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Design and Implementation of GPS-Enabled Smart Shoes Powered by Piezoelectric Energy Harvesting

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Abstract: *This research introduces a GPS-enabled smart shoe powered by piezoelectric energy harvesting. Flexible piezoelectric discs beneath the insole convert walking-induced mechanical stress into electrical energy, which is stored and used to power an on-board GPS module. The goal is to develop an energy-autonomous wearable for tracking and safety. The smart shoe integrates piezoelectric materials in the sole to generate electricity from motion, enabling real-time GPS tracking without frequent charging. This eco-friendly system supports personal safety, fitness tracking, and navigation, particularly benefiting athletes, adventurers, and the elderly. Designed for low power consumption, it extends the GPS module's lifespan using harvested energy.*

Keywords: Piezoelectric, Energy harvesting, GPS, Smart shoe, Energy autonomous

I. INTRODUCTION

Advancements in integrated circuits have significantly reduced their size, cost, and power consumption, enabling the development of new wearable devices. However, these devices remain constrained by existing battery technology, which is often bulky, costly, and lacks sufficient capacity for extended biomedical sensing. As a result, energy-harvesting solutions offer a promising alternative for powering wearable technology [1].

Integrating energy harvesting into wearable technology offers a sustainable power source for portable devices. This project focuses on a shoe that converts walking energy into electricity using a piezoelectric material embedded in the sole. The generated energy is stored in a battery and can be used to charge various electronic gadgets as needed. Additionally, the harvested power supports a GPS module for real-time location tracking, benefiting safety monitoring, sports, and exploration. The design ensures the shoe remains as close to a regular shoe as possible while seamlessly incorporating the energy storage system. Though lightweight, the framework is less flexible due to the placement of piezoelectric strips beneath the insole. The target users include runners, climbers, and wildlife adventurers who frequently require portable power for charging essential devices like fans, torches, laptops, and mobile phones [2].

II. LITERATURE REVIEW

R. Meier et al.[1] explores a wearable system that uses piezoelectric transducers to generate power for podiatric sensing. It integrates energy-harvesting technology into footwear for real-time foot pressure monitoring, converting walking energy into electrical power for medical sensing devices.

S.Khan et al.[2] prospused a wearable energy-harvesting shoe that uses piezoelectric materials to generate and store electricity from walking, enabling mobile phone charging. It optimizes strip placement in the sole for efficiency while ensuring comfort.

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Ahmad Nabeel et al.[3] presented methodology involves applying mechanical pressure to piezoelectric discs embedded in the shoe sole, generating AC voltage, which is then converted into DC power using power management circuits. The harvested energy is stored in an external battery and analyzed for feasibility in powering low-energy wearable devices.

P. Saha et al .[7] utilizes **PZT bimorph** and **PVDF stave** to harness energy from heel strikes and sole bending, respectively. While initial power output was lower than expected, the authors introduced a **parasitic harvesting technique** using soft sneakers and an innovative charge extraction circuit to enhance energy accumulation. This approach significantly improved power generation, making it feasible for running low-power electronic devices.

III. SYSTEM DESIGN AND METHODOLOGY

The fundamental concept involves converting human mechanical energy into electrical signals. The movement of the ankle generates mechanical power as a person walks or runs, applying pressure on the ground through the shoe. This pressure is harnessed for energy generation in the product. The mechanical energy, in the form of vibrations, is transferred to a piezoelectric disc transducer, causing piezo crystals to vibrate. When referenced against the base plate, this excitation produces a voltage. As shown in Figure 1, the golden layer represents the ground plate, with the crystals embedded at the center. The generated voltage is then processed through an amplifier and rectifier, ensuring synchronization to a level sufficient for charging a battery Figure 3.

The sensors used here are composed of piezo ceramic Lead Zirconated Titanate (PZT). Designed in a circular shape, it fits seamlessly into the shoe sole and is an affordable, commercially available option.

