

RESEARCH PAPER

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Analysis of the Use of Transcutaneous Electrical Nerve Stimulation in Muscle Fatigue With Electromyography Signal Monitoring (Transcutaneous Electrical Nerve Stimulation Parameters)

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ABSTRACT Muscle fatigue is a condition that occurs after a strong and prolonged muscle contraction, in which the muscle is no longer able to contract for a certain period of time. This fatigue can also result from overexertion but abnormal fatigue can also be caused by restriction or interference with different stages of muscle contraction. The purpose of this study was to analyze the use of TENS in muscle fatigue by monitoring EMG signals so that differences in muscle conditions can be monitored directly. TENS can aid the healing process by returning damaged muscle tissue to a normal state, which will result in pain reduction and consequently the prevention of muscle fatigue and other improved outcomes. The design of this tool consists of a voltage rectifier circuit, an intensity regulator, the intensity selection, and the SSR module. The data from the measurement results that have been taken has the maximum average error value of 0.12% for Frequency in Continuous Mode, for Frequency in Burst Mode it has the maximum average error value is 0.251%, while for Current has the maximum average error value of 10.1%. Based on the results of testing on patients, the results of the questionnaire test showed that there was a decrease in the level of fatigue between the test with the TENS method and the rest method, so it can be seen that the effect of using TENS can restore the performance of muscles experiencing muscle fatigue. The results of this tool can be used to monitor the results of therapy in muscle fatigue.

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I. INTRODUCTION

Muscle fatigue is a decrease in the ability of the muscles to generate a force [1]. Muscle fatigue refers to a process that approximates the true physiological definition of a reduced response to the same stimulation. The mechanisms that play a role in explaining fatigue have been generally classified as product accumulation and substrate depletion. Muscle fatigue in general can be assessed based on the percentage decrease in muscle strength, recovery time from muscle fatigue, and the time it takes for fatigue to occur [2]. Muscle fatigue triggers a decrease in the sensory ability of the skin [3], accumulation of metabolites in muscle fibers, and inadequate motor command in the motor cortex [4]. Musculoskeletal disorders alter muscle tone and body rigidity [5], and abnormal muscle shape can cause muscle damage [6][7]. TENS (Transcutaneous Electrical Nerve Stimulation) is a tool to stimulate the blood flow and muscle

nerves in humans [8]. TENS works by sending an electric current to the muscles that need therapy, causing the muscles to exercise passively [9]. TENS can aid the healing process by returning damaged muscle tissue to a normal state, which will result in pain reduction and consequently the prevention of muscle fatigue and other improved outcomes [10].

In several previous studies, TENS was created using triangular, monophasic, and asymmetrical biphasic waves. And the frequency used is from 10 Hz to 200 Hz. Y. Setiawan designed TENS with a triangular and square wave output, and has a maximum frequency of 70 Hz [8]. L. Mahmum designed TENS with square wave, triangular, and asymmetrical biphasic output, and has a frequency of 80 Hz, 150 Hz, and 200 Hz [9]. Risalia designed TENS with asymmetrical biphasic wave output and has a frequency of 50 Hz, 100 Hz, and 200 Hz [11]. Therapeutic methods in several conditions of muscle fatigue have been carried out by

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several researchers, both by taking rest, massage on fatigued muscles, giving coffee, heat therapy, and Electrical Stimulus [2][7][10][12][13][14][15][16][17][18][19][20]. EMG is a technique for measuring the electrical activity of muscles. EMG signals are used to evaluate fatigue by monitoring changes. activity Electrical signals generated by muscle fibers such as muscle weakness, numbness, certain types of pain, cramps, muscle disorders such as polymyositis or biomechanical movement of living beings. and can be used to determine the level of muscle weakness and strength for recovery purposes [12][21][22][23]. Monitoring the signal of muscles experiencing muscle fatigue can be done in 2 ways, namely, by comparing the EMG data before and after the occurrence of muscle fatigue, or by taking EMG data from before the occurrence of muscle fatigue to after the occurrence of muscle fatigue [1][23][24][25].

Based on the results of the problem identification, the authors intend to analyze the use of TENS in muscle fatigue with EMG signal monitoring (TENS parameters), the purpose of this study is to see the difference in muscle condition directly, so that the effectiveness of using TENS therapy on muscle fatigue can be known. The use of this design is more effective because it has advantages in terms of data collection on respondents, because by combining TENS and EMG the results of TENS therapy on muscle fatigue can be done directly using EMG so that the effect of using TENS therapy on muscle fatigue can be known.

II. MATERIALS AND METHODS

A. Experimental Setup

The experiment was conducted on 6 patients in the age category of 18 - 23 years in the Department of Electromedical Engineering Poltekkes Kemenkes Surabaya. Data collection was done by taking a questionnaire on the fatigue that was being experienced after doing TENS therapy.

