Energy Generating Shoes: An Experimental Study in Converting Footsteps as a Source of Energy to Generate Electricity

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ABSTRACT

The exploration continues to find ways to harness the energy sources, such as solar, wind, hydropower, geothermal, and ocean energy, which naturally replenish themselves without depletion. This research aimed to develop an innovative energy generating shoes which convert human steps into electricity. An experimental research design was utilized to carry out this study following TRIZ Method along with data collection techniques outlined in the study leading to firm conclusions about the shoes' effectiveness to generate electricity. The data was analyzed using linear regression or investigating the prototype since it enables the exploration of the correlation between two variables: the energy produced and a single predictor, like walking speed or exerted force. The results revealed that the correlation analysis yielded a value of 0.70, indicating a robust positive correlation, suggesting a strong relationship between the number of footsteps and the volts generated. Moreover, with a significant F-value of 0.30 surpassing the p-value of 0.05, there is sufficient evidence to assert that the regression model fits the data better than the model lacking independent variables. which it can be concluded that the energy-generating shoes produced a noteworthy amount of voltage during the trials. The study was constrained by the limited number of laboratory testing conducted by the researchers. It is recommended for future research to produce studies that will focus with multiple laboratory trials of the prototype.

Keywords: Renewable energy, human footsteps, regression, experimental, shoes generating electricity.

INTRODUCTION

Electricity is one of the most consumed energy sources in the entire world. Energy providers anticipate that distributing electricity in 2023 will be significantly more expensive, owing mostly to rising natural gas costs, and in the first half of 2022 evaluated in comparison to the same period in 2021, gas prices in Europe jumped by a factor of four and coal prices by a factor of more than three [1]. As a result, wholesale energy costs more than tripled in several locations [1]. The pricing index of the International Energy Agency (IEA) for major global power wholesale markets exceeded the first-half average from 2016 to 2021 [2]. Moreover, conventional energy is continuously increasing due to the high consumption of electronic devices such as laptops, phones, etc. and this, of course, may result in rising electric bills and can cause negative impacts on the environment. The average home electricity price in the Philippines is P9.88 per kWh, greater than the average price in other countries of Asia [3]. Meanwhile, the extinction of the power supply is also because of the immense population. As a result, the researchers must think of an alternative solution. As the population grows each year, so does the electricity demand [4]. For this reason, scientists and engineers are exploring renewable energy as a possible replacement for conventional resources like fossil fuels. Consequently, natural gas, nuclear energy, and coal are known as the world's environmental sources of electricity, and each comes

with an alarming risk in various ways. It is generally known that the extensive use of fossil fuel-generated electricity is a major component of these environmental threats by emitting greenhouse gases [5]. Nuclear energy, on the other hand, faces the issue of managing radioactive waste generated at each stage of the nuclear fuel cycle, which could hinder its development. Given the ease with which gaseous radioactive waste disperses through the atmosphere, it presents a serious threat to general humanity and the world [6]. Additionally, coal-fired power plants emit more than just carbon dioxide; other hazardous substances have an impact on people's health and can induce asthma or even a heart attack. Nitric Oxide (NO) and Sulfur Dioxide (SO2) emissions from coal burning have been linked to health problems such as asthma, lung cancer, and heart disease [7].

Humans need energy to sustain their lives and well-being, and as of 2022, the approximate number of people living on earth is 8 billion. It has many applications in a person's everyday life, and with emerging technology and its advancement, the use of natural power becomes more efficient [8]. As a result, the researchers found an alternative source to produce electricity by simply walking. Our footsteps can be used to create a power generation system that converts kinetic energy around a system into electrical energy. Piezoelectric materials are used to generate energy. The conversion of kinetic and electrical energies is one way to conceptualize the piezoelectric effect [9]. Human activities have the ability to produce energy. Researchers investigated the possibilities of the human body as a sustainable alternative energy source [10]. Piezoelectric materials were used, which transform human activity into electrical energy. These modern devices make our daily lives more convenient. Furthermore, finding a sustainable power source for these wearable devices has allowed them to lessen their reliance on, or even become independent of, external electrical power sources. It is preferable to scavenge or gather the energy generated by human movement while the individual is performing their usual or daily activities [11].

