

HYBRID PIEZO-MAGNETIC ENERGY HARVESTING SYSTEM FOR FOOTSTEP POWER GENERATION

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Abstract - The Hybrid Piezo-Magnetic Energy Harvesting System is designed to convert mechanical energy generated from human footsteps into usable electrical energy by integrating piezoelectric and electromagnetic energy harvesting techniques. The proposed system utilizes eight piezoelectric discs of 27 mm diameter along with two 100-turn electromagnetic coils to improve overall energy conversion efficiency and power generation. Electrical energy generated from both harvesting sections is rectified and stored in a rechargeable battery for later utilization. The stored energy can be effectively used for powering low-power applications such as LED lighting, sensor-based devices, LCD monitoring systems, and short-duration mobile charging demonstrations. Arduino Uno is used for system monitoring and control, while system performance and output characteristics are analyzed using Proteus simulation and Arduino IDE. Experimental results indicate that the hybrid system provides better output performance compared to standalone piezoelectric and electromagnetic harvesting methods. The proposed system offers a sustainable, cost-effective, and eco-friendly solution for renewable energy generation in high-footfall areas such as railway stations, shopping malls, airports, and smart city infrastructures.

Key Words: Hybrid Energy Harvesting, Piezoelectric Disc, Electromagnetic Coil, Footstep Energy Harvesting, Renewable Energy.

1. INTRODUCTION

With the rapid increase in global energy demand and depletion of conventional energy resources, renewable energy harvesting has become an important area of research. Energy harvesting refers to the process of capturing and converting ambient energy sources into usable electrical energy. Among various energy sources, mechanical energy generated from human activities such as walking, running, and vibrations is widely available and can be effectively utilized for power generation. Footstep energy

harvesting is an emerging technology that converts mechanical pressure from footsteps into electrical energy. High-footfall areas such as railway stations, airports, shopping malls, public walkways, and smart city infrastructures generate a large amount of mechanical energy daily, which can be harvested for useful applications. Piezoelectric energy harvesting works on the principle of converting mechanical stress into electrical voltage using piezoelectric materials and generally produces high voltage but low current. In contrast, electromagnetic energy harvesting operates based on Faraday's Law of Electromagnetic Induction, where relative motion between a magnet and coil generates electrical energy, usually producing higher current with comparatively lower voltage. To overcome the limitations of individual energy harvesting techniques, this project combines both piezoelectric and electromagnetic methods into a hybrid energy harvesting system. The hybrid approach improves overall efficiency and output performance by utilizing the advantages of both technologies. The generated energy is rectified, regulated, and stored in a rechargeable battery for future use. This harvested energy can power low-power applications such as LED lighting, sensors, embedded devices, and other low-power electronic devices. Therefore, the proposed Hybrid Piezo-Magnetic Energy Harvesting System provides an efficient, sustainable, and environmentally friendly solution for energy generation from daily human activities.

2. Body of Paper

2.1 Literature Review

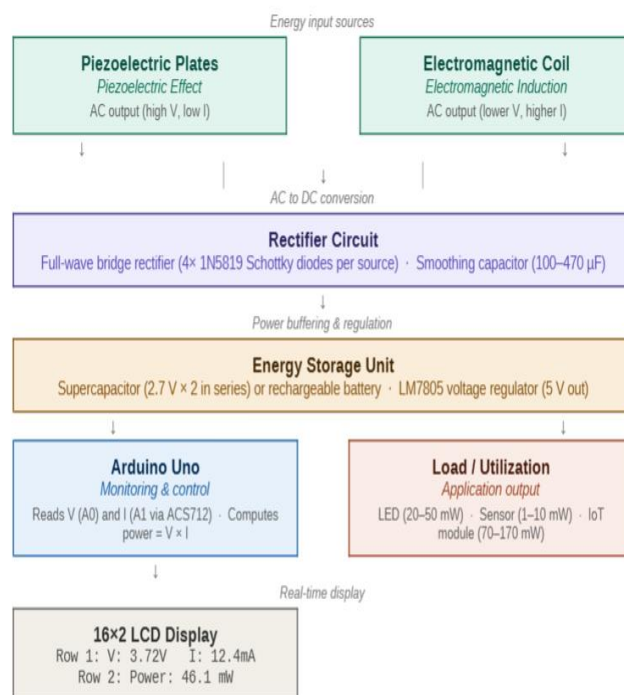
Energy harvesting has gained significant attention as a sustainable solution for generating electrical energy from ambient sources such as vibrations, pressure, and motion. Various methods such as piezoelectric, electromagnetic, thermoelectric, and solar energy harvesting have been studied extensively. Priya and Daniel J. Inman reported that piezoelectric materials effectively convert mechanical stress into electrical energy with high voltage output and good conversion efficiency. Shad Roundy et al. studied vibration-based

