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Energy Generation Through Vibration using Piezoelectric with Smart Monitoring System

Zul Adib Izzuddin Razali[1], **Suriana Salimin**[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Nowadays, electrical energy is crucial and becoming more in demand. Many energy resources have been mismanaged and depleted. A new method of generating power utilising a human population has been developed to produce the eco-friendly sources of electrical energy. The vibration generated between the surface of the roadway or walkway produced from vehicles vibrations and footstep are wasted. Electrical energy may be created and the need met by reusing this lost energy. A piezoelectric material is the type of transducer used to detect vibrations. The kinetic energy is converted into electrical energy by this sensor. The purpose of this research is to design the piezoelectric tile as an independent power source utilising the vibration into electrical energy. When the pressure from a footstep or vehicles are delivered to a piezoelectric material, the stress or force is converted into electrical energy. The piezoelectric materials then put on a wooden tile as a model for a piezoelectric tile to apply pressure to the piezoelectric materials. The output voltage then will be stored in the rechargeable battery as a storage device. This tile can be used in a crowded location like on a walkway, roadway or on workout equipment. This proposed design is combined with the smart monitoring system to monitor the battery voltage while the piezoelectric is used as a charging device.

Keywords: Energy Generation, Piezoelectric, Smart Monitoring System

1. Introduction

Because of the increased demands in the electrical distribution system as a result of population development, electrical energy generation has become a more important aspect of the power system. Energy generation through renewable energy which it comes from natural sources or processes is the most preferred because it produces no greenhouse gas emissions from fossil fuels and reduces some types of air pollution [1]. Millions of automobiles produce vibration on the pavement, which can not only harm the road but also cause environmental damage. There are ways to use the vibration energy produced and turn it into energy for public use. Currently, the vibration energy can be collected by using a piezoelectric sensor which is produced the electric charge from the kinetic energy.

**Corresponding author: suriana@uthm.edu.my*

In general, there are a variety of approaches for producing electrical energy from the movement of people or automobiles on roads. For the variation of pressure in the ground caused by exposed persons or automobiles crossing, a new approach is utilised, resulting in a constant pressure amplitude [2]. In Japan, a mechanical force was embedded in the subway ticket machine's floor to create power, using just piezoceramic and requiring no sophisticated mechanical construction [3]. Piezoelectric energy generation utilizes the mechanical strain caused by vehicles over pavement surfaces and harnessing the kinetic energy from moving vehicles and people's movement. It is the most preferred electromechanical transducer material for energy-efficient purposes, such as wireless and sensors, due to its compatibility with electronics and microsystems with high voltage and support for independent circuits [4].

In this project, the proposed system that is a piezoelectric energy generation system will produce clean, solid and moderate energy that utilize kinetic energy through vibration. The most common crystals used are Lead Zirconate Titanate crystals [4]. The quantity of electrical power that can be extracted from a standard piezo bending element in practice is computed using experimental data from prior research by applying 80 grams of stress to its tip at a frequency of 60 Hz. It can produce an open circuit voltage of 15V peak between its two electrical leads. When the leads are connected to the 8Kohm resistive load, the output to the load is 5.3 Vrms, representing a power output of 3.6mW. So, based on the experimental data it is enough to power the rechargeable battery [5]. The most important aspect of this project is using the most advanced monitoring system available while analysing data during the experiment to ensure reliable findings. The smart monitoring system is included in this system to easily monitor the data of power output [6].

