

An IOT Based Piezoelectric Energy Harvesting Walkway for Real Time Energy Monitoring

Siddhi Khamkar¹, Gayatri Jawanjal², Neha Khirolkar³, Dr. R. P. Patil⁴

¹Student, Department of Electronics and Telecommunication, Sinhgad College of Engineering

²Student, Department of Electronics and Telecommunication, Sinhgad College of Engineering

³Student, Department of Electronics and Telecommunication, Sinhgad College of Engineering

⁴Guide, Department of Electronics and Telecommunication, Sinhgad College of Engineering

Abstract - In the era of smart cities and sustainable technologies, the demand for renewable energy solutions is rapidly increasing. In this work, we design and build an IoT-based piezoelectric walkway that turns the force of human footsteps into usable electrical energy. Piezoelectric discs (PZT-5) are placed underneath the walking surface so that each step produces a small voltage. This alternating voltage is rectified, filtered and regulated through a buck–boost converter before being stored in a Li-ion battery–supercapacitor hybrid storage unit. An ESP32 microcontroller monitors voltage and current parameters and transmits these values to the Blynk IoT platform, where they can be viewed and controlled from a mobile dashboard in real time. The system achieved a peak voltage of 21.6 V and an overall efficiency of approximately 73%, confirming the feasibility of using piezoelectric materials for micro-energy generation. This paper demonstrates a cost-effective and eco-friendly solution that integrates renewable energy harvesting with IoT-based smart monitoring, suitable for applications in smart walkways, public spaces and low-power IoT devices.

Key Words: *Internet of Things, Piezo sensors ESP32, real-time monitoring, remote control, Blynk platform.*

1. INTRODUCTION

The expanding adoption of IoT infrastructure has facilitated unprecedented connectivity between physical sensors and digital platforms, supporting concurrent data collection, command execution, and computational analysis across diverse industrial and consumer applications [1,5]. Smart city implementations leverage IoT capabilities to optimize energy

consumption patterns, provide comprehensive facility supervision, and implement intelligent vehicular routing [2]. A fundamental impediment to widespread IoT deployment remains the limited availability of renewable, minimal-consumption power supplies for geographically dispersed sensing networks.

To address energy sustainability challenges in IoT systems, various energy recovery techniques have been developed, including photovoltaic conversion, thermoelectric generation, vibration-based collection, and stress-induced electrical generation [7,15]. Piezoelectric transduction stands out among these methods due to its capacity to transform mechanical deformation and motion into electrical signals, making it particularly valuable for human activity-based energy harvesting in pedestrian infrastructure and floor systems [6,9].

The piezoelectric effect enables electrical potential generation when crystalline materials experience mechanical strain. Pedestrian environments offer an ideal deployment scenario because footstep impacts deliver consistent mechanical stimulation [10]. Modern developments in piezoelectric material composition and signal conditioning technologies have significantly enhanced both the energy conversion efficiency and operational lifespan of these harvesting systems [8]. Modern developments in piezoelectric material composition and signal conditioning technologies have significantly enhanced both the energy conversion efficiency and operational lifespan of these harvesting systems.

In this work, an IoT-based piezoelectric energy harvesting walkway is proposed using multiple piezoelectric sensors, ESP32 microcontroller and the Blynk IoT platform. The

mechanical stimulation from pedestrian loading is transduced into electrical signals, accumulated in a system and simultaneously tracked for voltage and current metrics in real-time dashboard visualization. The proposed solution aims to demonstrate feasibility of sustainable energy generation and monitoring for smart infrastructure applications.

2. BODY OF PAPER

2.1 LITERATURE REVIEW

The concept of IoT was first introduced to describe interconnected objects capable of data exchange over the internet, laying the foundation for modern smart systems [5]. A comprehensive survey of IoT architectures, applications and enabling technologies, highlighting its role in large-scale sensing and monitoring systems [1]. Further emphasized the importance of IoT in smart city environments, particularly for energy efficiency and intelligent infrastructure management [2].

Extensive research has examined piezoelectric-based energy recovery approaches. Safaei and colleagues conducted a structured analysis encompassing material characterization, architectural implementations, and deployment scenarios [7]. Contemporary investigations have examined innovations in piezoelectric energy conversion, with emphasis on condition-based infrastructure assessment and oscillation-driven collection mechanisms [8]. These studies confirm the reliability and applicability of piezoelectric energy harvesters in real-world scenarios.

Numerous researchers have examined locomotion-powered energy recovery systems, demonstrating practical implementations that confirm the viability of extracting electrical energy from pedestrian activities [6]. Investigations have produced intelligent flooring systems integrating piezoelectric sensors that demonstrated reproducible electrical output under foot impact, while parallel efforts have prioritized the engineering and enhancement of piezoelectric tile arrays for urban walkway applications with focus on modularity and energy conversion rates [9,10].

