



Embedded System

Design And Construction Of A Back Muscle Injury Detection Device Based On The Fuzzy Logic Method

*M Aidil Hajri¹, Budi Rahmadya^{*2}*

^{1,2} Department of Computer Engineering, Faculty of Information Technology, Universitas Andalas, Padang, West Sumatra, 25163, Indonesia

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CORRESPONDENCE

Email: budi-r@it.unand.ac.id

A B S T R A C T

Lifting is a common task. This work typically requires muscle strength, especially the back muscles. However, this work carries a risk of back injury if performed incorrectly or inappropriately. Using a back muscle injury detection system can reduce the risk of back muscle injury. This system uses an EMG sensor to measure the electrical signals generated by muscle activity to gauge the level of muscle activity. This will be used as a reference for determining risk factors for back muscle injury. A buzzer sensor is used to provide information about muscle condition and warn of muscle injury. This system uses fuzzy logic to classify muscle activity levels while assisting the output process on the buzzer. The system successfully detects electrical signals in the back muscles with a range of 10 μ v - 30 μ v.

INTRODUCTION

Lifting is a common occupation. This work typically requires muscle strength, particularly the back muscles. However, this work carries the risk of back injury if performed incorrectly or inappropriately. According to a survey, 25.7% of workers experience back injuries while lifting [1].

Back muscle injuries are common in workers who frequently rely on their back muscles for tasks such as lifting [2]. These jobs are particularly risky because they overwork the back muscles, resulting in muscle cell damage. Lifting objects puts the back muscles under significant force, making them vulnerable to injury.

Avoiding the risk of back muscle injuries is crucial because these injuries not only cause pain but also can require a long recovery time and impact productivity. Data shows that while approximately 95% of people with low back pain recover within a few months, about 5% develop a chronic, debilitating condition [3].

In Indonesia, many workers who rely on back muscle strength experience back muscle injuries from their work. One article showed that medical personnel caring for patients who involve lifting, pulling, and bending experienced back muscle injuries with a prevalence of 63.7% in 2017 [4].

This chronic condition can last more than three months and affect daily activities, work, and quality of life. Furthermore, the recurrence rate after recovery is quite high, ranging from 20–44% within a year. Chronic back injuries contribute to global loss of work productivity, as low back pain is a leading cause of disability worldwide, with 619 million cases in 2020 and projected to increase to 843 million cases by 2050 [5].

Lifting safely without injuring your back muscles is crucial, as a back injury can make lifting and other activities difficult. Muscle injuries can affect a person's muscle strength, preventing them from performing their work optimally. Furthermore, muscle injuries can cause pain, which can be detrimental to a person's well-being. Muscle injuries can also have health impacts, and if severe, they can result in additional medical expenses.

Based on the data outlined previously, preventing back muscle injuries is highly urgent, given the potential negative impacts they can have on an individual's activity and quality of life. Therefore, the development of a device that can not only continuously monitor back muscle condition but also provide early warnings to users to anticipate the risk of injury is necessary.

There is research on detecting signs of muscle cramps or injuries, a study entitled " *Wearable Device for Early Detection of Muscle Cramps with Heating Pad* . " [6] In this study, muscle injuries or cramps were detected using heat sensors and heart rate sensors to measure and detect signs of muscle injury. This research aims to detect muscle cramps early so that users can receive immediate assistance during activities such as exercise and other activities.

In this research, it is hoped that the system will be able to detect back muscle injuries directly, quickly and accurately, to prevent them from occurring. With this system, it is hoped that workers who rely heavily on back muscle strength for tasks such as lifting can perform their jobs safely and securely without fear of back muscle injury.

METHOD

To meet the system requirements necessary to achieve the research objectives, the system to be developed must be designed in accordance with the identified functional and non-functional needs. The proposed design for the system is outlined as follows.