2. Materials and Methods

2.1 Software development

i.Piezoelectric design and modeling

The direct piezoelectric effect is an implementation of the applied force to a piezoelectric material. Due to the piezoelectric effect, the voltage will be generated by converting the strain caused by an applied force. There are many types of piezoelectric transducers in the market which are categorized according to their shapes, material build-up and applications. Several requirements have been set in this project to smooth the design and modeling process. Generally, a piezoelectric transducer changes the kinetic energy produced from the mechanical vibration to an AC source. Therefore, the uses of a rectifier is required for storage purposes to the rechargeable battery. To find the electrostatic charge developed, the Eq. 1 is stated

$$Q = cV \qquad Eq. 1$$

The change in polarization of the material is because of the piezoelectric material has an internal dipole from the electric displacement. Polarization is essentially charge per area but in this case, charge, Q is equal to piezoelectric coefficient, d and stress, X and force per area, F.

$$P = dX \qquad Eq. 2$$

$$Q = dF \qquad Eq. 3$$

The material's capacitance is defined by the material's permittivity under unconstrained tension. The formula is stated in Eq. 4,

$$C = \frac{\xi_r \xi_o \mathrm{T}}{A} \qquad \text{Eq. 4}$$

where ξ_r is the relative permittivity, T is the thickness and A is the area. Lastly, the voltage is essentially higher when there are increase in the force. For this project, to verify the equation stated below the demonstration of the piezoelectric effect will be done in COMSOL Multiphysics software according to the piezoelectric material properties to find the output of piezoelectric. The voltage of piezoelectric is stated in Eq. 5.

$$V = \frac{dFt}{\xi_r \xi_o \mathrm{A}} \qquad Eq. 5$$

Based on Figure 1, the properties of the material can be specified by using a method of interpolation, analytic and piecewise on the COMSOL software. The material of the piezoelectric transducer can be determined and simulated to find out the characteristics of piezoelectric materials.

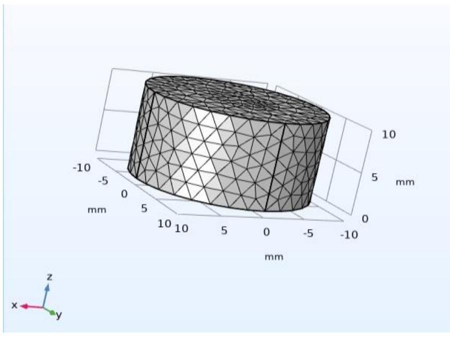


Figure 1: Design of Lead Zirconate Titanate (PZT-4) using COMSOL

For example, the use of COMSOL in this project is to determine the distribution of force and to demonstrate the direct effect of piezoelectric after the force is applied to the piezoelectric element. Before modelling and computing the piezoelectric material, the calculation must be done to get all the parameters that need to insert in the simulation. The procedure of the piezoelectric design in a COMSOL software is as shown in Figure 2.

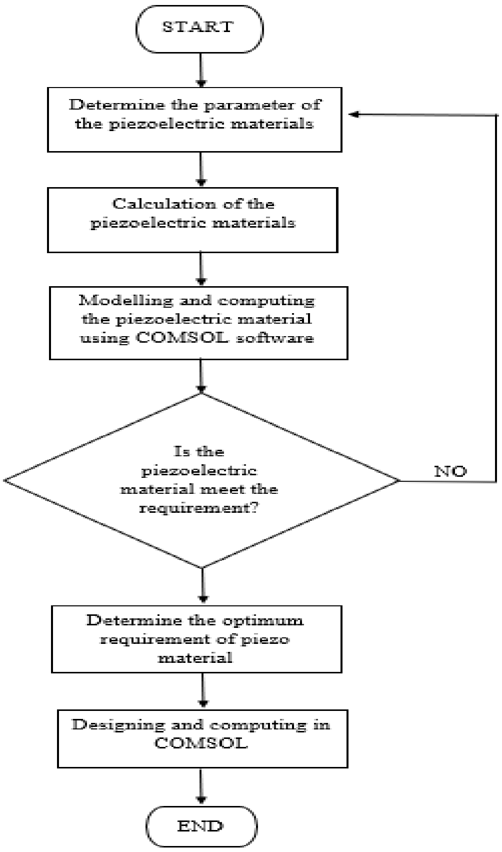


Figure 2: Design of piezoelectric procedure

ii.Configuration of piezoelectric device

The arrangement of piezoelectric materials to optimise the converter voltage is known as a piezoelectric array configuration. In most cases, many piezoelectric sensors are used and coupled in an array form. Multiple piezoelectric sensors arranged in a certain structure can provide optimal energy, which can then be utilised to gather low-frequency vibration energy. Series, parallel, combination series and parallel, and combination parallel and series are the four types of array connections used to produce electricity from piezoelectric. Figure 3 shows the output from harvesting the piezoelectric device displayed in Proteus software.