As IoT applications proliferate, the synergistic combination of distributed power generation with wireless telemetry has become increasingly important. Kulkarni and associates

developed an ESP32-based remote energy oversight framework, emphasizing its applicability in low-consumption sensor deployments requiring immediate data transfer [14]. ESP32 processors, featuring integrated wireless communication and efficient power consumption protocols, have become industry-standard components for IoT implementations, with comprehensive technical specifications available from manufacturers [3]. Dashboard platforms including Blynk facilitate accessible graphical interfaces enabling instantaneous system monitoring and remote operational command through web and mobile applications [4].

Recent comprehensive reviews highlight the criticality of merging sustainable power generation with intelligent analytical systems to establish next-generation infrastructure ecosystems [15]. Despite existing research, few investigations have comprehensively addressed the integration of piezoelectric flooring systems with concurrent IoT supervision and energy storage management protocols. This motivates the proposed system, which combines piezoelectric energy harvesting, ESP32-based sensing, and Blynk IoT monitoring to demonstrate a practical and scalable smart walkway solution.

2.2 METHODOLOGY

The subsequent sections describe the comprehensive system architecture and design approach employed in constructing the proposed platform. The operational framework encompasses transduction of kinetic energy from pedestrian locomotion into electrical signals, signal processing and energy accumulation within storage elements, and wireless transmission of monitored system variables to cloud-based visualization interfaces

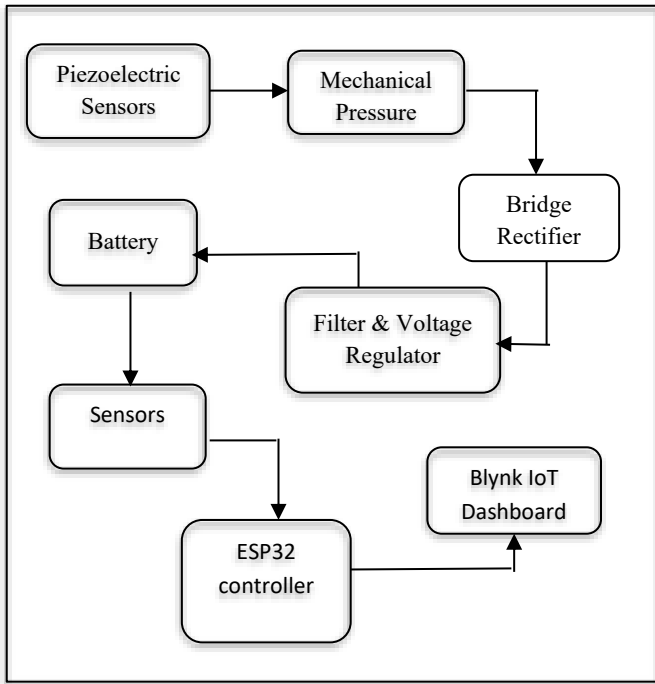


Fig 1: System Block Diagram

Figure 1 shows the complete workflow of proposed system.

Mechanical pressure represents the mechanical force applied on the walkway due to human footsteps or vibrations. The applied pressure acts as the input energy source for the system.

Piezoelectric transducers operate via the inverse piezoelectric phenomenon, whereby mechanical deformation induces electrical polarization. Footstep-induced loading produces alternating voltage signals across sensor leads, which must subsequently be standardized.

Full-bridge rectification circuit transforms the bidirectional voltage waveform into unidirectional current flow, establishing polarity consistency necessary for downstream battery charging and controller input requirements.

Integrated filtering and voltage stabilization circuitry attenuates harmonic distortions in the rectified signal, maintains output within specified operational ranges, and provides transient protection for energy storage and control electronics.

Lithium-ion battery assemblies serve as the primary energy storage medium, enabling sustained operational capacity of processor and sensor subsystems during intervals of minimal or zero footfall activity.

Integrated analog sensors quantify key electrical parameters including potential difference and current magnitude across both the energy generation and storage subsystems, with measurements continuously relayed to the processing unit for computational evaluation.

ESP32 microcontroller serves as the central processing architecture, executing periodic sensor sampling, performing computational analysis on the collected metrics, and establishing wireless TCP/IP communication with cloud-hosted data aggregation services via IEEE 802.11 transmission.

Blynk interface provides instantaneous graphical representation of system performance indicators including potential, amperage, and battery state, accessible through smartphone and web-based client applications for off-site supervision.

