Alerting System for Sport Activity Based on ECG Signals using Proportional Integral Derivative

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Abstract— **Exercise makes the body fit, but most people do not know the intensity of the exercise they are doing right or otherwise can be dangerous, because not everyone knows the maximum heart rate (MHR), Heart Rate Resting (HRRest), heart rate reserve (HRR) and Target Heart Rate (THR) for each individual, it is proposed an ECG signal-based warning system to find out how much a person's maximum limit in exercise based on age, gender, body mass index, MHR, RHR, THRmin and THRmax. The data is taken by using ECG sensors from the subjects who are doing sport activities using a treadmill by noting the resulted feature when the subject reaches the maximum limit of the heart rate (THRmax) target. Range is calculated from 50% of the THR value, which increases periodically during treadmill activities up to 85% of THR. When already exceed THRmax, then the system will automatically warn and decrease the level of exercise to medium to low levels in the cooling down level. For the % hardware errors in a row from 1 minute, 3 minutes, 5 minutes, and 10 minutes obtained % error with 0.77±0.14. The RMSE of the hardware and software test showed high accuracy because of the small value of error. The system succeeds to alert any intensity level of sport based on the Proportional integral derivative according to the bpm value generated by the subject during the treadmill exercise.**

Keywords— ECG, alerting system, heart rate monitoring, proportional integral derivative

I. INTRODUCTION

In 2011, the World Health Organization (WHO) reported more than 36 million people die of cardiovascular disease. Cardiovascular disease in Indonesia has the highest mortality rate than the other diseases. 63% of all deaths are caused by non-contagious diseases with the highest mortality rate of 30% in the CVD (Cardiovascular Diseases) [1].

Furthermore, the problem of overweight and obesity occur in all countries including Indonesia. Based on data from the Global Nutrition Report, a 10 % of the adult population in Indonesia is with overweight and a 2 % is with obesity (WHO,2007). Data from the basic medical research Indonesian health ministry in 2013, showed that the prevalence of obesity in the adult age group amounted to 15.4% and 13.5% of overweight. If the prevalence of obesity and overweight are combined, the prevalence of Indonesia's population are overweight of 28.9%. This is a fairly large amount for more than a quarter, or nearly one-third of Indonesia's population in age group of adults are overweight.

One of the efforts in preventing cardiovascular disease and obesity is by exercising. Sport is one of the necessities of human life in order to keep in shape, like a walking, swimming, jogging, running, treadmill, cycling, team sports, etc. [2]. One of the most popular sports in the room that can monitor a person's heart rate is treadmill, to find out some information about the heart we can do a treadmill test. Where the treadmill test is a recording of ECG, the electrocardiogram (ECG) is a recording of the electrode potential heart bioelectricity affixed to the surface of the body [2]. Its purpose is to assess the condition of the heart by recording the electrical activity of the heart, along with physical exercise. Sometimes complaints or symptoms of heart disease will arise during vigorous activities such as running and exercising [3].

The demand of healthcare is high due to the world's ageing population and prevalence of chronic is essential [4]. Wearable devices can continuous to monitor the vital-signs signals [5]. One of the vital signs is heart rate (HR). The value of HR can describe your level of fitness[6]. HR is important to be monitored in the normal condition, but in the training condition is more important[7].

In the training condition, monitoring our heart to work in optimal intensity for reaching maximal heart rate based on the body mass index. Based on the classification of body mass index (BMI) according to the criteria of the Asia-Pacific, a person is said to be overweight if they have a BMI from 23 to 24.9 and obese when the person is said to have a BMI ≥ 25. Meanwhile, someone categorized as overweight if BMI> 25 and obese if BMI > 27. (Ministry of health Indonesia,2013).

There are several factors that can affect the BMI, the age, gender, genetics, diet and physical activity (Asil, Eet al., 2014). One way to avoid infectiuos diseases for underweight and degenerative diseases resulting from excess weight is a physical activity or sport. So in this study is proposed to measure heart rate in healthy subjects in a state of the treadmill to see how the maximum heart rates are achieved by the subject with underweight categories, normal, overweight and obesity.

