

SMART ROAD ENERGY HARVESTER WITH VEHICLE DETECTION USING ARDUINO

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Abstract - The increasing demand for electrical energy and the rapid growth of transportation systems have created a need to explore new and sustainable sources of energy. Every day, a large number of vehicles move on roads and highways, producing significant pressure and vibration on the road surface. Normally, this mechanical energy is wasted and not utilized in any useful manner. The concept of a **Smart Road Energy Harvester** focuses on capturing this unused energy and converting it into electrical energy. The main objective of this project is to design and develop a system that can generate electrical energy from the pressure produced by moving vehicles and also detect the presence of vehicles on the road. In this system, **piezoelectric sensors** are placed under the road surface. When a vehicle passes over the road, pressure is applied to these sensors and they generate a small amount of electrical voltage. This voltage is then converted from AC to DC using a rectifier circuit and stored using capacitors or batteries.

To enhance the functionality of the system, **vehicle detection is implemented using sensors connected to an Arduino microcontroller**. Sensors such as ultrasonic or infrared sensors detect the presence of vehicles and send signals to the Arduino. The Arduino processes the sensor data and helps in monitoring the operation of the system. The generated electrical energy can be used to power small loads such as LED lights, traffic signals, or other low-power electronic devices.

Key Words: smart energy, Arduino, Piezoelectric Sensor

1. INTRODUCTION

The demand for electrical energy is increasing rapidly due to industrial development, urbanization, and the growing use of electronic devices. At the same time, traditional sources of energy such as coal, petroleum, and natural gas are limited and cause environmental pollution. Because of this, researchers and engineers are focusing on developing alternative and renewable energy sources that are sustainable and eco-friendly.

Road transportation is one of the most commonly used modes of transport in modern society. Every

day, thousands of vehicles move on highways, city roads, and bridges. When vehicles move over the road surface, a large amount of pressure and vibration energy is generated. In most cases, this energy is wasted and not utilized for any useful purpose.

The concept of **Smart Road Energy Harvester** aims to utilize this wasted mechanical energy produced by vehicles and convert it into electrical energy. This energy can then be stored and used for small electrical applications such as street lighting, traffic signals, or road monitoring systems.

1.1 Background of the Industry / User Problem

In recent years, the demand for electrical energy has increased significantly due to population growth, industrialization, and technological advancement. Many industries, transportation systems, and urban infrastructures require a continuous supply of electricity. However, traditional energy sources such as fossil fuels are limited and also contribute to environmental pollution and global warming.

At the same time, road transportation has increased rapidly, resulting in heavy traffic on highways and city roads. Every vehicle moving on the road produces mechanical pressure and vibrations on the road surface. This energy is normally wasted and not used in any beneficial way.

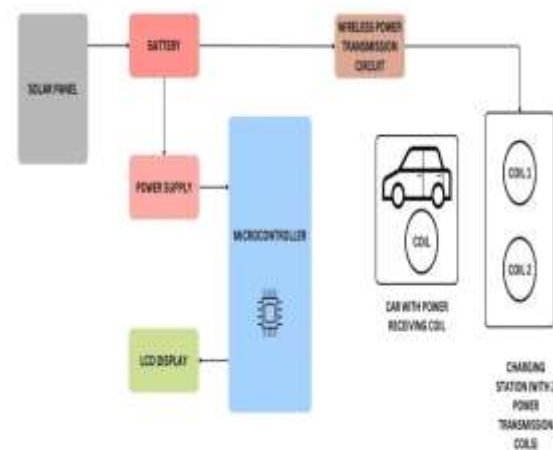


Fig.-1: Problem Solution Flow Diagram

1.2 Problem Statement

A large amount of mechanical energy is generated on roads due to the movement of

vehicles. However, this energy is generally wasted and not utilized for any productive purpose. At the same time, the increasing demand for electricity and the depletion of conventional energy resources have created a need for alternative energy generation methods.

Another challenge in modern transportation systems is the need for efficient vehicle detection and traffic monitoring systems. Traditional systems can be expensive and require complex infrastructure.

The main problem addressed in this project is how to convert the mechanical energy generated by moving vehicles into useful electrical energy and how to detect vehicle movement using a simple and cost-effective system.

This project proposes a solution using *piezoelectric sensors for energy generation and Arduino-based sensors for vehicle detection* to demonstrate a smart road system capable of producing renewable energy while monitoring vehicle movement.