2.3 EXPERIMENTAL RESULTS

1.Hardware Implementation

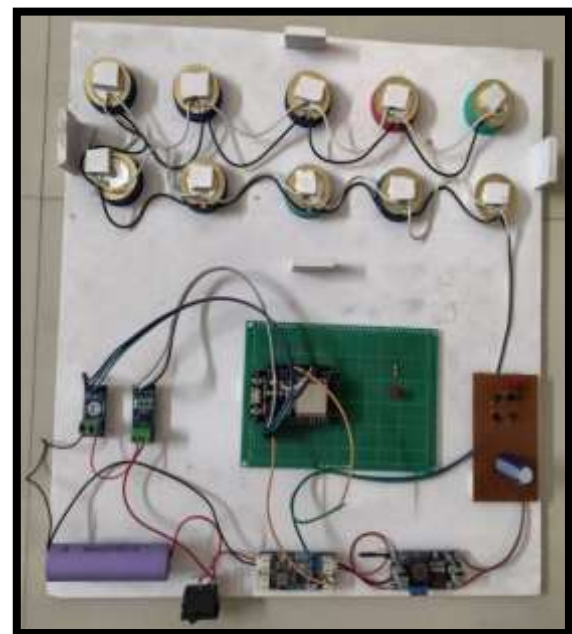


Fig 2: Hardware Model

The experimental platform illustrated in Figure 2 demonstrates a practical instantiation combining ESP32-based processing with distributed piezoelectric transducers. Ten piezoelectric disc elements strategically positioned beneath the walking surface generate alternating voltage signals proportional to applied pedestrian loading. Output voltage amplitude

demonstrates direct correlation with loading intensity, achieving peak values of 3.3 V under maximum footstep force. The inherent alternating character of piezoelectric generation necessitates AC-to-DC conversion via full-wave bridge rectification topology.

Post-rectification signal conditioning facilitates efficient charging of the lithium-ion accumulator, while parallel measurement circuitry acquires electrical characteristic data. The microcontroller executes cyclic ADC conversions at specified intervals, capturing real-time system performance variables. Leveraging integrated wireless connectivity, the ESP32 establishes continuous network tunnels transmitting instantaneous measurements to remote data aggregation infrastructure. An auxiliary buck-boost converter maintains the microcontroller voltage within specification despite input variations. The constructed prototype validates the technical feasibility of pedestrian-powered distributed generation with synchronized cloud-based performance telemetry.

2. Software Implementation



Fig 3: Blynk IoT Dashboard

Figure 3 shows the real-time monitoring output on the Blynk IoT dashboard for the piezoelectric walkway system. The measured voltage is 3.364 V and the current is 1.771 mA, which are generated when sufficient pressure is applied on the piezoelectric sensors. The charging status value '1' indicates that the battery is in the charging state. This confirms that the

harvested energy is successfully sensed by the ESP32 and transmitted wirelessly to the Blynk server for live monitoring.

Table 1: Effect of Applied Pressure on Output Voltage, Current and Power

Applied Pressure	Output Voltage (V)	Output Current (mA)	Output Power (mW)
Very Light Tap	0.8	0.3	0.24
Light Footstep	1.2	0.6	0.72
Normal Walking	1.5	0.9	1.35
Heavy Footstep	2.2	1.3	2.86
Strong Pressure	3.3	1.8	5.94

Table 1 summarizes the variation in output voltage, current and power generated by piezoelectric walkway increases with the applied mechanical pressure.

Case 1: Very Light Tap

When very light pressure is applied, minimal deformation of the piezoelectric sensor occurs, resulting in low electrical output. A voltage of 0.8 V, current of 0.3 mA and power of 0.24 mW are generated.

Case 5: Strong Pressure

Under strong applied pressure, maximum deformation of the piezoelectric sensor produces higher electrical output. The system generates 3.3 V, 1.8 mA and 5.94 mW indicating effective energy harvesting.

Table 2: Effect of Number of Piezo Sensors on Output Voltage

Sr. No	No. of Piezo Sensors	Output Voltage (V)
1	2	0.9
2	4	1.4
3	6	2.0
4	8	2.7
5	10	3.3

Table 2 shows the relationship between number of piezoelectric sensors used and output voltage generated.

Case 2: Four Piezo Sensors

With four piezoelectric sensors connected, the output voltage increases to 1.4 V due to the combined effect of multiple sensors under applied pressure.

Case 5: Ten Piezo Sensors

With ten piezoelectric sensors connected, the system achieves a maximum output voltage of 3.3 V, demonstrating the scalability and effectiveness of the proposed energy harvesting walkway.