The relationship between exercise intensity and heart rate is linear. That's mean, greater the intensity, the higher HR. Because of its predictability, you can use HR to prescribe running intensities. When the heart is working in light intensity (undertraining), so that calories will not burn enough to lost your weight or there is no benefit for the body. When the heart is working in high intensity (overtraining), you put yourself at risk for health problems and even a death. So, it is important to monitor the HR in order to work at its optimal intensity based on body mass index.

II. METHODOLOGY

A. The Procedure of Research

The procedure of this research starts from the design of the hardware for data acquisition from the ECG on the subject. The purpose of the data acquisition before the research was to find a right way of placing the electrodes on body of the subjects. So that, the output signal is good when taking data in realtime condition. Then the design of software that will be used for data acquisition in realtime before analyzed. The complete procedure of this research is shown in Figure 1.

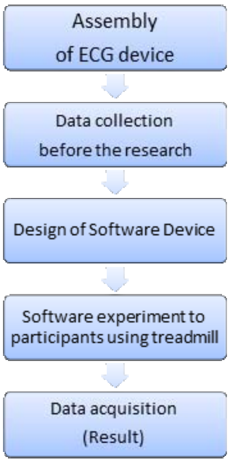

Fig 1 The Procedure of Research

B. Subjects

We analyzed the records of 15 healthy subjects of both sexes, aged between 20-40 years, in sinus rythm. The resulting study population consisted of 30 individuals, who were divided into three groups according to Body mass index (BMI): underweight (<18.5 kg/m^2), normal (≤18.5-<24.9), overweight and obesity, we combined into one class (≥ 25.0).

Table 1 Characteristics of the study population

Gender (M/F)	9/6
Age (years)	24.53 ± 0.83
Body weight (kg)	62.93±9.16
Height (cm)	165.40 ± 7.61
HR_{rest} (bpm)	68.67±5.46
Body mass index (kg/m²)	22.91±1.94

M: male; F:female

C. Wearable sensor

In this study, we use an ECG sensor. The AD8232 SparkFun Single Lead Heart Rate Monitor is a cost-effective board used to measure the electrical activity of the heart. This electrical activity can be charted as an ECG or Electrocardiogram and output as an analog reading. ECGs can be extremely noisy, the AD8232 Single Lead Heart Rate Monitor acts as an op amp to help obtain a clear signal from the PR and QT Intervals easily.

The AD8232 is an integrated signal conditioning block for ECG and other biopotential measurement applications. It is designed to extract, amplify, and filter small biopotential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement.

The AD8232 Heart Rate Monitor breaks out nine connections from the IC that you can solder pins, wires, or other connectors to SDN, LO+, LO-, OUTPUT, 3.3V, GND provide essential pins for operating this monitor with an Arduino or other development board. Also provided on this board are 3 electrode pins to attach and use your own custom sensors. Additionally, there is an LED indicator light that will pulsate to the rhythm of a heartbeat.

In the ECG sensor connected to Arduino Nano ATMega328 where ADC Resolution is used by 10 bits with ADC reference voltage equal to supply voltage of microcontroller, that is 3,3 Volt. Resolution of ADC per bit can be calculated by Equation:

$$Resolution = \frac{Vreff}{2^{10}-1} = \frac{3300\ mV}{1023} = 3.226\ mV/bit \quad (1)$$

The baudrate value is set at 115200 bps, no parity, and 1 stop bit. In the timer, there are two important configurations that must be set, namely timer prescaler and timer period. The prescaler timer functions are to divide the clock. Timer prescaler can be calculated by using Equation:

Frequency max = Clock Timer 2 / (Timer Prescaler +1) (2)

Where the Frequency max is as many as 1 MHz and Clock Timer 2 is as many as 60 MHz. The second configuration in the timer is the determination of the timer period that serves to set the desired sampling frequency [8]. In this study, we used sampling frequency Of 1 kHz. Timer period can be calculated by using Equation:

Frequency = Frequency max / (Timer Period+1) (3)

Where Frequency is set at 1 kHz according to the desired sampling frequency.

