K H Suhas, 2026, 14:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Footstep Power Generation for Smart Street Lighting and Charging

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Abstract- The increasing demand for renewable and sustainable energy sources has encouraged the development of innovative energy harvesting technologies. Footstep energy harvesting is a promising method that converts mechanical energy generated by human walking into electrical energy. This work presents the design and implementation of a piezoelectric-based footstep power generation system capable of producing electrical energy from pedestrian movement. In the proposed system, multiple piezoelectric sensors are installed beneath a footstep platform where they experience mechanical stress whenever a person steps on the surface. Due to the piezoelectric effect, the applied pressure produces electrical voltage that can be collected and processed. The generated electrical output is passed through a rectifier and voltage regulation circuit to convert it into stable DC power suitable for storage. The conditioned energy is stored in a rechargeable battery and later utilized for practical applications. The stored power is used for automated street lighting and an RFID-based charging station that allows authorized users to charge small electronic devices.

Keywords: Piezoelectric Sensor, Energy Harvesting, Footstep Power Generation, RFID Charging, Smart Lighting.

I. INTRODUCTION

Energy consumption is increasing rapidly due to population growth and technological development. Conventional energy sources such as coal, oil, and natural gas are limited and contribute to environmental pollution. Therefore, there is a strong need to explore renewable and sustainable energy sources that can reduce dependence on fossil fuels. human walking into electrical energy.

Footstep energy harvesting is an innovative approach that converts the mechanical energy produced by human walking into electrical energy. Whenever a person walks, mechanical pressure is exerted on the ground. This pressure can be captured and converted into electrical energy using devices such as piezoelectric sensors. Public places like railway stations, shopping malls, airports, and educational institutions experience heavy pedestrian traffic daily

System Overview

The proposed system is a piezoelectric-based footstep power generation system designed to convert mechanical pressure from footsteps into electrical energy. Piezoelectric sensors are placed beneath a floor plate where they experience mechanical stress when a person steps on the surface.

The generated electrical voltage is collected and passed through a rectifier circuit to convert it into DC power. The regulated power is then stored in a rechargeable battery. A microcontroller monitors the system operation and manages energy utilization.

System Development and Methodology

The system follows an energy harvesting approach using piezoelectric sensors. When a person steps on the platform, the applied pressure compresses the sensors, generating electrical voltage through the piezoelectric effect.

Since the output voltage generated by the sensors is irregular and alternating in nature, it is passed through a bridge rectifier to convert it into DC voltage. A voltage regulator ensures stable output. .

The regulated electrical energy is stored in a rechargeable lithium-ion battery. A microcontroller monitors the stored energy level and controls the operation of connected applications such as lighting and charging stations.

The generated electrical signal from the piezoelectric sensors is typically alternating and unstable in nature. Therefore, a bridge rectifier circuit is used to convert the alternating voltage into direct current (DC). A filtering capacitor is also included to smooth the rectified output and reduce voltage fluctuations This methodology ensures efficient energy harvesting, safe storage, and intelligent utilization of the generated electrical power while maintaining system reliability and user convenience.

II. LITERATURE SURVEY

In paper [1] recent review synthesizes the landscape of human footstep energy harvesting, comparing major transduction methods (piezoelectric, triboelectric, electromagnetic, and mechanical gear-based systems such as rack-and-pinion). The authors survey prototype performances, practical deployment contexts (stations, malls, pathways) and typical power ranges for each approach, and stress the trade-offs between per-step energy, device durability, and installation cost. They highlight rack-and-pinion as attractive for moderate displacement, low-frequency steps because it efficiently converts linear stroke torotary motion that can drive low-speed generators and be coupled with gearing for power amplification. There view concludes by recommending hybridization (e.g., adding storage and intelligent power management) to improve usefulness for real applications

The authors in [2] presents This broader review covers low-frequency kinetic harvesters (including footstep devices) and places rack and-pinion systems in context with emerging low RPM electromagnetic generators and tribo electric designs. The paper emphasizes device architectures and systems engineering: how mechanical gearing ,return springs, and locking/clutch arrangements influence cycle efficiency and durability. It identifies key metrics (energy per step, conversion efficiency, reset time, fatigue life) and reports that while gear-based systems can deliver higher instantaneous power than thin-film approaches, they require careful mechanical design to avoid rapid wear in high-traffic installations.

