Evolution in Electrical and Electronic Engineering Vol. 4 No. 1 (2023) 361-371

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Design and Implementation of Illuminate Doormat using Piezoelectric

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DOI: https://doi.org/10.30880/eeee.2023.04.01.051
Received 30 January 2023; Accepted 09 March 2023; Available online 30 April 2023

Abstract: The main goal of this project is to design a portable and cost-effective illuminate doormat that can charge a battery when someone steps on it. By producing energy sustainably and storing it for later use, this project offers an alternative to a current product. The concept behind the design and development of this project is around the idea of harvesting energy from wasteful energy sources that produce from such as footsteps. Due to the transfer of weight onto the ground or the surfaces of the road, a person losses energy when walking in the form of impact, vibrations, sound, etc. By conducting four stages of implementation, the first step was selecting the suitable type, size, and arrangement of piezoelectric materials that can generate the maximum amount of electric current needed for the intended application. Then, followed by designing the simulation circuit for the energy-supplying unit of the electrical energy converted and analysing the energy storage device before finally implementing and analysing the hardware performance of this illuminate doormat application. This illuminate doormat has 10 pieces of 27mm piezoelectric ceramic discs that had been connected in a series-parallel arrangement. The connection of these piezoelectric materials is capable of producing an output power energy of 13.3μW. The piezoelectric materials are also arranged in a way that allows them to fully exert the force of footsteps underneath the doormat. The AC voltage was converted to DC voltage by using a full wave diode bridge rectifier with a smoothing capacitor and connected with a voltage regulator and get a constant DC and protect from overvoltage with a maximum output of 3.68V. Then, it is connected to the DC to DC boost converter module to step up the voltage to 12V that sufficient for the 12V lithium-ion rechargeable battery.

Keywords: Piezoelectric, Piezoelectric Generator, Illuminate Doormat

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1. Introduction

Thermal energy, solar energy, mechanical energy, and other forms of ambient energy are all abundant in our natural surroundings. With the impending energy crisis, techniques for harvesting ambient energy will become increasingly important and valuable. One example of an ambient energy harvester is piezoelectric energy. Piezoelectricity is an electrical energy produced by the piezoelectric effect, which allows mechanical strain such as walking to be converted into an electric voltage that can be stored or used directly. This energy harvesting system is also known as footstep power generation. In this project, with the use of piezoelectricity, a footstep power generation was designed and developed. This system is applied on the illuminate doormat that can store energy and charge a battery when stepped. It will be implemented indoors such as in front of the building entrance, home door or lobbies.

There are many experiments and research papers that have been done related to piezoelectricity in the area of generating power from footsteps in recent years. Most are for small-scale electricity usage and are slowly expanding for larger-scale usage. For example, Yuandhana et al [1], a simple piezoelectric mat as a doorbell was proposed. This research paper presents a 3D design of a piezoelectric mat where it assembles and applies the piezoelectric directly to objects that require electrical energy by replacing the power source from the piezoelectric system and implementing it for house bells. Next, from Fernandes et al [2], a project consists of the motion of a human running or walking captured and transformed into electricity using piezoelectric sensors and further utilized to charge the battery of a mobile phone. Piezoelectric sensors are attached to the shoe sole. Electricity produced is stored and charged on portable electronic devices such as mobile phones. Then, in 2015, Nayan HR [3] develop a mechanical structure for a piezoelectric generator by designing a footstep of a piezoelectric energy harvesting model hardware prototype. This generator can supply an AC load with an inverter, DC load and mobile phone charger. Then, from Varsha.A et al in 2018 [4], a new proposed system using software for footstep power generation is proposed where the energy obtained from piezoelectricity is stored during the daytime and can be used during the night time. To power the lighting system at night, the relay will switch to a transistor. This project also used an ARM Controller to measure the voltage generated by the piezo sensors through the analogue port, which is then displayed on the 16 * 2 LCD display. Finally, from Suleiman et al [5], a new system is developed for the hardware where 35 piezo sensors are arranged in series/parallel in channels and put under a hard wooden wood and sheet of plywood which act as the floor mat prototype.

