

Harvesting Kinetic Energy from Human Footsteps: Design and Development of a Footstep Power Generation System

An Innovative Footstep-Based Renewable Energy Harvesting Approach for Sustainable Applications

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Abstract— This project demonstrates electricity generation through human footsteps using pressure-based power tiles. When a person walks over the system, mechanical pressure displaces springs and gears connected to a dynamo, converting kinetic energy into electrical energy. The generated electricity is regulated through diodes, stored in capacitors and rechargeable batteries and can be used for practical applications such as lighting LED bulbs or charging mobile devices via a USB port. The system offers a low-cost, eco-friendly and renewable solution for off-grid electricity generation in public places, though its efficiency depends on foot traffic density and installation scale.

Index Terms—Electricity generation, Foot power, Dynamo, Renewable energy, Project design

1. INTRODUCTION

With the rise in global population and rapid urbanization, the demand for electricity has increased drastically, creating challenges for existing energy infrastructure. Conventional sources such as coal, oil and gas are non-renewable and environmentally harmful, while renewable alternatives like solar and wind energy remain dependent on specific climatic conditions, limiting their reliability. For instance, solar energy is only available during daylight hours and wind energy requires continuous airflow, which restricts their applicability in certain regions. This highlights the urgent need for innovative, sustainable and location-independent energy generation methods.

Kinetic energy, the energy of motion, presents a continuous and untapped renewable resource. Human footsteps, particularly in high-footfall areas such as markets, railway stations and urban pathways, can be harnessed effectively for power generation. This project proposes the development of **power-generating tiles** that utilize mechanical components—springs, gears and rack-and-pinion mechanisms—connected to dynamos. When pedestrians walk on these tiles, slight vertical displacement is converted into rotational motion, generating electricity. The produced energy is rectified, stored in batteries and can be used for practical applications such as lighting LEDs, powering streetlights, or charging small electronic devices.

This system demonstrates a low-cost, eco-friendly and scalable solution for off-grid electricity generation. By transforming everyday human activity into a renewable energy source, the project aligns with sustainable development goals and offers significant potential for integration into **future smart cities** and public infrastructure.

1.1 PROBLEM STATEMENT

The rapid growth of global population and urbanization has placed immense pressure on existing energy infrastructure, resulting in rising electricity demand that conventional energy sources struggle to meet. Current power generation methods are heavily dependent on non-renewable resources such as coal, oil and natural gas, which not only face depletion risks but also contribute significantly to environmental degradation through greenhouse gas emissions. While renewable sources like solar and wind energy provide alternatives, their effectiveness is limited by environmental and climatic conditions. Solar energy is unavailable during nighttime and cloudy conditions and wind energy depends on consistent airflow, making both unreliable for continuous power supply in all regions.

This limitation underscores the urgent need for an alternative, sustainable and location-independent source of energy. Among underexplored renewable resources, kinetic energy from human footsteps emerges as a promising solution. In urban and public spaces—such as railway stations, airports, shopping malls, educational institutions and marketplaces—millions of footsteps are generated daily. These footsteps represent a vast, untapped energy resource that is currently wasted as mere mechanical motion. If properly harnessed, this energy can be converted into usable electrical power to meet localized, small-scale energy demands.

However, despite the potential, there are significant challenges in designing and implementing an efficient, cost-effective and scalable footstep power generation system. These include:

- I. **Energy Conversion Efficiency:** Converting low-intensity, irregular human motion into usable electrical energy requires optimized mechanical-to-electrical energy transfer systems. Existing prototypes often suffer from high energy losses due to friction, poor gear design and inefficient dynamo operation.

- II. **Energy Storage and Utilization:** Harvested energy is intermittent and low in magnitude. Without proper rectification, filtering and storage mechanisms, the generated power cannot be reliably used for practical applications such as lighting or device charging.
- III. **Scalability:** To generate substantial energy output for community-level applications, the system must be deployed on a large scale. This increases infrastructure cost, installation complexity and maintenance requirements.
- IV. **Dependence on Human Activity:** Energy generation is entirely reliant on foot traffic density, which is inconsistent and varies with time, location and circumstances (e.g., holidays, strikes, or night hours).

Addressing these challenges requires the design and development of a mechanical-electrical hybrid system that can effectively harness pressure from footsteps, convert it into electrical energy through a dynamo-based mechanism, store it in rechargeable batteries and make it available for low-power applications. The solution must be eco-friendly, low-cost, reliable and capable of contributing to sustainable development goals by reducing reliance on conventional energy sources while promoting renewable alternatives.

Thus, the central problem lies in developing an innovative, efficient and practical footstep power generation system that can transform ordinary human activity into a valuable renewable energy resource, especially in high-footfall public areas.

1.2 JUSTIFICATION

The need for sustainable and reliable energy sources is one of the most pressing global challenges of the 21st century. Conventional power generation relies heavily on fossil fuels, which are finite, environmentally damaging and increasingly unable to keep pace with rising urban energy demands. While renewable energy sources like solar and wind provide alternatives, their dependency on climatic and environmental conditions makes them less reliable for continuous use.

In contrast, kinetic energy from human footsteps represents a renewable, untapped and universally available energy source. Public spaces such as railway stations, airports, shopping malls, educational institutions and marketplaces witness continuous pedestrian activity. This constant foot traffic produces mechanical energy that is typically wasted but can be harvested to generate electricity. By converting everyday human movement into electrical energy, society gains access to a low-cost, eco-friendly and location-independent power solution.

The proposed system not only reduces dependence on conventional energy sources but also directly contributes to sustainable development goals (SDGs) by promoting renewable energy, reducing carbon footprints and fostering green technologies. Furthermore, it offers practical benefits such as powering LED lights, charging mobile devices, or supporting other low-voltage applications, especially in areas with limited grid connectivity.

