Harvesting Energy from Human Motion with Piezoelectric and Triboelectric Systems

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Abstract

This research demonstrates 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 nature as well, such as rainfall. These actions can generate mechanical energy that can be converted to electricity [5]. Piezoelectric materials produce electricity when mechanical stress is exerted on it [1], while triboelectric devices generate charges through contact and separation of materials [2]. Information and data from published prototypes show that piezoelectric floors can produce around 0.2 J per step (enough to light small LEDS) [1], while triboelectric floors generate high voltage but quite a short amount of current (0.0002-0.0003 J per step) [2]. By doing calculations, it was 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 [1][2]. In this research the feasibility, limitations, and potential urban applications of these energy-harvesting systems are highlighted.

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 such as walking and running generate energy that can be captured using specialized materials.

The research questions that will be guiding this study are:

a) Can human activity be used to generate usable electricity through piezoelectric and triboelectric systems?
b) What are the realistic applications of such energy?

This study focuses 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.

Theoretical Background

Piezoelectric Effect:

There are certain materials that can generate voltage when they are subjected to mechanical stress such as piezoelectric crystals (e.g. quartz, Rochelle salt) or ceramics (e.g. lead zirconate titanate, PZT). In energy harvesting, electricity is produced when foot pressure compresses or bends these materials [1]. Piezoelectric devices most of the time output alternating voltage, which is then rectified and stored. The output though depends on the force applied, material properties, and frequency of motion. [1]

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 earlier, 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. [2]

Key Notes:
Piezoelectric: high energy per step, moderate volate/current, expensive, brittle.
Triboelectric: low energy per step, high voltage, low corrent, cheaper, flexible.

Methodology and Results

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

Piezoelectric System:

In order to compare the two energy harvesting systems from human motion, the maximum power output, power density, energy per step and optimal load (resistance) will be required for each system.

1) The maximum power output (mpo) for piezoelectric floor tile was found out to be 249.6 mW in a tile area of 0.184 meters squared [1].

2) The power density is calculated by dividing maximum power output (mpo) with the tile area. So the power density for piezoelectric tile is 0.2496 W / 0.184m^2= 1.357 Wm^{-2}.

3) The formula for calculating energy per step is

Energy per step= maximum power x Time per step

Energy per step= (0.2496 W) x 0.75
= 0.187 joules per step

[Time per step is 80 pedestrians per min
So per step= 60 secs/80 steps=0.75seconds per step [1]]

4) The system successfully powered **two LEDs in series** with a voltage of 4.8V and a current of 0.052A [1]

Using Ohm's Law: R= V/I= 4.8V/0.052A=92.3 **Ω**

Below is a table summarizing all the values gathered from the piezoelectric system:

Table 1: Values from Piezoelectric Systems

Metric	Values
Max Power Output	249.6 mW
Power Density	1.36 Wm^{-2}
Optimal Load	~92 Ω
Energy Per Step	0.187 J/step

Triboelectric System:

Just as it was done with piezoelectric system, the values for max power output, power density, optimal load and energy per step is required to be calculated as well from the triboelectric floor tile harvesting system that was done in Thailand.

1)It is explicitly mentioned in their report that 0.2 mm thickness PTFE had a peak power of 13.26 mW with the contact surface area being 0.09 m^2. [2]

2) Power Density = Maximum Power ÷ Area

= 0.01326 ÷ 0.09 = 0.147 Wm^{-2}

3) It is also explicitly mentioned that for the 0.2 mm PTFE version, the energy per footstep generated by the TEHFT (Triboelectric Energy-Harvesting Floor Tile) was 0.27 mJ/step which is 0.00027 J/step. [2]