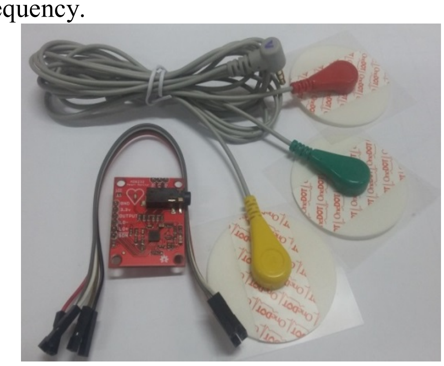

Fig 2 AD8232 ECG modul with electrodes

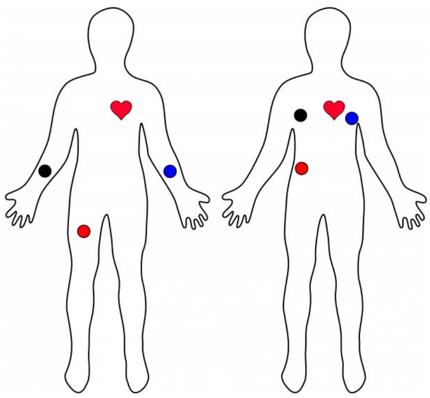

Fig 3 The methods of electrodes placement**[9]**

D. Sensor Placement

In this study, we use electrocardiography technique type Vectorcardiogram that is using 3 electrodes placed at the certain body points. This technique uses the potential modeling of the body as a three-dimensional vector using bipolar flop standard is shown in Fig.3, where we use the AD8232 ECG module in accordance with Fig.2, there are 3 electrodes placed on the chest. ECG recording has done with 3 Electrodes from ECG module attached at the subject bodies. The placement of electrodes is shown at Fig 4.

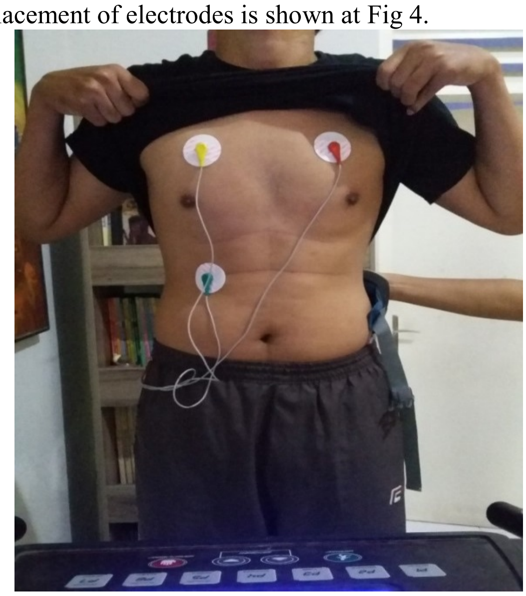

Fig 4 Placement of the Electrodes

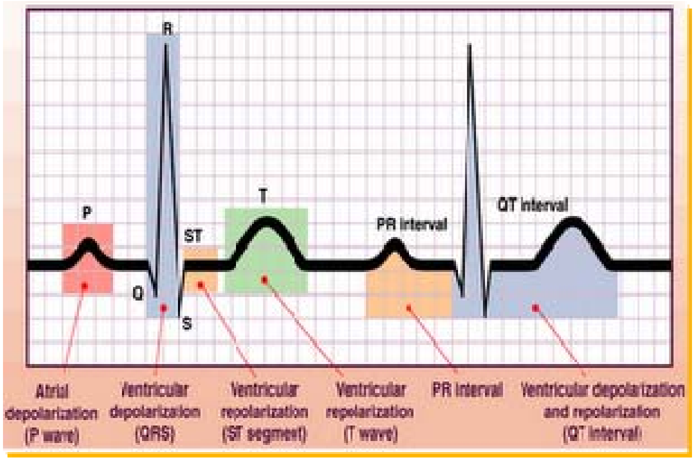

Fig 5 The Normal ECG wave[10]