Therefore, the importance of this project is to expand on the research on the advantages of piezoelectricity in energy harvesting systems from footsteps. It is also to solve the problem aroused from the past research project. The research papers from Yuandhana et al [1] and Nayan HR. [3], both research paper has the same problem aroused which is the resulting voltage output small and low power output. This show that the piezoelectric generator has poor source characteristic. Hence, the piezoelectric arrangement and the designed circuit need to be analysed to produce an optimum output voltage. Next, from a research paper by Fernandes et al [2], it is found that the optimum type of piezoelectric and positioning in the shoe sole need to be analysed for ideal power generation. The amount of deflection also must be limited so that the piezoelectric sensor does not fracture. Hence, the high durability of piezoelectric material needs to be determined. For the circuit design, a regulator circuit is needed so that it can protect the device if there are any changes from a constant rate. Besides, from the research paper by Varsha.A et al [4], the problem aroused is the energy harvesting capacity is not very appreciable. Finally, in a research paper by Pamela Kim et al[6], the problem aroused is the floormat is not waterproof and required high maintenance.

2. Materials and Methods

Figure 1 illustrates the block diagram of the overall illuminated doormat application by implementing the piezoelectric energy harvesting system, starting with the piezoelectric generator and progressing to the energy supplying unit (AC-DC converter, voltage regulator and DC-DC boost convertor) for the storage device and finally supply the application load.

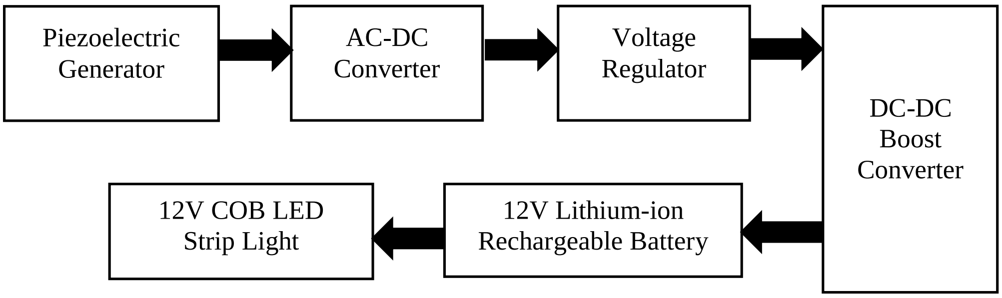


Figure 1: Block diagram of the illuminate doormat system

The overall system of this project is based on the piezoelectric energy harvesting system for illuminate doormat application. Starting from when someone stepped on the doormat, the piezoelectric sensor detects the vibration and generates electricity. Next, the voltage becomes an input to the AC to DC converter to convert the AC output produced by the piezoelectric generator to DC output. Then, the DC output is regulated to 5V using the voltage regulator and stepped-up using DC to DC boost converter to get sufficient output. The DC output is then stored in the energy storage device which is a 12V Lithium-ion battery and also charged the battery. Finally, the 12V DC LED strip light gets supplied from the battery. In implementing this project, there are four stages had been followed and conducted.

2.1 Stage 1: Selecting the suitable type, sizing, and arrangement/formation of the piezoelectric for the piezoelectric generator prototype

The first stage was doing the research study background to analyse the problem. After collecting all the data, proper planning had been made to solve the problem. Therefore, there are a few issues which are from the first objective of this project, the selected type, size and arrangement of the piezoelectric generator to find the most suitable one that can produce the maximum output power needed and sufficient for the 12V DC load. In selecting the suitable type of piezoelectric transducer, a research review from the research paper, datasheet and technical manual were collected and analysed. Four types of piezoelectric transducers as shown in Table 1 were analysed.

Table 1: Piezoelectric transducer

Name	Piezoelectric ceramic buzzer disc	Piezoelectric ceramic ultrasonic disc	Piezoelectric film vibration sensor	Piezoelectric vibration sensor with a proof mass
Structure Type	Circular diaphragm		Cantilever beam	
Based-Material	Ceramic / PZT		Polymer / PVDF	