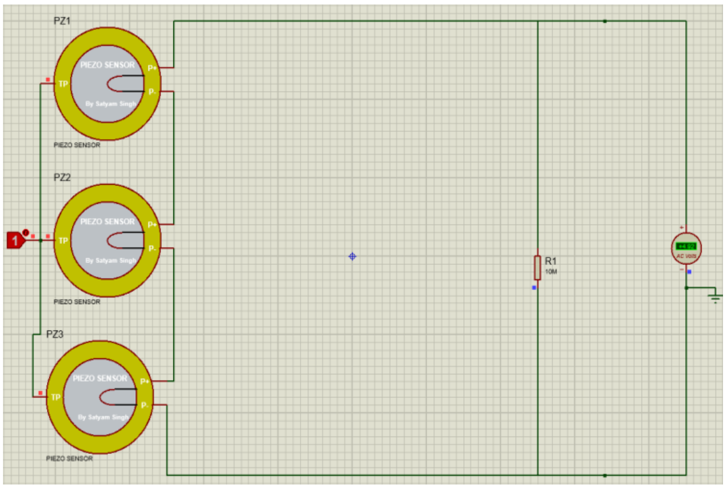


Figure 3: Proteus-designed configuration of piezoelectric sensor

2.2 Prototype development

The system is composed of three main parts: a piezoelectric circuit, a rectifier circuit, and a smart monitoring system. Between the top and bottom piezoelectric tiles are the piezoelectric sensors. This piezoelectric tile has a rectangular form and is made of plywood. The top tile was placed to create contact between the piezoelectric materials after the individual stepped on it. The piezoelectric transducer is positioned between the two tiles' gaps. The voltage produced by a piezoelectric tile is sent into a battery to recharge it. The voltage created is also sent through a rectifier, which converts the AC source to DC. Figure 4 represents the overall hardware design of piezoelectric power generation with a smart monitoring system.

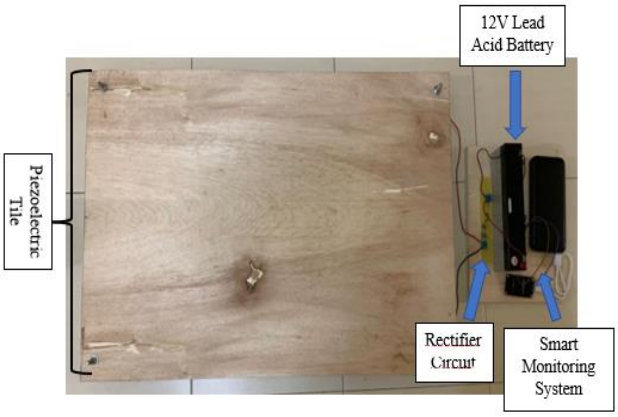


Figure 4: Overall piezoelectric generator with smart monitoring system

The piezoelectric generator was wired in series for greater power voltage and parallel for higher output current. The magnitude of the voltage output is discovered to be affected by the increase number of piezoelectric sensors. However, with a series connection, the current output is decreased, which will have an impact on the power output of the linked piezoelectric. Since the piezoelectric is a conserver device, the voltage it produces is indirectly impacted and absorbed by another conserver piezoelectric when they are linked in series, as there is no isolation between the piezoelectric.

2.2.1 Smart Monitoring System

The depth of discharge (DOD), temperature, and charging algorithm all have an impact on battery performance. Voltage sensors is used to monitor the batteries in this project's current system. Then, the state of charge is obtained in the system. This smart monitoring system is entirely based on NodeMCU ESP8266 WiFi module and Thingspeak application. The voltage sensor module that will be used to perform the system is DC 0-25V Voltage Sensor. This module is capable of measuring the voltages ranging from 0.02445V to 25V DC. For this project, the battery voltage will be displayed on the smartphone by using Thingspeak application. The proposed work is to continuously monitor the full charge capacity of the battery in the user interface. Figure 5 shows the block diagram of smart monitoring system.

