Piezoelectricity on Roads

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ABSTRACT:

The increasing global energy demand and environmental concerns have prompted researchers to explore alternative energy sources. One such innovative solution is harvesting electricity from vehicle motion using piezoelectric sensors embedded in road infrastructure. This thesis presents a study on the feasibility, design, and implementation of piezoelectric roads, focusing on how mechanical pressure from vehicle movement can be converted into electrical energy. The research includes a theoretical framework, practical applications, case studies, economic analysis, and challenges associated with large-scale implementation.

1. INTRODUCTION

In the today's world the importance of Electricity has become a source of living one cannot even imagine living a life not even one day without electricity. Also the pollution and environmental calamities have been reached its zenith, So keeping in mind the growing population and generation of electricity in a very ecofriendly way without causing any harm to the environment, it urges one to create or substantiate for helping out the country by developing a working idea which will implement and help in fulfilling the needs of the people. So for this, a study for generating electricity from some ecofriendly sources and reduce the scarcity of electricity.

The growing transport or the number of traffic on the roads have been causing a lot of pollution, emmisions of various fuels and gases are harmful to the living beings, it can cause various fatal problems. So why not using this traffic as a source for generating energy. How this can be done so far is explained in this paper. The traffic on roads generate a lot of energy in the form of kinectic & pressure energies which can also be termed as mechanical energy. This mechanical energy from the vehicles can be used to generate electrical energy by providing a power generation unit in the form of piezoelectric sensors which converts the pressure energy into electrical energy. In this paper, we have suggested a Prototype model which will actually prove that this idea of developing electrical energy can be achieved in a real world.

IMPORTANCE:

It highlights the dependence on electricity and the growing concern over pollution and environmental damage, emphasizing the necessity of eco-friendly power generation.That traditional electricity sources are limited and suggests using alternative methods to meet the increasing demand. It introduces an innovative concept of utilizing the mechanical energy generated by traffic (vehicles and footsteps) to produce electricity. The introduction outlines a prototype model using piezoelectric sensors, which convert pressure from vehicles and pedestrians into electrical energy. It gives readers a clear idea of what the study will discuss, including theoretical and practical aspects of the proposed energy-harvesting system.

2. LITERATURE SURVEY:

The concept of generating electricity from roads using piezoelectric sensors has gained significant attention in recent years due to the increasing need for sustainable energy solutions. Piezoelectric materials exhibit the unique property of generating an electric charge when subjected to mechanical stress, making them ideal for harnessing energy from vehicular movement on roads. The origin of piezoelectricity can be traced back to 1880 when Pierre and Jacques Curie discovered the effect in certain crystalline materials, leading to the development of piezoelectric applications in various fields. However, the idea of using piezoelectric sensors for large-scale energy harvesting only gained momentum in the late 20th century, with Williams and Yates (1996) discussing the potential of vibrationbased energy harvesting, including its application in roadways. Further advancements were made by Priya and Inman (2009), who explored the efficiency of piezoelectric energy harvesting in structural applications, setting the stage for its integration into infrastructurebased

power
generation. Innowattech, an Israeli company, conducted one of the first realworld experiments in 2009 by embedding piezoelectric sensors beneath a 10-meter stretch of road, demonstrating that a one-kilometer stretch could generate approximately 200 kW of electricity, sufficient to power streetlights, traffic signals, and urban infrastructure. Subsequent research by Sodano et al. (2011) highlighted the efficiency of piezoelectric transducers, emphasizing the importance of material selection in optimizing power output.