Taiwan) measuring instrument to calibrate the TENS output. Arduino Uno as a Microcontroller on the device. Solid State Relay (Omron, G3MB, China) was used as the driver for frequency generation, pulse shape, and therapy mode. For setting the current intensity using a resistor as a voltage division circuit. And This study is used a disposable electrodes ECG (OneMed, Jayamas Medical Industri, Indonesia).

2) EXPERIMENT

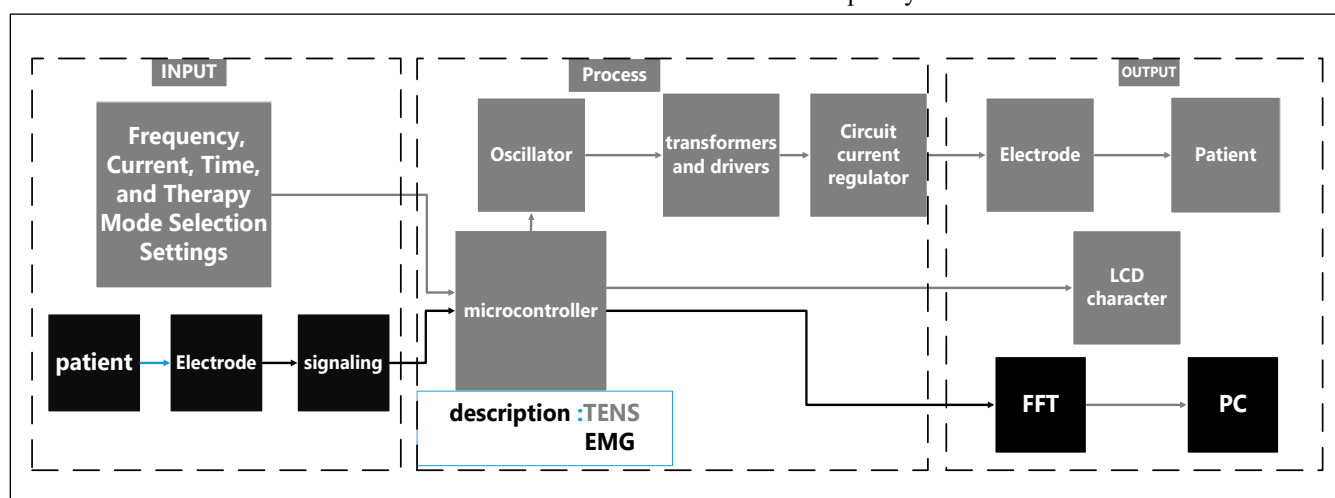
In this study, after the design of the device was completed, the current and frequency output of TENS were measured with a current setting of 10mA to 100mA with a range of 10mA and a frequency setting of 10 to 100 Hz with a range of 10 Hz. Measurements were carried out 10 times for each parameter using a Scope Meter and Oscilloscope. Each setting, the output of TENS was calculated to validate the results of this study. To see muscle fatigue, a questionnaire data was collected on the fatigue being experienced after doing TENS therapy.

B. The Diagram Block

As shown in **Figure. 1**, after the tool is turned on, then setting the frequency, current, and mode (Continuous or Burst), and therapy time. If everything is set, the microcontroller will issue commands to the driver and transformer circuit blocks. The driver and transformer circuit functions as a frequency generator, pulse shape, and therapy mode.

C. The Flowchart

The microcontroller program is built based on the flowchart as shown in **Figure. 2**. When the device is turned on, the LCD initialization process occurs. After the initialization process is complete, an option will appear to select the frequency to use.



1) MATERIALS AND TOOL

This study used a Scope Meter (Fluke Biomedical, 190M-4, USA) and Oscilloscope (GW Instek, GDS-3252,

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Figure 1. The Diagram Block of TENS

After selecting the frequency, an option will appear to choose the intensity of the current used. Then select the therapy mode used (Contiuous or Burst). And the last one is choosing the time setting for how long the tool will be used. When the therapy time ends, the output stops and a finished display appears on the LCD to indicate that the time is over.

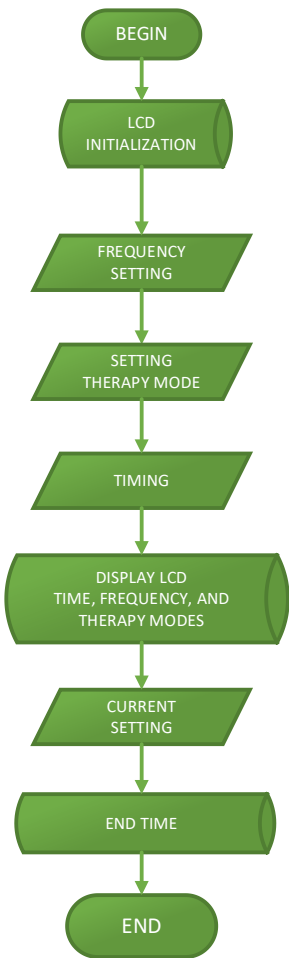


Figure 2. The Flowchart of TENS

III. RESULT

In this study, the TENS module was tested with a Oscilloscope and Scope Meter. The test results show the output parameters are appropriate and within the allowable tolerance range.