1.3 Objectives of the Project

The main objectives of this project are as follows:

1. To design and develop a system that can generate electrical energy from the pressure produced by moving vehicles on the road.
2. To use piezoelectric sensors for converting mechanical pressure into electrical energy.
3. To implement vehicle detection using sensors connected to an Arduino microcontroller.
4. To demonstrate the working of a smart road energy harvesting system using a small-scale prototype model.
5. To store and utilize the generated electrical energy for small applications such as LED lighting.

1.4 Need of the Project

The increasing consumption of electricity and the limited availability of conventional energy sources have created a strong need for alternative energy generation methods. Renewable energy technologies are essential for sustainable development and environmental protection.

Roads are used continuously by vehicles, which produce a significant amount of mechanical pressure and vibration. If this energy can be captured and converted into electrical energy, it can become a valuable renewable energy source.

- The need for this project arises from the following factors:
- Increasing demand for electrical energy.
- Wastage of mechanical energy generated by vehicles on roads.

- Need for renewable and eco-friendly energy sources.
- Requirement for smart transportation and traffic monitoring systems.
- Development of smart city infrastructure.

This project demonstrates how unused road energy can be utilized effectively while also providing vehicle detection capability using Arduino.

1.5 Overview of the System

The *Smart Road Energy Harvester with Vehicle Detection using Arduino* is designed to capture the mechanical energy generated by vehicles moving on the road and convert it into electrical energy. The system mainly consists of piezoelectric sensors, an Arduino microcontroller, vehicle detection sensors, and an energy storage circuit.

Piezoelectric sensors are placed beneath the road surface. When a vehicle passes over the road, pressure is applied to these sensors and they generate a small electrical voltage. This voltage is converted from AC to DC using a rectifier circuit and stored using capacitors or batteries.

The system also includes vehicle detection using sensors such as ultrasonic or infrared sensors connected to an Arduino microcontroller. These sensors detect the presence of vehicles passing over the road and send signals to the Arduino.

The Arduino processes the sensor data and controls the output system such as LEDs or display modules. The generated energy can be used to power small electrical devices such as street lights, road indicators, or traffic monitoring systems.

Table 1: Main Components of the System

Sr. No.	Component	Function
1	Piezoelectric Sensor	Converts mechanical pressure from vehicles into electrical energy
2	Arduino UNO	Acts as the main controller for the system
3	Ultrasonic / IR Sensor	Detects the presence of vehicles on the road
4	Bridge Rectifier	Converts AC output from piezo sensor into DC voltage
5	Capacitor / Battery	Stores generated electrical energy
6	LED / Display	Shows system output and vehicle detection

2. METHODOLOGY

The methodology of the paper explains the procedure used to design and implement the *Smart Road Energy Harvester with Vehicle Detection using Arduino*. The system is

developed by integrating piezoelectric sensors, an Arduino microcontroller, and vehicle detection sensors to generate electrical energy from road pressure and detect vehicle movement. The approach mainly involves designing a prototype model where sensors are placed beneath a road surface to capture mechanical pressure from moving vehicles and convert it into electrical energy. The generated energy is then processed and stored using electronic circuits.

2.1 System Architecture

The system architecture shows how different components of the project are connected and interact with each other. The main components of the system include piezoelectric sensors, a rectifier circuit, an energy storage unit, vehicle detection sensors, and the Arduino microcontroller.

Piezoelectric sensors are installed below the road surface to capture pressure generated by vehicles. The electrical output from these sensors is passed through a rectifier circuit to convert it into usable DC power. The stored energy can then be used to power small electronic devices such as LEDs.

At the same time, vehicle detection sensors send signals to the Arduino controller when a vehicle passes over the road. The Arduino processes this data and controls the output devices accordingly.

2.2 Working Principle

The working principle of the Smart Road Energy Harvester system is based on the **piezoelectric effect**. Piezoelectric materials have the ability to generate electrical voltage when mechanical pressure or vibration is applied to them.

In this system, piezoelectric sensors are placed under the road surface. When a vehicle moves over the road, the pressure produced by the vehicle compresses the sensors. This mechanical pressure is converted into electrical energy by the piezoelectric sensors.

The generated voltage is then passed through a rectifier circuit which converts AC voltage into DC voltage. The DC voltage is stored in capacitors or batteries for future use.

Meanwhile, the vehicle detection sensors detect the presence of vehicles and send signals to the Arduino microcontroller. The Arduino processes this information and activates output devices such as LEDs or display modules to indicate vehicle movement and system operation.

