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Fit-NES: wearable bracelet for heart rate monitoring

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Abstract

The heart is a vital organ that serves to pump blood to the whole body. A heart rate can be used as a healthy body parameter conditions. Growing evidence suggests that IT-based health records play essential role to drive medical revolution especially on data storage and processing. The heart rate measurement (HRM) process usually involves wearable sensor devices to record patient's data. This data is recorded to help the doctors to analyze and provide a better diagnose in order to determine the best treatment for the patients. Connecting the sensor system through a wireless network to a cloud server will enable the doctor to monitor remotely. This paper presents fit-NES wearable bracelet, an alternative method for integrating a HR measurement device using optical based pulse sensor and Bluetooth-based communication module. This paper is also present the benchmarking of proposed system with several various commercial HR measurement devices.

***Keywords**: heart rate measurement, pulse sensor, wearable, wireless, medical*

1. Introduction

Recently, information technology (IT) is being applied in more aspects as the numbers of medical equipment or medicational-purposes devices which can be connected into information-processing computers are growing day by day [1]. Growing evidence suggests that IT-based health records play essential role to drive medical revolution especially on data storage and processing [2]. The investigation of Wireless Body Area Network (WBAN) for healthcare system presents an intriguing study. Several studies have suggested that WBAN can provide continuous people's health monitoring with non-invasive technology [3, 4]. Among all of the possible medical services available to be improved by WBAN, heart rate monitoring (HRM) is one interesting subject. This method is used, for example, to analyze heart disease[3], [5, 6], sport training [7, 8], or correlation between heart rate and emotional condition [9].

Various method have been developed to measure human heart rate, for example, a typical ECG (Electrocardiogram) [10], intelligent pillow (pillow with ECG electrode) [11] or even using a camera-based face detection application [12]. Most of HRM measurement process usually involves sensor devices to record patient's data [13]. This data is recorded to help the doctors to analyze and provide a better diagnose in order to determine the best treatment for the patients. Pulse sensor refers to sensor which is able to measure heart rate of a living object. Connecting the sensor system through a wireless network to a cloud server will enable the doctor to monitor and examine the patients remotely, especially those who was required to be periodically examined.

Much effort has been devoted by several researchers develop a methods for increasing HR sensor's accuracy. Since accurate heart rate monitoring is essential in people's health, several study have been conducted to assess the accuracy and precision of the device for measuring heart rate [13–15]. However, an integrated solution has not been established yet, and there are somewhat divergent results. Previous research has developed a wearable health monitoring systems based on flexible and stretchable sensor for several human body health's parameter i.e. heart rate, temperature and metabolism parameter. The system is claimed to be have a capability for continuous monitoring without conspicuous comfortableness [13]. Meanwhile, another work has demonstrated an implementation of simple design of a wearable earlobe sensor for heart beat monitoring. This work proposed a method for evaluating heart beat time intervals between subsequent pulses and compared to intervals from classic

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electrocardiography. Their findings indicate that the method should be able for short and long-term home measuring and monitoring of HRV parameters [16]. A contactless pulse rate monitoring system based on camera is also developed recently to contribute on this field of research [17].

Another works present the intriguing solution using the wireless wearable device [18-20]. The devices are designed for monitoring physiological parameters i.e. heart rate, blood pressure, and body temperature. When the user is in critical condition, then a warning notification is issued to medical practitioner's mobile phone through internet. The result is claimed helps the doctors to monitor the health condition of the patient almost everytime and provide proper treatment at the critical time [21].

The aim of this research was to propose fit-NES, an alternative method for integrating a multi HR measurement device using optical based pulse sensor and Bluetooth-based communication module. Moreover, the sensor's data is received and processed by Android-based smartphone application. Particularly, the contribution of this paper is the benchmarking of proposed system with several various commercial HR measurement devices as a data validation method. The rest of this paper is organized as follows. Section II describes a literature review from related works conducted by several researchers. The development of system is presented in section III. Section IV describes result and discussion from the experiments. Finally, section V shows the final remarks of conclusion.

2. Research Method

2.1. Hardware Design

The basic functions of the system are described as followed:

- Providing a graphical user interface that is easy to navigate and understand for medical practitioner performing the HR measurement;
- Processing the data obtained from the sensor system as in parsing and checking
- Having other support functionalities such as data logging, simulation, picture saving, etc.

The system is illustrated in Figure 1. Data from HR bracelet is transmitted using Bluetooth. Bluno Beetle is used as main processing unit. The device is designed to have the ability toi nitiate and terminate the network with smartphone.