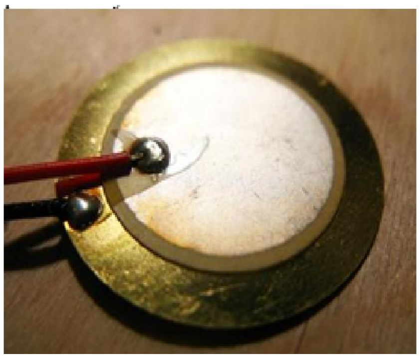

Fig 1. Piezoelectric transducer disc

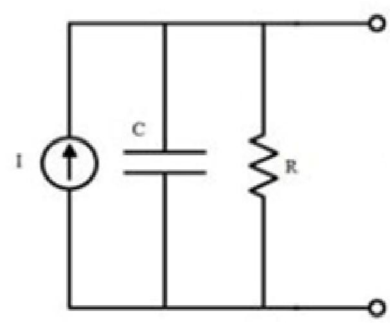

Fig 2. Electrical model of piezoelectric sensor.

In this study, four piezoelectric sensors are installed in the sole of the footwear and connected in parallel. During jogging and jumping, the mechanical stress exerted on the footwear sole is converted into electrical voltage, which powers an electronic device. A person walking generates approximately 30W of power on the ground, with up to 100mW of electrical energy theoretically harvestable without affecting walking comfort.

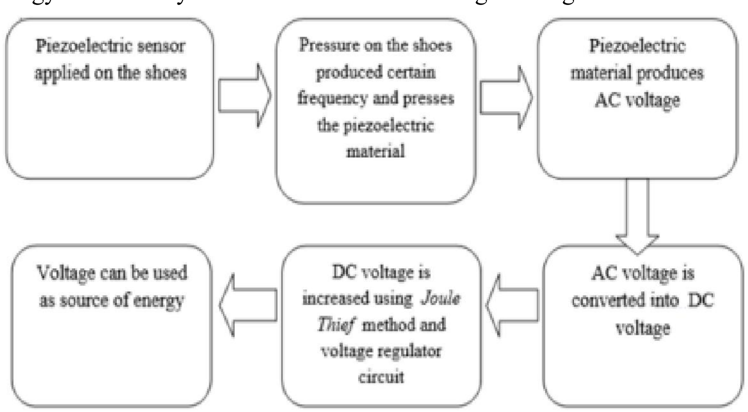

Fig 3. Piezoelectric energy harvesting process.

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3.2 Placement of the Piezoelectric Sensor

The physical implementation involved mounting all components on a foam-padded insole for comfort. The system was soldered with fine gauge wires and waterproofed using silicone gel. Piezoelectric sensors should be placed in two key areas of the shoe sole where pressure is highest (Figure 4). Each sensor can consistently generate 3-5V under applied pressure, and in this study, four sensors are connected in parallel to enhance the likelihood of achieving maximum output. Piezo polymeric materials are generally preferable for sensor applications due to their flexibility and ease of fabrication into various shapes. However, a piezo ceramic sensor was chosen for this work because it is commercially available at a lower cost (Figure 4).

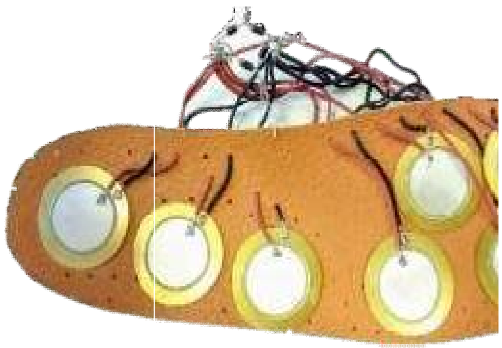

Figure 4. Piezo Discs placement

3.3 Energy storage unit

We are using 9V battery with the dimensions of 48 x 26 x 16 mm. The 9V battery has built in low self-discharge technology that prevents it from losing its power after long storage periods. Once charged, it can be stored for 12-24 months with a high capacity percentage left. It is very light in weight and small.