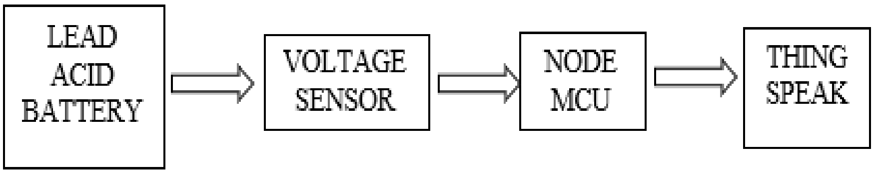


Figure 5: Block diagram of the smart monitoring system

3. Results and Discussion

3.1 Result from simulation

i. Results of COMSOL simulation

In this part, the simulation of direct piezoelectric effect by using an FEA simulation program known as COMSOL Multiphysics. The force will be applied to a piezoelectric element and from that force the piezoelectric element will produce voltage. The stress at bottom and top of piezoelectric device are as shown in Figure 6 and Figure 7. From the simulation results, the stress applied on the piezoelectric transducer can be displayed based on the various color and the scale of the applied stress.

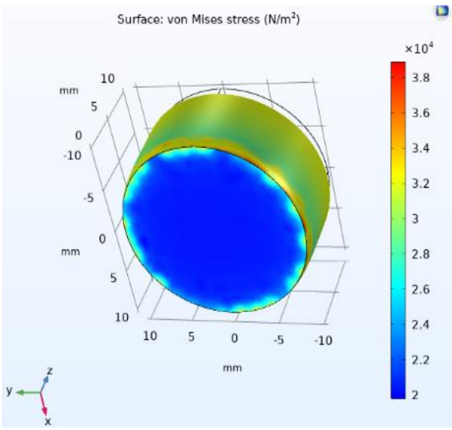


Figure 6: Stress at bottom of piezoelectric device

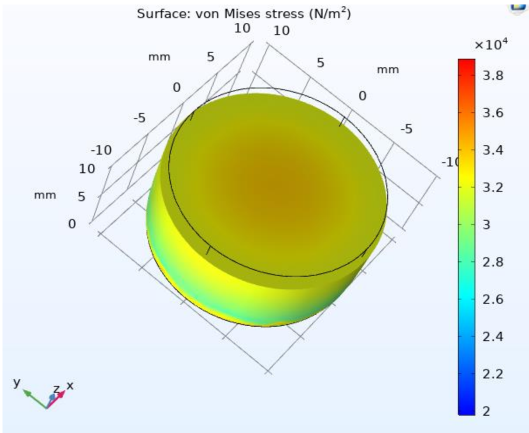


Figure 7: Stress at top of piezoelectric device

Figure 8 and Figure 9 show the simulation results of applied load and electric potential (V) of the piezoelectric device. From the result in Figure 8, the arrow displayed at the piezoelectric material shows the direction of the applied load on the piezoelectric which is 3.18 x 〖10〗^4 N/m^2. From the result in Figure 9, the electric potential (V) of piezoelectric device shows negative value because of the material cannot extend as the pressure is applied if the bottom region of the piezoelectric element is constrained.

