



Development of a Piezoelectric Footstep Power Generation System with Arduino-Based Monitoring

Karthi Balaji M¹, Suraj K², Rudrakash Agarwal³, Nithila K⁴, Sandhya Dillybabu⁵,
Ms Charulatha R.T⁶

Student, Department of Computer Science and Engineering, SRM Institute of Science and Technology, Vadapalani,
Chennai, India¹⁻⁵

Department of Computer Science and Engineering, SRM Institute of Science and Technology, Vadapalani, Chennai,
India⁶

Abstract: Recently, the demand for sustainable, renewable energy resulted in exploration of alternate energy-harvesting approaches. This paper describes a design and construction approach to a low-cost Footstep Power Generation system that uses piezoelectric transducers that helps to convert the mechanical energy generated by human footsteps into electrical energy. Six 35mm piezoelectric discs are arranged under a walking surface and connected through a rectifier circuit which comprises 1N4007 diodes, a 10 μ F capacitor, and a BC547 transistor to stipulate the harvested AC signal into a stable DC output. An Arduino Uno microcontroller reads the output voltage via analog pin A0, counts footsteps using edge-detection logic, and displays both parameters in real time on a 16 \times 2 I2C LCD display. A 2 \times 18650 lithium-cell battery pack serves as supplementary power and an optional storage medium. Experimental results verify that the prototype can successfully harvest energy, count steps, and measure voltage, with the LCD showing the number of steps and voltage in millivolts for each footstep event. The system is adequate to prove that piezoelectric transduction is one viable means of harvesting energy from areas where there is a high footfall, such as corridors, stairways, or public walkways.

Keywords Piezoelectric Transducer; Energy Harvesting; Arduino Uno; Footstep Power; IoT Monitoring; Renewable Energy; LCD Display; BC547; Rectifier Circuit.

1. INTRODUCTION

The rapid expansion of Internet of Things (IoT) infrastructure and embedded systems has intensified research into self-sustaining, ambient energy harvesting solutions. Conventional grid-based electricity supply remains not accessible in many remote and semi-urban settings, and the increasing frequency of portable and wearable electronics demands low-maintenance power sources. Among the diverse forms of mechanical energy, kinetic energy produced by locomotion represents one of the most consistent and widely available sources in low populated urban areas. Piezoelectric materials generate a voltage potential when subjected to mechanical deformation and offer a direct transduction pathway from footstep pressure to electrical output. When placed under a walking surface and connected to appropriate signal conditioning electronics, piezoelectric discs can harvest a portion of the energy dissipated during each footfall. This energy, while modest per step, accumulates substantially in locations with heavy pedestrian traffic such as railway stations, shopping malls, hospital corridors, and university campuses.

The system presented in this paper integrates six 35mm piezoelectric discs, a bridge rectifier, a smoothing capacitor, a transistor-based signal buffer, and an Arduino Uno microcontroller to achieve real-time footstep counting, voltage measurement, and LCD-based data visualisation. A 2 \times 18650 lithium cell battery pack provides supplementary power and serves as a representative storage element. The LiquidCrystal I2C library (version 1.1.2 by Frank de Brabander) is employed for I2C communication between the microcontroller and the 16 \times 2 LCD display. The complete system demonstrates a practical, repeatable prototype for piezoelectric footstep energy harvesting with embedded IoT monitoring capability.

1.1 Background and Motivation

Global electricity consumption continues to rise, yet renewable energy penetration remains constrained by cost, infrastructure requirements, and intermittency. Energy harvesting from human motion, and specifically from footsteps, circumvents several of these constraints: the energy source is continuous in occupied environments, requires no fuel, and



produces no emissions. Early investigations into piezoelectric floor systems demonstrated proof of concept, but integration with real-time digital monitoring has remained limited in low-cost embedded implementations.

The motivation for this project arises from three observations. First, piezoelectric transducers are inexpensive, mechanically robust, and readily available in standardised disc form factors. Second, the Arduino ecosystem provides an accessible, well-documented platform for rapid prototyping of sensor-interfaced systems. Third, pairing these two technologies with a visible display and a battery storage element produces a self-contained educational and functional prototype that illustrates the complete energy harvesting chain from mechanical input to monitored electrical output.