A. The TENS Design

The results of the TENS design made have an Alternating Biphasic pulse output with 10 frequency settings, namely 10-100 Hz with a range of 10 Hz, and 10 intensity selections, namely 10-100 mA with a range of 10 Hz, and has 2 therapeutic modes, namely continuous mode

and burst mode. The results of the TENS design are shown in Figure. 3.



Figure 3. The Design of TENS

1) THE VOLTAGE RECTIFIER

The voltage rectifier circuit is shown in Figure. 4. is as a full-wave rectifier output from the transformer. The main component of this circuit is a diode as an electric current rectifier capable of converting alternating electric current (AC) into direct electric current (DC). The output of the transformer which is alternating current will be converted into direct current, then the diode output will enter the capacitor as a filter to remove annoying noise.

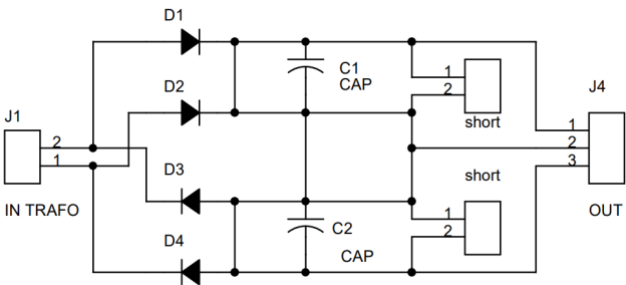


Figure 4. The voltage rectifier circuit

2) THE INTENSITY CONTROL

The intensity control circuit is shown in Figure. 5. serves as a current distribution, which is a dose setting for the intensity of the incoming current to the patient.

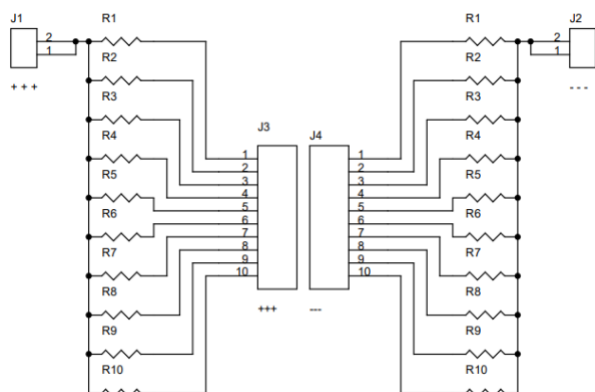


Figure 5. The intensity control circuit

3) THE INTENSITY SELECTION

The intensity selection circuit is shown in **Figure 6**. get input from the intensity control circuit. The output of the intensity control circuit will enter the NO leg on the relay, then as an election a rotary switch is used which is connected to the coil leg on the relay, when the rotary switch is connected to one of the existing relay coils, the current will come out according to the available selection. The selection of current intensity is adjusted to the patient's comfort and endurance.

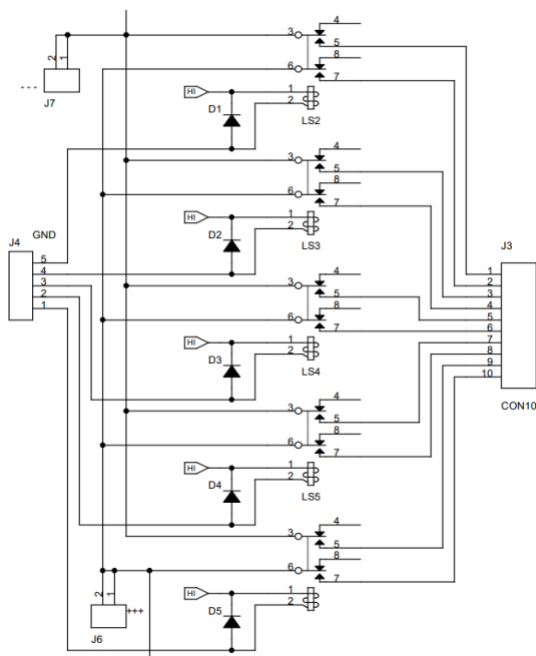


Figure 6. The intensity control circuit

4) THE SSR MODULE (SOLID STATE RELAY)

The SSR module shown in **Figure 7**. serves as a driver to adjust the frequency, pulse shape, and mode of the

desired TENS output according to user settings. The SSR module is divided into types, namely Low level trigger, in this type the SSR module will work when the input is given a logic 0 and High Level Trigger, in this type the SSR module will work when the input is given a logic 1. The module input is the output from the Arduino PWM pin.

