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Effect of Muscle Fatigue on Heart Signal on Physical Activity with Electromyogram and Electrocardiogram Monitoring Signals

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ABSTRACT Physical activity is an activity of body movement by utilizing skeletal muscles that are carried out daily. One form of physical activity is an exercise which aims to improve health and fitness. Parameters related to health and wellness are heart and muscle activity. Strong and prolonged muscle contractions result in muscle fatigue. The authors used electromyographic (EMG) signals to measure muscle fatigue by monitoring changes in electrical muscle activity. This study aims to analyze the effect of muscle fatigue on cardiac signals during subjects perform physical activity. This research method uses Fast Fourier Transform (FFT) with one group pre-test-post-test research design. The independent variable is the EMG signal when doing plank activities, while the dependent variable is the result of monitoring the EMG signal. The authors use MPF, MDF, and MNF to get more detailed measurement results and perform a T-test. The test results showed a significant value (p-value <0.05) in the pre-test and post-test. The Pearson correlation test got a value of 0.628, indicating a strong relationship between exercise frequency and plank duration. When the respondent experiences muscle fatigue, the heart signal is affected by noise movement artifacts that appear when doing the plank. It is concluded that the device in this study can be used properly. To overcome noise in the EMG signal, it is recommended to use dry electrodes and high-quality components. To improve the ability to transmit data, it is recommended to use a Raspberry microcontroller.

INDEX TERMS EMG, ECG, Muscle Fatigue

I. INTRODUCTION

Physical activity is an activity to move the body by utilizing skeletal muscles carried out daily. Sport is a form of physical activity that aims to help improve health and fitness. Increasing a person's physical fitness can be done through sports activities that aim to improve a person's physical condition and endurance [1]. One way is to do weight training. This weight training affects cardiovascular and muscle activity; heart and muscle activity are important parameters that must be measured [2][3]. In the world of sports, athletes need good physical fitness so they don't get tired quickly during exercise. Strong and prolonged muscle contractions result in a condition known as muscle fatigue [4]. Fatigue is generally defined as reduced muscle performance accompanied by a sensation of fatigue and muscle aches during physical activity. Another definition of fatigue is the inability to maintain muscle power output [5][6][7][8]. Muscle fatigue is a decrease in the ability to produce maximum strength from the muscles caused by exercise [9][10]. In everyday life, when the limbs perform intensive repetitive movements, the muscles can experience muscle fatigue. As a result, the muscle is unable to maintain its contraction [11][12]. Abnormal fatigue can also be caused by restriction or interference with different stages of muscle contraction. Muscle fatigue that occurs will result in a decrease in the work efficiency of the muscle [13][9].

Muscle fatigue is usually measured using electromyographic (EMG) signals, which are used to intercept bioelectrical signals from contracting muscles [14][15][16]. EMG is a technique for measuring the electrical activity of muscles. EMG is performed using a device known as an electromyograph which will provide a recording known as an electromyogram [17][18]. EMG signal is used to evaluate fatigue by monitoring changes in electrical muscle activity such as muscle weakness, numbness, certain types of pain, cramps, muscle disorders such as polymyositis or biomechanical movement of living beings and is used to determine the level of weakness and muscle strength [19][20]. Previous studies have processed EMG signals that show several muscle fatigue indices using the frequency domain. The Fourier transform is a method that is often used to estimate the spectrum of an EMG signal. Many studies have noted that frequency-based EMG variables are more sensitive to fatigue-related changes. The average frequency of the spectrum is used to determine the difference before and after experiencing fatigue [21][13]. Frequency-domain or spectral-domain features are commonly used to convert EMG signals in time-domain to frequency-domain and also to assess muscle fatigue. The Fourier transform of the autocorrelation function of the EMG signal is used to provide Power Spectral (PS) or Power Spectral Density (PSD) [22].

A previous study by Triwiyanto et al in 2017 analyzed the effect of muscle fatigue on the spectral and time-frequency domain parameters of the EMG signal using Continuous Wavelet Transform (CWT). The results found that when the muscles experience a state of fatigue, the spectrum parameters of the EMG signal will change. The results of the study stated that the average Instantaneous Mean Frequency (IMNF) decreased by 15.69%, and the average Instantaneous Mean Power Spectrum (IMNP) increased by 84.14% [11]. A 2019 study by B.N Cahyadi et al. analyzed muscle fatigue when performing arm movements with EMG signals and processed using MATLAB. The results of this study showed that the signal contraction of the deltoid and biceps muscles decreased steadily over time [9]. A previous study by Ahmed Ebied et al. in 2020 investigated forearm muscle fatigue using 8-channel EMG signals from 15 healthy subjects during isometric contractions. In this study, the median frequency (MDF) and root mean square (RMS) was used to measure the effect of muscle fatigue on frequency and amplitude. His method identified and assessed the subjects and channels most susceptible to fatigue [23]. In 2021, Andika Pradana Alfarabi researched the use of TENS on muscle fatigue using EMG parameters. Data was taken from 3 stages of data collection, namely during pre-, post-exercise and after TENS therapy. It was found that the Mean Power Frequency (MPF) value had a significant change before and after TENS therapy [24].

Based on the description of the literature study that has been described, several things need to be resolved through research, including developing and integrating ECG and EMG tools in detecting the effect of muscle fatigue on heart signals. Therefore, in this study, a tool for detecting the effect of muscle fatigue on cardiac signals on physical activity will be designed by monitoring ECG and EMG signals (EMG parameters). The use of this design is more effective because it has the advantage of combining two different tools, namely ECG and EMG.

