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FOOT STEP POWER GENERATION

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ABSTRACT

Electrical energy plays a vital role in modern life and its demand continues to grow rapidly. Unfortunately, conventional energy resources are being depleted and often wasted, prompting the need for sustainable alternatives. One innovative solution involves generating electricity from human movement, particularly the energy produced while walking. Every footstep creates mechanical vibrations between the ground and the foot, which typically dissipate without being utilized. However, this seemingly wasted kinetic energy can be captured and converted into useful electrical energy using piezoelectric technology. A piezoelectric transducer is a device capable of converting mechanical stress into electrical energy. When pressure from a footstep is applied to a piezoelectric material, it induces an electric charge due to the deformation of the material's internal crystalline structure. By connecting multiple piezoelectric transducers in a series-parallel configuration, the generated electrical output can be optimized for increased efficiency. These transducers are embedded beneath wooden tiles, simulating a "footstep tile" prototype. When placed in high-footfall areas—such as sidewalks, public transportation hubs, gyms, or shopping centers—these tiles can continuously generate electrical energy from pedestrian activity. The harvested energy can then be stored or used to power low-consumption electronic devices, lighting systems, or sensors in smart infrastructure applications. This approach not only presents a renewable and eco-friendly energy source but also encourages the integration of smart technology in urban planning, offering a step forward in sustainable energy solutions.

Keywords: Piezoelectric transducer, Footstep energy harvesting, Renewable energy, Kinetic energy conversion

I INTRODUCTION

The rapid depletion of fossil fuels and other non-renewable energy sources has led to a pressing need for alternative methods of energy generation. With the continuous rise in global energy demand, it is crucial to explore sustainable and eco-friendly solutions that can supplement or replace conventional power sources. Energy, defined as the capacity to perform work [1], is fundamental to modern life, and electricity remains one of its most widely used forms, especially as human populations and technological needs grow.

This study aims to capitalize on the increasing human population to generate electricity in a way that minimizes environmental impact. Unlike solar or wind energy, which are dependent on weather conditions, the proposed method operates independently of climate, offering a reliable alternative [2].

Human movement—particularly walking—results in energy loss through vibrations generated at each footstep. Instead of allowing this kinetic energy to go to waste, it can be harvested and converted into electrical power. The average person takes between 3,000 to 5,000 steps per day [5][6], representing a significant potential energy source. Vibrational energy from footsteps can be captured using various methods, including electromagnetic, electrostatic, and piezoelectric transduction techniques [7].

Among these, piezoelectric energy harvesting has shown promising results due to its simplicity, compact design, and direct conversion of mechanical pressure into electricity. Countries like the Netherlands and Japan have experimented with such systems. For instance, in the Netherlands, an electromagnetic system was embedded into a dance floor to produce electricity, but it required a floor displacement of about 10 mm and involved a complex and costly structure [9]. On the other hand, Japan successfully implemented piezoelectric tiles in subway ticketing areas, utilizing piezoceramic materials without complex mechanical parts [8][9].

Piezoelectric materials exhibit two key effects: the direct piezoelectric effect, where mechanical stress produces electrical energy [12–14], and the converse piezoelectric effect, where applied voltage induces mechanical deformation [13][14][16]. The direct effect is central to this study, where pressure from human steps causes piezoelectric transducers to deform and generate electrical charges.

In a typical energy harvesting setup, the alternating current (AC) generated from piezoelectric transducers is converted into direct current (DC) using a full-wave bridge rectifier. The DC output is then smoothed using a capacitor and stored for powering low-consumption devices. This system can be integrated into footpaths, stairways, platforms, or other high-traffic public areas.

Although the electrical output of a piezoelectric transducer is generally low, especially when unregulated, coupling multiple transducers in a series-parallel configuration and employing efficient circuitry can significantly enhance power generation. The harvested energy is suitable for lighting systems, signage, and other low-power appliances [2].

Several studies have explored similar applications. Arvind et al. proposed a system that harnesses human locomotion using circular piezoelectric transducers to power street lights [21]. Ghosh et al. explored urban electricity generation using mechanical rotation based on foot pressure and Faraday's Law [22]. In the medical field, Meirer et al. introduced a piezoelectric energy-harvesting shoe designed for athletes and patients needing podiatric monitoring [23]. Akshat Kamboj et al. also developed a footstep power generator that stores energy in 6V batteries for lighting purposes [24]. In Bangladesh, Nayan HR demonstrated a densely packed piezoelectric setup, showing that a single step could generate up to 1V using a 50 kg force, requiring about 9,600 steps to fully charge a 12V battery [25].

II RESEARCH METHOD

In this study, lead zirconate titanate (PZT) piezoelectric transducers were utilized to harvest kinetic energy generated by human footsteps. The electrical output of a PZT transducer is influenced by the structure of its ceramic material as well as the magnitude of the mechanical stress or strain applied. Each transducer used in this project features a crystalline structure with a 5 cm diameter. Under typical conditions, it generates an output voltage in the range of 0–12 V, though it can spike up to 30 V during high-impact events. The output current is approximately 5 mA.

