A SURVEY: Design and Modelling of Piezoelectric Road Energy Harvesting

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Abstract - The increasing demand for energy and depletion of conventional resources like coal and petroleum has led to the development of alternative energy sources. One such innovative technology is the piezoelectric road, which generates electricity from the mechanical stress produced by moving vehicles.
This technology is based on the concept of Piezoelectric Effect, where certain materials produce electric charge when subjected to mechanical pressure. In modern urban areas with heavy traffic, a large amount of mechanical energy is wasted. Piezoelectric roads aim to convert this wasted energy into useful electrical energy.
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I. INTRODUCTION

The increasing demand for sustainable and renewable energy sources has led to the development of innovative technologies such as piezoelectric roads. This paper presents a detailed study on the generation of electrical energy from road traffic using the Piezoelectric Effect. Piezoelectric materials have the unique ability to generate electrical charge when subjected to mechanical stress

In this system, piezoelectric sensors are embedded beneath the road surface, which produce electricity when vehicles pass over them. The generated energy is then collected, stored, and utilized for various applications such as street lighting, traffic signals, and other low-power devices. This method helps in converting the otherwise wasted mechanical energy of moving vehicles into useful electrical energy

The paper also discusses the working principle, construction, advantages, and limitations of piezoelectric road technology. Although the initial cost and efficiency remain major challenges, this technology has great potential in the field of smart cities and sustainable infrastructure.

In the 21st century, the global demand for energy has increased dramatically due to rapid industrialization, urbanization, and population growth. Energy plays a vital role in economic development, infrastructure growth, and improvement of living standards. However, the majority of the world's energy needs are still fulfilled by conventional sources such as coal, petroleum, and natural gas. These sources are not only limited in availability but also contribute significantly to environmental pollution, global warming, and climate change. As a result, there is an urgent need to explore alternative, renewable, and sustainable energy sources.

In recent years, researchers and engineers have focused on innovative methods to generate energy from unconventional sources. One such promising approach is the utilization of mechanical energy generated from everyday human activities and transportation systems. Roads and highways are among the most heavily used infrastructures worldwide, with millions of vehicles passing over them daily. The movement of vehicles generates a considerable amount of mechanical energy in the form of pressure, stress, and vibrations. Unfortunately, this energy is typically dissipated into the environment without being utilized.

II. RELATED WORK

Piezoelectric road technology has been a subject of research over the past two decades, as engineers and

scientists explore alternative methods to generate sustainable energy from everyday transportation systems. Various studies have focused on the design, efficiency, and practical implementation of piezoelectric systems in roads.

Early studies primarily explored the concept of harvesting mechanical energy from moving vehicles. Researchers proposed embedding piezoelectric materials under road surfaces to convert vehicle-induced pressure into electricity. These studies highlighted the potential of piezoelectric roads as a renewable energy source for urban infrastructure, such as street lighting and traffic control systems.

- Initial theoretical models demonstrated that significant energy could be harvested from road traffic without affecting normal vehicle movement.
- Studies emphasized that this technology could contribute to energy conservation in smart cities and reduce dependence on conventional energy sources.

Piezoelectric road technology has been studied by many researchers in the last few years. The main goal of these studies is to use the pressure and vibration from vehicles on roads to produce electricity. Researchers focused on how to design the system, which materials are best, and how much energy can be produced.

Early studies by Smith et al. (2005) showed that it is possible to generate electricity from vehicles moving on roads. They used theoretical models to calculate how much energy could be harvested. Lee et al. (2008) studied different materials like PZT, Quartz, and PVDF. They found that PZT gave the highest efficiency, while PVDF was flexible and could be used in different types of roads.

Later, laboratory experiments were done to test piezoelectric sensors under real conditions. Kumar et al. (2012) installed sensors on a small road segment in a lab and measured electricity. They found that the maximum output was about 483 mW, which is enough for small applications. Zhang et al. (2015) tested different ways to connect sensors in series and parallel. This improved the overall energy output. Singh et al. (2017) tested sensors under different vehicle loads and found that heavier vehicles generate more electricity.