II. MATERIALS AND METHODS

The study is conducted as experimental research. The authors proposed an EMG signal to measure muscle fatigue in this study. The materials and method will be explained in the following section.

DATA COLLECTION

In this study, researchers used the Fast Fourier Transform (FFT) method [25]with a group pre test-post test research design to measure the level of fatigue in the respondent's muscles. The independent variable is the EMG signal when doing plank activities, while the dependent variable is the result of monitoring the EMG signal. To get more detailed measurement results, researchers use MPF [26], MDF [25], and MNF [27] and perform a T-test. The author also uses the Pearson correlation test to test the correlation between one dependent variable and one independent variable**.** This study uses an analog EMG circuit, where this analog circuit consists of a series of instrumentation, Amplifier, HPF filter, LPF filter, notch filter, and Adder. The microcontroller uses Arduino Uno ATmega328 [25] as analog to digital signal data processing and Telemetry Viewer as an EMG signal display [24].

The data taken on the EMG is a muscle signal, while the data taken on the ECG is the Maximum Heart Rate (MHR) value. Measurements were made on ten respondents in the Electromedical Engineering campus environment with the following inclusion criteria; the sample population is taken from level 1 to level 3 students (Age 18-23 years) with no smoking weight: 60-70kg; 70-80kg; 80-90kg, gender (M), and an activity person

The location of the leads used is the Triceps [28]and Rectus Femoris muscles [29], with the Agcl electrode [25] as an EMG signal interceptor. Data retrieval two times monitoring, namely the first monitoring on respondents who are in prime condition or not doing any activities (pre-exercise). Before taking exercise data, respondents were given plank treatment to experience fatigue, and then monitoring was carried out post-exercise. Then the monitoring results were converted into a frequency domain using the Fourier transformation method (FFT) so that the frequency shift in the EMG can be seen clearly and an analysis of the effect of muscle fatigue on the heart could be analyzed seen.

FIGURE 1 shows how to collect data in this study; the respondent's position is in a plank state and will be monitored directly on the PC. The signal will be seen on the Telemetry Viewer V4 display with a sampling frequency setting of 3000Hz, and the data will be stored in CSV form, then processed using the MATLAB R2016a application to process FFT data. FIGURE 2 there is a block diagram of the system for EMG. AgcCl electrodes were used to tap the respondent signals in the triceps and rectus femoris muscles. The wires from the electrodes will enter the EMG analog circuit, starting with the instrument circuit to intercept signals with generally small voltages. then the EMG filter used is the HPF filter 20Hz 40db and the LPF filter 500Hz 40db; it is the frequency range for the EMG signal [13]. The notch filter circuit is used to filter out the 50Hz frequency that appears on the signal. There is a gain to amplifying a small signal output voltage. and an adder circuit to increase the reference voltage at the signal output. Afterward, the analog signal will be processed into digital using the Arduino Uno ATmega328 microcontroller. The signal will be processed using the MATLAB R2016a application to get the FFT results of the EMG signal. FIGURE 3 shows the flow diagram of the device; when the device is turned on, the user attaches electrodes to the respondent for signal tapping of the triceps and rectus femoris muscles. After the tool is turned on, it will initialize; after that it will get ADC data from the EMG instrumentation leads, which read muscle signals, which are then processed on the microcontroller and sent to the PC so that it can be monitored.