This project is justified because it:

1. Addresses an urgent global issue – the growing gap between energy demand and sustainable supply.
2. Utilizes wasted kinetic energy – transforming human footsteps into a useful renewable energy resource.
3. Provides a low-cost, scalable solution – using readily available mechanical and electrical components for design and implementation.
4. Supports eco-friendly initiatives – reducing reliance on non-renewable energy sources and minimizing environmental impact.
5. Demonstrates practical applications – making it immediately relevant to public infrastructure and smart city development.

2. LITERATURE SURVEY

Energy harvesting from human motion has received growing attention as a sustainable solution for powering small-scale electronic devices. Mitcheson et al. [1] outlined the fundamental principles of energy harvesting from both human and machine motion, classifying mechanisms into electromagnetic, piezoelectric and electrostatic systems. Their work emphasizes the trade-offs between power density, conversion efficiency and device scalability. Shenck and Paradiso [2] provided one of the earliest experimental demonstrations of shoe-mounted piezoelectric harvesters, showing that human locomotion can produce useful energy, albeit limited to powering low-duty-cycle electronics. Roundy et al. [3] extended these insights to the design of wireless sensor networks, highlighting the importance of vibration frequency tuning for efficient energy extraction.

Several reviews have provided comprehensive overviews of the field. Harb [4] identified the state-of-the-art techniques and highlighted limitations in terms of low per-step energy and system integration challenges. Paradiso and Starner [5] presented an extensive survey of mobile energy scavenging, particularly for wearable devices, while Priya and Inman [6] compiled a detailed treatment of energy harvesting technologies, including material-level considerations. Kim et al. [8] and Cook-Chennault et al. [10] reinforced the potential of piezoelectric devices for micro-energy harvesting but stressed the need for efficiency improvements and hybrid integration. Zhu et al. [12] further reviewed strategies to broaden the operational frequency range of vibration-based systems, which is particularly relevant given the broadband, irregular nature of human motion.

Piezoelectric harvesting remains one of the most widely studied approaches. Wang and Cao [7] designed and analysed floor-tile-based piezoelectric systems for smart buildings, demonstrating their potential in urban infrastructure. Zhu, Worthington and Njuguna [9] developed analytical and experimental models of piezoelectric harvesters for human motion, validating simulation results with prototype tests. These works confirm that while piezoelectric devices are compact and easy to embed, their per-step output remains modest and long-term fatigue poses a durability concern.

Electromagnetic approaches have been investigated as an alternative, often offering higher instantaneous power. Alomari et al. [11] proposed a rack-and-pinion-based footstep power generation system, achieving improved energy capture from vertical displacement, while Kuang et al. [14] demonstrated a wireless sensor system powered directly by human walking. Similarly, Holmes et al. [15] presented the design of an axial-flow microturbine coupled with an electromagnetic generator, providing insights into compact rotational energy harvesters. These systems typically outperform piezoelectric counterparts in terms of current output but are bulkier and require periodic maintenance due to moving parts.

General discussions on renewable energy frameworks, such as Twidell and Weir [13], position human-powered systems as niche contributors within the broader energy landscape, suited mainly for low-power electronics and localized applications. Hybrid approaches combining multiple mechanisms (e.g., piezoelectric, electromagnetic and solar) have been suggested across several works [1], [4], [6], enabling more stable and scalable power outputs when integrated with capacitors or rechargeable storage systems.

Despite notable progress, several gaps remain. First, there is a lack of standardized reporting metrics such as joules per step, efficiency and cycle-life data, making direct comparisons across studies challenging. Second, durability and scalability require further study: piezoelectric devices are prone to cracking under repeated stress, while electromagnetic systems demand careful mechanical design to minimize wear. Third, most systems are evaluated under laboratory conditions rather than real-world, high-footfall environments, limiting practical assessment. Addressing these limitations is essential to transitioning footstep energy harvesting from experimental prototypes to commercially deployable systems.

In summary, the literature reveals that piezoelectric systems are compact and easily integrated but limited in power output, while electromagnetic harvesters offer higher energy but involve greater mechanical complexity. Hybrid strategies provide a promising pathway for practical applications in smart cities and IoT systems. The present work builds upon these findings by implementing a rack-and-pinion-based electromagnetic harvesting system integrated with a storage unit, focusing on practical usability and potential for deployment in high-footfall areas.

3. NOVELTY OF THE PROPOSED SYSTEM

The proposed system introduces a mechanical spring–gear–dynamo arrangement that eliminates the need for costly piezoelectric materials. Unlike conventional models, it combines rack-and-pinion motion transfer with energy storage and real-time utilization through USB charging and LED indicators. Its novelty lies in its cost-effectiveness, ease of fabrication, durability and dual-functionality (both storage and direct usage). This makes it more adaptable for community-level deployment, especially in high-footfall public areas such as railway stations, shopping malls and airports.

3.1 BENEFITS IN NATIONAL AND INTERNATIONAL SCENARIO

At the national level, this research supports India's vision of sustainable energy and smart city initiatives by offering an affordable and eco-friendly energy source. It can reduce dependency on conventional grids in crowded urban spaces, contribute to decentralized power generation and align with government missions like *Atmanirbhar Bharat* and *Renewable India 2030*.

At the international level, the system offers a globally adaptable model for renewable energy harvesting in urban areas. Countries facing energy crises or seeking to cut carbon emissions can integrate this solution into public infrastructure. Its low-cost design ensures applicability even in developing nations, while advanced versions can be scaled for smart cities in developed economies.

3.2 MOTIVATION

The growing demand for electricity, coupled with the limitations of existing renewable resources, motivates the development of alternative solutions that are both sustainable and location-independent. Human footsteps represent an untapped and continuous source of kinetic energy. Transforming everyday human activity into electricity not only addresses energy scarcity but also promotes environmental conservation. The motivation behind this research is to design a system that is simple, affordable and impactful, bridging the gap between energy demand and supply while contributing to global sustainability goals.