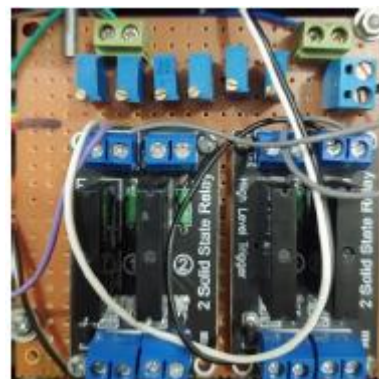


Figure 7. The intensity control circuit

B. The Listing Program for Arduino TENS

The listing program for Arduino was shown in the **Pseudocode 1**. This program functions to select each TENS parameter, namely Frequency, Time, and Therapy Mode. Which will then be displayed on the LCD Character display.

Pseudocode: 1. Program for Arduino TENS

```
void timer() {
  IF (menit >= 0) {
    waktu1 = millis();
    IF (waktu1 - waktu2 >= 1000) {
      detik--;
      waktu2 = millis();
    }
  }
  IF (detik < 0) {
    menit--;
    IF (menit >= 0) {
      detik = 60;
    }
  }
  IF (menit < 0) {
    detik=0;
    menit=0;
    frequency1=0;
    frequency2=0;
    burst=0;
    normal=0;
    burst==0;
    normal==0;
  }
}

void updateMenu() {
  // lcd.clear();
  lcd.setCursor(0, 0);
}
```

```

lcd.print("MODE TENS:");
lcd.setCursor(0, 1);
lcd.print("T:");
lcd.setCursor(9, 1);
lcd.print("F:");
}
void action1() {
  switch (menu1) {
    case 0:
      menu1 = 1;
      break;
    case 1:
      lcd.setCursor(10, 0);
      break;
    case 2:
      lcd.setCursor(10, 0);
      lcd.print("BURST ");
  }
}
void action2() {
  switch (menu2) {
    case 0:
      menu2 = 1;
      break;
    case 1:
      lcd.setCursor(11, 1);
      lcd.print("0 Hz");
      frequency1 = 0;
      frequency2 = 0;
      break;
    case 2:
      lcd.setCursor(11, 1);
      lcd.print("10 Hz");
      frequency1 = 10;
      frequency2 = 10;
      break;
    case 3:
      lcd.setCursor(11, 1);
      lcd.print("20 Hz");
      frequency1 = 20;
      frequency2 = 20;
      break;
    case 4:
      lcd.setCursor(11, 1);
      lcd.print("30 Hz");
      frequency1 = 30;
      frequency2 = 30;
      break;
    case 5:
      lcd.setCursor(11, 1);
      lcd.print("40 Hz");
      frequency1 = 40;
      frequency2 = 40;
      break;

```

```

case 6:
  lcd.setCursor(11, 1);
  lcd.print("50 Hz");
  frequency1 = 50;
  frequency2 = 50;
  break;
case 7:
  lcd.setCursor(11, 1);
  lcd.print("60 Hz");
  frequency1 = 60;
  frequency2 = 60;
  break;
case 8:
  lcd.setCursor(11, 1);
  lcd.print("70 Hz");
  frequency1 = 70;
  frequency2 = 70;
  break;
case 9:
  lcd.setCursor(11, 1);
  lcd.print("80 Hz");
  frequency1 = 80;
  frequency2 = 80;
  break;
case 10:
  lcd.setCursor(11, 1);
  lcd.print("90 Hz");
  frequency1 = 90;
  frequency2 = 90;
  break;
case 11:
  lcd.setCursor(11, 1);
  lcd.print("100Hz");
  frequency1 = 100;
  frequency2 = 100;
  break;
}}
void action3() {
  switch (menu3) {
    case 0:
      menu3 = 1;
      break;
    case 1:
      lcd.setCursor(2, 1);
      lcd.print("00:00");
      menit = 0;
      break;
    case 2:
      lcd.setCursor(2, 1);
      lcd.print("10:00");
      menit = 9;
      break;
    case 3:
      lcd.setCursor(2, 1);

```

```

    lcd.print("20:00");
    menit = 19;
    break;
case 4:
    lcd.setCursor(2, 1);
    lcd.print("30:00");
    menit = 29;
    break;
case 5:
    lcd.setCursor(2, 1);
    lcd.print("40:00");
    menit = 39;
    break;
case 6:
    lcd.setCursor(2, 1);
    lcd.print("50:00");
    menit = 49;
    break;
case 7:
    lcd.setCursor(2, 1);
    lcd.print("60:00");
    menit = 59;
    break;
}}
void action4() {
    switch (menu4) {
        case 0:
            menu2 = 1;
            break;
        case 1:
            lcd.setCursor(11, 0);
            lcd.print(" ");
            break;
        case 2:
            lcd.setCursor(10, 0);
            lcd.print("NORMAL");
            break;
    }
}
void tombol() {
    IF (start == 0) {
        IF (!digitalRead(selectButton) == 1) {
            start = 1;
        }
        IF (start == 0) {
        }
        IF (!digitalRead(frekButton) == 1) {
            menu2++;
            IF (menu2 > 11) {
                menu2 = 0;
            }
            action2();
            delay(500);
            WHILE (!digitalRead(frekButton) == 1);
        }
    }
}