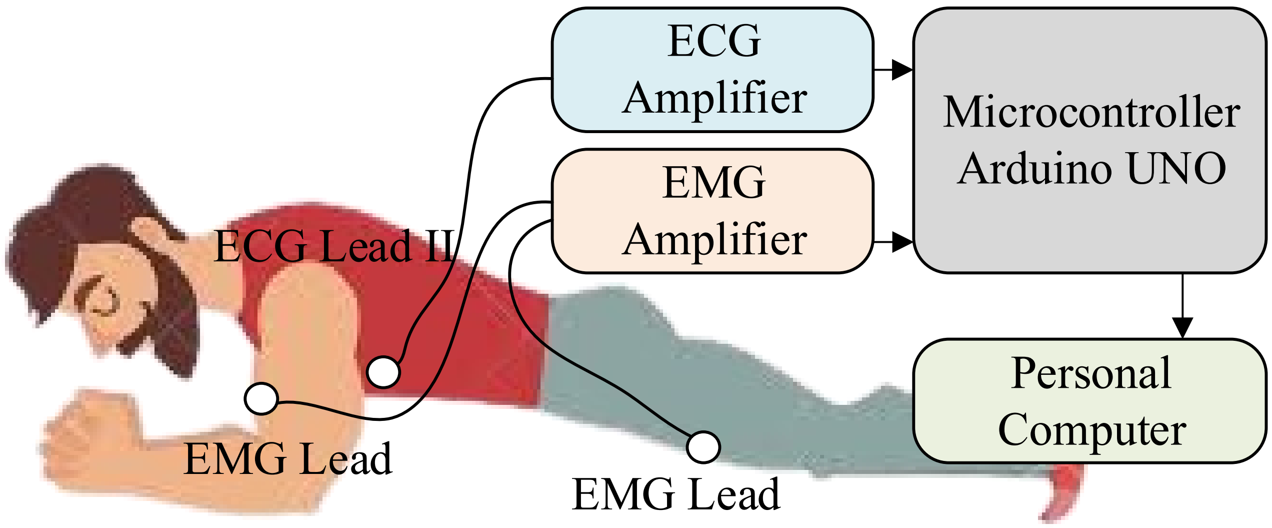

FIGURE 1. Illustration of data collection on respondents

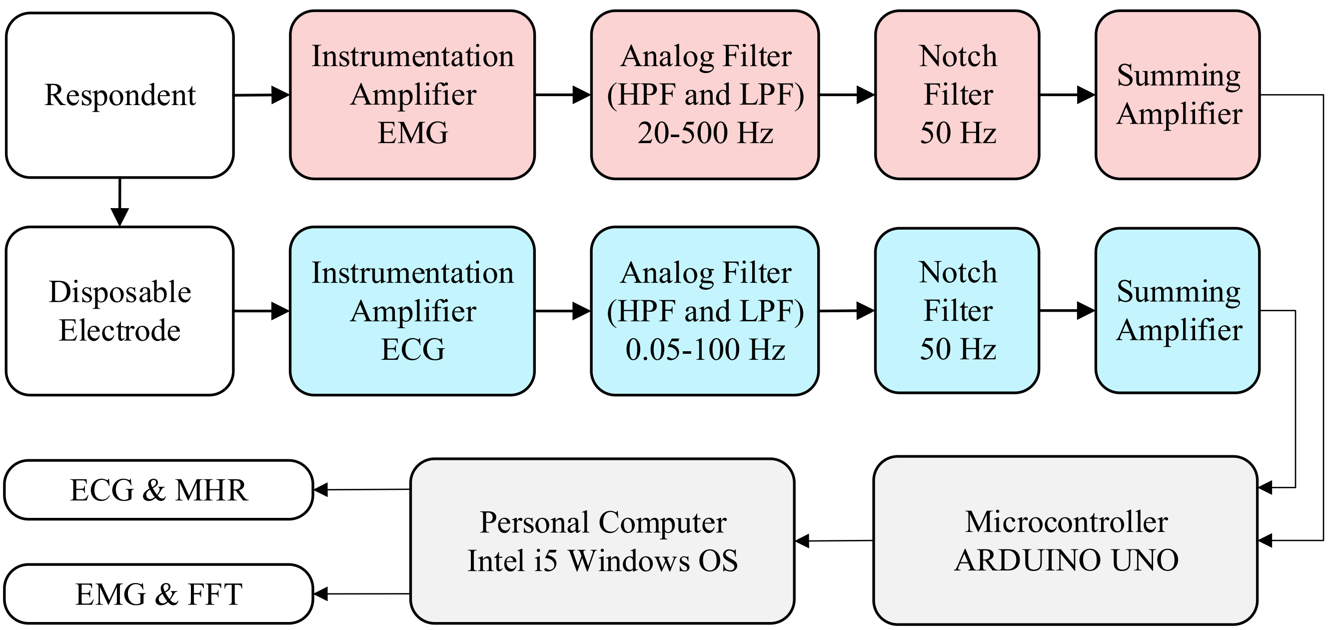

FIGURE 2 Block diagram of ECG and EMG design system

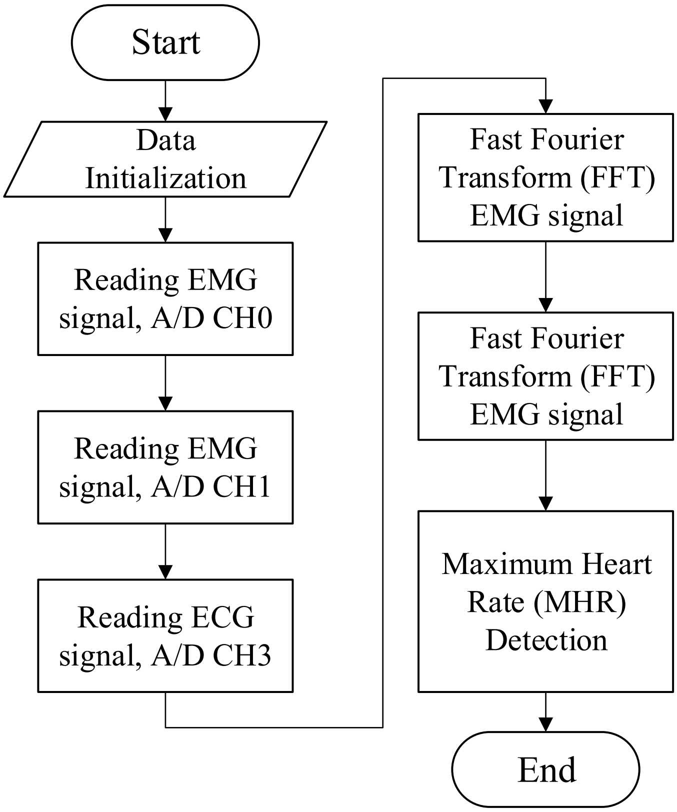

FIGURE 3. Arduino flowchart for data processing

B. DATA ANALYSIS

Measurements of each respondent were repeated five times. The value of the measurement is obtained by using the FFT. Fast Fourier Transform (FFT) divides a signal into different frequencies in a complex exponential function. Fast Fourier Transform (FFT) is an algorithm to calculate discrete Fourier transform quickly and efficiently. Because the signals in the communication system are continuous, the results can be used for Fourier transforms. Mathematically, FFT can be formulated [25] as follows (1):

