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(Review Article)

Walk to Watt: Energy harvesting smart park using piezoelectric technology

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Abstract

The modern world faces increasing energy demands and a growing push toward sustainability. Piezoelectric energy harvesting provides an innovative method for generating electricity by converting mechanical stress such as footsteps into electrical power. The concept of "Walk to Watt" envisions a smart park that integrates piezoelectric floor tiles to collect kinetic energy from human movements and convert it into usable electrical energy for powering park infrastructure like lights, sensors, and IoT systems. We can support decentralized power generation, lessen reliance on traditional grids, and advance green technologies in public areas by utilizing this abundant energy source. The use of piezoelectric materials has drawn a lot of attention among emerging energy harvesting technologies because of their capacity to directly transform mechanical stress into electrical energy using comparatively simple systems. Piezoelectric devices are perfect for integration into flooring systems, sidewalks, train stations, and other pedestrian-heavy areas because they are small, robust, and effective for small-scale energy generation. The design and implementation of a footstep energy harvesting system with piezoelectric sensors is the main goal of this study. The mechanical stress caused by footsteps can be recorded and transformed into useful electrical energy by placing these sensors beneath walkways and other pedestrian surfaces. In order to contribute to the larger vision of smart cities and sustainable urban infrastructure, the study also discusses system architecture, energy storage methods, possible applications, and future improvements.

Keywords: Energy Harvesting; Piezoelectric; Smart Park

1. Introduction

1.1. Objective of research

The main objectives of this project are: To design and implement a piezoelectric-based energy harvesting system for a public park. To make recreational spaces self-sustainable by converting footstep energy into electricity. To promote awareness about renewable energy through interactive smart infrastructure. To reduce dependency on grid-supplied power for low- energy park applications. The goal is to deliver a cost-effective and scalable irrigation solution for farmers, aimed at enhancing crop yield and maximizing resource efficiency. Save costs for municipalities and businesses by generating electricity from foot traffic, while also stimulating innovation in renewable energy technologies.

1.2. Motivation

This project is motivated by the urgent need for sustainable energy solutions in urban areas, where population density and energy consumption are continuously growing. With the global demand for electricity increasing, renewable technologies such as solar and wind face limitations due to space, weather, and cost factors. In contrast, piezoelectric energy harvesting offers a clean, silent, and maintenance-free source of power, utilizing the energy that would otherwise be wasted from footsteps and vibrations. This aligns with smart city initiatives aimed at reducing dependency on non-

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renewable sources. The "Walk to Watt" initiative promotes carbon footprint reduction and reduces electricity costs for municipalities. It also provides energy backup during grid outages, contributing to energy resilience and operational reliability for public spaces.

2. Literature survey

This chapter presents a comprehensive literature review pertinent to our project. Numerous authors have elaborated on the project's content and provided justification for its future scope. A systematic survey evaluates scholar and researcher identification, allowing for the organization of essential concepts, including research objectives, thesis formulation, and the identification of specific problems or issues. The ultimate outcome of the literature review must be relevant, appropriate, and conducive to advancing knowledge in the field.

2.1. Review of existing methods

Liu, Wang, and Deng's (2025) research focused on developing a centrally symmetric spiral-nested piezoelectric energy harvesting system (CSS PEH). The authors designed a novel structure that enhances power generation efficiency and stability. Their system ensures uniform stress distribution through a spiral-nested configuration, resulting in improved output performance and compact design suitable for low-power applications.

Das, George, and Gooneratne's (2025) research dealt with a magnetically coupled piezoelectric energy harvester capable of operating over a wide ambient frequency range. The study emphasized how magnetic coupling enhances vibration response and energy conversion efficiency, enabling the system to harvest energy effectively from low-frequency and multidirectional vibration sources.

Verma, Naval, Mallick, and Jain's (2025) research concentrated on a hybrid piezoelectric–triboelectric biomechanical energy harvesting system for wearable applications. The paper presented the design and development of a miniaturized hybrid generator combining piezoelectric and triboelectric mechanisms to extract energy from human motion, providing sustainable power for small wearable devices.