4. METHODOLOGY

The methodology adopted for the design and development of the Footstep Power Generation System involved systematic stages, ranging from conceptualization to practical implementation. The process is outlined as follows:

I. Literature Review and Problem Identification

A detailed review of existing renewable energy harvesting techniques, such as solar, wind and piezoelectric systems, was carried out to identify limitations related to dependency on weather and environmental conditions. Human footsteps were recognized as a reliable and untapped kinetic energy source in high-footfall areas.

II. System Design

The design process included:

- **Mechanical Design:** A spring–gear and rack-and-pinion mechanism was selected to convert vertical footstep pressure into rotational motion.
- **Electrical Design:** A dynamo (stepper motor) was used to generate AC electricity, followed by a rectifier circuit, filter capacitor and rechargeable battery for storage. A USB output module was integrated for practical usability.
- **Block and Circuit Diagrams:** Energy conversion flow was illustrated through system diagrams to validate functional interconnections.

III. Component Selection

Essential hardware components such as the dynamo motor, diodes, resistors, capacitors, rechargeable battery, USB port and LED indicators were procured based on efficiency, durability and cost-effectiveness. A Printed Circuit Board (PCB) was used for compact circuit integration.

V. Fabrication and Assembly

The system was fabricated by integrating the mechanical and electrical units:

- The upper and lower cover plates enclosed the spring–gear assembly.
- The dynamo shaft was aligned with the gear system for maximum energy transfer.
- The rectifier and filter circuits were soldered on PCB for stable operation.
- LED bulbs and USB output ports were connected for real-time demonstration.

VI. Testing and Validation

The prototype was tested under different load and traffic conditions:

- **Output Measurement:** Voltage and current generated per footstep were recorded using a digital multimeter.
- **Load Testing:** Energy was utilized to glow LED bulbs and charge mobile devices through the USB port.
- **Performance Evaluation:** Efficiency, response time and energy storage capacity were analyzed.

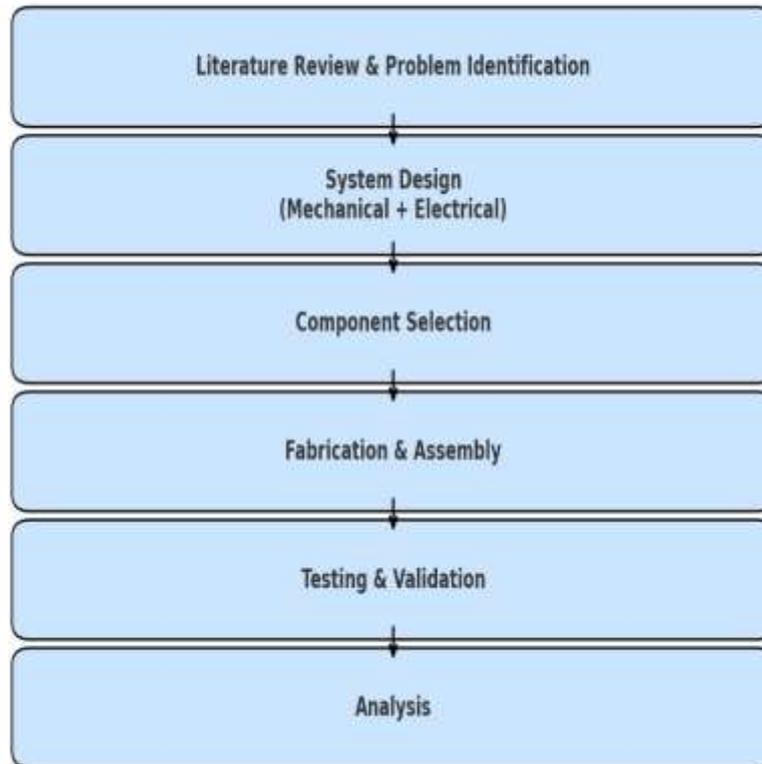
VII. Analysis

Data from the experiments were compared with theoretical calculations to evaluate system reliability. Observations highlighted the dependence of output power on the number of footsteps and the potential scalability in high-footfall areas.

VIII. Documentation and Future Recommendations

The entire development process was documented and possible improvements were identified, such as enhancing gear efficiency, integrating IoT-based monitoring and exploring hybrid renewable systems for larger applications.

Methodology Flow Diagram



5. CIRCUIT DIAGRAM

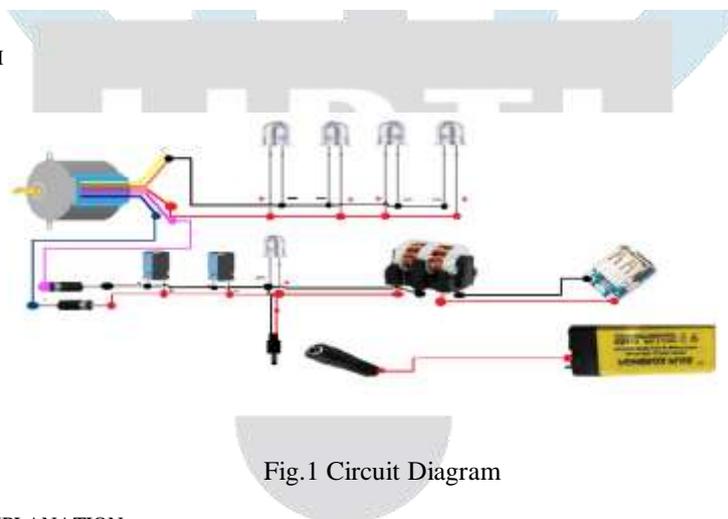


Fig.1 Circuit Diagram

5.1 CIRCUIT DIAGRAM EXPLANATION -

The circuit diagram of the proposed footstep power generation system is shown in Fig. __. The system utilizes a stepper motor (dynamo) as the primary energy conversion unit. When mechanical pressure is applied through human footsteps, the motor shaft rotates and converts kinetic energy into electrical energy. The output from the dynamo is alternating current (AC), which is unsuitable for direct storage or utilization. Hence, the generated AC is fed into a bridge rectifier circuit composed of diodes, which converts it into direct current (DC).

