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Power Generation Through Energy Harvesting Tiles using Rubber Flooring

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Abstract - Human motion-based energy harvesting has received considerable attention due to its renewable nature as an energy source for low power applications. This paper describes the design and implementation of an energy harvesting tile system in which energy is harvested in form of mechanical energy generated by human foot steps into electrical energy using piezoelectric sensors installed beneath rubber floorings. When pressure is applied to the tile, the piezoelectric sensors generate an alternating voltage proportional to the pressure applied. The harvested AC voltage is converted into DC voltage using a full-wave bridge rectifier and regulated using resistors for voltage stabilization and circuit protection. The processed voltage is monitored in real time by a microcontroller which recognizes footsteps using predefined voltage threshold values. The system does not use any battery or capacitor for energy storage but monitors and detects footsteps using voltage levels. The instantaneous voltage generated and the number of detected footsteps are displayed on a liquid crystal display (LCD). Experimentation with different footsteps confirms the ability of the system to detect footsteps and the variation of the output voltage with applied pressure. Although the generated power is minimal, the system successfully proves the feasibility of harvesting energy using footsteps. This design is inexpensive, easy to implement and can be used for educational purposes, intelligent flooring systems and further studies on renewable energy harvesting techniques.

Keywords - Energy harvesting, footstep power generation, piezoelectric tiles, renewable energy, rubber flooring.



Fig. 1. Energy harvesting tile prototype.

I. INTRODUCTION

There is an increase in demand for renewable energy sources and this has motivated scientists to come up with other ways through which energy can be harvested. The sources of energy that have been commonly used such as the fossil fuels are non-renewable and also pollute the environment [12]. This has led to energy harvesting from the surroundings and humans.

The global energy consumption pattern shows that there is an increase in the percentage of renewable energy within the energy generation portfolio due to technological advancements in solar and wind energy [12]. Apart from utility scale development in energy harvest, the use of ambient and kinetic energy harvesting technologies has been growing in the industry as an alternative way of powering low energy devices independently of the existing electricity network [8], [11]. Ambient and kinetic energy harvesting involves the conversion of unused energy from various sources such as vibration, heat gradient, and mechanical energy into electrical energy through the process of piezoelectric, electromagnetic, and triboelectric transduction [4], [11].

Wearing shoes when one is walking produces a lot of mechanical energy especially in areas with many people such as walkways, gyms, train stations, and educational centres. The mechanical energy produced in this case can be harnessed using piezoelectric devices. Piezoelectric devices produce electrical charges when exposed to mechanical pressure, therefore making them ideal for use in step powered generators [2], [8].

The term piezoelectric effect, discovered by Pierre and Jacques Curie in 1880, denotes the property of some crystal and ceramic materials to create an electric charge due to mechanical pressure [2], [9]. The most popular types of piezoelectric materials are PZT, PVDF and quartz that vary in their sensitivity, flexibility and price enabling one to choose the optimal material for each specific application [9], [13]. Due to simplicity of the structure, relatively high-power density and easy inclusion into miniature devices, piezoelectric conversion has become one of the most widely applied ways of energy generation due to ambient vibrations and mechanical movements [13], [15].

In this project, an energy harvesting tile design using piezoelectric sensors underneath rubber flooring will be developed. The purpose of the design is to harness energy from footstep pressure and track the electricity being produced. The project seeks to showcase the concept, practicability, and applications of footstep energy harvesting through a straightforward and affordable process.

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II. CIRCUIT DESIGN AND WORKING

General Architecture of the System. Piezo elements produce an alternating voltage under mechanical stress. Most electronic devices work on direct current, hence the alternating voltage produced is transformed to direct voltage through a full wave bridge rectifier using four diodes. The rectification technique ensures that both the positive and negative cycles of the input are utilized [7].

Resistors are installed in the circuit in order to restrict current and stabilize the voltage level, and in addition, they serve to shield sensitive electronics from voltage bursts. The voltage signal after rectification and conditioning is fed into the analogue port of the microcontroller, which periodically samples the voltage and compares it with a defined threshold level to detect whether a step occurs [6].