The selected type is a piezoelectric ceramic buzzer disc since it is the most suitable type to be applied for the piezoelectric generator in this project. This is because of its reversible high-frequency response, lightweight and easier to be applied for this application. Supported by three projects done by Nayan HR [3], Varsha. A et al. [4] and Ashwati et al. [6], also used piezoelectric ceramic (PZT) in a circular diaphragm which is the piezoelectric ceramic buzzer disc. Li Huidong et al. [7] also state that although piezoelectric ceramic discs have the disadvantages of having less capable of sustaining large strain and also being brittle, it able to provide higher output power output than other materials. Additionally, the piezoelectric ceramic disc is commonly used as a piezoelectric element in energy harvesting systems because of their low cost, good piezoelectric properties and can be used in various configurations. Then, further testing and analysis were conducted using different dimensions of piezoelectric ceramic disc (20mm, 27mm and 40mm) to choose a suitable sizing and finally, different arrangements of the piezoelectric generator (series, parallel and combination of series-parallel) using the selected piezoelectric transducer were tested and analysed to select the suitable arrangement for the piezoelectric generator. The tested procedure was by recording the data of AC voltage, DC voltage and DC current using the multimeter. The piezoelectric ceramic discs were pressed 30 times and the measured value was recorded. The recorded data was key in into Microsoft Excel for graph plotting and data analysis. From the measured recorded data, the value for minimum, maximum, average and differences values were recorded. The piezoelectric ceramic discs were also tested using the oscilloscope to capture and analyse the shape AC output waveform.

2.2 Stage 2: Designing simulation circuit for energy supplying stage of the electrical energy converted using the Proteus 8 Professional Simulation

In the second stage, the circuit diagram for the energy-supplying stage was designed using the Proteus 8 Professional Software. It consists of the AC supply voltage (piezoelectric generator) connected with AC to DC converter (full wave bridge rectifier and smoothing capacitor), voltage regulator, DC to DC converter, energy storage device (12V battery) and the application load (12V lamp). The software was used to do the simulation circuit to analyse the output voltage and current at each branch and analysed the output waveform from the oscilloscope.

2.3 Stage 3: Analysing the energy storage device

Then, in the third stage, the energy storage device which is the 12V Lithium-ion rechargeable battery was analysed. Based on the previous study and data analysis, the number of footsteps required for the rechargeable battery was calculated. The number of footsteps required for the 12V, 2200mAh to be fully charged is also calculated. Finally, the battery discharging and charging time estimation were also calculated. By using the formulae;

$$Number\ of\ footstep = \frac{P_{led}}{P_{footstep}} \qquad Eq. 1$$

where,
$P_{footstep}$ = Output power by footstep, W
P_{led} = Output power by LED strip light, W

145 steps are needed to fully charge the battery based on the previous study and data analysis while 82707 steps are needed for the 12V, 2200mAh to be fully charged. By using the formulae

$$Battery\ life = \frac{Amp\ hour\ of\ battery, Ah}{Draw\ current, A} \qquad Eq. 2$$

a 12V, 2200mAh Li-ion battery was estimated to take 2.4 hours to discharge with 0.916A charging current, while it takes 10 hours to charge considering 10% of losses in case of battery charging and 14 hours to charge considering 40% of losses in case of battery charging.

2.4 Stage 4: Implementing and analysing the hardware performance of the illuminate doormat application.

Finally, the PCB was designed for hardware implementation. This is the stage where the hardware is being developed. After the circuit hardware had been done, the performance of the hardware which consists of the piezoelectric generator, AC to DC converter, voltage regulator, DC to DC converter, energy storage device and the application load was analysed. After being satisfied with the result, the data obtained were recorded.

3. Results and Discussion

The results and discussion section presents data and analysis of the study.

3.1 Result of different sizing of piezoelectric buzzer ceramic disc

Four different sizings or dimension of piezoelectric buzzer ceramic disc (20mm,27mm, 27mm with cavity case and 40mm) was tested and analysed following the testing procedure. The recorded data was AC voltage (V_{AC}), DC voltage (V_{DC}) and DC current (A_{DC}) using a multimeter for 30 presses. Table 2 shows the plotted graph of the recorded values and the captured output AC waveform using the oscilloscope during pressing for different sizing of piezoelectric ceramic discs while Table 3 shows the comparison summary analysis of the tested piezoelectric ceramic disc from the recorded data.