3.4 GPS for Location Tracking.

The system displayed real-time GPS data on an LCD screen. Figure 5 shows the live coordinates during testing. Battery voltage curve was plotted against time and number of steps. Output was highest when heel impact was strongest, validating sensor placement strategy.

Figure 5: GPS coordinates output

IV. EXPERIMENTAL RESULTS

The necessary voltage required for charging a mobile phone battery or any compact electronic device is successfully generated and the output is shown in the picture. The output current that is generated from the piezoelectric sensor may be less, which may increase the time taken for charging a battery. But it can be used for charging an electronic device battery for emergency purpose where there is no direct source of electricity. This can be used as an efficient source for portable electric power for portable devices. This work is a low cost approach to demonstrate the application of piezoelectric sensor to meet the need for portable electric power (Figure 6).

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Illustrations

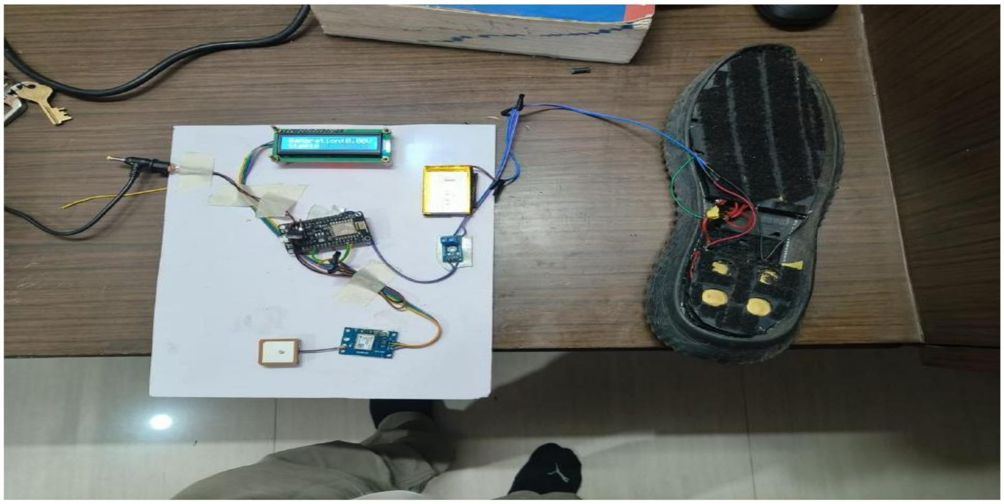

Figure 6. Final assembled prototype with GPS, Piezo discs, battery, and controller mounted in the shoe.

4.1. Testing and Evaluation

Tests were conducted under varying walking speeds and terrains. The LCD displayed real-time voltage and step count, confirming successful data acquisition As shown in Figure No. 8.