$$S(f) = \int_{-\infty}^{\infty} s(t)e^{-j2\pi ft}dt \quad (1)$$

where S(f) is the signal in the frequency domain, s(t) is the signal in the time domain, $s(t)e^{-j2\pi ft}$ is the constant value of a signal, f (frequency) and t (time). The authors use MPF, MDF and MNF to get more detailed measurement results. MPF is the result of the sum of the magnitude weights at each frequency divided by the number of magnitudes [26]. The average power frequency can be formulated as follows:

$$MPF = \frac{\sum_{i-1}^{N/2} f(i)xmag(i)}{\sum_{i-1}^{N/2} mag(i)} \quad (2)$$

where N is the amount of data, f(i) is the number of frequencies at I, and mag(i) is the signal magnitude at i. The median frequency is half of the total power, or TTP (dividing the total area of power into two equal parts). The median frequency can be formulated as follows:

$$MDF = \sum_{i=1}^{MDF} Pj = \sum_{i=MDF}^{M} Pj = 1/2 \sum_{i=1}^{M} Pj \quad (3)$$

where Pj is the EMG power spectrum at frequency j and M is the length of frequency [25]. MNF is the average value of the power frequency of a signal from i = 1 to M [27]. The mean frequency can be formulated as follows :

$$MNF = \frac{\sum_{i=1}^{M} FiAi}{\sum_{i=1}^{M} Ai} \quad (4)$$

where M is the frequency length, Fi is the frequency at I,Ai is the amount of data at i. In this study using paired t-test (paired t-test) using Ms. Excel, paired t-test is used to test data on one research object that gets 2 different treatments [30]. The t-test can be formulated as follows :

$$t = \frac{x-\mu}{S/\sqrt{n}} \quad (5)$$

where t is the coefficient t, x = sample mean, μ = population mean, S = standard deviation, and n = number of samples. Pearson correlation produces a coefficient used to measure the strength of the linear relationship between two variables [31]. The Pearson correlation test can be formulated as follows:

$$r_{xy} = \frac{n\sum_{i=1}^{n} XiYi - \sum_{i=1}^{n} Xi \sum_{i=1}^{n} Yi}{\sqrt{\left(n\sum_{i=1}^{n} Xi^2 - \left(\sum_{i=1}^{n} Xi\right)^2\right)\left(n\sum_{i=1}^{n} Yi^2 - \left(\sum_{i=1}^{n} Yi\right)^2\right)}} \quad (6)$$

where r_{xy} is the correlation coefficient of the x and y variables, Xi is the i-th data value for the X variable, Yi is the i-th data value for the Y variable and n is the number of data. The standard deviation is a value that indicates the level (degree) of variation in a group of data or a standard measure of deviation from its mean. The standard deviation (SD) formula can be shown in the equation:

$$SD = \sqrt{\frac{\sum(xi-x)^2}{(n-1)}} \quad (7)$$

where xi indicates the amount of the desired values, x indicates the average of the measurement results, n shows the number of measurements.

III. RESULT

The highest EMG amplitude values tend to be during contraction, and the lowest EMG amplitude values are during relaxation. The most considerable contraction value obtained from respondent 1 for the Triceps is 1100 mV, and the lowest value during relaxation in the Triceps muscle is 600 mV, while the value for the Rectus Femoris is 1700 mV and the lowest value during relaxation in the Rectus Femoris muscle is 1000 mV.

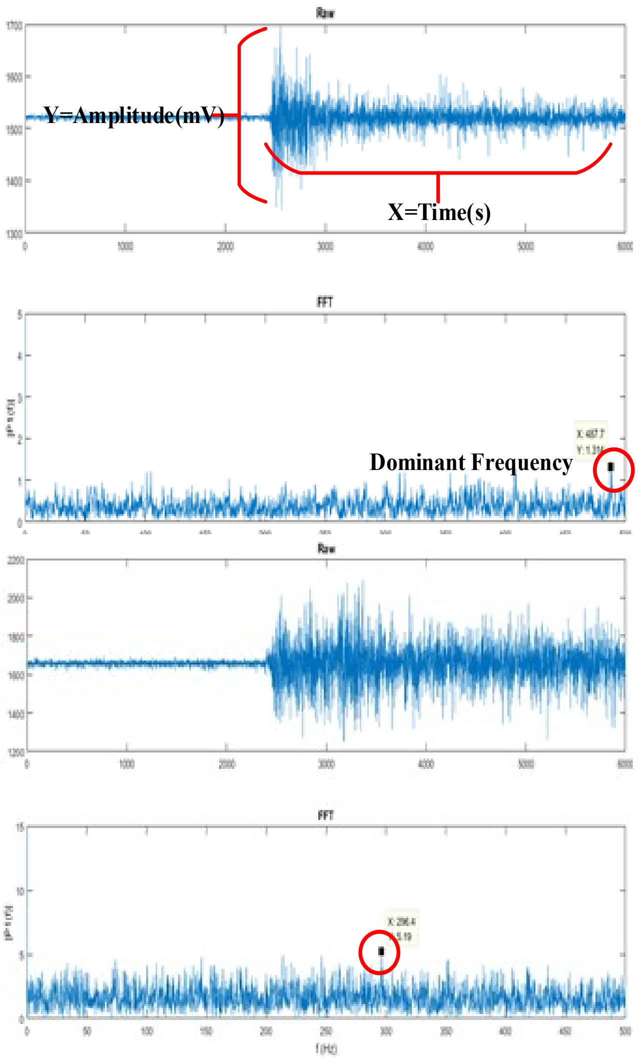

FIGURE 1. **Graph of EMG and FFT signals at the time of pre-exercise (Upper is the output of the triceps muscle and the bottom is the output of the Rectus Femoris muscle)**