```

```

    IF (!digitalRead(timButton) == 1) {
        menu3++;
        IF (menu3 > 7) {
            menu3 = 0;
        }
        action3();
        delay(500);
        WHILE (!digitalRead(timButton) == 1);
    }
    IF (!digitalRead(burstbutton) == 1) {
        menu1++;

        IF (burst == 0) {
        }
        IF (menu1 > 2) {
            menu1 = 0;
        }
        action1();
        delay(500);
        burst=1;
        normal=0;
        WHILE (!digitalRead(burstbutton) == 1);
    }
    IF (!digitalRead(normalbutton) == 1) {
        menu4++;
        IF (normal == 0) {
        }
        IF (menu4 > 2) {
            menu4 = 0;
        }
        action4();
        delay(500);
        normal=1;
        burst=0;
        WHILE (!digitalRead(normalbutton) == 1);
    }
    IF (start == 1){
        tampil();
        IF (!digitalRead(timButton) == 1) {
            menu1++;
            IF (menu1 > 3) {
                menu1 = 0;
            }
            action1();
            delay(500);
            // menu1=max(menu1,1);
            WHILE (!digitalRead(timButton) == 1);
        }
        IF (!digitalRead(frekButton) == 1) {
            menu2++;
            IF (menu2 > 11) {
                menu2 = 0;
            }
            action2();
        }
    }
}

```

```

delay(500);
WHILE (!digitalRead(frekButton) == 1);
}
IF (!digitalRead(timButton) == 1) {
  menu3++;
  IF (menu3 > 7) {
    menu3 = 0;
  }
  action3();
  delay(500);
  WHILE (!digitalRead(timButton) == 1);
}
}
void tampil() {
  IF (start == 1) {
    timer();
    IF (menit < 10) {
      lcd.setCursor(2, 1);
      lcd.print("0");
      lcd.setCursor(3, 1);
      lcd.print(menit);
      lcd.setCursor(4, 1);
      lcd.print(":");
    }
    IF (detik < 10) {
      lcd.setCursor(4, 1);
      lcd.print(":");
      lcd.setCursor(5, 1);
      lcd.print("0");
      lcd.setCursor(6, 1);
      lcd.print(detik);
    }
    IF (menit >= 10) {
      lcd.setCursor(2, 1);
      lcd.print(menit);
      lcd.setCursor(4, 1);
      lcd.print(":");
    }
    IF (detik >= 10) {
      lcd.setCursor(4, 1);
      lcd.print(":");
      lcd.setCursor(5, 1);
      lcd.print(detik);
    }
  }
  IF ((detik < 0)&&(menit < 0)) {
    frequency1=0;
    frequency2=0;
    detik = 0;
    menit = 0;
    burst=0;
    normal=0;
    start==0;
    normal==0;
    burst==0;
  }
}

```

```

IF(burst==0){
  mod3();
}
IF(normal==0){
  mod3();
}
IF(burst==1){
  mod2();
  normal==0;}
IF(normal==1){
  mod1();
  burst==0;}
}
}
void mod1() {
  pwmWrite(led1, 230);
  pwmWrite(led2, 25);
}

void mod2() {
  pwmWrite(led2, 25);
  pwmWrite(led1, 255);
  delay(300);
  pwmWrite(led2, 0);
  pwmWrite(led1, 255);
  delay(200);
  pwmWrite(led2, 0);
  pwmWrite(led1, 230);
  delay(300);
  pwmWrite(led2, 0);
  pwmWrite(led1, 255);
  delay(200);
}

void mod3() {
  pwmWrite(led1, 255);
  pwmWrite(led2, 0);
}
}
void loop() {
  bool success2 = SetPinFrequencySafe(led2, frequency2);
  bool success1 = SetPinFrequencySafe(led1, frequency1);
  updateMenu();
  tombol();
  tampil();
}

```

C. TENS Output Measurement

Before the TENS design was tested on humans, the module was calibrated using an Oscilloscope and Scope Meter. **Figure. 8** show the TENS signal from Oscilloscope. **Figure. 9.** Show the TENS signal from Scope Meter.

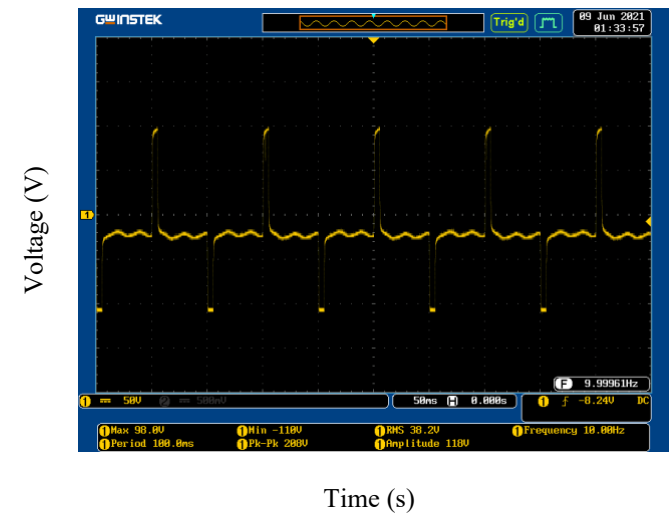


Figure 8. TENS Signal from Oscilloscope (10 Hz)

