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Monitoring Heart Rate and Body Temperature using Wireless Technology (Zigbee)

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Abstract. Wireless technology has increasingly emerged as one of the demanding technologies in healthcare industry. Monitoring patients' condition is a crucial task in any hospital to ensure patients are in good and stable condition. Wireless sensor network is the solution and has been widely introduced in measuring vital signs of patients such as temperature, heart rate, oxygen saturation, respiratory rate and others from remote location. Zigbee Network or accurately known as IEEE 802.15.4/Zigbee on the other hand is known to be a low power consumption device with good and stable data transmission range, higher network flexibility and large number of nodes. This work is discussing on integrating heart rate and temperature sensors to a wireless transceiver Zigbee (Xbee) module and is used to measure patients' conditions from remote location (nurse's station). Series of tests have been conducted using these devices to measure patients' heart rate and body temperature for different genders and age group at lying down position. This is to ensure that the devices developed are reliable, stable and producing the same results as conventional devices (thermometer and heart beat reader). Results obtained are very encouraging; the developed devices are producing stable readings and are capable of transmitting information at reasonable distance.

Introduction

With increase in patient's number, and decrease number of workforce in healthcare industry, an alternative is sought using current technologies that are increasingly accepted by the community called wireless technology. According to statistics provided by World Health Organization (WHO) 2012, from 57 countries, 55% of these listed countries facing health workforce crisis due to the implementation of the national plan and yet only 9 of the selected 26 Human Resources for Health (HRH) crisis countries have a monitoring and evaluation system and strategy. From this statistics, Malaysia is not listed as one of the countries with difficult deficit of health workforce. However, this may change in time as Malaysia economic is growing very fast and with the current unhealthy lifestyle, increasing number of health problem is unavoidable [1]. Current practice of local hospitals, the health workforce (nurses) would visit the patients at a certain time interval, 2 to 3 times per day. A medical professional (doctor) would visit the patient twice per day or according to the patient's conditions. At each visit, certain health parameter of every patient is taken and is known as vital signs. Vital signs of a human include heart rate, human body temperature, blood pressure, oxygen saturation and respiratory rate. For general warded patients, temperature, heart rate and blood pressure are the most frequently monitored [2]. Since this work is discussing on development of wireless heart rate and temperature monitoring, only details of these vital signs will be discussed in the next section.

Background Study

The study is done based on required information to be included in designing the device. Theories on human vital signs and technologies used are essentials in designing the determining the device appropriate threshold. Following are the criteria's that are taken into account in order to determine the appropriate threshold for patient health monitoring.

Heart Rate. According to [3], heart rate is the total of heart cycles that occur in every minute and is counted as beats per minute (bpm). Human heart pumps blood throughout the body in order to transfer oxygen and nutrient and to release carbon dioxide and toxin. Heart rate is the frequency of the heart cycle where it depends on the demand of oxygen in a body. Heart rate normally differs according to age groups. This provides an effect such as heart "racing", lightheadedness or dizziness. In some cases, if the abnormal heart rhythm last for a long time this may affect one heart's function and can lead to fatality. Types of irregular heart rhythm are shown in Table I below.

TABLE I. SYMPTOMS OF IRREGULAR HEART RHYTHM [4]

Symptom	Effect
Palpitation – Skipped beat	• Seems like heart missed a beat but actually had an early heartbeat
Fluttering	• Due to extra "skipped beats" that occurs right after another – caused by abnormal heart rhythms
Bradycardia – Slow heartbeat	• Too slow than 60 beats per minute – not enough blood carrying oxygen to the body • Symptoms : i. Fatigue ii. Dizziness iii. Lightheaded iv. Fainting or near fainting
Tachycardia – Rapid heartbeat	• Too quickly (above 100 beats per minute) – lower chambers, or ventricals do not have enough time to fill with blood, cannot pump to the rest of the body • Symptoms: i. Skipping a beat ii. Beating out of rhythm iii. Palpitations iv. Fast heart beat v. Shortness of breath vi. Chest pain vii. Dizziness viii. Lightheadedness ix. Fainting or near fainting
Chaotic, Quivering or Irregular Rhythm	• A sign of Atrial fribillation (Afib). • Ventricular fibrillation (VF) – passing out or fainting – can cause sudden cardiac death within minutes after fainting
Presyncope – almost fainting	• A sign of a heart rhythm disorder • Should be evaluated carefully
Syncope – Fainting	• Happens suddenly without warning • Should be evaluated by a doctor – can cause sudden cardiac death