In paper [3] An experimental study testing multiple transducer geometries compared a rack- and pinion harvester against a linear generator under real loading. Reported results showed the rack- and pinion module produced on the order of 1.2 W per event in their test configuration, while an alternative linear generator yielded ~80 mW under the same conditions— demonstrating that a well-matched mechanical advantage can substantially increase usable output per step.

The authors in [4] presents This engineering article presents a systematic design, prototyping, and test procedure for a rack-and pinion footstep tile. It documents component selection (rack stroke, pinion diameter, gear ratio), generator coupling,and return spring sizing, and provides experimental curves of generated voltage/current vs applied load/ displacement.The study’s contribution is rigorous performance characterization — showing how small changes in rack stroke or pinion size shift the electrical output and mechanical efficiency — and it suggests optimized configurations for different use cases (high-throughput public areas vs. low-traffic corridors).

In paper [5] A large body of practical prototype reports (academic conference and journal project papers) document rack-and-pinion footstep tiles: simple lab prototypes, stair-integrated units, and chain/gear variants. These papers commonly report demonstration useful loads (LED arrays, small battery charging) and emphasize low cost and ease of fabrication. However, many note limited net energy per step (tens to hundreds of millijoules upto a few joules depending on design) and stress the importance of cumulative pedestrian traffic to make installations worth while .Collectively these prototypes show feasibility and are a rich source of design patterns (spring resets, damping choices, safety/comfort tradeoffs).

The authors in [6] presents Recent studies have explored the use of hybrid energy harvesting systems combining piezoelectric sensors with electromagnetic generators to improve overall efficiency. These systems aim to capture both pressure and motion-based energy from footsteps, resulting in higher power output compared to single-method systems.

The regulated electrical energy is stored in a rechargeable lithium-ion battery. A microcontroller monitors the stored energy level and controls the operation of connected applications such as lighting and charging stations.

The research highlights that integrating multiple energy conversion techniques can overcome the limitations of low output in piezoelectric-only systems and enhance reliability in real-world applications.

In paper [7] Some researchers have focused on optimizing the structural design of footstep platforms to maximize energy generation. By using layered materials, spring-based mechanisms, and force distribution techniques, the pressure applied by footsteps can be effectively transferred to piezoelectric sensors. The studies show that proper mechanical design significantly increases energy conversion efficiency without increasing the number of sensors, making the system more cost-effective.

The authors in [8] presents Advancements in smart energy management systems have enabled better utilization of harvested energy. Research has shown that integrating microcontrollers with efficient power management algorithms can improve energy storage and distribution. These systems prioritize critical loads such as lighting and enable controlled access to energy through technologies like RFID and wireless communication. This approach enhances system performance and supports the development of smart and sustainable infrastructure

In paper [9] Recent research has investigated the use of energy harvesting floors embedded with piezoelectric sensors in smart buildings and public infrastructure. These systems are designed to generate electricity from continuous pedestrian movement and store it for low-power applications such as lighting and sensor networks. The studies indicate that although the power generated per step is small, the cumulative energy over time can be significant in crowded areas. This approach demonstrates the potential of footstep energy harvesting as a sustainable and supplementary power source for smart city applications.

