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Piezoelectric Energy Harvesting Tile with Complete Power Chain

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Abstract

Piezoelectric energy-harvesting tiles are a promising way to convert mechanical energy from human footsteps into usable electricity.
This work introduces the design, making, and testing of a piezoelectric tile system that uses PZT-based ceramic parts inside a strong structural material. The tile is made to produce the most strain when people walk on it, and a special circuit is used to collect and prepare the electricity generated. Testing shows that a single tile can produce voltages in the tens of volts and power in the milliwatt(mW) range when people walk on it normally. When multiple tiles are connected in different ways, the average power increases. The study shows that piezoelectric tiles can work for low-power uses like lighting paths, signs, and sensors in busy areas. However, challenges like efficiency, cost, and long-term durability need to be solved before these tiles can be used widely.

1. Introduction

The need for renewable and local energy sources is growing, which has led to interest in collecting mechanical energy from human activity, like walking on floors and sidewalks.

Piezoelectric materials can turn mechanical stress into electricity, making them a good way to use this energy without changing urban areas much. Among these ideas, piezoelectric floor tiles are especially appealing because they can be placed in places like sidewalks, train stations, and shopping malls to make electricity from regular walking.

Recent studies have examined various tile designs, such as bending elements, impact-based structures, and vibration-driven setups, all aimed at increasing the strain on the piezoelectric material to extract more energy.

However, the power produced is usually very small, and there are issues such as low efficiency and high material and electronics costs. This work solve these problems by creating a small, modular tile that works best under normal footstep forces and is connected to an efficient energy collection system.

2. Materials

2.1 Piezoelectric Sensor Array

- Material: Lead zirconate titanate (PZT) ceramic discs (27–35 mm diameter, 0.4–0.8 mm thick).
- Configuration: 4–8 discs in series-parallel arrangement to optimize voltage (1–20 V AC peak) and current (μA–mA range).
- Function: Converts footstep-induced mechanical stress into electrical potential via piezoelectric effect.

2.2 Bridge Rectifier

- Components: Four 1N4007 silicon diodes (1000 V PRV, 1 A forward current).
- Topology: Full-wave bridge configuration.
- Function: Converts AC piezo output to pulsating DC, utilizing both half-cycles for >80% efficiency

2.3 Filter Capacitor

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- Type: Electrolytic capacitor (100–2200 µF, 16–25 V rating).
- Placement: Connected across bridge rectifier output.
- Function: Stores charge during voltage peaks and discharges during troughs, reducing ripple for stable DC.

2.4 Li-ion Battery (Energy Storage)

- Type: 18650 rechargeable lithium-ion cell.
- Specifications: 3.7 V nominal, 2000 mAh capacity.
- Function: Stores harvested energy from footsteps for continuous USB/Arduino supply.

2.5 LM2596 DC-DC Buck Converter Module

- Specifications: 7–40 V input, 1.25–35 V adjustable output, 3 A max current.
- Efficiency: 75–90% switching regulation.
- Function: Converts variable rectified DC to stable 5 V for battery charging and system supply.

2.6 TP4056 Li-ion Charging Module

- Input: 5 V DC.
- Output: CC-CV charging for 3.7 V single-cell Li-ion (up to 1 A).
- Features: Overcharge/over-discharge/short-circuit protection.
- Function: Safely charges 18650 battery from 5 V regulated bus.

2.7 MT3608 Boost Converter

- Specifications: 2–24 V input, 5 V adjustable output, 2 A max current, 93% efficiency.
- Function: Steps up 3.7 V battery voltage to stable 5 V USB supply using switching regulation.