The symptom of irregular heart rhythm leads to three (3) major categories of heart diseases and disorders. They are electrical, an abnormal heart rhythms, circulatory, a high blood pressure and Coronary Artery Disease (CAD) and structural, a heart muscle disease. Table II shows the major categories, definitions, effects and symptoms of heart diseases. From the information, the developed device can be designed according to the specification that would be able to detect such symptoms that are critical to the patients and enables the health workforces to identify the exact condition of the patients from gathered data [4, 5, and 6].

Body Temperature. Human body temperature is a measurement of average body heat where comparison and reaction is made between the inner body part of the body and surrounding areas. The temperature differs depending on one's daily routines and activities. Sudden increase of human temperature may lead to several categories of diseases and can cause brain damage or even fatality if not attended immediately. Normal human body temperature is from 36.1°C to 37.3°C [3]. However, according to [7] there are different ranges of normal body temperature for both adult men and women. This is as shown in Table II.

TABLE II. NORMAL BODY TEMPERATURE RANGE FOR MEN AND WOMEN [7]

Place	Normal Range *(°C)*	Men *(°C)*	Women *(°C)*
Oral	33.2 -38.2	35.7 – 37.7	33.2 – 38.1
Rectal	34.4 – 37.8	36.7 – 37.5	36.8 – 37.1
Tympiac	35.4 – 37.8	35.5 – 37.5	35.7 – 37.5
Axillary	35.5 – 37.0	-	-

Illnesses that are related to core human body temperature and heat–related are fever, malaria, hyperthermia, hypothermia, heat stroke, meningitis and etc. Symptoms of these illnesses are based on several conditions such as headache, nausea, dizziness, muscle cramps and even coma. These illnesses need to be closely monitored when detected to certain age group or certain types of patients such as babies, young children, pregnant women and nursing mothers as well as elderly patients [5, 6]. Table III shows the intrinsic factors that influence human core body temperature. The Hypothermia disease is when the temperature drops between 28°C to 35°C where the metabolic rate falls. Fever is when the temperature rise above 38°C and is a normal response to infection, inflammation or drug therapy. Lastly, the Hyperthermia is when the core temperature risen above 40 °C and where the body temperature out of control [8].

TABLE III INTRINSIC FACTORS THAT INFLUENCE ONE'S TEMPERATURE [8]

Factor	Effect
Ovulation	High Body Temperature
Circadian rhythm	High temperature in evening and low in early hours of morning
Age	Young and older Inability to maintain equilibrium
Exercise	High body temperature
Thyroid hormones	High metabolic rate High body temperature

Wireless Sensor Network for Continuous Monitoring. In order to provide better services to the patients, health workforce and medical professionals needs to obtain accurate and reliable data readings. It is also important that the readings obtained are reliable because these readings would then lead to the type of medication or assistance that the medical professionals would provide.In the current advanced and emerging technology, body sensors have been developed vastly. These body sensors are providing reliable and accurate readings to the medical professionals and also shall provide safety and comfort to the patients when being worn.

From [9], interview sessions that was conducted, agreed that patient monitoring should be done wirelessly with regards to patients' location. The need and demands from doctors to monitor different vital signs wirelessly has been on demand in many different ways and would help them to provide better service to the patients. From [10], the authors suggest that wireless medical devices for continuous monitoring are important due to some diseases or disorders produces episodes rather than continuous abnormalities. These episodes especially for many cardiac diseases are important and life threatening if it is undetected promptly [10].Our research work discusses on the design of two different types of body sensor wearable devices that detect body temperature and heart rate of patient respectively. To ensure the medical professionals obtain sufficient and reliable data from the patients, continuous wireless monitoring network is introduced. This would enable the workforce to monitor their patients from their workstation at any time. Medical errors can be reduced due to prompt action by medical professionals and workforce.

