Proceedings of 8th International Conference on Mechanical, Industrial and Energy Engineering 2024
02-04 January, 2025, Khulna, BANGLADESH
SciEn Conference Series: Engineering Vol. 3, 2025, pp 445-449 https://doi.org/10.38032/scse.2025.3.119

Development of Power Generation System from Footsteps Using Piezoelectric Sensor

*Plaban Rudra Paul, Ananya Islam, Abu Talha, Ananti Afnan Ahona, Md. Hasan Ali**

Department of Energy Science and Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh

ABSTRACT
Piezoelectricity is the phenomenon of electricity generation in response to mechanical strain, and has become an effective means for power generation. The present study focuses on creating a system that generates electrical energy harvesting from human walking. Densely populated areas such as temples, schools, colleges, cinema halls, public roads and other places where people walk around all day are the most suitable places for integrating the setup. Instead of prior studies that primarily focuses on voltage measurement and series connection concentrated construction, this study introduces parallel connection between piezo sensors and deals with both current and voltage. Four piezoelectric sensors are utilized to convert the applied force into electricity. Experimental results demonstrate the feasibility of the proposed system in generating consistent, usable power under typical walking conditions. The module developed in the study can generate maximum output voltage of 3.6 V, a current of 0.0104 mA, and consequently a power of 0.0374 mW in response to a maximum weight of 22.5 kg. This method of energy generation is highly significant to utilize human footsteps without producing any noise, emissions, or environmental pollutants. The findings of the study contribute to the growing field of piezoelectric-based energy harvesting, offering insights into optimizing sensor configurations for scalable applications in sustainable urban infrastructure.

Keywords: Mechanical pressure, Piezoelectric sensor, Vibration energy.

Copyright @ All authors
This work is licensed under a Creative Commons Attribution 4.0 International License.

1. Introduction

In the fast-growing world renewable energy is becoming more popular compared to conventional energy due to its Environmental and economic benefits [1]. For example solar energy, wave energy, wind energy, bio-energy and so more. Wave energy has gained popularity recently, and companies are developing electric generators specifically made to use this renewable energy source to produce power [2]. Piezoelectricity generation has made the journey of wave power generation one step forward. Due to low cost and free availability, it is being used in various fields nowadays [3]. Human locomotion is a great source of vibrational energy that can be utilized for this purpose [4]. The harnessing of footsteps during human walking is highly beneficial and significant, particularly in densely populated nations such as Bangladesh. This concept could be applied in various high-traffic areas including streets, train stations, bus terminals, and religious sites throughout the country [5]. This technology utilizes the piezoelectric effect to produce electricity. Materials exhibiting piezoelectric properties give a rise in electrical charge when it is subjected to mechanical pressure. Electricity is generated by piezoelectric sensors when pressure is applied to them [6]

The Curie brothers, Pierre and Jacques, both physicists, were the first to discover the phenomenon of Piezoelectricity [7]. Their discovery in 1880 revealed that certain crystals exhibit electrical charges on specific areas of their surface when subjected to compression. This finding was influenced by Pierre Curie's earlier research on the pyroelectric effect, which demonstrated electrical potential generation corresponds to variation in temperature and was related to crystal symmetry. Pyroelectric materials are a type of piezoelectric materials. The word "piezo" means "to press" and "pyro" means "fire" in Greek [7][8].

In the latest studies, scientists have been looking into how piezoelectricity can be improved by using better materials and engineering techniques in high-tech systems. Lead-based piezoelectric materials have been extensively used in piezoelectric sensors due to high excellent piezoelectric properties [9]. Susmriti et al. [10] analyzed that Due to Pb toxicity, PZT-based devices can harm the consumer in the long run. Lead-free materials such as potassium niobate (KNN), bismuth titanate and formulations like $xBiCoO_3$-$y(Bi0.5Na0.5)TiO_3$-$zKNbO_3$ gaining attention due to their environmental benefits and potential for high-performance applications [11,12].

