

FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSORS AND ARDUINO

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ABSTRACT: This paper presents the design and implementation of a footstep power generation system that converts the mechanical energy produced by human walking into electrical energy. The proposed system employs pressure-based sensing elements installed beneath walking surfaces to harvest energy from footsteps. This harvested energy is processed through an integrated energy conversion and storage circuit, resulting in usable electrical power. The system is designed to offer an eco-friendly and sustainable solution for generating electricity in high-traffic environments, such as railway stations, shopping malls, and public pathways. The generated electricity can be applied to low-power uses, including lighting and signal indicators. Key design considerations include cost-effectiveness, durability, and ease of installation, ensuring suitability for real-world deployment. Experimental results demonstrate that the system consistently generates electrical output from repeated human movement. By encouraging the use of renewable energy sources and decreasing reliance on conventional power generation methods, this approach contributes to energy conservation and sustainable development.

Keywords: Energy harvesting, footstep power generation, piezoelectric sensors, renewable energy, sustainable systems.

I. INTRODUCTION

The rapid growth in global population and industrialization has significantly increased the demand for electrical energy, leading to the depletion of conventional energy resources such as coal, petroleum, and natural gas. This has created an urgent need to explore alternative and sustainable energy generation methods that are environmentally friendly and efficient. Although renewable energy sources such as solar and wind power are widely adopted, they are highly dependent on environmental conditions and often require large-scale infrastructure and high installation costs. In recent years, researchers have focused on micro-scale energy harvesting techniques that utilize ambient energy available in the environment. One such promising and innovative approach is footstep power generation,

which involves converting mechanical energy generated during human walking into electrical energy using piezoelectric sensors. Piezoelectric materials exhibit the unique property of generating electrical charge when subjected to mechanical stress, making them highly suitable for applications involving pressure and vibration-based energy harvesting [1].

Footstep power generation systems can be effectively implemented in high foot-traffic areas such as railway stations, airports, shopping malls, pedestrian pathways, and educational institutions, where a significant amount of mechanical energy is produced and usually wasted. Several studies have demonstrated the feasibility of embedding piezoelectric sensors in floors and pavements to capture energy from human footsteps and convert it into usable electrical power [2], [3]. Researchers have investigated different configurations of piezoelectric sensors, including series and parallel connections, to increase voltage output and improve overall system efficiency [4]. In addition, the design of mechanical structures and platforms has been optimized to ensure uniform distribution of pressure on the sensors, thereby enhancing energy conversion performance [5].

Furthermore, efficient power conditioning circuits such as bridge rectifiers and filtering units have been developed to convert the generated alternating voltage into stable direct current suitable for practical applications [6]. Energy storage systems, including rechargeable batteries and supercapacitors, have also been integrated into these systems to store the harvested energy for later use, improving the reliability and usability of the system [7]. Recent advancements in this field include the integration of microcontroller-based monitoring systems, which enable real-time measurement and display of generated voltage and system performance parameters [8]. However, despite these developments, many existing systems face limitations such as low power output, inefficient monitoring mechanisms, and lack of user interaction capabilities.

To overcome these limitations, this paper presents the design and implementation of a footstep power generation system using piezoelectric sensors integrated with a microcontroller-based monitoring unit. The proposed system converts mechanical energy into electrical energy, processes the generated output, and displays real-time voltage values using a display interface. The system is designed to be simple, cost-effective, and easy to implement, making it suitable for both practical deployment and educational applications. Moreover, this approach promotes the efficient utilization of otherwise wasted mechanical energy and contributes to the development of sustainable and eco-friendly energy solutions. The proposed system focuses on improving energy conversion efficiency, enabling real-time monitoring, and ensuring reliable performance in high foot-traffic environments, thereby supporting the advancement of smart energy systems.

II. MATERIAL AND METHODOLOGY

System Design

The proposed footstep power generation system is designed to convert mechanical energy generated from human footsteps into electrical energy using piezoelectric sensors and to monitor the generated output using a microcontroller-based system. The overall architecture of the system is illustrated in Fig. 1. The system consists of piezoelectric sensors, a bridge rectifier circuit using diodes, a filtering capacitor, resistors, a transistor for signal conditioning, a regulated direct current output stage, a rechargeable battery unit, an Arduino Uno microcontroller, and output devices such as a liquid crystal display and a light emitting diode indicator.

Piezoelectric sensors are the primary energy harvesting components used in the system. These sensors operate based on the piezoelectric effect, where an electrical charge is generated when mechanical stress is applied. In this system, multiple piezoelectric discs of 35 mm diameter are used and arranged beneath a rigid acrylic platform. The platform ensures uniform distribution of pressure across all sensors and protects them from mechanical damage. The sensors are connected in a combination of series and parallel configurations to increase the overall voltage and current output. When a person steps on

the platform, mechanical pressure is applied to the sensors, resulting in the generation of an alternating voltage signal.