energy harvesting systems and demonstrated their capability in powering low-power electronic devices and wireless sensor networks. Joseph A. Paradiso and Thad Starner presented energy scavenging techniques for mobile and wireless electronics, highlighting the importance of renewable energy harvesting in portable systems. Paul D. Mitcheson et al. discussed energy harvesting from human motion and machine movement for low-power wireless applications. Recent research indicates that hybrid energy harvesting systems combining piezoelectric and electromagnetic methods provide improved efficiency and better power output compared to standalone systems. Such systems are increasingly suitable for powering modern low-power embedded devices, IoT sensors, and smart monitoring systems.

2.2 Proposed System

The proposed Hybrid Piezo-Magnetic Energy Harvesting System converts mechanical energy generated from human footsteps into electrical energy using both piezoelectric and electromagnetic energy harvesting techniques. The system consists of eight piezoelectric discs of 27 mm diameter connected in parallel configuration to maximize output current and improve energy generation. These discs are strategically placed to receive maximum pressure during footstep application. The electromagnetic section consists of two copper coils, each having 100 turns, placed above and below the magnet assembly. Permanent magnets move relative to these coils when pressure is applied on the tile surface. This relative motion generates electrical energy based on Electromagnetic Induction. The hybrid arrangement improves energy harvesting performance by combining the high-voltage characteristics of piezoelectric discs with the higher current generation capability of electromagnetic harvesting. The generated AC output from both sections is rectified into DC voltage and stored in a rechargeable battery for future use in low-power applications.

2.3 Block Diagram



2.4 Hardware Setup

The hardware setup of the proposed system consists of eight piezoelectric discs, two electromagnetic coils, permanent magnets, bridge rectifier circuits, rechargeable battery, Arduino Uno, and a 16×2 LCD display. The piezoelectric discs generate voltage under mechanical pressure, while electromagnetic coils generate electrical energy due to relative motion between the coil and magnet. Bridge rectifier circuits convert the AC output into DC voltage for usable electrical power. The generated electrical energy is filtered and stored in a rechargeable battery for future use. Arduino Uno is used for voltage monitoring and system control, while the 16×2 LCD display provides real-time output voltage monitoring. The complete hardware setup is designed to achieve efficient energy harvesting from human footsteps while maintaining low cost and practical implementation.



2.5 Working Principle

The system operates by converting mechanical pressure generated from human footsteps into electrical energy using hybrid energy harvesting techniques. When a person steps on the tile surface, mechanical pressure is applied to the piezoelectric discs and electromagnetic assembly. Due to mechanical deformation, the piezoelectric discs generate electrical voltage. Simultaneously, movement of the permanent magnet relative to electromagnetic coils produces electrical energy through Faraday's Law of Electromagnetic Induction. The generated AC output from both harvesting sections is passed through bridge rectifier circuits to obtain DC voltage. The rectified output is filtered and stored in a rechargeable battery for future use. Arduino Uno continuously monitors the system output and displays real-time voltage values on the LCD display. The stored energy can be utilized for powering low-power devices such as LEDs, sensors, and embedded systems.

2.6 Simulation

The proposed Hybrid Piezo-Magnetic Energy Harvesting System was simulated using Proteus 8 Professional and Arduino IDE before hardware implementation to verify circuit performance and system functionality. The simulation setup consisted of Arduino Uno, a 16x2 LCD display, input switch, resistor network, and LED output indicator. The footstep pressure was simulated using a switch mechanism representing input from piezoelectric and electromagnetic harvesting sections. Arduino IDE was used for program compilation and verification. The code compiled successfully for Arduino Uno without errors. Memory utilization was efficient, with program storage usage of 4388 bytes (13%) and dynamic memory usage of 91 bytes (4%), indicating stable and optimized system performance.