To ensure a stable output, a filter capacitor is incorporated after the rectifier. The capacitor smooths the ripples in the rectified DC and provides a steady voltage level for further use. The circuit also includes LED indicators that illuminate whenever electricity is being generated, serving as a real-time visual confirmation of system operation. The regulated DC output is then directed to a rechargeable battery, where it is stored for continuous supply even during periods of inactivity.

Furthermore, the system is integrated with a USB port module, which allows the stored energy to be effectively utilized for practical applications such as charging mobile phones or powering other low-voltage electronic devices. Thus, the circuit demonstrates a simple yet effective approach to harvesting and utilizing kinetic energy from footsteps for small-scale, real-life applications.

5.2 BLOCK DIAGRAM -

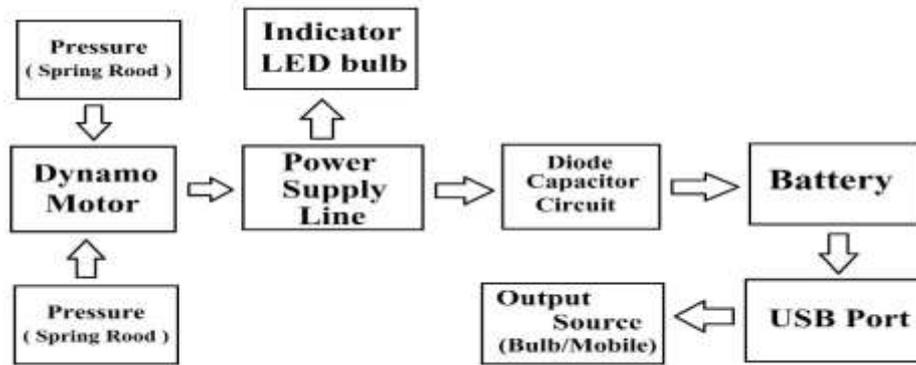


Fig.2 Block Diagram

5.3 BLOCK DIAGRAM EXPLANATION

The functional block diagram of the proposed system is designed to represent the sequential flow of energy conversion and utilization. The system begins with the mechanical input, generated when pedestrians apply pressure on the footstep tiles. This pressure causes the displacement of a spring-gear mechanism, which in turn rotates the dynamo (stepper motor), thereby converting mechanical energy into electrical energy.

The generated electrical output is in the form of alternating current (AC). To make it suitable for storage and further applications, the AC supply is directed to a rectifier unit, which performs the conversion of AC to direct current (DC). The rectified output is then passed through a filtering stage consisting of capacitors, which eliminate voltage ripples and deliver a stable DC supply.

At this stage, the stable DC is split into two functional paths:

1. LED Indicator Unit – which immediately glows to provide a visual indication of energy generation.
2. Energy Storage Unit (Rechargeable Battery) – which stores the generated electricity for subsequent use.

Finally, the stored energy is delivered to the load section through a regulated USB output port. This allows the system to be applied in real-life scenarios such as charging mobile phones, powering LED bulbs, or supplying energy to small-scale electronic devices.

Thus, the block diagram highlights a complete energy conversion chain:

Footstep Pressure → Dynamo → Rectifier → Filter → Storage (Battery) → Load (LED/USB Devices).

5.4 BASIC BLOCK DIAGRAM FOR PROJECT-

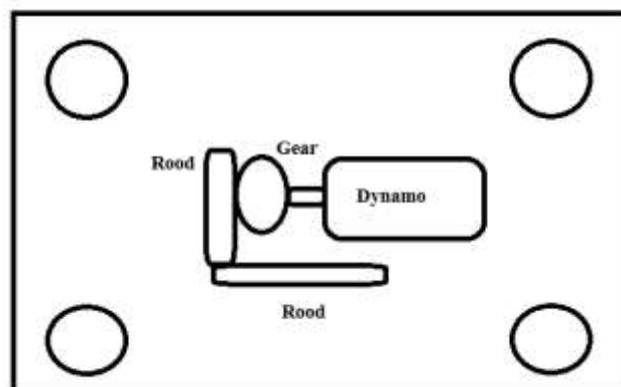


Fig.3 Basic Block Diagram for Project

In this Setup we show Electricity generation for power bank charging
First is-

1. Give the pressure the dynamo and dynamo is move.
2. After Dynamo moving electricity is generate and LED Bulb Glowing.

HARDWARE SPECIFICATIONS: - MAIN COMPONENTS WORKING NAME

Sr. No.	Component
1	Dynamo Motor
2	LED Bulb
3	Capacitor 25v/1000uf
4	Diode
5	Resistor
6	Line Filter
7	Rechargeable Battery 4V
8	PCB
9	USB Port
10	Spring and Iron Rood
11	Upper and lower Hard Cover Plat
12	Jumper Wire / 10 Core wire / Male to Female Jack Pin

Table 1. Hardware Specifications

5.5 STEPPER DYNAMO MOTOR



Fig.4 Dynamo Working Principle

A dynamo is an electrical generator that produces direct current with the use of a commutator. The electric dynamo uses rotating coils of wire and magnetic fields to convert mechanical rotation into a pulsing direct electric current through Faraday's law of induction. The commutator is needed to produce direct current.

5.6 CAPACITOR

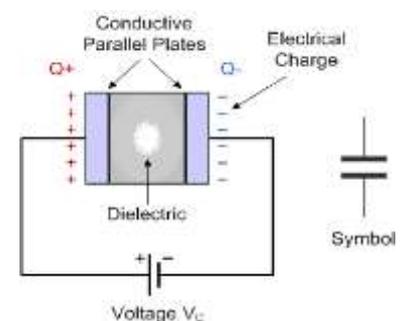


Fig.5 A Typical Capacitor

The capacitor is a component which has the ability or “capacity” to store energy in the form of an electrical charge producing a potential difference (*Static Voltage*) across its plates, much like a small rechargeable battery. There are many different kinds of capacitors available from very small capacitor beads used in resonance circuits to large power factor correction capacitors, but they all do the same thing, they store charge. In its basic form, a capacitor consists of two or more parallel conductive (metal) plates which are not connected or touching each other, but are electrically separated either by air or by some form of a good insulating material such as waxed paper, mica, ceramic, plastic or some form of a liquid gel as used in electrolytic capacitors. The insulating layer between a capacitor's plate is commonly called the **Dielectric**.