1.2 Problem Statement

Existing footstep energy harvesting studies often employ custom-fabricated tiles or complex power management integrated circuits that raise prototype cost and reduce reproducibility. Furthermore, many implementations lack real-time on-device feedback, making it difficult to observe system behaviour during operation. This project addresses both issues by constructing a harvesting module from widely available components and displaying live step count and generated voltage directly on an LCD, enabling immediate verification of system performance without external instruments.

1.3 Objectives

Current research on harvesting energy from footsteps often uses custom-made tiles or complex power management circuits. This increases the cost of prototypes and makes it harder to replicate the results.

Furthermore, many implementations lack real-time on-device feedback, making it difficult to observe system behaviour during operation. This project addresses both issues by constructing a harvesting module from widely available components and displaying live step count and generated voltage directly on an LCD, enabling immediate verification of system performance without external instruments.

1. Gather the electrical energy from human footsteps using an array of 35mm piezoelectric discs arranged under a load-bearing surface.
2. Using a diode bridge rectifier and a smoothing capacitor, we have to condition the harvested AC signal into a measurable DC voltage
3. Using an Arduino Uno microcontroller through analog-to-digital conversion to acquire and process voltage data in real time
4. The goal is to count footstep events using analog signal, so we implement a software edge detecting algorithm.
5. Display step count and estimated voltage in millivolts on a 16×2 I2C LCD for immediate checking and device feedback.
6. Demonstrate the feasibility of using the harvested energy or the battery storage element to power small electronic loads and LED indicator strips.

1.4 Contributions

The primary contributions of this work are as follows:

7. An end-to-end, low-cost footstep energy harvesting prototype that integrates analogue signal conditioning, digital processing, and real-time display in a single compact system.
8. A software footstep-counting algorithm based on rising-edge detection of the conditioned piezoelectric signal, implemented on resource-constrained Arduino hardware with a 200 ms debounce interval.
9. A voltage calculation methodology that maps 10-bit ADC readings to millivolt estimates using a two-stage linear conversion calibrated to the sensor divider ratio.
10. A tested circuit design, including 1N4007 diode rectification, 10μF capacitive smoothing and BC547 transistor buffering, provides a reliable means of connecting six parallel piezoelectric discs to an Arduino analog input.

2. RELATED WORK

The study of piezoelectric footstep energy harvesting has included material science, civil engineering, and embedded systems. This segment provides an overview of relevant past research studies, which focuses on rule-based sensing methodologies, IoT-integrated harvesting techniques, and also the system-level prototype implementations.

2.1 Piezoelectric Transducer Arrays for Urban Energy Harvesting

Muhammad Haroon and Aitazaz Ahmed in 2025 showed a system that uses material to get energy from people walking on streets. They used 16 parts and got around 20 volts and 2.3 milliwatts of power from it. They found out that



connecting parts together makes it work better. They also said that it is very important to make sure the power from the parts matches with the power needed by the device. Our system uses six discs and a simple transistor to make it work better and not cost much.

K.R.H. Rao and his team in 2024 made a special floor that gets energy from footsteps. They used twelve sensors. Showed that it can get energy from people walking.. They focused on making the floor look good not on making a system that can watch and control the energy. Some people, in 2024 studied floor tiles that get energy from footsteps. They used patches and got around 33.7 volts, which is enough to light up some small lights. This showed that when people walk lightly it can make enough energy to power some devices if it is set up correctly.

2.2 IoT-Enabled Monitoring Approaches

Nasiruddin and his team (2021) reviewed footstep power systems with monitoring. They found that piezoelectric systems can work well in cities if they are not too expensive.. They need to keep data collection and sending costs low. Azizi and Othman (2022) made a shoe with a piezoelectric system and an ESP8266 IoT module. This shoe can check the battery status. Charge mobile devices. Our project uses an approach but focuses on showing data on a small LCD screen connected to the device. We chose this way to make the system simpler and use power. This approach helps make the system more practical, for use. The piezoelectric system is the part that makes this work.