Two geometrical configurations of the PZT transducer were considered: circular and square shapes. It was observed that the circular transducer responds more effectively to stress applied at the center—making it more suitable for footstep-based pressure. In contrast, the square-shaped transducer shows better output when stress is applied at its edges or corners. Based on oscilloscope readings, the circular transducer consistently produced higher voltage outputs under foot pressure due to greater structural deflection. Therefore, the circular PZT transducer was selected as the optimal shape for this footstep energy harvesting application.

To optimize both voltage and current output, multiple piezoelectric transducers were interconnected in a series-parallel configuration. Since the electrical output from these transducers is in alternating current (AC) form, it must be converted to direct current (DC) before storage or use. A full-wave bridge rectifier was implemented for this purpose.

The rectifier circuit consists of four diodes and two capacitors, as illustrated in *Figure 1*. One capacitor function as a smoothing capacitor to eliminate ripple from the DC waveform, while the other serves as an energy storage unit. The operation of the full-wave rectifier is divided into two cycles: the positive half-cycle and the negative half-cycle of the AC signal.

- During the positive half-cycle, diodes D1 and D2 are forward-biased and conduct current, while D3 and D4 are reverse-biased and remain inactive.
- In the negative half-cycle, diodes D3 and D4 conduct, while D1 and D2 are reverse-biased.

In both cases, current flows in the same direction through the capacitors, resulting in a steady DC output. The smoothing capacitor filters out any remaining AC ripple, ensuring a stable voltage level. The storage capacitor, connected in parallel, accumulates the converted energy, which is then ready for use in powering low-energy electronic devices. Fig.1 shows the bridge rectifier with Storage Capacitor. The experimental setup is illustrated in Fig 2. This system effectively demonstrates how mechanical energy from foot traffic can be harvested, rectified, and stored for later use.

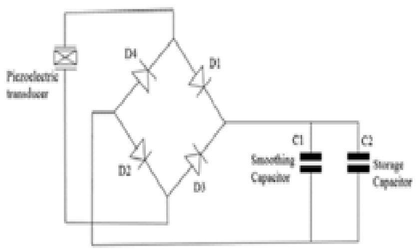

Fig. 1 Bridge rectifier with Storage Capacitor.

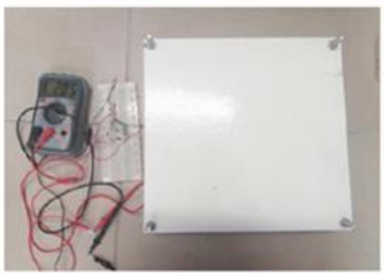

Fig. 2 Experimental Setup

III RESULTS AND DISCUSSION

The electrical output generated by the piezoelectric transducer is in the form of an alternating current (AC) waveform. This raw AC signal is not suitable for direct storage or for powering most electronic devices, which typically operate on direct current (DC). Therefore, it is essential to rectify and filter the AC signal before it can be utilized effectively.

This section of the study confirms that the piezoelectric tile system can effectively convert mechanical energy into usable electrical energy, and the rectification process is crucial in transforming the raw output into a form compatible with electronic circuits. The efficiency and reliability of the system were validated through repeated testing, and the voltage waveform before rectification serves as a baseline to compare the improved output after processing.

IV PIEZOELECTRIC TRANSDUCERS

In this study, the piezoelectric transducers were configured using a combination of series and parallel connections to optimize their electrical output. Before finalizing the configuration, different connection methods were evaluated to determine which setup would yield the best balance of voltage and current output.

As illustrated in Figure 4, three piezoelectric transducers were initially connected in series. In a series connection, the voltages of individual transducers add up, resulting in a higher total output voltage. However, the current remains the same as that of a single transducer, which may limit the energy available for load applications.

Next, as shown in Figure 5, the transducers were arranged in a parallel configuration. In this setup, the current output is increased by combining the individual currents of each transducer, while the voltage output remains equivalent to that of a single unit. This method is useful when higher current is needed, but voltage enhancement is not critical.

To leverage the benefits of both series and parallel arrangements, a series-parallel configuration was implemented, as depicted in Figure 6. In this design, two sets of three piezoelectric transducers connected in series were then combined in parallel. This hybrid approach enables an increase in both voltage and current, making the system more efficient and suitable for energy harvesting from footstep pressure.