Chun et al. [13] utilized the concept of rack and pinion for the development of a footstep power generator to reduce the mechanical complexity structure. Song et al. [14] developed a pavement block piezoelectric energy harvester (PBPEH) of four-layered structure made up of 24 piezoelectric devices. An output voltage of 38.52 Vmax, current of 3.85 mAmax, and power of 148.3 mWmax (3.7 W/m2) was obtained when subjected to a 100 kg weighted person. For testing the feasibility of energy harvesters in commercial level Abidin et al. [15] constructed a prototype where they have used 3 piezoelectric sensors. By connecting them in series and parallel connection they assessed the performance of the prototype. They obtained maximum power of 5.97µW in parallel connection of piezo sensors. Meirer et al. [16] proposed a piezoelectric energy harvesting shoe system for podiatric sensing which measures the pressure exerted on the sole of the wearer’s foot. This module was able to generate 10-20 µJ energy in each step of walking. In corresponding to this type of work Pendem et al. [17] constructed a shoe integrated with piezoelectric sensor and battery as power storage medium. They have connected 4 sensors in series connection and obtained maximum voltage of 1.2V corresponding to the weight of 65 kg.

Previously researchers have focused on integrating piezoelectric materials into footwear or wearable devices for power extraction. Many have installed piezoelectric tiles in a train station to generate power from passenger footsteps. But these studies found that power generation was feasible but limited. For long run these proposed systems lacks in durability and efficiency as they continuously exposed to mechanical stress. Also, Efficiency is further decreased by material limitations, such as the deterioration of piezoelectric materials like PZT. Few prior research only measured voltage and connected sensors in series, neglecting current, limiting insights into overall power output. If a sensor fails or generates less voltage in a series design due to uneven pressure or damage, the total output voltage may be considerably affected. This can make the system less reliable. In contrast, parallel configurations allow for more consistent output even if one sensor is less efficient or fails, as the current from the other sensors continues to flow.

In this study, four piezoelectric sensors were utilized in parallel connection to harvest energy from human footsteps, specifically to enhance current output while maintaining manageable voltage levels. This system advances the state-of-the-art by enhance power output and ensure system reliability, overcoming the limitations of series-based designs prone to sensor failure. Also, it demonstrates scalability and feasibility for integration into preferred place by analyzing the construction experimentally. The parallel arrangement ensures a steady current, in contrast to series configurations frequently investigated in earlier studies to increase voltage, which makes it appropriate for applications where steady energy flow is necessary for charging or direct usage. This study introduces a unique approach by precisely selecting the number of piezoelectric components and prioritizing a parallel design, which may enhance the scalability and flexibility of footstep energy systems.

2. Methodology

2.1 Piezoelectric materials

Lead Zirconate Titanate (PZT), Polyvinylidene Fluoride (PVDF), Lithium Niobate ($LiNbO_3$), Gallium Phosphate ($GaPO_4$), Rochelle Salt (Potassium Sodium Tartrate), Barium Titanate ($BaTiO_3$), Lead Titanate ($PbTiO_3$), Pb $(Zr,Ti)O_3$ (PZT-based Composites) are the most used piezoelectric materials around the world [18]. PZT is considered as the most popular material utilized in piezoelectric sensors. It has been used widely due to its strong piezoelectric properties like greater sensitivity, high curie temperature, stability, electromechanical coupling etc. [19]. Although lead toxicity is an issue of concern, PZT's performance advantages dominate in applications where efficiency, durability, and sensitivity are paramount. Ongoing research into lead-free piezoelectric materials may eventually offer viable replacements, but for now, PZT remains the best choice for high-performance piezoelectric applications.

2.2 Piezoelectric effect

The ability of some materials to produce an electric field in response to applied mechanical strain is known as the piezoelectric effect. In Fig.1, when mechanical pressure is exerted to a piezoelectric material, the material undergoes some structural. It caused positive and negative charges to be displaced inside the material's crystal lattice as a result of this structural deformation. The change in crystal causes polarization to occur which creates a dipole moment. The piezoelectric material transforms into piezoelectricity throughout the polarization-generating process.