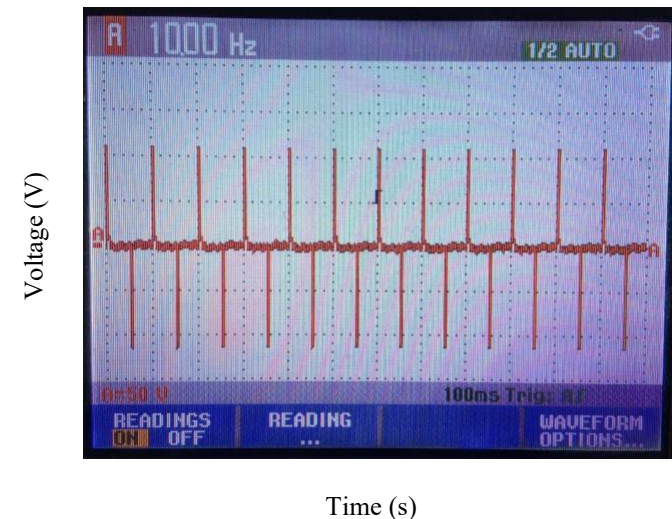


Figure 9. TENS Signal from Scope Meter (10 Hz)

1) MEASUREMENT OF ERROR VALUE

In this study, the TENS design was tested 5 times on each parameter using Oscilloscope and Scope Meter.

Table I. MEASUREMENT OF ERROR VALUE AT FREQUENCY IN CONTINUOUS MODE

Setting Value (Hz)	Error (%)	Tolerance (%)
10	0	± 20
20	0,010	± 20

Table II. MEASUREMENT OF ERROR VALUE AT FREQUENCY IN BURST MODE

Setting Value (Hz)	Error (%)	Tolerance (%)
10	0,010	± 20
20	0,045	± 20
30	0,023	± 20
40	0,015	± 20
50	0,058	± 20
60	0,022	± 20
70	0,251	± 20
80	0,014	± 20
90	0,137	± 20
100	0,021	± 20

Table III. MEASUREMENT OF ERROR VALUE AT CURRENT

Setting Value (mA)	Error (%)	Tolerance (%)
10	7,20	± 20
20	1,75	± 20
30	10,10	± 20

40	3,33	±	20
50	5,44	±	20
60	3,33	±	20
70	1,37	±	20
80	3,34	±	20
90	0,86	±	20
100	0,87	±	20

In **Table I**, it can be seen that the minimum error value is 0% and the maximum error value is 0.012% for Frequency in Continuous Mode, in **Table II**. it can be seen that the frequency value in Burst Mode has a minimum error value of 0.01% and a maximum error value of 0.251%, while in **Table III**. it can be seen that the current value has a minimum error value of 0.86% and a maximum error value of 10.1%.

D. Test Results on Patients

The test is carried out by testing the performance of the tool which is assessed by the respondents in the form of a questionnaire. The test was conducted on 6 respondents, with 2 therapeutic methods, the TENS method and the rest method. Data collection was carried out 5 times for each respondent. The questionnaire used is a questionnaire with a numerical scale that uses an 11 point scale where 0 means there is no feeling of fatigue, 1 is mild fatigue, 10 is severe fatigue.

1) REST METHOD

This method is is carried out by resting for 10 minutes after exercising. The following are the results with testing by respondents.

Table IV. MEASUREMENT OF ERROR VALUE AT CURRENT

No.	Mean (fatigue scale)
P1	2,6
P2	3,0
P3	2,2
P4	3,6
P5	2,2
P6	2,8

Total	2,7
-------	-----

Table IV. shows the results of testing the rest method using a questionnaire, data collection was carried out 5 times on the respondents. From the data above, it can be seen that the smallest average value is 2.2 and the largest average value is 3.6. From the test results obtained, it can be seen that the total average for all respondents is 2.7 which indicates a mild fatigue scale.

2) TENS METHOD

This method is carried out with TENS for 10 minutes after exercising. The following are the results with testing by respondents.

Table V. TEST RESULTS ON THE TENS METHOD

No.	Mean (fatigue scale)
P1	2,4
P2	2,4
P3	2,2
P4	2,6
P5	1,4
P6	2,6
Total	2,3

Table V. shows the results of testing the rest method using a questionnaire, data collection was carried out 5 times on the respondents. From the data above, it can be seen that the smallest average value is 1.4 and the largest average value is 2.6. From the test results obtained, it can be seen that the total average for all respondents is 2.3 which indicates a mild fatigue scale.