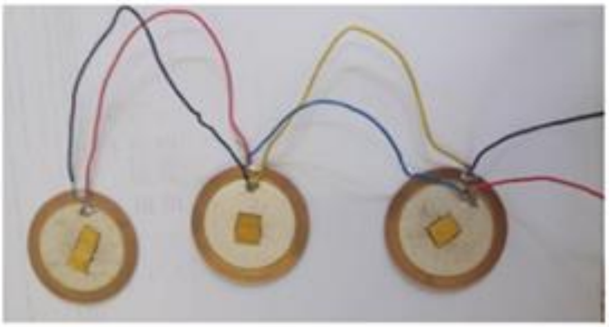

Fig.3 Serries connection of Piezoelectric Transducer

Fig.4 Parallel connection of Piezoelectric Transducer

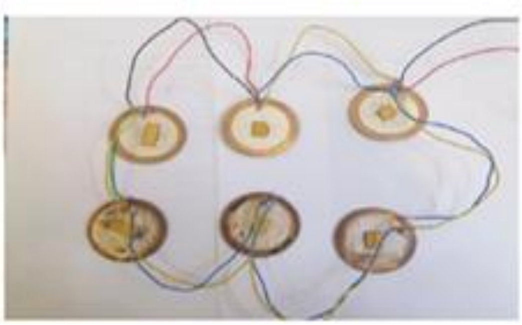

Fig.5 Serries Parallel connection of Piezoelectric Transducer

In a series configuration, the system exhibits a high voltage output. This is due to the additive nature of voltage in series circuits—each individual transducer contributes to the total voltage. However, a limitation of this setup is that the current output remains low, as the current in a series connection is restricted to the level produced by a single transducer. Conversely, when the transducers are arranged in a parallel configuration, the output behavior is reversed. The setup results in a higher current output, since the currents from each transducer combine, but the voltage remains relatively low, constrained to that of one transducer. This trade-off between current and voltage poses a challenge when both parameters are required in sufficient amounts for practical energy harvesting applications.

To address this limitation, a hybrid connection strategy was implemented. Specifically, two sets of three piezoelectric transducers connected in series were then combined in parallel, forming a series-parallel configuration. This approach effectively merges the advantages of both configurations: the series units contribute to higher voltage, while the parallel arrangement enhances the overall current output.

The measurements taken from this configuration demonstrated balanced and satisfactory levels of both voltage and current, making it more suitable for real-world applications, especially in powering low-power electronic devices. The series-parallel arrangement provides a more efficient and practical solution for harvesting and utilizing energy from footstep pressure compared to using series or parallel connections alone.

V ANALYSIS OF THE PIEZOELECTRIC TILE DESIGN AND FUNCTIONALITY

The piezoelectric tile, as illustrated in Fig. 6, was developed as a platform to capture mechanical energy generated through footstep or pumping activities and convert it into electrical voltage. The design incorporates six piezoelectric transducer cells, which are strategically positioned between the upper and lower sections of the tile structure to maximize energy collection.

The tile itself is constructed in a square form factor using durable wooden blocks, chosen for their availability, cost-effectiveness, and mechanical strength. The six piezoelectric cells are embedded between the two wooden layers of the tile, forming the core energy harvesting component of the system. To ensure structural integrity and mechanical responsiveness, the tile is secured at all four corners with screws.

To enhance functionality, springs are installed at the corners of the tile, allowing the upper wooden surface to compress under pressure and return to its original position after being stepped on. This spring-loaded mechanism not only increases the durability of the tile by absorbing impact forces but also optimizes pressure application on the piezoelectric transducers during each compression cycle.

The piezoelectric elements are precisely positioned within the gap between the upper and lower wooden layers to ensure effective strain is applied during every step. The setup was tested by having participants perform repeated foot-press and pumping actions on the tile. During these activities, the mechanical pressure generated by each step was converted into electrical energy by the six piezoelectric cells.

Fig. 6 Piezoelectric tile

The design reflects a practical and efficient approach to ambient energy harvesting, particularly in high-traffic areas or exercise zones, where frequent human motion can be transformed into useful electrical power for low-energy applications, such as LED indicators, wireless sensors, or energy storage systems.

VI CONCLUSION

The experimental findings affirm that the voltage output of the piezoelectric tile increases proportionally with the duration of applied pressure or foot activity. Longer application times correlate with more footsteps or forceful impacts, thereby enhancing the overall energy harvested. The data supports the existence of a linear relationship between the duration of force application and the voltage generated, reinforcing the efficiency of piezoelectric transducers in kinetic energy harvesting.

This study demonstrates that piezoelectric tiles are particularly effective in high-footfall environments, making them highly suitable for deployment in public infrastructure such as pedestrian pavements, subway station entry points, staircases, and even on interactive dance floors. Moreover, they hold potential for integration into fitness-oriented surfaces, like treadmill bases or exercise mats for activities such as jumping, stepping, or skipping—where regular, repeated impact can generate continuous power.

The electrical energy captured from such tiles, though relatively low in magnitude, is sufficient to power low-consumption electronic systems, including streetlights, stairway lighting, signage boards, and other small-scale appliances. This highlights the technology's viability as a supplementary and eco-friendly power source, contributing to sustainable urban energy solutions by converting everyday human movement into usable electricity.

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