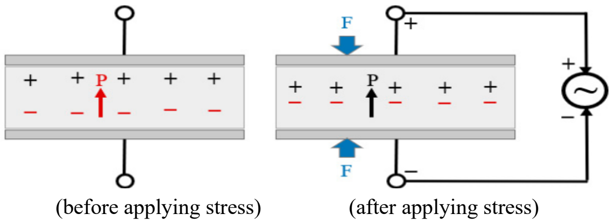

Fig.1 Illustration of the direct piezoelectric effect [20]

2.3 Major components

Table 1 includes a list of accessories and their specification that had been implemented for the complement of the study.

Table 1 List of components, their specifications and quantity used in the proposed system.

Name of the Accessories	Specifications	Quantity
Piezoelectric Sensor	Resonant Resistance:300 ohm max Capacitance: 16000pF +/- 30%	04
Diode (1N007)	Avg. Forward Current: 1.0 A Peak Forward Surge Current: 30 A Instantaneous Forward Voltage: 1.0V. Reverse Current at rated DC blocking voltage: 5.0 µA @C25° C	05
Capacitor	Capacity: 47 µF	1
Resistor	1kohm	1
Breadboard		1
Wire		
Multimeter		1
LED		

2.4. Developed system

The piezoelectric power generating circuit was shown in Fig.2 containing the piezoelectric sensor, diode rectifier, capacitor and LED as major components. Once the AC voltage generated from the piezoelectric transducer was converted into DC voltage using the bridge rectifier, the circuit efficiently managed the DC power. However, the DC output from the bridge rectifier contains harmonics and ripples, as the rectifier only converted the negative part of the AC wave into a positive. The capacitor was typically placed after the rectifier in order to vanish the fluctuation in voltage from DC output. When the voltage level rises the capacitor gets charged and discharged with the drop of voltage level that ensures steady DC voltage across the load. The DC voltage powers the LED, which is a low-power device. The LED will light up as long as there is sufficient voltage and current coming from the piezoelectric energy system.

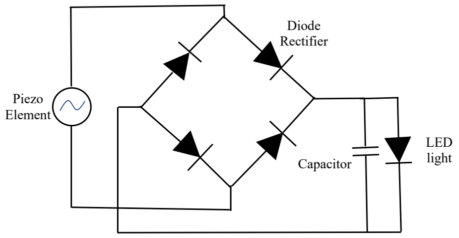

Fig.2 Circuit diagram of piezoelectricity generation

The basic design system of the block diagram shown in Fig.3 external mechanical pressure (e.g., footsteps) was applied to the piezoelectric sensors. The piezoelectric sensors exhibit a piezoelectric effect to convert the mechanical vibrations into electrical. In this case, the mechanical stress applied to the sensors created an alternating current (AC). As DC load was used in our developed system, it required direct current (DC) for operation, and the AC output from the piezoelectric sensors was passed through an AC-to-DC rectifier circuit. The rectifier converted the alternating current to a direct current, which can be used to power DC loads. The DC power generated was then used to power a DC load, LED light. The current and voltage were measured across the load using a multimeter.

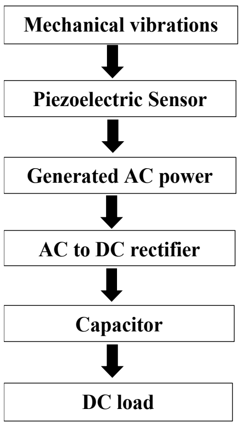

Fig.3 Block diagram of the designed system

Fig.4 depicts the experimental setup for footstep power generation which comprises of component listed in table 1.0. The developed model is highly useful and simple to extract power that maybe wasted previously. Throughout the implementation of 4 piezoelectric sensor and other accessories current voltage and power has been measured.
The positive terminals (red wires) of all sensors are connected together to make a common point and the negative terminals (black wires) are also connected together to form another common point, then the two common points are attached to the breadboard, forming a parallel circuit. Each piezo sensor contributes its share of the power to the load, making the overall system more efficient in terms of current generation. The total current is the sum of the currents produced by each sensor. Therefore, a parallel connection helps increase the total current output without increasing the voltage.