Table 2: Result of different sizing of piezoelectric ceramic disc

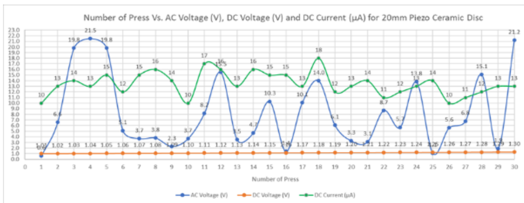
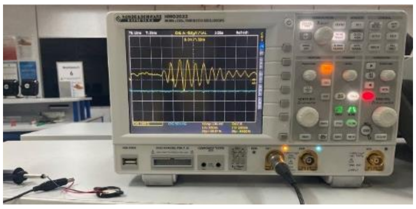
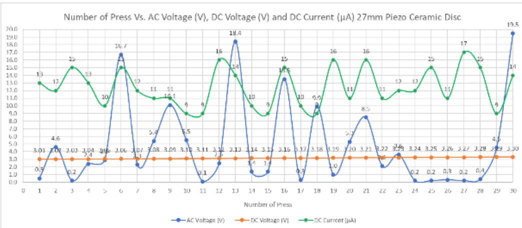
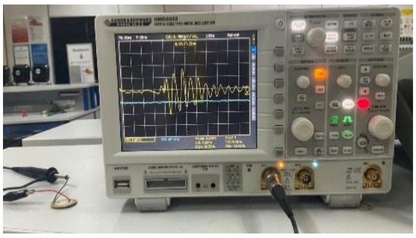
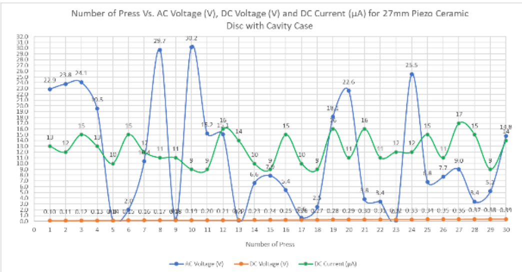
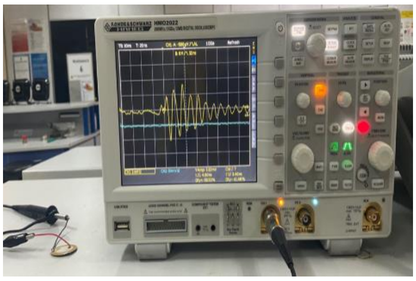
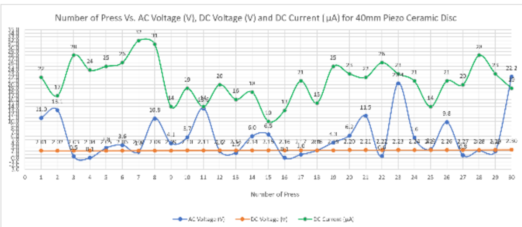
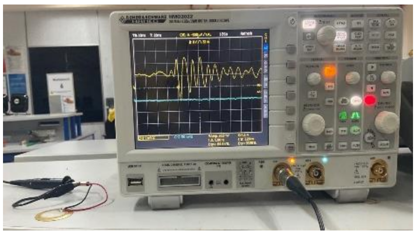
Sizing or dimension of Piezo Ceramic Disc	Graph for Number of presses vs. AC voltage (V), DC voltage (V) and DC current (µA)	Output AC Waveform using oscilloscope during pressed
20mm Piezo Ceramic Disc		
27mm Piezo Ceramic Disc		
27mm Piezo Ceramic Disc with Cavity Case		
40mm Piezo Ceramic Disc		

Table 3: Comparison summary analysis of the tested piezoelectric ceramic disc

Dimension of Piezo Ceramic Disc	Average AC Voltage (V) from single press	Value of DC Voltage (V) increases after 30 presses	Average DC current (μA) from single press	Value of amplitude voltage ,V_{Amp} (mV) from ocscilloscope during pressed	Pricing	Issues
20mm Piezo Ceramic Disc	8.4	0.29	13.5	1.84	RM2.80 per piece (Low price)	Too small for application and low durability
27mm Piezo Ceramic Disc	4.8	0.29	13.5	3.32	RM0.48 per piece (Lowest Price)	The electrode and ceramic layer easily crack and burn
27mm Piezo Ceramic Disc with Cavity Case	11.2	0.29	12.4	3.32	RM1.80 per piece (Medium Price)	Need to press harder since there is aluminium case
40mm Piezo Ceramic Disc	5.8	0.29	21	3.52	RM4.90 per piece (Medium Price)	and too big for application

