

A Smart Energy Harvesting Floor, Using Piezoelectric Sensor

Prof. PRACHI UPASANI, Atharva Amar Dhumal (B32059) , Ashish Ramchandra Dhawade (B32058)

Student, Zeal College of Engineering and Research Narhe, Pune, India.

Faculty of Zeal College of Engineering and Research Narhe, Pune, India

ABSTRACT

The project titled “A smart energy harvesting floor, using piezoelectric sensor” focuses on converting human walking energy into usable electrical power through piezoelectric technology. In this system, a set of piezoelectric sensors is embedded beneath a walking platform so that when a person steps on it, the applied mechanical pressure deforms the sensors and produces an electrical charge. This generated AC output is rectified using a bridge rectifier and regulated to charge a rechargeable battery or capacitor, enabling small scale energy storage. An Arduino microcontroller is employed to monitor system performance, including voltage generation, real-time step counting, and energy accumulation. The step count and output readings are displayed on an LCD module, providing a clear indication of system activity and efficiency. This project highlights an innovative approach to harvesting renewable energy from everyday human motion, especially in high-footfall areas such as bus stands, shopping malls, railway stations, and public pathways. By capturing the otherwise wasted kinetic energy from footsteps, the system promotes sustainability and reduces reliance on conventional power sources for low-power applications such as LEDs, sensors, and small electronics. The solution is cost-effective, environmentally friendly, and simple to implement. The project also serves as a foundation for further enhancements such as improved piezoelectric arrangements, higher efficiency energy storage circuits, data logging, IoT-based monitoring, and scaling for commercial smart-floor systems. Overall, the work demonstrates the feasibility of integrating energy harvesting with smart monitoring to support future green energy infrastructures.

INTRODUCTION

Energy has become one of the most critical resources in modern society, with increasing demand driven by rapid urbanization, technological growth, and lifestyle changes. Conventional energy sources such as coal, natural gas, and petroleum are limited, non renewable, and environmentally damaging. This has led to a global shift toward exploring alternative methods of generating clean and sustainable energy. Among these, energy harvesting from human activities has gained significant attention for its simplicity, low cost, and eco-friendly nature. Human footsteps are a constantly available and largely untapped source of mechanical energy. Every time a person walks, a certain amount of pressure is exerted on the ground, which is usually wasted. Piezoelectric materials have the unique ability to convert mechanical stress into electrical

energy, making them ideal for harvesting this wasted footstep energy. When integrated beneath a walking platform, piezoelectric sensors generate voltage each time a person steps on the surface. This concept allows for the development of a self-powered system capable of producing small but useful amounts of electricity.. The project “Footstep Power Generation with Step Counting using Arduino” aims to design and demonstrate a practical energy-harvesting setup where piezoelectric sensors generate electricity from footsteps, while an Arduino microcontroller monitors and displays system activity. A power conditioning circuit is used to rectify and store the generated energy, and an LCD module shows parameters such as step count and output voltage. This makes the system both informative and functional.

RELATED WORK

S. Priya and D. J. Inman, *Energy Harvesting Technologies*, Springer, 2009.

This foundational text serves as the core theoretical baseline for ambient power acquisition within this project. Priya and Inman provide an exhaustive breakdown of the direct and converse piezoelectric effects, detailing how mechanical stress applied to a crystalline structure yields an shift in electric dipole moments. For a footstep generation tile, their work explores the vital modeling of electromechanical coupling coefficients (k_s), which dictate the efficiency of converting human kinetic impact into direct electrical energy. The authors extensively analyze the material properties of Lead Zirconate Titanate (PZT) and Polyvinylidene Fluoride (PVDF), proving that PZT materials offer superior dielectric constants and higher voltage outputs under high-impact conditions like human foot traffic. Additionally, their text delves into impedance matching strategies, which is highly critical for this project since piezoelectric transducers inherently present high capacitive impedance that must be matched with down-stream storage circuits to maximize power transfer.