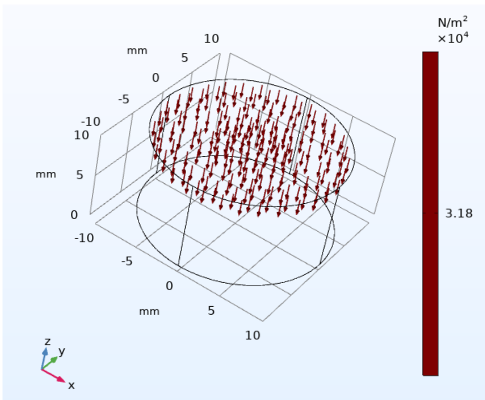


Figure 8: Applied load on piezoelectric device

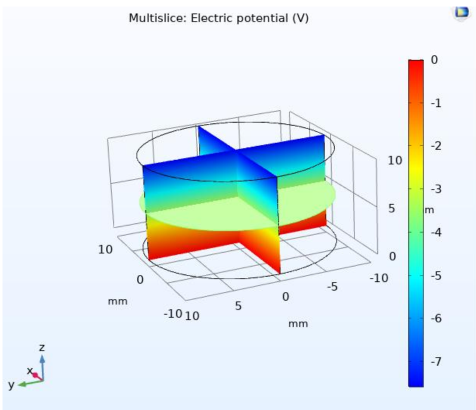
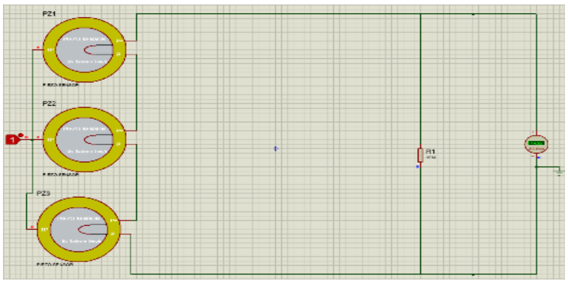
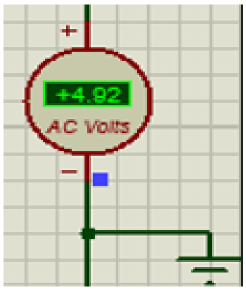
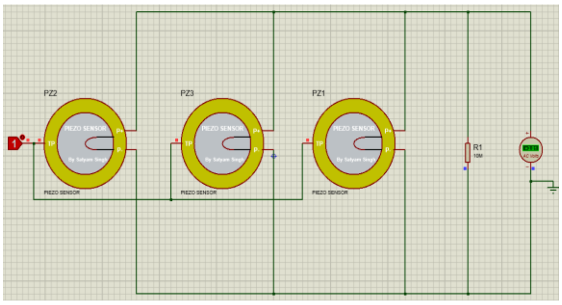
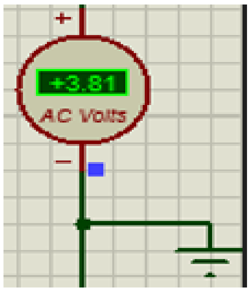
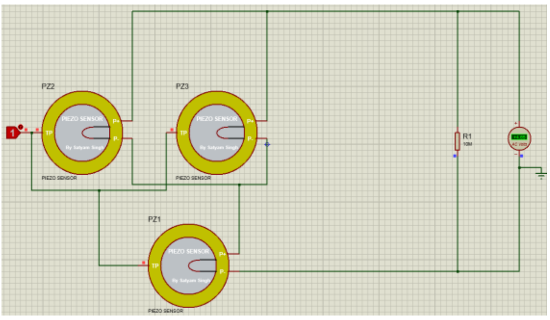
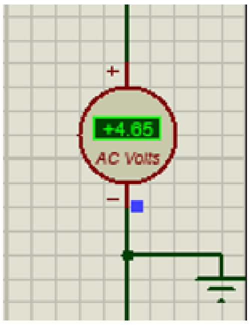
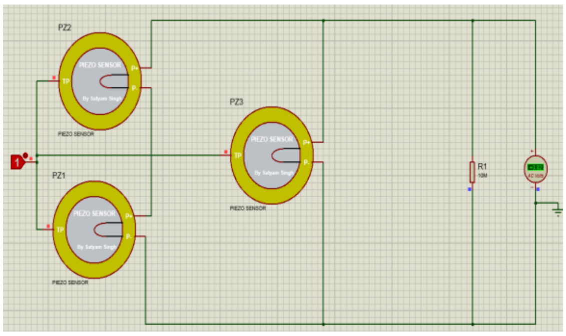
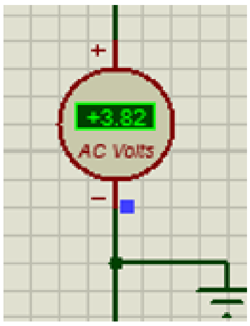