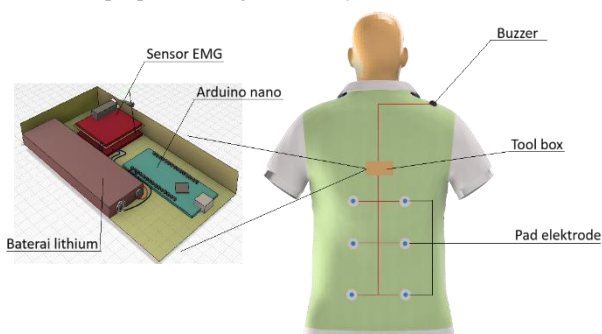


Figure 1. General System Design

From the image above, the system will use a design where the entire device will be in the form of a *wearable device*. This device is commonly used as a real-time human body condition monitor to provide users with direct information about their current state. The device will be placed on various parts of the body to detect how the user lifts objects to prevent lower back muscle injuries. To detect lower back muscle conditions, the EMG sensor will be modified into a garment with an EMG sensor built into it. All input will then be processed by an Arduino Nano, and the output will sound a warning buzzer to alert the user.

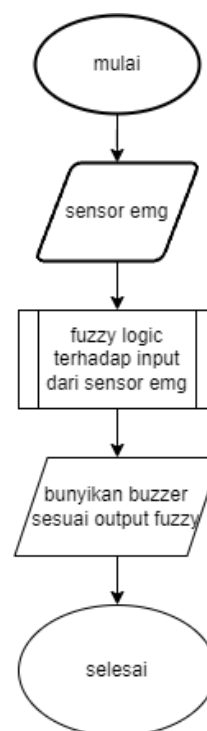


Figure 2. General System Design Flowchart

The image shows that the input represents the value from the EMG sensor, which monitors muscle condition through electrical signals generated by the muscle. This input is a continuous sinusoidal signal, so it needs to be processed to make a decision that will be issued by the output. Therefore, *fuzzy logic is used*. Logic facilitates decision-making and groups input based on values that will ultimately influence the output. Once the values have been determined based on the *fuzzy degree*, they are processed for decision-making. If the results indicate muscle injury, a buzzer will sound as a warning to the user to stop their activity because it could result in muscle injury. The use of *fuzzy logic* The logic in this tool is also so that the system does not misinterpret the condition of the muscles when taking measurements.

RESULTS AND DISCUSSION

The hardware implementation of this system uses an EMG (*Electromyography*) sensor that functions to detect the electrical activity of the back muscles as an indicator of muscle tension levels. This sensor is connected to an Arduino Nano microcontroller that acts as a data processing unit for EMG signals. The data obtained is then processed through software using a fuzzy logic method, which is able to classify muscle activity levels into categories such as normal, mild tension, or at risk of injury. This system is designed to provide a warning to the user if an abnormal muscle activity pattern is detected, so that the user can immediately correct posture or reduce the activity load to avoid back injury.

The tool designed in this project consists of several main components, namely two EMG Muscle Sensor V3 sensors as muscle activity detectors, an Arduino Nano microcontroller to process sensor data, four 9V batteries as a power source for each sensor and Arduino, and a power bank used as a backup or alternative power source. The entire set of tools is placed in a

10x8x5 cm project box, which functions as a protective container and organizes electronic components. For sensor placement, three electrode pads are used on each side of the back. The green pad serves as a ground and is placed around the shoulder blade, while the red and yellow pads are placed in the *latissimus dorsi muscle area* on the lower back with a distance of about 3 cm vertically (top to bottom), and are installed parallel to the left and right of the back. This configuration allows the sensors to capture muscle activity signals symmetrically from both sides of the body, so that the system can analyze muscle movement or tension more accurately.