Wireless Sensor Network. The current technologies used in hospitals are telemetry applications based on Wireless Medical Telemetry System (WMTS) and Wireless Local Area Network (WLAN). WMTS is a standard that transfers signals utilized in telemetry for the electrical transfer of patient information meanwhile WLAN is used for data transmission in local area network in closed area wirelessly [9]. Wireless sensor network has emerged throughout the years. Having technologies such as Infrared, Bluetooth, Zigbee and others as wireless transmission network, enables it to be used for psychological signals communication transmissions [11]. Table 6 provides the characteristics of common radio choices.

The Bluetooth technology provides better transmission rate, but the startup time is low and can only supports up to several meters in range thus, making the IEEE 802.15.4/Zigbee the best transmission method with low power consumption and suitable for continuously monitoring in hospitals. Meanwhile, 802.11b (Wi-Fi) has limited standards that is not suited for low power consumption. Other than stated the above, the Infrared technology only provides line of sight transmission and also angle limit problem, it has not been used in the physiological signal transmission [11,12].

Zigbee Network. Zigbee network is built on the IEEE 802.15.4 protocol which is low-rate with wireless personal area network (WPAN) standard. The Zigbee alliance, a consortium developed by companies, enables low production cost, low power consumption and two-way communication. This network is able to operate in the industrial, scientific and medical (ISM) unlicensed radio frequency bands. The global frequency band for the Zigbee network is 2.4GHz, while Europe uses 868MHz and US uses 915 MHz frequency band. A Zigbee network can work simultaneously with 254 slaves and one master [9, 10].The IEEE 802.15.4 defines the physical layer (PHY) and media access control (MAC) layer. The PHY layer supports three radio bands as stated in above paragraph with 16 channels for 2.4 GHz frequency, 10 channels for 915MHz frequency and single channel for 868MHz frequency with data rate individually defined 250Kbps, 40Kbps, and 20Kbps respectively [12].

The Zigbee standard defines only the networking, application and security layers of the protocol and adopts the IEEE 802.15.4 PHY and MAC layers as part of the networking protocol. The standard consists of two devices in a wireless network, Full-Function Devices (FFDs) and Reduce-Function Devices (RFDs). FFD is capable of performing all duties described in the standard and capable in accepting any role in the network. As for RFD, it is used for simpler applications due to limited capabilities [12].

Zigbee has 3 networking topologies, Star, Mesh and Tree as illustrated in Fig. 1. Star topology is where every device is capable of communication with only the PAN coordinator. *PAN coordinator* is the principle controller of a personal area network (PAN). If a device is not acting as a coordinator, it is simply known as *device*. The peer-to-peer topology, each device can communicate directly with other devices if placed in close distance. If there is no restriction between devices when communicating, the topology network is known as Mesh. Tree topology is where a Zigbee coordinator (PAN) establishes the initial network. The routers form the branches and relay the messages. The end device acts as leaves of the tree whereby it does not participate in message routing [12].

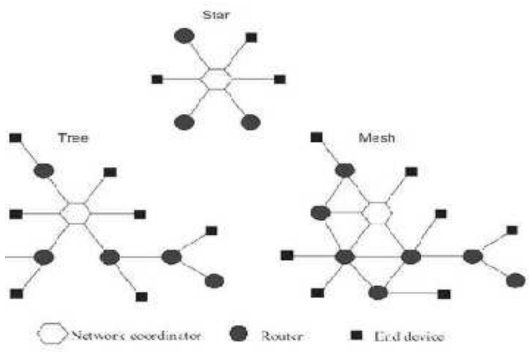

Fig. 1. Zigbee Network Topologies [13].

Hardware and Software Implementation

The wearable integrated wireless monitoring device detects and calculates the temperature or heartbeat reading of a person respectively. This section discusses on the methodology used on conducting this research work.