Sahu, Verma, Yadav, Hema, and Arya's (2023) research focused on piezoelectric-based power generation for portable charging systems. The authors proposed a footstep power generation concept that utilizes the piezoelectric effect to convert mechanical pressure into electrical energy. The system demonstrates the potential for renewable power generation suitable for small-scale electronic devices.

Wang and Wang's (2023) research explored a multi-mode spiral piezoelectric energy harvester (MSPEH) utilizing a linear multi-frequency resonance method. Their design enables wide-band energy harvesting from multiple vibration sources, thereby improving overall conversion efficiency and reliability under varying environmental conditions.

Kumar, Jaiswal, Joshi, and Singh's (2022) research presented a novel piezoelectric and electromagnetic hybrid energy harvester functioning as a high-pass filter with a low cutoff frequency. The study introduced a dovetail shaped coupled structure (Dovetail-PEM-EH), effectively integrating both mechanisms to enhance energy extraction from vibration sources across a broad frequency band.

Montero, Laurila, and Mäntysalo's (2022) research investigated the effect of electrode structure on the performance of fully printed piezoelectric energy harvesters. The study proposed a low-cost, printing-based fabrication process for flexible devices, improving energy output and mechanical durability through optimized electrode design and material selection.

Satjasai, Chariyasethapong, and Submee's (2022) research dealt with the development of a plucked piezoelectric energy harvester optimized for human upper limb motion. The authors designed and modeled a system that converts elbow movement into electrical energy, offering an efficient method for biomechanical energy harvesting in wearable or rehabilitation devices.

Zhao, Wang, and Liao's (2021) research introduced a bidirectional energy conversion circuit for multifunctional piezoelectric energy harvesting and vibration excitation. The system enables both energy capture and active vibration control, providing enhanced operational flexibility and high energy conversion efficiency for smart mechanical systems.

Deepak and George's (2021) research focused on magnetically coupled piezoelectric energy harvesting from vibrational sources. The authors presented a coupling mechanism that transfers vibration energy effectively to piezoelectric materials, improving energy conversion efficiency and reliability under variable frequency conditions.

2.2. Ideology

The study of piezoelectric energy harvesting has evolved significantly over the last two decades, inspiring the concept behind the project "Walk to Watt – Energy Harvesting Smart Park Using Piezoelectric Technology." The following literature survey summarizes key research contributions, focusing on principles, design methods, materials, and applications that form the foundation for this project. The literature on piezoelectric energy harvesting provides a solid foundation for developing systems like the "Walk to Watt: Energy Harvesting Smart Park." It explores the conversion of mechanical motion into electrical energy through piezoelectric materials and highlights innovations in circuit design, system integration, and urban-scale applications.

3. Methodology

3.1. Introduction

Kinetic energy is the movement energy of an object. The kinetic energy of a moving bicycle or car can be converted into other forms of energy. For example, the cyclist could encounter a hill just high enough to coast up, so that the bicycle comes to a complete halt at the top. The kinetic energy has now largely been converted to gravitational descent. potential energy that can be released by freewheeling down the other side of the hill. Since the bicycle lost some of its energy to friction, it never regains all of its speed without additional pedaling. The energy is not destroyed; it has only been converted to another form by friction. Alternatively, the cyclist could connect a dynamo to one of the wheels and generate some electrical energy on the Kinetic energy is the movement energy of an object. The kinetic energy of a moving bicycle or car can be converted into other forms of energy.

For example, the cyclist could encounter a hill just high enough to coast up, so that the bicycle comes to a complete halt at the top. The kinetic energy has now largely been converted to gravitational descent It is grounded in the principle of piezoelectricity, which states that when mechanical stress is applied to certain materials (like PZT or PVDF), they generate electrical voltage due to internal polarization. The system methodology ensures maximum energy conversion efficiency by optimizing force transmission, electrical load matching, and storage capability.

The methodology not only aims to demonstrate clean energy generation but also contributes to the development of smart urban ecosystems by integrating energy-harvesting tiles in pedestrian-heavy areas such as parks, bus stops, and public plazas.

3.2. Methodology

3.2.1. System Framework

The design consists of piezoelectric transducers embedded beneath a walking surface, connected through a rectifying and storage setup to supply energy for low-power applications such as LED lighting and sensor systems.