The generated alternating voltage from the piezoelectric sensors is not directly usable for electronic circuits; therefore, it is passed through a bridge rectifier circuit consisting of 1N4007 diodes. The rectifier converts the alternating voltage into direct voltage by allowing current to flow in only one direction. A capacitor of suitable value is connected across the rectifier output to smooth the voltage and reduce ripple components caused by irregular footstep pressure. This ensures a stable and continuous direct voltage output.

Resistors are used in the circuit for current limiting and voltage division purposes, ensuring safe operation of electronic components. A BC547 transistor is used as a switching and amplification device to condition the low-level signals generated by the sensors before feeding them into the microcontroller. The regulated direct current output is then stored in a rechargeable lithium-ion battery (18650 cells) using a suitable holder. The battery acts as an energy storage unit, allowing the harvested energy to be used for powering low-power devices.

The Arduino Uno microcontroller serves as the central processing unit of the system. It is responsible for reading the generated voltage using its analog input pins, converting it into digital form using an internal analog-to-digital converter, and processing the data. The microcontroller runs a program developed using the Arduino integrated development environment, which continuously monitors the voltage levels and detects footstep events based on threshold conditions.

The processed data is displayed in real time on a liquid crystal display using an inter-integrated circuit communication interface. The display shows parameters such as generated voltage and number of steps. Additionally, a light emitting diode is connected as an indicator to provide visual feedback whenever a footstep is detected. The overall system is designed to be compact, cost-effective, and easy to implement, making it suitable for practical applications in energy harvesting investment.

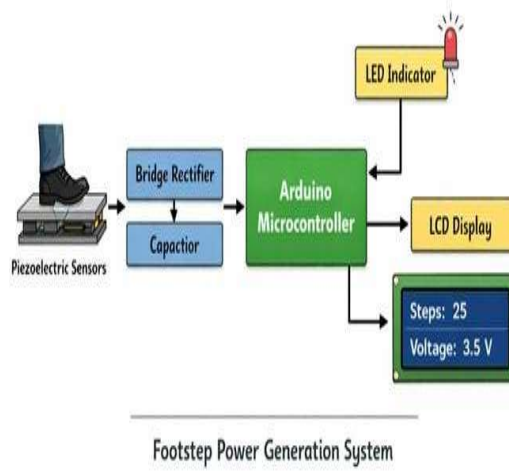


Fig. 1. Block diagram of proposed footstep power generation system.

B. Working Methodology

The working of the proposed system is carried out in a sequential and continuous process involving energy conversion, signal conditioning, storage, and monitoring. Initially, the system remains in an idle state while continuously monitoring the input from the piezoelectric sensors. When a person steps on the platform, mechanical pressure is applied to the sensors, causing deformation in the piezoelectric material. This deformation generates an alternating electrical signal due to the piezoelectric effect.

The generated alternating voltage is immediately passed through the bridge rectifier circuit, where it is converted into direct voltage. The rectified output contains fluctuations due to varying pressure, which are minimized using a capacitor connected across the output. The capacitor stores charge during peak voltage and releases it during voltage drops, thereby stabilizing the output. The stabilized voltage is then directed to two paths: one for energy storage and the other for monitoring. In the storage path, the energy is stored in the rechargeable battery, allowing accumulation of energy over multiple footsteps. In the monitoring path, the voltage is supplied to the Arduino microcontroller through analog input pins. The microcontroller converts the analog voltage into digital values and processes the data to detect footstep occurrences.

The system uses threshold-based logic to differentiate between valid footsteps and noise signals. Each time a valid footstep is detected, the microcontroller increments the step count and calculates the corresponding voltage. The processed data is then sent to the liquid crystal display, where it is shown in real time. The light emitting diode indicator is simultaneously activated to provide visual confirmation of energy generation. The entire process operates continuously for every footstep, enabling real-time energy harvesting and monitoring. The system demonstrates reliable performance under repeated operations and effectively converts mechanical energy into usable electrical energy. This methodology ensures efficient utilization of human-generated mechanical energy and highlights the practical feasibility of implementing such systems in real-world environments such as public walkways and smart city infrastructures.

III. RESULT AND DISCUSSION

The proposed footstep power generation system was successfully designed, implemented, and tested using piezoelectric sensors integrated with an Arduino-based monitoring unit. The system was evaluated under different footstep conditions to analyze its electrical and operational performance. When mechanical pressure was applied to the platform, the piezoelectric sensors generated electrical energy in the form of alternating voltage, which was subsequently converted into direct voltage using a bridge rectifier circuit and stabilized through a filtering capacitor. Experimental observations indicated that the system is capable of producing an output voltage in the range of 3 to 5 volts per footstep under normal walking conditions. The output voltage was found to vary based on the magnitude of the applied force and the number of sensors activated simultaneously, with higher pressure and multiple sensor engagement resulting in increased voltage output.

In addition to voltage generation, the system's power output was estimated by considering the corresponding current produced by the piezoelectric sensors, yielding a low but usable power range suitable for micro-energy applications. The efficiency of the system is influenced by mechanical-to-electrical conversion losses, rectification losses in the diode bridge, and minor dissipation within the energy storage components. Despite these losses, the system demonstrates satisfactory performance for low-power energy harvesting applications. The Arduino microcontroller effectively monitored the generated voltage and detected footstep events in real time, with minimal processing delay, ensuring accurate and responsive system behavior. The measured voltage levels and step counts were displayed clearly on the liquid crystal display, while the light-emitting diode indicator provided immediate visual confirmation of energy generation, thereby enhancing system interactivity.