System Architechture. The system hardware architecture for heart rate and temperature monitoring are as shown in Fig. 2. The architecture begins with few subjects placed at a remote location where each subject is embedded with a Zigbee, Xbee-Pro transceiver module with temperature or heartbeat sensors. Data from each sensor device is collected by the microcontroller and then transmitted using the Zigbee Xbee-Pro transceiver to the Zigbee SKXBEE (receiver). From the receiver, the transmitted data will go through the Ethernet system route that the developer used to the nurse station. One of the routes is through the Wireless Area Network (WAN) which is connected to the computer that can send the trigger to the nurse station if the reading exceeds the predefined limit. The other route is where all the collected data will be kept in the system database for future references [14].

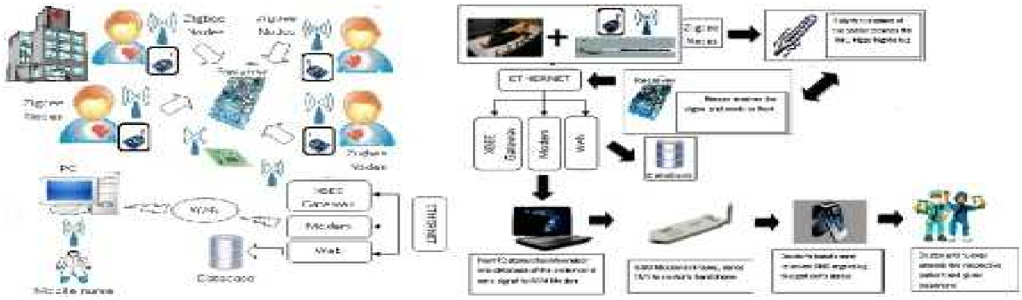

Fig. 2. System Hardware Architecture for Wireless Heart Rate Monitoring (left) and System Hardware Architecture for Wireless Temperature Monitoring (right) [14,15]

Sensors. In this project, Thermistor is used for measuring human body temperature and a heart beat sensor that consist of LED and photodiode is used to measure patient heart rate. The temperature sensors, there are several types of sensors found that can be used to measure body temperature such as miniature Piezo film sensor, Micro- Thermocouples sensors, RTD, Thermistor and Integrated Circuit (I.C) sensors. The advantages and disadvantages of each sensor were discussed in our previous work as published in [15]. This was done to determine the most suitable temperature sensor to be implemented on our prototype

The heartbeat sensor is placed on patients' fingertip to detect the pulses generated. The amount of blood at fingertip varies in each heartbeat. The heartbeat readings can be observed by a bright LED and photodiode. The blood volume at the fingertip determines the intensity of the reflected light. Each blood volume gives different readings. This sensor produces an analogue signal that can be fed into microprocessor. For each heartbeat, the signal will increase in amplitude and heartbeat rate level is to be determined by using the programming code on the microprocessor [16].

Taking into account on low temperature range, cost, fast response time, accuracy and human body temperature ranges (below 50°C), the choice of Thermocouple sensor and I.C sensor were the first eliminated. The main usage of this work is only to provide a small temperature range (within 0°C to 45°C); therefore RTD and Thermistor was the most suitable sensor for this approach. However, Thermistor was found to be the most suitable sensor due to RTD was found to be expensive and provides slow response time [17].

Microcontroller. The design of the device consists of a microcontroller. For testing purposes, the microcontroller used was Arduino Uno, a basic board that uses Atmega328P IC. The Arduino Uno board is equipped with different functions that are ready to be used. User only needs to code the microcontroller using its available open license software as needed. The board is convenient to be used where it can be easily connected to the computer by using a USB cable or AC – to – DC adapter for power source [18]. After the preliminary testing were conducted on these devices, the prototypes were then designed with a microcontroller circuit which consists of the same microcontroller IC Atmega328P, a crystal and a set of capacitors connected with the Xbee module and sensor. The Atmega328P which is Atmel Pico-Power 8-bit AVR RISC-based microcontroller combines 32KB ISP flash memory with read-while-write capabilities, 1024B EEPROM, 2KB SRAM and 23 general purpose I/O lines [19].

