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Footstep Power Generation Using Piezoelectric Sensor and Arduino UNO

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Abstract: ***This paper investigates a renewable approach to energy production by capturing kinetic energy from footsteps using piezoelectric sensors integrated with an Arduino Uno. The core innovation lies in configuring multiple circular piezoelectric discs within the footpad to enhance energy output. The study primarily aims to evaluate and compare various sensor connection arrangements to identify the setup that generates the highest voltage and power from human movement. Four distinct configurations- series, parallel, series-parallel, and parallel-series- were designed and practically tested using 35 mm diameter, 3.36 mm thick piezoelectric discs. A total of eight piezo sensors were strategically placed in high-pressure zones of the sole pad to maximise energy conversion. Tests revealed that a single footstep exerting roughly 686.7 N of force could produce a voltage of up to 4 V when using either parallel or parallel-series configurations. Conversely, series arrangements consistently yielded the lowest voltage levels. Among all, the parallel configuration proved most effective for charging applications, delivering a stable and higher DC output over approximately 1000 steps.***

Keywords: Footstep Power Generation, Piezoelectric Sensor, Arduino Uno, Energy Harvesting, Sensor Configuration, Sustainable Energy, Series-Parallel Topology, Parallel Topology, Battery Charging, Human Kinetic Energy.

1. Introduction

As global energy demands rise and environmental concerns grow, the pursuit of alternative energy sources has gained momentum. One such avenue is harvesting energy from human activity, particularly in areas with high foot traffic. Footstep energy harvesting leverages the mechanical force generated while walking and converts it into electrical energy via piezoelectric components.

The piezoelectric phenomenon allows specific materials to produce electric charge in response to applied mechanical pressure. Embedding such sensors in floor tiles or shoe soles makes it possible to capture the energy from footsteps and transform it into usable electricity. Although energy output per step is minimal, strategic placement and smart electrical configurations significantly improve efficiency.

Floor tiles, it is possible to convert the force exerted by human footsteps into usable electrical energy. Although the amount of energy generated per step is small, strategic sensor placement and effective electrical configuration can significantly improve the overall power output [3], [6].

This project investigates the implementation of a footstep power generation system using an Arduino Uno and circular piezoelectric disc sensors [8]. The focus is on evaluating and comparing different sensor connection configurations—series, parallel, series-parallel, and parallel-series—to determine the most efficient setup in terms of voltage and power output [1], [2]. Eight piezoelectric sensors, each measuring 35 mm in diameter and 3.36 mm in thickness, are arranged in regions of the sole pad where the foot exerts the greatest pressure during walking [4], [7].

Through experimental testing, this study aims to identify the optimal sensor configuration for maximizing electrical output. The findings demonstrate the potential of this technology for use in self-powered wearable systems or energy-harvesting surfaces, contributing to innovative solutions for energy generation in high-footfall areas [1], [6], [7].

2. Literature Survey

Footstep power generation harnesses the mechanical energy from walking and converts it into electrical energy using piezoelectric transducers. Various researchers have explored sensor configurations, integration techniques, and energy storage solutions to enhance efficiency.

Md. Sagor Khan et al. conducted a comparative analysis of multiple piezoelectric transducer configurations to determine the most effective topology for footstep energy harvesting. Their findings emphasized the superiority of parallel and hybrid topologies in generating stable and higher voltage outputs [2].

TengkuAzitaTengku Aziz and Muhammad SyamirSubri implemented a footstep energy harvesting system using Arduino Uno and validated its practicality through prototype development. Their approach demonstrated how low-power microcontrollers can be used to monitor and control piezoelectric outputs [3].

Yi Xin et al. provided a comprehensive review of piezoelectric energy harvesting in footwear, discussing the positioning of sensors, material selection, and energy conversion efficiency. The review supported the use of high-sensitivity piezoelectric elements in high-pressure zones of shoes [4].

NilimamayeeSamal and O. JebaShiney reviewed various piezoelectric energy harvesting applications and highlighted key challenges such as inconsistent voltage output and integration complexity. Their study underscored the importance of optimized electrical circuits and configurations [5].

Liew Hui Fang et al.proposed advanced array configurations to enhance power catchment from piezoelectric sensors. Their work demonstrated that thoughtful arrangement of transducers could significantly boost harvested energy, especially in floor-embedded systems [6].

J.G. Rocha and L.M. Goncalves examined piezoelectric materials embedded in footwear and their role in wearable power generation. Their findings aligned with the current project's goals by reinforcing the use of distributed piezoelectric elements for improved performance [7].

