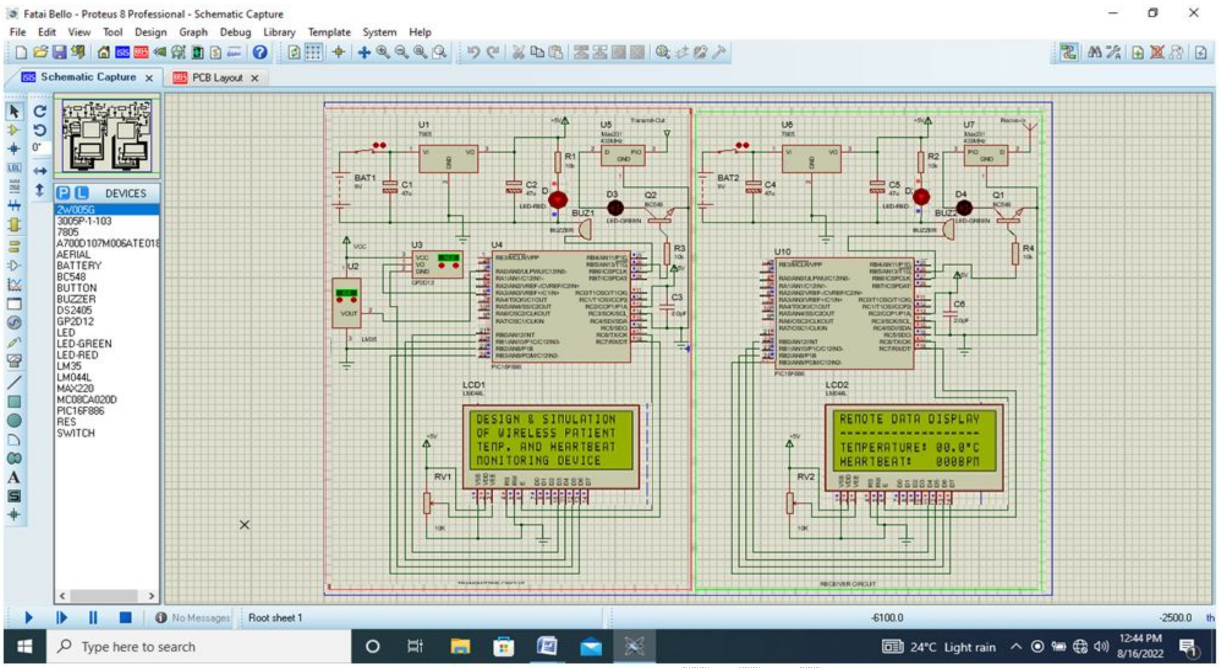


Fig. 14: Simulated circuit when poweredON and initialized

When the switch is 'ON' as shown in Figure 14, supply from the battery passed across the filter and to the regulator which regulates the voltage from 9v to 5v. The red LED glow is an indication that 5V power supply output to the system is present, for both transmitter and receiver units.Transmitter LCDs displays banner while the remote LCD displays zero readings for both temperature and heartbeat. While Green LEDs remains "OFF" as no data has been transmitted or received.