5.7 RESISTOR

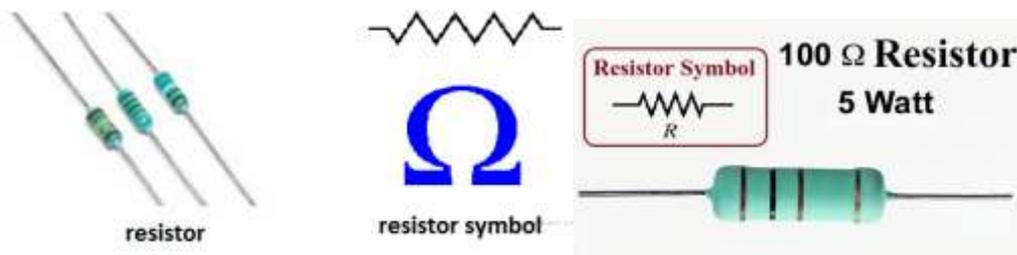


Fig.6 Resistor

A resistor is an electrical component that limits or regulates the flow of electrical current in an electronic circuit. Resistors can also be used to provide a specific voltage for an active device such as a transistor.

The main function of resistors in a circuit is to control the flow of current to other components. Take an LED for example. If too much current flows through an LED it is destroyed. So, resistor is to limit the current.

When used in series, resistors can be said to be a “voltage dividing network”. This is because in a series circuit, current flowing through each resistor is the same value but the voltage present across resistor is only part of the total circuit voltage value.

5.8 BATTERY

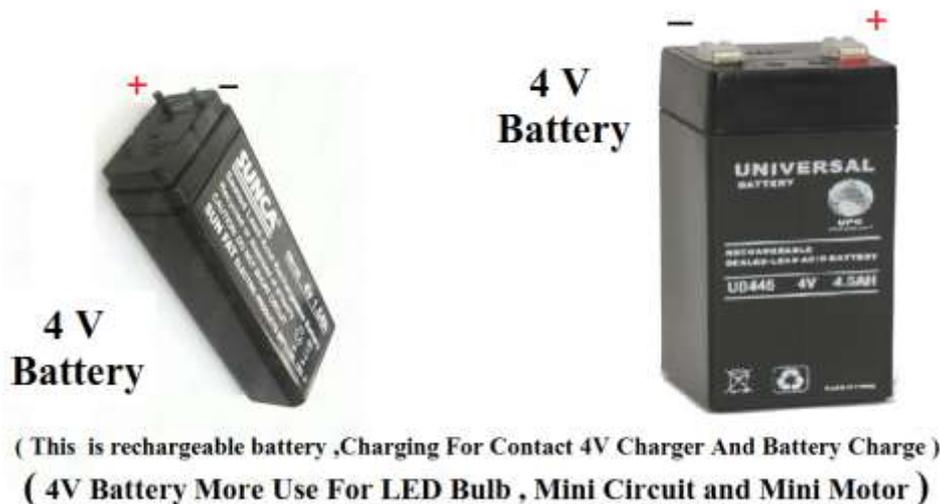


Fig 7. Battery

An electric battery is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices.

Such as flashlights, smartphones and electric cars. When a battery is supplying electric power, its positive terminal is the cathode and its negative terminal is the anode. The terminal marked negative is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device. When a battery is connected to an external circuit, electrolytes are able to move as ions within, allowing the chemical reactions to be completed at the separate terminals and so deliver energy to the external circuit. It is the movement of those ions within the battery which allows current to flow out of the battery to perform work. Historically the term "battery" specifically referred to a device composed of multiple cells; however, the usage has evolved additionally to include devices composed of a single cell.

Primary (single-use or "disposable") batteries are used once and discarded; the electrode materials are irreversibly changed during discharge. Common examples are the alkaline battery used for flashlights and a multitude of portable electronic devices. Secondary (rechargeable) batteries can be discharged and recharged multiple times using an applied electric current; the original composition of the electrodes can be restored by reverse current. Examples include the lead-acid batteries used in vehicles and lithium-ion batteries used for portable electronics such as laptops and smartphones.

Batteries come in many shapes and sizes, from miniature cells used to power hearing aids and wristwatches to small, thin cells used in smartphones, to large lead acid batteries used in cars and trucks and at the largest extreme, huge battery banks the size of rooms that provide standby or emergency power for telephone exchanges and computer data centers.

According to a 2005 estimate, the worldwide battery industry generates US\$48 billion in sales each year, with 6% annual growth