E. ECG recording

Ecg signal is a bioelectrical signal which depicts the cardiac activity of the heart by attaching electrodes at different outer surface of the human skin, electrical cardiac signals can be recorded by an external device. These currents cause the contractions and relaxations of heart by stimulating cardiac muscle [10]. Fig 5 shows a schematic representation of a normal ECG and its various waves [10].

Usually the normal adult heart rate is between 60-100 bpm, except for athletes, because they are already accustomed to exercising, so your heart rate of athletes trained the range of 50 [2]. Each person has his fatigue threshold respectively. When observed from the value Heart Rate (HR), each person has a minimum and maximum values during exercise. Karvonen formula is a mathematical formula that can help to determine the value of a person's Heart Rate Training Zone. On a normal ECG waveform, interval of PQRST wave has described: P-R interval = 0.12 - 0.20 Sec, QRS width = 0.08 - 0.12 Sec, Q-T interval 0.35 - 0.43 Sec, P wave interval = 0.11 Sec. The amplitude of normal ECG wavefrom represents : P wave : 0.25 mV, R wave : 1.60mV, Q wave : 25% or R wave, T wave: 0.1 -0.5 mV [11].

Everyone has their own threshold of exhaustion. When it is observed from the Heart Rate (HR) score, each person has a minimum and maximum value during exercise. Karvonen formula is a mathematical formula that can help to determine the value of a person's Heart Rate Training Zone.

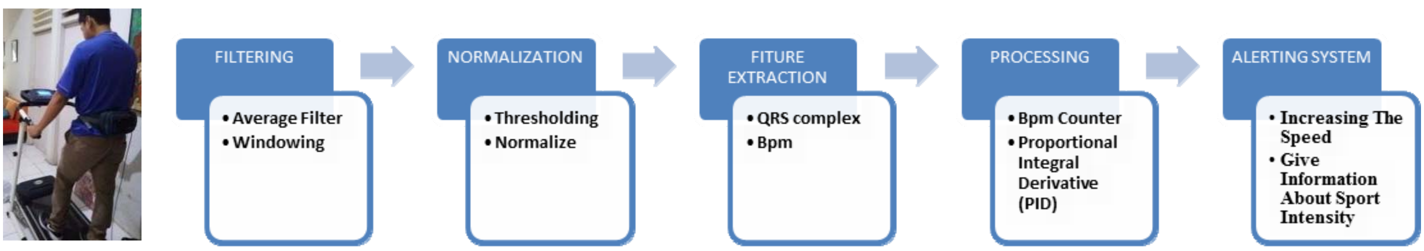

Fig 6 Alerting System for Sport Activity

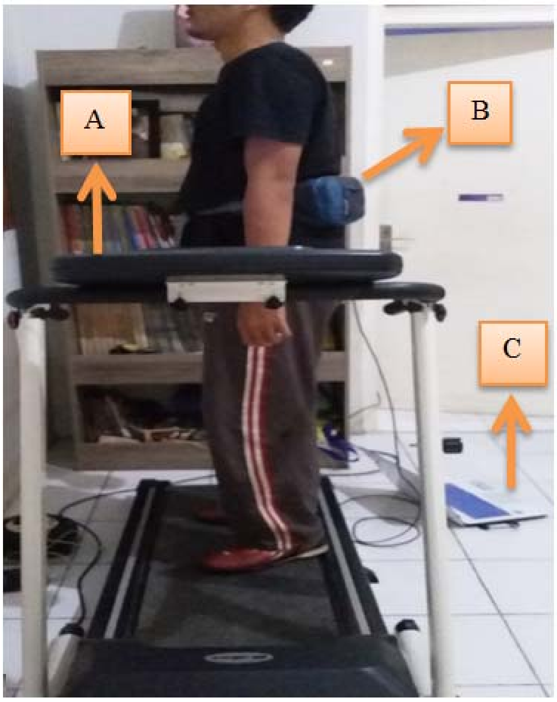

Fig 4 A. The treadmill for acquisitions ECG data, B. ECG module, C. PC for read ECG data in real-time