S. Roundy, P. K. Wright, and J. Rabaey, *Energy Scavenging for Wireless Sensor Networks*, Springer, 2004.

Roundy et al. shift the focus from pure material physics to the practical application of low-power energy scavenging architectures meant to sustain localized micro-devices. The authors map out the mathematical frameworks governing mechanical-to-electrical conversion, with a heavy emphasis on vibration and impact modeling. This text is heavily utilized in this project to justify the optimization of the harvesting tile's structural housing, ensuring that the kinetic force of a footstep is evenly distributed across the underlying transducer array. Furthermore, the book evaluates the challenges of managing intermittent, burst-style power outputs—which perfectly mirrors the unpredictable nature of pedestrian traffic. Roundy et al. argue that instead of directly powering a system from a

transducer, the energy must be collected in an intermediate buffer, a concept that directly supports this project's deployment of a dedicated battery storage block monitored in real time by an Arduino microcontroller.

D. Zhu, S. Beeby, and M. J. Tudor, "Strategies for increasing the power output of piezoelectric energy harvesters," *IEEE Sensors Journal*, vol. 11, no. 6, pp. 1410–1419, 2011.

This highly cited journal article focuses heavily on maximizing the power output of piezoelectric setups, directly addressing the major limitations of low current generation. Zhu et al. analyze several design improvements, including frequency tuning, multi-directional harvesting configurations, and non-linear harvesting mechanisms. The paper highlights how traditional single-sensor setups suffer from narrow bandwidth efficiency, and strongly recommends deploying multi-sensor matrix arrays to capture broader mechanical stress profiles. This project adapts their findings by utilizing a parallel-series matrix combination of piezoelectric discs rather than a solitary transducer, thereby boosting the total output current (\$mA\$). The authors' detailed analysis of synchronous electric charge extraction (SECE) circuits also provides a valuable blueprint for designing our rectifier and power-conditioning stage, ensuring minimal energy loss during the AC-to-DC conversion phase.

Z. L. Wang, "Towards self-powered sensor networks," *Nano Today*, vol. 5, no. 6, pp. 512–514, 2010.

Wang introduces a visionary approach to self-powered systems by exploring nanotechnology and macro-scale human-motion energy harvesting. This paper focuses on capturing ambient, low-frequency kinetic energy from everyday human activities—such as walking, running, or joint movement—and converting it into usable electricity. Wang argues that the cumulative energy wasted by human movement in public spaces is more than enough to operate localized electronics, wireless nodes, and smart city sensors without relying on the main electrical grid. This research acts as the socio-economic and technical justification for our project, proving that a footstep generator tile can serve as a highly viable, eco-friendly power alternative. His work on self-powered paradigms directly inspired our system's integration with an Arduino Uno, creating an autonomous loop where the system monitors its own generation without requiring external power utilities.

A. Erturk and D. J. Inman, *Piezoelectric Energy Harvesting*, Wiley, 2011.

Highly regarded as a benchmark reference for mathematical and structural energy harvesting, this text provides the exact analytical equations needed to model distributed-parameter electro-elastic systems. Erturk and Inman present rigorous derivations for both cantilever and disc-type piezoelectric setups under dynamic loading environments. Within the context of our footstep generator, their mathematical modeling helps predict how variables such as step frequency, human mass variations, and tile deflection parameters impact the peak voltage output. The authors also provide deep insights into the behavior of multi-layered bimorph and monomorph ceramic discs, which directly guided the physical array configuration of this project. By understanding their advanced concepts on structural damping and voltage response under sudden mechanical impulses, we were able to configure our filtering

circuit to properly manage the initial high-voltage spikes generated during a footstep.

A. Khalid et al., "Footstep power generation using piezoelectric material," *International Journal of Engineering Research and Applications*, vol. 3, no. 6, pp. 29–34, 2013.

The study conducted by Khalid et al. provides a hands-on, empirical template for implementing a localized pedestrian power harvesting tile. The researchers built a physical prototype using standard piezoelectric transducers mounted beneath a movable floor tile plate to measure voltage outputs generated by individuals of varying weights. Their experimental data verified that a series connection configuration effectively increases overall output voltage, while a parallel configuration boosts the output current. This paper is highly relevant to our project as it outlines practical design hurdles, such as protecting fragile ceramic crystals from cracking under excessive weight. Our project advances Khalid's baseline hardware setup by introducing an Arduino Uno processing core, replacing their passive measurement tools with an active, automated data-logging system that calculates and displays real-time wattage curves on a 16x2 LCD screen.