The bridge rectification technique is commonly used in piezoelectric energy harvesting applications because it is a simple process that involves passive components unlike other active rectification methods, which involve more complex control circuitry [7], [9]. Microcontroller-based embedded systems, especially Arduino, are increasingly gaining popularity in energy harvesting applications because they can perform all the functions mentioned above in one low-power embedded system [13].

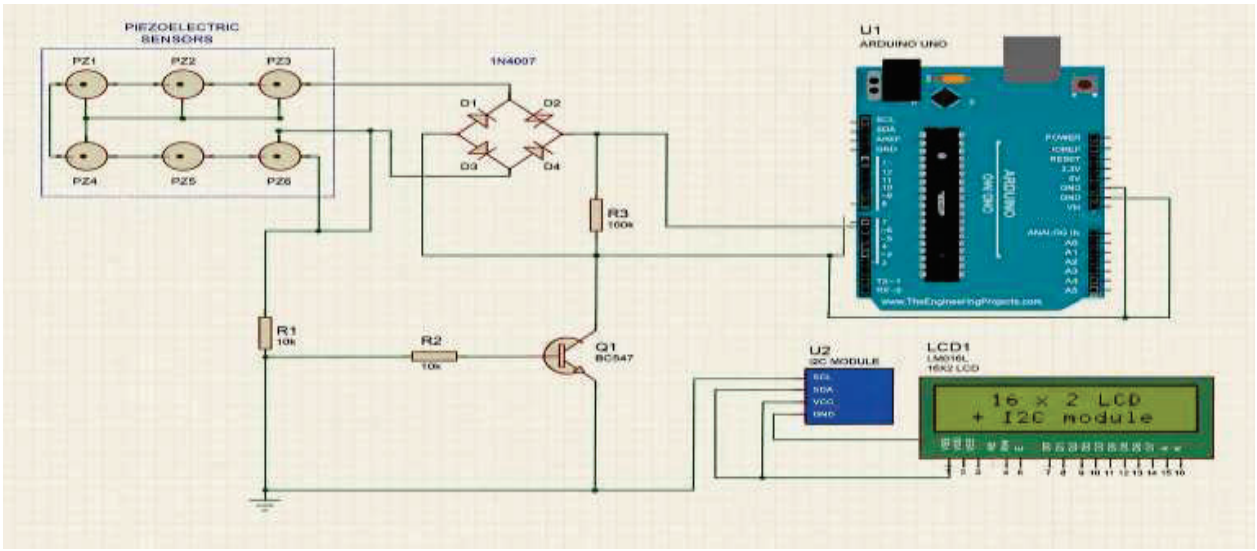


Fig. 2. Complete circuit schematic of the piezoelectric energy harvesting tile system

III. METHODOLOGY

Methodology for the working of the system starts with the application of pressure to the tile by using mechanical force. When a person stands on the tile, the force applied gets transmitted from the rubber flooring to the piezoelectric sensors that produce alternating voltage because of mechanical deformation.

AC to DC conversion of the generated voltage is done using the bridge rectifier circuit. The voltage is controlled by the microcontroller. In case the voltage goes beyond the preset threshold value, the step is detected as a footstep [6], [7]. The microcontroller increases the value of step counter accordingly. Along with that, the current value of the voltage and the total steps are displayed on the LCD screen simultaneously.

The threshold detection mechanism is a commonly adopted technique in energy-efficient sensing systems since it does not entail the computational burden involved in signal processing on a continuous basis while at the same time delivering efficient event detection regardless of the load condition [6], [7]. This technique will help identify any actual footsteps from any noise or vibration within the environment in the process of energy harvesting through footsteps.