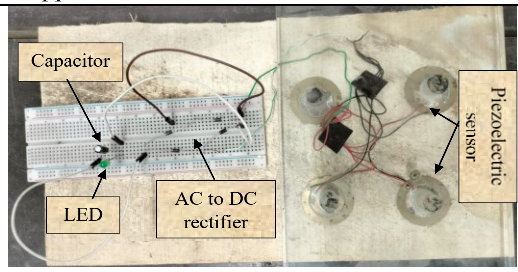

Fig.4 DC Power generating circuit

AC to DC bridge rectifier converts alternating current (AC) into direct current (DC). It typically consists of four diodes arranged in a "bridge" configuration. These diodes are connected in a way that allows current to flow only in one direction, which converts the AC input waveform (that alternates between positive and negative cycles) into a unidirectional (positive-only) output. It ensures that regardless of the AC input polarity, the output across the load is always in one direction, producing a pulsed DC waveform.
The major components used in the setup are configured below in Fig.5 piezoelectric sensor serves as the main power-generating component throughout the system. It is employed with the piezoelectric effect to transform changes in pressure or force into an electrical charge. These sensors are based on the characteristics of particular materials, which create an electric charge in reaction to mechanical stress. A diode is a device which allows current flow through only one direction. That is the current should always flow from the Anode to the cathode. The high voltage and current carrying capabilities of the 1N4007 diode make it suitable for use in power supply and rectification applications. A capacitor is a fundamental electronic component that stores electrical energy in an electric field. It consists of two conductive plates separated by an insulating material called a dielectric. The primary function of a capacitor is to store and release electrical energy in a circuit.is of two conducting plates separated by an insulating material called the dielectric. The multimeter is used for measuring current, voltage, power and capacitance.

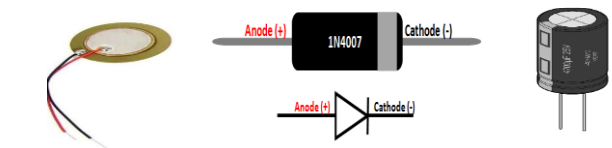

Fig.5 Major components used in the piezoelectricity generation

3. Results and discussion

The experiment was carried out in the "Solar and Wind Energy" lab which is under the Department of Energy Science and Engineering. Minimal external vibrations were ensured in order to avoid inappropriate output associated with proposed system. The sensors were sensors embedded in a wooden base and placed on floor surface to simulate real walking conditions. The inside temperature and humidity were maintained the same as the outside. The study was conducted in two distinct steps to evaluate the performance of piezoelectric sensors under different configurations.

3.1 Effect of different weights on piezoelectric sensors

In this step, four piezoelectric sensors were connected in parallel. A varying weight, ranging from 10 kg to 22.5 kg, was applied to the sensors. For each weight, the voltage and current generated by the sensors were measured across the load. These measurements were used to calculate the power output (Power = Voltage × Current). The data for the current, voltage, and corresponding power values for each applied weight are recorded in Table 2.

Table 2 Power output from the different weight on piezo disks

Serial No.	Weight(kg)	Voltage(V)	Current(A)	Power (mW)
01	10	2.8	0.0075	0.0210
02	12.5	2.9	0.0083	0.0240
03	15	3.1	0.0087	0.0270
04	17.5	3.2	0.0096	0.0307
05	20	3.4	0.0101	0.0343
06	22.5	3.6	0.0104	0.0374

The increased weight on the piezo disks caused the generation of higher current and voltage with the associated model as shown in Fig. 6