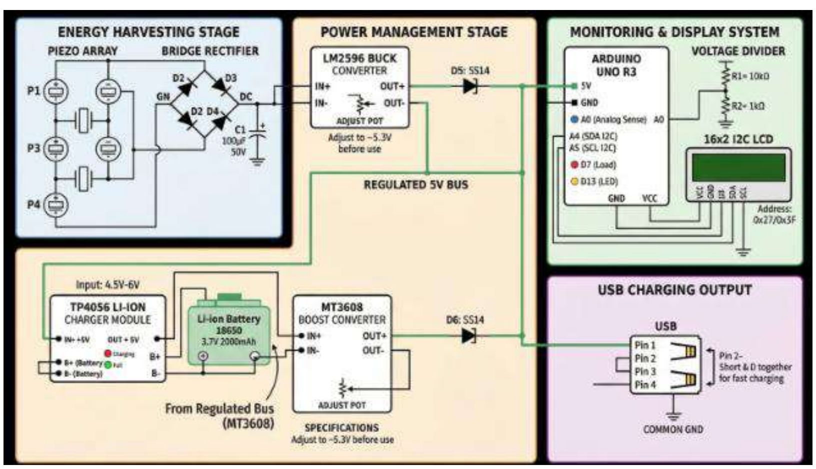

Figure 1: Energy harvesting System

2.8 USB Type-A Female Connector

- Type: Standard 5 V/2 A charging port (pin 1: +5V, pin 4: GND).
- Function: Provides compatible interface for smartphones and portable devices

2.9 Arduino Uno R3

- Microcontroller: ATmega328P, 5 V operation, 14 digital I/O, 6 analog inputs.
- Function: Monitors voltages, counts steps, controls outputs, logs data via serial

2.10 16×2 LCD Display (I2C)

- Interface: I2C (SDA/SCL lines only).
- Function: Real-time display of piezo voltage, step count, power, battery status.

3. **Methodology**

3.1 System Design

A piezoelectric floor tile prototype was developed to convert mechanical energy from footsteps into electrical energy. The system consists of energy generation (PZT array), rectification, voltage regulation, energy storage, and output delivery stages, along with an Arduino-based monitoring unit.

3.2 Piezoelectric Tile Fabrication

Multiple PZT discs (27–35 mm) were arranged in a series-parallel configuration on an acrylic base. The design supports forces of 300–800 N and stepping rates of 60–100 steps/min, producing AC voltage peaks of approximately 15–40 V.

3.3 Power Conditioning and Storage

The AC output was converted to DC using a 1N4007 bridge rectifier with a smoothing capacitor. An LM2596 buck converter regulated the voltage to 5 V, which was used by a TP4056 module to charge a 3.7 V, 2000 mAh Li-ion battery using CC–CV charging.

3.4 Output and Monitoring

An MT3608 boost converter stepped up the battery voltage to 5 V for USB output. An Arduino Uno monitored voltage via a voltage divider and displayed data on an I2C LCD. Step counting was implemented using voltage peak detection.

3.5 Experimental Procedure

The system was tested under controlled stepping conditions (light, normal, heavy) at 60–100 steps/min. Voltage, current, battery charging, and output performance were measured using an oscilloscope, multimeter, and Arduino logs. Each test was repeated ten times.

3.6 Data Analysis and Safety

Power per step, total energy, and system efficiency were calculated. Results were analyzed using mean and standard deviation, with graphical representation of performance trends. Safety measures included fuses, enclosures, and thermal monitoring, along with consideration of piezoelectric fatigue.

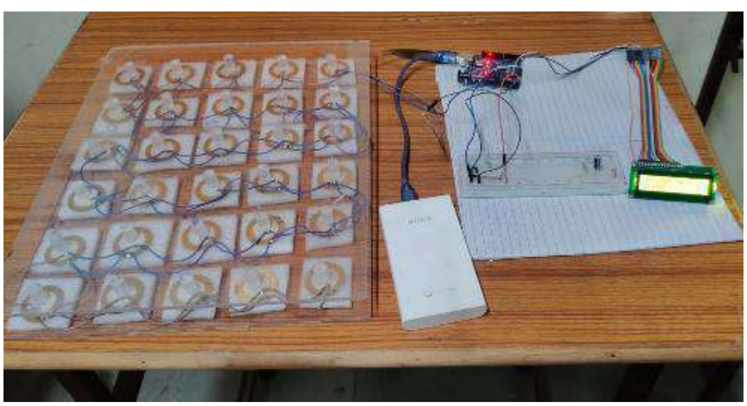

Figure 2: Piezoelectric Tile

4. **Working Principle**

4.1 Piezoelectric Tile and Transducer Array

When a user applies force on the tile, the embedded piezoelectric discs undergo mechanical deformation. This deformation produces an alternating electrical signal due to the direct piezoelectric effect. The discs are arranged in a combined series–parallel configuration to enhance both voltage and current output. Repeated footsteps generate continuous voltage pulses, forming the primary energy source for the system.