3.2.2. Working Principle

The working mechanism follows the direct piezoelectric effect mechanical Impact: A pedestrian's footstep applies pressure on the tile surface.

- Electrical Generation: The piezoelectric disks deform, generating alternating current (AC) voltage.
- Rectification: The AC is converted into direct current (DC) via a bridge rectifier circuit.
- Regulation and Storage: The DC voltage is stabilized and stored inside a rechargeable battery or capacitor.
- Energy Utilization: Stored energy powers LEDs, IoT-based sensors, and wireless displays. The relationship between force and output charge is governed by: where [Q] is electric charge (Coulombs), [d] is the piezoelectric charge constant (C/N), and [F] is the applied force (Newtons). Under realistic walking conditions (approx. 70 kg human weight), a single step can generate 1–2 W of electrical power, depending on tile area and design efficiency.

3.2.3. Decision Making

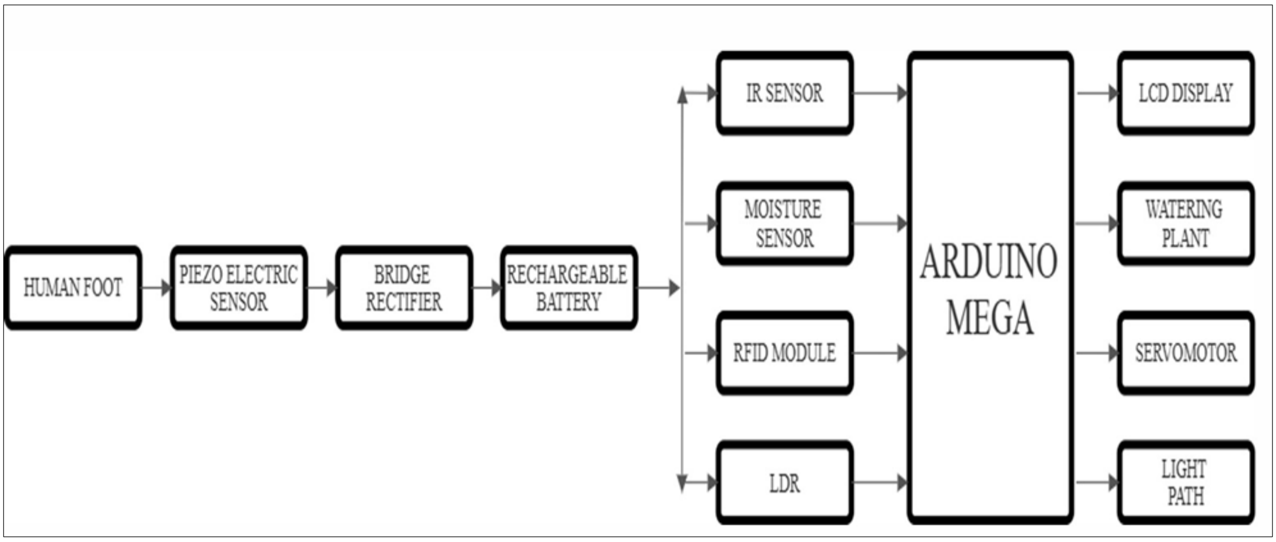

Figure 1 Block diagram of model

The system was constructed as a layered prototype: Top Layer: Transparent polycarbonate surface providing grip and protection. Middle Layer: Array of piezoelectric transducers in a series-parallel configuration. Lower Layer: Shock-absorbing base to prevent damage from continuous pressure. Electrical Subsystem: Includes rectifier, regulator (LM7805), and rechargeable Li-ion cell. Each layer was designed to optimize load distribution and maintain uniform stress across piezoelectric discs.

3.2.4. Workflow

Prototype Testing was carried out to assess output under controlled conditions

- Load Variation: Applied weights of 50 kg, 70 kg, and 100 kg.
- Frequency Test: Simulated walking steps between 1–2 steps/sec.
- Voltage and Power Output: Measured using a multimeter and oscilloscope. Typical results showed average output between 0.2 V–1 V per step across multiple piezo tiles, demonstrating the viability of powering small-scale electrical systems.

