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Footstep Power Generation

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Abstract

This study introduces an innovative approach to energy production by harnessing human kinetic energy from footsteps to generate electricity, offering a sustainable energy source for daily use. The research focuses on the conversion of kinetic energy into electrical energy through a specially designed footstep power generation system. Emphasis is placed on the structural design, mechanism, and overall system functionality to optimize energy conversion. A prototype mechanism was developed and tested to analyze the voltage output and efficiency under varying human weights. Experimental results demonstrated a correlation between the weight of individuals and the voltage generated per step, highlighting the system's capability and efficiency in producing electrical energy. As a result of this study, the proposed mechanism that can create electricity with high efficiency up to 0.2%, and the design findings for footstep power generation demonstrate that the kinetic energy of human footsteps can be turned into electrical energy. This work paves the way for practical applications of footstep power generation as a renewable and accessible energy solution.

1. Introduction

Footstep power generation is an innovative technology that converts the kinetic energy of human footsteps into electricity. This concept, inspired by historical devices like treadmills and hand-cranked generators, has gained momentum in the 21st century as researchers explore more efficient methods for energy harvesting [1]. By capturing energy from human movement, footstep power generation aligns with the global push for clean and renewable energy sources, offering a sustainable way to meet growing energy demands.

This technology operates by converting mechanical energy into electrical energy through mechanisms such as piezoelectric materials, electromagnetic induction, and electrostatic induction. Piezoelectric materials generate electricity from mechanical stress, making them ideal for embedding flooring to harness foot pressure. Electromagnetic induction and electrostatic induction offer alternative approaches to capturing energy [2]. Modern systems focus on maximizing efficiency, durability, and seamless integration into urban environments like train stations and malls. Advances in materials, such as flexible piezoelectric films, have improved performance while making the technology adaptable to various settings.

The future of footstep power generation holds exciting possibilities, from using nanotechnology to create ultra-efficient devices to integrating systems with smart grids and IoT platforms for optimized energy management [3]. By deploying this technology in high-traffic areas, we can generate significant renewable energy while fostering environmental sustainability. With continued research and development, footstep power generation could become a widely adopted clean energy solution, transforming everyday human activity into a resource for powering a greener future [4].

This study aims to design and develop a prototype of a footstep power generation system and analyze the efficiency of the generated voltage.

2. Methodology

Footstep power generation has gained significant attention as a renewable energy solution, leveraging human movement to meet rising energy demands. Researchers have explored various mechanisms, including piezoelectric sensors, electromagnetic transduction, and mechanical systems like rack-and-pinion setups [2]. Piezoelectric technology, which generates electricity from mechanical stress, has been widely studied. For instance, Srinivasan et al. [5] designed a system that used piezoelectric tiles to power streetlights [5]. Similarly, Kim et al. [6] developed a self-powered floor tile using optimized piezoelectric materials, generating 42 V peak voltage with a limitations range of 50 kg to 80 kg weight of person.

The rack-and-pinion mechanism as shown in Figure 1 has emerged as a promising alternative for large-scale energy harvesting. This approach, explored by Ismail et al. [7], demonstrated a power output of 34 W per step under optimal conditions. However, research indicates the need for significant improvements to enhance efficiency and scalability. The current project seeks to address these gaps by developing an optimized rack-and-pinion footstep tile mechanism. Through dynamic modeling, simulation, and rigorous testing, the system aims to improve energy efficiency while addressing user comfort and durability challenges, paving the way for practical applications in high-traffic areas.

Fig. 1 *Mechanism of rack and pinion gear*

Mechanical energy harvesting systems have also been explored, often combining piezoelectric materials with other mechanisms. Panthongsy et al. [8] described a piezoelectric cantilever-based floor tile with an efficiency of 17.2 %. These setups demonstrated varying efficiencies, with power outputs ranging from 0.36 W to 34 W per step. Although effective, mechanical systems face challenges such as durability and the need for optimal load conditions to maximize energy capture. Figure 2a and figure 2b is the working principle of the piezoelectric and its mechanism application.

