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Integrating Emerging Network Technologies to Heart Rate Monitoring System to Investigate Transmission Stability and Accuracy : Preliminary Results

Nurul Fauzana Binti Imran Gulcharan[1], Muhammad Afham Bin Mohd Azhar[1], Hanita Daud[2], Nursyarizal Mohd Nor[1], Taib Ibrahim[1]

[1]Universiti Teknologi Petronas, Department of Electrical and Electronics Engineering, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

[2]Universiti Teknologi Petronas, Department of Fundamental and Applied Science, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

***Abstract*— Monitoring patients' condition is one of the crucial tasks in any hospital to ensure patients are in good and stable condition. Conventional method carried out by nurses/doctors especially on measuring blood pressure, heart rate, oxygen saturation, body temperature and respiratory rate are conducted in every four hours interval in most hospitals in Malaysia. This will lead to serious problem if in between this interval patients' condition is becoming critical. This paper presents preliminary work on real time monitoring on patients heart rate from remote location using Wireless Sensor Network. Three subjects of the same age group were chosen and their heart rates were monitored at sitting and laying positions. RF and Zigbee networks were used as communication medium to transmit data to remote location. These readings were bench marked with conventional handheld heart beat reader to investigate which method is producing accurate and stable readings. After few readings were taken it was found that Zigbee network is able to produce stable and accurate readings comparable to handheld reader.**

***Keywords*— heart rate, real-time monitoring, wireless monitoring, Zigbee, RF Network,Wireless Sensor Network**

I. INTRODUCTION

Wireless technology has emerged as one of the evolving technology for many applications especially in healthcare industry. Medical devices, information technology and communication have already converged in providing potential in obtaining access from many places even at homes [1]. Wireless monitoring in medical site provides an advantage for the medical professionals to give better service to the patients.

There are many different types of common wireless identification network technology that are being used widely. Radio Frequency (RF), Zigbee Network, Bluetooth and Wi-Fi are among the technologies that are being used extensively in many applications. Characteristics of each of this network are as shown Table I. These network technologies are the ones that have been integrated to Wireless Sensor Network (WSN) technology. WSN is known to be the most significant technology in this century which consists of spatially distributed autonomous sensor to monitor physical or environmental conditions. For healthcare industry, these sensors are placed strategically on human body which creates a wireless body area network (BAN) to monitor various vital signs which provides real – time feedback to the user and medical personnel [1].

TABLE I. CHARACTERISTIC OF COMMON RADIO CHOICES [1]

Technology	Data Rate	Idle Current	Startup Time
802.15.4	250 Kbps	7mA	Low
Bluetooth	1 Mbps	22mA	Medium
802.11	11 Mbps	160mA	High
UWB	100Mbps	2mA	Low

Nowadays, many researchers have conducted research in monitoring human vital signs. Vital sign is the ability to provide different types of information's on patient's condition and is considered as an important health parameter (blood pressure, heart rate, oxygen saturation, body temperature and respiratory rate). This paper will focus only on monitoring human heart rate.

Heart rate is the number of times the heart beats in a unit of time, usually in a minute. Heart rate occurs due to the heart pumps the blood throughout the body. The heart rate or pulse rate is the frequency of this heart cycle, and more specifically, the number of heart cycles that occur every minute [2]. The reading of the heart rate is counted as beats per minute (bpm) where the heart beat is counted in 60 seconds time. The blood is circulated throughout all parts of the body in order to transfer oxygen and nutrient and to release carbon dioxide and toxin from body. Heart beat frequency depends on the oxygen demand in the body. When the body is in a relaxing condition, the oxygen demand is low and vice versa. Resting heart rate for both genders are different according to age group [3].

Heart rate monitoring is to ensure the safety of the heart condition (normal and abnormal reading monitoring at real-time basis), fitness level of the heart condition and also ability to spot the developing health problems.

There are two (2) heart diseases that are most common which can lead to fatality. The first is Coronary artery disease (CAD) which happens when the arteries that supply blood to the heart muscle becomes hardened and narrowed due to build up (atherosclerosis) of cholesterol and other material (plaque). The CAD disease can also weaken the heart muscle which then contributes to heart failure and arrhythmias [4].