The output voltage generated by the piezoelectric materials is directly proportional to the applied force. Therefore, from the output AC voltage can be assumed that the higher the value of the AC voltage, the larger amount of the force or pressure exerted. Apart from that, the DC voltage for all the piezoelectric ceramic discs have a steadily increasing output graph. This is because after having been connected with the full wave bridge rectifier with a smoothing capacitor, the output DC voltage has been rectified and the negative cycle has been removed. The function of the smoothing capacitor is also to store energy which led to a steadily increasing in the output of the DC voltage. Moreover, the DC current also shows a fluctuating graph for all four piezoelectric ceramic discs. In addition, the output of the AC waveform for all the piezoelectric ceramic discs shows a distorted sine wave. The differences among them are the amplitude of the waveform when the piezoelectric ceramic disc is pressed. Hence, a 40mm piezo ceramic disc has the highest amplitude voltage, V_{Amp} which is 3.52mV Hence, the larger the dimension of the piezoelectric ceramic disc, the higher the amplitude of the waveform.

Based on the comparison in Table 3, the most suitable sizing to be applied for the piezoelectric generator is a 27mm piezoelectric ceramic disc without a cavity case. This is because, compared to 20mm and 40mm piezoelectric ceramic disc dimensions, it is the most suitable size to be used. Next, it also produces good average output for AC voltage and DC current. After 30 presses, it was able to increase by 0.29V same as the other sizing dimensions. Although 40mm piezoelectric ceramic disc have the highest durability with good output, the sizing and cost also affect it being chosen. Therefore, the selected sizing of the piezoelectric transducer for the arrangement of piezoelectric generator testing analysis is a 27mm piezoelectric ceramic disc without a cavity case.

3.2 Result of arrangement/formation for piezoelectric generator prototype

Three different arrangements of formation or arrangement (in series, parallel and series-parallel) for piezoelectric generator prototype were tested and analysed by following the testing procedure. The recorded data was AC voltage (V_{AC}), DC voltage (V_{DC}) and DC current (A_{DC}) using multimeter. The recorded data was AC voltage (VAC), DC voltage (VDC) and DC current (ADC) using a multimeter for 30 steps. Table 4 shows the plotted graph of the recorded values and the captured output AC waveform using the oscilloscope during pressing for different arrangements of the piezoelectric generator while Table 5 shows the comparison summary analysis of the tested piezoelectric generator arrangement from the recorded data.

Table 4: Result of different arrangements of the piezoelectric generator

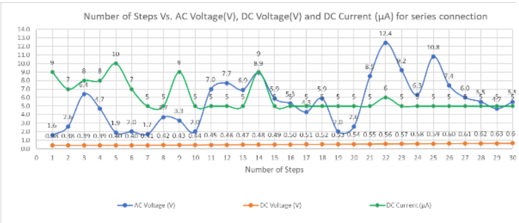
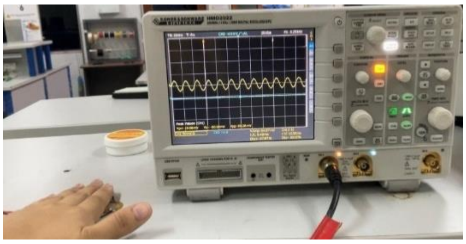
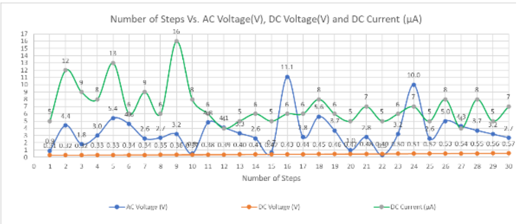
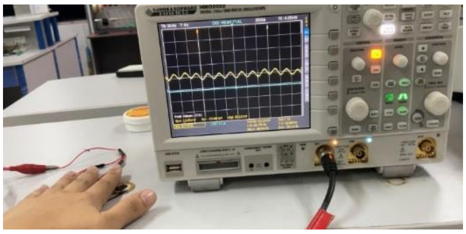
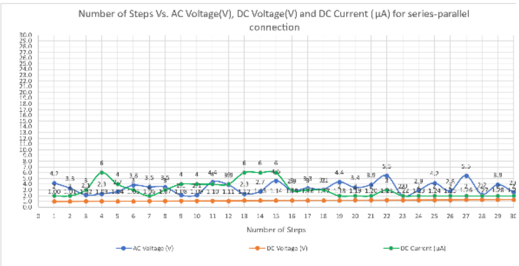
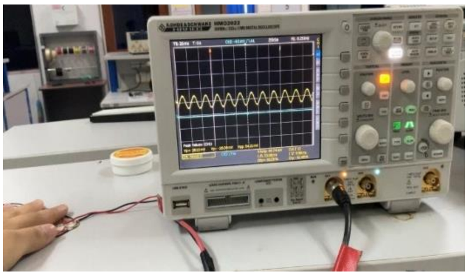
Arrangement of piezoelectric generator	Graph for Number of presses vs. AC voltage (V), DC voltage (V) and DC current (μA)	Output AC Waveform using oscilloscope during pressed
Series		
Parallel		
Series-parallel		