With discoveries, we can stand out and gain recognition elsewhere. It is a very useful method for harnessing human-generated energy from the environment and converting it into electrical power and with innovative technologies, we may distinguish ourselves from other nations and gain their respect. In today's world, the majority of individuals engage in energy harvesting [12]. Individuals sought to conserve energy or did so in an easy fashion that might be used in an emergency, such as a power outage, or they simply charged their devices for free. As we all know, the Philippines frequently encounter power interruptions which is why there is a need to ponder and implement the utilization of kinetic energy as a source of electric energy. Using renewable energy is an effective source of energy that will provide electricity to charge or power electronics, especially in times of emergency [13].

Hence, this study aims to determine the utilization of walking or footsteps, as an alternative source to generate electricity. The researchers have chosen kinetic energy as a source to produce electrical energy because human beings dissipate energy all the time, it is also conveniently accessible, and is a viable alternative to electrical power supplied by batteries. Moreover, accumulating kinetic energy is a sustainable way to generate power that does not deplete natural resources. Currently, it has been established that obtaining energy from human movement is a practical and promising method of continually powering wearable electronics devices. By conducting this study, the researchers will be able to facilitate sources of electricity as well as reduce its usage. The researchers find this study challenging because of the sustainability and production of the device. Nonetheless, developing this study will lead to more sustainable sources of energy which will help emit the utilization of burning fossil fuels and greenhouse gasses.

METHODS

A. Research Design

The study seeks to conduct an experiment with generating electricity from walking as a source of energy. An experimental design improves the ability of the researchers to establish and assert new findings through accurate and exact factual evaluation and measurement. Using this method, it will allow the researchers to investigate the potential of utilizing locomotor movement as a new technique to generate electricity. To achieve one of the study's objectives, the researchers will use experimental research to investigate the effects of a useful relationship, which is demonstrated whenever active changes in one variable result in simultaneous

changes in another.

An experimental design involves carefully balancing several factors, such as "power," "generalizability," several types of "validity," "practicality," and cost [14]. An experiment will have the best chance of producing valuable evidence to alter the current body of knowledge in a given scientific subject if these features are balanced prior. Moreover, true-experimental design is considered the most accurate form of experimental research as it utilizes mathematical and statistical analysis to validate or reject a hypothesis. A controlled and experimental group are utilized in a true-experimental study [15].

B. Research Instrument

To gather the necessary data, the researchers will provide one part of the questionnaire. Part I will consist of interview questions that will be answered and modified by the researchers themselves to determine the production, materials, and performance of the shoe-generating energy.

The research instrument that will be used in this study is adapted from the study entitled "Designing A Sustainable Energy-harvesting Stairway: determining product specifications using TRIZ method" [16]. To complement the experiment, the researchers modified the questionnaire. The research instrument will assist the researchers in gathering the data necessary to accomplish this study.

C. Research Procedure

The experiment that the researchers will conduct is an adopted procedure from the Senior High School students of Ocana National High School. The materials and equipment to be utilized will remain the same for the reason that the result of their study was not mentioned. The researchers find this helpful for it is attainable for the researchers to conduct. The experiment’s duration will be undertaken for a month to test its effectiveness, performance, and durability.

Applications examined by experimental analysis will be subjected to experimental tests, literature studies, and questionnaires by the researchers. Researchers will do literature reviews to figure out additional information to carry out the energy-generating shoes.

To craft a piezoelectric pressure sensing shoe insole, begin by gathering all necessary materials and tools. Next, cut a vinyl tile to match the size and shape of the shoe's insole. Position a piezoelectric transducer at the center of the cut vinyl and trace its outline using a compass. Proceed to draw a circle inside the traced transducer outline and carefully cut it out using an electric drill. Apply contact adhesive around the drilled hole and affix the piezoelectric transducer securely. Create a bridge diode to filter and convert DC to AC, then cut and attach a small piece of foam to the transducer's center for cushioning. Utilize a soldering rod to attach the bridge diode and capacitor to the transducer, connecting them with hookup wires to form a circuit. Finally, remove the shoe's insole, insert the vinyl with the components into the shoe, and reinsert the shoe's insole. Following these steps meticulously will result in a functional piezoelectric pressure sensing shoe insole, ideal for monitoring foot pressure and gait dynamics.