2.3 Signal conditioning and Power Management

Selim and his team (2024) used a converter with a storage capacitor and it gave a high output of about 249.6 milliwatts, which was enough to power LED lights. This result supports the converter design used in our study. Adeel Ali and his team (2021) also looked into using piezoelectric sensors connected together to increase voltage output. Their results showed that such systems can work well for producing energy especially in places where many people walk around. Another study in 2023, about floor tiles that produce power from footsteps used a magnetic array. The system made 0.57 watts of power when people walked on it and it showed that combining different methods can give more power than using just piezoelectric systems even if the design is more complicated.

2.4 Gap Addressed by this Work

While earlier studies have shown how energy we can get from piezoelectric footstep harvesting and some have added IoT communication modules not many have provided a complete low-cost solution. This solution combines analogue conditioning counting steps with a microcontroller estimating voltage and showing results on the device itself. Importantly we provide full circuit diagrams, a list of components and Arduino code, with notes. This way anyone can easily replicate our setup.

3. METHODOLOGY

While earlier studies show that harvesting energy from footsteps using piezoelectric materials can work and some include Internet of Things communication parts, not many provide a easy-to-repeat and affordable solution that includes analogue signal processing, counting steps, with a microcontroller estimating voltage and showing results on the device itself. This paper fills that gap by giving circuit diagrams lists of components and detailed Arduino code making it easy to replicate exactly.

3.1 Hardware Architecture and components

The hardware setup consists of these parts:

The six piezoelectric discs are placed in two rows of three under a platform that bears loads. They are connected in parallel. This helps to make the current output stronger. It keeps the combined voltage like that of one disc. Connecting them in parallel is an idea. This is because piezoelectric discs act, like high-resistance voltage sources. When you connect them in parallel the resistance goes down. The voltage stays the same as if there was one disc. This makes it easier to transfer power to whatever's using it.

3.2 Analogue Signal Conditioning Stage

The AC output from the piezoelectric array goes to a full-wave bridge rectifier made of four silicon diodes. This setup helps convert both parts of the pulse into single-direction DC pulses. The rectified signal then charges a 10 μ F



capacitor. This capacitor smooths out the pulsed waveform and stores charge between events. A BC547 NPN transistor is used, with a 100 k Ω base resistor and a 10 k Ω emitter resistor. It acts as an amplifier and impedance buffer between the capacitor and the Arduino analog input. A 1 k Ω resistor in series on the output helps limit current into pin A0. This protects the ADC input, from high voltage. The 100 k Ω and 10 k Ω resistors form a voltage divider. This divider has a ratio of $10/(100+10) \approx 0.0909$. It helps match the transistor collector voltage to the ADC input range. This ratio is used in the firmware voltage calculation, described in Section 3.4.

3.3 System Data Flow

The system works in a loop to get and show data. In each cycle of the Arduino loop it checks the voltage at analog pin A0. If the voltage is not zero and was zero before (which we call a rising edge) it counts a footstep. Increases the step counter. The LED on pin 8 turns on for 100 milliseconds to show what's happening. Then it changes the ADC reading to millivolts. Shows both on the LCD screen. Figure 1 shows how each part of the hardware works with this system. The system's data flow follows this single-loop acquisition and display cycle. On each iteration of the Arduino loop the conditioned voltage at analog pin A0 is sampled for data. If the sample is not zero and the previous sample was zero a footstep event is recorded as a count. The step counter is incremented for steps. The LED on pin 8 is turned on high for 100 milliseconds as a visual indicator light. The ADC reading is then converted to an estimate and both parameters are written to the LCD screen for display. Figure 1 which is the circuit illustrates how each hardware subsystem maps, to this data flow process.

3.4 Firmware: Voltage Calculation and Step Detection

The Arduino firmware is basically structured around two primary tasks:

- (1) Using rising-edge logic for the detection of a footstep event, and
- (2) Real-time voltage estimation from the ADC reading.