Table 5: Comparison summary analysis of the tested piezoelectric generator arrangement

Arrangement /formation of the piezoelectric generator	Average AC voltage (V) from single step	Average DC voltage (V) from a single step	Average DC current (μA) from single step	Value of DC voltage increases after 30 steps (V)	Average output power from a single step (μW)	Value of amplitude voltage ,V_{Amp} (mV) from oscilloscope during pressed
Series	5.4	0.50	5.9	0.26	2.95	54.87
Parallel	3.5	0.43	7	0.26	3.01	23.12
Series-Parallel	3.3	1.15	3.1	0.29	3.6	45.74

Based on the three different arrangements/formations of the piezoelectric generator, the graph trend of the AC voltage for series and parallel formation rapidly increased and decreased. However, for the series-parallel connection, the fluctuation becomes decreased and smoother. The DC voltage for all arrangements has a steadily increasing output graph. This is because after having been connected with the full wave bridge rectifier with a smoothing capacitor, the output DC voltage has been rectified and the negative cycle has been removed. The smoothing capacitor was also able to store energy which led to a steadily increasing in the output of the DC voltage. Moreover, the DC current also shows a fluctuating graph for all arrangements. But, as the number of steps increases, the values of the DC current become steadily stable. Compared with all the graph's trends for each formation, the series-parallel formation shows a better graph trend. Apart from that, the output waveform is sinusoidal. The differences among them are the amplitude of the waveform. The highest amplitude voltage before applied pressure is in parallel arrangement followed by series and series-parallel arrangements. From that, it can be concluded that when connected in a series-parallel arrangement, the amplitude voltage becomes smaller and will become a steady straight line.

Based on the comparison summary in Table 5, the piezoelectric generator in the series-parallel is the most suitable arrangement/formation to be applied for this project. Although it produced the smallest voltage, however, it produced the highest voltage increment for 30 steps of 0.29V and average output power from a single step of 3.6 μW compared to series and parallel arrangement. Supported by a project done by Varsha.A et al. [4], Ashwati et al. [7] and Siti Khadijah [8], also applied the series-parallel arrangement. Moreover, a research paper by Suleiman, A.D [5] also applied this arrangement and stated that this formation enables energy to flow down numerous sets or channels to its destination and can reduce the number of probable failure spots. Therefore, the selected arrangement/formation of a piezoelectric generator for this project is a piezoelectric generator in series-parallel formation.

3.3 Final prototype of the piezoelectric generator for energy harnessing stage

Table 6 shows the selected type, sizing, and arrangement/formation of the piezoelectric generator with its justification while Figure 2 shows the finalized prototype.