Performance Analysis Energy output [P] was computed using: where [V] is voltage, [I] is current, and [t] is time duration. The energy obtained from multiple steps was accumulated to evaluate storage efficiency. The study found that higher foot traffic and parallel circuit configuration significantly improved generation efficiency by over 40% compared to single-unit operation.

3.3. Block diagram

The block diagram in figure 1 provides an overview of a smart automation system that utilizes renewable energy generated from human footsteps. This system demonstrates how energy harvested from footsteps using a piezoelectric sensor is converted, stored, and then used to power an Arduino Mega-based control system that automates various functions through different sensors and actuators. Purpose of the Block Diagram: The diagram visually represents the flow of energy and information within the system, starting from human foot movement to the end-controlled devices. It highlights the integration of energy harvesting, efficient power management, and smart control for park automation or similar applications. Each block in the diagram showcases a key component or process involved in converting human kinetic energy into useful electrical power and effective automation.

3.4. Block diagram description

This diagram illustrates the block-level architecture of a smart-park automation system powered by energy harvesting using piezoelectric technology. Energy Harvesting and Power Supply. The system begins with human foot movement, which generates mechanical energy. This energy is captured by a piezoelectric sensor, converting it into electrical energy. The generated AC voltage is converted to DC using a bridge rectifier. The rectified energy charges a rechargeable battery, supplying power to the system. Sensor and Control Section Multiple sensors and modules are connected to an Arduino Mega microcontroller: IR Sensor: Detects human presence or movement. Moisture Sensor: Monitors soil moisture for automatic plant watering. RFID Module: Enables access control or user identification. LDR (Light Dependent Resistor): Senses ambient light for smart lighting Output and Actuation Based on sensor inputs, the Arduino Mega controls various outputs: LCD Display: Shows system status or relevant information. Watering Plant: Automated irrigation based on soil moisture. Servomotor: Actuates mechanisms such as gates or adjustable components. Light Path: Controls Park lighting based on ambient light and movement. This integration allows for smart park automation, utilizing renewable energy from foot traffic to power sensors, displays, irrigation, access control, and lighting systems.