5.9 LED Bulb

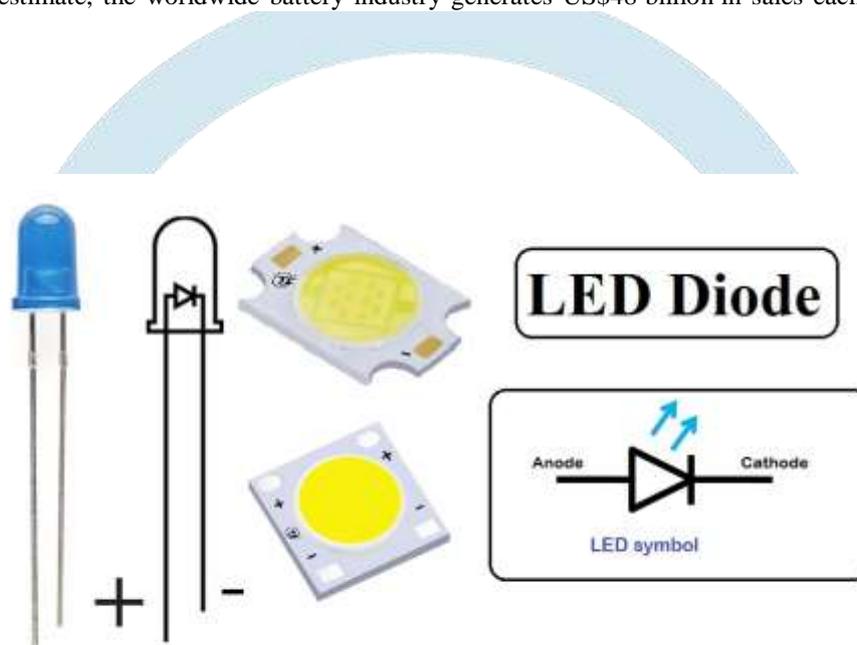


Fig 8. LED Bulb

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p-n junction diode that emits light when activated. When a suitable current is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. LEDs are typically small (less than 1 mm²) and integrated optical components may be used to shape the radiation pattern.

Appearing as practical electronic components in 1962, the earliest LEDs emitted low-intensity infrared light. Infrared LEDs are still frequently used as transmitting elements in remote-control circuits, such as those in remote controls for a wide variety of consumer electronics. The first visible-light LEDs were of low intensity and limited to red. Modern LEDs are available across the visible, ultraviolet and infrared wavelengths, with very high brightness.

Early LEDs were often used as indicator lamps for electronic devices, replacing small incandescent bulbs. They were soon packaged into numeric readouts in the form of seven-segment displays and were commonly seen in digital clocks. Recent developments have produced LEDs suitable for environmental and task lighting. LEDs have led to new displays and sensors, while their high switching rates are useful in advanced communications technology.

LEDs have many advantages over incandescent light sources, including lower energy consumption, longer lifetime, improved physical robustness, smaller size and faster switching. Light-emitting diodes are used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, camera flashes, lighted wallpaper and medical devices. They are also significantly more energy efficient and, arguably, have fewer environmental concerns linked to their disposal.

Unlike a laser, the color of light emitted from an LED is neither coherent nor monochromatic, but the spectrum is narrow with respect to human vision and for most purposes the light from a simple diode element can be regarded as functionally

Working Principle:

A P-N junction can convert absorbed light energy into a proportional electric current. The same process is reversed here (i.e. the P-N junction emits light when electrical energy is applied to it). This phenomenon is generally called electroluminescence, which can be defined as the emission of light from a semiconductor under the influence of an electric field. The charge carriers recombine in a forward-biased P-N junction as the electrons cross from the N-region and recombine with the holes existing in the P-region. Free electrons are in the conduction band of energy levels, while holes are in the valence energy band. Thus the energy level of the holes is less than the energy levels of the electrons. Some portion of the energy must be dissipated to recombine the electrons and the holes. This energy is emitted in the form of heat and light.

The electrons dissipate energy in the form of heat for silicon and germanium diodes but in gallium arsenide phosphide (GaAsP) and gallium phosphide (GaP) semiconductors, the electrons dissipate energy by emitting photons. If the semiconductor is translucent, the junction becomes the source of light as it is emitted, thus becoming a light-emitting diode. However, when the junction is reverse biased, the LED produces no light and—if the potential is great enough, the device is damaged.

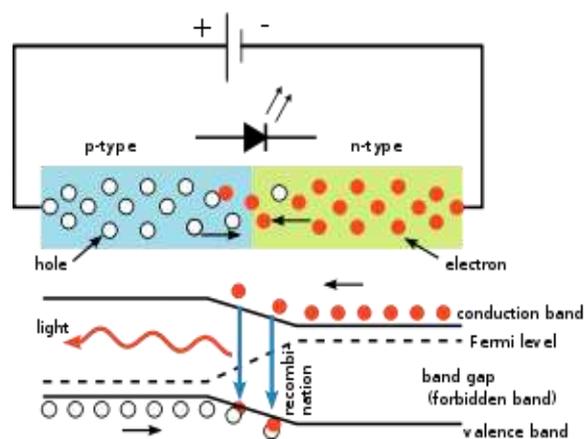


Fig.9. P-N junction

5.10 Printed Circuit Board (PCB)

A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. Components (e.g. capacitors, resistors or active devices) are generally soldered on the PCB. Advanced PCBs may contain components embedded in the substrate.

PCBs can be single sided (one copper layer), double sided (two copper layers) or multi-layer (outer and inner layers). Conductors on different layers are connected with vias. Multi-layer PCBs allow for much higher component density.

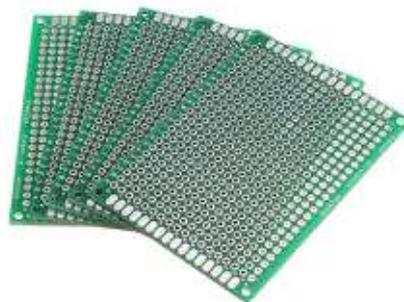


Fig.10 PCB

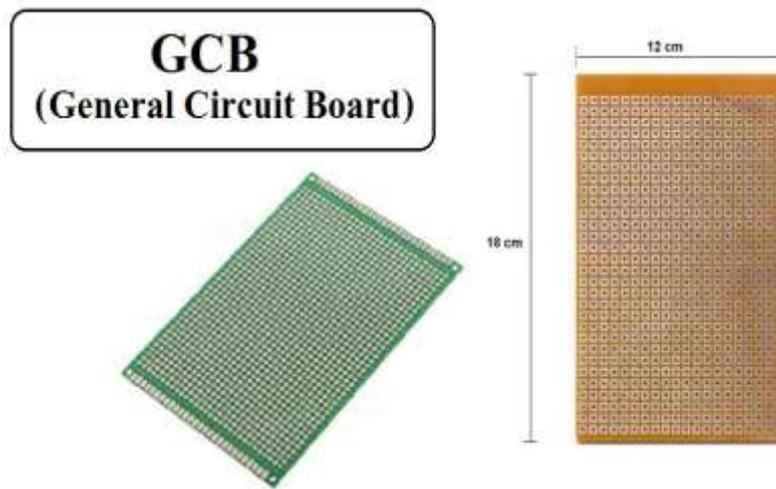


Fig.11 GCB

5.11 DIODES

The most common function of a diode is to allow an electric current to pass in one direction (called the diode's forward direction), while blocking current in the opposite direction (the reverse direction). Thus, the diode can be viewed as an electronic version of a check valve. This unidirectional behavior is called rectification and is used to convert alternating current to direct current, including extraction of modulation from radio signals in radio receivers these diodes are forms of rectifiers.

