Footstep Energy Harvesting System: Design, Implementation and Performance Analysis

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***Abstract*— Energy harvesting from everyday human activity offers a sustainable pathway to power low-consumption electronic devices without depending on conventional fossil-fuel-based electricity. This paper presents the design, development, and performance evaluation of a Footstep Energy Harvesting System that converts the mechanical energy of human footsteps into usable electrical energy using piezoelectric transducers. The system integrates 35 mm piezoelectric discs, a bridge rectifier, a voltage regulation and storage stage, and a NodeMCU ESP32 microcontroller for real-time monitoring through the Blynk IoT platform. Multiple piezoelectric discs were wired in parallel to enhance current output, and a BC547 transistor-based charge controller was employed to prevent overcharging of the lithium-ion storage battery. The prototype was evaluated through functional, integration, durability, environmental, and safety test cases, achieving high accuracy and reliability across most parameters. The results demonstrate that footstep energy harvesting is a practical micro-energy solution for powering LEDs, sensors, and low-power IoT devices in high-footfall public spaces such as railway stations, malls, and educational institutions, while also promoting awareness of renewable and eco-friendly energy practices.**

***Index Terms*— Footstep Energy Harvesting, Piezoelectric Effect, Renewable Energy, Energy Conversion, IoT Monitoring, Sustainable Infrastructure**

I. INTRODUCTION

Conventional energy generation continues to rely heavily on fossil fuels, contributing to environmental degradation and resource depletion. In parallel, the mechanical energy produced by everyday human activities such as walking is largely dissipated as waste. Footstep energy harvesting systems address this gap by capturing the kinetic energy of human footsteps and converting it into electrical energy, offering a low-cost, renewable, and eco-friendly micro-power generation approach suitable for high-footfall public areas such as railway stations, airports, shopping malls, walkways, and educational institutions [5].

Two principal mechanisms are commonly used for such energy conversion: the piezoelectric effect and electromagnetic induction [5]. Piezoelectric materials generate an electric charge when subjected to mechanical stress, a phenomenon first described by the Curie brothers in 1880 [7]. Electromagnetic systems, on the other hand, rely on Faraday's law of induction, wherein relative motion between a magnet and a coil induces a voltage. This work focuses on a piezoelectric-based footstep energy harvesting system, supported by rectification, regulation, and storage circuitry, along with IoT-based real-time monitoring.

II. OBJECTIVES

- To harness mechanical energy from human footsteps and convert it into usable electrical energy.
- To promote sustainable and renewable energy generation in high-footfall areas.
- To design an efficient, cost-effective, and durable system suitable for urban and rural installations.
- To reduce dependency on conventional power sources for low-energy applications such as LED lighting and mobile charging.
- To integrate the system with smart infrastructure for real-time monitoring and efficient energy management.

III. LITERATURE REVIEW

Footstep power generation technology harnesses the mechanical energy generated by human footsteps and converts it into electrical energy through energy-harvesting mechanisms [5]. One common method uses piezoelectric materials, which generate an electric charge in response to mechanical stress: when a person steps on a piezoelectric tile or mat, it deforms slightly, creating a voltage difference across the material [1], [2], [6]. Another approach employs electromagnetic generators based on electromagnetic induction, where the movement of magnets relative to coils of wire induces current. Mechanical systems such as rack-and-pinion arrangements convert the linear motion of footsteps into rotational motion to drive a generator [5]. In all cases, the generated electricity is typically low voltage and must be regulated and stored using diodes, capacitors, and rechargeable batteries before it can power external devices [3].

Public infrastructure installations, such as Pavegen tiles, have demonstrated the practical feasibility of harvesting renewable energy from pedestrian traffic while simultaneously providing footfall data for smart city applications [5]. Advances in durable and flexible piezoelectric materials, together with integration with IoT networks, have further enhanced the efficiency, lifespan, and applicability of such systems in self-sustaining sensor networks. Prior studies on piezoelectric floor tiles and floor structures have examined tile design, frequency up-converting mechanisms, and the feasibility of installation in building interiors [1]– [4].

IV. RESEARCH METHODOLOGY

The proposed system converts the mechanical pressure of a footstep into a regulated, stored electrical output through five functional stages: energy capture, energy conversion, power conditioning, energy storage, and load management. Piezoelectric discs embedded beneath the walking surface capture pressure and generate an alternating voltage. This output is passed through a bridge rectifier (four 1N4007 diodes) to convert AC to DC, after which a voltage regulator and filtering capacitors stabilise the signal before it charges a rechargeable lithium-ion battery (3.7 V, 2200 mAh). A BC547 transistor-based charge controller prevents overcharging, while a NodeMCU ESP32 microcontroller reads the sensor output, drives an LED load, and transmits real-time data — including footstep count, voltage, and battery status — to the Blynk IoT dashboard.