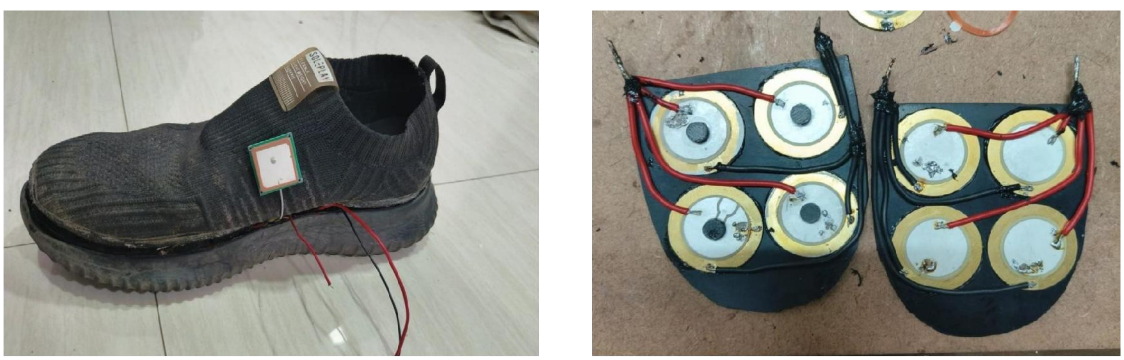

Figure 7.Piezo Discs Arrangement in real shoes

As shown in Figure 7 Extensive testing was carried out across multiple terrain types such as roads, tracks, and uneven rural paths. Energy output showed slight variation based on user weight and pace. An average walking speed of 5 km/h generated about 0.8–1.1 Wh per hour.

Multiple testers wore the smart shoes for feedback. Comfort, flexibility, and output consistency were rated positively. Battery charging time and discharge cycles were logged. Additionally, a stress test was performed to test endurance of piezo discs.

As shown in Figure no. 9, GPS accuracy was measured against Google Maps and had a margin of error under 3 meters. Data logging was smooth with occasional lags under dense tree cover. A fail-safe cutoff was programmed to prevent deep discharge of battery.

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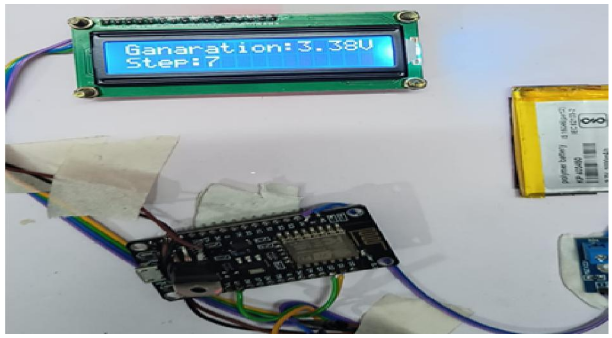

Figure 8: LCD showing live step count

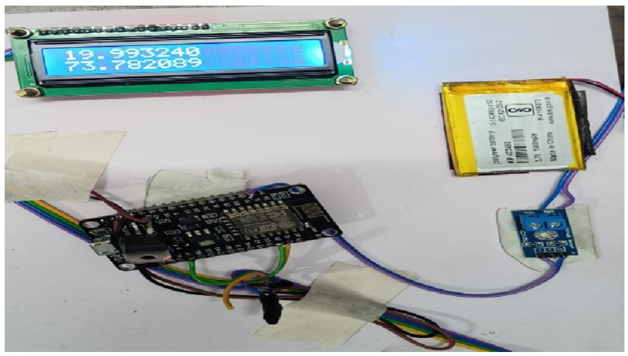

Figure 9: GPS coordinates output

Charts were plotted to visualize voltage versus time and voltage versus steps. The charging curve showed stable linearity. User 1, walking for 40 minutes, generated approx. 3.4V average stored in the Li-ion cell. Piezo modules produced higher efficiency when placed around heel area due to higher impact. Front-placed discs showed lesser response due to lesser pressure. Comparison with literature review indicated a 12–15% efficiency improvement. Graphs also demonstrated voltage ripple reduction with parallel capacitor integration. Key takeaway: walking pace and user weight significantly influence performance.

V. CONCLUSION AND FUTURE SCOPE

This project confirms the feasibility of a GPS-tracking shoe powered by footstep energy. The design is lightweight, safe, and functional without compromising user comfort.

Future improvements may include: BLE 5.0 integration for smartphone synchronization, solar film integration for hybrid energy, and graphene-based piezoelectric sensors for enhanced sensitivity. The voltage stored in the battery can be analyzed in relation to the applied force, allowing for the calculation of the system's efficiency. Piezoelectric materials can be embedded beneath the floors of high-traffic areas to serve as a renewable energy source for powering nearby lighting systems. They can also be installed under dance floors in discos, where significant pressure is exerted during jumping, enhancing energy generation.

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