IEEE 802.15.4/ Zigbee Network using Xbee-Pro OEM RF Modules. Zigbee alliance has numerous companies that produce various types of Zigbee network modules. For this research, the Xbee-Pro OEM RF Module was chosen as the transceiver module at the transmitter end. The Xbee – Pro OEM RF Module, a Zigbee – based wireless device standard helps to reduce the implementation cost by simplifying the communication protocols and reducing the data rate. The module uses RF transceivers frequency for communication transmission but uses the Zigbee standard protocol for networking, application and security layers. The Xbee – Pro OEM RF Module comes with a interface software that is provided by Digi International, designed to enable a simple and user friendly GUI as well as to interact with the firmware files found on Digi's RF products [16].

Hardware Mechanism Design

This section discusses on the proposed preliminary designed mechanism to measure heart rate and body temperature respectively.

Proposed Design Mechanism of Heart Rate Measurement. The proposed design of the heart rate measurement is as shown in Fig. 3. The heart rate monitoring device was tested with two different wireless module, RF module and Zigbee module. Heart beat reading is transmitted to a computer by using two (2) types of transmitter and receiver, RF and Zigbee. From [14], the experiment conducted has proven that the RF transceiver module used was unable to provide stability in terms of data transmitting and transmitting in longer distance range.

The strip that hold the heart beat sensor and the existing device is worn on the subject simultaneously. The reading was taken in time frame of 60 seconds while the subject was lying down and in sitting position as discussed in details in [15]. It was found that lying down position gave good and stable readings and will be adopted in this work later.

From our preliminary findings in [14] and [15], transponder that uses Zigbee module is explored further for both heart rate and temperature monitoring where the patients are in lying down position. Fig. 3 shows the preliminary design of the Zigbee (Xbee) transceiver attached with heartbeat sensor strip and Zigbee (Xbee) receiver that is connected to the computer respectively [14].

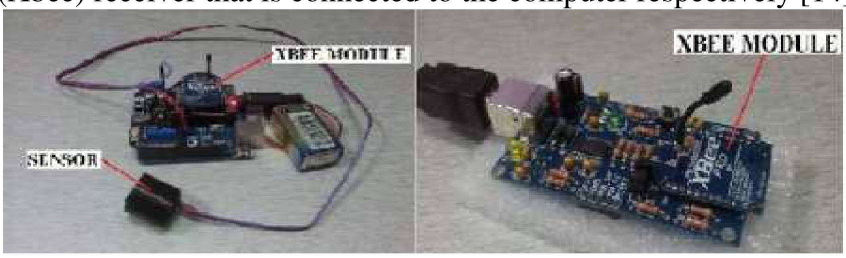

Fig. 3. Preliminary Prototype Zigbee (Xbee) Transceiver with Heartbeat sensor strip on Arduino microcontroller (left) and Zigbee (Xbee) Receiver (right) [14].

Proposed Design Mechanism of Body Temperature Measurement. Fig. 4 is showing hardware connection of the proposed device for wireless monitoring of human body temperature. The Zigbee (Xbee Module) transceiver attached with the temperature sensor and the Zigbee SKXBEE that is being connected to the computer as a local host. The sensor (Thermistor) is connected to the microcontroller and later to the transmitter end circuitry. Whenever the sensor detects the body temperature at a certain time interval, the microcontroller will send the digitalized signal to the Xbee Module to be transmitted to the receiver. Once the receiver end which is the SKXBEE receives the signal, it will display whatever reading captured through the X-CTU interface [15].