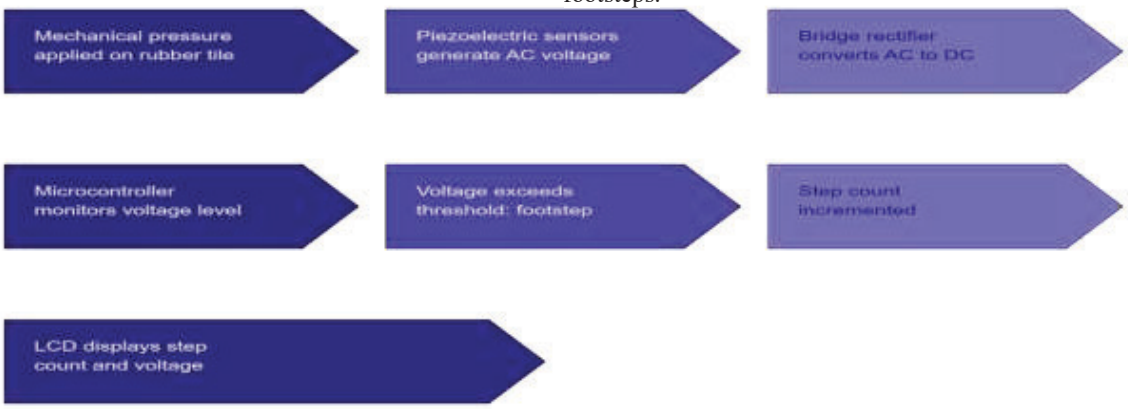


Fig. 3. Methodology flow of the energy harvesting and step-detection process.

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IV. KEY LYTICAL DIFFERENCES

Comparison with existing literature on piezoelectric floor tiles reveals a number of features that make the developed prototype different from other traditional prototypes, specifically, in terms of the material used for floorings, energy storage mechanism, integrated functions, and overall cost [1], [6], [10].

1. Floor terial and Protection Layer:

• ***Exist ng Research Floor Tiles:*** *Tend to have rigid top floor material such as wooden, ceramic, porcelain or acrylic plates sitting directly on piezoelectric ceramics (such as PZT disc). Though these are efficient at transferring the impact force but cause high brittleness and mechanical fatigue leading to degradation of sensor with continuous steps [1], [6].*

• ***P oposed Floor Tile:*** *Incorporates soft rubber floor material. Rubber functions as a protective cushion to even distribute the mechanical load, prevent micro-cracking in piezo sensors and increases life span of the sensor.*

2. nergy Storage vs. Real-Time Processing:

• ***Traditional Research Tiles****: Include solely the energy storage devices (supercapacitors, rechargeable lithium batteries, boost converter) to increase efficiency of energy harvesting of microwatts and milliwatts for use by other loads [3], [10].*

• ***Proposed Tile:*** *Functions as a direct real-time sensing and tracking system that does not require any batteries or capacitors. The absence of such elements ensures absence of energy dissipation owing to their self-discharge and charging circuits.*

3. System Fun ionality & Embedded Logic:

• ***Traditional Research Tiles:*** *Concentrate mainly on the production of pure electrical energy (V_RMS, power density per m²) and not actual software processing [5], [7].*

• ***Propose Tile:*** *Consists of a microcontroller (Arduino Uno) along with an I2C LCD display of size 16 x 2. The tile does analogue sampling of voltage and step-counting along with energy conversion at the same time.*

4. Cost nd Implementation Complexity:

- ***Traditional Research Tiles:*** *Typically depend on sophisticated mechanical force multipliers, spring gear systems, or dense arrays of PZT, resulting in extremely expensive prototyping [6], [9].*
- ***Propose Tile:*** *Considers only low-cost, readily available parts such as the 1N4007 bridge rectifier, conventional piezo disks, rubber sheet, and microcontroller, hence its economic nature.*

V. SULTS AND DISCUSSION

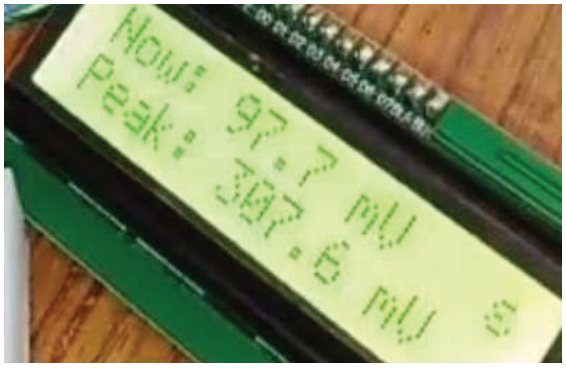
Testing of the prototype was carried out for the purpose of experimentation under varying conditions of footstep including single steps, repeated steps, and high force. The findings reveal that there is an increase in voltage with the increase in force used which means there is successful conversion of mechanical energy to electrical energy [7], [15].