III. PROPOSED METHODOLOGY

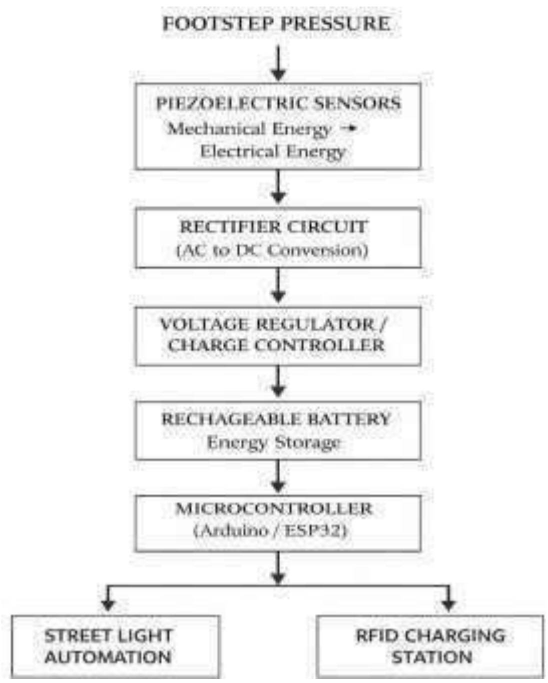

Fig 1: Proposed System

The proposed system is designed using a square platform of approximately 50 × 50 cm, which serves as the main surface for capturing mechanical energy from human footsteps. Multiple piezoelectric sensors are installed beneath the platform in a distributed arrangement so that pressure applied at any point on the surface can be effectively detected. When a person steps on the platform, the applied force causes slight deformation of the piezoelectric sensors, generating electrical voltage due to the piezoelectric effect. The electrical output produced by the sensors is alternating and varies depending on the applied pressure. Therefore, the generated voltage is passed through a bridge rectifier circuit to convert the alternating output into direct current

(DC). A filter capacitor and voltage regulation stage are used to smooth and stabilize the output voltage. The regulated electrical energy is then stored in a rechargeable lithium-ion battery, allowing energy generated from multiple footsteps to accumulate over time. A microcontroller unit monitors the stored energy and controls its distribution for different applications. The stored power is utilized for automated street lighting, where LED lights operate using the harvested energy, and an RFID-based charging station, which allows authorized users to charge small electronic devices. This methodology ensures efficient energy harvesting, storage, and utilization while maintaining system stability and user convenience.

IV. IMPLEMENTATION OF PROPOSED SYSTEM

The system begins with piezoelectric sensors placed beneath a platform where mechanical pressure from footsteps generates electrical voltage. The generated electrical signal is passed through a rectifier circuit to convert the alternating voltage into direct current. A voltage regulator or charge controller stabilizes the output voltage before storing it in a rechargeable battery. A microcontroller monitors the stored energy and controls its utilization. The stored power is used for street light automation and an RFID-based charging station, allowing authorized users to charge electronic devices.

Footstep Pressure

The process begins when a person walks or steps on the platform installed with the energy harvesting system. Human footsteps create mechanical pressure and vibration on the surface. This mechanical force acts as the primary source of energy for the system.

1. Piezoelectric sensors play a crucial role in the energy harvesting process. These sensors have the ability to convert mechanical stress into electrical voltage through the piezoelectric effect. When pressure from footsteps is applied, the piezoelectric material deforms slightly and generates an electrical charge across its terminals
2. Rectifier Circuit

The electrical signal generated by the piezoelectric sensors is generally alternating in nature and fluctuates depending on the pressure applied. Since most electronic devices require direct current (DC) for operation, the generated AC signal must be converted into DC.

3. Voltage Regulator / Charge Controller

The output from the rectifier circuit may still contain fluctuations and may not be stable enough for storage or direct usage. A voltage regulator or charge controller is therefore used to maintain a constant and safe voltage level.

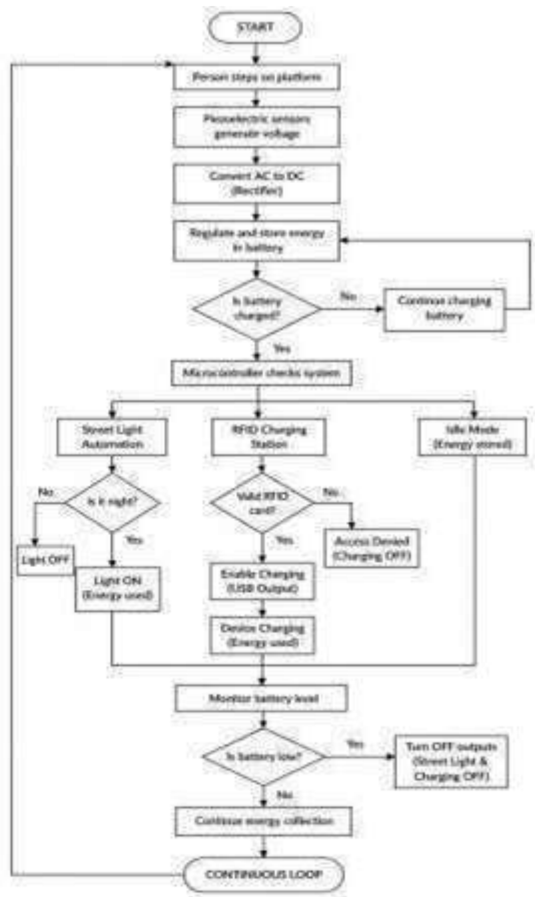

Fig 2: Implementation of Proposed System

V. RESULTS AND DISCUSSION

The proposed piezoelectric footstep energy harvesting system was developed and tested to evaluate its ability to generate electrical energy from human footsteps.