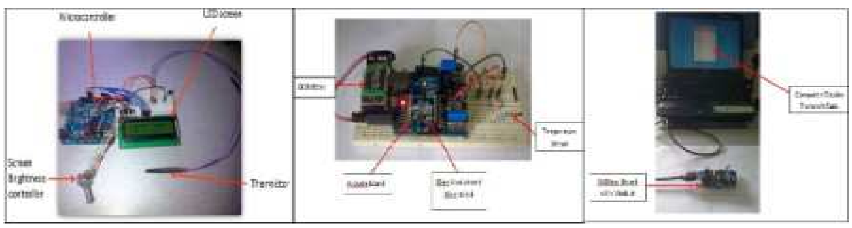

Fig. 4. Preliminary Prototype design of microcontroller embedded with temperature sensor and LCD monitor (left) Preliminary Prototype design Zigbee (Xbee) Transceiver with Temperature sensor on Arduino Uno Microcontroller (centre) and Zigbee (Xbee) Receiver Connected with Host (right) [15]

The prototypes as shown in Fig. 4 have been transferred to PCB form (Fig. 5) in order to utilize the size and make it more comfortable to be worn by patients. These prototypes are to be tested again to ensure that the readings are as good as our preliminary findings.

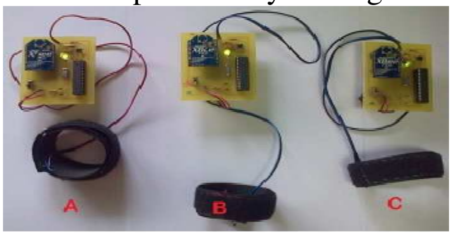

Fig. 5. Temperature and Heartbeat Monitoring Device using Zigbee

Results And Discussions

This section discusses the implementation of the developed devices as discussed in [14] and [15] that have been transferred to PCB form to few subjects of different gender and age groups. Two age groups were chosen, 26-35 and 56-65, for both male and female. The earlier one represents the older generation and then representing the elderly age. Results obtained are discussed here.

Testing of the Developed Heart Rate and Temperature Monitoring Devices on PCB for Stability And Reliability. The device that was developed as discussed earlier and as shown in Figure 5 and Figure 6 were transferred on a PCB and was tested again to ensure the reliability and accuracy of data. At this stage, the device was tested on different aged group and gender to identify the reading threshold of different ages and gender according to literature. The average reading was taken on both gender for (i) age group 56 to 65 and (ii) age group of 26 to 35 years old according to the table as shown in Table IV below.

TABLE IV. RESTING HEART RATE FOR MEN AND WOMEN[14]

	Resting Heart Rate for Men						Resting Heart Rate for Women					
Age	**18-25**	**26-35**	**36-45**	**46-55**	**56-65**	**65+**	**18-25**	**26-35**	**36-45**	**46-55**	**56-65**	**65+**
Athlete	49-55	49-54	50-56	50-57	51-56	50-55	54-60	54-59	54-59	54-60	54-59	54-59
Excellent	56-61	55-61	57-62	58-63	57-61	56-61	61-65	60-64	60-64	61-65	60-64	60-64
Good	62-65	62-65	63-66	64-67	62-67	62-65	66-69	65-68	65-69	66-69	65-68	65-68
Above Average	66-69	66-70	67-70	68-71	68-71	66-69	70-73	69-72	70-73	70-73	69-73	69-72
Average	70-73	71-74	71-75	72-76	72-75	70-73	74-78	73-76	74-78	74-77	74-77	73-76
Below Average	74-81	75-81	76-82	77-83	76-81	74-79	79-84	77-82	79-84	78-83	78-83	77-84
Poor	82+	82+	83+	84+	82+	80+	85+	83+	85+	84+	84+	84+

The readings were taken multiple of times to ensure the stability and accuracy of the device and the sensor itself. Fig. 6 left and centre show the multiple readings taken from 2 subjects with different gender aged 56 to 65 years old. From these figures, the reading shows instability with the assumption of uncomfortable environment that leads to stress and irregular heart beat at the start of the reading. After about 10th second, the reading for both subjects starts to stabilize. It is also seen that the sensor and device was able to transmit the average reading of heart rate according to this age group.