The second is called arrhythmias and occurs due to the changes in the normal beating rhythm of the heart on which the heart can beat either too fast (tachycardia) or too slow (bradycardia) or even with irregular rhythm. During this condition, the heart may not be able to pump sufficient amount of blood to the body thus leading to the brain damaged, heart and even other organs damaged and can be life threatening [5].

Thus monitoring patients' heart rate continuously is very crucial to ensure they are always in good and stable conditions. This paper will discuss on usage of RF and 802.15.4/Zigbee technology in monitoring human heart rate from remote location as normally practice in hospitals. Since this is a preliminary work on determining the suitable technology to be integrated with the WSN, hospital environment is created with three subjects of the same gender and age group to investigate the most stable and accurate readings. Each subject heart beat readings from heart beat sensor that is attached to his body is transmitted to remote location (host computer) via these networks. These two (2) network technologies are well known in sensor monitoring and will be further discussed in Section II.

II. HARDWARE DESCRIPTION

To discuss on methodology of this research work, the implementation is done in two (2) parts by using two (2) types of wireless technology, an Arduino Microcontroller and heart rate sensor. These two technologies are used to investigate the one that would provide a stable reading with minimum error as well as to determine which body posture that provides more stable reading. Details of the hardware architecture used in this work are discussed in this section.

A. System Hardware Architecture

The system hardware architecture is as shown in Fig. 1. The architecture begins from few subjects placed at a remote location where each subject is embedded with a Zigbee Xbee transceiver module with heart beat sensor. The data collected by the transceiver microcontroller will then be transmitted to the Zigbee receiver. From the receiver, the transmitted data will go through the Ethernet system route that developer uses. One route is through the Wireless Area Network (WAN) which will be connected to the computer that can send the trigger to the mobile nurse available. The other route is where all the collected data will be kept in the system database.

B. RF Network and Zigbee Network

RF is a wireless monitoring method that uses certain radio frequency channels to transfer the data in a two way communication. The RFID system is classified through recurrent criteria such as operating frequencies, types of transponders, modes of energy, data transmission, and etc [1]. Through literatures, the classification chosen for the RFID system active transponder is to operate in Ultra High Frequency (UHF). The active transponder with UHF frequency range is able to transmit in a long range and remotely [6, 7].

802.15.4/Zigbee on the other hand is a standard that is built on the IEEE 802.15.4 standard and specifies the MAC and PHY (physical) layers [1]. Zigbee also provides higher network flexibility, larger number of nodes (enables it to communicate in wider range of pattern nodes) and better transmission range with low power consumption. Data sent and receive is reliable and can be sent repetitively [8, 9].

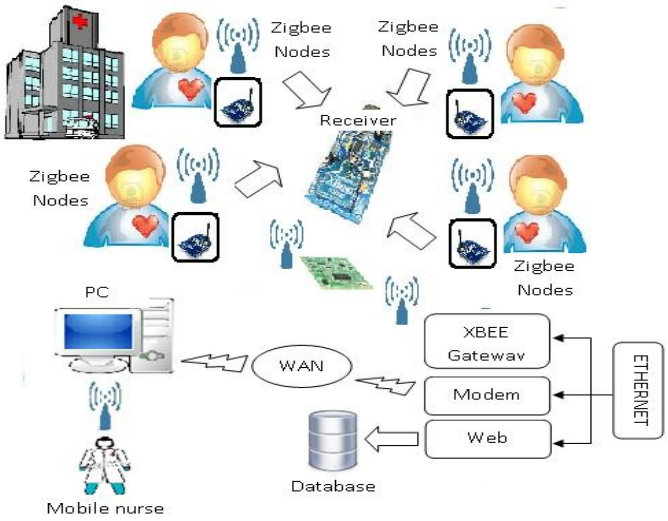

Fig. 1. System Hardware Architecture

C. Microcontroller

This preliminary work uses Arduino Uno microcontroller, a basic board that uses ATmega328 IC. The Arduino Uno board is equipped with different functions that are ready to be used. The user only needs to code the microcontroller using its available X – CTU and Arduino software. 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. In the future, the Arduino Uno board will be replaced with other smaller sized but with similar specification microcontroller [10].