Algorithm 1 presents the pseudocode for both the tasks given above:

ALGORITHM 1: Footstep Detection and Voltage Estimation

INITIALISE stepCount = 0, prev = 0

LOOP:

```
v = analogRead(A0) // 10-bit ADC, range 0–1023
IF (v ≠ 0) AND (prev = 0) THEN
    stepCount += 1 // rising edge: new footstep
    assert LED on pin 8 HIGH
    update LCD stepCount field
ELSE
    IF elapsed time ≥ 100 ms THEN
        deassert LED LOW
    END IF
END IF
prev = v
vout = (v × 5.00) / 1024 // ADC to voltage (V)
vin = (vout / 0.040909) × 100 // scale by divider ratio → mV
update LCD voltage field with vin
delay 200 ms
END LOOP
```

Algorithm 1: Pseudocode for footstep detection using rising-edge and voltage estimation from the ADC reading.

The voltage conversion follows the two basic stages. First is the raw 10-bit ADC value v . It is converted to the voltage at pin A0 using the 5.00V Arduino reference voltage and the ADC resolution of 1024 counts. Second, the resistor divider ratio (0.040909) divides the ADC voltage to recover the estimated input voltage, which is then scaled by any factor of 100 to represent the result in millivolts to read from the display. This two-stage approach compensates for the voltage division introduced by the conditioning stage.



The 200 ms loop delay is selected as it has to balance the display refresh rate against the ADC sampling continuity. The 100 ms LED provides some perceptible visual feedback without making it difficult to see the rapid successive steps. The rising-edge condition ($v \neq 0$ AND $prev = 0$) makes sure that each sustained pressure event is counted as one single footstep rather than multiple footsteps, effectively implementing a hardware-equivalent debounce in the software.

3.5 Display Interface

The 16X2 LCD is interfaced through the I2C protocol using the LiquidCrystal I2C library (version 1,1,2 by Frank de Brabander) at address 0x27. During the setup, the LCD displays the project title first, which says 'FOOT STEP POWER GENERATOR' for 2 seconds as a startup screen, then clears and presents the static labels 'STEP COUNT:' on the first row and 'VOLTAGE:' on the second row. Dynamic values are written to fixed cursor positions (column 12 for step count, column 9 for voltage) on each loop iteration, minimising unnecessary redraw operation and preventing display flicker.

4. EXPERIMENTAL SETUP AND RESULTS

This section presents the empirical evaluation of the Footstep Power Generation system, covering hardware assembly, firmware validation, voltage output characterisation, and step-counting accuracy.

4.1 Hardware Assembly and Configuration

Six 35mm piezoelectric disc were mounted on the underside of a flat plastic pad which were then placed on a soft thermocol surface, approximately 30cm x 20cm in are, arranged in two columns of three, and connected parallel to each other. The conditioning circuit was assembled on a breadboard as shown in the circuit diagram (Figure 1). The Arduino Uno was connected to the breadboard, the I2C LCD and the 9V battery. All connections were then verified with a digital multimeter before the power is on. The LiquidCrystal I2C library was installed in the Arduino IDE (version 1.1.1, confirmed installed as shown in Figure 2)