The results of the FFT can be seen in FIGURE 4 is the result of the graph when the respondent is pre-exercised, and FIGURE 5 is the result of the graph when the respondent is post-exercised. At the time of pre-exercise and post-exercise, there is a change in the frequency value which means that the respondent experiences muscle fatigue. In the FFT results, the change in frequency is less visible; therefore, researchers use other methods so that muscle fatigue in respondents can be seen

Then the authors took data from MPF, MDF, and MNF to see muscle fatigue in respondents. MPF, MDF and MNF are parameters used to measure the average frequency of the EMG signal. Following are the results of MPF, MDF and MNF data on respondents pre- and post-exercise. the results show that the MPF value changes in the amplitude value, the MDF and MNF values show a frequency shift in the respondent's data

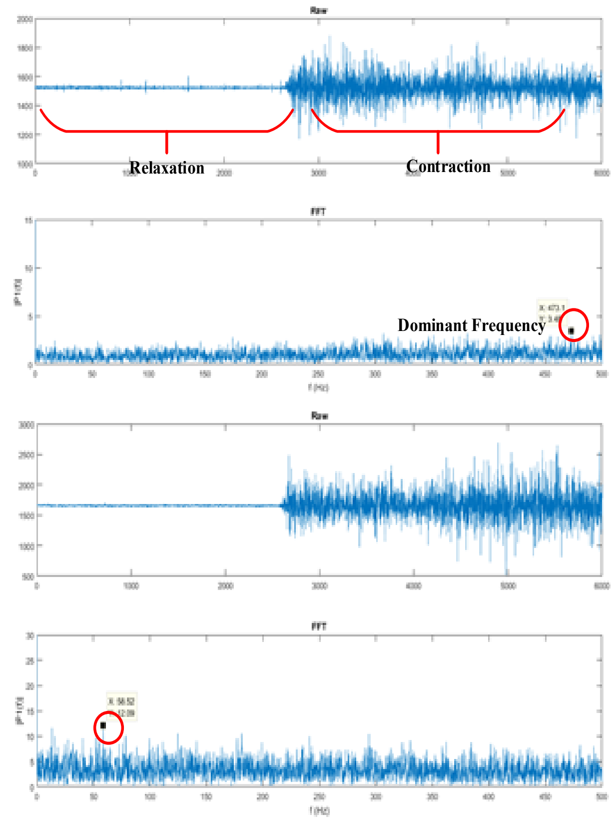

FIGURE 2. **Graph of EMG and FFT signals at the time of post-exercise (Upper is the output of the triceps muscle and the bottom is the output of the Rectus Femoris muscle)**

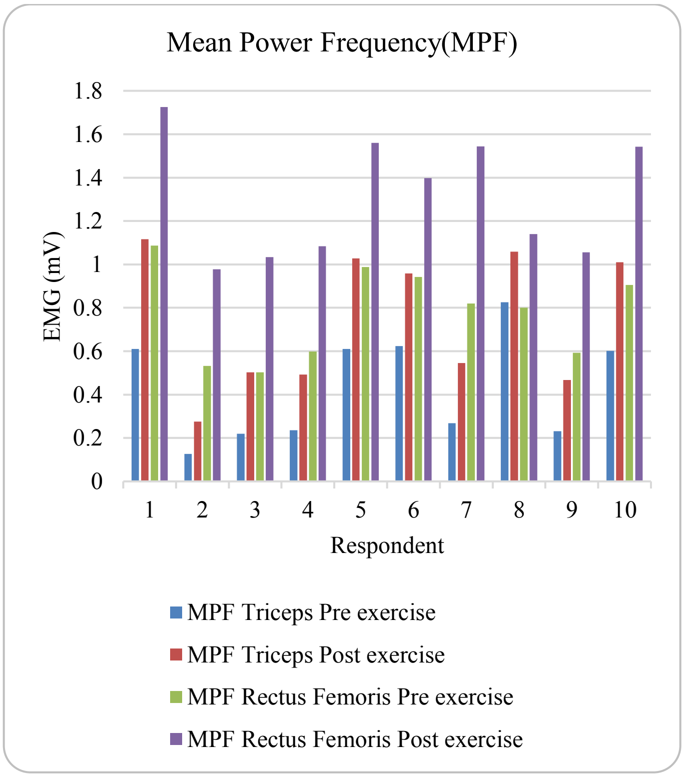

FIGURE 3. **shows the results of the MPF (Mean Power Frequency) graph**

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generated from measurements on the Triceps and Rectus Femoris muscles