D. Experimental Procedure

Testing of the developed devices and data collection were conducted in hospital replication based where two (2) assumptions were taken into account (i) age and gender and (ii) subject's position. For the first assumption, three (3) subjects were chosen with same gender (male) and same age group (between 18 – 25 years old). Second assumption was made by requesting the subjects to sit and later lie down while data collection process was done. Posture positions are as shown in Fig.2.

Fig. 2. Subject in lying position (left) and sitting position (right) [11, 12]

The strip that hold the heart beat sensor and the existing handheld device was worn on the subject simultaneously. The reading was taken in time frame of 60 seconds while the subject was in lying down and in sitting position, one after another. Heart beat reading was transmitted to a computer by using two (2) types of transmitter and receiver, RF and Zigbee. Analysis was made to investigate the wireless monitoring method that can provide stable data and also which posture can provide a better reading. Fig. 3 shows the RF transceiver part with heartbeat sensor strip while Fig. 4 shows the RF receiver that was connected to the computer. On the other hand, Fig. 5 and Fig. 6 show the Zigbee (Xbee) transceiver attached to heartbeat sensor strip and Zigbee (Xbee) receiver that was connected to the computer respectively.

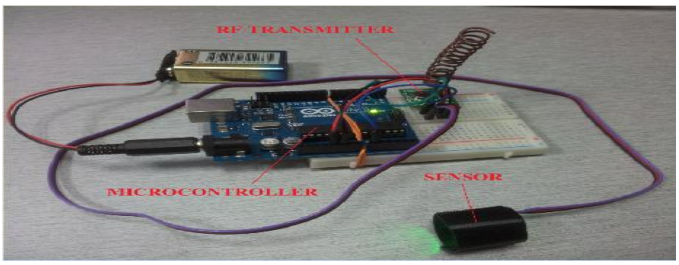

Fig. 3. RF Tranceiver with Heartbeat sensor strip

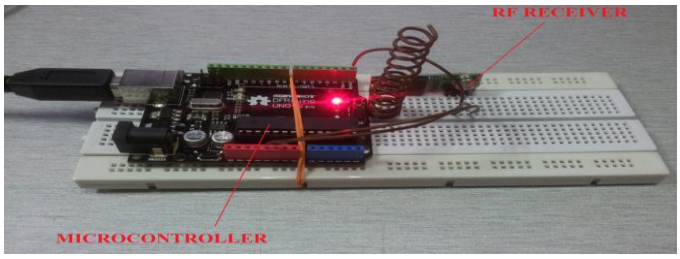

Fig. 4. RF Receiver

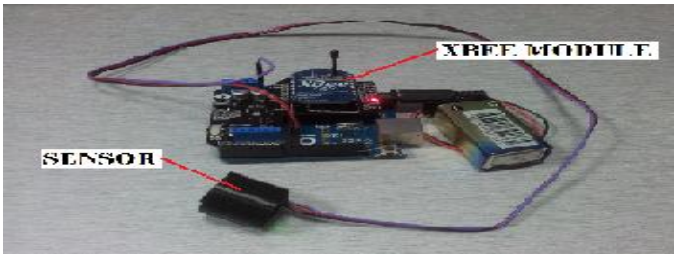

Fig. 5. Zigbee (Xbee) Tranceiver with Heartbeat sensor strip

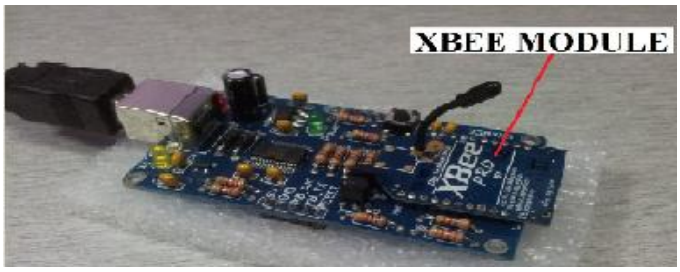

Fig. 6. Zigbee (Xbee) Receiver

III. SOFTWARE DESCRIPTION

Two types of software were used when developing the prototypes and are discussed here.