Table 6: The selected type, sizing and arrangement/formation of the piezoelectric generator with its justification

Description	Selection	Justification
Type	Piezoelectric ceramic disc	High-frequency response, lightweight, low cost, good piezoelectric properties and can be used in various configurations
Sizing	27mm Piezoelectric ceramic disc	Good and acceptable output voltage and current, lowest price and medium durability
Arrangement	Series-Parallel arrangement	Highest voltage increment and output power

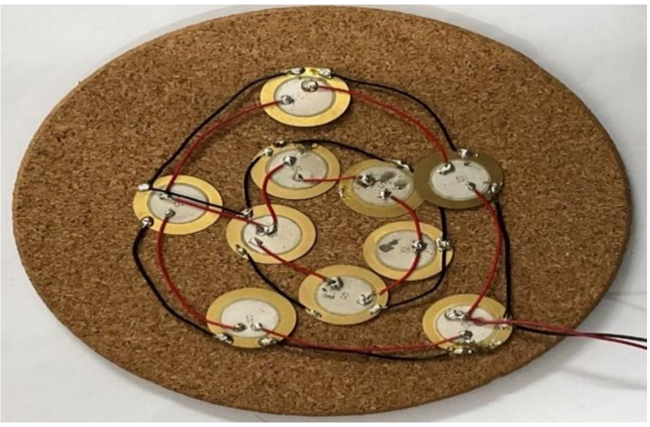


Figure 2: Final prototype of the piezoelectric generator

3.4 Simulation result for the overall designed circuit of energy supplying stage

Figure 3 shows the simulation result for the overall designed energy supplying system with output waveform from the oscilloscope. The selected voltage to run this simulation is $30V_{pk}$ which is the maximum output voltage of the piezoelectric ceramic disc can produce. Hence, the V_{RMS} voltage is 20.4V as shown in the AC voltmeter that is connected to the piezoelectric generator. After the input AC source is converted to DC at the AC to DC converter, the voltage step-up to 28.0V. Passing through the voltage regulator the voltage step-down to 3.68V. Then, the voltage step-up at the DC-to-DC converter to 11.9V. Finally, the output DC voltage is stored in the 12V Battery to supply the 12V DC lamp. For the result from the oscilloscope, Channel A was connected to the piezoelectric generator to analyse the AC output waveform. Channel A shows an AC waveform with 6.75Vpk. Channel B show a constant DC output of converted DC after being connected with a full wave bridge rectifier and smoothing capacitor where the output was 3.75VDC. Then, the constant 3.75VDC regulated voltage at Channel C while the output of constant 12VDC of DC-to-DC boost converter at Channel D.

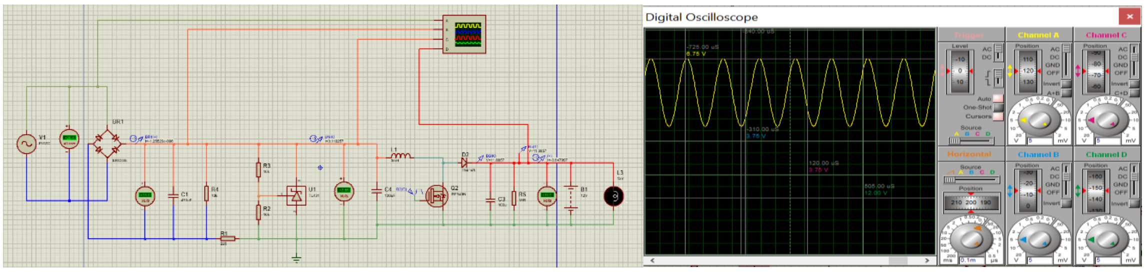


Figure 3: Simulation result for overall designed energy supplying system with oscilloscope

3.5 Hardware Implementation

Energy supplying unit hardware consists of AC to DC converter with the voltage regulator on the PCB donut board that is connected with the MT3608 module, DC to DC boost converter and DC female power jack connecter. Figure 4 shows the overall implementation of the illuminate doormat where the piezoelectric generator underneath the doormat was connected with the circuit of AC to DC converter with voltage regulator, DC to DC converter and the 12V li-ion rechargeable battery at the sides of the doormat. The battery is connected to the COB LED strip light that was attached to each sides of the underneath doormat.