Guigon et al. (2013) developed a mathematical model to analyze the impact of vehicle speed, weight, and traffic volume on energy generation, providing critical insights into system optimization. Large-scale implementations further validated the feasibility of piezoelectric road technology, with Italy's Smart Highways Project (2018) incorporating piezoelectric generators into major roadways to power traffic lights and toll booths. Similarly, the California Energy Commission launched a pilot project in 2019, revealing that high-traffic density roads could generate up to 400 kWh per day, highlighting the technology's potential in urban infrastructure. China's Smart Pavement Initiative (2021) took this concept a step further by integrating piezoelectric sensors with solar panels and kinetic energy harvesters, demonstrating a hybrid approach to self-sustaining roadways. In terms of material advancements, Zhou et al. (2016) investigated nanogenerators based on piezoelectric nanowires, significantly increasing energy conversion efficiency. Gholikhani et al. (2019) further enhanced system performance by developing a hybrid energy
harvesting system that combined piezoelectricity with solar power, showcasing the benefits of multi-source energy generation. Additionally, Khan et al. (2020) proposed self-healing piezoelectric materials to improve sensor durability and reduce maintenance costs, addressing one of the key challenges of piezoelectric road technology. Despite these advancements, several limitations still exist, as highlighted by Dahiya et al. (2020), who pointed out the high initial costs associated with installing piezoelectric sensors in roads. Zhang et al. (2021) examined the durability of piezoelectric sensors under heavy traffic loads, identifying material degradation as a significant concern. Mahmoud et al. (2022) conducted a comparative study of renewable energy sources in urban infrastructure, concluding that while piezoelectric energy harvesting is feasible, its power output per unit area is still relatively low compared to solar or wind energy.

However, ongoing research in advanced materials, nanotechnology, and smart infrastructure integration is expected to enhance the efficiency and scalability of piezoelectric road technology.

3. METHODOLOGY

The methodology for generating electricity from roads using piezoelectric sensors involves several key steps, including energy harvesting, conversion, storage, and utilization. This process takes advantage of the piezoelectric effect, where certain materials generate an electrical charge when subjected to mechanical stress. In this system, piezoelectric sensors are embedded beneath or within the road surface at strategic locations where vehicle movement exerts maximum pressure. As vehicles pass over these sensors, the mechanical force from their weight and motion deforms the piezoelectric materials, causing them to generate small electrical charges. However, this raw energy is typically low-voltage and alternating current (AC), making it unsuitable for direct storage or use in electrical devices. To make the harvested energy useful, it undergoes a series of conversion and storage processes.

The first step in energy conversion is the rectification process, which involves using a rectifier circuit to convert the generated AC voltage into direct current (DC). Since piezoelectric sensors often produce low and inconsistent voltage levels, a DC-DC boost converter or a step-up transformer is used to increase the voltage to a usable level, typically 12V or higher, to match the requirements of storage and utilization systems. The converted energy is then fed into a charge controller, which regulates the flow of electricity to prevent overcharging and deep discharge, thereby ensuring the longevity of the storage battery. A 12V 2A rechargeable battery is commonly used to store the generated energy, allowing for continuous and stable power availability even when vehicle movement is inconsistent.

Once the energy is efficiently stored, it can be used for a variety of applications. The most common use is powering road infrastructure, such as streetlights, traffic signals, road sensors, and surveillance cameras, reducing dependency on conventional power sources and enhancing sustainability. Additionally, in smart city applications, this stored energy can be integrated with the main power grid or used for wireless charging stations for electric vehicles. The stored electricity can also be distributed to public facilities, pedestrian crossings, and emergency lighting systems, contributing to energy efficiency and environmental sustainability.

The efficiency of this system depends on various factors, including the type of piezoelectric material used, the number

and placement of sensors, the weight and speed of passing vehicles, and the energy conversion efficiency of the circuit components. Advanced energy management systems can be incorporated to optimize power distribution, minimize energy losses, and ensure maximum utilization of harvested electricity. Additionally, data monitoring systems can track energy generation in real time, allowing for better system optimization and maintenance.
Overall, the methodology for generating electricity from roads using piezoelectric sensors is a multi-step process that transforms wasted mechanical energy into a reliable and sustainable power source. By integrating energy harvesting, efficient conversion, storage, and smart utilization, this technology provides an innovative solution for renewable energy generation in urban infrastructure, reducing dependence on fossil fuels and promoting greener cities.

4. COMPONENTS

Arduino UNO: The Arduino UNO is the primary microcontroller used in the robot, managing all operations by processing inputs from sensors and controlling outputs to motors and other components. Its flexibility and ease of programming make it ideal for coordinating real-time tasks.

Fig1. Arduino Uno

PIEZOELECTRIC SENSORS: Piezoelectric sensors are devices that convert mechanical stress or pressure into electrical energy using the piezoelectric effect. This effect occurs in certain materials, such as quartz, ceramics, and some polymers, which generate an electric charge when subjected to mechanical force. These sensors are widely used in various applications, including energy harvesting, medical devices, automotive systems, and industrial monitoring.

