Muscle Activity Energy Harvesting Analysis Using Electromyography

Pooja Sidharthan
MTech, Dept. of ECE
Vidya Academy of Science & Technology
Thrissur, Kerala, India
poojasid05@gmail.com

Dr. S. Swapna Kumar
Professor, Dept. of ECE
Vidya Academy of Science & Technology
Thrissur, Kerala, India
drsswapnakumar@gmail.com

ABSTRACT

Renewable energy sources are highly demanded because they are an essential component of existence. Using piezoelectric transducers, energy can be obtained from the motion of the human body. In this proposed work, it is taken into account how the energy expended while walking and exercising can potentially be turned into something useful. The piezoelectric transducers in the suggested system are used to apply muscular force. With the aid of a bridge rectifier, the AC signal from piezoelectric transducers is changed into DC. The energy is then captured by a supercapacitor and added to the DC signal using a DC-DC boost converter. It undergoes discharge to a rechargeable battery as a result of the supercapacitor's rapid rate of discharging. As a result, the Arduino and the electromyography sensor, which examines muscle activity, may be powered up. By lifting some known weights and comparing them to an electromyography reading, a mathematical model can be utilized to calculate the effort done. More voltage and current are produced by combining series and parallel piezoelectric transducers. Electromyography sensors are used to examine amplitude variations made while lifting various known weights. It analyses deviations between conceptual work completed and measurable value.

Keywords—Energy harvesting, electromyography, piezoelectric transducer.

I. INTRODUCTION

In the modern and future worlds, energy is a crucial necessity. A sustainable environment and a power-free future are made possible by cutting-edge technological advancements. Environmental contamination is thought to be caused in part by the usage of non-renewable energy sources. In order to contribute to a better environment, more renewable energy sources and research are therefore required. Solar, wind, thermal, biomass, hydro, vibrations, and radio-frequency are a few examples of free energy or renewable energy sources. These are clean, limitless, and fiercely competitive energy sources. Energy harvesting is a process that involves removing energy from the environment, capturing it, and storing it for use in wireless sensor networks and other small, autonomous devices. Historically, these devices have been powered by electrochemical batteries. However, unlike electrical devices, batteries have a limited lifespan that is frequently shorter. The price of charging or replacing rises as a result [1].

The three primary energy harvesting methods used today to produce electrical energy from vibration sources are electrostatic, electromagnetic, and piezoelectric energy. In order to produce power from environmental vibration sources, piezoelectric energy harvesters appear to be a feasible solution. They benefit from converting mechanical strain into electrical energy without losing any more power, as well as having a high power density, being simple to use, and being able to be manufactured at different scales [2]. Electrocardiograms (ECG), oximeters, heart rate monitors, and electromyography sensors (EMG) are only a few examples of implantable biomedical devices and medical sensors that can be powered by piezoelectricity [3].

Topaz, lead titanate, and quartz are a few examples of piezoelectric transducers. The net electric dipole moment in these materials is zero due to the random arrangement of the solid particle charges inside. When piezoelectric materials are subjected to stress or force, positive and negative particles begin to build up towards their two extremities, creating a potential difference between the charged surfaces [4]. The amount of electrical energy produced rises as a result, and instant power is also provided without the need for additional power sources. The neurological system controls every movement of the human body that results from the skeletal and muscular systems. Muscle contraction is brought about by electrical impulses sent by nerves, more specifically motor neurons (motor nerves). The electromyography (EMG) method recognizes the action potential generated by the tissues when muscle cells are activated. A medical technique called electromyography, or EMG, measures and monitors the electrical activity caused by the contraction of skeletal muscles and enables the identification of changes in membrane potential as they pass along fibers [5]. EMG is therefore the total of electrical potentials from muscular tissue.

This paper describes the piezoelectric energy harvesting from muscular movements. Supercapacitors, which charge quickly compared to conventional capacitors, can be used to store the gathered energy. The paper also offers a brief overview of the study on supercapacitor discharge and storage of the energy harvested. Also provided are several assessments of muscle movement. Table 1 displays comparable works. The rest of the post is structured as follows. The design for the suggested work is presented in Section 2. Section 3 presents an analysis of the suggested system. The paper has concluded with Section 4.

TABLE I: Comparison of related works

Ref.	Objective	Output voltage/ power	Limitation
[10]	Voltage generation from PZT	5V	Piezo's low current wasn't taken into account.
[11]	Voltage generation from PZT	2.3V / 12 µW	Only a prototype of the system existed.
[12]	Voltage generation from PZT	37V	Uncomfortable skin around the human eye was taken into account.