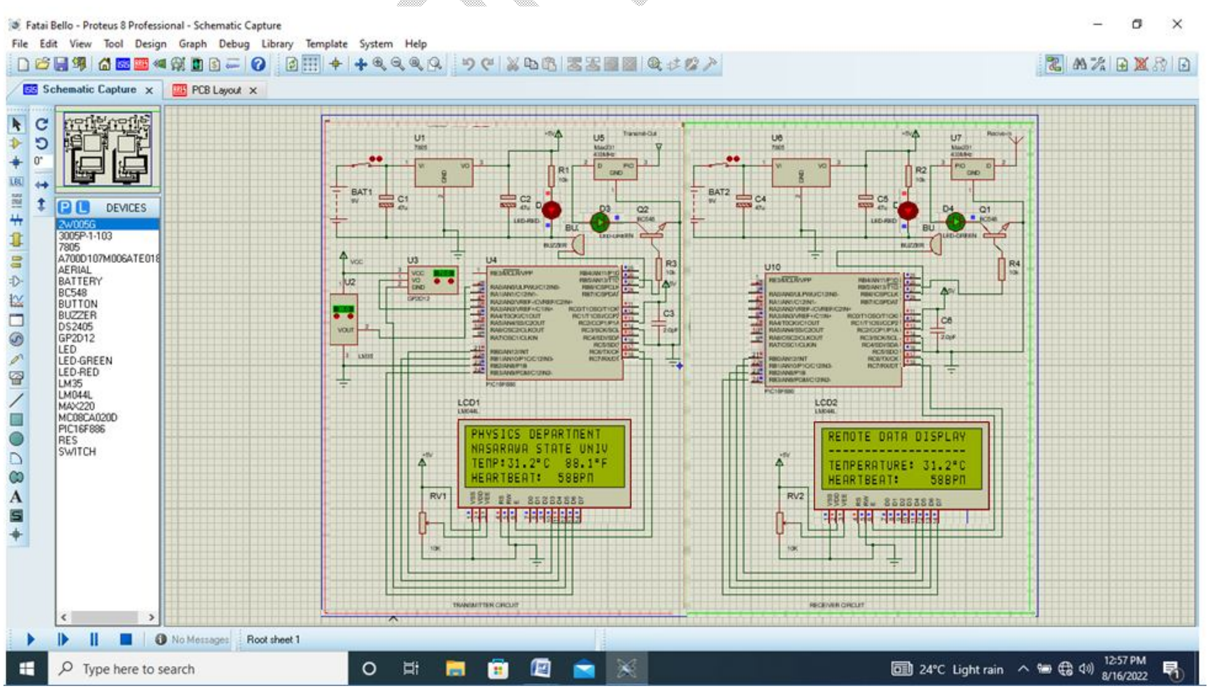


Fig 15: Simulated result showing transmitter and receiver reading at 31.2°C.

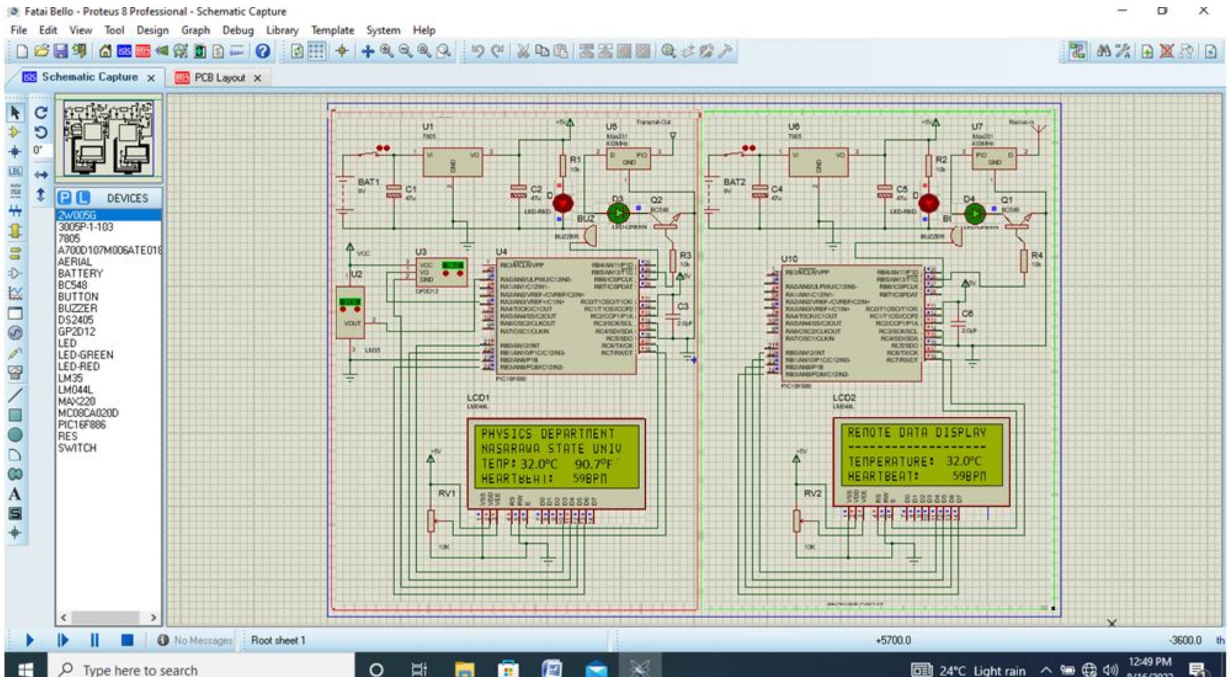


Fig. 16: Simulation showing transmitter and receiver reading at 32.0^{o}C.