TRANSFER OF KINETIC ENERGY TO ELECTRICAL ENERGY

In order for the researchers to store the generated electricity, the researchers built a bridge diode rectifier circuit of four diodes that is used in the process of converting alternating current from the input terminals to direct current on the output terminals. Then, six (6) pieces of piezoelectric transducers were used that will be the source of energy. The researchers made the storage and outlet to enable it to charge. The device produces seven (7) volts but the battery that was utilized has a capacity of 4.3 volts only but the battery can handle this amount of voltage because of the bridge diode that adjusts the flow of electricity. The device was able to charge, due to the combined three (3) piezoelectric transducers that enabled it to produce electricity. Due to walking and the strong pressure, it delivers, there is a result of greater voltages produced. Additionally, through the use of the battery case which is a large part of the device for the charges or electricity produced by the piezoelectric transducers and so the stored electricity stays because the electricity will go to the most

storage of the battery (4.3 volts).

The shoes are fitted with a system that has an energy harvesting circuit to store the electrical energy produced by the piezoelectric effect. The electrical charge generated by the piezoelectric material is collected by this circuit and transformed into a form that may be used, typically electrical energy contained in a rechargeable battery. There are rectifiers and capacitors and/or batteries in the energy harvesting circuit. The rectifier changes the piezoelectric effect's alternating current (AC) into direct current (DC). The voltage regulator makes sure that the electrical energy is stored in the battery at the proper voltage level.

RESULTS AND DISCUSSIONS

1. Trial Procedures in Acquiring Electrical Energy

The first trial of experimentation, the piezoelectric device was employed and it was then inserted into the shoe's insole. The researchers thereafter attempted running and walking (in place) while wearing the shoes in order to ascertain whether it would be successful. As a result, electricity was generated. However, the generated electricity was not stored in the capacitor. The generated electricity also decreased rapidly in a couple of seconds. In addition, the excessive usage of the device inside the shoe caused some parts of the device to detach.

Fig. 1: First Trial of Generating Electricity

In the second trial, replacing the capacitor, the energy storage and release device was a super capacitor. The researchers tested the piezoelectric transducer once more to find out how well it could be used to produce energy by walking or running. However, regardless of how much energy had been generated, there was not enough of it to consume and store, thus over time, more power was lost than was gained. Moreover, the second trial failed due to incorrect procedures such as the inverted use of diodes and capacitor which lead to zero results after testing it.

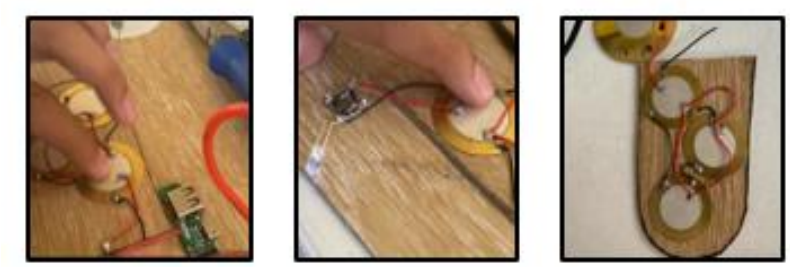

Fig. 2: Second Trial of Generating Electricity

For the third trial, the researchers added a few materials, which includes three piezoelectric transducers perinsole and power bank module. Similarly to the procedures done on the second experimentation trial, the researchers utilized a power bank module along with a multimeter to test if it was able to conserve energy.

Fortunately, its generated electricity reached four (4) volts and the energy was finally stored. To test its effectiveness, an LED was also used to see if it would light up and it successfully did. Although the researchers were able to store the electrical energy, the battery rapidly lost its charge without consuming it yet.

Fig. 3: Third Trial of Generating Electricity

Figure 3 shows the third trial of experimentation by the researchers, which was to examine the effects of incorporating various materials in order to assess whether any noticeable changes would occur and whether this could potentially result in the production and the longer storage of additional energy.

After conducting deep research, the researchers concluded to add a battery case, a new power bank module (as a replacement to the module used in test three since it was not compatible with the researchers' device), and a battery (as a replacement to the super capacitor used in test two).

Lastly, the result of test four is the most successful in comparison to the previous trials done by the researchers. The only difference of trial four is it is able to store energy and the stored energy can be finally consumed unlike the devices done from trials one to three. Trial four's energy stays inside the battery and would only be reduced when consumed. Furthermore, it showed improvements in holding the amount of voltage and time of consumption.