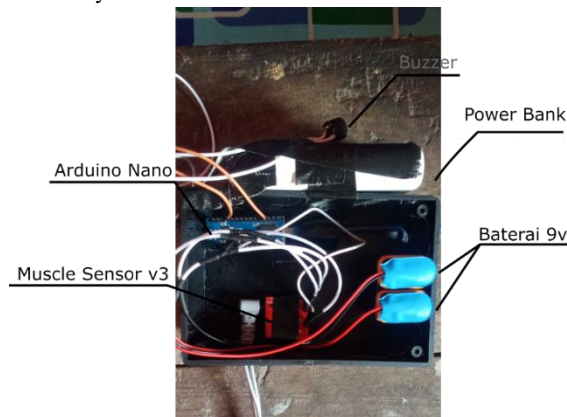


Figure 3. System Implementation on a project board that contain the processing component



Figure 4. The placement of the electrode pad from EMG sensor to measure the back muscle signal

The software implementation on this tool is in the form of the application of the fuzzy logic method. This fuzzy logic method is created in the Arduino IDEA software to edit and process the code used to manage the Arduino in terms of controlling the entire device control system. The programming language in this Arduino IDEA is based on the CPP programming language. The program will classify the level of muscle activity into 3 classes: rest, work, and heavy work. The three classes have different value ranges from low to high EMG sensors. The fuzzification process will use a process where the results of the EMG sensor input will be made into a degree form in the fuzzification process. The value is then compared to each class to see how many degrees are owned based on each class that has been created. After being determined, the defuzzification process is carried out to determine

how much the output value is according to the fuzzy logic that has been created.

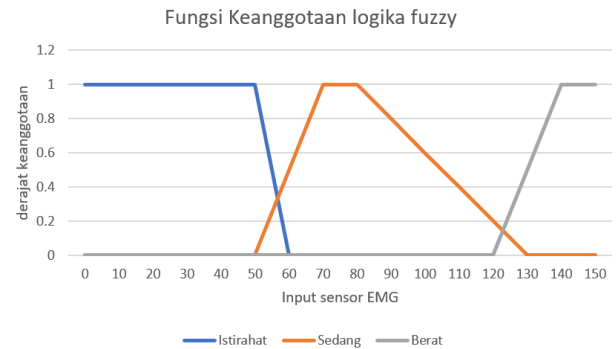


Figure 5. The diagram of a fuzzy logic for classification of muscle activity level

EMG sensor testing is performed to detect muscle activity levels and assess the potential for muscle injury. The process begins with the placement of EMG electrodes at strategic points in the muscles, such as around the shoulder blades and lower back, to capture the electrical signals generated when the muscles contract. During the test, subjects are asked to perform various physical activities at varying intensities, ranging from rest to light activity to vigorous activity. The EMG sensor then records the signal amplitude generated from each activity level. Low signal values typically indicate the muscle is at rest or inactive, while moderate to high values indicate increasingly intense muscle contractions.

Table 1. Muscle signal testing on every weights

No.	EMG values	Muscle Signal(μv)	Information
1.	32	7.56	Rest
2.	33	7.79	Rest
3.	44	10.39	Movement (without lifting objects)
4.	47	11.10	Movement (without lifting objects)
5.	55	12.99	Lifting a load of 15 kg
6.	57	13.46	Lifting a load of 15 kg
7.	60	14.17	Lifting a 20kg load
8.	66	15.58	Lifting a 20kg load
9.	120	28.33	Lifting a 25kg load
10.	140	33.06	Lifting a 25kg load

To convert the EMG sensor values from the Arduino Nano into actual voltage output, we need to understand that the analog signal read by the Arduino is the result of a voltage conversion into a digital value by the ADC (Analog to Digital Converter). The Arduino Nano has a 10-bit ADC with a reading range from 0 to 1023, which represents a voltage between 0 and 5 volts. Therefore, each digital value can be converted to a voltage with the formula:

$$V = (\text{ADC_value} / 1023) \times 5 \text{ volts}$$

For example, when the EMG sensor value shows 150, the actual voltage can be calculated as:

$$V = (150 / 1023) \times 5.00, V \approx 0.732 \text{ volts}$$

Thus, a value of 150 on the EMG sensor reading on the Arduino Nano is equivalent to a voltage of approximately 0.732 volts.