IV. DISCUSSION

Based on the measurement results, the output shows that the TENS module made has results that are still within the permissible tolerance range. The data taken has a minimum error value of 0% and a maximum error value of 0.012% for Frequency in Continuous Mode, for Frequency in Burst Mode it has a minimum error value of 0.01% and a maximum error value of 0.251%, while for current has a minimum error value of 0.86% and the maximum error value of 10.1%.

This is a development of the TENS module, because this module is equipped with 10 frequency settings (range 10 - 100 Hz), 10 current settings (range 10 - 100 mA), and 2 therapy modes namely continuous and burst, and this TENS module is equipped with EMG module. When compared with the previous TENS module research, which did not have current settings and frequency selection limitations, and was not equipped with an EMG module [8][9][11].

The combination of the TENS module and the EMG module allows changes in muscle condition to be monitored so that the effects of TENS therapy on muscle fatigue can be known.

However, this study did not consider the muscle fatigue experienced by respondents during TENS therapy [1][18][19][22].

V. CONCLUSION

The purpose of this study was to analyze the use of TENS in muscle fatigue by monitoring EMG signals so that differences in muscle conditions can be monitored directly, so that the effectiveness of using TENS therapy against muscle fatigue can be determined. Based on the test results on patients, the results of the questionnaire test on the TENS method showed a level of 2.3 (mild fatigue) while the resting method showed a level of 2.7 (mild fatigue), so it can be seen that the effect of using TENS can restore muscle performance that is experiencing muscle fatigue. In the future, this research can be developed by adding Symmetric Biphasic and Asymmetric Biphasic pulses as a comparison of therapeutic methods for muscle fatigue.