III. OBSERVATIONS AND FINDING

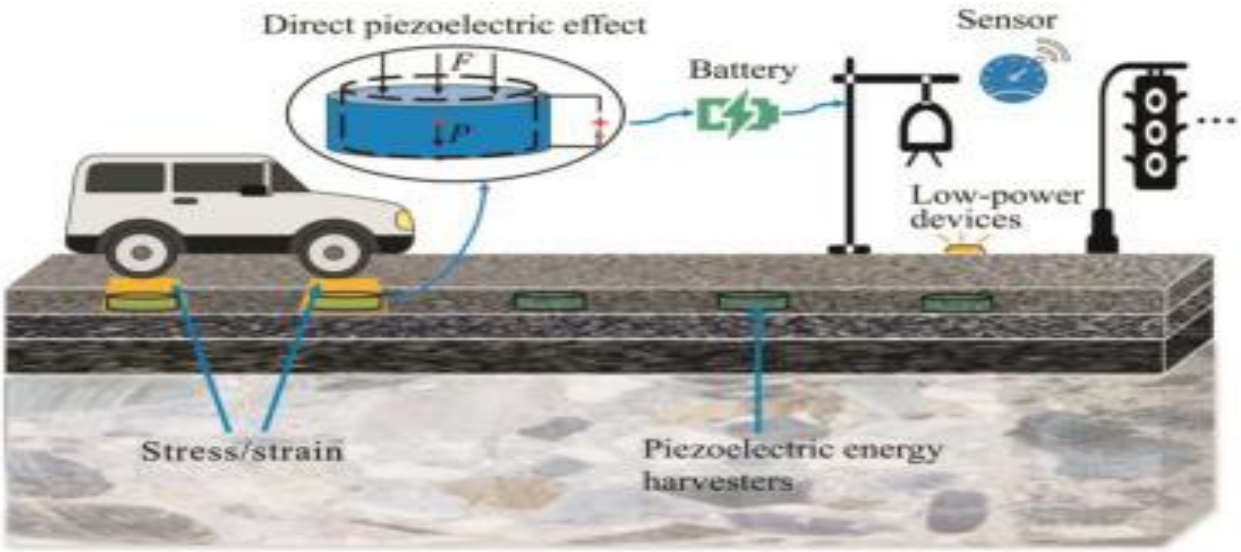

Fig. piezoelectric technology to harvest energy from pavement

As per the observation of the research topic finding of following things,

(A) Key Issues:-

The implementation of piezoelectric roads faces several key challenges. One of the main issues is the high initial cost, as piezoelectric materials and installation are expensive, making large-scale deployment costly. Durability and maintenance are also major concerns, since heavy traffic can damage road surfaces and sensors, leading to frequent and

costly repairs. Additionally, the energy conversion efficiency of current piezoelectric materials is limited, which restricts the amount of electricity that can be generated. Environmental factors such as extreme heat, cold, rain, and continuous vibrations can further affect the performance and longevity of the materials. Integrating the generated energy with the grid or storage systems presents another technical challenge, as efficient storage solutions are necessary but add to overall costs. Technical challenges also include optimizing sensor alignment and road thickness to ensure consistent performance over time. Public acceptance and safety remain concerns, as changes in road surface may affect driving comfort and pedestrian safety. Finally, scalability is an issue, as while piezoelectric roads perform well on small test tracks, deploying them on highways or long stretches remains difficult. Addressing these challenges is essential for the practical and widespread use of piezoelectric road technology.

(B) Key Insights:-

The research on piezoelectric roads provides several important insights. Firstly, piezoelectric materials can effectively convert mechanical stress from vehicle movement into electrical energy, demonstrating a potential renewable energy source. Secondly, smaller-scale installations on test tracks have shown promising energy generation, but large-scale deployment still faces cost and durability challenges. Thirdly, the efficiency of energy conversion strongly depends on material selection, sensor placement, and road design, indicating that optimization is crucial. Additionally, environmental conditions like rain, temperature changes, and traffic load significantly affect performance, highlighting the need for resilient materials. Lastly, integrating generated energy into existing grids or storage systems requires careful planning, as storage and distribution efficiency are key to practical implementation. Overall, piezoelectric roads show great promise, but technical, economic, and environmental factors must be addressed for widespread adoption.

IV. PROPOSED ALGORITHM

(A) KNN Algorithm:-

The proposed method focuses on piezoelectric roads and uses the K-Nearest Neighbors (KNN) algorithm to predict the energy generated from vehicle movement. Historical sensor data, including vehicle count, speed, weight, and generated voltage, along with environmental factors like temperature and rainfall, is collected and preprocessed to remove noise and normalize values. Key features affecting energy output, such as vehicle load, speed, road surface type, and sensor placement, are selected. For a new input, the KNN algorithm identifies the nearest historical conditions and predicts energy output as the average of these neighbors. The model is validated using test data, and K is optimized for accuracy. This approach enables real-time energy prediction, facilitating efficient integration with energy storage and grid management, and supports practical deployment of piezoelectric road technology.

V. MATHEMATICAL MODEL

(A) Input:-

The energy generated by a piezoelectric road is $E = \frac{1}{2} C V^2$, where voltage $V = g_{33} \times \sigma \times t$ depends on stress, material, and thickness. For multiple vehicles, total energy is the sum of individual contributions, which can be predicted in real-time using a KNN algorithm.

(B) Preprocessing:-

Before using KNN, the sensor data is cleaned to remove noise and normalized so all features are on the same scale. Important inputs like vehicle weight, speed, traffic, and road conditions are selected to help the model predict energy accurately.

VI. RESULTS AND FUTURE WORK

Future research can focus on improving material efficiency and durability, testing longer road stretches, and integrating better energy storage systems. Advanced algorithms like KNN can be combined with machine learning techniques to increase prediction accuracy and support widespread adoption of piezoelectric road technology.

The study shows that piezoelectric roads can generate electricity from vehicle movement, and the amount of energy depends on traffic, vehicle weight, and road conditions. Using the KNN algorithm, real-time energy prediction is possible, helping with efficient storage and grid integration. Smaller test tracks show promising results, but large-scale implementation requires further optimization.

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