Fig. 4: Fourth Trial of Generating Electricity

2. Relationship Between the Footsteps and Energy Generated

Table 1 presents the number of trials and every trial includes the number of footsteps, amount of voltage, and the time of consumption of the device. In the first trial, the researchers have done one hundred seventy-six (176) footsteps which resulted in two (2) volts. But the time of consumption is 0 since the energy generated by the researchers was not able to stay inside the capacitor, meaning the researchers were able to generate electricity but the energy was not stored. The generated electricity decreased without consuming it yet.

Similarly for trials two (2) and three (3), given also that there were missing procedures in producing the device.

The table below showed that trial one (1) has a higher number of footsteps than trial three (3), but trial three (3) has a greater amount of voltage than trial one (1) and this is only because of the materials and procedure done by the researchers. Since trial one (1) used only one (1) piezoelectric transducer, it generated a very small amount of energy. Unlike trial three (3) which was composed of three (3) piezoelectric transducers, it was able to generate electricity faster.

Table 1: Number of footsteps and amount of energy generated

Trial	Number of Footsteps	Amount of Voltage	Time of Consumption
1	176	2 V	0 seconds
2	120	0 V	0 seconds
3	130	5 V	0 seconds
4	248	7 V	40 seconds

In comparison to trials three (3) and four (4), considering they both contain three (3) piezoelectric transducers, the higher the number of footsteps were done, the higher the voltage the device can generate. This proves that there is indeed a relationship between the number of footsteps and the amount of energy that can be generated.

Table 2: Correlational analysis of relationship between footsteps and voltage generated

No. of Steps	Volts
No. of Steps	1
Volts	0.696475867

The correlation analysis resulted in a 0.70 value suggesting a strong positive correlation. Thus, there is a strong positive correlation between the number of footsteps and volts generated. The regression analysis below supports this correlation.

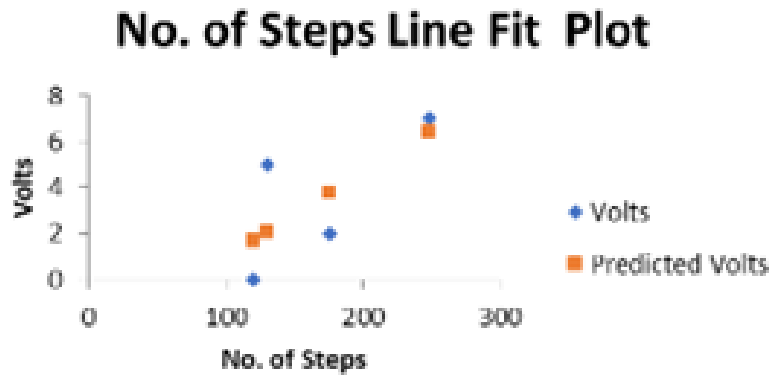

Fig. 5: Regression Analysis

The predicted volts suggest an upright trend which supports the strength and direction of the linear relationship between number of footsteps and volts generated by the shoes.

Table 3: Regression statistics

Regression Statistics	Value
Multiple R	0.696476
R Square	0.485079
Adjusted R Square	0.227618
Standard Error	2.732464
Observations	4

However, since trials are limited to 4, the r-square is 0.5 suggesting a moderate prediction accuracy.

Table 4: One-way analysis of variance (anova)

	df	SS	MS	F	Significance F
Regression	1	14.0673	14.0673	1.88409	0.30352
Residual	2	14.9327	7.46636		
Total	3	29			

Finally, since the significance F value (0.30) is greater than the p-value of 0.05, it can be said that there is enough evidence to conclude that the regression model fits the data better than the model with no independent variables. Thus, the energy generating shoes have produced a significant amount of voltage during the trials.

3. Implications During and After the Experiment

The effectiveness of each product alternative is adapted from the study entitled "Designing A Sustainable Energy-harvesting Stairway: determining product specifications using TRIZ method" [16]. This questionnaire helped the researchers to gather further data to help with the recommendations and points to improve in this study.

This will help the researchers determine whether human-generated energy can replace conventional electrical energy and reduce its harmful effects on the environment. It will ask questions regarding the effectiveness of the shoe-generating energy itself.