II. DESIGN & METHODOLOGY

Different body parts' muscle action is converted into electrical energy by the piezoelectric energy harvesting process. A piezo-based energy harvesting system for electromyographic analysis is the suggested system. To acquire the most output power possible from piezoelectric transducers, a number of them can be coupled in a series-parallel configuration. A bridge rectifier is used to rectify the AC input from the piezo to produce a DC voltage. This voltage is increased to store in a supercapacitor, discharging it into the battery in the process. As a result, the supercapacitor's energy can be used to power the microcontroller and EMG sensor during piezo energy harvesting. The supercapacitor drains the battery when there is no energy harvesting, which powers the microcontroller and EMG sensors. To examine the movement of the muscles during work, EMG sensors are positioned on various muscles. It has been mathematically estimated how much effort is required to raise certain weights.

A. Mathematical approach

1) Using the piezoelectric effect: numerous mechanical energy sources, such as the human body's various movements, heartbeat, breathing, and vibrations, are present in both the ambient environment and the human body. Piezoelectric energy harvesting is a method for transforming mechanical energy into electrical energy. The ability of some crystalline materials to acquire an electric charge proportionate to mechanical stress is known as the direct piezoelectric effect, which was first discovered in quartz by Pierre and Jacques Curie in 1880 [[6], [7]]. The fundamental idea of the power-harvesting direct piezoelectric action is illustrated in (1).

$$D = d_{ij}T_j + \varepsilon^T E_k \qquad (1)$$

where D is the electric displacement, T is the stress tensor, E is the electric field, ε^T is the dielectric permittivity under a zero or constant stress, d is the direct piezoelectric charge coefficient [[6], [8]] where i and k varies from 1 to 3, and j varies from 1 to 6.

2) Piezoelectric energy harvester equivalent circuit: From an electrical standpoint, a piezoelectric transducer can be represented by a tiny signal equivalent circuit, as shown in figure 1. The left side of the equivalent circuit, where the voltage source Vm accepts the alternating input force, is represented by the mechanical component. The capacitor, Cm, provides stiffness for the piezoelectric beam, while the resistor, Rm, represents parasitic damping and the inductor, Lm, represents mass. The diagram's electrical component is displayed on the right, where Rl represents the external load, Cp the piezoelectric output capacitance, and Vout the output voltage across the piezoelectric.

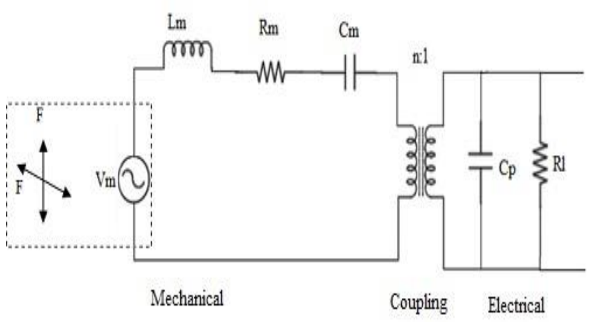


Figure 1: Equivalent circuit of piezo harvester

The mechanical and electrical portions are connected by a transformer with a winding ratio of n:1, where n is the generalized electromechanical coupling factor [6].

3) Work-done based: To calculate the work done by EMG analysis, a mathematical approach has been done. If the work is done as a result of force F, the displacement is S, and the angular movement with the force direction is θ, then the amount of work done, W, may be equated as indicated in (2).

$$W = F * S * cos\theta \qquad (2)$$

Work done by lifting a weight of 'm' kg against gravity from 0 to h meter [9], then the work done becomes,

$$W = m * g * h \qquad (3)$$

where, g is the earth's gravitational constant, which is 9.81m/s^2.