Results are as mentioned below

“Fig 3: Smart Street Lighting Using LDR” shows the automatic operation of street lighting using harvested footstep energy. The LDR sensor detects surrounding light intensity and automatically controls the LED during dark conditions.

“Fig 4: Accessing Charging Station Using RFID Cards” illustrates the RFID-based charging system where authorized users can securely access the charging station using RFID cards for controlled energy utilization.

“Fig 5: ThingSpeak Web Dashboard” presents the real-time monitoring dashboard used to display generated voltage, sensor readings, and overall system performance for analysis and monitoring purposes.

The rectified and regulated voltage was successfully stored in rechargeable lithium-ion battery, which accumulated from multiple footsteps over time. Experimental observations showed that the output voltage increased when several piezoelectric sensors were connected together in series or parallel configurations. The system demonstrated the capability to generate sufficient electrical energy to power low-power devices such as LED lights. The stored energy was successfully utilized to operate an automated street lighting system, which turned on the LED light using the harvested energy.

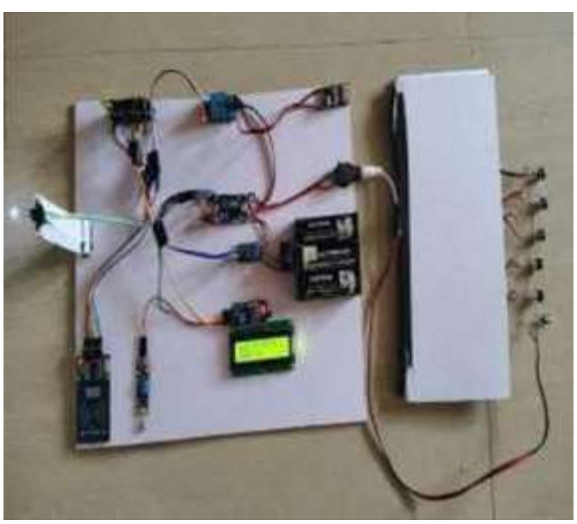

Fig 3: Smart Street Lighting Using LDR

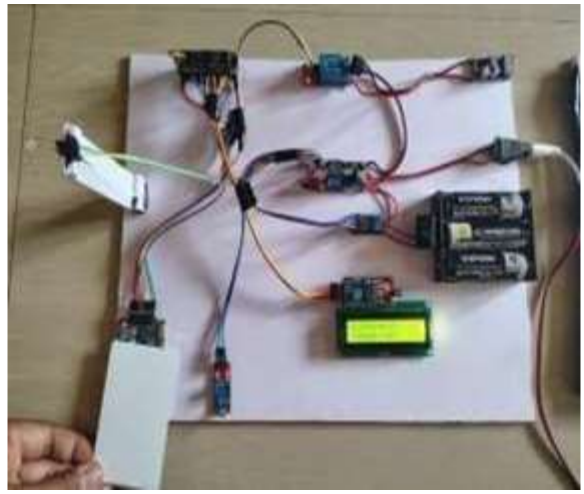

Fig 4: Accessing Charging Station Using RFID- Cards

Fig 5 : ThingsSpeak Web Dashboard

VI. CONCLUSION AND FUTURE SCOPE

The piezoelectric footstep energy harvesting system provides a simple and environmentally friendly method for generating electrical energy from human movement. By converting mechanical pressure from footsteps into electrical energy, the system demonstrates how everyday activities can contribute to renewable energy generation. The integration of energy storage, automated street lighting, and RFID-based charging stations increases the practical usefulness of the system. This technology can be implemented in public areas with high pedestrian traffic to generate sustainable energy. In the future, the system can be improved by increasing the number of piezoelectric sensors to generate higher power output. Integration with IoT technology can allow remote monitoring and energy management. Such systems can contribute to smart city infrastructure and promote the use of renewable energy sources

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