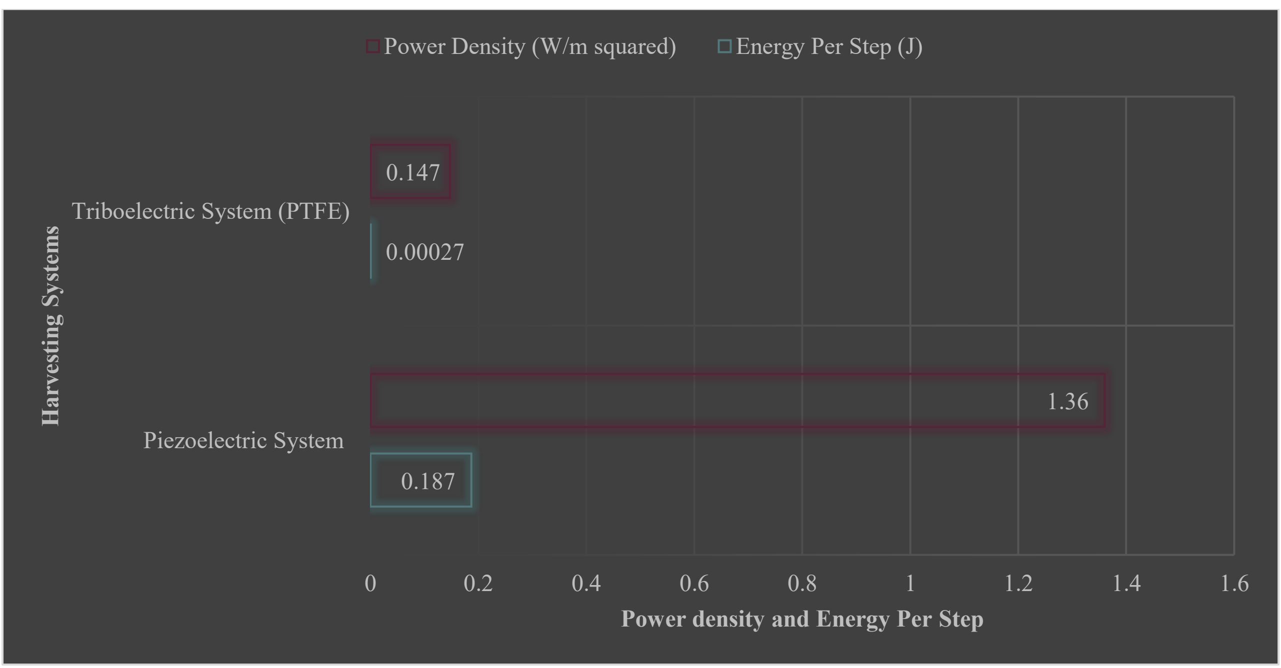
4) The optimal load is directly stated for 0.2 mm PTFE version as well which is 1.1MΩ. [2]

All the values are summarized in the table below:

Table 1: Values from Triboelectric Systems

Metric	Values
Max Power Output	13.26 mW
Power Density	0.147 Wm^{-2}
Optimal Load	1.1M Ω
Energy Per Step	0.00027 J/step

A bar chart is produced that shows the comparison of the Power density and the Energy per steps of each energy harvesting system which is shown below:



Power Density and Energy per Step
Comparison

Discussion

By looking at the tables and graph, piezoelectric systems produce significantly more energy per step and power density than triboelectric systems. The power density of piezoelectric system is 9 times higher than that of PTFE (tribolelectric system). Similarly, the energy per step of a piezoelectric system from the graph is around 693 times more than that of PTFE! The piezoelectric tile's optimal load (~92Ω) is much easier to work with for standard electronics compared to the triboelectric tile's 1.1 MΩ requirement. As a result, in terms of efficiency and power level, piezoelectric systems are superior to triboelectric system although there are some limitations to it as well which is discussed later.

Applications

Piezo floors are useful in such a way that it can be placed in high-traffic areas for lightning systems such as powering emergency lighting, pathway lighting, or status indicators in smart buildings. It also has applications in other fields such as wireless sensor networks for powering temperature sesnors or in security systems for powering CCTV cameras. On the other hand, tribo floors can be used for self-powered sensors as it generates a large voltage and thus doesn't require external power. [5] It was demonstrated that TENGs (triboelectric nanogenerators) can be used for walking energy harvesting to create a self-powered tracking system [3].

Some limitations are still present right now. Piezoelectric and triboelectric systems both produce insufficient energy for charging 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.

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. Hybrid systems (Piezo + Tribo + Solar) can be manufactured that are more efficient than the current ones in the future [4]. 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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