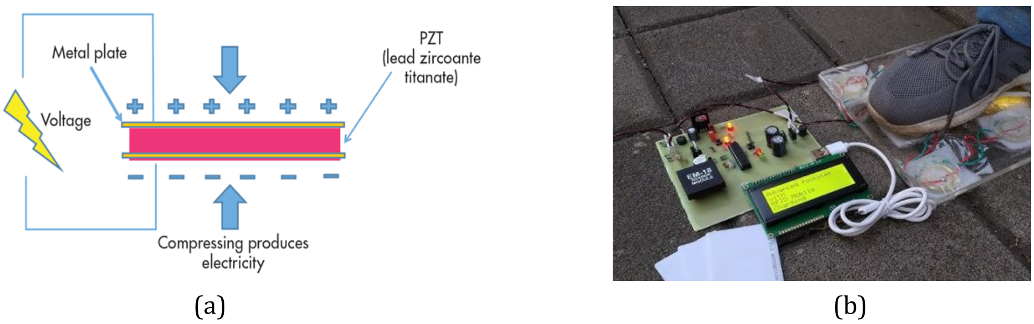

Fig. 2 a) *Piezoelectric working principle*, b) *Mechanism application*

Hybrid approaches, combining piezoelectric materials with electromagnetic systems, have shown promise in improving power output and efficiency. For example, Zhou et al. [9] developed a paver that combined piezoelectric and electromagnetic transduction, generating up to 42.87 V under optimal parameters. Despite these advancements, most hybrid systems face limitations, such as the energy not being harvested uniformly and producing less power due to the limitation of movement of piezoelectric [10]. Figure 3a and Figure 3b are the exploded view and the full assembly of this hybrid design, respectively.

(a) (b)

Fig. 3 a) *Exploded view of electromagnetic hybrid system*, b) *Full assembled of electromagnetic hybrid system*

3. Methodology

The design criteria for the project are based on achieving the study's objective, which is to generate electrical power using a mechanism that converts the kinetic energy generated by human feet. However, the finished product must meet various engineering standards, including endurance in a range of settings, the geometry of the mechanism, and many other considerations. This is to build a project design while also becoming a high-quality, efficient standard module. This is to build a project design while also becoming a high-quality, efficient standard module. This process will include an evaluation phase that is divided into two parts: the House of Quality (HOQ) and the Product Design Specification (PDS) as shown in table 1 and table 2 [11]. In short, the purpose of HOQ is to assess current demands or to propose a new and superior idea. PDS's objective is to conduct an evaluation of project mechanism design. Both elements are required before beginning an engineering drawing to collect data that will become guidelines during project design.

Table 1 *House of Quality project*

Market requirement (WHATs)	Efficient materials	Rugged design	Low-cost material	Modular design	Simple integration	Sustainable materials	Voltage regulation
High energy efficiency	9	3	1		3	3	9
Durable design		9	1	3		3	3
Cost-effective system	3		9	1	3		1
Compact and portable	1	1	3	9	9		3
Easy to install and maintain	1		3	9	9		1
Environment friendly	3		3			9	3
Reliable energy output	9	3	1			3	9

Table 2 *Product design specification project*

Introduction	
Title	Footstep Power Generation
Design problem	Design a footstep power generation mechanism that can convert from human kinetic energy to electricity.
Intended purpose	- To generate electricity from human step kinetik energy. - To store the generated energy to storage.
Special features	- Consist of USB plug that can be used for charge the device. - Able to read the voltage generated through the LCD.
Data Requirement	
Functional performance	- The product should be able to generate electricity form human step. - The sensor can generate electricity to its maximum potential.

Operating environment	Suitable to any wheather conditions for outdoor and need the flat surface for intallation, also at the place of high traffic humans.
Economic	- The selling price of the product should not more than RM 6000. - Low maintenance cost. - Life span more than 10 years
Geometric limitation	- Total weight of the product should be less then 50kg - The size of product should be (806Wx98Hx813L)mm.
Maintenance, repair, retirement	- The product part should be easy to handle for maintenance and cleaning purpose. - No major repair during the product economic life.
Safety	- The product can withstand from any type of pressure without changing their original shape. - No sharp edges and all the tiles in the same level.
Pollution	Should be ecofriendly.
Ergonomics	- Simple operation steps and user-friendly. - Not easy to slip and has the gripping texture at the tiles.
Appearance	- Have the aesthathic value appearance in term of shape and simple colour

The concept development phase of building a Footstep Power development system entails thinking and testing several ideas for harnessing kinetic energy from footsteps and converting it into electrical power. This phase investigates various energy-harvesting techniques such as piezoelectric materials, DC motors, and electromagnetic induction to determine the best method for efficient power generation. It also considers the necessary components, such as an energy storage unit (e.g., rechargeable battery), a circuit for regulating and storing power, and any additional features, such as voltage displays or sensors. The basic purpose of concept generation is to build a design that is both viable and sustainable, utilising human energy to produce practical power as shown in figure 4 below.