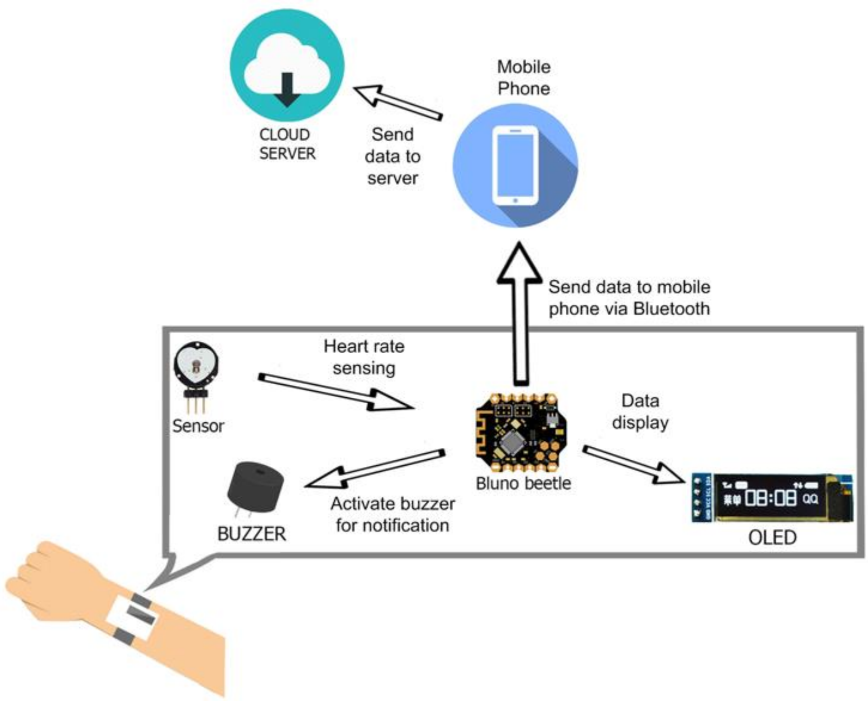


Figure 1. System block diagram

2.2. HR Bracelet Data Transmission Design

In this scheme, the system is consisted of three subsystems, which are sensor nodes, an android smartphone which acts as a personal server, and a data server as a storage and processing media. Bluetooth is used as communications protocol between sensor nodes and the smart phone while the smart phone and the data server was connected through internet.

HR sensor transmission flowchart is shown by Figure 2 The sensor is initiated and ready for reading process. There were two kinds of different data communications throughout the system: the communication for sensor nodes to mobile phone and between the mobile phone and data server. Each communication uses serial Bluetooth and internet connection, respectively.

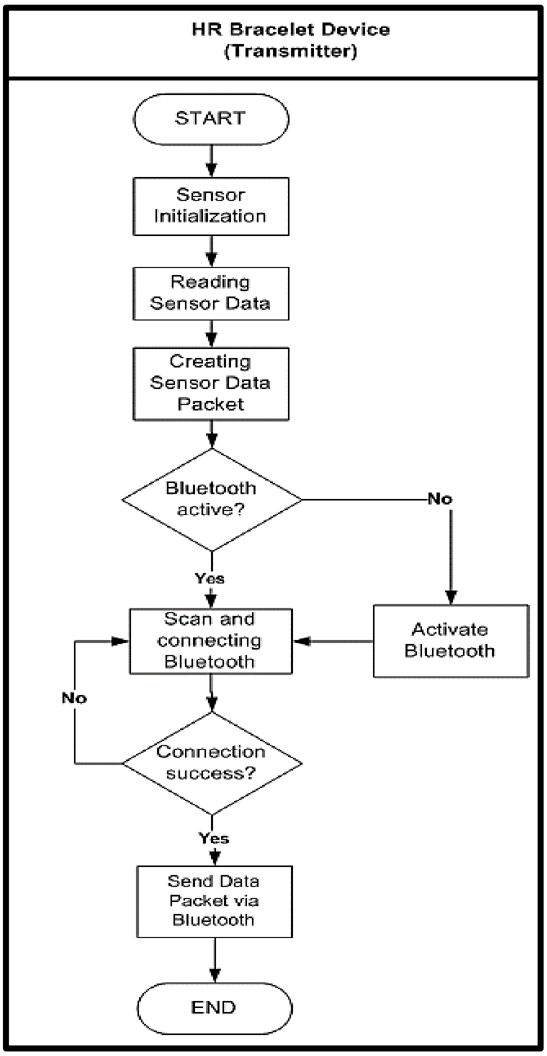
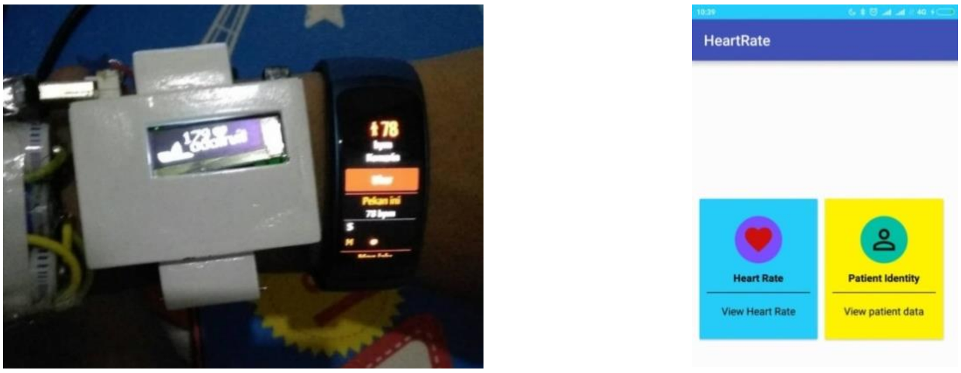