2.3 Hardware Implementation

The hardware implementation of the system includes several electronic components and sensors. Piezoelectric sensors are used for generating electrical energy from vehicle pressure. These sensors are connected to a bridge rectifier circuit to convert the generated AC voltage into DC voltage.

An Arduino UNO microcontroller is used as the main controller of the system. It receives input signals from vehicle detection sensors and controls the output devices.

The generated energy is stored using capacitors or batteries, and LEDs are used as output indicators to show the working status of the system.

2.4 Software Implementation

The software part of the system is developed using the **Arduino programming environment**. The Arduino is programmed to read signals from the vehicle detection sensors and process the input data.

The program continuously monitors the sensor signals. When a vehicle is detected, the Arduino activates the output system such as LEDs or displays. The program also allows monitoring of the sensor data through the serial monitor for testing and debugging.

The Arduino software is simple and easy to modify, which makes the system flexible and suitable for demonstration purposes.

2.5 System Flow Process

The overall working process of the system can be explained in the following steps:

1. A vehicle moves over the road surface.
2. Pressure from the vehicle acts on the piezoelectric sensors placed below the road.
3. The piezoelectric sensors generate electrical voltage due to the applied pressure.
4. The generated voltage is converted from AC to DC using a rectifier circuit.
5. The electrical energy is stored in a capacitor or battery.

This methodology demonstrates how mechanical energy from moving vehicles can be converted into electrical energy while simultaneously detecting vehicle movement using Arduino.

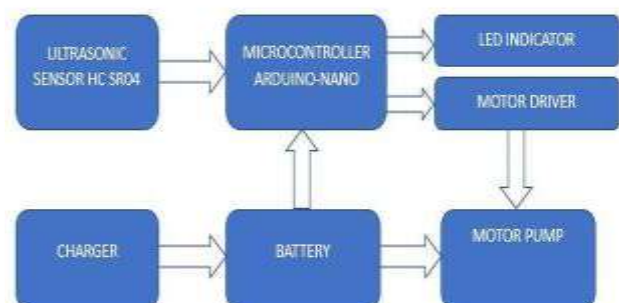


Fig- 2: Vehicle detection using IR/Ultrasonic sensors

3. DESIGN AND IMPLEMENTATION

This chapter explains the design and implementation of the *Smart Road Energy*

Harvester with Vehicle Detection using Arduino. The system is designed to convert mechanical pressure generated by moving vehicles into electrical energy while also detecting vehicle movement on the road.

The design includes both hardware and software components. The hardware part consists of sensors, electronic circuits, and the Arduino microcontroller. The software part includes the Arduino programming used to control and monitor the system.

The implementation of the system is carried out by assembling the sensors and electronic components on a prototype model that represents a road surface.

3.1 System Design

The system is designed to capture mechanical pressure generated by vehicles moving on the road and convert it into electrical energy using piezoelectric sensors. These sensors are placed beneath the road surface so that when a vehicle moves over the road, pressure is applied to the sensors.

The generated electrical energy is then processed through a rectifier circuit to convert it into usable DC power. This energy can be stored in capacitors or batteries and used for small applications such as LED lighting.

At the same time, vehicle detection sensors such as ultrasonic or infrared sensors are placed near the road surface. These sensors detect the presence of vehicles and send signals to the Arduino microcontroller.

The Arduino acts as the main control unit of the system. It receives signals from the sensors and controls output devices such as LEDs or display modules.

3.2 Hardware Implementation

The hardware implementation of the project includes various electronic components and sensors.

The main component used for energy generation is the **piezoelectric sensor**. These sensors generate electrical voltage when pressure is applied. Multiple piezo sensors can be connected together to increase the generated energy.

The output from the piezo sensors is connected to a **bridge rectifier circuit** which converts the AC voltage produced by the sensors into DC voltage. A **capacitor or battery** is used to store this generated energy.

The system also includes **vehicle detection sensors** such as ultrasonic sensors or infrared sensors. These sensors detect the presence of vehicles and send signals to the Arduino microcontroller.

An **Arduino UNO** board is used as the main controller of the system. It receives signals from

the sensors and controls the output devices accordingly.

LEDs are used as output indicators to show the working status of the system.

3.3 Software Implementation

The software part of the system is implemented using the **Arduino programming environment**. The Arduino program is written to read signals from the vehicle detection sensors and process the input data.