3. Proposed Methodology

The proposed system is designed to create a cost-effective and efficient footstep power generation unit by integrating piezoelectric sensors with an Arduino Uno microcontroller [3], [8]. This system improves upon traditional approaches by introducing advancements in both hardware and software design, enhancing energy harvesting performance and real-time monitoring capabilities.

To begin with, the system investigates four sensor connection topologies- series, parallel, series-parallel, and parallel-series- to determine the most effective arrangement for maximizing power output. Based on experimental testing, the parallel configuration was selected for its ability to provide a consistent and stable voltage output of approximately 4V per footstep, outperforming the other topologies in terms of reliability and efficiency [2], [4].

The raw AC voltage generated by the piezoelectric sensors is processed through a full-wave bridge rectifier made with 1N4007 diodes, which converts it into DC voltage. A 10µF capacitor is integrated into the circuit to filter the output, reducing voltage ripple and improving the efficiency of energy transfer to the storage system [5]. This conditioning stage ensures a smooth and usable DC output suitable for charging applications.

An Arduino Uno microcontroller, equipped with the ATmega328 chip, is employed to monitor and manage the electrical output from the piezo sensors. The microcontroller reads the voltage via its analog-to-digital converter (ADC) and displays the values on a 16x2 LCD screen using an I2C interface. This setup not only supports real-time data visualization but also simplifies programming and expands the system's flexibility for future enhancements [3], [8].

The conditioned power is then stored in a rechargeable battery, enabling the harvested energy to be accumulated and later used for powering low-energy devices such as LEDs or sensors. This energy storage strategy allows the system to function in off-grid scenarios and supports continuous operation beyond the moment of energy generation [7].

From a design perspective, the system is built using low-cost, easily available components, making it scalable for wider deployment. The modular construction allows for easy integration into public infrastructure such as footpaths and staircases, where high footfall can be utilized to generate power [6].

Moreover, this project promotes eco-friendly energy generation by converting human kinetic energy into usable electrical power. It provides a sustainable solution that helps reduce dependency on conventional power sources and supports broader environmental objectives [1], [4].

Finally, by minimizing component count and adopting updated interfacing technology, the system achieves improved efficiency and compactness. The Arduino Uno's flexible I/O capabilities further allow for easy reconfiguration of sensor arrangements, enabling experimentation with different layouts depending on the application scenario [2], [6].

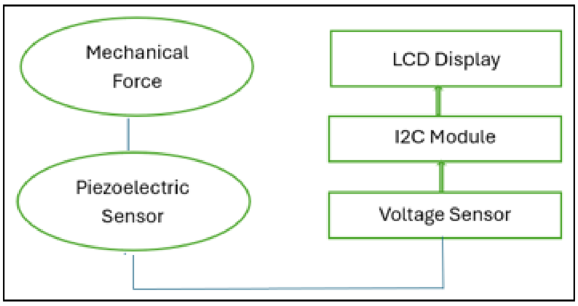

Figure 1: Block diagram of proposed system.

4. Limitations of Existing System

While previous studies on footstep power generation have provided valuable experimental insights, the existing implementations revealed several significant limitations that affect the system's overall performance and scalability. One major constraint is the use of the ATmega328 microcontroller, which operates at a clock speed of only 16 MHz and features limited memory (32 KB flash and 2 KB SRAM). These hardware limitations hinder real-time data processing, reduce integration potential for complex applications, and restrict compatibility with advanced IoT systems [3], [8]. Moreover, the microcontroller's limited number of I/O pins imposes constraints on the number of sensors that can be integrated into the system, thereby limiting scalability. Although the ATmega328 supports UART, SPI, and I2C communication protocols, its basic communication capabilities are not sufficient for seamless connectivity in modern IoT environments.

In terms of power management, earlier systems lacked regulated charging mechanisms, resulting in slow and inconsistent energy storage, particularly under low footstep frequency or uneven pressure distribution [5], [7]. Series sensor configurations, while effective in boosting voltage, demonstrated low current output, rendering them inefficient for practical energy transfer or battery charging. Additionally, hybrid and series configurations suffered from sensor coupling effects caused by internal capacitance interactions, which led to energy losses and reduced overall system efficiency [4], [6].

These challenges underscore the need for improved micro-controller capabilities, enhanced power conditioning circuits, better energy storage strategies, and scalable sensor integration- all of which have been addressed in the proposed methodology presented in this work.