Figure 2. HR sensor transmission flowchart

For remote monitoring application, an android smartphone with data recording software installed was used. This software has a function to retrieve data from sensor nodes, and then combine them in a CSV file and forward the file to the data server via internet. A smartphone-side application was developed for the smartphone, with the ability to communicate with the sensor nodes. This application was able to retrieve data from sensor nodes, combine the data in a CSV (comma separated value) file, and then save the resulting file in its memory. Afterwards, the smartphone was able to forward the file to the server through internet connection.

3. Results and Analysis
3.1. Pulse Sensor Test Results and Benchmarking

To assess the performance of proposed system, two commercial smartwatches and two smart strap are used as a benchmark for heart rate measurement[14], [22,23]. Samsung Gear Fit 2, 4Fit Connect, Geonaute OnRhythm 110, and Geonaute Smart Runner's Dual HRM belt. HR data per second was converted to beats per minute (bpm) automatically by the data acquisition software program prior to analysis. Figure 3 shows the proposed system was placed on the wrist to testing with Samsung Gear Fit 2 and 4Fit Connect.



(a) (b)

Figure 1. (a) Proposed system paired with commercial sensor
(b) Built-in commercial sensor application on smartphone

Subjects were grouped into gender (male and female). To assess the performance of wearable sensor in a controlled research environment, all participants were asked to engage in three same activity categories i.e. resting, walking, and jogging. Their heart rate is recorded simultaneously using each device [24]. Each device are connected to respected built-in application on smartphone. Meanwhile, the proposed system is developed to facilitate datalogging and transmitting data [25, 26].The dataset consisted of 80 minutes of data (10 minx8 subjects). Each subject is given 2 minutes for resting condition test as a baseline, 4 minutes for walking, and 4 minutes for jogging. Figure 4 and Figure 5 shows the HR comparison test data between proposed system, Samsung Gear Fit 2, Geonaute OnRhythm 100, Geonaute Dual HRM Belt, and Connect 4Fit. The results are served as a baseline data for next activity experiment. The proposed system has demonstrated a consistent HR output with negligible error with other smartwatch. The error was a modest between 6-8 bpm, which indicate the precision of individual measurements for both male and female subjects.