Figure 9: Electric potential (V) of the piezoelectric device

ii. Results of piezoelectric configuration

The configuration of the piezoelectric device is considered in this project. Thus, the simulation is carried out on Proteus to determine the best array connection for piezoelectric devices. Table 1 shows the simulation results for each configuration of piezoelectric and output generated.

Table 1: Configuration of piezoelectric and output generated

Type of configuration	Output
 Series connection	
 Parallel connection	
 Two parallel one series connection	
 Two series one parallel connection	

3.2 Result from experiment

The system is composed of three main parts: a piezoelectric circuit, a rectifier circuit, and a smart monitoring system. Walking and jumping activities were done to create the force for piezoelectric tile. The voltage created is also sent through a rectifier, which converts the AC source to DC. The voltage produced by a piezoelectric tile is sent into a battery to recharge it.

3.2.1 Analysis of generated output

The piezoelectric materials produce an alternating current (AC) rather than a constant current. To transform this variable voltage to a linear one, a bridge circuit is employed. After then, the output DC voltage is saved in a rechargeable battery. The output waveform of the piezoelectric is indicated from the oscilloscope as in Figure 10 and Figure 11. The output waveform of the piezoelectric material before rectified and after rectified by the bridge rectifier circuit when the pressure was applied to it. From the DC waveform, it can be proven that the difference of the amplitude is because of the process of the compression and expansion when the force applied to the tile.