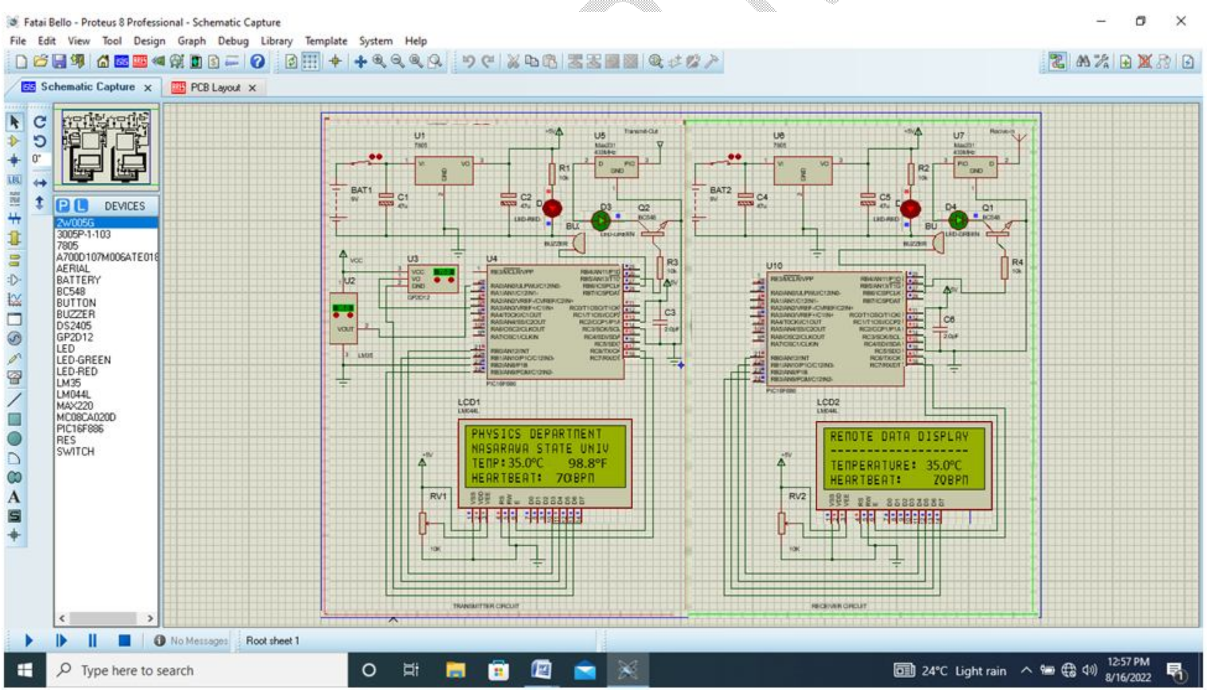


Fig. 17: Simulation showing transmitter and receiver reading at 35.0^{o}C.

Figure 15 to 17 is simultaneous simulation results of both transmitter and receiver indicating parameters of body temperature at 31.2^{o}C, 32.0^{o}C and 35.0^{o}C. As well as heartbeat readings at 58BPM, 59BPM and 70BPM respectively.In this situations, the green LED is "ON" showing transmission and reception taking place simultaneously as the value transmitted corresponds with the one at the remote station.

3.2Hardware Construction

3.2.1 Circuit Construction

The construction of the hardware device was carried out first on a bread board to ensure that the circuit is working as required, then transferred to the Vero board for permanent soldering. The shunt and limiting resistors were connected to limit and control the flow of current to the input terminals of each component. The constructed circuit showing the top viewof the device on Vero board is shown in Figure18.