Furthermore, the generated energy was stored in rechargeable lithium-ion batteries, demonstrating the feasibility of integrating energy storage for continuous usage in practical applications. The system exhibited stable performance under repeated loading and continuous operational conditions, indicating good durability and mechanical reliability of the platform design. However, the overall power output remains relatively low and is primarily suitable for low-power devices such as LED lighting, wireless sensor nodes, and small-scale monitoring systems. The performance of the system is also

dependent on human activity patterns, leading to variability in energy generation. The proposed system offers significant potential for scalability by increasing the number of piezoelectric sensors and optimizing their configuration in series or parallel arrangements. In high foot-traffic areas such as transportation hubs, commercial buildings, and public pathways, large-scale implementation can enhance total energy output and contribute to sustainable energy solutions. Compared to existing methods, the proposed system provides improved real-time monitoring capability and practical implementation advantages. Future improvements may include the integration of advanced energy storage devices such as supercapacitors, implementation of maximum power point tracking techniques, and incorporation of IoT-based remote monitoring systems to further enhance efficiency and functionality. Overall, the system presents an eco-friendly, cost-effective, and innovative approach to harvesting energy from human motion for smart infrastructure applications.

TABLE I
COMPARISON OF FOOTSTEP POWER GENERATION SYSTEMS

Ref.	Method Used	Monitoring Feature	Output Efficiency	Application Area
[1]	Piezoelectric vibration harvesting	Not available	Moderate	Sensor networks
[2]	Energy harvesting techniques study	Not available	Moderate	General applications
[3]	Piezoelectric energy systems	Limited monitoring	Moderate	Industrial usage
[4]	Vibration-based energy harvesting	Not available	Low to Moderate	Structural monitoring
[5]	Hybrid energy harvesting methods	Limited	High	Industrial and IoT systems
[6]	Piezoelectric review systems	Not available	Moderate	Research applications
[7]	Sensor-based energy systems	Available	Moderate	Wireless systems
[8]	Vibration energy conversion	Not available	Moderate	Embedded systems
Proposed	Footstep power generation (This Work)	Real-time monitoring (Arduino + LCD)	Moderate	Smart cities, public areas

The comparison presented in Table I highlights the performance of the proposed system in relation to previously reported methods. It is observed that most existing systems lack real-time monitoring capabilities and focus mainly on energy generation. In contrast, the proposed system integrates real-time monitoring using a microcontroller and display unit,

improving system usability and practical implementation. Although the output efficiency remains moderate, the proposed approach provides a cost-effective and user-friendly solution suitable for smart city and public area applications.

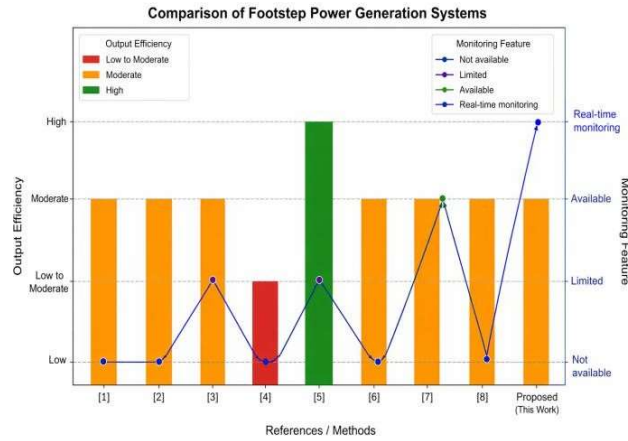


Fig. 2. Comparison of footstep power generation systems based on output efficiency and monitoring features.

Fig. 2 shows the comparison of the proposed footstep power generation system with existing methods based on output efficiency and monitoring features. It can be observed that most of the existing systems provide moderate efficiency with limited or no monitoring capability. In contrast, the proposed system offers real-time monitoring using a microcontroller and display unit, making it more suitable for practical applications.

IV. CONCLUSION

This paper presented the design and implementation of a footstep power generation system using piezoelectric sensors and a microcontroller-based monitoring unit. The system successfully converts mechanical energy generated from human footsteps into electrical energy and displays real-time output using a liquid crystal display. Experimental results demonstrated that the system is capable of generating measurable voltage suitable for low-power applications. The proposed system is simple, cost-effective, and environmentally friendly, making it suitable for deployment in high foot-traffic areas such as public walkways, railway stations, and shopping malls. Although the generated power is limited, it can be effectively utilized for small-scale applications such as lighting and sensor systems. The integration of real-time monitoring improves usability and system performance. Future improvements can focus on increasing energy output by optimizing sensor arrangement, using advanced materials, and integrating hybrid energy harvesting techniques. The system can also be extended with wireless communication for remote monitoring and smart city applications. Overall, the proposed work demonstrates the practical feasibility of utilizing human motion as a renewable energy source.

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