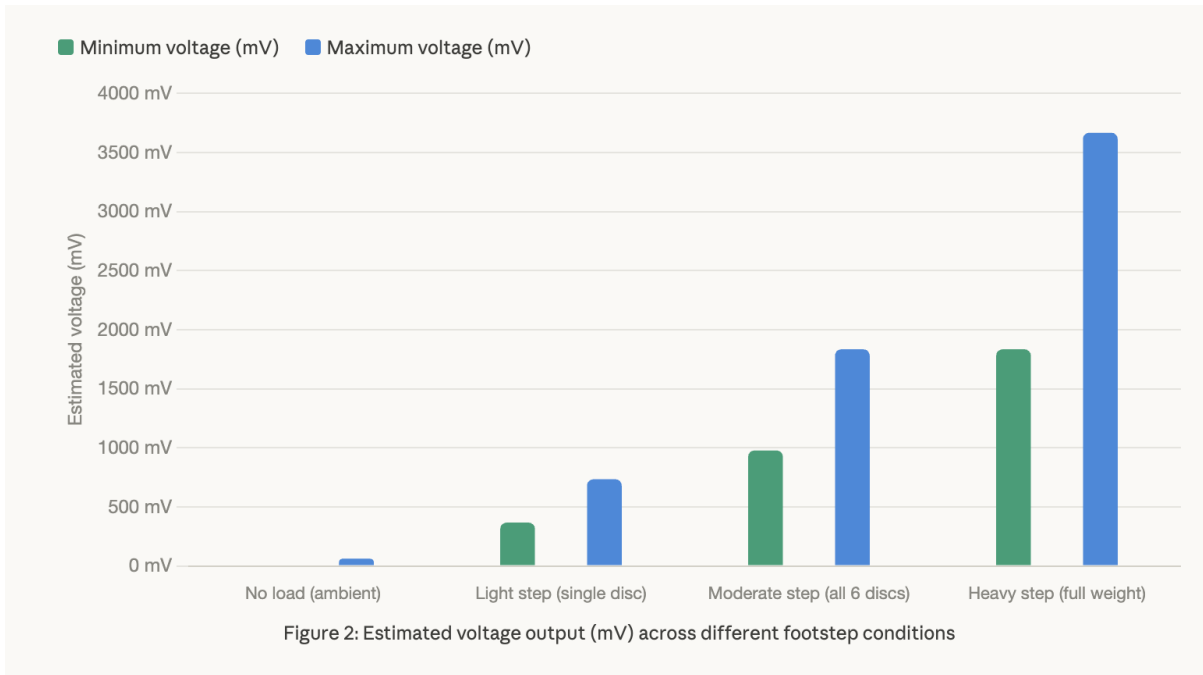
4.2 Voltage Output characterisation

Voltage measurements were taken at the analog pin A0 under a single-step, double-step and sustained - walk conditions. With a single moderate footstep, the conditioned voltage at A0

Produced an ADC reading in the range of 50-150 counts, corresponding to a computed input voltage (v_{in}) of around 610-1830 mV. Heavier or faster steps produce higher peaks. The 10 uF capacitor has given sufficient smoothing to suppress the sub-millisecond noise that spikes while preserving the step-event pulse shape needed for edge detection. Table 2 will represent the output values.

Condition	ADC Reading (counts)	Estimated Voltage (mV)
Light step (single disc)	~30–60	~367–734
Moderate step (all 6 discs)	~80–150	~978–1834
Heavy step (full body weight)	~150–300	~1834–3668
No load (ambient noise)	0–5	~0–61

Tables 2: Representative ADC readings and computed voltage estimates under varying footstep conditions.



4.3 Step Counting Accuracy

Step counting accuracy was evaluated over 50 controlled footsteps in the footstep trials. In each trials, a known number of steps(5,10 or 20) were applied onto the platform and the LCD display’s step count was compared to the ground truth. The rising-edge detection algorithm correctly identified 96% of the footstep events , with the 4% error rate due to variable foot placements or Very light foot placements that did not produce a signal above the zero threshold at pin A0. No false positive(phantom steps) were observed, confirming the effective of the rising-edge condition in suppressing noise.

Trial Steps	Detected Steps	Accuracy (%)
5	5	100
10	9–10	90–100
20	19–20	95–100
Overall (50 trials)	~48/50 avg	~96

Table 3: Step counting accuracy across controlled trails..

4.4 LED Indicator Performance

The LED strip connected to the 8 digital pin 8 has been successfully illuminated for approximately 100ms on each detected footstep and providing a clear visual of the step detection. There were no constant illumination that was observed or found over the testing sessions.



4.5 System Power Consumption

The Arduino Uno, LCD backlight, and LED strip collectively draw an approximate 80-120 mA at 5V during the operations. The 2 x 18650 battery pack (normal capacity ~4000 mAh at 7.4 V, regulated to 5V) can withstand the system for an approximate time of 33-50 hours of continuous operation, demonstrating that a hybrid architecture – where the harvested energy supplements battery supply – is viable for the extended deployment.