4.2 Rectification and Filtering Stage

The alternating output from the piezoelectric array is converted into direct current using a full-wave bridge rectifier. Both halves of the AC signal are utilized to produce a unidirectional output. A capacitor connected across the rectifier smoothens the waveform by reducing voltage fluctuations, providing a more stable DC input for further processing.

4.3 Voltage Regulation using Buck Converter

The rectified voltage, which varies with applied force, is regulated using an LM2596 buck converter. This converter steps down the voltage to a constant 5 V using a high-frequency switching mechanism and feedback control. The regulated output serves as a stable supply for charging and control circuits.

4.4 Battery Charging and Energy Storage

The regulated 5 V supply is fed into a TP4056 charging module to charge a 3.7 V lithium-ion battery. The module employs a constant current–constant voltage (CC–CV) charging method to ensure safe and efficient charging. Protection features prevent overcharging, deep discharge, and short circuits, enabling reliable energy storage.

4.5 Voltage Boosting for Load Supply

An MT3608 boost converter is used to step up the battery voltage to a constant 5 V output suitable for external devices. It operates using an inductor-based switching mechanism and maintains stable output through feedback control, ensuring consistent performance despite variations in battery voltage.

4.6 USB Output Interface

The boosted 5 V output is provided through a USB Type-A port for charging external devices. Proper configuration of data lines enables compatibility with standard USB-powered devices. Protective elements such as fuses or current limiters are included to safeguard against overload or short-circuit conditions

4.7 Arduino-Based Monitoring System

An Arduino Uno is integrated for real-time monitoring and basic control. Voltage levels are measured using a resistive voltage divider and analog input pins. The system estimates electrical output parameters such as voltage and energy generation, and may also track battery status and system performance.

4.8 Display and User Interface

A 16×2 I2C LCD is used to display system parameters including voltage levels, step count, and estimated power generation. The I2C interface reduces wiring complexity. Additional indicators such as LEDs provide visual feedback for system status and operation.

4.9 Overall System Operation

The system converts mechanical energy from footsteps into electrical energy, which is rectified, regulated, and stored in a battery. The stored energy is later supplied as a stable 5 V output for external use. The Arduino continuously monitors system parameters and updates the display, demonstrating an integrated approach to piezoelectric energy harvesting.