A. *Arduino Uno Software and XCTU*

Arduino Uno microcontroller has its own open license software that enables users to code the microcontroller as needed. For this work, this software was used with the RF transceivers and Zigbee Network for coding purposes. A Zigbee Xbee transceiver module uses two types of software. X-CTU is a software 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 [13]. The microcontrollers has been programmed to digitalize the direct current (DC) signal (analogue form) obtained from the heart beat sensor. In order to observe the accurate amount of subject heart beat per minute (bpm), the program has been coded to only provide a maximum of 60 readings in 60 seconds.

IV. RESULTS AND DISCUSSION

As explained in Section II, part C, the first experiment procedure with assumption made where three (3) subjects are lying down and sitting. Comparison is made between current technology (direct), RF technology and Zigbee technology. All the subjects were male age group between 18-25 years old with different weight group; the resting heart rate for men should be in the range according to Table II.

TABLE II. RESTING HEART RATE FOR MEN READING REFERENCE [14]

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

A. *Experimental A*

The first experiment subjects A, B and C was in lying down position when the readings were taken. Three (3) readings were taken which were reading using handheld

device(direct), zigbee and RF transmission. Figure 7 shows readings obtained from subjects A, B and C using handheld device. Fig. 8, Fig. 9 and Fig 10 show readings obtained for each subject from the three methods used respectively.