Equating (2) and (3),

$$F * S * cos\theta = m * g * h \qquad (4)$$

Let m, g, h, S and θ are known values, then

$$F = \frac{m * g * h}{S * cos\theta} \qquad (5)$$

Curve fitting of data linear set of data that can be thought of as a parabola, where the value of the coefficients a, b, and c is determined by the curve's shape [9].

$$y = a + bx + cx^2 \qquad (6)$$

By least-square fitting, the parabola is to be fitted to the given points (x1, y1), (x2, y2) .., (xn, yn). If the error for the estimated value and measured value is e, then summation of error is

$$S = \Sigma ei^2 = (yi - a - bxi - cxi^2)^2 \qquad (7)$$

By the principle of least square, the value of S is minimum, therefore,

$$\frac{\partial S}{\partial a} = 0, \frac{\partial S}{\partial b} = 0, \frac{\partial S}{\partial c} = 0 \qquad (8)$$

By solving (6) and dropping suffix,

$$\begin{aligned} \Sigma y &= na + b\Sigma x + c\Sigma x^2 \\ \Sigma xy &= a\Sigma x + b\Sigma x^2 + c\Sigma x^3 \\ \Sigma x^2 y &= a\Sigma x^2 + b\Sigma x^3 + c\Sigma x^4 \end{aligned} \qquad (9)$$

Equations in (9) are known as normal equations. The equation of the parabola for the best fit can be derived by solving a, b, and c and substituting in (6) [9].

III. ANALYSIS

A. Variation of a piezo's produced voltage and current under various surfaces

A 35mm piezo ceramic transducer is placed under different surfaces. The maximum voltage and current produced by tapping on the piezo were examined using a single piezo. The piezo was set up on various base materials, such as the floor, cardboard, thermocol, and sponge. Using a Multimeter, the output is measured. The piezo's output will be AC voltage, and the current generated will be minimal in the range of milliamps.

The voltage and current produced by tapping a single piezo ceramic transducer under various surfaces are shown in Table II. Figure 3 illustrates how the table is plotted graphically using the Graph Maker programme.

TABLE II: Voltage and current generated by a piezo transducer.

Surface	Voltage (V)	Current (mA)
Floor	3.18	0.84
Cardboard	6.9	1.73
Thermocol	11.13	3.2
Sponge	16.24	6.7

In Figure 2, the variation in piezo output voltage and current under various base surfaces is represented graphically.

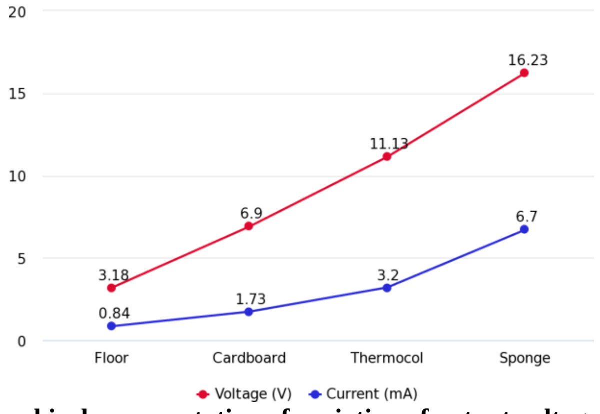


Figure 2: Graphical representation of variation of output voltage and current

B. Output variation based on various piezo topologies.

Piezoelectric transducers can be connected in three different ways: series, parallel, and series-parallel combination. On a sponge surface, six piezoelectric transducers were arranged and connected in three distinct ways.

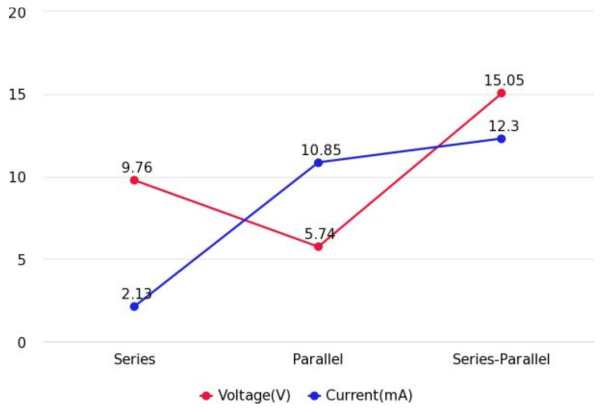
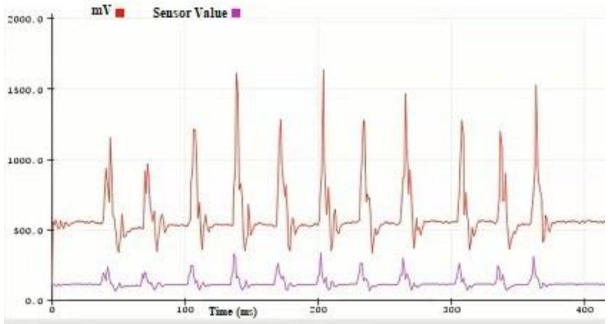