The system has shown successful detection of steps and stable working even after repeated use. The capability to monitor the voltage in real time and step counting makes it possible for the system to give reliable output without the use of any power storage devices.

The results are in line with the rest of the literature on piezoelectric energy harvesting where there is an observed direct relationship between the amount of mechanical force and the open-circuit voltage produced [13], [15]. This similarity strengthens the theory behind the transduction process and justifies the usage of the inexpensive sensor configuration in the current prototype.



(A)



(B)

Fig. 4. Results on LCD Module

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VI. GRAPHICAL ANALYSIS

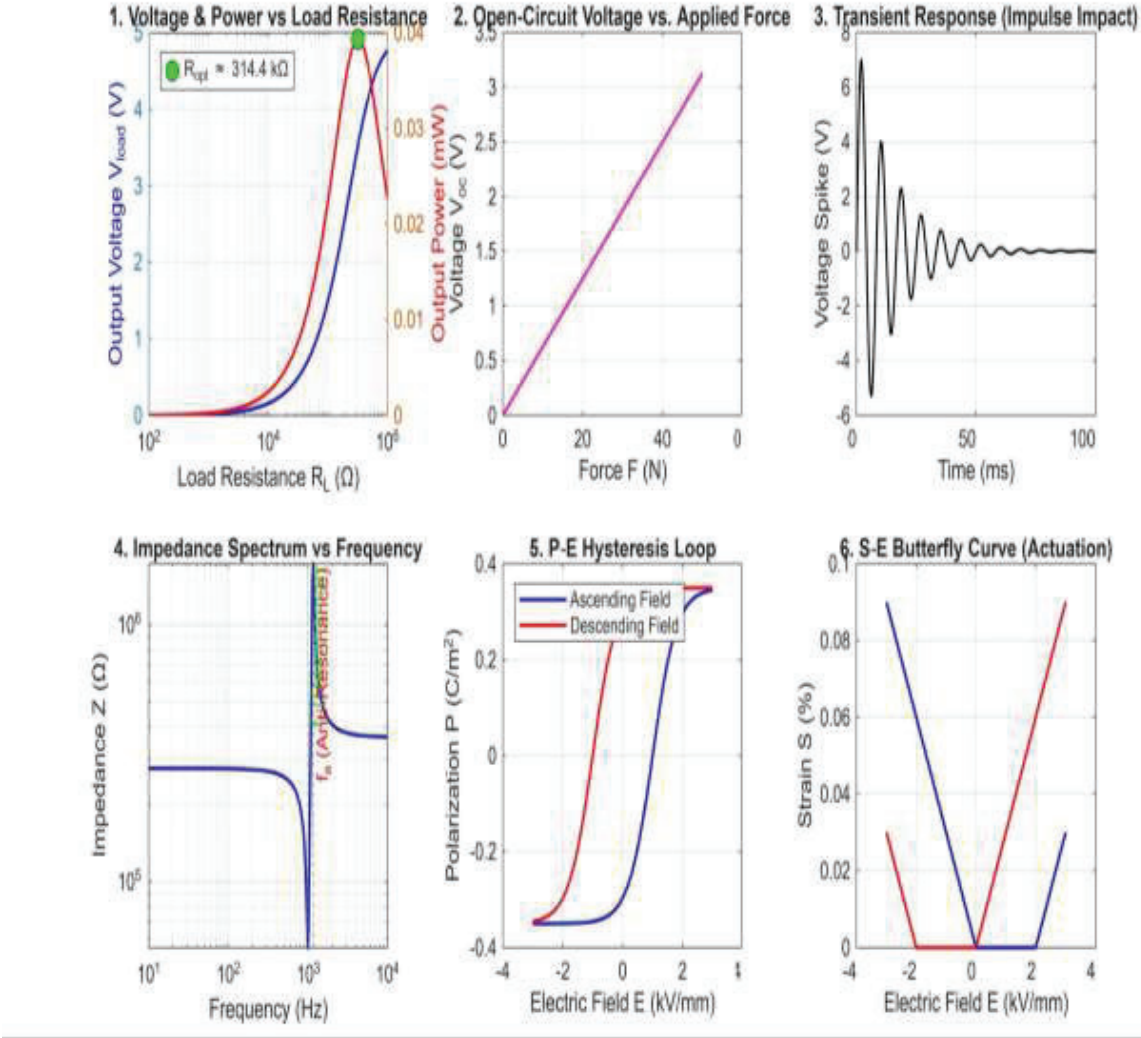


Fig. 5. Different graphs for analysis

VII. APPLICATIONS

Such a piezo tile design can be employed in various areas like intelligent pavements, gyms, dancing floors, and heavily trafficked places for energy generation [6], [11]. The proposed design may also act as an educational demo model for renewable energy systems and energy harvesting from piezoelectric effect. Moreover, the design can also be incorporated into low-power sensing applications.

Furthermore, the increasing interest in smart structures has led to a new scope for footstep power generation technology. Researchers have focused on incorporating the technology in IoT based occupancy sensing, footfall analysis in retail and transport centres, and self-powered wireless sensors which will not require battery replacement in inaccessible areas [4], [11], [14].

Besides application at the level of buildings, piezoelectric tiles based on footsteps are now becoming popular in the transportation sector, with applications in overpasses for pedestrians, subways, pedestrian walkways, and shoulder roads for vehicles. It has been found that tile transducers, which are compact and indirect touch point type, can handle thousands of loading cycles and can be used to directly power LED lights through foot and vehicle traffic, while cost-effective tile designs can operate battery-free Bluetooth Low Energy beacons for pavement monitoring [16], [17].

In addition, the technology shows potential in rehabilitation and medical applications, with the aid of instrumented flooring, where there is no need for any kind of wearable sensors to assist in gait monitoring and fall risk assessment in elderly or impaired patients [11], [14]. With the advent of disasters, and in remote locations where the power grid is not available, arrays of such smart tiles can serve as an additional source of power for emergency lighting and signs in the evacuation paths in case of grid failure, whereas in sports facilities like gymnasiums,

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stadiums, and dance halls, the same concept can be extended for performance analytics.