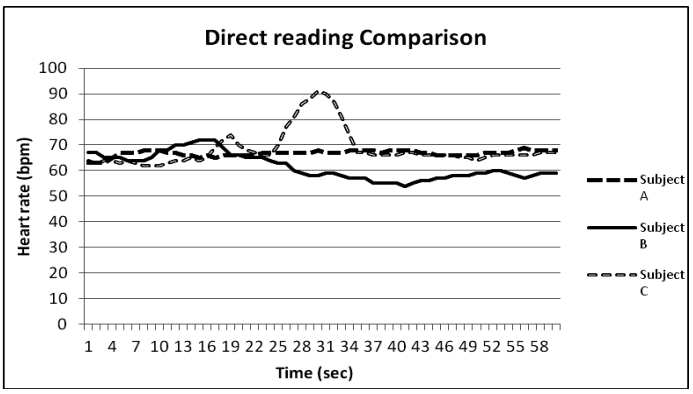

Fig. 7. Readings from Handheld Device for the Three Subjects

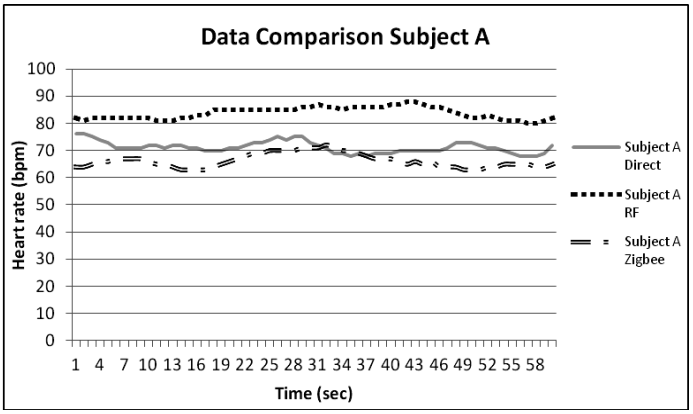

Fig. 8. Reading for Subject A On Device, RF And Zigbee

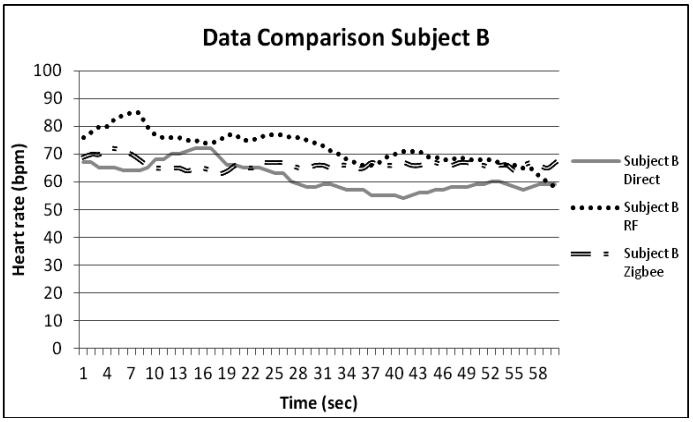

Fig. 9. Reading for Subject B On Device, RF And Zigbee

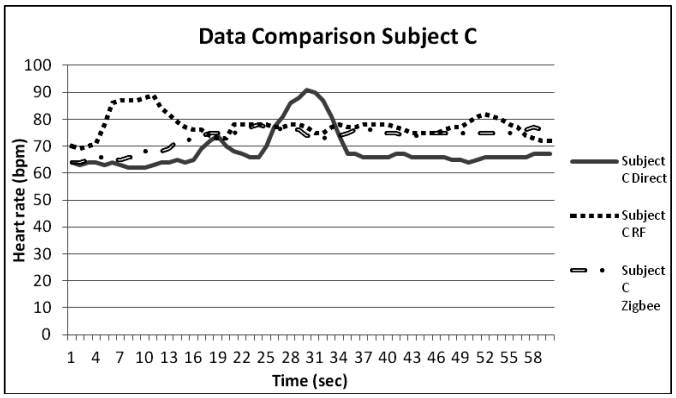

Fig. 10. Reading for Subject C On Device, RF And Zigbee

Fig. 7 shows graphical data obtained from subject A, subject B and Subject C through direct reading using device when the subjects were lying down. This data collection was made as benchmarking to other readings using other methods. From this figure and in reference to Table II, subject B provides excellent and stable reading, subject A is on average, and subject C is unstable at the beginning and stabilizes and reaches excellent reading towards the end. The differences in readings can be due to internal factors such as stress, tired or food consumption of each individuals.

Fig. 8, Fig. 9 and Fig. 10 shows reading comparison between direct approach and the two wireless method RF and Zigbee for subject A, B and C. From these figures, Zigbee method provides stable reading in terms of heart rate where the value is nearing the direct approach. The RF method on the other hand, takes some time to stabilizes and provide better reading of the subjects.

B. Experimental B

In the second experiment, subjects A, B and C were in sitting position when readings were taken. Three (3) readings were taken as in the first experiments which were reading using handheld device, Zigbee and RF transmission. Fig.11, Fig. 12, Fig.13 and Fig 14 show readings obtained for each subject from the three methods used.