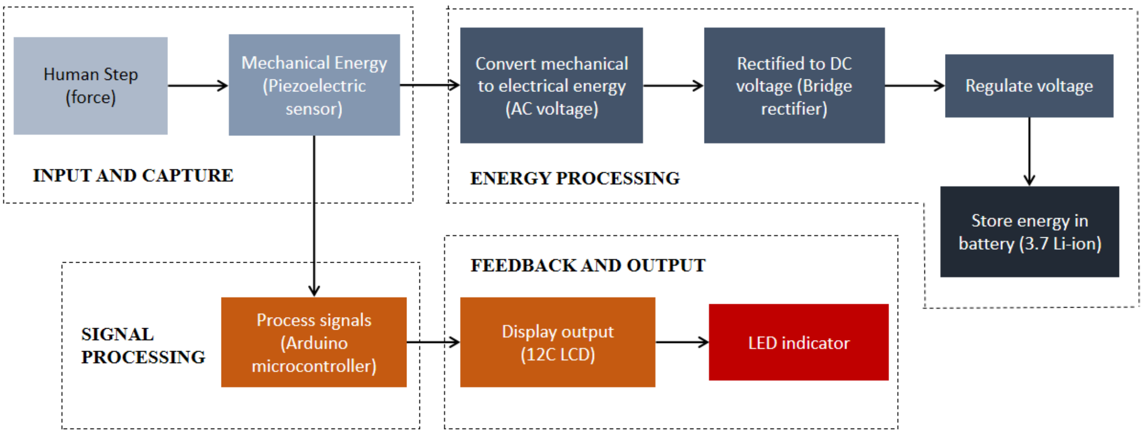

Fig. 4 *Function structure of the project*

3.1 Product Prototype

Figure 5 is the final prototype produced after completing the 3D modelling in SolidWorks. This project proceeds to the following step, which is to create a complete prototype with a project scale that is somewhat smaller than the original dimensions. In addition, the prototype produced has characteristics that are slightly different from the original drawing but still follow the original concept of the project. This is done to estimate the cost of the fabrication procedure while also maximising the functionality of the prototype to meet project objectives. Before starting the prototyping process, all machine and fabrication tool requirements are identified, and suitability is assessed in building each part of the project efficiently. Below is the basic tools and machine used in fabrication process. Figure 6 is the piezoelectric with bottle cap mechanisme used in prototype.