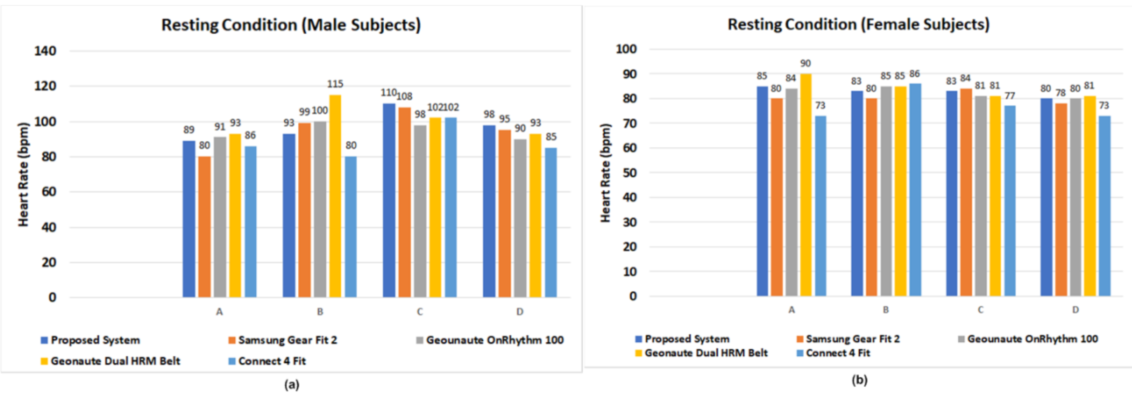
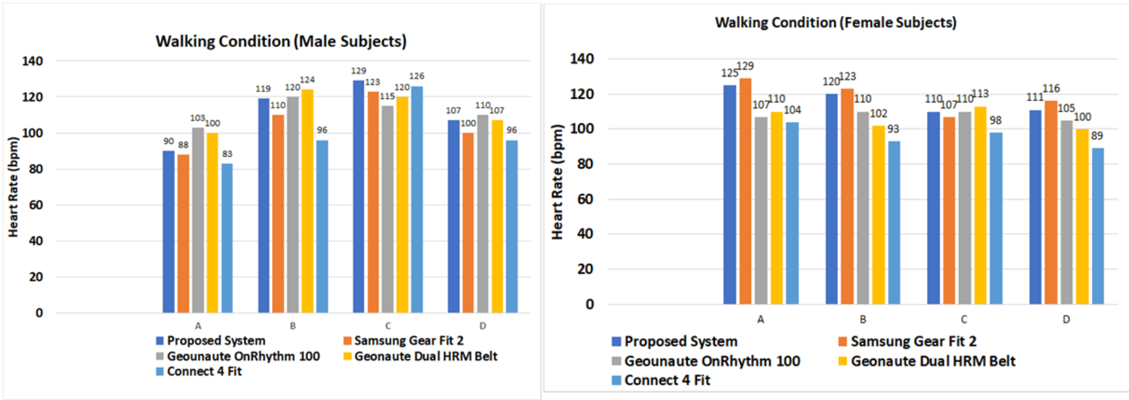


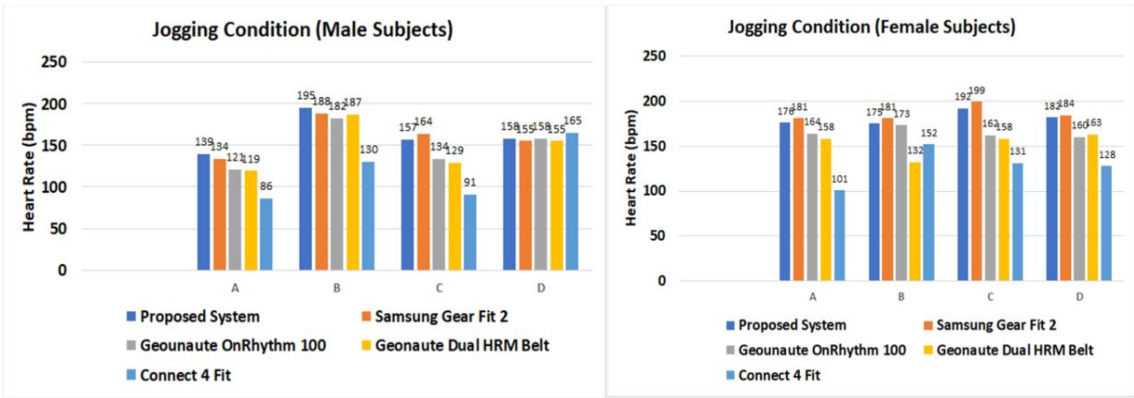
Figure 4. Results for resting condition for (a) male and (b) female subjects



(a) (b)

Figure 5. Results for walking condition for (a) male and (b) female subjects

Experiment results on Figure 6 show both male and subjects HR data on 4 minutes walking condition. Subjects are asked to walk in slow pace (about 5 km/hour) and a series of data are transmitted to smartphone and desktop. As experiment begun. The individual HR is rising and each device is compared. The HR value varies ranging from 83 to 129 bpm. The female subjects HR are slightly higher than male subjects.



(a) (b)

Figure 6. Results for jogging condition for (a) male and (b) female subjects

After walking, subjects are asked to engage in jogging activity. Jogging pace is set between 8-10 km/hour. This result shows that most of individual HR is higher than 120 bpm for all device. The highest value is 199 bpm. This value is still on permissible range. Variation HR value could be indicating inaccurate measurement process. This could be caused by unstable positioning of the device and also movement of the wrist. Although the experimental setting was specifically designed to deal with these issues, some participants HR data are registered with inconsistent result. The results also state that the Connect 4Fit gave the unlikely output when compared with other three commercial devices.