4.1 Hardware Requirements

- Piezoelectric sensors (35 mm disc) — multiple discs wired in parallel to enhance current output
- Bridge rectifier (1N4007 diodes) for AC to DC conversion
- Voltage regulator (e.g., LM7805 / LM317) and filtering capacitors
- Rechargeable lithium-ion battery (3.7 V, 2200 mAh) with BC547-based charge controller
- NodeMCU ESP32 microcontroller with integrated Wi-Fi and Bluetooth connectivity
- Load device (LED bulb / strip), breadboard, and wiring connections

4.2 Software Requirements

The system firmware was developed in the Arduino IDE using C/C++. The ESP32 continuously samples the analog output of the piezoelectric sensor, applies a threshold-based detection algorithm to register valid footsteps, drives the LED load, and publishes the footstep count to the Blynk cloud dashboard for real-time remote monitoring through virtual pin V0.

4.3 System Architecture

The conceptual design follows a modular architecture comprising an Energy Generation Module, a Power Conditioning and Storage Module, a Microcontroller/Monitoring Module, a Display/Output Module, and a Load Management Module. Data flow between modules is captured through structured entities — FootstepEvent, EnergyStorageStatus, SystemStatus, and DisplayData — which record voltage, current, energy generated, and battery charge percentage for each detected footstep and aggregate them into system-level status for the user interface.

4.4 Implementation

The prototype was implemented on a breadboard with six piezoelectric discs connected in parallel across the harvesting platform, feeding a full-wave bridge rectifier and a voltage-divider network before interfacing with the ESP32 analog input pin (GPIO 34). Firmware logic reads the analog sensor value each loop cycle and compares it against a calibrated

threshold to register a discrete footstep event, incrementing a counter, briefly activating an indicator LED, and updating the Blynk virtual pin. An initial implementation using a single fixed threshold produced unstable, rapidly toggling footstep counts due to sensor value fluctuation near the boundary; this was resolved by introducing hysteresis through separate upper and lower thresholds (1200 and 800 respectively), which eliminated false triggering and produced stable, reliable footstep detection, LED operation, and IoT data updates.

System performance was evaluated by applying controlled loads of 50–100 kg to the harvesting platform to measure voltage response, energy conversion efficiency, and long-term durability, in addition to functional, integration, environmental, and safety testing described in Section 5.

V. RESULTS AND DISCUSSION

The system was subjected to functional, integration, durability, environmental, and safety test cases. Functional testing verified system initialisation, footstep pressure application, energy conversion, and energy storage; two of four functional processes (system initialisation and footstep pressure application) achieved 100% efficiency, while energy conversion and energy storage exhibited minor voltage fluctuation, giving an overall functional accuracy of 88.75%. Integration testing, which verified interaction between the piezoelectric sensor, rectifier, storage unit, regulator, and load device, achieved 100% accuracy across all cases, including correctly handled failure conditions such as absence of footstep pressure or weak sensor signal. The outcomes of all test categories are summarised in Table 1.

Table 1: Summary of test categories and results

Test Category	Key Parameters Evaluated	Result / Efficiency
Functional Testing	System initialisation, footstep detection, energy conversion, energy storage	88.75% accuracy
Integration Testing	Sensor–rectifier–storage–load interaction	100% success
Durability Testing	10,000+ repeated footsteps, mechanical stress	No damage observed – 100%
Environmental Testing	Temperature variation, moisture exposure	Stable operation – 100%
Safety Testing	Surface slip risk, electrical insulation	No injury risk – 100%
Admin / Maintenance	Sensor addition, removal, error handling	100% success

Final performance testing further confirmed that power output increased progressively with footstep force (light, medium, and heavy), that the storage unit sustained continuous load operation without failure, and that the platform withstood over 10,000 repeated footsteps without mechanical damage or performance degradation. Environmental testing confirmed stable operation across temperature variation and light moisture exposure, while safety testing verified that the walking surface posed no slipping or injury risk and that protective circuitry prevented electrical hazards during overload conditions. Overall, the system demonstrated reliable energy generation, efficient storage, and stable, safe operation suitable for deployment in high-footfall public infrastructure.

VI. CONCLUSION

This paper presented the design, implementation, and evaluation of a piezoelectric-based Footstep Energy Harvesting System integrated with IoT monitoring through the Blynk platform. The system successfully converts the mechanical energy of human footsteps into stable, regulated electrical energy capable of powering low-consumption devices such as LEDs and sensors. Although the energy output of an individual footstep is small, the cumulative effect in crowded, high-footfall spaces such as railway stations, airports, and shopping malls can be significant, making the technology a practical and scalable micro-energy solution.

Despite limitations such as low per-step energy output, relatively high installation cost, and material durability under continuous mechanical stress, the system demonstrated high reliability across functional, integration, durability, environmental, and safety test cases. With continued advancement in piezoelectric and electromagnetic materials, energy storage technologies, and smart-city integration, footstep energy-harvesting represents a promising and

sustainable step toward greener, more energy-conscious urban infrastructure.

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