Harvesting Energy from Human Motion with Piezoelectric and Triboelectric Systems

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Abstract

This research will be showing the potential to harvest energy from human motion using piezoelectric and triboelectric systems. We do many simple actions such as walking, running and there are many simple actions in the nature as well such as rainfall. These actions can generate mechanical energy that can be converted to electricity as well. Piezoelectric materials produce

electricity when mechanically a stress is exerted on it, while triboelectric devices generate charge through contact and separation of materials. Information and data from published prototypes show that piezoelectric floors can produce around 0.2 J per step (enough to light small LEDS), while triboelectric floors generate high voltage but quite a short amount of current (0.0002-0.0003 J per step). By doing calculations, it is found that fully charging a smartphone using this method would require billions of footsteps. However, to power low energy applications such as sensors, LEDS etc is considered feasible. I will highlight in this research the feasibility, limitations, and potential urban applications of these energy-harvesting systems.

Introduction

Modern societies rely heavily on electricity, which creates a need for renewable and alternative energy sources. We have already discovered many of these sources, i.e. sunlight, wind and even water. But human movements remain an untouched sustainable source of mechanical energy. Everyday actions-walking and running- generate energy that can be captured using specialized materials.

The research question that will be guiding this study is:

Can human activity be used to generate usable electricity through piezoelectric and triboelectric systems, and what are the realistic applications of such energy?

This study will focus on:

1) Comparing **piezoelectric** and **triboelectric** harvesting systems.

2) Analyzing real-world energy outputs from published prototypes.

3) Evaluating practical applications for low-power devices and urban infrastructure.

Background Theory

Piezoelectric Effect:

There are certain materials that can generate voltage when stress is applied to them mechanically such as crystals or ceramics (e.g. lead zirconate titanate, PZT). In energy harvesting, electricity is produced when foot pressure compresses or bends these materials. Piezoelectric devices most of the time output alternating voltage. It is then rectified and stored. The output though depends on the force applied, material properties, and frequency of motion.

Triboelectric Effect:

We know that when two materials make contact and separate, electrons transfer from one material to another. This results in the creation of voltage difference. Triboelectric nanogenerators (TENGs) use this phenomenon to convert mechanical motion into electricity. However, as mentioned in the abstract, TENGs normally produce high voltage but very low current. Materials commonly used in triboelectric harvesters include PTFE, PDMS, or Kapton. Its output is based on several factors such as material choice, surface area, and movement frequency.

Key Notes:

- Piezoelectric: high energy per step, moderate voltage/current, expensive, brittle.
- Triboelectric: low energy per step, high voltage, low current, cheaper, flexible.

Methodology

Note: This research is secondary research as it relies entirely on published experimental data. No physical experiments were conducted.

1.Sources of Data:

- Selim KK et al., *Energies*, 2024 – Piezoelectric floor tile energy output, voltage, current.

- Thainiramit P et al., *Materials*, 2022 – Triboelectric floor output, voltage, current, LED applications.
- Yao M et al., *Beilstein J. Nanotechnol.*, 2020 – Triboelectric floor/wearable textile demonstrations.
- Hanly S., *Mide Tech Blog*, 2017 – Piezo shoe feasibility for phone charging.
- Alotibi F & Khan M., *Appl. Sci.*, 2025 – Modeling cumulative energy in high-traffic areas.
- Wang ZL., *Faraday Discuss.*, 2014 – Principles and performance considerations of triboelectric generators.

2. Data Collection Process:

 Energy, voltage, and current values were extracted from tables and graphs.

 Experimental conditions (person weight, step frequency, surface type, materials) were noted.

 Data for piezoelectric floors, insoles, triboelectric floors, and wearable textiles were completed.

3. Data Analysis:

 Converted all energy outputs to **Joules per step**.

 Calculated **daily energy generation**:

$$\text{Total Energy} = \text{Energy per Step} \times \text{Number of Steps}$$

 Compared outputs to **device energy requirements**: LEDs (~0.1 W), smartphones (~40,000 J).

4. Comparative Analysis:

 Energy per step for piezo vs triboelectric (bar chart) was plotted.

 Voltage vs current (scatter plot) to visualize differences was plotted.

 Feasibility and limitations based on output, durability, and cost were evaluated.

5. Reproducibility:

- Students can replicate by accessing the cited sources, extracting energy data, performing calculations, and plotting graphs for analysis.