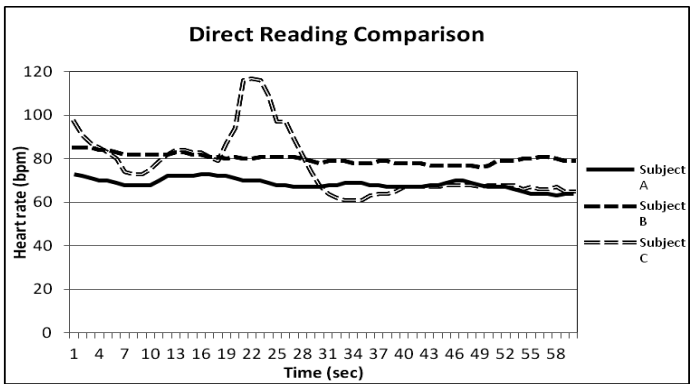

Fig. 11. Readings from Handheld Device for the Three Subjects

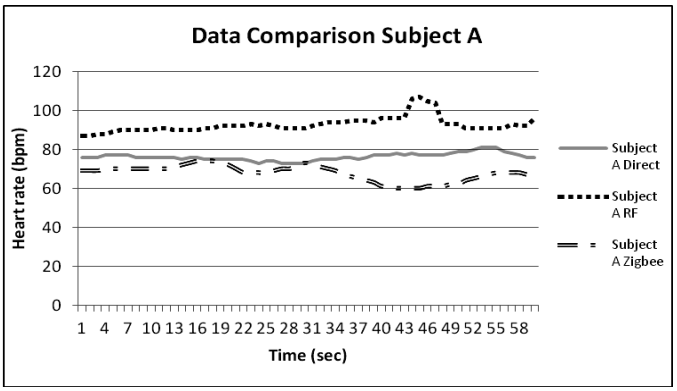

Fig. 12. Reading for Subject A On Device, RF And Zigbee

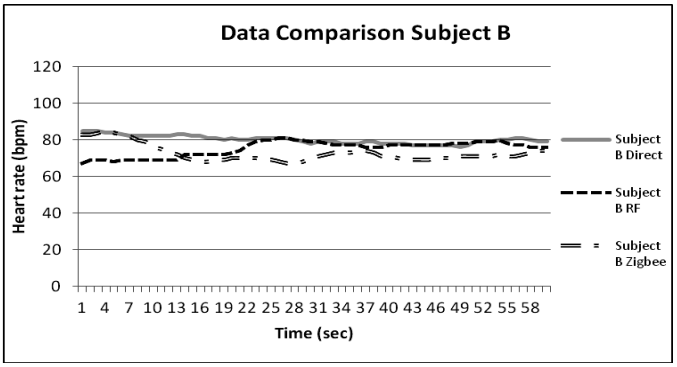

Fig. 13. Reading for Subject B On Device, RF And Zigbee

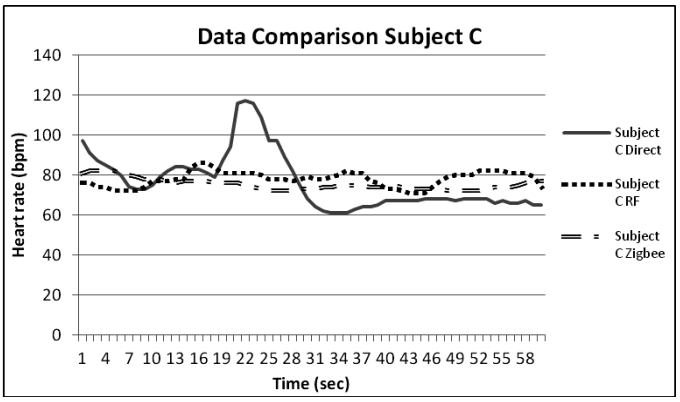

Fig. 14. Reading for Subject C On Device, RF And Zigbee

From Fig. 11, graphical data obtained from subject A, B and B through direct method as in section A is made as benchmarking for other methods. From these figures and in reference to Table II, all the subjects obtained below average resting heart rate readings. In contrast with Fig. 7, Fig. 11 seems to provide higher heart rate readings. The possibility for this condition is that the subject is not in proper resting condition.

Fig. 12, Fig. 13 and Fig. 14 shows the readings comparison between direct approach and two wireless method RF and Zigbee for subject A, B and C respectively. From these figures, again the Zigbee method provides stable reading where the heart rate readings is nearing to the direct approach. The RF approach on the other hand, takes some time to stabilizes and provide better reading of the subject. However, data for RF produces sudden peaks in graph during the reading was taken. The lower the bpm reading of the subject, the better the condition of the subject is.

From Fig. 8 to Fig. 14, it can be seen that Zigbee method provides stable and excellent reading for all the subjects in both sitting and lying down positions. This suggests that Zigbee method can be taken or used as real – time data transmitting method in wireless monitoring for better, accurate and stable reading. However, more tests on other posibble conditions and constraints are to be carried to further justify this claim.

C. Experimental C

The third discussion is investigating the condition on which postures, lying (condition A) or sitting (condition B) positions produces more stable and reliable data. This is taken from the direct reading using handheld device. Results are shown as in Fig. 15, Fig. 16 and Fig. 17 for subject A, B and C respectively.