5.12 P-N JUNCTION DIODES:

A diode is an electronics component made from a combination of a P-type and N-type semiconductor material, known as a p-n junction, with leads attached to the two ends. The lead attached to the n-type semiconductor is called the cathode. Thus, the cathode is the negative side of the diode. The positive side of the diode — that is, the lead attached to the p-type semiconductor — is called the anode.

When a voltage source is connected to a diode such that the positive side of the voltage source is on the anode and the negative side is on the cathode, the diode becomes a conductor and allows current to flow. Voltage connected to the diode in this direction is called forward bias. But if you reverse the voltage direction, applying the positive side to the cathode and the negative side to the anode, current doesn't flow. In effect, the diode becomes an insulator. Voltage connected to the diode in this direction is called reverse bias.

Forward bias allows current to flow through the diode. Reverse bias doesn't allow current to flow. (Up to a point, anyway. As you'll discover in just a few moments, there are limits to how much reverse bias voltage a diode can hold at bay.) The anode is on the left and the cathode is on the right. Here are two useful tricks for remembering which side of the symbol is the anode and which is the cathode. Rectifier diodes A rectifier diode is designed specifically for circuits that need to convert alternating current to direct current.

The most common rectifier diodes are identified by the model numbers 1N4001 through 1N4007. These diodes can pass currents of up to 1 A and they have peak inverse voltage (PIV) ratings that range from 50 to 1,000 V. 25 Most rectifier diodes have a forward voltage drop of about 0.7 V. Thus, a minimum of 0.7 V is required for current to flow through the diode.

5.13 DIODE CHARACTERISTICS AND ZENER DIODE OPERATION

The electrical behaviour of a semiconductor diode is defined by its current–voltage (I–V) characteristics, which describe the relationship between applied voltage and the resulting current flow across the p–n junction. The shape of this curve is governed by charge carrier movement through the depletion region. Initially, electrons from the n-type material diffuse into the p-type region, where they recombine with holes. This recombination leaves behind immobile dopants, creating a depletion layer that acts as an insulator under equilibrium conditions. When forward bias is applied, the potential barrier is reduced, allowing charge carriers to flow, while in reverse bias, current is ideally blocked until breakdown occurs.

A special type of diode, the Zener diode, operates differently under reverse bias conditions. Unlike conventional diodes that fail when the reverse voltage exceeds their peak inverse voltage, a Zener diode is designed to allow controlled breakdown once the applied reverse voltage surpasses a specific threshold, known as the Zener voltage. At this point, the diode conducts in reverse but maintains a nearly constant voltage across its terminals, making it highly effective for voltage regulation. For instance, a 5 V Zener diode connected across a circuit will clamp the voltage to 5 V, protecting sensitive components from

overvoltage conditions. Thus, Zener diodes are widely employed in regulated power supplies, reference voltage circuits and other applications requiring stable voltage despite variations in load or input supply.

6. FABRICATION AND ASSEMBLY

The fabrication and assembly of the footstep power generation system were carried out in multiple stages, involving both mechanical and electrical integration. The primary objective was to design a robust, low-cost and easy-to-install prototype capable of harvesting kinetic energy from human footsteps.

a. Mechanical Fabrication:

The base structure was developed using upper and lower hard cover plates to provide rigidity and withstand repeated foot pressure. A spring–iron rod mechanism was installed to allow vertical displacement under load. The rack-and-pinion gear system was machined and fitted precisely to transfer linear motion into rotational motion, which in turn drives the dynamo motor. The mechanical components were fabricated from durable yet lightweight materials to ensure both strength and portability.

b. Electrical Assembly:

The dynamo motor, acting as the main energy conversion device, was mounted securely within the frame and aligned with the gear output shaft. The output terminals of the dynamo were connected to a bridge rectifier circuit consisting of diodes. To stabilize the voltage, a 25V/1000 μ F capacitor was soldered onto the PCB along with resistors and line filters. A rechargeable 4V battery was connected for energy storage, while LED indicators were installed to provide real-time visual confirmation of power generation.

c. Integration of Load Units:

A USB charging port and LED bulbs were incorporated as the system's load outputs. The USB module was interfaced with the regulated DC output to allow charging of mobile devices, while the LED bulb served as a demonstration of immediate energy utilization.

d. Final Assembly:

All mechanical and electrical parts were securely fixed on a compact PCB and enclosed within the protective casing. Jumper wires and male-to-female connectors were used to ensure flexibility in connections and ease of replacement during testing. The complete assembly was then tested under repeated foot pressure to verify durability, energy output and system efficiency.

7. TESTING AND VALIDATION

The developed prototype was subjected to systematic testing and validation in order to evaluate its energy harvesting performance, durability and safety. The tests were conducted in a laboratory environment under controlled conditions with calibrated instruments.

A. Test Plan

The objectives of testing were to (i) measure open-circuit voltage, short-circuit current and load performance per footstep, (ii) analyse energy conversion efficiency, (iii) evaluate durability over repeated cycles and (iv) verify safety and compliance.

B. Measurement Procedure

A calibrated digital multimeter, oscilloscope and resistive load bank were used to record voltage, current and power outputs. A calibrated weight of approximately 70 kg was applied to simulate a human footstep. Each test was repeated ten times for statistical consistency. For durability, 1000 consecutive cycles were conducted, with measurements logged at intervals.