The purpose of why we must know maximum heart rate is using Korvonen formula's method, we will have the more accurate heart rate range, remembering the goal is to stay as high as possible and that heart rate range to get the greatest cardiovascular output and see improvements over time things like decreases in your resting heart rate and increases in what's called your VO2 max the efficiency of your cardiovascular system.

To calculate the intensity of exercise we need to know the heart rate rest because each subject has a heartbeat at different rests. From these cases, we can know and determine the right sport intensity on each subject.

The Karvonen formula is a mathematical formula that helps determine the heart rate training zone [9].

1) Calculate the resting heart rate (RHR) (4)
2) Calculate the estimated value of the maximum heart rate (MHR) by using the following formula:
   MHR for men = 220-age (5)
   MHR for women = 226-age (6)
3) Calculate the value of heart rate reserve (HRR)
   HRR = MHR-RHR (7)
4) Calculate the lower limit of heart rate training zone
   THRmin = (HRR . lower intensity limits %) + RHR (8)
5) Calculate the lower limit of heart rate training zone
   THRmin = (HRR . intensity upper limit %) + RHR (9)

The process undertaken to detect QRS complexes or find the heart rate value is obtained from the interval between detection of the rising edge of the QRS pulse to the next QRS pulse using Eq.

$$\text{Heart Rate} = \frac{60}{R-R}\ (\text{bpm}) \qquad (10)$$

Preprocessing step involves removal of noise from sources such as electrode contact noise, baseline drift, muscle contraction, power line interference and motion artifacts. Also QRS detection was carried out in this stage [12]. A well known and acceptable Pan Tompkins algorithm are employed as a real time QRS detection algorithm based on the analysis of slope, amplitude and width of QRS complex [11].

Finding variants and standards The complex deviation of QRS is used in the following formula:

$$Mean = \sum_{i=0}^{i=filter} bpm \qquad (11)$$

$$S^2 = \frac{\sum_{i=1}^{n}\left(x_1 - \bar{x}\right)^2}{n-1} \qquad (12)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}} \qquad (13)$$

On the ECG AD8232 module there are 2 kinds of filters, namely low pass filter and high pass filter and there is already a cut-off frequency of 0.05 Hz. To refine the output of ECG signal, in this research using two simple filter method that is Average filter and windowing filter in accordance with the block digram.

The in-amp in the AD8232 applies gain and high-pass filtering simultaneously. This capability allows the in-amp to amplify a small ECG signal by 100 while rejecting electrode offsets as large as ±300 mV.

$$mv(t) = K_p\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}\right) \qquad (13)$$

Mv(t) = output dari pengontrol PID atau Manipulated Variable
Kp = Konstanta Proporsional
Ti = Konstanta Integral
Td = Konstanta Derivatif
E(t) = error (The difference between the set point and the actual level)

III. EXPERIMENTAL AND RESULTS

In this research, we use signal processing application, it can be seen that sending data from hardware to PC using serial and data read by the application. We must first input data to the Graphical User Interface. In order for the appropriate level of sports with each person can be achieved optimally.

Firstly, in the GUI in Figure 8, we have to enter data about gender, weight, age, height, and time specified in 1 minute to measure heart rate rest, because HRR is our heart's benchmark in normal circumstances or not, normal HRR has a range of 60-80 bpm. After that, calculate the MHR and body mass index, the result of RHR measurement for 1 minute is inserted into the RHR column circled in yellow is shown in Fig 10. After that set the time on the program with 30 minutes for exercising. The output of ECG signals can be seen in Fig.9 when the subject still excercise in treadmill, the original signal ECG and after filtering the signals.