During simulation, two operating conditions were analyzed:

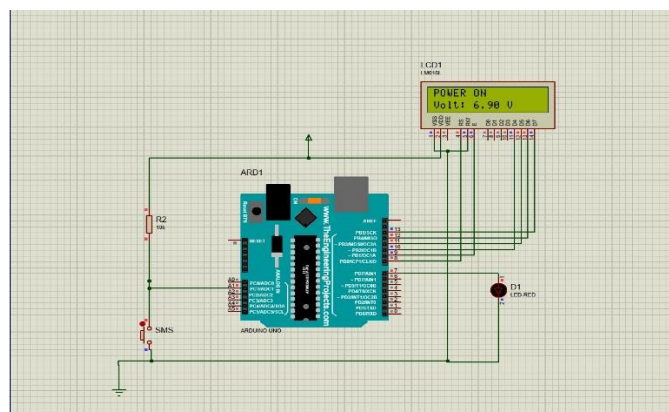
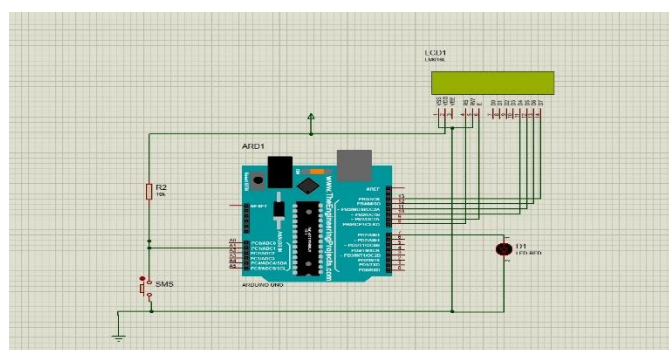
1. **POWER OFF Condition** – No pressure applied; system remained inactive.
2. **POWER ON Condition** – Footstep pressure applied; energy generation occurred and output voltage was displayed on the LCD.

During simulation, the LCD displayed an output voltage of approximately **6.90V**, confirming successful energy conversion and system monitoring.

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IQM: arduino:avr:uno
Using board 'uno' from platform in folder: C:\Users\Prathmesh\AppData\Local\Arduino15\packages\arduino\hardware\avr\1.8.6
Using core 'arduino' from platform in folder: C:\Users\Prathmesh\AppData\Local\Arduino15\packages\arduino\hardware\avr\1.8.6

Detecting libraries used...
Using cached library dependencies for file: C:\Users\Prathmesh\AppData\Local\Arduino15\sketches\889188646808346AE565037ED0A012\sketch\peso_sensor.ino.cpp.aerged
Alternatives for LiquidCrystal.h: [LiquidCrystal.h.a.7]
resolve(LiquidCrystal.h)
I -> candidates: [LiquidCrystal.h.a.7]
Using cached library dependencies for file: C:\Users\Prathmesh\AppData\Local\Arduino15\libraries\LiquidCrystal\src\LiquidCrystal.cpp
Generating function prototypes...
Using cached sketch with function prototypes.
Compiling sketch...
Using previously compiled file: C:\Users\Prathmesh\AppData\Local\Arduino15\sketches\889188646808346AE565037ED0A012\sketch\peso_sensor.ino.cpp.o
Compiling libraries...
Compiling library "LiquidCrystal"
Using previously compiled file: C:\Users\Prathmesh\AppData\Local\Arduino15\sketches\889188646808346AE565037ED0A012\libraries\LiquidCrystal\LiquidCrystal.cpp.o
Compiling core...
Using precompiled core: C:\Users\Prathmesh\AppData\Local\Arduino15\cores\arduino\avr-uno-h0324848b8ec815065c1cc19597c7\core.a
Linking everything together...
"C:\Users\Prathmesh\AppData\Local\Arduino15\packages\arduino\tools\avr-gcc\7.3.0-atmel3.6.1-arduino7/bin/avr-gcc" -w -Os -g -fno-linker-plugin -Wl,-T,"C:\Users\Prathmesh\AppData\Local\Arduino15\packages\arduino\tools\avr-gcc\7.3.0-atmel3.6.1-arduino7/bin/avr-objcopy" -O hex -j .eeprom --set-section-flags ".eeprom=alloc,load" --no-sections .eeprom --no-sections .eeprom --no-sections .eeprom --no-sections .eeprom -o hex -R .eeprom "C:\Users\Prathmesh\AppData\Local\Arduino15\sketches\889188646808346AE565037ED0A012\sketch\peso_sensor.ino.cpp.o" "C:\Users\Prathmesh\AppData\Local\Arduino15\libraries\LiquidCrystal\LiquidCrystal.cpp.o" "C:\Users\Prathmesh\AppData\Local\Arduino15\cores\arduino\avr-uno-h0324848b8ec815065c1cc19597c7\core.a"
Sketch uses 4388 bytes (13%) of program storage space. Maximum is 32256 bytes.
Global variables use 91 bytes (4%) of dynamic memory, leaving 1957 bytes for local variables. Maximum is 2048 bytes.
  