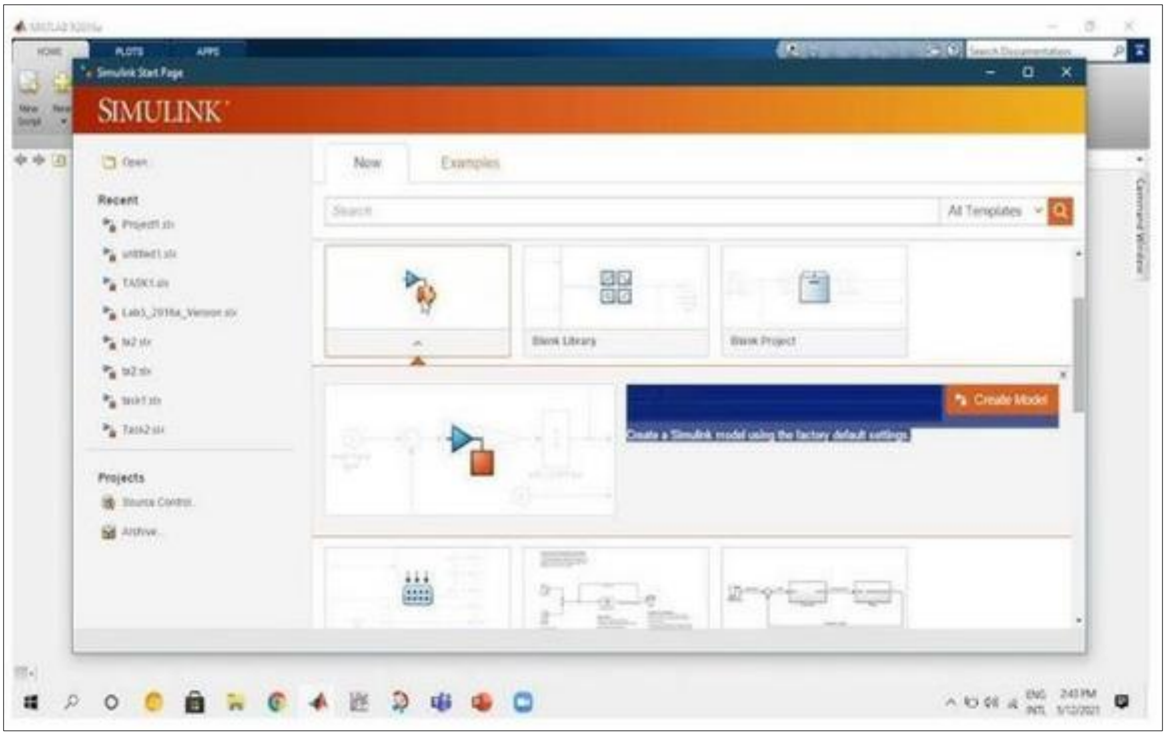

Figure 2 MATLAB hierarchical building block path

4. Software description

4.1. Introduction

The MATLAB (Matrix Laboratory) is a high-level programming and simulation environment widely used for numerical computation, data analysis, and modelling. It provides an interactive interface where users can perform matrix operations, visualize data, and design control systems or signal processing applications. MATLAB also supports Simulink for graphical modelling of dynamic systems. Being cross-platform and user-friendly, it is extensively used by engineers, researchers, and students for simulation, analysis, and automation in various fields of science and technology.

4.1.1. MATLAB (Matrix Laboratory)

A graphical editor for building hierarchical blocks is shown in figure 2. Extensive libraries of predefined blocks for modelling various system components. Simulation engines supporting both fixed-step and variable-step solvers. Data visualization tools such as scopes for analysing simulation outputs. Project and data management tools. Simulink Start Page and Its Parts the Simulink Start Page is the initial interface that allows quick access to starting new models, projects, and examples. Here's a breakdown of its major parts as visible in the image: Simulink Banner and Menu: At the top, this section offers access to file, plot, and app menus, as well as MATLAB's main interface functions.

4.2. Navigation panel

- Open: Option to open existing models. Recent: List of recently used projects or models (with .slx extension).
- Projects: Source control and archive options for project-based management. Central Workspace:

- New Tab: Allows the creation of new models or libraries. Common options include 'Blank Model', 'Blank Library', and some example templates.
- Examples Tab: Provides access to example models for learning and reference purposes.
- Search Bar: Find templates or examples quickly.
- Block Templates/Thumbnails: Visual representations for creating a new library, project, or opening example system models.
- Create Model Button: A prominent button (“Create Model”) initiates the process of building a model using default settings or a selected template.

Common Simulink Components Simulink’s component library is organized into several categories:

Continuous: Blocks like Integrator, Transfer Function, State-space. Discrete: Discrete equivalent operations.