3.2. Basic Wireless Connection and Data Streaming Evaluation Results

Wireless communication testing is conducted to ensure the bracelet can communicate and sent the data to smartphone. A smartphone-side application was developed for the smartphone, with the ability to communicate with the bracelet. This application was able to retrieve data from sensor and then save the resulting file in its memory .The application was also able to sent an SMS message when the heart rate value exceed the normal value as a emergency warning. Figure 7 shows the emergency SMS notification example.

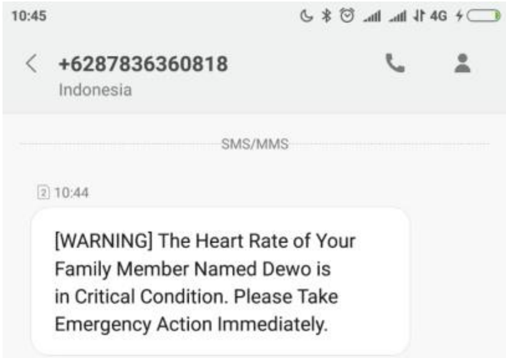


Figure 7. Emergency SMS notification

Table 1 shows that the frequency of the data obtained using 2-100 data package. The data frequency obtained shows results ranging in the range 6-7 Hz. The period of time between data varies between 160-170 ms. After HRM process, a series of data are transmitted and stored on the phone memory.

Table 1. Data Streaming Results

N data	Time (ms)	Data frequency (Hz)
2	162	6.17
5	643	6.22
10	1490	6.71
20	3158	6.33
25	3964	6.30
50	8084	6.18
100	16345	6.11

3.3. Outdoor and Indoor Wireless Connection Evaluation Results

The system is designed to be tested in two different applications: outdoor application and indoor for clinic application. The test is performed to evaluate wireless module connectivity both indoor and outdoor. Meanwhile, a hallway is used as an indoor testing ground. The results are varies depend on distance range between bracelet-smartphone and different obstacle given.

Table 2 shows the result of outdoor wireless connectivity test. Figure 8 (a) shows that outdoor test is conducted on open space. Test subject is required to worn the HR bracelet and walk slowly away from smartphone. From 0–67.79 meter, data is transmitted to smartphone with several second delay. Although typical Bluetooth's signal range can reach up to 100 meter, the data suggest that signal lost is occurred beyond 67.79 meter range [27]. Aside from response time/delay problem, a series of sensor's data are still transmitted to smartphone continuously.

Table 2. Wireless Connectivity Test Results: Distance vs Response Time

No	Distance between bracelet and smartphone (meter)	Response Time (Second)
1	0	Real Time
2	36.41	5
3	44.18	7
4	67.79	10

Meanwhile, to simulate the effects of signal reflection inside patient examination room, a curtain is placed between smartphone and bracelet, as shown in Figure 8 (b). HR bracelet is set to transmit data continuously and the smartphone is moving slowly. Table 3 shows the data from test results. The data can be still transmitted up to 45.6 meter. Compared to outdoor test result, the performance is not actually affected by such obstacle. It provides an assessment whether the system can be implemented on clinic or hospital.


(a) (b)

Figure 2. (a) Outdoor and (b) Indoor test

Table 3. Indoor Wireless Connection Test using Curtain as Obstacle

No	Distance between bracelet and smartphone (meter)	Response Time (Second)
1	0	Real Time
2	7,2	3
3	20,14	5
4	45,6	7

Nevertheless, a major concern in Bluetooth wireless connection lies on a number a device that can be supported by a smartphone at a time [27]. By using Bluetooth version 1-3, only one device can be paired to smartphone.

4. Conclusion

This paper successfully presented an alternative method for integrating a HR measurement device using optical based pulse sensor and Bluetooth-based communication module. Firstly, the results shows that the proposed system sensor's accuracy level for HR measurement is within acceptable margin of error when it's compared with commercial sensor. Aggregate mean biases ranged from 6-8 bpm. These important results indicate that there are losses corresponding to bracelet position on wrist. Incorrect device position could affect the results and gave the low-quality HR data. Future works on this field should be directed at different sensor placement on subject's body e.g. torso. Secondly, the wireless data communication protocol has been tested on outdoor and indoor environment within 0-67.79 m range. The experiment has demonstrated that response time varies between 0–7 seconds correlated to distance between bracelet and smartphone device. A further interesting issue worth exploring is Bluetooth Low Energy (BLE) as a wireless communication module.

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