MICROCONTROLLER BASED DESIGN AND DEVELOPMENT OF A REAL TIME BODY TEMPERATURE AND HEART RATE MONITORING SYSTEM

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Abstract - *Body temperature and heart rate are some of the vital signs routinely measured in medical facilities. The ability to effectively monitor these parameters is key to ensure proper healthcare is delivered. Most health monitoring systems work in offline mode but it is of great need that a system be developed to enable remote monitoring of the patient in real time. In addition, numerous challenges still exist in healthcare services. They include medical professionals taking a long time to examine patients, patient data retrieval is still conventional, equipment and technology in use has become obsolete and the challenges posed by the novel covid-19 pandemic. To solve the problem, we design an autonomous prototype based on Arduino technology, to alert medical professionals when these parameters are abnormal. The study relieves the burden of medical practitioners in monitoring the patient, shortens the time in taking patient data and minimizes the risk of misdiagnosis. It also enables real time remote monitoring. The prototype readings are then compared with those of the electronic thermometer and sphygmomanometer using correlation, regression and the Bland-Altman method comparison technics to ascertain agreement.*

Key Words: Agreement, Bland-Altman plot, Body temperature, Health monitoring, Heart rate, Photoplethysmography, Prototype.

1 INTRODUCTION

Health is one of the global challenges for humanity [1]. The World Health Organization outlines that the highest attainable standard of health is a fundamental right for a human.

Body temperature and heart rate, are some of the vital signs that are routinely monitored remotely [2]. They give some important indicator of the body's health condition. Normal body temperature varies from person to person and changes throughout the day. The normal range for body temperature is 36.1°C to 37.8°C. The physiological damages and fatality will occur when there is a difference for more than ±3.5°C from the normal temperature [3].

The most common places for measuring temperature are in the armpit, mouth, ear, and rectum [3]. According to [4], temperature readings for various parts of the body might be shown to be different. Intrinsic factors affecting temperature include ovulation, circadian rhythm, age, exercise and thyroid hormones. For skin temperature, the measurement is also affected by the ambient conditions.

A normal resting heart rate varies from person to person, depending on several factors [5]. A normal resting heart rate for adults' ranges from 60 to 100 BPM [5]. If the heart rate is higher than the normal, the condition is known as tachycardia while if it is lower than the normal, it is known as bradycardia.

This paper describes the design of an autonomous patient monitoring prototype based on Arduino to monitor the body temperature and heart rate of a patient and send the data to a remote end where it is displayed and the physician able to examine them.

The prototype readings are compared with those of established methods to ascertain agreement levels. The design is non-invasive hence suitable for containing the spread of the novel covid-19 virus.

2 THEORETICAL CONSIDERATIONS

2.1 Einstein and Stefan-Boltzmann's laws

The MLX 90614 infrared non- contact sensor is used. It uses the heat radiated from the body to determine its temperature. Human body temperature is a function of the average kinetic energy of the molecules that dissipate as phonons. The Einstein's formula predicting the heat capacity per mole at constant volume is given by (1).

$$C_\nu = 3K_B N\left(\frac{h\nu}{K_B T}\right)^2 \frac{e^{h\nu/K_B T}}{(e^{h\nu/K_B T}-1)^2} \text{ .... } (1)$$

Where: K_B is the Boltzmann's constant, N is total number of molecules, h is Plank's constant, ν is frequency of vibration of the optical photons and T is absolute temperature.

From (1) it is noted that the heat energy is directly related to the frequency of the vibrations of the optical photons. The intensity of the frequency of the energy is what is measured when temperature is read by non-contact means.

An infrared temperature sensor is made of a thermopile. The conversion of the reading from the thermopile and the emissivity into temperature is by Stefan-Boltzmann's law (2).

$$P_{rad} = \sigma\varepsilon A T^4 \text{ .... } (2)$$

Where: σ is the Stefan-Boltzmann constant, ε is emissivity of the subject, A is area of the thermopile in the sensor, T is the temperature (Kelvins) being determined and P_{rad} is energy per unit of time corresponding to the energy transfer to the thermopile.

For the MLX 90614 sensor to measure correctly, condition (3) must be fulfilled.

$$S = 2 \,.\, D.\tan(\alpha) \text{ .... } (3)$$

Where: S is the subject's frame dimension, D is distance from the subject and ∝ is field of view (FOV) of the sensor.