Figure 4: Overall implementation of the illuminate doormat

4. Conclusion

The summative end is that this project is completed. The main objective of this research is to design and implement an illuminated doormat that can charge a battery by utilising the piezoelectric footstep power generation that can be placed indoors, such as in front of doors, lobbies, or building entrances. Due to that, the first step is by identifying the suitable type, dimension and arrangement of the piezoelectric transducer. Based on the research reviews, systematic reviews and measured data analysis, the selected type was a piezoelectric ceramic disc with 27mm dimension arranged in a series-parallel connection. Two sets of five pieces 27mm piezoelectric ceramic discs were connected in series and both sets were then connected in parallel to form one connection. From the series-parallel arrangement, it can be concluded that the output produced for current is higher but the voltage is lower compared to the series and parallel arrangement. The output waveform of the piezoelectric generator produces a sinusoidal waveform when there is pressure applied however when there is no applied pressure the waveform becomes distorted due to disturbances. Furthermore, by using Proteus 8 Professional Software, energy supplying circuit was designed and simulated. The maximum voltage that can be produced by the voltage regulator is 3.68V which is sufficient for the Direct Current (DC) to DC boost converter to step up into 12V output. The PCB layout design was also generated from the Proteus 8 software before implementing the hardware. On the other hand, the maximum power that can be obtained from the piezoelectric generator is 13.3μW. For the energy storage analysis, the supposed number of footsteps needed to supply the load was calculated where 145 steps are needed to supply the 12V,11 W COB LED strip light based on the previous study. However, the number of footsteps required to fully charge the 12V Li-ion rechargeable was also calculated where it needed 82706 steps. This show that the output power produced by the piezoelectric generator without any energy supplying circuit does not able to charge the battery. The time taken for the battery discharging and charging time was also taken note of. However, this project takes a long time and does not sufficient to charge up the 12V,2200mAh lithium-ion without the energy-supplying circuit. Hence, it needed an energy-supplying circuit and the doormat needed to be placed in an area with continuous people coming such as front lobbies or building entrances. Finally, this doormat has been customed with a length of 55cm and 35cm in width. The area of the doormat is $0.26m^2$. The piezoelectric generator was placed at the centre of the underneath doormat while the COB LED strip light was attached underneath the doormat for eye comfort due to the ray of light. Then, the energy-supplying system was placed next to the doormat. After implementing this illuminate doormat, it can be concluded that this illuminate doormat is eco-friendly and cost-friendly. Apart from it does not give any harm to the environment impact, and on top of that it can utilise waste energy from human footsteps.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] Yuandhana, G., Lisdiana, K., Ghifari, R. H., Shadrina, S. N., Rusdiana, D., & Suwandi, T. (2021). Piezoelectric Mat as Doorbell. Indonesian Journal of Multidiciplinary Research, 1(1), 103–106. Available: https://doi.org/10.17509/ijomr.v1i1.33788

[2] Fernandes, M., Patil, M., Desai, V., & Desai, A. (2017). Implementation of Piezoelectric Sensors for Generation of Power. International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), 6(4), 5232–5236. Availble: https://doi.org/10.15680/IJIRSET.2017.0604018

[3] Nayan HR. (2015). Power Generation Using Piezoelectric Material. Journal of Material Science & Engineering, 04(03). Available: https://doi.org/10.4172/2169-0022.1000171

[4] Varsha, A., Anu, R. R., & Nisha, K. C. R. (2018). Harnessing Energy from Piezo Sensors Through Footsteps. International Journal for Research in Applied Science and Engineering Technology, 6(5), 1694–1700. Available: https://doi.org/10.22214/ijraset.2018.5277

[5] Suleiman, A & Abdulhamid, I. (2022). Piezoelectric Energy Harvesting Floor Mat for Low Power Applications. International Journal of Current Research in Science Engineering & Technology.

[6] Ashwathi, A., Brindha M. D., Esther, R. R., & Veena B. (2017). Micro Energy Harvesting Using Piezoelectric Material. International Research Journal of Engineering and Technology (IRJET), 4(5), 2667–2671. Available: https://www.irjet.net/archives/V4/i5/IRJET-V4I5676.pdf

[7] Li, Huidong., Tian, C., & Deng, Z. D. (2014). Energy harvesting from low frequency applications using piezoelectric materials. Applied Physics Reviews, 1(4), 041301. Available: https://doi.org/10.1063/1.4900845

[8] Siti Khadijah, S. Design and Development of Eco-Energy Floor Mat. Degree. Thesis. Universiti Tun Hussein Onn Malaysia; 2016