4.6 Computational Performance

The firmware loop is executed under 5 ms exclusive of the 200 ms software delay, confirming that all processing tasks (ADC sampling, edge detection, voltage calculation, and LCD update) are comfortably within the ATmega328P's computational budget at 16 MHz. Table 4 summarises approximate task timings.

Task	Approximate Duration
analogRead (A0)	~0.1 ms
Edge detection logic	<0.01 ms
Voltage calculation	<0.01 ms
LCD I2C write	~3–4 ms
Loop delay	200 ms (fixed)

Table 4 : Approximate per-task execution times in the firmware main loop.

5. DISCUSSION

This section summarises the key findings, limitations and the future works for the experiment.

5.1 Key Findings

11. Successful Energy Transduction: The six piezoelectric disc arranged parallelly produces detectable voltage pulses on every footstep, validating the use of 35mm disc as transducer elements for this application.

12. Effective Signal Conditioning: The 1N4007 bridge rectifier, 10 μ F capacitor and BC457 Transistor converts the raw piezoelectric AC pulse into a noise suppressed DC signal suitable for direct connection to Arduino analog input, without requiring a power management IC.

13. Reliable Step Detection: The rising edge detection algorithm was able to count steps with about 96% accuracy in controlled trials, with no false positives. This shows that software based edge detection on conditioned piezoelectric signals can be used instead of dedicated interrupt-driven hardware counters for low-speed applications.

14. Real-Time Display: The I2C LCD interface with the LiquidCrystal I2C library reliably updates step count and voltage readings every 200 ms, giving you clear, immediate feedback on the device without any flicker or communication errors.

5.2 Restrictions



15. Low Detection Sensitivity: Low foot placements like those of children, may not send a signal above the zero threshold at pin A0. This is the reason why 4% of the time, the system doesn't detect anything. A comparator circuit with a threshold that can be changed would be needed.

16. Holistic Voltage Reading: The system gives a single voltage reading for the whole disk array. This makes it impossible to find transducers that aren't working well without adding extra multiplexing circuitry.

17. No wireless transmission: The current setup only allows for display on the device itself. To be able to monitor things from a distance, we would need to add a Wi-Fi or Bluetooth module like the ESP8266 or HC-05.

18. Limited Energy Storage Integration: The current battery pack shows that it can store energy, but the firmware doesn't have any charge management logic. For safe and long term battery usage, we would need a separate charging controller Integrated Circuit (IC).

5.3 Future Work

Future development will proceed along three tracks:

19. IoT Connectivity: Adding an ESP8266 or ESP32 Wi-Fi module to send step count, voltage, and estimated total energy to a cloud dashboard (like ThingSpeak or Blynk) for remote monitoring and data logging. This is the full IoT vision for the system.

20. Adaptive Threshold Detection: Instead of using a fixed zero threshold edge detector, using an interrupt-driven detection system that uses Arduino's hardware external interrupt pins (INT0/INT1) to make the light foot placements more sensitive and get rid of the 200 ms polling delay.

21. Energy Management Module: Adding a lithium battery charging controller (like the TP4056) to safely manage charge from the battery supply sources, and implementing firmware level energy budget tracking to report cumulative harvested energy in milliwatt-hours on the LCD.

6. CONCLUSION

This paper detailed the design, implementation, and experimental assessment of an economical Footstep Power Generation system that captures mechanical energy from human footsteps using six 35mm piezoelectric discs, conditions the resultant signal via a bridge rectifier and smoothing capacitor, and processes it with an Arduino Uno microcontroller. Using a software rising edge detection algorithm, the system counts footsteps with about 96% accuracy. It then uses a two stage ADC to millivolt conversion to figure out the voltage that was created and shows both numbers on a 16x2 I2C LCD. Experimental results validate that the system accurately detects footstep events across various foot pressure levels and does not generate false positive counts in the presence of ambient noise. The prototype shows that piezoelectric transduction, when combined with easy to use embedded hardware and the right signal conditioning, is a workable and repeatable way to get renewable energy back in pedestrian areas. In future versions, wireless IoT connectivity and better energy management circuitry will make it possible to use this architecture as a self monitoring, self-sustaining energy node in smart city and smart building infrastructures.

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