This is shown in Figure 1.

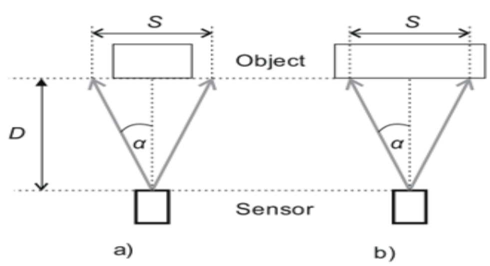


Figure -1: Field of view. (a) wrong and (b) correct measurement setup

2.2 Beer-Lambert law of transmittance

The XD-58C pulse sensor amped infrared sensor was used. It's working principle is based on the emission of infrared light by a photo-emitter which penetrates the skin and blood vessels. This light is captured by the photo detector to measure the blood stream, as observed in Figure 2.

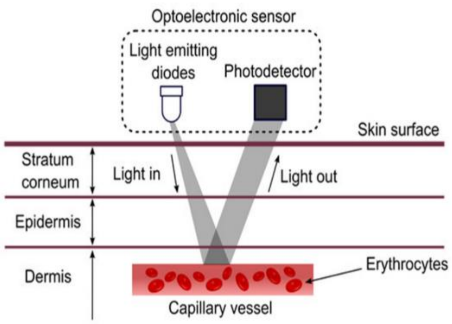


Figure -2: Working principle of the XD-58C sensor

The Beer-Lambert law for light transmission in an absorbing medium shown in Equation 4 illustrates the linear relationship between absorbance and concentration of the absorbing medium. It states that 'the absorbance of a medium is proportional to its thickness.'

$$I = I_o e^{-(\mu_a d)} \quad (4)$$

Blood is a highly scattering medium, the Beer-Lambert's law is modified to include an additive term G due to scattering losses and a multiplier B to account for the increased optical path length due to scattering and absorption. This is shown in Equation 5 and it forms the basic theory for our measurement.

$$I = I_o e^{-(\mu_a dB + G)} \quad (5)$$

Where: I is the transmitted intensity, I_o is input light intensity, μ_a is absorption coefficient, d is distance between source and detector, B is a multiplier accounting for the increased optical path length due to scattering and absorption and G is a factor dependent upon the measurement geometry and the scattering coefficient of the tissue interrogated.

3 METHODOLOGY

3.1 Hardware design

Temperature is sensed by focusing the MLX 90614 on the forehead of a subject. For measuring heart rate, the XD-58C is clipped on the left-hand fingertip. Both sensors are connected to the Arduino Mega and the software ensures the sensors are functional and well-integrated. The measured parameters are then displayed on an LCD. In addition, the ESP 8266 Wi-Fi module allows the signals from the sensors to be transferred wirelessly to a personal computer for monitoring. The data is displayed using ThingSpeak Internet of Things. Hardware design is shown in Figures 3 and 4.