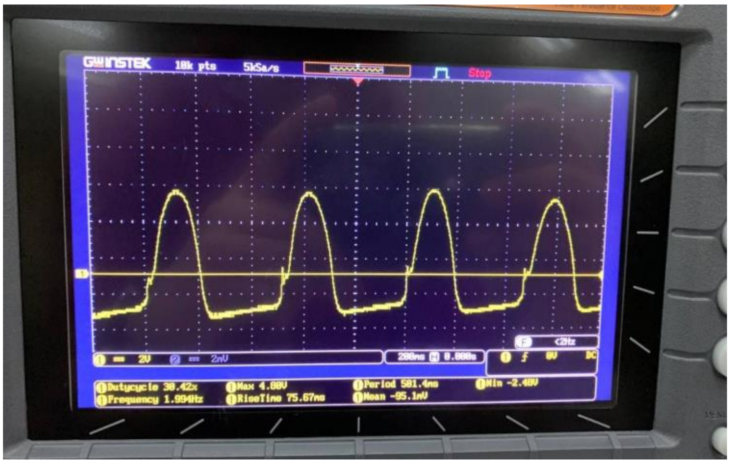


Figure 10: AC output of the piezoelectric before rectified

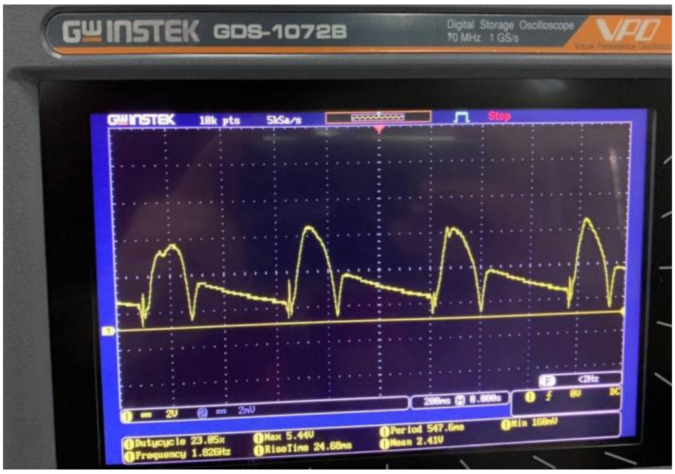


Figure 11: DC output of piezoelectric after rectified

3.2.2 Analysis of Piezoelectric Tile

Subjects weighing 48kg, 60kg, 108kg, 118kg, 125kg, and 170kg were utilised to test the piezoelectric tile, as shown in Table 2. They were instructed to walk and hop on the tiles to perform foot press or pumping actions in order to evaluate the piezoelectric tile's voltage producing capabilities. The voltage produced is determined by the load exerted to the piezoelectric tile. In principle, when a larger or heavier person step or jumps on this piezoelectric tile, the voltage created is higher than when a smaller one does. The force and the voltage produced have a linear relationship as shown in Figure 12.

Table 2: Results of generated voltage varied from applied weight

Weight (kg)	Voltage (V)
48	14.29
60	17.21
108	24.65
118	27.19
125	28.5
170	32.23

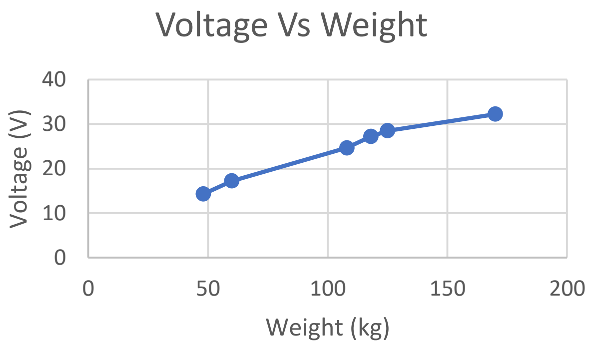


Figure 12: Output Voltage of Piezo Tile Vs Applied Weight

3.2.3 Results of the battery charging circuit

The measurement of voltage was taken directly from the output of the piezoelectric tile for the open-circuit test. For the short circuit test, the output of the piezoelectric tile was connected with the diode and 12V battery to determine the input voltage of the piezoelectric tile. The average current of the piezoelectric tile was determined by applying a fixed weight of 60 kilograms to the piezoelectric to calculate the current and power generated as shown in Table 3.

Table 3: The average voltage, current and power of piezoelectric tile

Voltage (V)	Current (mA)	Power (W)
6.38	56.8	0.36
6.45	57.5	0.37
5.95	52.5	0.31
7.05	63.5	0.45
6.68	59.8	0.40
6.77	60.7	0.41

3.2.4 Result of Smart Monitoring System

The results of battery voltage during charging was obtained from Thingspeak. The result of the charging was obtained approximately for 15 minutes to show how much the battery can recharge if the piezoelectric tile frequently applied to the force. The result is shown in Figure 13.

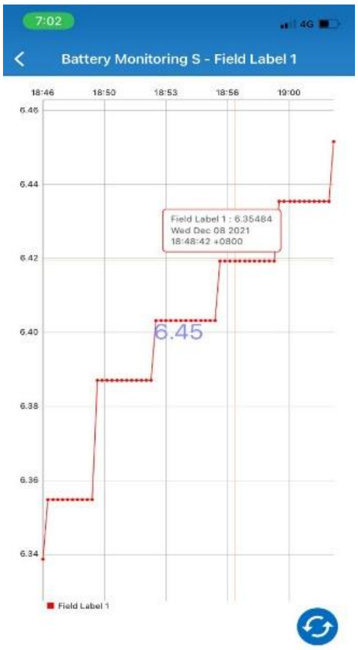


Figure 13: Voltage of the battery

Table 4 and Figure 14 shows the result of the battery voltage that has been monitored for 12 hours when the force was applied to the piezoelectric tile to charge the battery. The input of this system was the vibration applied to the piezoelectric. The voltage sensor was used to determine the battery's voltage. After that, the signal is analysed by the monitoring system, and the data received by the voltage sensor is sent to the Thingspeak for battery voltage monitoring via the NodeMCU ESP8266. Voltage measurements from the smartphone and the Thingspeak website have begun showing in the data, which can be seen in Microsoft Excel spreadsheet format. The voltage of the battery can be viewed by using a smartphone and website for continuous monitoring.