Fig. 18: Top view of constructed device

3.2.2 Casing and Packaging

A casing measuring 20cm x 15cm x 5cm was finally provided to the system for mechanical protection.It is provided with 4no. of 0.25cm diameter hole within 0.5cm diameter groove at the edges of its top side for screw locks, 2nos. of 3cm x 6cm hole for LCDs placed 3cm apart for transmitter (Tx) and receiver(Rx) consecutively with 4nos. of 0.5cm diameter hole, 2 each spaced 2cm apart for power and Tx/Rx indicator LEDs. At the Front view, there are 2nos. of 4cm x 2cm switches for Tx and Rx modules consecutively. Also 2 nos. of 0.25 diameter holes provided at left and right views for Tx and Rx antenna. Finally, provision of 8nos. 0.5cm diameter holes, 2 for each of the 4 sides (except Top and Bottom sides has been made for the system ventilation. The complete isometric diagram of the casing showing its three views (Front, Side and Top) and the various dimensions is shown in Figure 19.

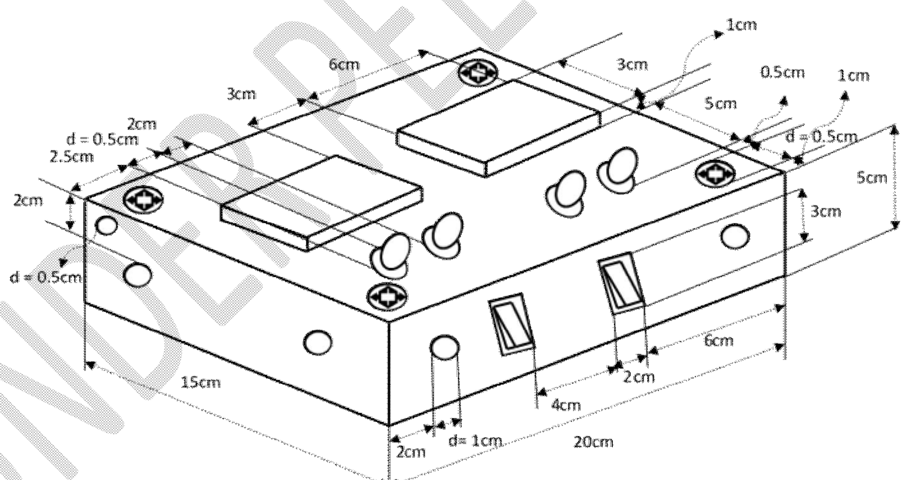


Fig. 19: The isometric diagram of the casing

3.3Circuit Testing

In this study, the multi meter was used to perform the continuity and power ON test. Test results shows that the soldering was perfectly done asthere were no short circuits along the paths, or broken conductors, damaged components, or excessive resistance along the circuit. Also, voltage output for each stage was according to the specification for the simulated circuit.

3.4 Performance Evaluation Test

UNDER PEER REVIEW

To ascertain the functionality of the constructed device, a performance evaluation was carried out with 20 subjects who volunteered to use the device to measure his body temperature and heartbeat. Measurements were carried out at different times of the day and at different situations (resting and after different levels of exercise activities), the result was recorded and presented in Table 1.

Table 1: Body temperature and heartbeat readings

S/N	Body Temperature (°C)	Digital Thermometer (°C)	Pulse Rate (bpm)
1	31.2	31.2	58
2	32.5	32.4	59
3	33.0	33.3	61
4	34.0	34.0	64
5	35.0	34.8	70
6	36.2	36.2	76
7	38.0	38.1	86
8	39.0	39.0	96
9	40.2	40.2	106
10	41.9	41.8	116
11	43.0	43.0	126
12	44.0	44.2	137
13	45.0	45.1	146
14	46.0	45.7	157
15	46.9	46.7	166
16	48.0	48.0	176
17	48.9	48.6	185
18	49.7	49.9	195
19	51.0	51.2	205
20	52.0	52.0	214

UNDER PEER REVIEW

From Table 1, we see that increase in body temperature results to increase in heart rate. The reason is that the body has to work harder when the temperature increases, this increase work results in a higher heart rate. Warmer temperature causes the heart to beat faster and place considerable strain on the body. When the body temperature is high, the body must move more blood to the skin to cool while also maintaining blood flow to the muscles. It takes the heart about 76bpm in keeping the body cool at about 36.2°C normal body temperature, but when the work load on the heart increases with activities and exercise, especially in hot weather,higher heartbeat may lead to increase body temperature. For every degree the body temperature increases, the heart beats about 10bpm faster.The relationship between the measured temperature and the digital thermometer reading is shown in Figure 20.