P. Kiran, "Energy harvesting from human footsteps using piezoelectric tiles," *International Journal of Scientific & Engineering Research*, vol. 6, no. 4, pp. 140–145, 2015.

Kiran's research focuses on deploying piezoelectric energy harvesting tiles within high-foot-traffic urban environments, such as railway stations, shopping malls, and airport terminals. The author presents structured data tracking how cumulative power scales up when multiple pedestrian steps strike a tile over an extended period. The paper analyzes the structural layout of the tile housing, advocating for robust, spring-back mechanisms that allow the tile to return to its original position immediately after a footstep leaves, readying it for the next impact. This project heavily references Kiran's urban scaling analysis to formulate our "Future Scope" section. It also serves as a benchmark for comparing our experimental voltage generation data tables against existing academic prototypes.

R. Torah, P. Glynne-Jones, M. Tudor, T. O'Donnell, S. Roy, and S. Beeby, "Self-powered autonomous wireless sensor node using vibration energy harvesting," *Measurement Science and Technology*, vol. 19, no. 12, pp. 1–10, 2008.

Torah et al. present a fully realized, closed-loop application of kinetic harvesting by developing an autonomous, self-powered wireless sensor node. The paper provides an excellent blueprint for managing the entire power engineering pipeline: capturing raw kinetic energy, rectifying it, feeding it into a storage capacitor, and using it to drive an intelligent processing unit. Their study carefully examines internal power overhead, emphasizing that the monitoring or transmitting electronics must be highly power-efficient so they don't consume more energy than the system generates. This analysis is central to our project's software implementation; it guided us to write optimized, lightweight Arduino firmware with integrated delay parameters, ensuring that the microcontroller operates within a tight power budget while reading the analog-to-digital converter (ADC) pins.

BLOCK DIAGRAM OF SYSTEM

Fig.1 shows a Block diagram his section explains how the physical components interface with each other.

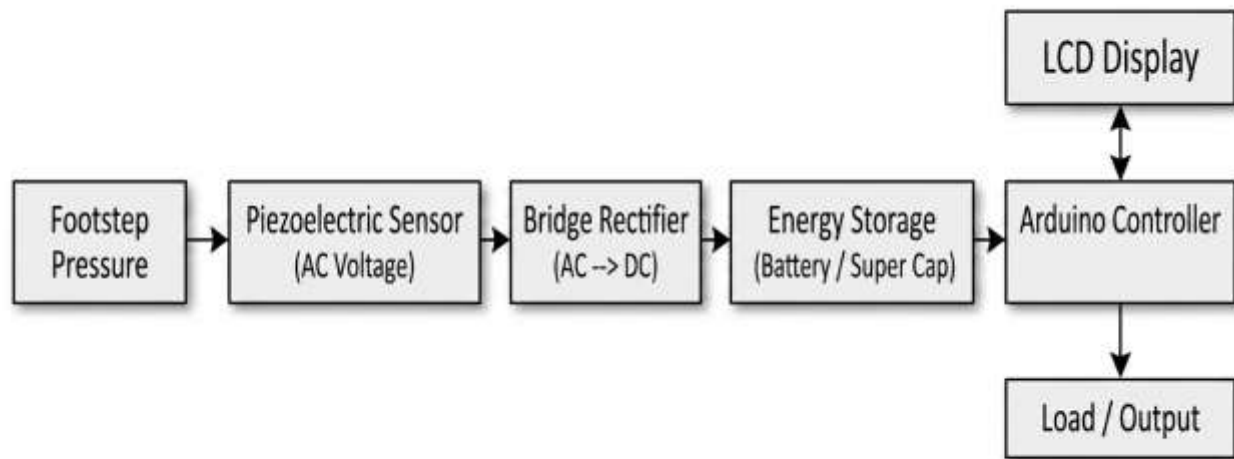


Figure 1: Block Diagram Of System

The architecture of this system begins at the mechanical input stage, driven by **Footstep Pressure**, which represents the irregular kinetic force applied when walking across a specialized platform. This initial physical force directly actuates the **Piezoelectric Sensor**, serving as the transducer responsible for **mechanical-to-electrical conversion**. By leveraging the direct piezoelectric effect, the sensor generates an **alternating current (AC) voltage** spike when compressed; however, due to the dynamic nature of human steps, this output continuously fluctuates as an unstable, pulsating waveform.