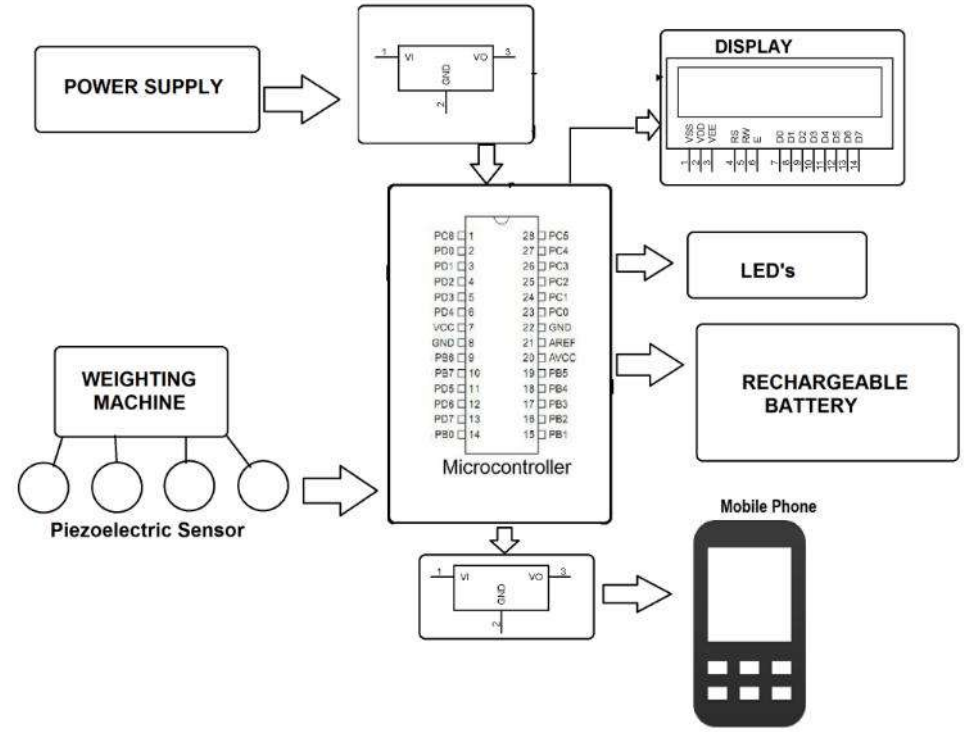

Figure 3. Overall System Operation

5. Applications

5.1 Smart Infrastructure and Public Walkways

Piezoelectric energy harvesting tiles can be deployed in high-footfall public areas such railway stations, airports, shopping malls, and pedestrian walkways. The mechanical energy generated from human footsteps can be converted into electrical energy and utilized powering low-power devices such as LED lighting, information displays, or environmental sensors. This technology contributes to sustainable urban infrastructure and energy-efficient smart cities.

5.2 Smart Transportation Hubs

Transportation hubs such as metro stations, bus terminals, and airports experience continuous pedestrian movement. Integrating piezoelectric tiles in flooring systems can enable real-time energy harvesting from passenger movement. The harvested energy can be used for powering local monitoring systems, ticketing displays, or low-power communication devices.

5.3 Smart Building Energy Management

Piezoelectric flooring systems can be integrated into intelligent building infrastructure to collect energy from occupants' movement. The generated energy can support small-scale building automation components such as occupancy sensors, automated lighting control systems, and environmental monitoring units.

5.4 Educational and Research Demonstration Platforms

Piezoelectric energy harvesting tiles provide an effective experimental platform for demonstrating energy conversion principles, sensor interfacing, and embedded system integration. Such systems are widely used in academic laboratories and research environments to study renewable energy harvesting techniques and smart sensing technologies.

5.5 Sustainable Micro-Power Generation **Systems**

Although the power generated by individual piezoelectric tiles is relatively small, large-scale deployment across public infrastructure can contribute to micro-energy generation networks. This approach supports the concept of distributed renewable energy systems for powering low-energy electronics and monitoring devices.

6. Advantages

6.1 Renewable Energy Source
Piezoelectric tiles generate electricity from human movement, which is naturally available and continuous in crowded areas.

6.2 Eco-Friendly Technology
These tiles do not produce pollution or harmful emissions, making them environmentally safe and sustainable

6.3 Utilization of Wasted Energy
Mechanical energy from footsteps is usually wasted, but these tiles convert it into useful electrical energy.

6.4 Easy Installation
These tiles can be installed in existing infrastructure such as malls, railway stations, and footpaths, without major changes.

6.5 Suitable for High Traffic Areas
Places like airports, metro stations, and stadiums can generate significant energy due to continuous movement.

7. Conclusion

This work presents the design and implementation of a piezoelectric floor tile system capable of converting mechanical energy from human footsteps into usable electrical energy.

The developed prototype integrates multiple stages, including piezoelectric energy generation, rectification, voltage regulation, battery charging, and boosted output delivery, along with real-time monitoring using a microcontroller.

Experimental observations indicate that the system is capable of producing power in the milliwatt range under typical walking conditions (60–100 steps per minute). The harvested energy can be effectively stored in a lithium-ion battery and utilized to power low-energy applications such as sensors or small electronic devices. This demonstrates the feasibility of using human motion as a supplementary energy source, particularly in areas with high pedestrian traffic.

Although certain limitations such as piezoelectric material fatigue and conversion inefficiencies remain, the proposed modular architecture allows for further optimization and scalability. The system highlights the potential of piezoelectric energy harvesting as a sustainable solution for micro-power generation in smart infrastructure and urban environments.

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