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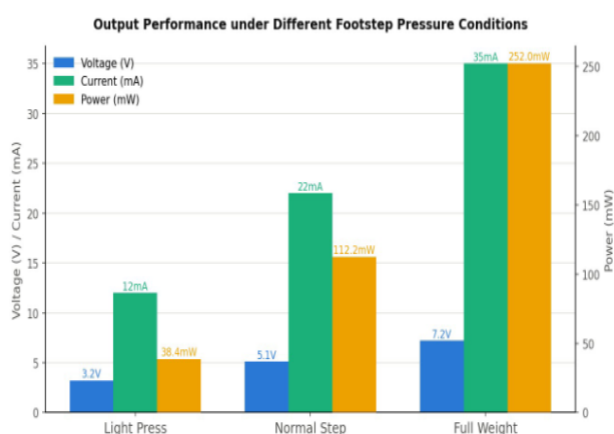


2.7 Result and Discussion

The performance of the Hybrid Piezo-Magnetic Energy Harvesting System was evaluated under three different footstep pressure conditions: light press, normal step, and full body weight. The output voltage, current, and power were measured and analyzed to evaluate the system's energy harvesting capability. Experimental observations indicate that system performance improves with increased footstep pressure, as higher mechanical force generates greater deformation in

piezoelectric discs and increased magnet movement in the electromagnetic section, resulting in improved electrical output.

Test Condition	Voltage (V)	Current (mA)	Power (mW)
Light Press	3.2	12	38.4
Normal Step	5.1	22	112.2
Full Weight	7.2	35	252



The results show that output voltage, current, and power increase proportionally with applied pressure. Under light press conditions, the system generated 3.2 V with 12 mA current and 38.4 mW power output. During normal walking conditions, output increased to 5.1 V, 22 mA current, and 112.2 mW power. Under full body weight conditions, the system achieved maximum output of 7.2 V and 35 mA current, producing 252 mW power. These results confirm that higher mechanical pressure improves energy harvesting performance, as increased force enhances both piezoelectric deformation and magnet displacement in the electromagnetic section. The hybrid configuration demonstrated significantly better output performance than standalone piezoelectric or electromagnetic harvesting methods due to the combined advantages of higher voltage generation from piezoelectric discs and improved current generation from electromagnetic harvesting.

System	Voltage (V)	Current (mA)	Power (mW)
Piezoelectric Only	4.2	15	63.0
Electromagnetic Only	2.8	18	50.4
Hybrid System	7.2	35	252.0

From the comparison table, it is observed that the hybrid system provides significantly higher power output compared to individual harvesting techniques. This proves that integrating piezoelectric and electromagnetic harvesting improves overall system efficiency and power generation capability. The harvested energy can be stored in a rechargeable battery and utilized for low-power applications such as LED lighting, LCD monitoring, sensor-based embedded systems, and other low-power electronic applications. For your paper, I recommend avoiding “mobile charging” unless you actually demonstrated it in hardware, because 252 mW is generally too low for practical phone charging.