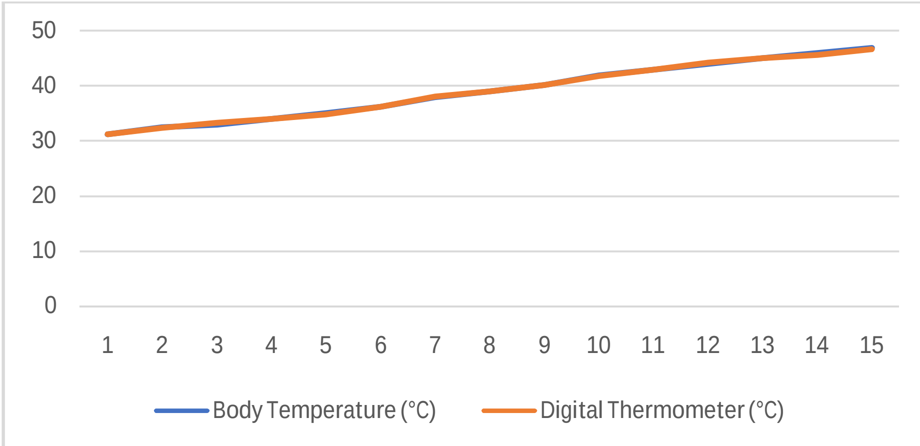


Fig. 20: Comparison of measured temperature with digital thermometer reading

4. Discussion

The simulated and constructed wirelessheartbeat and body temperature monitor subjected to various test have revealed vital information that validates its functionality. The continuity test revealed that the circuit was continue with no short circuits along the paths, or broken conductors, damaged components, or excessive resistance along the circuit and the soldering was well done. While the power ON test shows that, the voltage at the different terminals was according to the requirement and specification of the simulated circuit. Performance evaluation test have shown that body temperature and heartbeat readings can be taken simultaneously with the constructed device.The body temperature is an independent determinant of heart rate and respiration rate, where every degree increase in body temperature causes approximately 10bpm increase on heartbeat rate.The device recorded a heartbeat rate of 76bpm at normal body temperature of 36.2°C. This finding is in line with the findings of Alam et al. [21] who obtained same resultusing wireless body area network. The design is also similar to that of Amoran et al. [3] who designed and constructed a microcontroller based pulse rate and temperature monitor with GSM module and Parihar et al. [7] who proposed a heartbeat and temperature monitoring system for remote patients using Arduino. But quite different from Javadpour et al.[22]who designed separately temperature monitoring system incorporating an array of precision wireless thermometers and Nasir et al. [23]who designed and developed a temperature monitoring system based on PIC microcontroller and wire communication protocol.Also different from Khalaf Abdullah [24] who proposed a remote heart rate monitor system using NodeMcu microcontroller and easy pulse sensor v1.1,Prasath [25] who also proposed wireless monitoring of heart rate using microcontroller and Goel et al. [2] who designed separately heart rate monitoring system using fingertip through IOT.

5. Conclusion

This project centered on the design and simulation of an efficient and affordable heartbeat and body temperature monitoring device using Proteus 8.4. Performance analysis has shown the relationship between heartbeat and body temperature and can be measured simultaneously with the device. The wireless device is cost effective, light weight, durable and easy to use by both the care giver and patient's relative. In situations where the readings are abnormal, the LEDs will blink repeatedly to indicate that the patient is in danger. The device can be used as a health monitor device at home capable of sending message to health officers and families in case of emergency.

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UNDER PEER REVIEW

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UNDER PEER REVIEW

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