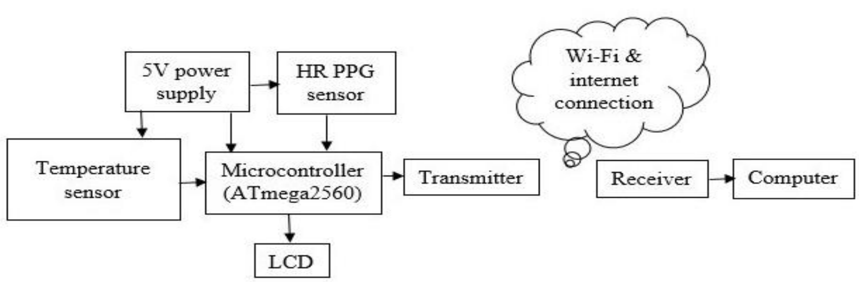


Figure -3: Hardware block diagram

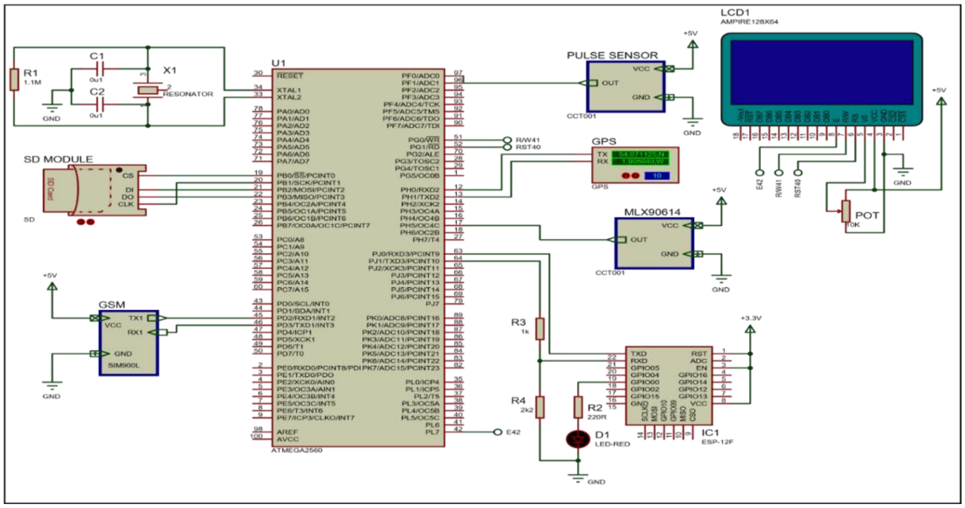


Figure -4: Proteus simulation diagram

3.2 Software design

It consists of the Integrated Development Environment (IDE) application program used in the Arduino module with the C ++ programming language. The Arduino mega uses open-source Arduino mega IDE for compiling and uploading programs to the board. The result of program data created in the text editor (sketch) is stored in files with extension (.ino). The design begins with the creation of the MLX 90614 and the XD-58C sensor outputs data readings being directly sent to the Arduino in the form of input voltages. The MLX 90614 output is converted from the library in the form of Fahrenheit then turned to Celsius. Similarly, the XD-58C output is converted from the library in the form of beats per minute. Further, the sensors data are stored in the database. Sensor data is displayed on the LCD on the patients end and can also be remotely sent to the computer via the Wi-Fi connection, and short message service. Figure 5 illustrates the operation of the software.