3. CONCLUSIONS

The Hybrid Piezo-Magnetic Energy Harvesting System was successfully designed and implemented to convert mechanical energy generated from human footsteps into usable electrical energy. The system combines eight piezoelectric discs of 27 mm diameter and two electromagnetic coils with 100 turns each to improve overall energy harvesting efficiency. The hybrid configuration effectively combines the high-voltage output characteristics of piezoelectric harvesting with the higher current generation capability of electromagnetic harvesting. Experimental results demonstrated that the system generated 3.2 V under light press conditions, 5.1 V during normal step conditions, and 7.2 V under full body weight conditions. The maximum output current achieved was 35 mA with power output reaching 252 mW. Comparative analysis showed that the hybrid system performs significantly better than standalone piezoelectric and electromagnetic harvesting methods. The harvested energy can be stored in a rechargeable battery and utilized for low-power applications such as LED lighting, LCD monitoring, and embedded sensor systems. This system provides a cost-effective, sustainable, and environmentally friendly solution for renewable energy generation in high-footfall locations such as railway stations, shopping malls, public walkways, and smart city infrastructures. Future improvements may include increasing the number of piezoelectric discs, optimizing coil design, enhancing battery storage efficiency, and integrating IoT-based wireless monitoring for smart energy management.

ACKNOWLEDGEMENT

We express our sincere gratitude to our project guide, Prof. Himangi Ashutosh Navare, Department of Electronics and Telecommunication Engineering, Sinhgad College of Engineering, Pune, for her valuable guidance, continuous support, and encouragement throughout the development of this project. Her technical expertise, suggestions, and motivation greatly helped us in completing this work successfully. We also thank the Head of Department and all faculty members of the Electronics and Telecommunication Engineering Department for providing the necessary facilities and support. Finally, we express our heartfelt thanks to our family and friends for their constant encouragement and support throughout the project.

REFERENCES

- [1] S. Priya and D. J. Inman, *Energy Harvesting Technologies*, Springer, 2009.
- [2] S. Roundy, P. K. Wright, and J. Rabaey, *Energy Scavenging for Wireless Sensor Networks*, Springer, 2004.
- [3] A. Khaligh and O. C. Onar, *Energy Harvesting: Solar, Wind, and Ocean Energy Conversion Systems*, CRC Press, 2010.
- [4] J. A. Paradiso and T. Starner, "Energy Scavenging for Mobile and Wireless Electronics," *IEEE Pervasive Computing*, vol. 4, no. 1, pp. 18–27, 2005.
- [5] M. Ferrari, V. Ferrari, D. Marioli, and A. Taroni, "Improved Energy Harvesting from Piezoelectric Devices," *Sensors and Actuators A: Physical*, vol. 162, no. 2, pp. 425–431, 2010.
- [6] S. Chalasani and J. M. Conrad, "A Survey of Energy Harvesting Sources for Embedded Systems," *IEEE SoutheastCon*, 2008.
- [7] P. D. Mitcheson, E. M. Yeatman, G. K. Rao, A. S. Holmes, and T. C. Green, "Energy Harvesting from Human and Machine Motion for Wireless Electronic Devices," *Proceedings of the IEEE*, vol. 96, no. 9, pp. 1457–1486, 2008.
- [8] Faraday, M., *Experimental Researches in Electricity*, Philosophical Transactions of the Royal Society, 1831.
- [9] Y. Gao, X. Wang, and Z. Liu, "Hybrid Piezoelectric-Electromagnetic Energy Harvesting System for Low-Power Applications," *IEEE Access*, vol. 8, pp. 145632–145641, 2020.
- [10] H. Yang, J. Park, and S. Kim, "Footstep Energy Harvesting Using Hybrid Piezoelectric and Electromagnetic Mechanisms," *Sensors*, vol. 21, no. 9, pp. 3150–3162, 2021.
- [11] R. Chandra, P. Sharma, and M. Verma, "Design and Analysis of Hybrid Energy Harvesting Floor Tiles for Smart City Applications," *International Journal of Energy Research*, vol. 46, no. 4, pp. 5120–5135, 2022.
- [12] M. Safaei, A. Ahmed, and T. Rahman, "Efficient Footstep Energy Harvesting for Sustainable Smart Infrastructure," *Renewable Energy*, vol. 197, pp. 1184–1195, 2023.
- [13] S. Patel and R. Kumar, "Recent Advances in Piezoelectric Energy Harvesting Systems: A Review," *Energy Reports*, vol. 10, pp. 420–438, 2024.
- [14] K. Lee and D. Kim, "IoT-Based Smart Energy Monitoring for Hybrid Energy Harvesting Systems," *IEEE Internet of Things Journal*, vol. 12, no. 2, pp. 1850–1862, 2025.