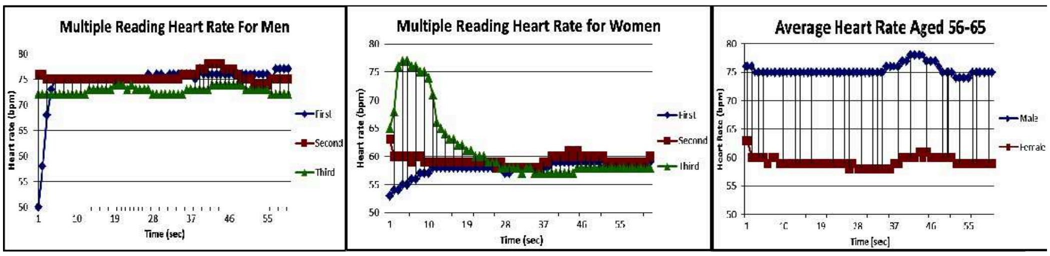

Fig. 6. Multiple heart rate reading of men for age group 56 to 65 (left), Multiple heart rate reading of women for age group 56 to 65 (centre) and Average heart rate reading for age group 56 to 65 (right)

From Fig. 6 (right), the readings averages these readings are considered as stabilized and are following the readings expected for this age group according to gender. It is also suggested the first reading is taken after the 10 seconds (in delay) to remove the instability that occurs prior to data collection.

The second age group of 26-35 years old data is shown as in Fig. 7. The figure shows the multiple readings taken from respective subjects of different gender. From the results, the average reading was taken and displayed in Fig. 7 (right).

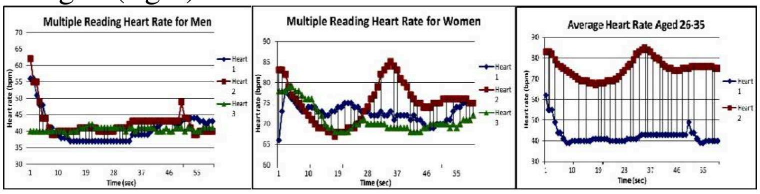

Fig. 7. Multiple heart rate reading of men for age group 26 to 35(left), Multiple heart rate reading of women for age group 26 to 35 (centre) and Average heart rate reading for age group 56 to 65

Fig. 7 left and centre shows the multiple readings taken from 2 subjects with different gender aged 26 to 35 years old. From this figure, the readings also show instability as discussed in Fig. 6. After about 10th second, the reading for both subjects starts to stabilize. It is also seen that the sensor and device was able to transmit the average reading of heart rate according to this age group. The heart rate of men is low due to the subject is living a lifestyle of an athlete.

In conclusion the average reading taken on both gender for (i) age group 56 to 65 and (ii) age group of 26-35 years old for male and female are able to produce the same results as expected by this age groups.The experiment continues with the temperature reading where the temperature sensor was placed at the armpit of the subjects for approximately 30 seconds. Fig. 8 (left and centre) shows the multiple reading of body temperature taken from 2 subjects male and female respectively for aged 56 to 65 years old. Fig. 8 (right) shows the average reading of both male and female of the same age group.

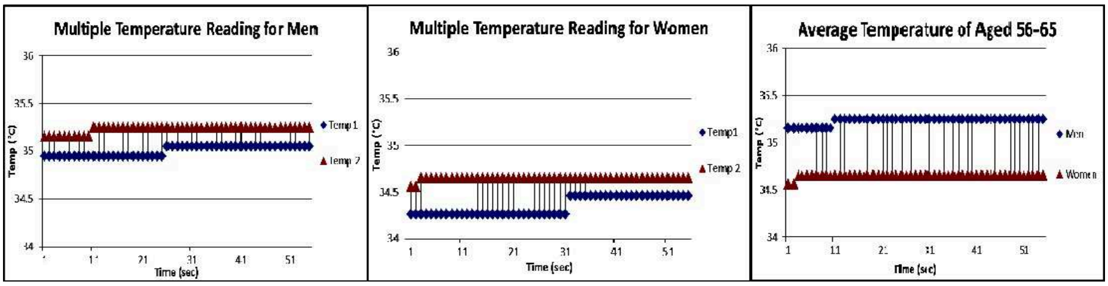

Fig. 8. Multiple temperature reading of men for age group 56 to 65 (left) , Multiple temperature reading of women for age group 56 to 65 (centre) and Average temperature reading of women for age group 56 to 65 (right)

From these figures, the reading shows stability in terms of data collection from sensor for both genders. It is seen that the sensor and device was able to transmit the average reading of temperature as discussed in [15].The second age group of 26-35 years old data is shown as in Fig. 9 (left and centre). This figure shows the multiple reading of body temperature taken from 2 subjects male and female respectively for aged 26 to 35 years old. Fig. 9 (right) shows the average reading of both male and female of the same age group.