3. CONCLUSIONS

This investigation confirms the operational viability of transforming human ambulation-derived mechanical energy into electrical signals via piezoelectric transduction, with subsequent energy conditioning and accumulation within hybrid battery-supercapacitor arrays. The microprocessor architecture successfully executed concurrent functions encompassing instantaneous electrical metric acquisition and bidirectional communication with cloud-based monitoring infrastructure, delivering comprehensive operational transparency.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to **Dr. R. P. Patil**, our project guide, for providing invaluable guidance, continuous encouragement, and expert suggestions throughout the research work titled "**An IoT-Based Piezoelectric Energy Harvesting Walkway for Real-Time Energy Monitoring.**" Their technical expertise and constructive feedback were instrumental in the successful completion of this project.

We are thankful to the **Department of Electronics and Telecommunication Engineering, Sinhgad College of Engineering**, for providing the necessary infrastructure, laboratory facilities, and academic support required for carrying out this research work.

We would also like to express our gratitude to **Dr. R. S. Kawitkar**, Head of the Department, and all the faculty members of the department for their valuable insights and support during the course of this project.

Our sincere thanks go to the **Dr. S. D. Lokhande**, Principal, for creating an environment conducive to learning and research and for providing the resources needed to complete this work successfully.

We are grateful to our project team members for their dedication, cooperation, and collective efforts that contributed significantly to the development and implementation of the proposed system.

We acknowledge with gratitude all those who directly or indirectly contributed to the successful completion of this research work.

REFERENCES

- [1] L. Atzori et al., "The Internet of Things: A survey," *Computer Networks*, 2010.
- [2] A. Zanella et al., "Internet of Things for smart cities," *IEEE IoT Journal*, 2014.
- [3] Espressif Systems, "ESP32 Technical Reference Manual," 2023.
- [4] Blynk Inc., "Blynk IoT Platform Documentation," 2024.
- [5] K. Ashton, "That 'Internet of Things' thing," *RFID Journal*, 2009.
- [6] M. Haroon and A. Ahmed, "Footsteps Power Generation Using Piezoelectric Energy Harvester," *Spectrum of Engineering Sciences*, vol. 3, no. 6, pp. 45–54, 2025.

- [7] S. Safaei, M. A. Sodano, and J. Anton, "Piezoelectric Energy Harvesting: A Systematic Review of Reviews," *Machines*, vol. 10, no. 12, art. 312, 2022, doi:10.3390/machines10120312.
- [8] Y. Wang, R. Zhu, and H. Luo, "Recent Advances in Piezoelectric Energy Harvesting Technologies for Structural Health Monitoring," *IEEE Access*, vol. 11, pp. 26470–26485, Mar. 2023, doi:10.1109/ACCESS.2023.3250071.
- [9] P. Kumar, S. Patel, and M. Singh, "Development of Smart Energy Harvesting Floor Using Piezoelectric Sensors," *IEEE Transactions on Instrumentation and Measurement*, vol. 73, pp. 1–9, Apr. 2024, doi:10.1109/TIM.2024.3362714.
- [10] J. M. P. Perez and L. V. Rodrigues, "Design and Optimization of Piezoelectric Tile for Smart Walkways in Sustainable Cities," *IEEE Sensors Journal*, vol. 24, no. 7, pp. 8834–8845, Apr. 2024, doi:10.1109/JSEN.2024.3372935.
- [11] Y. Wang, R. Zhu, and H. Luo, "Recent Advances in Piezoelectric Energy Harvesting Technologies for Structural Health Monitoring," *IEEE Access*, vol. 11, pp. 26470–26485, Mar. 2023, doi:10.1109/ACCESS.2023.3250071.
- [12] P. Kumar, S. Patel, and M. Singh, "Development of Smart Energy Harvesting Floor Using Piezoelectric Sensors," *IEEE Transactions on Instrumentation and Measurement*, vol. 73, pp. 1–9, Apr. 2024, doi:10.1109/TIM.2024.3362714.
- [13] J. M. P. Perez and L. V. Rodrigues, "Design and Optimization of Piezoelectric Tile for Smart Walkways in Sustainable Cities," *IEEE Sensors Journal*, vol. 24, no. 7, pp. 8834–8845, Apr. 2024, doi:10.1109/JSEN.2024.3372935.
- [14] R. V. Kulkarni, P. V. Ghate, and M. R. Patil, "IoT-Based Power Monitoring and Energy Management System Using ESP32," *International Journal of Emerging Technology and Advanced Engineering*, vol. 13, no. 3, pp. 122–129, 2023.
- [15] T. P. Singh and S. Sharma, "IoT-Enabled Smart Energy Harvesting Systems: A Comprehensive Survey," *IEEE Internet of Things Journal*, vol. 11, no. 2, pp. 1928–1942, Feb. 2024, doi:10.1109/JIOT.2024.3369205.