Table 5: Energy generating shoes' characteristics

Product Characteristics	Yes	No
Not slippery	✓	
Does not cause any electric shock	✓	
Could load a heavy weight		✓
Easy to take care	✓	
Energy-efficient (does not overheat)		✓
Remains stable when stepped on		✓
Pressure-sensitive	✓	
Durable	✓	

Easy to repair		✓
Chemical-fluids-resistant (e.g., water, etc.)		✓
Temperature-and-extreme-weather-resistant	✓	
Stable output of electric current	✓	
Easy to assemble and install	✓	

After the researchers tested the device, there were several implications during and after the experiment which includes:

Device. The energy-generating shoes generated different amounts of energy based on the wearer's movement, speed, and duration of exercise during the testing. The reliability and consistency of the device's power supply was impacted by this variation. After testing the energy generating shoes, high-energy-demand devices were not directly powered by the energy the shoes produced. In these circumstances, the energy produced was stored in a shoe- based intermediate energy storage unit (such as the battery), which then provided a more dependable and stable power output to the device. To maximize the use of the harvested energy and increase the device's running time, energy efficiency became essential. Furthermore, the mechanical forces that are applied to energy-generating shoes when they are being worn during physical activity or while walking generate power. The device was durable from pressures and kept its toughness over time. Based on the results, the device continuously functions and performs despite enduring the repetitive, occasionally arduous movements involved in walking or running.

Examiner. While wearing the device integrated inside the shoe, the wearer had trouble having a snug and comfortable fit. The device was not able to perform the shoe's flexibility, cushioning, or breathability. Even so, the device was still easily utilized for it does not contain complicated measures in using the device. Energy-generating footwear somewhat changed the wearer's stride and movement habits. A person's gait or running form is impacted by the extra weight or variable force distribution in the shoes. The researchers have established that it is crucial to make sure that these changes don't affect biomechanics or raise the danger of accidents. The footwear should encourage a smooth and effective stride while providing power. For the successful adoption and acceptance of energy-generating shoes, the examiner's overall user experience was quite positive. The production of the shoes was heavily influenced by elements like comfort, practicality, usability, and durability. As a result of the device being attached to just one shoe, there is an imbalance that can be observed. Furthermore, after utilizing the device, the wearer's health or safety were not jeopardized by the energy-generating shoes that were created. It reduces the chance of suffering from wounds like blisters, sprains, or falls. The shoes provide sufficient cushioning and support to safeguard the feet and lessen joint stress.

Energy Produced. The energy-generating mechanism within the shoe maximized the efficiency of converting mechanical energy into electrical energy. A greater percentage of the energy produced by the wearer's footsteps was gathered and usable as a result of higher efficiency. Enhancing energy generation efficiency makes sure that more power is produced with the same amount of wearer effort. The energy-generating shoes generated different amounts of energy, depending on the wearer's activity level, speed of walking or running, and shoe design. It's critical to optimize the technology to produce a significant amount of useful energy because the energy production may vary. Longer gadget usage times or more efficient charging are made possible by higher energy output.

PRODUCTION OF THE SHOES

1. Costing. Utilizing a diverse range of materials procured at accessible prices. The foundational pair of shoes was obtained through the researchers, ensuring cost-effectiveness. Essential components included a 30-peso marker for initial design outlines and 40 pesos worth of styrofoam for structural reinforcement. Precision in assembly was guided by a compass, while the secure placement of

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components was facilitated by 60 pesos' worth of double-sided tape.

Electrical functionalities were supported by capacitors and 1N4007 rectifier diodes, totaling 87 pesos, essential for energy conversion and storage. Integration of 75 pesos' worth of 15mm piezoelectric transducers into the sole enabled efficient energy harvesting from footsteps. Electrical connectivity was ensured with 30 pesos' worth of hookup wire, while 30 pesos' worth of contact adhesive provided robust bonding. A 65-peso power bank module facilitated efficient energy storage, complemented by a 150-peso battery and a 40-peso battery case for sustained power supply. Through meticulous assembly and integration of these materials, the team achieved significant strides in wearable technology innovation. The resulting energy-generating shoes exemplify the team's commitment to sustainable energy solutions, leveraging everyday movement to generate electrical power efficiently and effectively.

Meanwhile, the researchers have developed a full set of essential equipment for the development and testing of energy-generating shoes. This assistance considerably simplifies our research efforts by reducing the requirement to include equipment prices in our budgeting calculations. Conversely, The digital multimeter was required for accurate measurement of the electricity generated and stored in the capacitor. The cuts needed were made with the utilization of Electric drill. Lastly, Using a soldering iron and rod, the bridge diode and piezoelectric transducer were connected together with hookup wire to form a complete circuit.