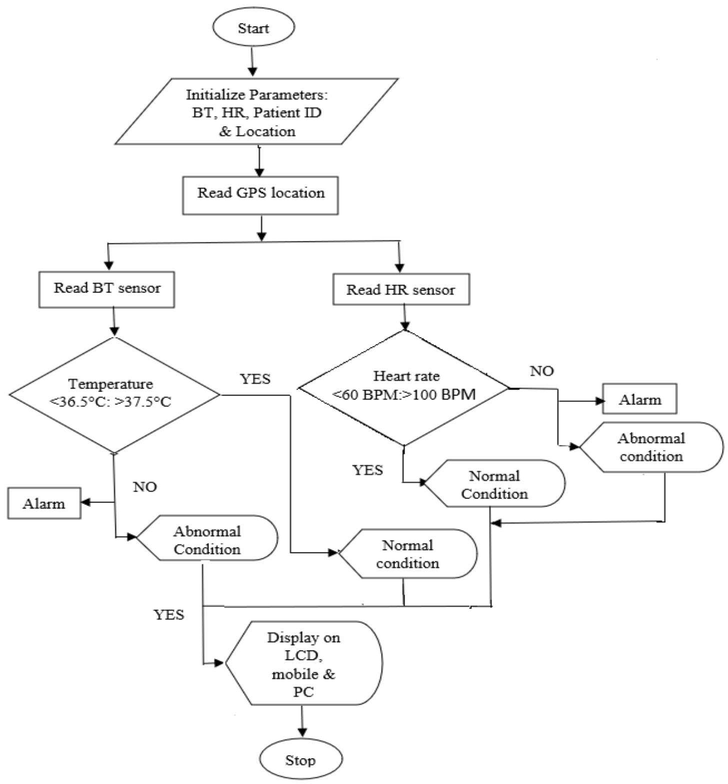


Figure -5: Software design

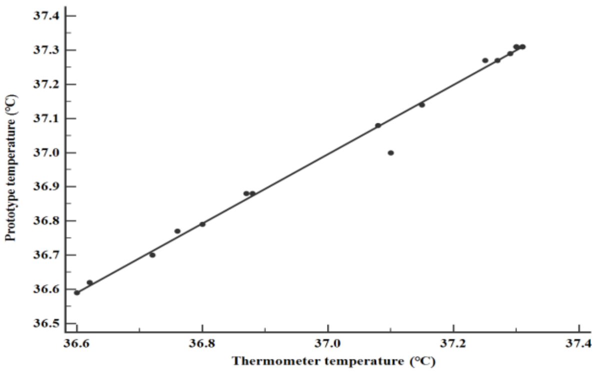
4 RESULT AND DISCUSSION

Using the prototype, temperature and heart rate of four subjects was monitored against that measured by the clinical thermometer and sphygmomanometer respectively. Temperature and heart rate signals were recorded in parallel from each subject. The length of the recordings made was 20 minutes, at least more than the 5 minutes which is the standard duration in several medical examinations [6].

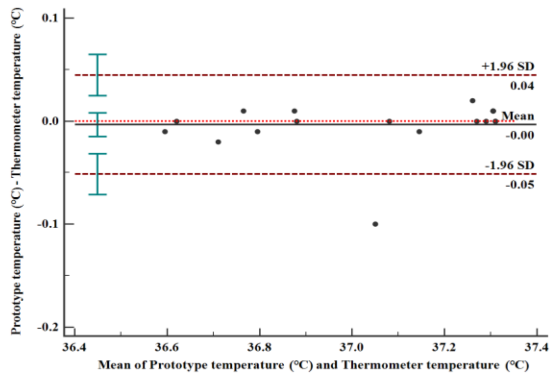
Data analysis was done using the MedCalc statistical software program. Correlation, regression and Bland and Altman analysis techniques were employed as shown in Figures 6 to 9. Clinical temperature bias and precision estimates of ± 3.5°C and ±0.2°C, respectively, were established *a priori* as the maximum parameters to indicate acceptable agreement between the methods and precision of the difference [3,7]. Similarly, bias and precision estimates of ± 5 BPM was established for the heart rate.

4.1 Body temperature and heart rate data analysis for the four subjects

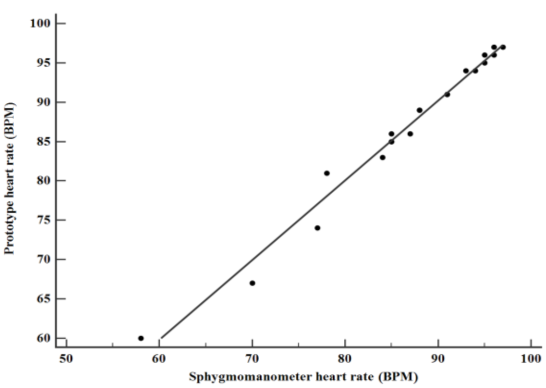
Subject A



(a)



(b)



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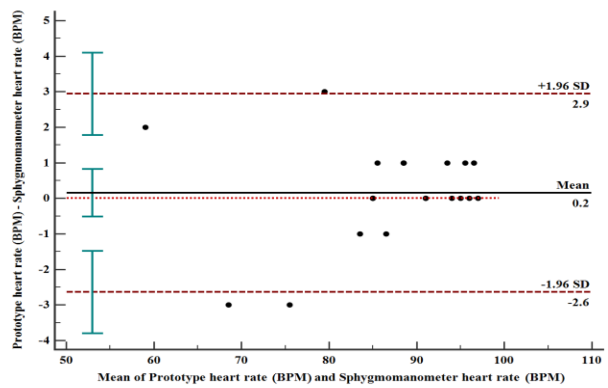


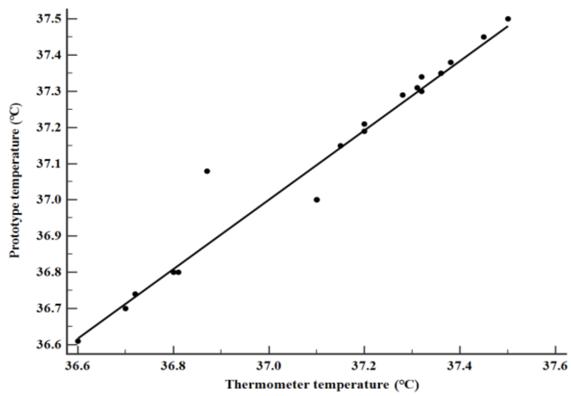
(d)