Table 4: Battery voltage monitoring results for 12 hours

Date / Time	Battery Voltage (V)
20/12/2021 12:21pm	7.274
20/12/2021 12:33pm	7.258
20/12/2021 12:45pm	7.323
20/12/2021 12:56pm	7.395
20/12/2021 13:00pm	7.395
20/12/2021 13:24pm	7.490
20/12/2021 13:54pm	7.626
20/12/2021 14:20pm	7.853
20/12/2021 14:31pm	7.986
20/12/2021 14.38pm	8.092
20/12/2021 14:52pm	8.192
20/12/2021 17:07pm	8.356
20/12/2021 19:23pm	8.639
20/12/2021 20:02pm	8.859
20/12/2021 20:20pm	9.029
20/12/2021 20:50pm	9.207
20/12/2021 21:03pm	9.378
20/12/2021 22:30pm	9.789
20/12/2021 23:08pm	9.884
20/12/2021 23:40pm	10.029

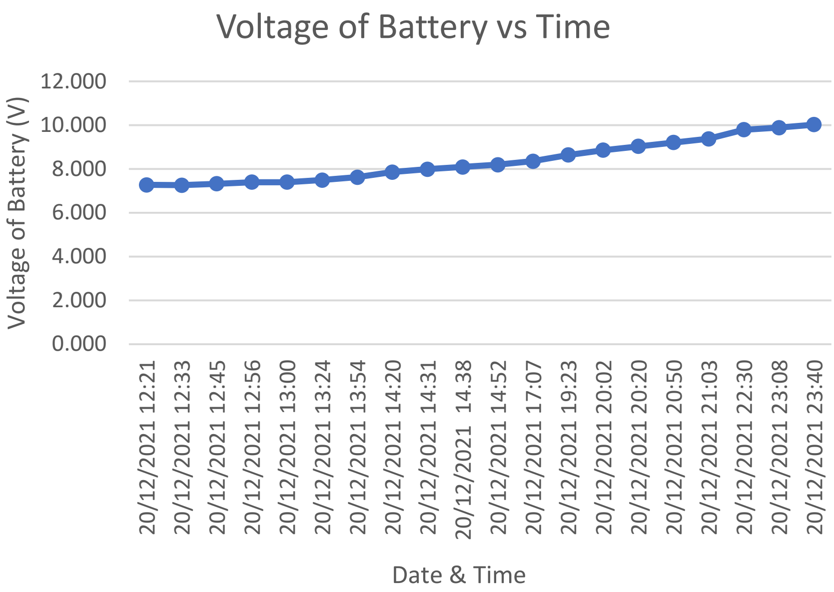


Figure 14: Voltage of battery vs Time

4. Conclusion

In the future, piezoelectricity could be a highly important source for alleviating the global energy crisis. Street lights that are powered by the pressure exerted by moving cars or people on the piezoelectric material used for lighting are one example of where piezoelectricity may be employed. It can also be used to power the roadside signboards. The installation of piezoelectric material for collecting electrical energy for multiple uses can also be done in congested roadways and airports. This research studied and created an idea to increase energy savings via piezoelectric energy collecting in roadways using simulation and experimentation to determine the effectiveness of this prototype for real-world implementation. Since the voltage generated in this system can be stored as a charge in a battery for future use, this system is capable of powering small electrical appliances and electronic gadgets such as cell phones, radio stereo, television, fan, and even powering street lights on the roadway and walkway whereby vehicles or people run on the laid piezoelectric materials on the road. The objective of this proposed piezoelectric energy harvesting has been achieved and the circuit of harvesting energy from vibration using piezoelectric was designed and developed. The effectiveness of the piezoelectric for energy generation has been tested where its generated output exceeds the aim of the prototype can generate and also its capability to charge the battery despite the fact that the prototype needs more improvement. The smart monitoring system in this project works effectively since the battery voltage can be monitored in real time and wirelessly through the Thingspeak application.

Acknowledgement

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