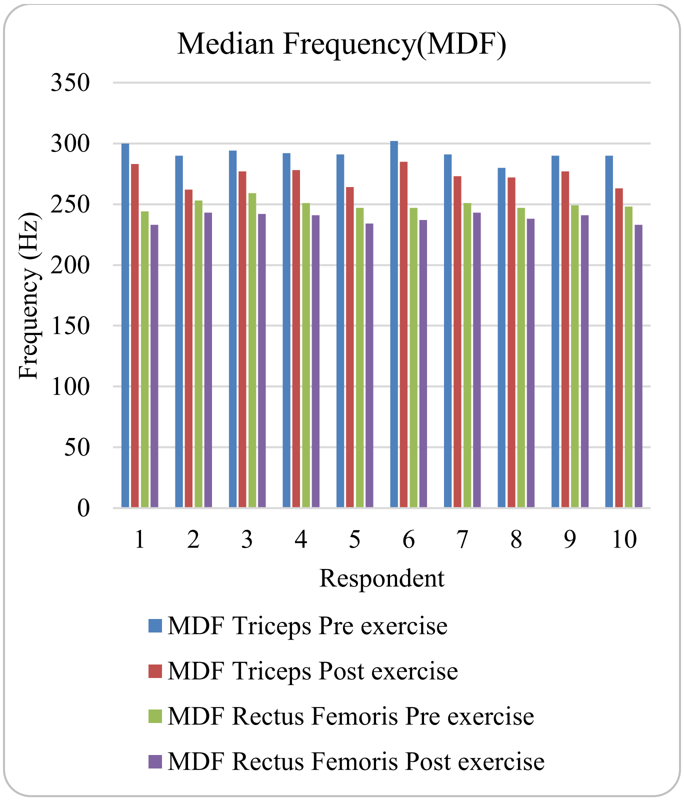

FIGURE 4. shows the results of the MDF (Median Frequency) graph generated from measurements on the Triceps and Rectus Femoris muscles

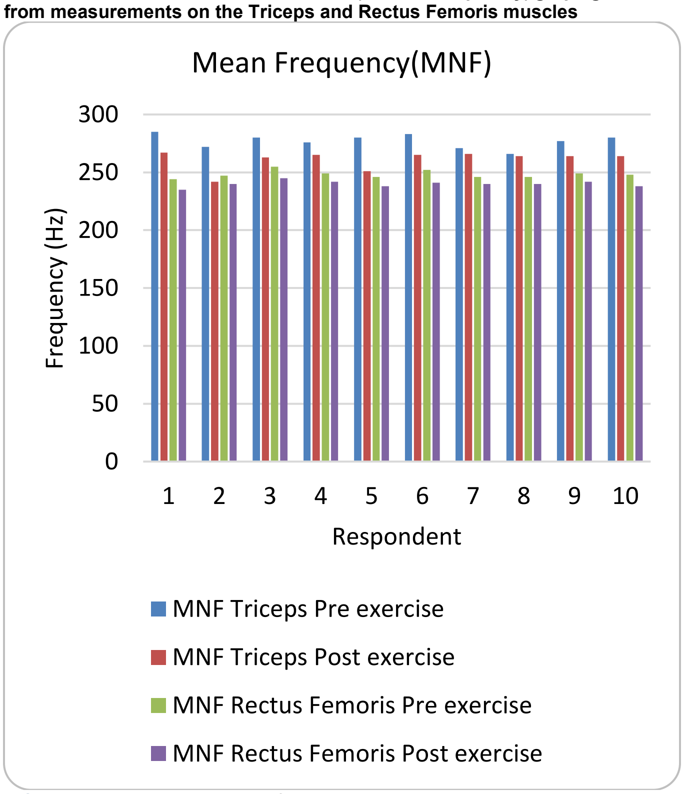

FIGURE 5. shows the results of the MNF (Mean Frequency) graph generated from measurements on the Triceps and Rectus Femoris muscles

In the results of the graphs in FIGURE 6, MPF data on respondents in the Triceps muscle shows the average value for pre-exercise±SD respondents is 0.4354 ± 0.24565, in the Rectus Femoris muscle shows the average value in pre-exercise±SD is 0.7766 ± 0.2443, and in post-exercise±SD the Triceps muscle shows an average value of 0.7454 ± 0.3206, in the rectus Femoris muscle, shows an average value in post-exercise±SD is 1 .3062 ± 0.3247. The results of FIGURE 7, MDF data on respondents in the Triceps muscle showed the average value for pre-exercise±SD respondents was 292.01 ± 7,416; in the Rectus Femoris muscle, the average value for pre-exercise±SD was 249.7 ± 5.072, and in post-exercise±SD of the Triceps muscle showed an average value of 273.47 ± 11.8441, in the Rectus Femoris muscle the average value of post-exercise±SD was 238.47 ± 5.9325. The results of FIGURE 8, MNF data on respondents in the Triceps muscle showed the average value in pre-exercise±SD respondents was 276.99 ± 7.1898; in the rectus femoris muscle, the average value in pre-exercise±SD was 248.26 ± 4 0.0544, in post-exercise±SD the Triceps muscle showed an average value of 260.94 ± 10.9158, in the Rectus Femoris muscle the average value in post-exercise±SD was 240.04 ± 4.0681.

FIGURE 9 and 10 are the plotting on the telemetry viewer to see the shape of the ECG and EMG signals. On display are ECG Lead 1, Lead 2, and Lead 3, EMG 1 is the Triceps muscle lead, and EMG 2 is the Rectus Femoris muscle lead. FIGURE 9 shows that during pre-exercise, there is no visible effect on the ECG signal when the EMG signal contracts. In FIGURE 10, during exercise (plank activity), the respondent's ECG signal is affected by EMG contractions, resulting in noise movement artifacts. In FIGURE 11, post-exercise shows the same results as respondents pre-exercise.