Figure -6: Body temperature and heart rate analysis graphs for subject A

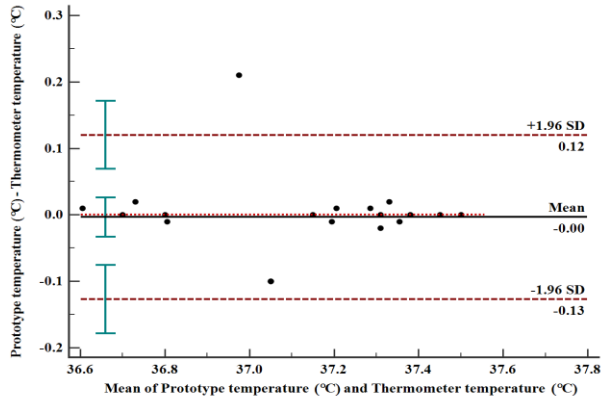
A linear positive relation exists in the measurement of temperature and heart rate of subject A against those measured by the thermometer and sphygmomanometer as shown by the respective linear equations in Figure 6a and 6c.

The Bland-Altman plots in (6b and 6d) show that the systematic error (bias) is -0.00°C and 0.2 BPM for temperature and heart beat respectively. The thermometer measures 0.00 °C more than the prototype. The prototype measures 0.2 BPM more than the sphygmomanometer.

Subject B



(a)



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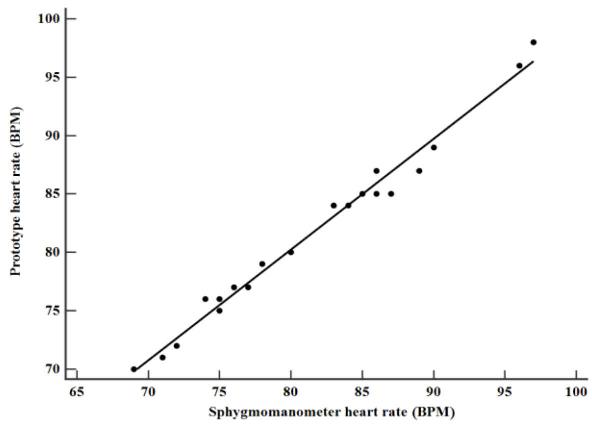

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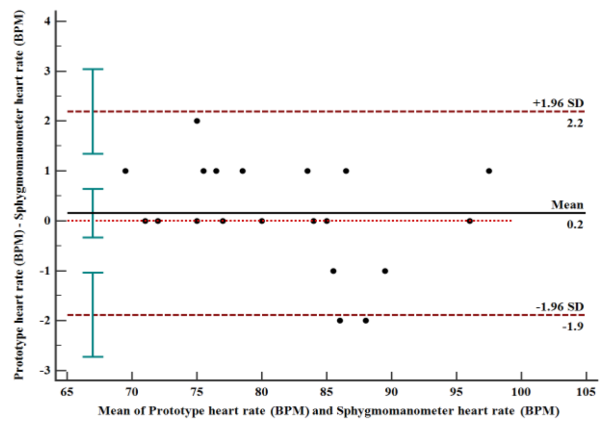