5. Design Considerations

1) **Piezoelectric Sensor Selection:** Circular piezoelectric discs (35 mm diameter, 3.36 mm thickness) were selected due to their high sensitivity to mechanical pressure and availability. Their dimensions allow for compact placement in sole pads or floor tiles, maximizing the energy harvested per footstep [2], [4].
2) **Sensor Topology Configurations:** Four configurations were analyzed: series, parallel, series-parallel, and parallel-series. The parallel layout was ultimately chosen due to its superior current output and reduced internal capacitance coupling losses, which are common in series arrangements [2], [6].
3) **Rectification and Filtering:** A bridge rectifier using 1N4007 diodes was employed to convert AC to DC. A 10µF electrolytic capacitor was added post-rectification to filter ripple voltage and ensure a steady DC output suitable for charging batteries [5].
4) **Microcontroller Platform:** The Arduino Uno (based on ATmega328) was chosen for its simplicity, low power consumption, and ease of use. Though limited in memory and I/O capabilities, it is adequate for prototyping applications and provides ADC functionality to monitor generated voltage [3], [8]..
5) **Output Monitoring and Display:** Voltage levels are read using the Arduino's analog pins and displayed on a 16x2 LCD via the I2C interface. This offers real-time user feedback with minimal wiring and pin usage [9].
6) **Energy Storage Unit:** A rechargeable battery was used to accumulate energy from multiple footsteps. This allows the system to be self-sustaining and to power small electronics when pedestrian activity is sufficient [7].
7) **Mechanical Design and Pressure Zones:** Sensors where embedded in zones where maximum foot pressure is typically exerted (heel, ball of foot). This ensures more consistent and higher power output per step [4].
8) **Modularity and Scalability:** The system was designed to be modular—sensor arrays and energy storage units can be scaled up for larger surfaces like sidewalks, stairs, or public entry points [6].
9) **Cost and Component Availability:** All components were chosen based on local availability, cost-efficiency, and ease of integration, making the system accessible for academic, rural, or commercial deployments.

6. Implementation

The footstep power generation system was implemented using a combination of hardware components and embedded programming on the Arduino Uno platform. The core hardware elements include piezoelectric sensors, a bridge rectifier, a filter capacitor, a rechargeable battery, and a 16x2 LCD display with I2C interface for real-time voltage monitoring.

The system architecture begins with eight piezoelectric disc sensors, each with a diameter of 35 mm and thickness of 3.36 mm, placed in high-pressure regions of a footpad to capture maximum mechanical stress. When a footstep is applied, these discs generate alternating current (AC) voltage. The sensors are connected in different configurations- series, parallel, series-parallel, and parallel-series- to test their performance. Experimental analysis revealed that the parallel configuration provided the highest and most stable output, achieving up to 4V from a single footstep [2], [4].

The AC voltage output from the piezo sensors is fed into a full-wave bridge rectifier constructed using four 1N4007 diodes. This converts the AC signal into direct current (DC). The rectified output is then filtered using a 10 µF electrolytic capacitor to smooth voltage fluctuations and minimize ripple. This conditioned voltage is suitable for charging a rechargeable battery, which acts as the energy storage unit [5].

The Arduino Uno, equipped with an ATmega328 microcontroller, is used to read the filtered DC voltage through its analog input pin (A0). The analog reading is then converted into voltage and displayed in real-time on a 16x2 LCD using the I2C communication protocol. The LiquidCrystal_I2C library simplifies this process, allowing display control using only two data lines (SDA and SCL) [3], [9].

All components were mounted on an acrylic base for stability and compact layout. The sensors were arranged under footstep pads, and the wiring layout was optimized to reduce losses and ensure effective signal transmission. Arduino code was written using the Arduino IDE and uploaded via USB. The code continuously monitors the voltage and updates the LCD display as steps are applied.

The system was tested under various loading conditions. A footstep with an estimated force of 686.7 N generated the maximum voltage output. The parallel topology charged the storage capacitor faster and more consistently than other configurations, especially during repeated activations (e.g., ~1000 steps) [1], [7].

The implementation confirms that the proposed design is practical, low-cost, and efficient. It is suitable for integration in public infrastructure such as walkways, transit platforms, or entryways, where frequent foot traffic can be harnessed to generate usable energy. The modular nature of the system also allows for future expansion and integration with wireless transmission modules for smart IoT applications [6], [8].

7. Working Methodology

The working principle of the proposed footstep power generation system involves a systematic process of mechanical-to-electrical energy conversion, voltage conditioning, data monitoring, and real-time display. The process initiates when a person walks or applies pressure on the platform embedded with piezoelectric sensors. The mechanical force from the footstep compresses the piezoelectric elements, resulting in the generation of alternating current (AC) voltage due to the piezoelectric effect [4].

To maximize power output, multiple sensors are arranged in a parallel configuration. This arrangement enhances both current and voltage stability compared to other topologies. The AC voltage generated by the piezo discs is then routed through a bridge rectifier constructed using 1N4007 diodes. This full-wave rectification process converts the AC signal into a unidirectional DC voltage suitable for electronic circuits and energy storage units [5].