Figure 3: Three alternative piezo topologies' output voltage and current

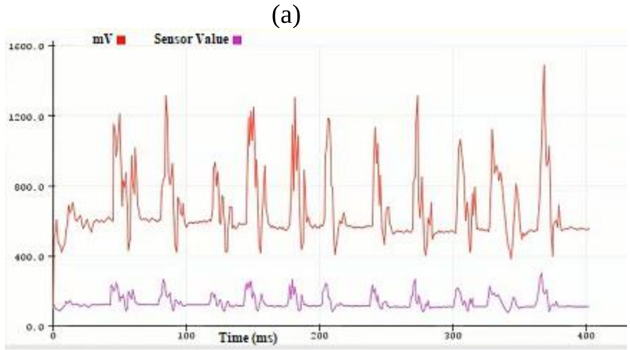
Piezo sensors are connected in series to produce the highest AC voltage and the least amount of current. When piezo's are connected in series, the entire circuit will fail if even one of them is destroyed. Parallel circuits can be utilized to eliminate this problem. However, combining piezo sensors in parallel results in the highest current and lowest voltage, which is not practical. Three piezo sensors are connected in series with the other three in parallel to maintain a balance in the voltage and current.
Figure 3 illustrates the Graph Maker plot of the output voltage and current produced by the piezo sensors in three different pressure combinations.

C. Signal analysis based on EMG

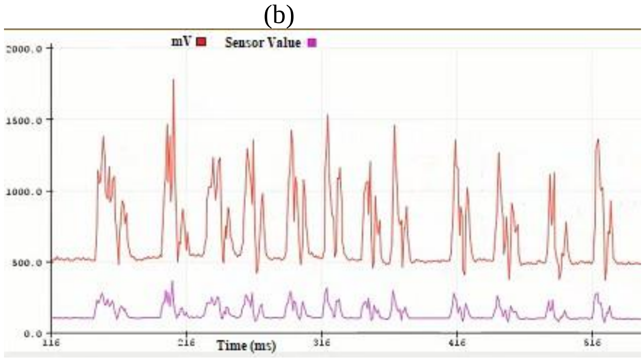
1) Lifting various known weights: Placing of EMG sensors on the Biceps Brachii muscles. It was thought to be possible to lift weights of 0.25 kg, 0.5 kg, and 1 kg. The amplitude of the signal varies as a result of different weight lifting, and this change is plotted in the Arduino IDE.
Figure 4 depicts the change in signal amplitude while lifting various weights of 0.25 kg, 0.5 kg, and 1 kg. An action potential, which results from muscular contraction, has a millivolt-voltage range. A normal and effortless muscle contraction and relaxation is brought on by lifting 0.25 kg. The signal changes when a 1 kg weight is raised. The amount of time needed for muscle to relax to a resting potential increases as the weight does as well.



(a)



(b)



(c)

Figure 4: Variation in EMG signals (a) 0.25kg (b) 0.5kg (c) 1kg weight lifting.

2. Fisting of hand: A hand and finger strengthening exercise is to make fists and then release them. The placement of the EMG sensors on the Flexor Carpi Radialis muscle, which can be activated by creating fists.

The Flexor Carpi Radialis muscle contracts and relaxes in response to making and releasing fists as depicted in Figure 5. Figure 6 depicts the amplitude variation of the EMG signal that results from pressing a sponge ball while creating fists.