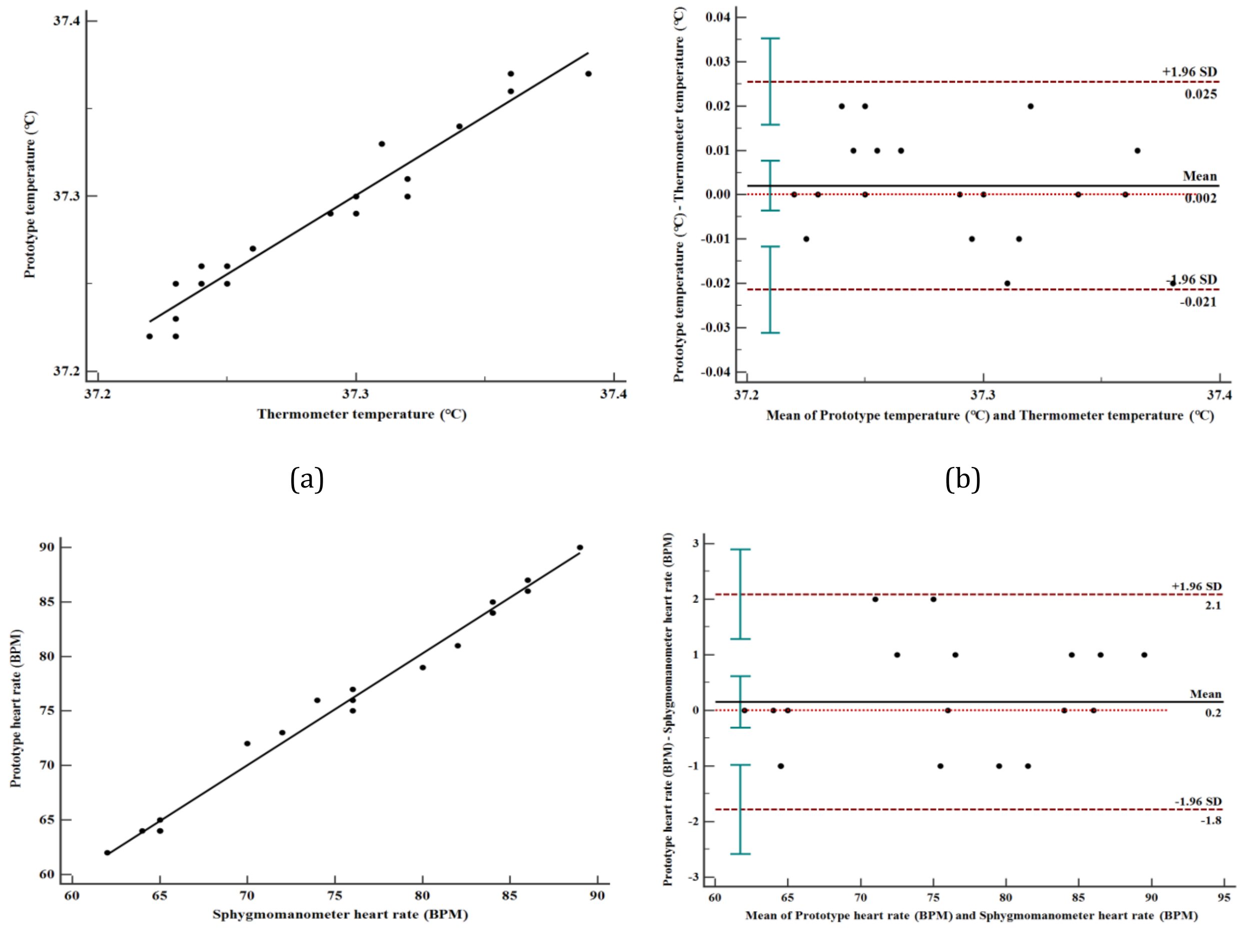
(d)

Figure -7: Body temperature and heart rate analysis graphs for subject B

A linear positive relation exists in the measurement of temperature and heart rate of subject B against those measured by the thermometer and sphygmomanometer as shown by the respective linear equations of Figure 7a and 7c.

The Bland-Altman plots in (7b and 7d) show that the systematic error (bias) is -0.00°C and 0.2 BPM for temperature and heart rate respectively. On average the clinical thermometer measures 0.00°C more than the prototype. Alternatively, the prototype reading for the heart rate is 0.2 BPM more than that of the sphygmomanometer.

Subject C



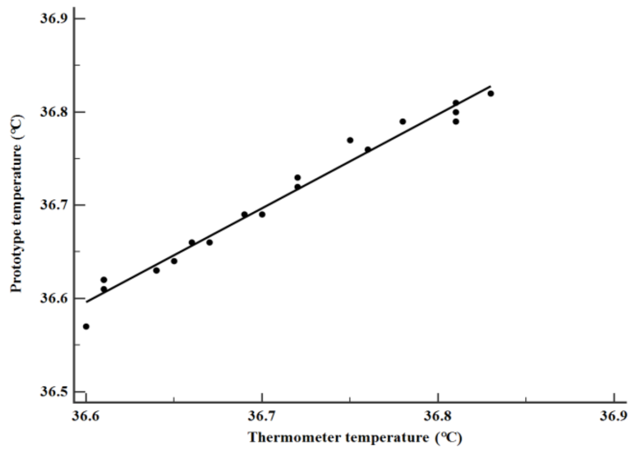
(a) (b) (c) (d)