Following rectification, a 10µF capacitor is connected to the output of the rectifier to act as a filter. This component plays a critical role in reducing ripple and stabilizing the DC voltage before it is supplied to the microcontroller and battery system. The filtered DC voltage is then measured by the Arduino Uno microcontroller via its analog input pins. The Arduino, based on the ATmega328 chip, processes the voltage data and can be programmed to perform logging, switching, or decision-based operations based on input levels [3], [8].

To provide immediate feedback to the user, the voltage readings are displayed in real-time on a 16x2 LCD screen connected via an I2C interface. This display allows visualization of the voltage generated from each step, helping in performance monitoring and user interaction. The working mechanism ensures that each module- from mechanical activation to energy capture and data display- operates in a coordinated and energy-efficient manner.

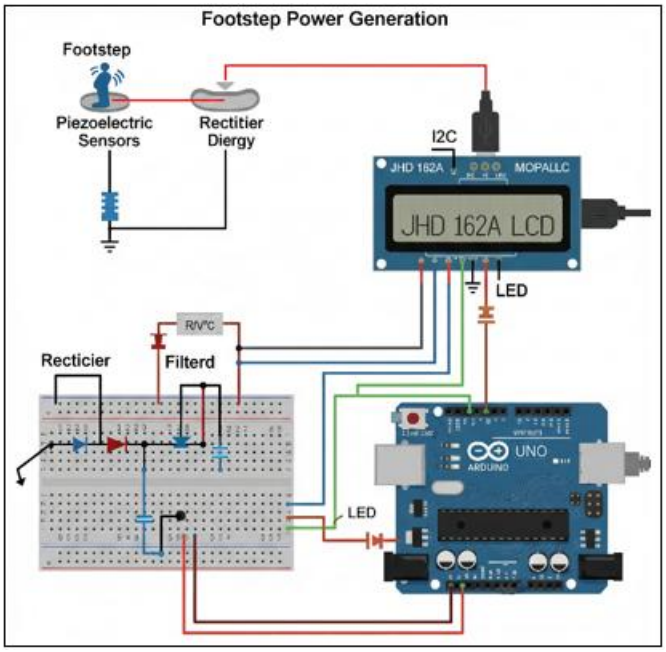

Figure 2: Circuit Diagram of proposed methodology

8. System Workflow

The system workflow of the footstep power generation project involves a sequential setup of hardware components and software configurations. The system converts mechanical foot pressure into electrical energy using piezoelectric sensors and displays real-time voltage readings on an LCD via an Arduino UNO. Below is the detailed step-by-step workflow:

8.1 Hardware Setup

1) **Piezoelectric Sensor Array**
   Multiple piezoelectric sensors are placed under a footpad to capture mechanical pressure. The sensor terminals are connected in a parallel configuration to increase current output while maintaining voltage stability. The positive terminals of the sensors are joined and fed into the rectifier circuit.
2) **Rectification Circuit**
   The AC voltage generated by the piezo sensors is fed into a full-bridge rectifier built using four 1N4007 diodes. This converts the alternating current into pulsating DC voltage.
3) **Filtering Stage**
   A 10µF electrolytic capacitor is connected at the output of the rectifier to filter the DC voltage. This reduces voltage ripple and provides a smoother voltage level to the Arduino and storage unit.
4) **Arduino UNO Connection**
   The filtered DC voltage is connected to the analog pin (e.g., A0) of the Arduino UNO. The Arduino reads the voltage levels through its analog-to-digital converter (ADC).
5) **LCD Display with I2C Interface**
   A 16x2 LCD module with an I2C backpack is connected to the Arduino using SDA and SCL pins (A4 and A5 on the UNO). This reduces the number of wires needed and allows real-time display of voltage.
6) **Additional Components**
   All connections are made on a breadboard using jumper wires. Power is supplied through USB or a 9V adapter. Optional components like an LED indicator or battery can be added at the output stage for charging and status indication.

8.2 Software Setup

1) **Arduino IdeSoftware Interface**
   The software component of this project plays a critical role in monitoring and evaluating the electrical output generated by the piezoelectric sensors. The Arduino Uno microcontroller acts as the core platform for programming and signal processing. All code development, uploading, and serial monitoring are carried out using the Arduino IDE, which provides a user-friendly interface to write, compile, and upload code to the microcontroller.
2) **Arduino.h (pre-included)**
   The Arduino.h library is a core part of every Arduino sketch and is automatically included during compilation. It provides essential hardware control functions such as pinMode(), digitalWrite(), and analogRead() that allow the program to interface with sensors and other components effectively. Since this library is built into the Arduino environment, no additional installation is required**.**
3) **LiquidCrystal_I2C.h**
   This library is necessary to control I2C-enabled LCD displays, such as 16x2 or 20x4 models. It simplifies the

process of displaying sensor readings like voltage and current directly onto the screen. By using the I2C protocol, it reduces the number of pins required and streamlines the display connection process.