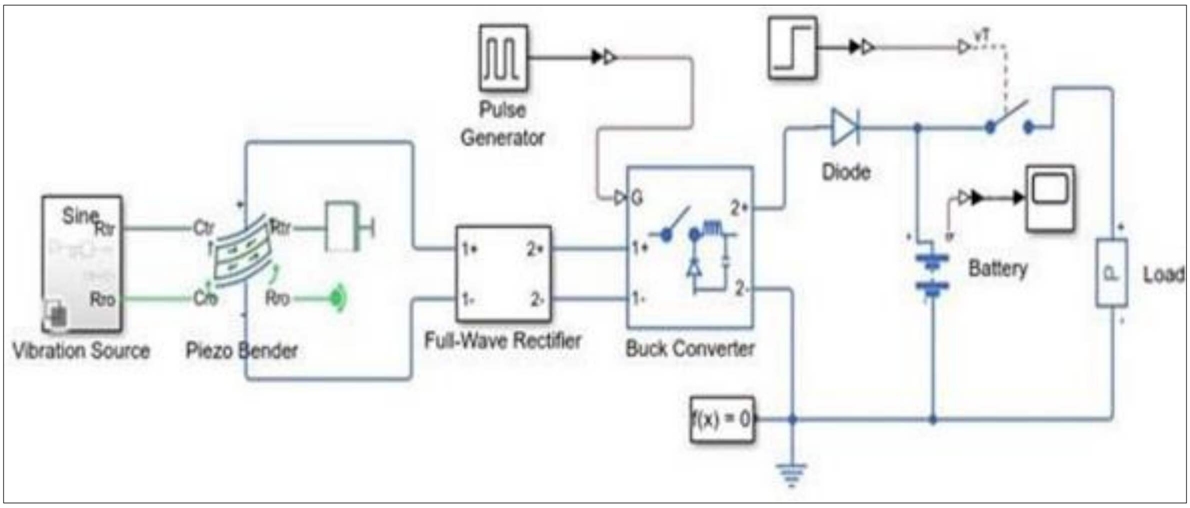

Figure 3 MATLAB Simulink block diagram

- Math Operations: Blocks for arithmetic: Sum, Gain, Product, Abs, Math Function.
- Signal Routing: Multiplexer, Demultiplexer, Switch. Sources: Signal generators (step, sine wave, clock). Sinks: Output viewers (scopes, displays, to workspace).

Ports and Subsystems: Entry and exit points for signals (Inport, Outport), grouping of blocks (Subsystems).

4.3. Software results

The output in the given figure 3. is electrical energy provided to a load, which is powered by a battery that gets charged using energy harvested from a piezoelectric system. The primary output is the regulated DC power supplied.

The system harvests mechanical vibration energy using a piezoelectric bender, converts it into electrical energy, and processes it through a full-wave rectifier to produce DC voltage. A buck converter then regulates this DC voltage to a suitable level for charging a rechargeable battery. The battery stores the harvested energy and provides a stable output to the connected load (such as an electronic device or sensor system). The output to the load is a regulated and continuous DC power, maintained by the charge stored in the battery and managed by the buck converter and associated control circuitry.

4.4. Output characteristics

The output is a smoothed DC voltage and current, suitable for low-power electronic devices. The output voltage and current depend on the efficiency of the energy harvesting process, the capacity of the battery, and the regulation provided by the buck converter. The system ensures the load receives power even if the vibration (energy harvesting) fluctuates, as the battery acts as an energy buffer. This output configuration is typical in self-powered sensor nodes or portable electronics using piezoelectric energy harvesting.

5. Hardware description

5.1. Introduction

Hardware description has an overview about the hardware set up and components which were used in this project. Namely microcontroller-based board (Arduino MEGA), Piezoelectric sensor, IR sensors, Lithium-Ion battery, Servomotor, Light dependent resistor, Relay module, Bridge rectifier, Liquid crystal display. The role, specifications and range of the each and every used in it is briefed as follows

5.2. Arduino mega

The Arduino Mega in figure 4. is a powerful microcontroller board based on the ATmega2560. It is designed for projects requiring a large number of input/output pins or higher processing power. It is an upgraded version of the Arduino Mega and is ideal for complex applications like robotics, IoT, and automation systems.

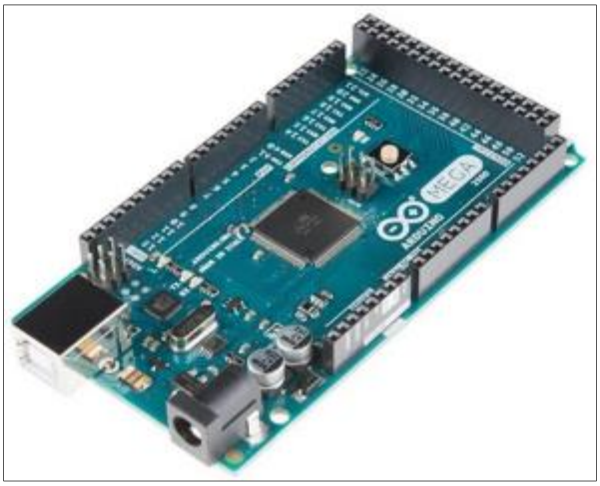

Figure 4 Arduino Mega

5.2.1. Specifications:

- Digital I/O Pins: 54 pins, with 15 supporting PWM output.
- Analog Input Pins: 16 pins, marked as A0 to A15.
- Serial Ports: 4 UARTs for hardware serial communication.
- Memory: 256 KB Flash (8 KB for bootloader), 8 KB SRAM, and 4 KB EEPROM.
- Clock Speed: 16 MHz.
- Operating Voltage: 5V, with input voltage ranging from 7V to 12V (recommended) or 6V to 20V (limit).
- Power Supply Options: USB cable, power jack, or Vin pin.
- Dimensions: 101.52 mm x 53.3 mm, weighing 37 g.