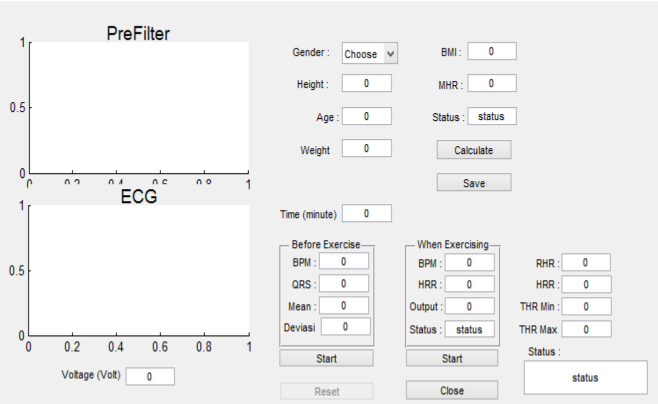

Fig 5 Graphical User Interface for Measuring Heart Rate

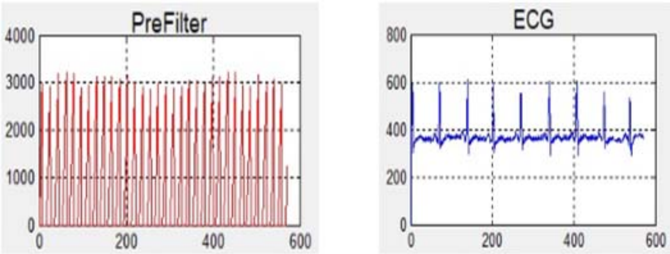

Fig 6 ECG Signal After Filtering and The Original Signal ECG When Exercise

Fig 7 The GUI after RHR measurement and while Excercise

Fig 8 Colling Down Status When Reaching THRmax

When we entered the 0-50% phase of the heart rate target, there is a warning to the Graphical User Interface on the PC because we have started to enter the phase very light.

After entering the phase of 65% of THR is a light phase, there is an order to raise the speed to the level above it. Likewise the next to the upper limit of the THR is 85%. After exceeding 85% of THR, there is a warning to the cooling down phase. The fig 11 is shown that the subject is in the maximum status of the target heart rate and the system gives the alerting to cool down. The heart rate of subject is 171 bpm, the value exceeds the maximum target heart rate limit.

Controls performed for orders increase the speed per level is performed using proportional integral derivative (PID). The value of constant of each variable is Kp = 5, Ki=10 and Kd = 10, with set point value is 167. The phase when the sport is complete without skipping each other, so that the benefits of exercise can we feel and not in vain. For those who have overweight and obesity can adjust the exercise pattern when exercising, especially using a treadmill. Because every person has a different age, gender, body mass index, maximum heart rate, HRR and RHR.

To calculate % error in hardware testing for heart rate data retrieval, use the following formula:

$$RMSE = \sqrt{\frac{\sum (Xdata.i - Xcheck.i)^2}{n}} \quad (14)$$

$$\% \ Error = \frac{Measured\ Value - Accepted\ Value}{Accepted\ Value \times 100} \quad (15)$$

Root mean square error (RMSE) obtained from the resting heart rate data for 1 minute recorded is 0.092, with the number of samples obtained is 59488, after using equation 14, means that the smaller RMSE indicates a high degree of accuracy.

For data recording starting from 10 minutes of warmed up, 5 minutes at speed 3, to the cooling down phase, each RMSE is respectively 0.086, 0.060, 0.083, 0.146.0.072, 0.123, 0.007. The results obtained have shown high accuracy in each phase, among the phases, in the core phase at 5 speed with a duration of 5 minutes obtained RMSE higher than the others, because in this phase, the speed of the treadmill has started fast, So the body begins to adapt to run at a high starting speed. Generally of all phases have shown a high degree of accuracy based on the value obtained by using the RMSE equation.