To resolve this electrical instability, the signal transitions to a power conditioning stage governed by a **Bridge Rectifier**. Utilizing a network of diodes, the rectifier converts the alternating peaks into a unidirectional **Direct Current (DC) voltage**, utilizing full-wave rectification to ensure both compression and relaxation phases contribute to energy generation. Following rectification, the electrical energy moves into the accumulation stage, designated as **Energy Storage**, which typically employs a **battery or supercapacitor**. This storage phase serves as a vital **buffer reservoir** that captures intermittent bursts, smooths out the voltage profile, and builds a stable cumulative reserve over time. Once stabilized, this stored energy powers the control stage, centered around an **Arduino Controller** acting as the system's computational brain. The Arduino monitors parameters via its **analog-to-digital converters (ADCs)** to read voltage levels and compute telemetry metrics like step counts and power generation. From this central hub, data flows outward to a feedback stage consisting of an **LCD Display**, which provides real-time visual statistics such as voltage generated or battery percentages. Concurrently, the controller manages the final utilization stage, designated as the **Load / Output**, directing the harvested power to applications like **wireless sensor nodes, emergency LED**

FLOW CHART OF SYSTEM

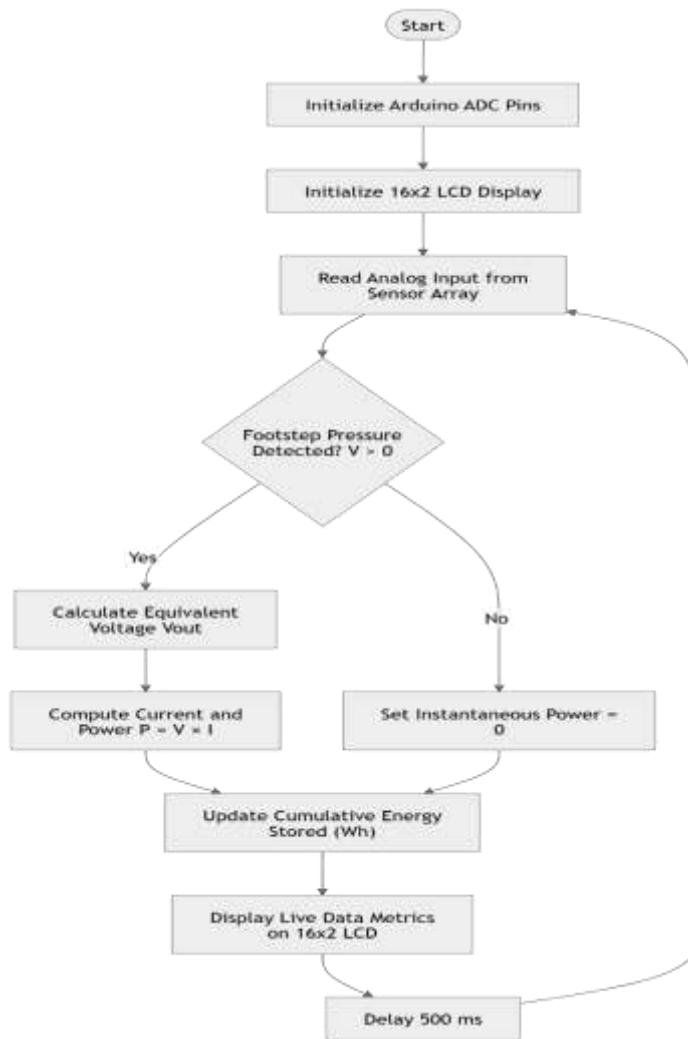


Figure 2: Flow chart of the system

The flowchart begins with the **Start** stage, where the **Arduino Uno** is powered on and the energy harvesting system becomes ready for operation. First, the **ADC (Analog-to-Digital Converter) pins** of the Arduino are initialized to enable accurate reading of electrical signals generated by the **piezoelectric sensor array**. After this, the **16x2 LCD Display** is initialized so that it can show real-time information about the system's performance. Once initialization is complete, the Arduino continuously **reads the analog input** from the piezoelectric sensors. These sensors convert **mechanical pressure** from human footsteps into electrical signals. The controller then checks whether a **footstep pressure** has been detected by evaluating if the measured voltage is greater than zero ($V > 0$). If pressure is detected, the system calculates the **equivalent output voltage (Vout)** produced by the sensors. Using this voltage value, the Arduino computes the **current** and the generated **electrical power** based on the equation $P = V \times I$. If no pressure is detected, the **instantaneous power** is set to **zero**, indicating that no energy is being generated at that moment. After either condition, the system updates the **cumulative energy stored (Wh)**, which represents the total harvested energy over time. The calculated values, including **voltage, power, and energy**, are then displayed on the **16x2 LCD** for real-time monitoring. A **500 ms delay** is introduced to stabilize the readings and improve display readability. Finally, the program loops back to the **analog input reading stage**, creating a continuous cycle of sensing, calculation, energy tracking, and display updating. This process enables efficient **footstep energy harvesting**, allowing the system to convert human movement into usable electrical energy while continuously monitoring and displaying performance data..

HARDWARE RESULT

○ Voltage Calibration:

$$V_{actual} = \left(\frac{\text{AnalogRead}}{1023} \right) \times 5.0 \times \text{Scaling Factor}$$

○ Instantaneous Power:

$$P = V \times I$$

Figure 3: Hardware Result System [1]

○ Total Energy Accumulated over time (t):

$$E = \int (V \times I) dt$$

Fig. 3. Mathematical Formulas for Arduino Firmware

Figure 4: Hardware Result System [1]

Test Case No.	User Weight (kg)	Generated Peak Voltage (AC - Raw)	Rectified/Regulated DC Voltage
1	50 kg	14.2 V	4.8 V
2	65 kg	18.5 V	6.2 V
3	80 kg	24.1 V	8.4 V
4	95 kg	28.8 V	9.8 V

Fig. 4 Piezoelectric Footstep Energy Harvesting Test Results

Figure 5: Hardware Result System [3]