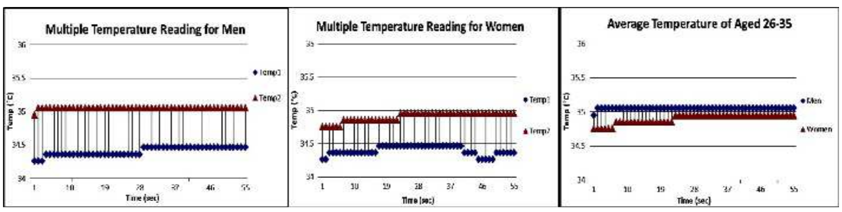

Fig. 9. Multiple temperature reading of women for age group 26 to 35 (left), Multiple temperature reading of women for age group 26 to 35 (centre) and Average temperature reading of women for age group 26 to 35(right)

From the results obtained and displayed as shown in the Fig. 6 to Fig. 9 above, stability and reliability of the sensors and devices developed on PCB where achieved. Further investigation is to be carried out on the transmission range.

Testing of the Developed Heart Rate and Temperature Monitoring Devices on PCB for Maximum Transmission Distance. The developed devices were measured simultaneously for maximum transmission distance. The maximum distance for each device is as shown in Fig. 10 (left) for heart rate monitoring and Fig. 10 (right) for temperature monitoring respectively. It was found that the distance strength of the device is influenced by the strength of the battery or voltage supply. The maximum distance the devices were able to be detected by the reader was approximately in between 187.5 meter to 300 meter with stable data transmission for about 1 and half hour. Further recommendation is to investigate on the possible outcomes and solution to replace the battery used with rechargeable sources and circuits to ensure smooth and continuous monitoring. Battery life time and life span and all the issues related to it will be discussed separately in other paper.

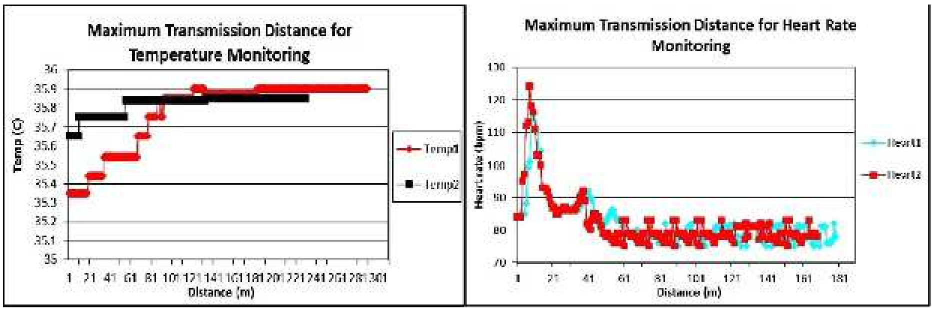

Fig. 10. Maximum transmission distance for temperature monitoring device using Zigbee (left) Maximum transmission distance for heart rate monitoring device using Zigbee (right)

Conclusion

From the series of test conducted using the wireless Zigbee technology, results shown stability and improved reading range when the power supply or battery is in full capacity. The sensors that was embedded in the device also shows reliability for long term use as the device was tested multiple times in one experiment procedure. The preliminary prototype from previous trials were has provide reliable data. When transferred to PCB form, the proposed devices data transmissions was successful and were also able to provide a reliable and stable reading of a subject's condition when compared with the preliminary prototype. From the series of test also provides useful information in determining the suitable threshold of a patient's condition healthy, normal, abnormal or fatal (need medical assistants). Further exploration on the proposed device will be conducted on enhancing the network topology of the Zigbee network system and solution in providing better power source capacity to the device to provide longer lifetime when in use.

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