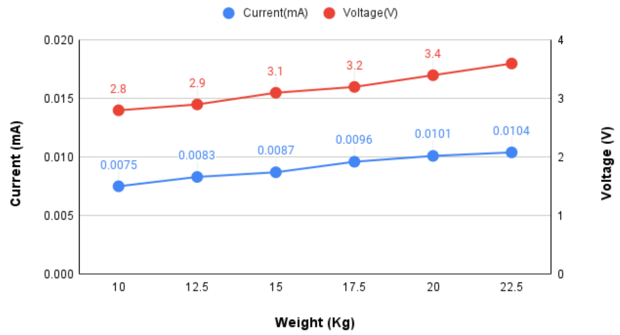

Fig.6 Voltage and Current Output from Different Weights on Piezo Disks

The graph entitled "Weight vs Current and Voltage" in Fig.6 shows the relationship between the applied weight on piezoelectric disks and the resulting voltage and current generated by the sensors, based on the data provided in Table 2. A minimum output voltage of 2.8V has been observed for the applied weight of 10 kg and reached a maximum voltage of 3.6V as the weight of 22.5 was applied to the system. The output voltage was increased when the system was subjected to increased applied weight. The increased weight causes the piezoelectric material to deform more substantially and more electric discharge to be generated. This higher charge accumulation increases the potential difference (voltage) across the sensor. As a result, as the applied weight increases, the voltage output also increased. Also, the output current increased in similar pattern with applied weight. Initially output current of 0.0075 mA was observed when we applied a weight of 10 kg to the system. The current reached a maximum value of 0.0104 mA for an applied weight of 22.5 kg. The rise in current is more gradual, indicating that the piezoelectric sensors are more sensitive to generating voltage with increasing weight, while the current output increases at a slower rate. The current increased because the flow of this accumulated charge became greater as more weight was applied.

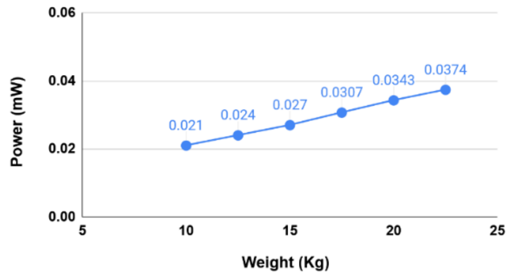

Fig.7 Power generated from the different weights on piezo disks

The graph in Fig.7 shows a positive linear relationship between weight and power output. As the weight applied to the piezoelectric sensors increases, the power output increases proportionally. At 10 kg, the piezoelectric sensors produced a power output of 0.021 mW. As more weight is applied, the sensors experience greater mechanical deformation, leading to higher electrical output (both voltage and current), which in turn results in higher power generation. And reached 0.024 mW for an applied weight of 12.5 kg. The highest power output was 0.0374 mW at a maximum weight of 22.5 kg. In comparison with similar type of work performed by Pendem et al. [16] also used 4 piezoelectric sensors but obtained output voltage of 1.2V which is less than our obtained voltage. This improvement underscores the effectiveness of our design enhancements, which contribute to greater energy conversion efficiency.

3.2 Effect of the number of piezoelectric sensors

In the second step, a constant weight of 15kg was applied and the number of piezoelectric sensors was varied from 1 to 4. For each configuration (1, 2, 3, or 4 sensors), the voltage, current, and power output were measured and recorded in Table 3. When a single piezo disk was subjected to mechanical pressure, it produced 3.2 volts' voltage and 0.0063mA current across the load. The observed voltage for each case remained almost the same with multiple number of piezo sensors in parallel connection. However, the maximum current observed was 0.0085 mA increasing from the initial value. It was due to the characteristics of pressure distribution in developed systems. As the weight was applied centrally, when the number of sensors increased, the weight pressure was distributed through each sensor in the same amount causing the effective available weight to be reduced for each sensor. This indicates that the pressure applied to the piezoelectric transducers was distributed and leads to a lower output current for each sensor. Also, the piezoelectric material can't hold the electric charge for a long time as it acts as a leakage path. So, it may diminish within a short time, reducing the overall current output.