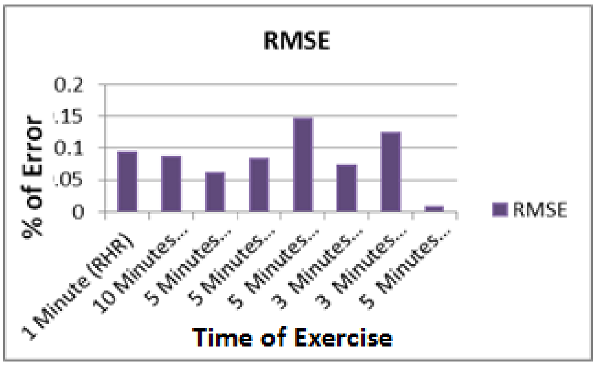

Fig 9 Root Mean Square Error for Hardware

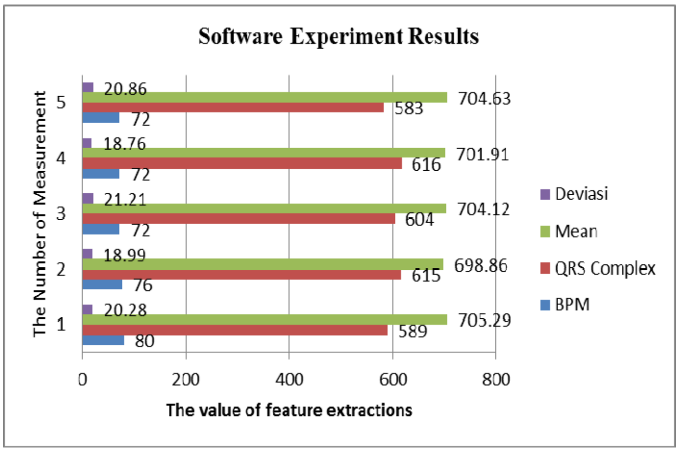

Fig 10 The Software Precision

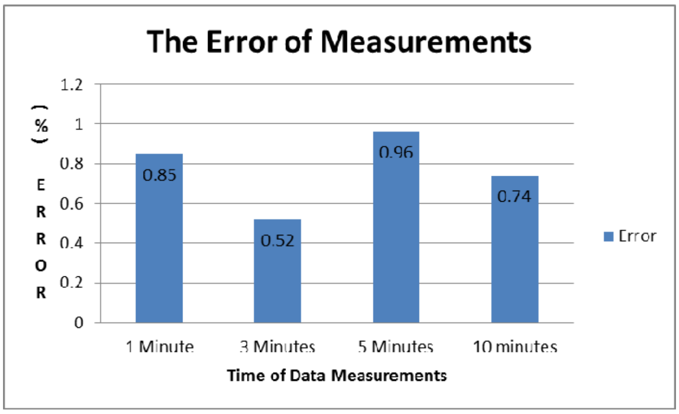

Fig 11 The Percentage Error of Hardware

For the software experiment results when we viewed from the graph shown in Fig 13 from the test results for 5 times the measurement with the same subject for 1 minute, then obtained high precision of the software.

In Fig 14, the % error of hardware in a row from 1 minute, 3 minutes, 5 minutes, and 10 minutes obtained % error of 0.85, 0.52, 0.96, 0.74 with 0.77±0.14. The smaller error value the higher of the precision.

IV. CONCLUSION AND FURTHER RESEARCH

From the results of this study can be concluded that with the use of the proposed device, can monitor the heart rate while exercising, especially the use of treadmill. In addition to heart rate monitoring, the proposed device can also provide treadmill level information and warnings according to exercise intensity based on heart rate targets. The use of the PID algorithm is used for the provision of information and the safe warning of a treadmill alert based on the safe zone of the heartbeat.

For the future research, It is advisable to use embedded systems and data to be sent to smartphones, so we can easily monitor the heart rate while doing sports activities.

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