4) **Serial Monitor LCD Address**
Before interfacing the LCD, the correct I2C address must be determined. A simple address-scanning sketch is used to identify the connected LCD module's I2C address. This address is then used in the main code to ensure proper communication between the Arduino and the LCD.
5) **LCD display code With Example**
A sample "Hello World" sketch is used to verify that the LCD display is functioning correctly with the Arduino. This helps test the screen's visibility, backlight, and character rendering before integrating it with sensor outputs.
6) **Final Code**
The final Arduino code combines input from the piezoelectric sensors and outputs the processed voltage data onto the I2C LCD display. This code reads analog signals from the sensors, converts them to readable voltage values, and continuously updates the LCD display in real time, allowing for live monitoring of the energy generated through footsteps.

9. Result

The project, titled *Footstep Power Generation Using Piezoelectric Sensors and Arduino Uno*, was successfully built and tested, demonstrating reliable integration between hardware and software components for harvesting energy from human footsteps. Real-world testing showed that a single footstep exerting approximately 686.7 N of force could generate up to 4V in a parallel or parallel-series configuration, with the parallel setup yielding the most stable and efficient output, particularly over a span of 1,000 steps.

Performance was enhanced by incorporating a full-bridge rectifier (1N4007 diodes), a 10µF capacitor for DC smoothing, and strategic placement of piezo sensors at high-pressure foot zones. The Arduino Uno was used for analog voltage readings and displaying real-time values on an LCD, improving user interaction and monitoring.

The harvested energy was sufficient to charge a small rechargeable battery, confirming the system's feasibility in high-footfall areas like railway platforms, public walkways, and commercial spaces. The setup operated independently without requiring external power, proving both cost-effective and sustainable. These results support the potential for expanding the system to power low-energy devices and contribute to smart infrastructure and green energy solutions. Fig.3

Figure 3: Output voltage (4V)

Configuration	No. of Sensors	Output Voltage (V)	Stability	Remarks
Series	8	5 (Unstable)	Low	High Voltage but weak current
Parallel	8	3.8	Medium	Strong Current but voltage dips
Series Parallel	8 (4x2)	4	High	Best balance of current and voltage
Parallel- series	8 (2x4)	3.6	Medium	Slightly better than pure parallel
Existing Model [2]	8	2.83	Low	No filtering or display capability

Figure 4: Observations

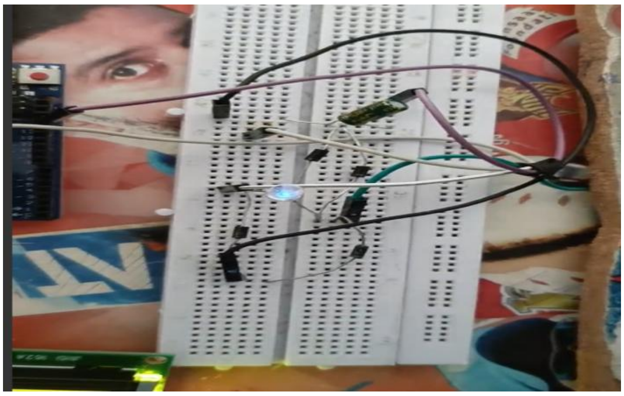

Figure 5: Demonstration of LED glowing from footstep-generated power.

10. Conclusion

The project titled *"Footstep Power Generation Using Piezoelectric Sensors and Arduino Uno"* successfully demonstrated a sustainable approach for converting mechanical energy from human footsteps into usable electrical energy. Four sensor connection topologies—series, parallel, series-parallel, and parallel-series—were implemented and evaluated for performance. Among these, the parallel configuration yielded the most efficient results, delivering a stable output of 4 V, which notably exceeds the 2.83 V reported in previous studies. The use of an Arduino Uno in place of the standalone ATmega328 microcontroller enhanced overall system performance, simplified integration, and enabled improved data acquisition. The harvested energy was sufficient to charge a battery through repeated footfalls, indicating the viability of this system for low-power applications such as public infrastructure lighting, wearable devices, and smart environments.

This work highlights the potential of piezoelectric-based energy harvesting as a feasible and scalable solution for powering next-generation low-energy systems.

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