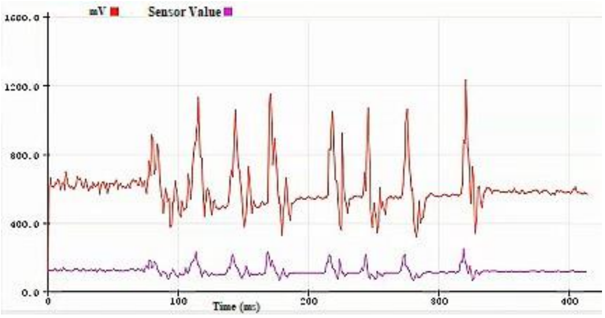


Figure 5: Contraction and relaxation of Flexor Carpi muscle

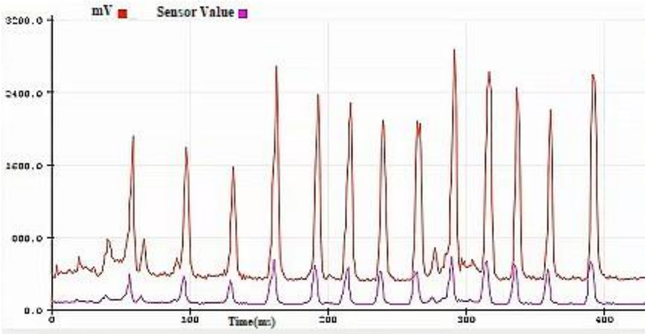


Figure 6: Amplitude variation of EMG signal

3) Calf muscle EMG signal variation: The electrodes were positioned on the calf muscle to examine the EMG signal variance. Figure 7 depicts the calf muscle contracting and relaxing as pressure is applied to the ground.

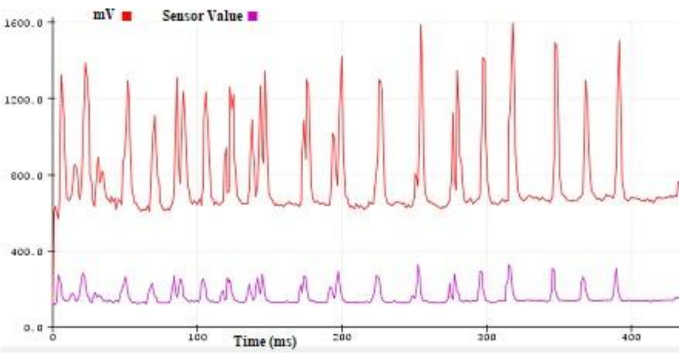


Figure 7: EMG signal variation of calf muscles

D. Relation between conceptual work done and EMG signal

Different weights were chosen, including 0.25kg, 0.5kg, and 1kg weights. The height of 0.5 meters and the gravitational constant, g = 9.81 m/s^2, were chosen.

Figure 8 shows the deviation of measured and conceptual link between job completed and EMG value lifting 'm' kg of weight is W= m×9.81×0.5 joules [1 calorie = 4.2 joule]. This is calculated in Table III. The action potential value for various known weights is shown in Table IV.

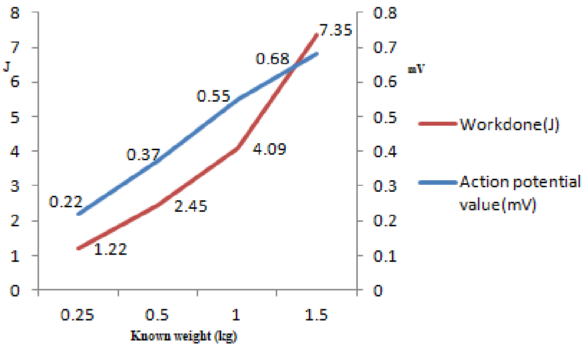


Figure 8: Work-done deviation and EMG value

TABLE III: Work done for different weights and calorie burned

Sl. no.	Known weight (kg)	Work done (J)	Calorie (cal)
1	0.25	1.23	0.30
2	0.5	2.45	0.58
3	1.0	4.90	1.16

TABLE IV: Action potential value measured for different weights

Sl. no.	Known weight (kg)	Action potential (mv)
1	0	0.18
2	0.25	0.20
3	0.5	0.33
4	1.0	0.52

Figure 8 depicts the linear relation between work done and the EMG voltage.

IV. CONCLUSION & FUTURE SCOPE

This paper's contribution is the implementation of a piezo energy harvesting system based on the human body. Three different piezo topologies and the differences in voltage and current the piezo produced under various surfaces were examined. The EMG signals acquired by placing the sensor on different human body muscles were also found. The proposed project will continue to draw enough energy from the human body to power the sensor. This paper's contribution is the implementation of a piezo energy harvesting system based on the human body. Three different piezo topologies and the differences in voltage and current the piezo produced under various surfaces were examined.

Additionally, the EMG signals that were collected by placing the sensor on different human body muscles were found. By continuing to draw enough energy from the body, the proposed device will be able to power the sensor.

In the future, the power produced by muscle contractions might be transferred to a buck-boost converter to boost both current and voltage values, which would increase power output and make the energy storage system more effective. Despite the fact that humans occasionally have low energy, having a lot of piezo coupled together in series and parallel can build up with greater energy. The suggested approach may one day be utilized to monitor muscle activation during physical activities like yoga poses, workouts, and physiotherapy, as well as when playing video games. The planned work demonstrates the need for more research and analysis.

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