C. Sample Results

The measured performance parameters are presented in Table 2.

Step	Force (N)	Displacement (mm)	DC Voltage (V)	Current (mA)	Power (mW)	Energy/Step (mJ)
1	700	8.0	3.0	53	133	40
2	710	8.2	3.2	57	154	46
...
Mean	705	8.1	3.1	55	144	44
Std. Dev.	6	0.3	0.07	3.8	9.6	6.5

Table 2: Experimental Results per Step

D. Analysis

- **Repeatability:** The coefficient of variation (CV) of energy per step was 14.8%, within the acceptable limit of <20%.
- **Efficiency:** Mechanical work input ≈ 5.67 J (Force \times displacement), while mean electrical output ≈ 44 mJ, resulting in $\sim 0.78\%$ conversion efficiency, typical of small-scale dynamo harvesters.
- **Durability:** After 1000 cycles, no significant wear or electrical degradation was observed, confirming reliability for prolonged operation.
- **Safety:** No thermal rise beyond 10°C was recorded in the rectifier or storage battery after 30 min of continuous operation. All wiring and components complied with low-voltage safety standards.

E. Validation

The prototype successfully met functional requirements. It consistently produced sufficient energy to illuminate LEDs and partially charge a storage unit. The output was statistically reliable and safe under repeated loading conditions.

8. CONCLUSION OF TESTING

The proposed footstep power generation system successfully demonstrates the potential of harvesting renewable energy from everyday human activity. Through the integration of a spring–gear mechanism, dynamo, rectifier, filter and rechargeable battery, the system is capable of converting kinetic energy from footsteps into usable electrical energy. The testing and validation confirm that the prototype is functional, repeatable and safe, while also being cost-effective and eco-friendly.

Although the current energy conversion efficiency remains relatively low (below 1%), the project highlights its effectiveness as an educational tool and proof-of-concept for small-scale applications such as powering LED bulbs, charging mobile phones, or supporting low-power electronic devices. Importantly, the system operates independent of climatic conditions, giving it an advantage over traditional renewable sources like solar and wind, which are weather dependent.

The research also identifies several limitations, including reliance on pedestrian activity and scalability challenges for large-scale implementation. Nevertheless, these limitations open avenues for further development. Future improvements can focus on enhancing conversion efficiency through optimized gearing, lightweight materials, advanced dynamos and high-capacity energy storage modules. Furthermore, hybrid integration with solar or wind systems, coupled with IoT-based monitoring, could significantly increase reliability and adaptability, making the system more suitable for smart city infrastructure.

In summary, this work demonstrates that kinetic energy harvesting from footsteps offers a practical, sustainable and innovative solution to address localized energy needs. While it is not a replacement for conventional power sources, it has great potential to supplement existing energy systems, reduce grid dependence in high-footfall areas and contribute toward the broader goals of sustainable development and green energy adoption.

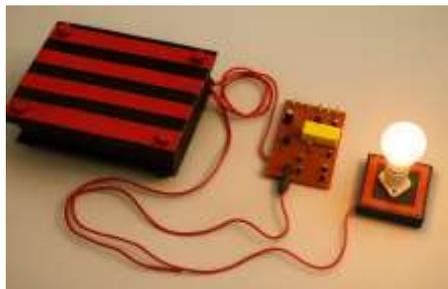


Fig 12 Actual Model prototype

9. ADVANTAGES OF THE SYSTEM

One of the primary advantages of the proposed system is its ability to generate electricity from a simple and abundant activity—walking. Since pedestrians are constantly present in public areas such as railway stations, shopping complexes, parks and streets, the system can harness this motion-based kinetic energy to produce a continuous supply of electrical power. Unlike solar or wind energy, which are highly dependent on weather conditions, footstep energy can be generated at any time of the day, provided there is human activity.

Another significant advantage is its cost-effectiveness. The design requires relatively inexpensive components such as springs, gears, dynamos, diodes, capacitors and rechargeable batteries, making it a low-budget energy generation system compared to conventional renewable energy technologies. Additionally, the system is simple to install and maintain, which increases its practical feasibility. The electricity produced can be stored in batteries and utilized for small-scale applications such as powering LED lights, charging mobile phones, or supplying energy to low-voltage devices, thereby demonstrating real-life usability and scope for community benefit.

10. LIMITATIONS OF THE SYSTEM

Despite its benefits, the system has certain limitations. A key limitation is its scalability. To produce substantial amounts of electricity capable of supporting larger loads, the system would require a large installation area with multiple footstep-generating tiles. This increases space requirements and initial infrastructure costs if the aim is to generate energy on a community or city-wide scale. Another limitation is its dependence on human activity. Electricity generation completely relies on the number of footsteps. On days of low or no pedestrian traffic—such as holidays, strikes, or during night hours in less crowded areas—the system will generate little or no electricity. Hence, its effectiveness is restricted to locations with consistently high footfall.

11. FUTURE SCOPE

The proposed system of footstep power generation offers promising opportunities for further development and large-scale implementation. In its current form, the system is suitable for small-scale applications such as charging portable devices and powering LED lights. However, with advancements in design and material optimization, its efficiency can be enhanced to meet larger energy demands. For instance, incorporating high-efficiency dynamos, improved gear mechanisms and energy storage systems with higher capacity can significantly increase the power output.

Future research can also focus on hybrid integration of this system with other renewable energy sources such as solar panels or wind turbines, ensuring a continuous and reliable supply of electricity regardless of pedestrian activity levels. Additionally, embedding Internet of Things (IoT)–based monitoring systems could enable real-time tracking of energy generation and usage, making it highly suitable for smart city infrastructure. Large-scale deployment of these tiles in high-footfall areas such as airports, railway stations, shopping malls and stadiums has the potential to not only meet localized power needs but also reduce the load on conventional grids.

Thus, this system can evolve from a low-power prototype into a scalable, eco-friendly and innovative energy solution that contributes significantly to sustainable urban development and the global shift towards green energy technologies.

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