Figure -8: Body temperature and heart rate analysis graphs for subject C

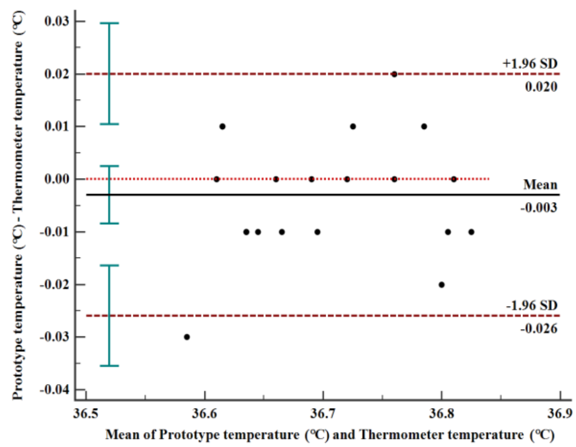
A linear positive relation exists in the measurement of temperature and heart rate of subject C against those measured by the thermometer and sphygmomanometer as shown by the respective linear equations of Figure 8a and 8c.

The Bland-Altman plots in (8b and 8d) show that the systematic error (bias) is 0.002°C and 0.2 BPM for temperature and heart rate respectively. On average the clinical thermometer measures 0.002°C more than the prototype. The prototype reading for the heart rate is 0.2 BPM more than that of the sphygmomanometer.

Subject D



(a)



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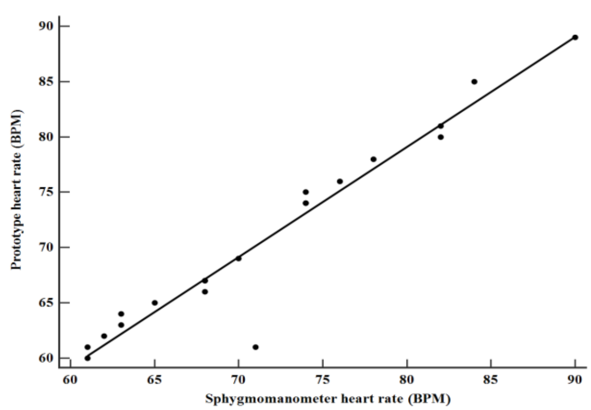
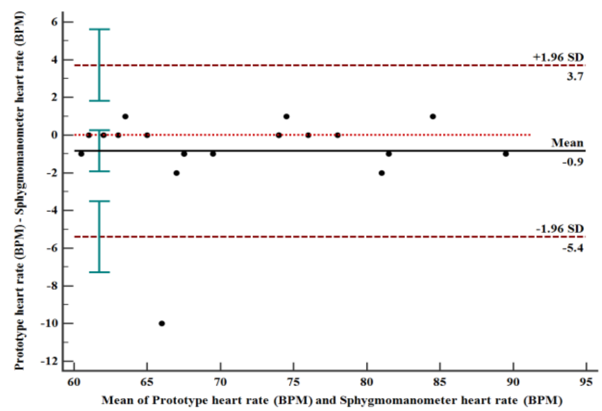


(c)



(d)

Figure -9: Body temperature and heart rate analysis graphs for subject D

There is a linear relationship in the measurement of temperature and heart rate of subject D against those measured by the thermometer and sphygmomanometer as shown by the respective linear equations of Figure 9a and 9c.

The Bland-Altman plots in (9b and 9d) show that the bias is -0.003°C and -0.9 BPM for temperature and heart rate respectively. On average the thermometer measures 0.003°C more than the prototype while the prototype reading for the heart rate is 0.9 BPM more than that of the sphygmomanometer.

5 CONCLUSIONS

In this paper, a prototype model for monitoring body temperature and heart rate is developed. The prototype was then used in monitoring the temperature and heart rate of four subjects. The readings of the prototype were then compared with those of the thermometer and sphygmomanometer for temperature and heart rate respectively. From the findings, it can be concluded that the measurements of the prototype in monitoring temperature and heart rate are in agreement with those of the thermometer and the sphygmomanometer. Hence, the prototype can replace the two methods in monitoring temperature and heart rate.

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