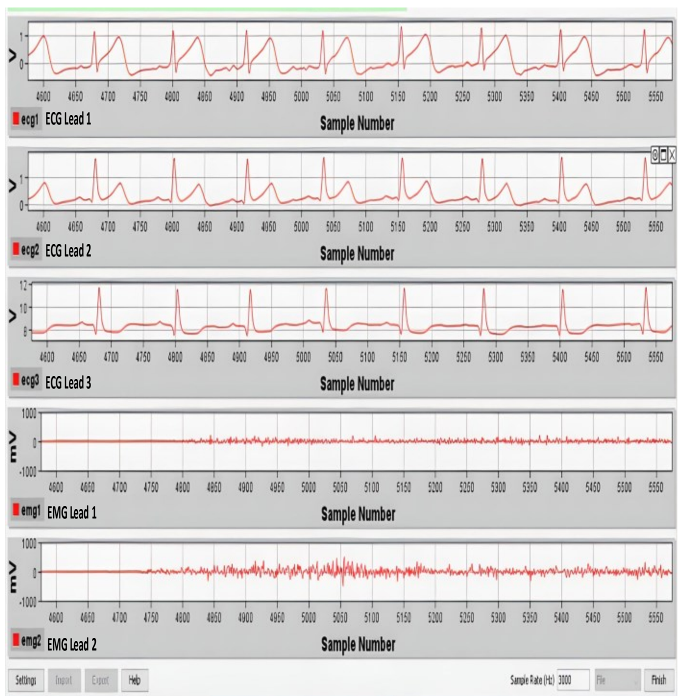

FIGURE 6. The results of plotting ECG and EMG signal data in the Telemetry Viewer during Pre Exercise on respondents

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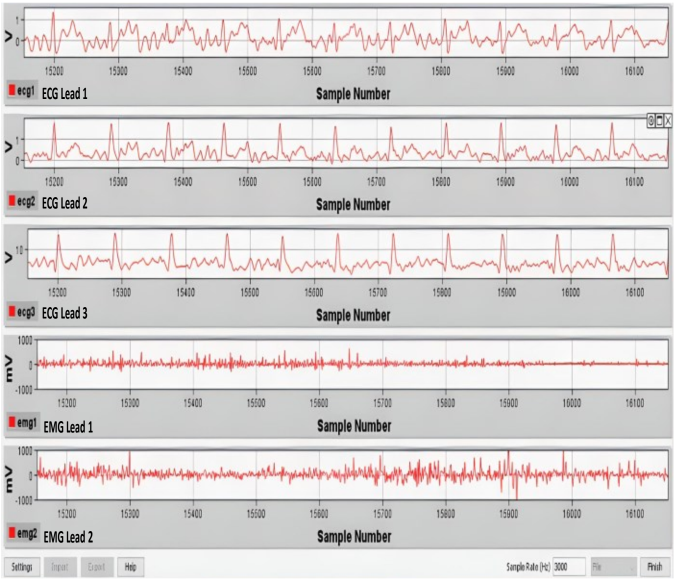

FIGURE 7. The results of plotting ECG and EMG signal data in the Telemetry Viewer during Exercise on respondents

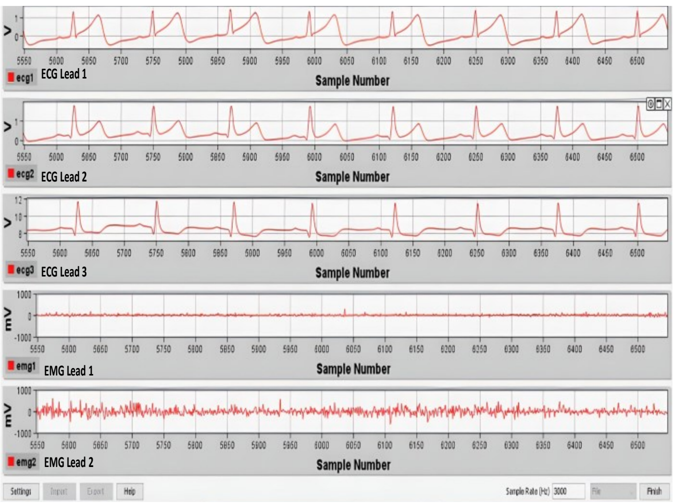

FIGURE 8. The results of plotting ECG and EMG signal data in the Telemetry Viewer during Post Exercise on respondents