In educational and institutional campuses, where the application of the current prototype takes place, energy harvesting tiles located at entranceways, hallways, and stairs can provide two services concurrently, namely, the demonstration of renewable energy principles to students as well as supplying anonymous data on foot traffic for the management of campus energy systems or space utilization.

VIII. CONCLUSION AND FUTURE SCOPE

This proof-of-concept device successfully proves that energy can be generated from the mechanical energy produced by footsteps through the use of piezoelectric sensors. This device is a low cost and effective way to monitor the voltage output of the system as well as to detect the steps being taken.

Future improvements could involve the incorporation of energy storage units like batteries or super capacitors, wireless data transmission capability and scaling of the system for use in the real world [3], [4].

Footstep harvesting as a means of energy extraction represents one component of the broader research being conducted in creating self-powered and battery-less electronics in mobile, wearable, and embedded environments, where it is anticipated that their use will increase as low-power sensors and IoT devices become more ubiquitous [3], [14].

In terms of materials used, the next iteration of the technology could see the rigid PZT discs replaced by flexible or printable piezoelectric polymers, which have shown improved fatigue endurance and better ability to integrate with various flooring materials without significant reductions in voltage output [9], [18]. Additive manufacturing and sensor arrays on a tile-by-tile basis, according to comparative reviews of piezoelectric floor tile studies, appear to be an important consideration towards large-scale application of this technology [18].

With respect to the electronic aspect of the design, switching the present passive bridge-rectifier frontend to a self-powered and synchronized switching mechanism would enhance energy conversion efficiencies without adding complexity or maintenance issues associated with the inclusion of active battery management circuits, providing a compromise design between the present battery less setup and one supported by batteries [19]. Integrating the tile output to low-power communication protocols like BLE and LoRa and light analysis would facilitate the real-time delivery of step-count and voltage information to building or smart-city management dashboards.

The integration of basic classification algorithms using machine learning could help detect footsteps more reliably under varying conditions of load, walking pace, and ambient noise, as well as provide additional metrics such as the footstep pattern and density from the very voltage signal that is being collected [6], [13]. Lastly, deploying a number of interconnected tiles instead of a single prototype would help establish the power production capacity, endurance, and efficiency of the design prior to full-scale deployment [1], [10].

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