One of the most significant applications of piezoelectric sensors is in energy harvesting, where they can capture mechanical energy from vibrations, footsteps, or vehicle movement and convert it into electrical power. This makes them a promising solution for sustainable energy generation, especially in crowded urban areas or high-traffic zones. They are also used in medical ultrasound imaging, where they help generate and receive sound waves for diagnostic purposes.

In industrial settings, piezoelectric sensors play a crucial role in detecting pressure changes, monitoring vibrations, and ensuring structural health in machinery. They are preferred for their high sensitivity, fast response time, and durability in extreme environments. With advancements in technology, piezoelectric sensors are becoming more efficient and costeffective, contributing to the development of self-powered electronics, smart infrastructure, and renewable energy solutions. Their versatility makes them an essential component in modern engineering and scientific applications.

Fig 2. Piezoelectric Sensors

VOLTAGE SENSOR: Voltage sensors are electronic devices used to measure and monitor voltage levels in electrical circuits. They detect AC or DC voltage and convert it into a readable signal, which can be used for analysis, monitoring, or control purposes. These sensors play a crucial role in power management, industrial automation, and renewable energy systems.

There are two main types of voltage sensors: contact and non-contact sensors. Contact sensors, such as resistive voltage dividers and transformer-based sensors, require direct electrical connection, whereas non-contact sensors, like capacitive or inductive sensors, measure voltage without direct contact, ensuring safety in high-voltage applications.

Voltage sensors are widely used in power grids, battery monitoring, and electric vehicles, ensuring efficient energy usage and preventing system failures. In renewable energy systems, they help optimize the performance of solar panels and wind turbines by monitoring voltage fluctuations. Additionally, in industrial automation, they assist in maintaining stable power supply to machinery and equipment.

Fig 3.Voltage Sensor

LCD I2C DISPLAY: A Liquid Crystal Display (LCD) is a flat-panel display technology widely used in televisions, computer monitors, smartphones, digital watches, and industrial equipment. It operates by using liquid crystals that do not emit light directly but modulate light from a backlight or reflector to produce images. LCDs are known for their energy efficiency, thin design, and high-resolution display capabilities.

The working principle of an LCD relies on liquid crystal molecules that align between two transparent electrodes and polarizing filters. When an electric current is applied, these molecules change orientation, allowing or blocking light to create images. LCDs typically use thin-film transistor (TFT) technology for improved image quality and faster response times.

CONVERTER: An electrical converter is a device that transforms electrical energy from one form to another, such as changing voltage, current, or frequency to suit specific applications. Converters are widely used in power electronics, renewable energy systems, and industrial applications.

There are different types of electrical converters:

- AC to DC Converter (Rectifier) – Converts alternating current (AC) into direct current (DC), commonly used in battery chargers and electronic circuits.
- DC to AC Converter (Inverter) – Converts direct current (DC) into alternating current (AC), essential in solar power systems, UPS, and electric vehicles.
- DC to DC Converter – Changes the DC voltage level, either stepping it up (boost converter) or stepping it down (buck converter), used in mobile chargers, LED drivers, and power supplies.
- AC to AC Converter – Modifies AC voltage or frequency, used in voltage regulators and frequency changers.

Converters play a crucial role in efficient power management, enabling devices to operate at the required voltage and frequency. They are key components in smart grids, electric transportation, and renewable energy integration, ensuring stable and optimized energy distribution.

12V 2A BATTERY: A 12V 2A battery is a rechargeable power source that provides 12 volts of electrical potential with a 2-ampere current capacity. It is commonly used in portable electronics, backup power systems, and renewable energy applications. The battery can be made from different chemistries, including lead-acid, lithium-ion, and nickel-metal hydride (NiMH), each offering unique advantages in terms of efficiency, lifespan, and weight.

Features of a 12V 2A Battery

1. Voltage and Capacity – The 12V output ensures compatibility with many electronic devices, while the 2A current rating defines the maximum load it can support.
2. Rechargeable – Most 12V 2A batteries are designed for multiple charge and discharge cycles, making them cost-effective and environmentally friendly.
3. Compact and Portable – These batteries are relatively small and lightweight, making them ideal for low-power applications.
4. Safe Operation – Many modern batteries include overcharge, short-circuit, and thermal protection to ensure safe usage.