REFERENCES

- [1] D. Yuliansyah, "Deteksi Kelelahan Otot Menggunakan Sinyal Emg Dan Detektor Gaya Pada Gerak Dasar Ekstensi Dan Fleksi Knee-Joint Untuk Evaluasi Penggunaan Functional Electrical Stimulation Pada Sistem Rehabilitasi Lower Limb," *Sepuluh Nop. Inst. Technol.*, p. 171, 2017.
- [2] Y. Utama, "Pengaruh Pemberian Kopi Terhadap Kelelahan Otot," *Skripsi, Univ. Diponegoro*, pp. 1–18, 2010.
- [3] J. Han, S. Park, S. Jung, Y. Choi, and H. Song, "Comparisons of changes in the two-point discrimination test following muscle fatigue in healthy adults," *J. Phys. Ther. Sci.*, vol. 27, no. 3, pp. 551–554, 2015, doi: 10.1589/jpts.27.551.
- [4] R. M. Enoka and J. Duchateau, "Muscle fatigue: What, why and how it influences muscle function," *J. Physiol.*, vol. 586, no. 1, pp. 11–23, 2008, doi: 10.1113/jphysiol.2007.139477.
- [5] G. M. Um, J. S. Wang, and S. E. Park, "An analysis on muscle tone of lower limb muscles on flexible flat foot," *J. Phys. Ther. Sci.*, vol. 27, no. 10, pp. 3089–3092, 2015, doi: 10.1589/jpts.27.3089.
- [6] R. J. Butler, H. P. Crowell, and I. M. C. Davis, "Lower extremity stiffness: Implications for performance and injury," *Clin. Biomech.*, vol. 18, no. 6, pp. 511–517, 2003, doi: 10.1016/S0268-0033(03)00071-8.
- [7] J. S. Wang, "Therapeutic effects of massage and electrotherapy on muscle tone, stiffness and muscle contraction following gastrocnemius muscle fatigue," *J. Phys. Ther. Sci.*, vol. 29, no. 1, pp. 144–147, 2017, doi: 10.1589/jpts.29.144.
- [8] Y. Setiawan, H. G. Ariswati, and Lamidi, "Tens triangle and square wave microcontroller," *J. Ilmiah, Tek. Elektromedik, Politek. Kemenkes Surabaya, Surabaya*, pp. 1–8, 2016, Accessed: Sep. 10, 2021. [Online]. Available: <http://digilib.poltekkesdepkes-sby.ac.id/view.php?id=818>.
- [9] L. Mahmunim, H. G. Ariswati, and E. D. Setioningsih, "TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION," *J. Ilmiah, Tek. Elektromedik, Politek. Kemenkes Surabaya, Surabaya*, pp. 1–7, Jun. 2018, Accessed: Sep. 10, 2021. [Online]. Available: <http://digilib.poltekkesdepkes-sby.ac.id/view.php?id=2629>.
- [10] L. A. V. Ramos *et al.*, "Comparison Between Transcutaneous Electrical Nerve Stimulation and Stabilization Exercises in Fatigue and Transversus Abdominis Activation in Patients With Lumbar Disk Herniation: A Randomized Study," *J. Manipulative Physiol. Ther.*, vol. 41, no. 4, pp. 323–331, 2018, doi: 10.1016/j.jmpt.2017.10.010.
- [11] D. S. Hj Endang, H. Torib, and Risialia, "Rancang Bangun Elektrostimulator Berbasis Mikrokontroler," *J. Ilmiah, Tek. Elektromedik, Politek. Kemenkes Surabaya, Surabaya*, 2014.
- [12] M. Vromans and P. Faghri, "Electrical Stimulation Frequency and Skeletal Muscle Characteristics: Effects on Force and Fatigue," *Eur. J. Transl. Myol.*, vol. 27, no. 4, pp. 239–245, 2017, doi: 10.4081/ejtm.2017.6816.
- [13] P. Gagnon *et al.*, "Impact of preinduced quadriceps fatigue on exercise response in chronic obstructive pulmonary disease and healthy subjects," *J. Appl. Physiol.*, vol. 107, no. 3, pp. 832–840, 2009, doi: 10.1152/jappphysiol.91546.2008.
- [14] G. Lattier, G. Y. Millet, A. Martin, and V. Martin, "Fatigue and recovery after high-intensity exercise. Part II: Recovery interventions," *Int. J. Sports Med.*, vol. 25, no. 7, pp. 509–515, 2004, doi: 10.1055/s-2004-820946.
- [15] T. Yan and Z. Lin, "Long-term effectiveness of neuromuscular electrical stimulation for promoting motor recovery of the upper extremity after stroke," *J. Rehabil. Med.*, vol. 43, no. 6, pp. 506–510, May 2011, doi: 10.2340/16501977-0807.
- [16] D. H. Kang, J. K. Jeon, and J. H. Lee, "Effects of low-frequency electrical stimulation on cumulative fatigue and muscle tone of the erector spinae," *J. Phys. Ther. Sci.*, vol. 27, no. 1, pp. 105–108, 2015, doi: 10.1589/jpts.27.105.
- [17] M. S. Cho, R. J. Park, S. H. Park, Y. H. Cho, and G. A. Cheng, "The effect of microcurrent-inducing shoes on Fatigue and pain in Middle-age people with plantar fasciitis," *J. Phys. Ther. Sci.*, vol. 19, no. 2, pp. 165–170, 2007, doi: 10.1589/jpts.19.165.
- [18] M. Vromans, "Force and Fatigue Development Following Electrical Stimulation: The Effect of Frequency and Fiber Type," *Master's Theses, Univ. Connect.*, pp. 1–58, 2017.
- [19] M. Behringer, S. Grützner, J. Montag, M. McCourt, M. Ring, and J. Mester, "Effects of stimulation frequency, amplitude, and impulse width on muscle fatigue," *Muscle and Nerve*, vol. 53, no. 4, pp. 608–616, 2016, doi: 10.1002/mus.24893.
- [20] E. D. Setioningsih, J. Purwanto, and T. A. Sardjono, "Analisa efek terapi panas terhadap kelelahan otot," *Master Thesis, Electr. Engineering, Sepuluh Nop. Inst. Technol.*, pp. 1–7, 2010.
- [21] J. S. R. Gaurav Raj, Neelam Rup Prakash, "IoT Based EMG Monitoring System," *Int. Res. J. Eng. Technol.*, vol. 04, no. 07, pp. 355–361, 2017, [Online]. Available: <https://www.irjet.net/volume4-issue7>.
- [22] M. Vromans and P. D. Faghri, "Functional electrical stimulation-induced muscular fatigue: Effect of fiber composition and stimulation frequency on rate of fatigue development," *J. Electromyogr. Kinesiol.*, vol. 38, no. May 2017, pp. 67–72, 2018, doi: 10.1016/j.jelekin.2017.11.006.
- [23] A. Kumar, S. K. Pahuja, and A. Singh, "Real time monitoring of muscle fatigue and muscle disorder of biceps brachii using Surface Electromyography (sEMG)," *ICSCCC 2018 - 1st Int.*

Conf. Secur. Cyber Comput. Commun., pp. 401–405, 2018, doi: 10.1109/ICSCCC.2018.8703279.

- [24] P. S. Mohana, “Muscle Fatigue Analysis Using EMG Obtained from IoT Based Neurorehabilitation Device,” *Master's Thesis, State Univ. New York*, pp. 1–24, May 2020.
- [25] A. B. Raharjo, B. Fatukhurrozi, and I. Nawawi, “Analisis sinyal electromyography (emg) pada otot biceps brachii untuk mendeteksi kelelahan otot dengan metode median frekuensi,” *J. Electr. Eng. Comput. Inf. Technol.*, vol. 1, pp. 1–5, 2020.

ATTACHMENT

- Schematic + Board Circuit :
<https://drive.google.com/drive/u/0/folders/1c4QnKHtIBdgVRo-gvspo-ph9h-oC--gB>
- Listing Program :
https://drive.google.com/drive/u/0/folders/1kwwp3GKc1ZuLeMUs2f7cYCZleyG_gD5H