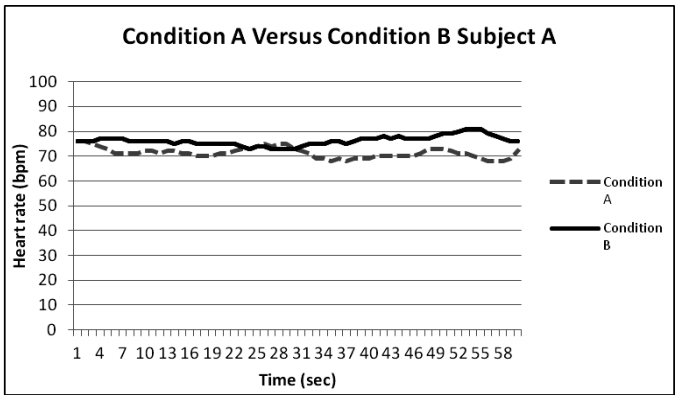

Fig. 15. Condition A Vs. Condition B for Subject A

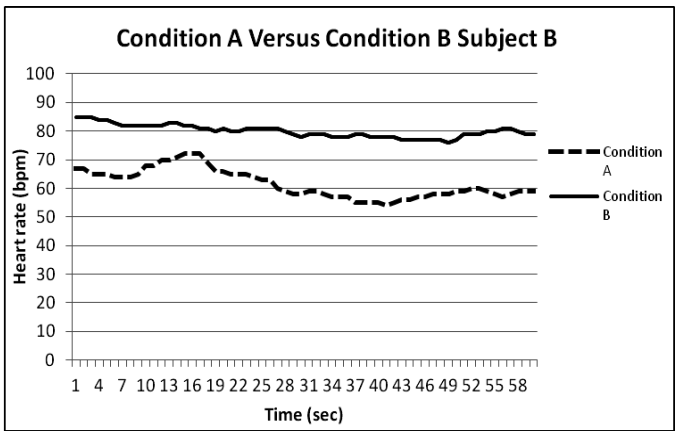

Fig. 16. Condition A Vs. Condition B for Subject B

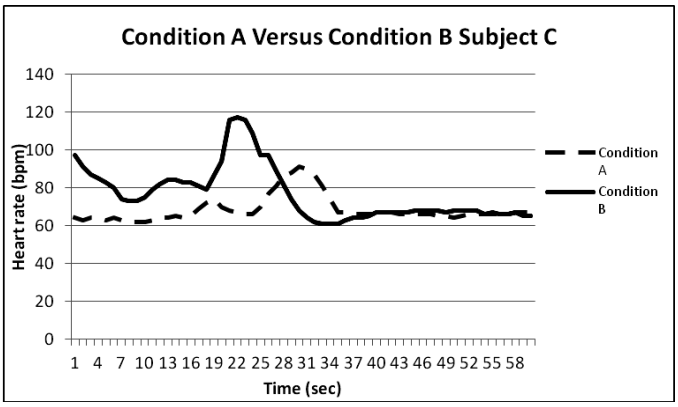

Fig. 17. Condition A Vs. Condition B for Subject

Fig. 15, Fig. 16 and Fig. 17 show all the subjects in two different positions while taking the readings to investigate the accuracy and stablity of the heart rate readings. Condition A the lying down position shows more stability in providing the heart rate reading. When in lying position, the blood in body can flow smothly to every area thus providing better intensity of blood flow. This helps the heart to settle (rest) thus providing a more excellent range of heart rate reading.

V. Conclusion

From the experiment in comparison of wireless technology in wireless monitoring system, it shows that RF technology is capable of transmitting efficient data. However, RF needs a certain time interval for it to stabilize and produce accurate readings. Meanwhile, Zigbee provides the most stable and accurate reading from the beginning of readings for both positions.

It is also seen that a patient needs to be in a lying position in order to provide a better and stable reading due to sufficient blood flow of the body and due to the fact that the heart beat sensor is obtaining heart rate reading from the thickness of blood under the skin.

In conclusion, Zigbee technology allows users and researchers to develop more accurate wireless monitoring mechanism on real time basis. Zigbee is not only capable of providing accurate real-time monitoring data for sensors but also capable of providing power efficiency for longer monitoring usage.

VI. Future Work

The research was conducted to the same age group and gender but with different body mass. Further research needs to be conducted to other age group and different gender of different background (athlete, old people, children, etc.). The future work of the research is also to include two other vital signs parameter, temperature and blood pressure monitoring in different sets of transceiver as well as to consider the usage of repeater to further extend the communication range.

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