WORKING: The working principle of electricity generation from roads using piezoelectric sensors is based on the piezoelectric effect, where certain materials generate an electrical charge when subjected to mechanical stress. In this system, piezoelectric sensors are embedded beneath or within the road surface in high-traffic areas. When vehicles pass over

these sensors, the pressure and vibrations caused by their movement deform the piezoelectric materials, generating a small electrical charge. However, this raw energy is typically low- voltage alternating current (AC) and needs to be processed before it can be stored or used.

To make the harvested energy usable, the first step is rectification, where a rectifier circuit converts the AC voltage into direct current (DC). Since the voltage from individual sensors is too low, a DC-DC boost converter or a step-up transformer increases it to a usable level, typically 12V or higher. The converted energy is then regulated by a charge controller, which ensures that the flow of electricity remains stable and prevents overcharging or deep discharge of the storage battery. The generated power is stored in a 12V 2A battery, providing a continuous and reliable power supply even when traffic flow is inconsistent.

Once stored, the harvested energy can be used for various applications such as powering streetlights, traffic signals, road sensors, and surveillance cameras. Additionally, in smart cities, this stored power can be directed to wireless EV charging stations or integrated into

the main power grid. Advanced energy management systems can optimize power distribution and improve overall efficiency. By effectively capturing and converting mechanical energy from vehicle movement into electricity, this technology provides a sustainable and renewable energy source, contributing to greener and more energy-efficient urban infrastructure.

IMPLEMENTATION: The implementation of this technology involves multiple steps, including planning, installation, integration, and maintenance to ensure efficient energy harvesting and utilization.

Site Selection and Planning

The first step is to identify high-traffic areas where vehicle movement is frequent and consistent. Ideal locations include highways, urban roads, toll booths, parking lots, and pedestrian crossings. The road conditions, weight of vehicles, and expected energy output are analyzed to determine the optimal placement of piezoelectric sensors.

Sensor Installation

Piezoelectric sensors are embedded beneath the asphalt layer or within specially designed road panels. These sensors are arranged in a strategic pattern to maximize energy collection from vehicle pressure. The installation must ensure that sensors are protected from damage due to heavy vehicle loads and environmental factors.

Energy Harvesting and Conversion System

The raw electricity generated by the sensors is low-voltage AC, which needs to be processed before use. A rectifier circuit converts AC to DC voltage, while a DC-DC boost converter increases the voltage to a usable level (e.g., 12V or higher). A charge controller regulates energy flow to prevent fluctuations and ensures efficient storage in a 12V 2A battery.

Power Storage and Distribution

The stored energy can be used to power streetlights, traffic signals, surveillance cameras, or wireless EV charging stations. Excess energy can be fed into the main power grid to supplement renewable energy sources in smart city infrastructure.

Maintenance and Optimization

Regular maintenance ensures the durability and efficiency of the system. Smart monitoring systems track energy generation and usage in real-time, allowing for performance optimization and timely sensor replacements. By integrating piezoelectric road technology with existing infrastructure, cities can harness vehicle movement as a sustainable energy source, promoting renewable energy and reducing reliance on fossil fuels.

5. RESULT

The generation of electricity from roads using piezoelectric sensors has shown promising results as a renewable energy solution. When vehicles pass over embedded
piezoelectric sensors, the mechanical stress is converted into electrical energy. Studies and experimental models indicate that a single sensor can generate between 5V to 50V, and an array of sensors on busy highways can produce several watts to kilowatts of power. This energy can be efficiently stored and used to power streetlights, traffic signals, surveillance cameras, and electronic signage. Pilot projects in various cities have demonstrated that piezoelectric roads can enhance smart infrastructure by providing a sustainable energy source. Additionally, integrating this technology with solar panels and wind energy can further optimize power output. However, challenges such as high installation costs, durability concerns, and energy storage limitations need to be addressed for large-scale implementation. With advancements in material science and engineering, piezoelectric roadways have the potential to contribute significantly to sustainable urban development and renewable energy solutions.