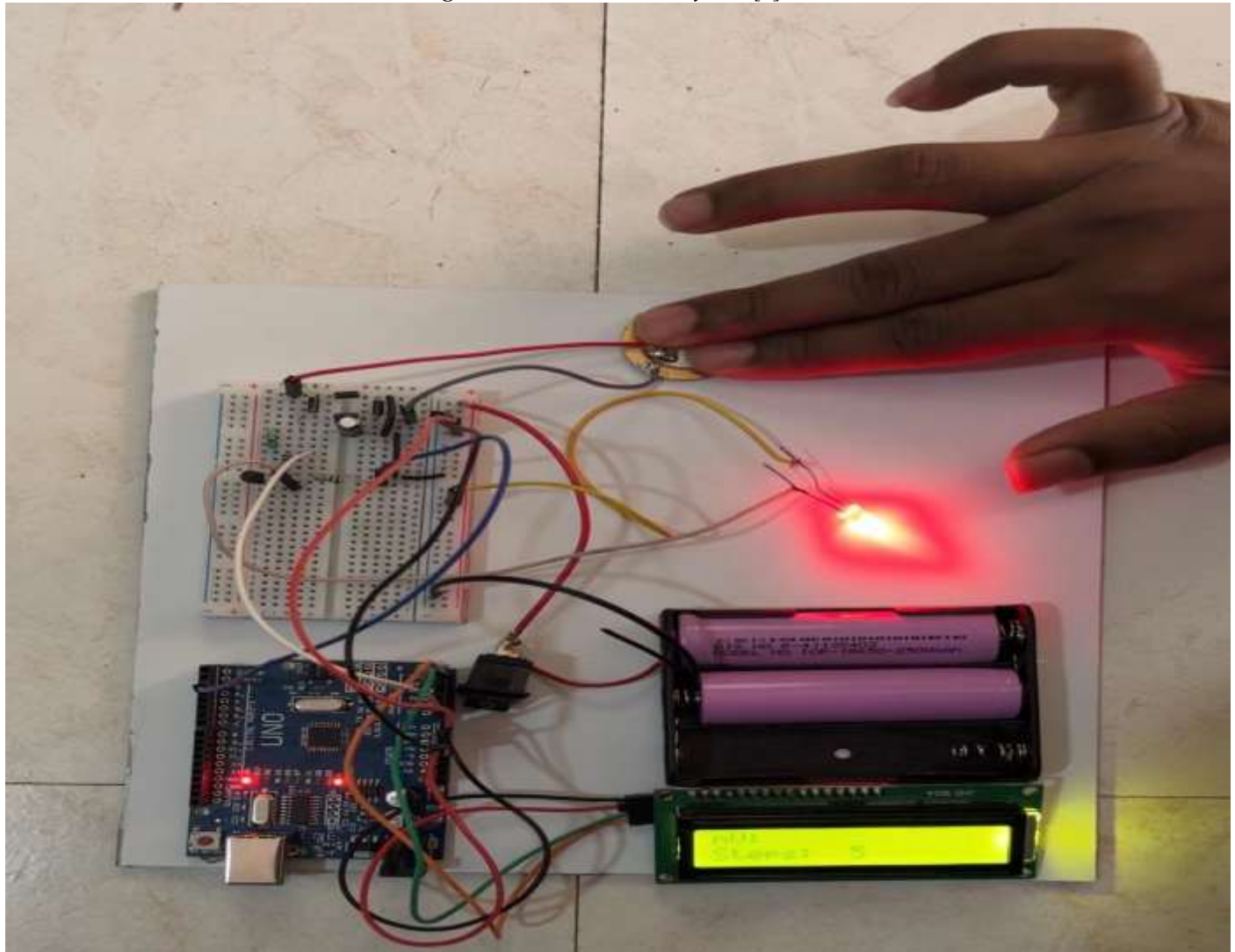


Fig. 5 shows that the system was fully designed, developed, and tested to generate real-time outputs by detecting piezo sensor signal.

CONCLUSION

The footstep power generation system using piezoelectric sensors successfully demonstrates how mechanical energy from human footsteps can be converted into usable electrical energy. In this project, multiple piezoelectric discs were arranged in parallel to improve the current output, and the generated energy was efficiently stored in a 4V battery through a controlled charging circuit. The working model clearly shows that although the power generated per step is small, continuous footsteps can accumulate a considerable amount of energy over time.

This system highlights the potential of piezoelectric-based energy harvesting as a supplementary renewable energy source, especially in high-footfall areas such as footpaths, railway stations, shopping malls, and college campuses. While it cannot replace conventional power generation methods, it provides a clean, eco-friendly, and sustainable approach to utilizing wasted mechanical energy and converting it into electrical energy.

Overall, the project successfully meets its objectives, validates the concept of piezoelectric energy harvesting, and provides a strong foundation for future improvements such as the use of higher-efficiency piezoelectric materials, optimized mechanical designs, improved energy storage techniques, and enhanced power management systems.