This is still the voltage from the EMG sensor amplifier, not the signal from the muscle. To determine the magnitude of the muscle signal generated, divide the voltage value by the EMG sensor's gain, where:

$$\text{Gain} = 207 \times \frac{50\text{k}\Omega}{1\text{k}\Omega} = 10,350$$

Muscle signal = tension / gain

$$\text{Muscle signal} = 0.732 / 20,700 = 35.4 \mu\text{V}$$

The gain used is the maximum gain provided by the *muscle sensor* v3 module, which has a resistance of 100 k Ω and a 20,700-fold amplifier. This results in a muscle signal strength of approximately 35.4 μV when the muscle is working hard.

The next test is carried out by carrying out a lifting test according to the previous test, then observing and comparing the EMG sensor results with the muscle level classification that has been made.

Table 2. Comparison of every EMG sensor detected and the fuzzy output

No.	EMG values	Degree of Activity
1.	63	0.16
2.	70	0.16
3.	80	0.16
4.	86	0.16
5.	90	0.16
9.	107	0.38
10.	108	0.42
11.	118	0.52
12.	122	0.56
13.	125	0.62
14.	127	0.68
15.	128	0.72

The relationship between EMG sensor values and the degree of muscle activity levels analyzed using fuzzy logic shows that the higher the value, the lower the level of muscle activity. The higher the detected EMG value, the higher the degree of muscle activity. In this system, EMG values range from 0 to 150, which are then converted to degrees of muscle activity ranging from 0 to 1. Degree 0 indicates the muscle is in the most relaxed or inactive state, while degree 1 indicates the muscle is in maximum activity or very active. With a fuzzy logic approach, changes in EMG values can be interpreted gradually and more flexibly to more accurately reflect variations in muscle activity levels.

CONCLUSIONS

Based on testing, this device is capable of accurately detecting muscle activity levels based on movement intensity and applied load. The device performed well across a wide range of activities, from unloaded movements to lifting heavy objects. Measurements showed an EMG signal reaching approximately 0.7 volts, which is due to the strong and active characteristics of the back muscles during use. This testing demonstrates the effectiveness of the EMG sensor for objective muscle monitoring and potential injury detection.

REFERENCES

- [1] H. Yang, S. Haldeman, ML Lu, Dan D. Baker, "Low Back Pain Prevalence And Related Workplace Psychosocial Risk Factors: A Study Using Data From The 2010 National Health Interview Survey," J Manipulative Physiol Ther, Vol. 39, no. 7, Pg. 459–472, Sep 2016, Doi: 10.1016/J.Jmpt.2016.07.004.
- [2] N. D. Utami Dan S. Km. , M. E. D. F. Syarifah Has, "Hubungan Sikap Kerja Dengan Kelelahan Otot Punggung Pada Karyawan Proses Packing Pt. Bagindo Tuban," Journal Of Public Health Science Research, Vol. 4, No. 1, Mei 2023, Doi: 10.30587/Jphsr.V4i1.5633.
- [3] L. Smith, "19 Back Injury Statistics: How Many Back Injuries Occur Each Year?," September 2022.
- [4] EE Suryawijaya, YMT Siahaan, IPF Purba, and V. Hartoyo, "Factors Contributing to the Incidence of Low Back Pain in Healthcare Workers in Siloam Hospitals Lippo Village Karawaci," Neurona, Vol. 38, No. 4, pp. 286–291, Sep 2021.
- [5] World Health Organization, "Low Back Pain," June 2023.
- [6] KM Prasanna, R. Raagini, K. Sadhana, And J. Revathi, "Wearable Device For Early Detection Of Muscle Cramp With Heating Pad," In 2023 International Conference On Bio Signals, Images, And Instrumentation (Icbsii), 2023, Pg. 1–5. Doi: 10.1109/Icbsii58188.2023.10181084.

AUTHOR(S) BIOGRAPHY



M Aidil Hajri

Born in Pariaman on march 23, 2000, he attended SMA N 1 Pariaman and is currently pursuing a degree in Computer Engineering at the Faculty of Information Technology, Andalas University.