5.3. Piezoelectric sensor

The Piezoelectric Sensor in figure 5. converts mechanical stress into electrical energy using the piezoelectric effect. When pressure, vibration, or force is applied to its crystal, it generates voltage.

The way a piezoelectric material is cut defines one of its three main operational modes

- Transverse
- Longitudinal
- Shear

Figure 5 Piezoelectric Sensor

5.4. Lithium ion battery

A lithium-ion battery, or Li-ion battery, is a type of rechargeable battery that uses the reversible intercalation of Li+ ions into electronically conducting solids to store energy. Li-ion batteries are characterized by higher specific energy, energy density, and energy efficiency and a longer cycle life and calendar life than other types of rechargeable batteries. Lithium-ion batteries can be a fire or explosion hazard as they contain flammable electrolytes. Progress has been made in the development and manufacturing of safer lithium-ion batteries. Lithium-ion solid-state batteries are being developed to eliminate the flammable electrolyte.

5.5. Servomotor

The SG90 Servo Motor is a small and lightweight motor. It works on PWM (Pulse Width Modulation) signals to control the shaft position from 0° to 180°. It is simple, low-cost, provides precise angular movement.

Tiny and lightweight with high output power. Servo can rotate approximately 180 degrees (90 in each direction) and works just like the standard kinds but smaller. You can use any servo code, hardware or library to control these servos. Good for beginners who want to make stuff move without building a motor controller with feedback and gear box, especially since it will fit in small places. It comes with a 3 horns (arms) and hardware.

5.6. Light dependent resisitor

LDR (Light Dependent Resistor) is a light-sensitive device. Its resistance decreases when light intensity increases and increases when light intensity decreases. It is made of semiconductor materials like cadmium sulphide. LDRs are widely used in automatic lights, solar garden lamps, light meters, etc.

- Function: LDRs have high resistance in darkness and low resistance in light, making them useful as light sensors.
- Applications: Commonly used in street lighting, alarm systems, and automatic lighting controls.
- Working Principle: They operate on the principle of photoconductivity, where the resistance decreases as light intensity increases.

5.7. Relay module

A relay module is an electronic device that switches electrical circuits on or off using an electromagnetic relay. It features 1-8 channels, with electromagnetic relays (SPDT or DPDT) rated for 5-30V DC or 250V AC, 10A. It has a trigger voltage of 3.3V, 5V, or 12V DC.

5.8. Bridge rectifier

Bridge Rectifier KBPC5010 is a power electronic device. It converts AC (Alternating Current) into DC (Direct Current) using four diodes arranged in a bridge configuration. It has high current handling capacity (up to 50A) and voltage rating (up to 1000V).

Bridge rectifiers are widely used in

- Power Supply Circuits: To convert AC mains voltage to a usable DC voltage for electronic devices.
- Battery Chargers: To provide the necessary DC voltage for charging batteries.
- Circuit Diagram: The diagram includes four diodes connected to an AC input and a load resistor, showing how current flows in each cycle.

Figure 6 Software Results

5.9. Liquid crystal display

- LCD (Liquid Crystal Display) is an electronic display device. It is thin, lightweight, and consumes low power compared to LED or CRT displays.
- Module Size: 80mm x 36mm x 12mm,
- Display Size: 64mm x 16mm.It is easy to interface with Arduino.

For example, a character positive LCD with a backlight has black lettering on a background that is the color of the backlight, and a character negative LCD has a black background with the letters being of the same color as the backlight.

6. Results

6.1. Introduction

The graph represents the battery charging performance of the piezoelectric energy. The X-axis shows Time (seconds) and the Y-axis shows Battery Charge (mAh) Initially, the charge is constant, then gradually increases as energy is harvested, followed by a slight drop due to load usage, confirming effective energy conversion and storage.

6.2. Software result

The provided graph in figure 6. displays battery charge (in mAh) over a short time scale, typically seen in simulation or lab testing environments. The charge value starts steady, rises gradually after the initial flat section, peaks, and then decreases.

6.3. Description

- The graph represents battery charge over time.