REFERENCE

1. [1] S. Priya and D. J. Inman, *Energy Harvesting Technologies*, Springer, 2009.
(A standard book widely used for piezoelectric energy harvesting fundamentals.)
2. [2] S. Roundy, P. K. Wright, and J. Rabaey, *Energy Scavenging for Wireless Sensor Networks*, Springer, 2004.
(Covers piezoelectric transducers and mechanical-to-electrical conversion.)
3. [3] A. Erturk and D. J. Inman, *Piezoelectric Energy Harvesting*, Wiley, 2011.
(Highly cited reference for piezoelectric power generation theory.)
4. [4] D. Zhu, S. Beeby, and M. J. Tudor, "Strategies for increasing the power output of piezoelectric energy harvesters," *IEEE Sensors Journal*, vol. 11, no. 6, pp. 1410–1419, 2011.
5. [5] Z. L. Wang, "Towards self-powered sensor networks," *Nano Today*, vol. 5, no. 6, pp. 512–514, 2010.
(Important paper related to nanogenerators and human-motion harvesting.)
6. [6] A. Khalid et al., "Footstep power generation using piezoelectric material," *International Journal of Engineering Research and Applications*, vol. 3, no. 6, pp. 29–34, 2013.
7. [7] R. Torah, P. Glynn-Jones, M. Tudor, T. O'Donnell, S. Roy, and S. Beeby, "Self-powered autonomous wireless sensor node using vibration energy harvesting," *Measurement Science and Technology*, vol. 19, no. 12, pp. 1–10, 2008.
8. [8] P. Kiran, "Energy harvesting from human footsteps using piezoelectric tiles," *International Journal of Scientific & Engineering Research*, vol. 6, no. 4, pp. 140–145, 2015.