Table 3 Table for generated power according to the number of piezoelectric transducers (15 Kg).

Number of sensors	Voltage(V)	Current(mA)	Power(mW)
1	3.2	0.0063	0.02016
2	3.1	0.0068	0.02108
3	3.2	0.0076	0.02432
4	3.2	0.0085	0.0272

According to the proposed system, the voltage, current, and power produced have been increased with a number of piezoelectric transducers when constant weight is applied as shown in Fig.8.

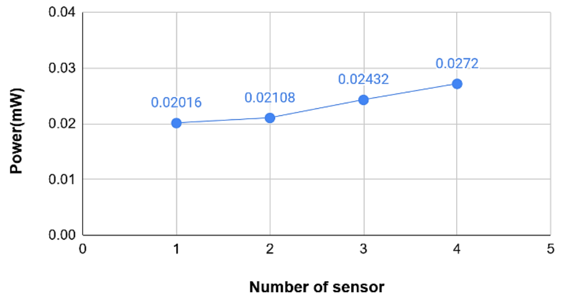

Fig.8 Power Output from Different Numbers of Piezo Disks

The graph entitled in Fig.8 shows the power output (in milliwatts, mW) produced by varying numbers of piezoelectric disks. The power generated from a single piezoelectric sensor was observed 0.02016 mW. And the maximum power observed was 0.0272 mW for 4 sensors connected in parallel connection. The power developed was increased from 0.02016 to 0.0272 mW for a higher piezoelectric effect generated due to multiple sensors. The more the number of piezoelectric disks, the more power can be harnessed from the developed model. Abidin et al. [15] used 3 piezoelectric sensors and obtained maximum power of 5.97µW in parallel connection, it improves the admissibility of our proposed work.

4. Conclusion

In the study, though very little power has been extracted from the sensors, a great deal will be using this system as a walkway tile in public places like footpaths, rail-station, convention centers, concert areas, party places and many more, as these places get thousands of footsteps. Increased weight on the piezoelectric sensors leads to higher power generation due to increased mechanical deformation, which generates more voltage and current. Hence maximum power of 0.0374 mW was observed by connecting four piezo disks in parallel connection in response to weight pressure of 22.5 kg. One led light of 5mm was effectively lit by the proposed prototype. Also increasing the number of sensors boost the overall power output, even for a constant load, suggesting that the system's performance can be improved by using more piezoelectric elements in parallel. This system can easily sum up the power and able to provide the power as commercial aspects. The connections were stablished perfectly in the system to get the best possible output and the objectives were fulfilled in the whole process.

5. Recommendations

Piezoelectric effect might be an excellent future alternative for harvesting a new energy source notion. Because excessive pressure exerted by footfall is squandering on the pathways, actions can be made to convert these mechanical forces into electrical power. This concept may be readily performed in a highly populated nation like Bangladesh to get electrical energy. Additionally, integrating the system with smart grids or microgrids can enable efficient energy distribution in urban infrastructure.

References

[1] Pimentel, D., Rodrigues, G., Wang, T., Abrams, R., Goldberg, K., Staecker, H., Ma, E., Brueckner, L., Trovato, L., Chow, C. and Govindarajulu, U., “Renewable Energy: Economic and Environmental Issues,” BioScience, vol. 44, no. 8, pp. 536–547, 1994

[2] Cohen, R. Energy from the ocean. Philosophical Transactions of the Royal Society of London Series a Mathematical and Physical Sciences, 307405–437, 1982

[3] Li, H., Tian, C. and Deng, Z.D., “Energy harvesting from low frequency applications using piezoelectric materials,” Applied Physics Reviews, vol. 1, no. 4, p. 041301, 2014

[4] Selim, K.K., Yehia, H.M. and Abdalfatah, S., “Human Footsteps-based Energy Harvesting Using Piezoelectric Elements,” Energies, 2023.