2. Size of the Shoes. As for the experiment, the shoe size used was US size 6 for women. It was observed that the wearer felt slight discomfort while walking. In terms of future manufacturing of the shoes, the energy-generating shoes designed for teens and adults are available in a range of sizes to suit various foot dimensions and preferences. Each size is crafted with comfort and fit in mind, ensuring wearers can comfortably use them throughout the day while benefiting from the integrated energy-harvesting technology. These shoes often feature adjustable elements and ergonomic considerations to accommodate different activities and lifestyles, providing both support and effective energy generation. But this needs further research in order to successfully obtain comfortable and well-made shoes.

3. Manufacturing Techniques.
   a. Advanced Material Choices - Use state-of-the-art materials for piezoelectric transducers and shoe components to boost efficiency and durability. This includes exploring flexible, lightweight materials that seamlessly integrate into shoe designs.
   b. Compact Circuit Design - Developing efficient, compact circuits for energy conversion and storage. This involves miniaturizing components such as bridge diodes and capacitors to optimize space and performance within the shoe.
   c. Optimized Ergonomic Design - Refining shoe designs through comprehensive ergonomic studies and user feedback to maximize comfort and performance. This includes customizing fit and cushioning for various foot shapes and activities.
   d. Automated Assembly and Testing - Implementing automated assembly lines and rigorous testing protocols to maintain high production standards and efficiency, ensuring every pair meets quality benchmarks.
   e. Market Research and Adaptation - Continuously gather market insights and adapt manufacturing processes to meet evolving consumer preferences and technological advancements, enabling agile product development and competitive market positioning.
   f. By leveraging these advanced manufacturing approaches, companies can establish themselves as leaders in the emerging energy-generating shoe market, offering innovative products that blend sustainability with state-of-the-art technology and user-focused design.

4. Target Market. Energy-generating shoes provide customized advantages for different age groups, improving their everyday activities and supporting sustainability.
   a. Teenagers - Are often tech-savvy and active, can use the generated energy to charge their smartphones, fitness trackers, or other electronic devices, supporting their dynamic lifestyles and reducing dependency on conventional power sources.

b. Adults - Those with outdoor or physically demanding jobs, can benefit from the practicality of charging essential devices such as phones, GPS units, or portable power banks directly from their footwear, ensuring they remain connected and efficient throughout their busy days.

By catering to the specific requirements of different age groups, energy-generating shoes provide adaptable and useful applications, promoting a more sustainable future.

ETHICAL CONSIDERATIONS

Ethical considerations pertaining to the use of generating electricity through walking states that the use of renewable energy, specifically mechanical energy helps minimize the consumption of traditional-based energy such as natural gas, oil, nuclear, etc. It is necessary in order for the community to conserve conventional electricity. Since the human body had been identified as another source of energy that has no chemical or any harmful additives, can be easily accessed as an alternative source, and the prime producer of energy is already present, the researchers aim to produce energy generating shoes by simply walking in order to limit the damaging effects caused by conventional electricity and in order to make an alternative product that would possibly help the environment and economical state of the Philippines. The researchers only intend to make self-made and uncomplicated energy generating shoes that do not involve the use of harmful procedures and outcomes.

CONCLUSION

In conclusion, the concept of energy-generating shoes has the potential to be a novel and interesting way to produce renewable energy. It is possible to transform mechanical energy into electrical energy by capturing the kinetic energy generated when moving forward or backward, offering a sustainable power source for a number of uses. Technology-wise, design, engineering, and testing procedures are used in the creation and manufacture of energy-generating footwear. The researchers must take into account elements like user comfort, energy conversion efficiency, and compliance with safety regulations. Innovation is fueled by ongoing research and development projects that strive to enhance user experience, durability, and energy generation capabilities. Hence, it should be noted that the findings demand for further study and laboratory testing. Due to this, the researchers' experimentation involved some trials and errors caused by various events along the way, which helped them eventually produce the alternative energy-generating shoes in a span of one month. The energy-generating shoes have the potential to be used for practical purposes, but the proposed prototype lacks sufficient validity as a substitute for traditional energy sources due to the study's lack of laboratory tests. Nevertheless, the researchers established a relationship between the number of footsteps and the amount of electricity it can generate. As the number of footsteps increases, so does the amount of voltage it can generate. Overall, energy-generating shoes are an interesting advancement in the field of renewable energy.

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