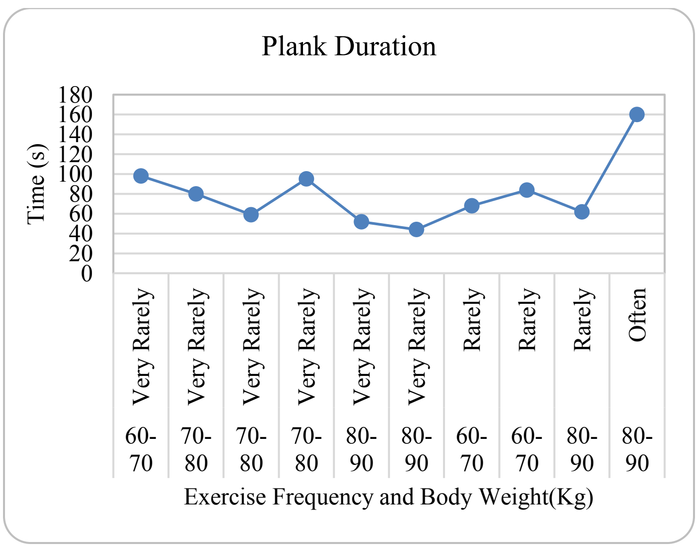

FIGURE 9. Exercise frequency of respondents when doing plank

Above is a figure of respondent's data results when doing plank activities. In FIGURE 12, the results of the respondent's data are three respondents weighing 60-70Kg, three considering 70-80Kg, and four weighing 80-90Kg. At a weight of 60-70Kg, two respondents with a frequency of infrequent exercise, and one respondent with a very rare frequency. At a weight of 70-80Kg, three respondents with a very rare frequency. At a weight of 80-90Kg, two respondents with very rarely exercise frequency, one respondent with frequent frequency, and one respondent with infrequent frequency. The very rare frequency has an average plank duration of 1m11s, the rare frequency has an average duration of 1m11s, and the frequent frequency has a duration of 2m40s.

After doing the T-test by comparing the two stages of data collection, the values obtained from the Triceps and Rectus Femoris muscles in the respondents can be seen as a significant difference in the results of the MPF, MDF and MNF values (pValue <0.05) at the pre-test and post-test.

In the results of the data FIGURE 12, Pearson correlation test is performed using Ms. Excel. The author uses the correlation coefficient guideline in accordance with the literature [31]. The test showed a strong correlation coefficient of 0.628, which means that the relationship between exercise frequency and plank duration is strong.

IV. DISCUSSION

The value of the EMG amplitude is read by the EMG circuit. Pins A3 and A4 on Arduino are input from recording the triceps and rectus femoris muscles, and then the ADC data is processed by the Arduino UNO ATmega328 microcontroller. Then for recording the EMG signal using the telemetry viewer V4 application, which will be connected to Arduino using serial communication. After completion of recording the EMG signal will be saved in CSV format. The resulting data will be processed using the MATLAB R2016a application in order to change the data from the time domain to the frequency domain (FFT). The authors use MPF, MDF, and MNF to get more detailed measurement results and perform a T-test.

On FFT results, at the time of pre-exercise and post-exercise, there is a change in the frequency value which means that the respondent experiences muscle fatigue. The test results showed a significant value of MPF, MDF, and MNF (pValue <0.05) in the pre-test and post-test, which indicates that respondents experience fatigue in line with research conducted by A. Alfarabi [24] and Marten Giri [32]. During exercise (plank activity), the respondent's ECG signal is affected by EMG contractions, resulting in noise movement artifacts. This is also found in research conducted by Luis, Francisco et al. [33] and Paiva [3]. On the results of the Pearson correlation test between the frequency of exercise and the duration of the plank, it was found that there was a strong relationship between the two variables. This is due to several factors that affect a person's exercise, such as age, gender, lifestyle, genetics, muscle strength, muscle endurance, cardiac endurance, and exercise frequency [34].

Compared to previous studies, the advantage in this study is that there is a combination of 2 ECG and EMG devices that function to see the effect of muscle fatigue on cardiac signals. While the drawbacks/weaknesses are the inefficient analog EMG circuit and noise at the output of the EMG circuit at the pin electrode or less pressing during relaxation. To overcome the noise of the EMG signal output, dry electrodes and high quality components are recommended. In addition, there is lost data on the EMG signal per second when displayed simultaneously with the ECG signal. To increase the ability to transmit data, it is recommended to use a Raspberry microcontroller with higher specifications in sending data. The development of ECG and EMG can be implemented to monitor medical rehabilitation patients during physical activity. Wireless monitoring is no stranger to this world. Further developments in ECG and EMG monitoring tools are made wirelessly [35][36].

V. CONCLUSION

This study aims to optimize the use of ECG and EMG to unify measurements during physical activity. It may be concluded that a tool to detect the effect of muscle fatigue on cardiac signals on physical activity by monitoring ECG and EMG signals (EMG parameters) has been successfully developed and can be used properly. The results of the FFT data show a frequency shift, and the results of the MPF, MDF, and MNF values indicate a change in values which suggests that the respondent is experiencing muscle fatigue. This means that the respondent's muscle fatigue affects the heart signal, characterized by noise movement artifacts. In testing using the T-test on the pretest and posttest, there was a significant change in value (pValue <0.05) in MPF, MDF, and MNF. For testing the Pearson correlation on exercise frequency with plank duration, the correlation coefficient value was 0.628, which means it has a strong relationship. For future work, multiple wireless connections should be proposed, so users can easily use the tool to perform physical activities and can be accessed through various applications.

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ATTACHMENT

a. **Schematic and board circuit = LINK**
https://drive.google.com/drive/folders/1m43TP9QWG5WIk3DkwSTgvgSjfOz0Kitn?usp=sharing

b. **MPF, MDF, MNF Result Table = LINK**
https://drive.google.com/drive/folders/1UFvCR2q9ZzO3OK21tFzUuDPkoMW6W06A?usp=sharing

c. **Result Table T-test and Correlation Pearson = LINK**
https://drive.google.com/drive/folders/1pMSIRnje8zq1BRHriL_iwg3Lzbn8oNwX?usp=sharing