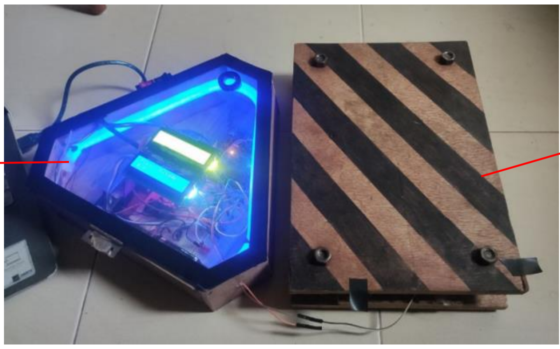

Fig. 5 *Fully assembled prototype with simple mechanism*

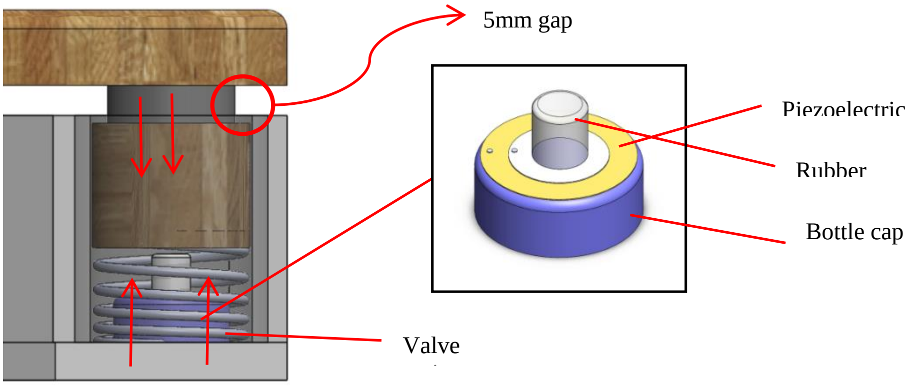

Fig. 6 *Piezoelectric with bottle cap mechanism used in prototype*

4. Results

The footstep power generation prototype was tested to determine the voltage output produced by humans of varying weights stepping on the power generation plate. To ensure accuracy and dependability, the test was performed five times for each weight category, and the average voltage generated was calculated. In the first test scenario, a modified setup was used by mounting the piezoelectric sensor to a bottle cap. This improvement sought to improve sensor efficiency by increasing the applied force on a specific location, which could result in larger voltage generation. The bottle cap was designed to operate as a pressure concentrator, increasing the sensor's ability to convert mechanical energy into electrical energy. By comparing the average voltage output from this updated sensor setup to the unmodified version, we can determine whether the alteration increased energy conversion efficiency. Table 3 and table 4 below are the result of voltage generated from experiments or testing on prototype mechanisms.

Table 3 *Piezoelectric with bottle cap voltage generated*

No	Weight range (kg)	Voltage generated / step (V)					Voltage average
		V1	V2	V3	V4	V5	(Vavg)
1	90 - 95	19.87	18.11	19.02	19.58	18.08	18.90
2	80 - 90	17.58	15.15	17.05	18.96	16.71	17.09
3	70 - 80	16.94	17.96	14.91	12.75	12.39	14.99
4	60 - 70	12.08	9.38	13.37	10.68	12.86	11.67
5	50 - 60	4.45	8.35	5.42	7.64	4.61	7.02

Table 4 *Piezoelectric without bottle cap voltage generated*

No	Weight range (kg)	Voltage generated / step (V)					Voltage average (Vavg)
		V1	V2	V3	V4	V5	
1	90 - 95	13.30	12.92	13.43	13.02	12.63	13.06
2	80 - 90	10.82	11.12	11.05	11.42	10.91	11.06
3	70 - 80	9.45	8.96	9.65	10.12	9.35	9.51
4	60 - 70	7.81	8.64	8.02	7.91	8.52	8.18
5	50 - 60	6.21	6.15	7.02	6.82	6.72	6.58

The prototype was tested five times by stepping on the project plate. The goal was to determine the average voltage per step generated. The results show that for the first test with the piezoelectric condition and the bottle cap, the average voltage value created for each increment in weight range is directly proportionate. This can be stated that the more a person weighs, the higher the voltage created in one step by the footstep power generator. For example, at the first data point in the chart, the weight range of 90 kg to 95 kg can produce an average of 18.90 volts every step. While the weight range of 50kg to 60kg can only generate 11.88 volts per step on average. This comparison explains the difference of 9.88 volts for these two weights range. In terms of voltage fluctuation and consistency, the data for the piezo sensor without a bottle cap is more consistent, and the voltage reading fluctuation is more even than that of the piezo sensor with the bottle cap. However, the piezo sensor with a bottle cap produces a larger voltage. The setup with the bottle cap attachment achieved an efficiency of 0.2%, which is more than double the efficiency of the normal condition setup, measured at 0.096%. This significant difference demonstrates that the bottle cap attachment enhances the energy harvesting capability of the piezoelectric sensor by providing a more effective mechanism to transfer force and generate voltage.

4. Conclusions

The footstep power generation project successfully achieved its objectives by introducing an innovative method of harnessing energy from human kinetic force, specifically footsteps. This initiative demonstrated the potential of converting kinetic energy into electrical energy, paving the way for sustainable and eco-friendly power solutions. The project focused on designing and constructing a functional mechanism and system capable of capturing and converting energy from foot pressure. Through the development and testing of a basic prototype, the project validated the feasibility of using human activity as a practical energy source for daily applications. The analysis of the voltage generation efficiency revealed promising results, underscoring the potential for further optimization of the system. This study not only highlights the importance of energy conversion research but also sets a foundation for future innovations in renewable energy. The findings contribute to the growing body of knowledge on sustainable energy solutions and offer a practical approach to reducing dependency on traditional power sources, aligning with global goals for sustainable development and environmental preservation.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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