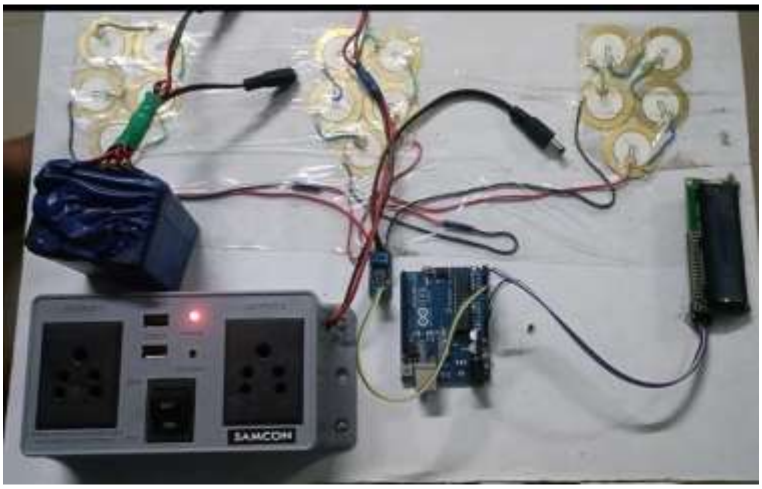

Fig 4.Hardware Architecture

FUTURE SCOPE: The concept of footstep power generation using piezoelectric sensors to store energy in a battery and charge mobile devices offers significant potential for future

development and application. As we look ahead, there are several areas in which this technology can evolve, become more efficient, and expand its range of applications. Below are key aspects of its future scope:

6. CALCULATION

Traffic Periods in Energy Generation:

The energy generation potential in public places is directly influenced by pedestrian traffic throughout the day. To analyze this, the day is divided into three distinct traffic periods: Rush Hour, Mid Traffic, and Low Traffic. Each period varies in terms of the average number of people passing per hour and the duration of activity. This segmentation helps in accurately estimating the number of individuals contributing to energy generation and calculating the total energy harvested during each timeframe. The table below summarizes the traffic flow and corresponding energy output based on footstep power generation for each traffic period, ultimately providing a daily total.

Traffic Period	Avg People/ Hour	Duration	People Total	Energy/ Person (Wh)	Total Energy (Wh)
Rush Hour	2000	3 hrs	6000	0.0167	100.2 Wh
Mid Traffic	800	6 hrs	4800	0.0167	80.2 Wh
Low Traffic	300	3 hrs	900	0.0167	15.0 Wh

Fig.5. **Traffic Periods in Energy Generation**

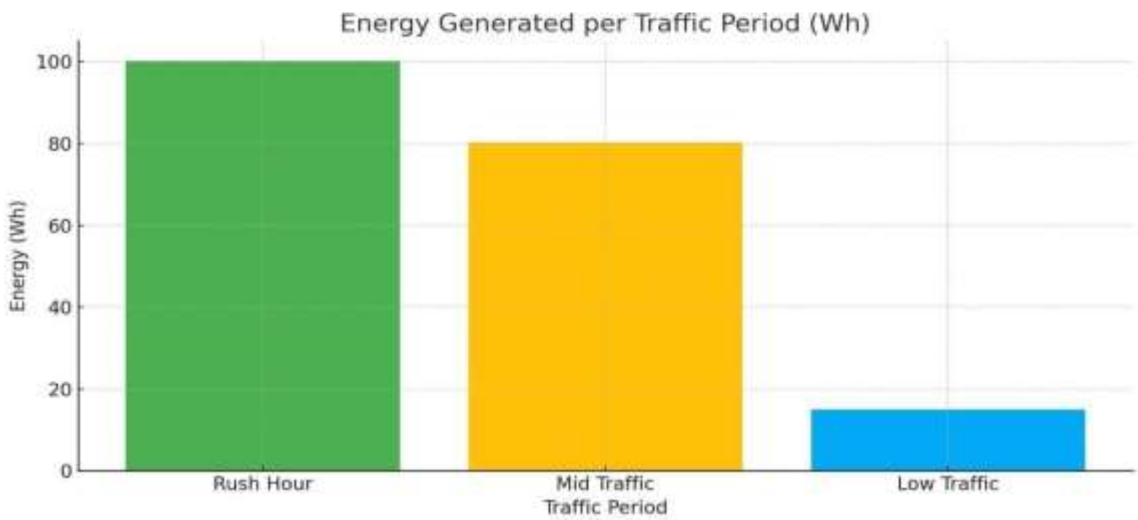

Fig.6. **Traffic Periods in Energy Generation Bar Graph**

Key Assumptions Recap:

Energy generated per person = ~0.0167 Wh (from earlier) Total daily energy = 195.4 Wh

Each step uses a tile of approx. 30 cm x 30 cm (0.09 m²)

Now let's calculate based on a realistic number of piezo tiles needed to absorb that much foot traffic and generate that energy.

1. Total Footsteps per Day:

11,700 people × 1 step per person on the tile= 11,700 steps (roughly one tile interaction each)

2. Piezo Tile Energy Output per Step:

Let's assume:

Each tile (30×30 cm) outputs ~0.0167 Wh per step (same as per person estimate) So to cover 11,700 steps, you need only 1 tile receiving all those steps

BUT, in reality, no single tile gets stepped on every time, so you need to spread the traffic across tiles.

3. Distribution Across Multiple Tiles Let's say:

You install a 2-meter-long path = ~6–7 tiles in length And 1 meter width = ~3 tiles across

That's about 18–21 tiles total

So each tile gets about ~557 steps/day (11,700 ÷ 21) Each tile:

557 steps × 0.0167 Wh = ~9.3 Wh/day per tile To get ~195 Wh/day:

You need ~21 tiles total, each roughly 30×30 cm Total length: ~2 m long × 1 m wide piezo mat Summary :

Total piezo tile length needed: 2 meters Width: 1 meter

Number of tiles (30×30 cm): ~21 tiles

This setup can generate ~195 Wh/day with estimated traffic

What Can 195 Wh Do?

Power 39 LED bulbs (5W) for 1 hour Charge a laptop (~60Wh) three times Charge 15 phones (~13Wh)

Power a small fan for ~5–6 hours

2.Implementation on Highways :

Cost Estimation for 1km road:

Size of road: length = 1km = 1000 m, width = 2 m Area of road = length*width = 1000*2= 2000 sq.m Size of 1 sensor: 1 sq.ft = 0.0929 sq.m

Gap between two sensors: 1.5 (from each side) = 1.5*2 = 3 m

Area of road on which sensors been installed: 2000/3 = 666.67 sq.m= 667 sq.m No. Of Sensors required for 1 km road = Area of road/size of one sensor

= (667/0.0929)

= 7179.76 = 7180 Nos.

Cost of 1 sensor = 1000 Rs (approx)

Cost of 7180 sensors = 7180*1000=7180000 Rs = 70 lakh (approx)

Power Generation:

Case study: Hyderabad outer Ring Road Project Overall Budget of the Project: 6700 crore

8 lane road of 158 km stretch is laid.

If Piezoelectric road constructed, the budget of project = 1.5 times overall budget

= 1.5* 6700 crore Energy generated from 1 km single lane road = 44000 kwh per year Energy generated from 158 km 8 lane road = 158*8*44000 kwh

= 55616000 kwh energy generated Government of India chages Rs. 5 on average per 1 kwh,
Hence, cost of 55616000 kwh = 5*55616000 = 270000000 crore = 27 crore The amount which is invested on this road will get returned in only 4 years. This piezoelectric road has an average life of 30 years
Hence, income generated in the next 26 years would be a profit.

7. CONCLUSION

The use of piezoelectric sensors for electricity generation from roads presents a sustainable and innovative approach to energy harvesting. The results from various studies and pilot projects demonstrate that high-traffic roads can serve as a continuous source of renewable energy. The generated electricity can be effectively used for smart road infrastructure, including street lighting, traffic management systems, and sensor-based monitoring. Although challenges such as high initial costs, durability, and energy storage remain, continuous advancements in piezoelectric materials and power management can significantly improve efficiency and feasibility. With further research and large-scale implementation, this technology can contribute to reducing dependence on fossil fuels, enhancing energy sustainability, and promoting eco- friendly urban development.

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