[5] Cavagna, G.A., Willems, P.A., Legramandi, M.A. and Heglund, N.C., “Pendular energy transduction within the step in human walking,” The Journal of Experimental Biology, vol. 205, no. 21, pp. 3413–3422, 2002

[6] Kolhatkar, S., Kalambe, S., Khan, M., Borkar, V., Kirnapure, S. and Sapate, V., “Power Generation from Footsteps by Using Piezoelectric Sensor,” International Journal of Innovative Science and Research Technology (IJISRT), pp. 2188–2189, 2024.

[7] Mason, W.P., “Piezoelectricity, its history and applications,” The Journal of the Acoustical Society of America, vol. 70, no. 6, pp. 1561–1566,1981.

[8] Ruman, M.R., Das, M. and Mahmud, S.I.,Human footsteps for energy generation by using piezoelectric tiles. In 2019 Innovations in Power and Advanced Computing Technologies (i-PACT) (Vol. 1, pp. 1-6). IEEE, 2019.

[9] Wang, S., Wen, L., Gong, X., Liang, J., Hou, X. and Hou, F. Piezoelectric-based energy conversion and storage materials. Batteries, 9(7), p.371,2023.

[10] Peng, W., Chang, J., Zhao, J., Wang, D., Liu, Z., Wang, G. and Dong, S., “Enhanced piezoelectric properties and thermal stability of LiNbO3-modified PNN–PZT ceramics,” Journal of Materiomics, vol. 10, no. 5, pp. 995–1003, 2023.

[11] Aksel, E. and Jones, J.L, “Advances in Lead-Free Piezoelectric Materials for Sensors and Actuators,” Sensors, vol. 10, no. 3, pp. 1935–1954,2010.

[12 Panda, P.K, “Review: environmental friendly lead-free piezoelectric materials,” Journal of Materials Science, vol. 44, no. 19, pp. 5049–5062, 2009

[13] Ang, C.K., Al-Talib, A.A., Tai, S.M. and Lim, W.H, “Development of a footstep power generator in converting kinetic energy to electricity,” E3S Web of Conferences, vol. 80, p. 02001, 2019.

[14] Song, G.J., Cho, J.Y., Kim, K.B., Ahn, J.H., Song, Y., Hwang, W., Do Hong, S. and Sung, T.H., “Development of a pavement block piezoelectric energy harvester for self-powered walkway applications,” Applied Energy, vol. 256, p. 113916,2019.

[15] Abidin, N.A.K.Z., Nayan, N.M., Azizan, M.M., Jamel, N., Ali, A., Azli, N.A. and Nordin, N.M. Performances of multi-configuration piezoelectric connection with ac-dc converter in low frequency energy harvesting system. In Journal of Physics: Conference Series (Vol. 2550, No. 1, p. 012001). IOP Publishing, 2023.

[16] Meier, R., Kelly, N., Almog, O. and Chiang, P. A piezoelectric energy-harvesting shoe system for podiatric sensing. In 2014 36th Annual international conference of the IEEE engineering in medicine and biology society (pp. 622-625). IEEE. 2014.

[17] Pendem, Sireesha, Kancharla Suresh, Sudhamani Chilakala, Suraya Mubeen, and Nazia Shabana. "Smart shoe based on piezo electric sensors for low power applications." In AIP Conference Proceedings, vol. 2477, no. 1. AIP Publishing, 2023.

[18] Safaei, M., Sodano, H.A. and Anton, S.R. A review of energy harvesting using piezoelectric materials: state-of-the-art a decade later (2008–2018). Smart materials and structures, 28(11), p.113001, 2019

[19] Kang, M.G., Jung, W.S., Kang, C.Y. and Yoon, S.J.. Recent progress on PZT based piezoelectric energy harvesting technologies. In Actuators (Vol. 5, No. 1, p. 5). MDPI. 2016.

[20] Han, H. and Ko, J “Power-Generation Optimization Based on Piezoelectric Ceramic Deformation for Energy Harvesting Application with Renewable Energy,” Energies, vol. 14, no. 8, p. 2171, 2021.