- It starts at approximately 800 mAh and rises slightly above 800.0030 mAh before dropping again.
- The curve is initially flat, then rises linearly, peaks, and decreases

Challenges

- Accurately measuring very small changes in mAh (in the microampere- hour range) requires highly precise instrumentation, which can be expensive and sensitive to noise.
- Battery simulations or measurements at tiny intervals can be influenced by environmental factors like temperature or inherent sensor inaccuracy.

Limitations

- The graph scale shows minute charge variations, so any sensor or sampling error can significantly impact data validity.
- The time window is very short (from 0 to 1 unit), which may not represent the real-world charging/discharging behavior of larger batteries or longer cycles.
- The system or software might not capture gradual losses such as self- discharge or leakage current if sampling frequency is low or accuracy is limited.

7. Discussion

While the graph provides valuable insights into fine-scale battery dynamics during a charging cycle, its main utility lies in controlled environments for research and development. The resolution and time scale are best suited for diagnostic or academic purposes rather than extended real-life use cases.

8. Conclusion and Future Scopes

Introduction

The battery charge graph provides a detailed visualization of how a battery responds to short-term charging and discharging cycles, which is critical for understanding the real-time dynamics of energy storage systems. Such analysis is especially relevant in fields like energy harvesting, where energy from ambient sources is accumulated in small increments and needs to be efficiently captured, stored, and used by electronic devices. Through high-resolution monitoring, researchers and engineers can assess the battery’s ability to store and deliver energy under dynamic conditions, informing improvements in both hardware and management algorithms.

Summary of findings

The analysis of the battery charge graph reveals that the battery experiences a slight increase in charge followed by a decrease within a very short timeframe, illustrating both charging and discharging dynamics in a controlled environment. The findings highlight the precision of measurement and short-term response of the battery but also show the limitations in representing real- world, long-term trends.

This type of analysis is best suited for research and calibration purposes, offering valuable insights into rapid changes but not covering practical battery usage over extended periods.

Contribution to energy harvesting

The depicted battery charge graph offers valuable insights into energy harvesting applications by demonstrating the ability to monitor, store, and utilize small energy packets generated from ambient sources□. It reveals how efficiently a battery can capture and retain harvested energy during short bursts and subsequently deliver it when needed, which is a fundamental aspect of successful energy harvesting system design.

This precise measurement of short-term charging and discharging helps engineers optimize power management algorithms, improve the efficiency of energy conversion circuits, and enhance storage strategies—especially for low-power devices operating on intermittent energy sources (such as vibration, solar, or thermal energy).

The research supports the development of robust, reliable electronic systems that maximize the use of harvested energy in real-world application.

Conclusion

In conclusion, the battery charge graph demonstrates the short-term charging and discharging patterns of a battery with high precision, highlighting both dynamic response and measurement sensitivity.

While useful for analysing rapid charge changes and evaluating system performance in a controlled lab environment, its main limitations include the inability to represent long-term battery behavior and potential susceptibility to noise or measurement errors at such fine scales.

Therefore, this analysis is most valuable for diagnostic research, calibration, and early-stage system testing, rather than assessing real-world, long-term battery performance.

Limitations and future enhancements

Limitations

- Short Observation Period: The graph only captures battery behaviour within a short time frame, making it unsuitable for analysing long-term performance, degradation, and capacity loss.
- Limited Dynamic Range: The charge variation shown is extremely small, so the results may not generalize to batteries under normal or high-load conditions, where larger fluctuations occur.
- Measurement Sensitivity: High-precision readings at microampere-hour levels are susceptible to electrical noise and sensor inaccuracies, potentially impacting the validity of the results.
- Lack of Realistic Load: The test conditions may not represent practical scenarios, such as variable loads, temperature changes, and cyclical charging/discharging typical in real applications.
- No Long-Term Effects: Phenomena like self-discharge, internal resistance growth, or capacity fade are not observed.

Future enhancements

- Extended Monitoring: Increase the sample period to observe long-term charge/discharge cycles, revealing aging, efficiency, and realistic degradation patterns.
- Broader Operating Conditions: Test the battery under varying temperatures, loads, and environmental conditions to simulate real-world usage.
- Advanced Noise Filtering: Incorporate improved filtering or signal processing techniques to minimize measurement errors and ensure data consistency at very low charge changes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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