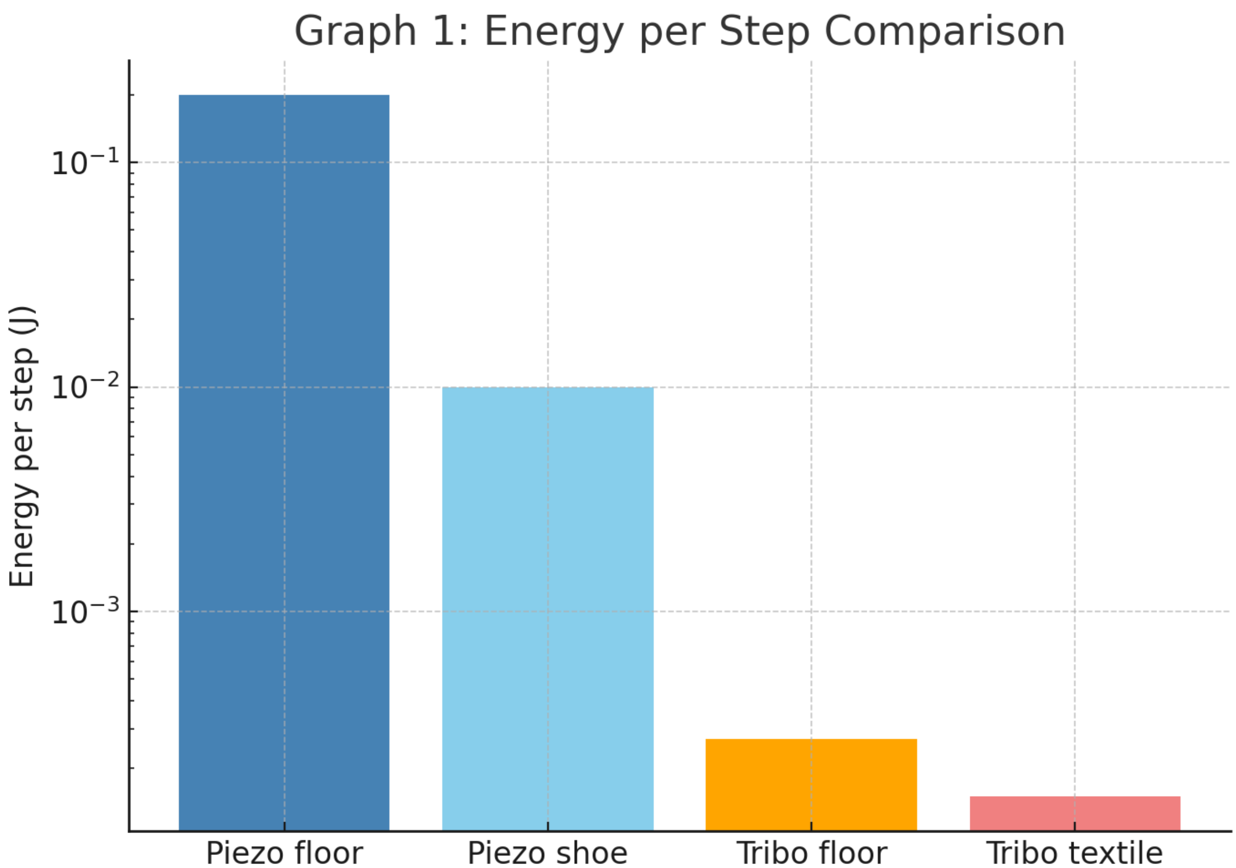
Results

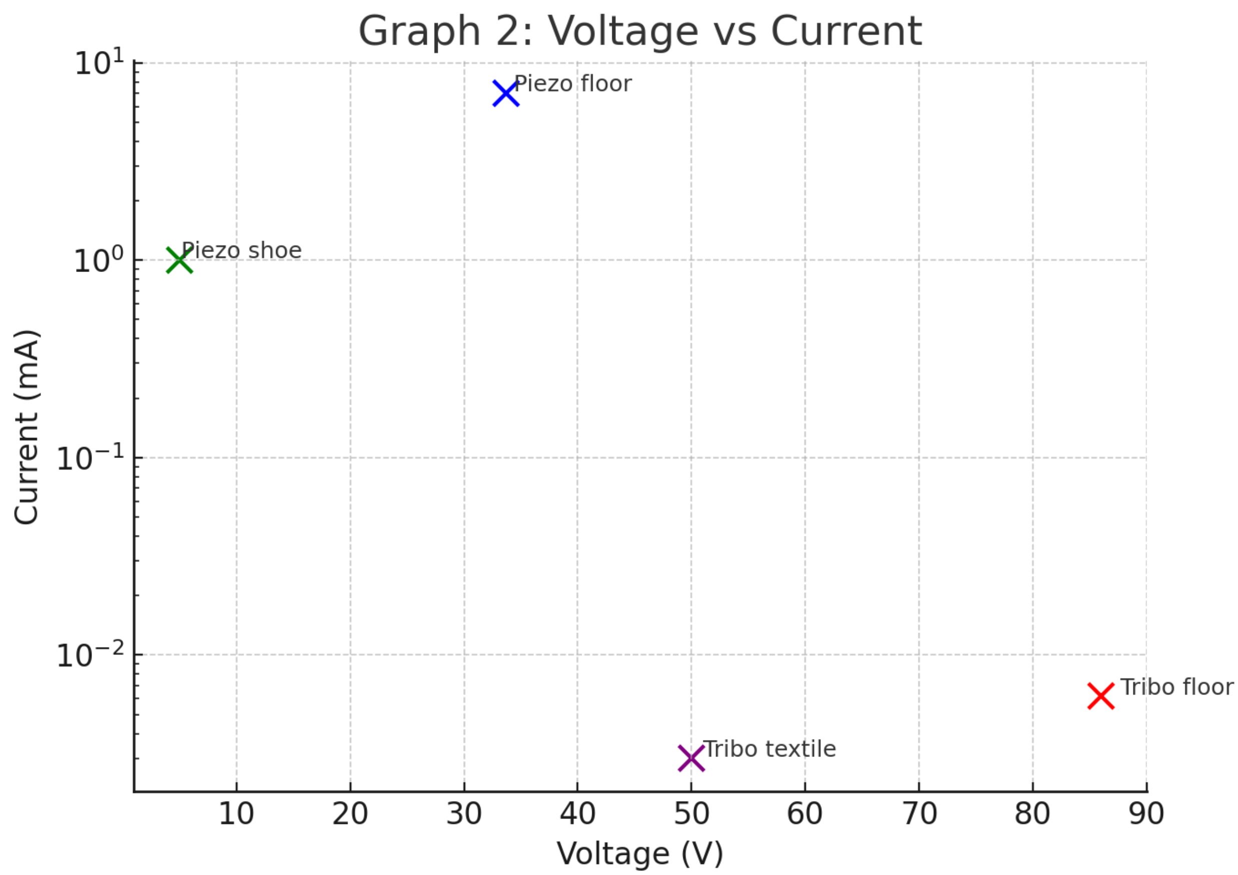
Table 1- Piezoelectric Systems

Prototype/System	**Energy per Step (J)**	**Voltage (V)**	**Current (mA)**	**Application**
Floor Tile (Pavegen)	0.2	33.7	7	LEDs, small sensors
Shoe Insoles	0.01	5	1	Wearables

Table 2- Triboelectric Systems

Prototype/System	**Energy per Step (J)**	**Voltage (V)**	**Current (µA)**	**Application**
Floor TENG (wavy electrodes)	0.00027	86	6.2	LEDs, footstep counter
Smart Textile (shoe/fabric)	0.00015	50	3	Wearables


Graph 1: Energy per Step Comparison
Energy per step (J)
10^{-1}
10^{-2}
10^{-3}
Piezo floor
Piezo shoe
Tribo floor
Tribo textile



Discussion

- **Comparison:** Piezoelectric systems produce substantially more energy per step than triboelectric systems. Triboelectric systems produce high voltage but extremely low current compared to PS.

- **Applications:**

  - Urban infrastructure: piezo/tribo floors can be placed in high-traffic areas for LEDs, sensors, or footstep counting.

  - Wearables: TENG fabrics can be used for powering health sensors or indicators.

- **Limitations:**
    - Still produces insufficient energy for smartphones or other high-power devices.
    - Piezo devices are brittle and expensive whereas tribo devices have tiny energy output per step.
    - Both require energy storage and conditioning circuits.
- **Future Prospects:**
    - Hybrid systems (Piezo + Tribo + Solar) can be manufactured that are more efficient than the current ones.
    - Advanced nanomaterials to improve efficiency and durability.

Conclusion

The fact remains true that by itself, piezoelectric harvesters can only produce 0.2 J per footstep while triboelectric devices produce around 0.0002-0.0003 J per step. Neither can charge smartphones efficiently at one go. They are only suitable for low-power applications such as LEDs, sensors, or wearable electronics. However, improvements can be brought furthermore as this new form of renewable energy is studied and experimented on more. This stands as a very solid way to replace fossil fuel energy by renewable energy in bustling streets and areas by focusing on the aspects of material choice, design, and energy management circuits to make it more efficient and practical.

References

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