The program continuously checks whether a vehicle is detected by the sensors. When a vehicle passes over the road surface, the sensor sends a signal to the Arduino. The Arduino processes this signal and activates the output devices such as LEDs.

The software also allows monitoring of the sensor signals using the serial monitor in the Arduino IDE. This helps in testing and debugging the system during development.

The Arduino program is simple and easy to modify, which makes the system flexible for further improvements.

3.4 Testing and Implementation

After designing and assembling the system, testing is carried out to verify the working of the project. During testing, pressure is applied on the road surface to simulate the movement of vehicles.

When pressure is applied, the piezoelectric sensors generate electrical voltage. This voltage is then converted and stored using the electronic circuit.

At the same time, the vehicle detection sensors detect the presence of an object and send a signal to the Arduino microcontroller. The Arduino processes this signal and activates the LED or output indicator.

The testing results show that the system successfully demonstrates the concept of converting mechanical pressure from road traffic into electrical energy while detecting vehicle movement using sensors.

4. RESULT AND APPLICATION

This chapter presents the results obtained from the implementation of the **Smart Road Energy Harvester with Vehicle Detection using Arduino**. The performance of the system is evaluated based on energy generation and vehicle detection capability. The results show how the system works under different conditions and how the generated energy can be utilized for practical applications.

The prototype model demonstrates that mechanical pressure produced by vehicles moving over the road can be converted into electrical energy using piezoelectric sensors. The

system also successfully detects the presence of vehicles using sensors connected to the Arduino microcontroller.

4.1 Result Analysis – Performance Metrics

The performance of the Smart Road Energy Harvester system is analyzed based on the electrical output generated by the piezoelectric sensors and the accuracy of the vehicle detection system.

During testing, pressure was applied on the piezoelectric sensors to simulate the movement of vehicles over the road surface. When pressure was applied, the sensors generated a small electrical voltage. This voltage was converted into DC using a rectifier circuit and stored using a capacitor.

The generated electrical energy was used to power a small LED indicator, demonstrating the ability of the system to convert mechanical energy into electrical energy.

The vehicle detection sensors also performed successfully during testing. When an object or vehicle passed near the sensor, the sensor detected the presence of the vehicle and sent a signal to the Arduino microcontroller. The Arduino then activated the LED to indicate vehicle detection.

The results show that the system successfully demonstrates the concept of road energy harvesting and vehicle detection using simple electronic components.

4.2 Economic Analysis and Return on Investment

The Smart Road Energy Harvester system is designed as a low-cost prototype model using easily available electronic components. The components used in this project include piezoelectric sensors, Arduino microcontroller, ultrasonic or infrared sensors, rectifier circuits, capacitors, and LEDs.

The cost of these components is relatively low compared to other complex energy harvesting systems. Because the system uses simple components and does not require heavy mechanical structures, the overall installation and maintenance cost is reduced.

If this technology is implemented on a large scale in high traffic areas such as highways, toll plazas, and parking areas, it can generate electrical energy continuously as vehicles pass over the road. This generated energy can be used for applications such as street lighting, traffic signals, and road monitoring systems.

Although the amount of energy generated from a small prototype model is limited, large-scale implementation with multiple sensors can increase energy generation and provide better return on investment over time.

4.3 Applications of the System

The Smart Road Energy Harvester system has several practical applications in modern transportation and smart city infrastructure.

One of the main applications is in **highways and busy roads**, where a large number of vehicles pass daily. The mechanical pressure from these vehicles can be converted into electrical energy and used for road lighting or monitoring systems. Another application is in **toll plazas and speed breakers**, where vehicles slow down and apply more pressure on the road surface. This pressure can be effectively used to generate electricity.

The system can also be used in **parking areas and smart city projects** to generate renewable energy and monitor vehicle movement.

Additionally, the system can support **traffic monitoring systems** by detecting vehicle movement using sensors connected to the Arduino microcontroller.

4.4 Advantages and Limitations

The Smart Road Energy Harvester system provides several advantages in terms of renewable energy generation and smart road infrastructure.

One of the major advantages is that it utilizes the mechanical energy generated by moving vehicles which is normally wasted. This helps in promoting renewable and sustainable energy solutions.

Another advantage is that the system is eco-friendly and does not produce pollution. It also supports the concept of smart cities and intelligent transportation systems.

The system is simple in design, cost-effective, and easy to implement as a prototype model. It also allows integration with sensors for vehicle detection and monitoring.

However, the system also has certain limitations. The amount of electrical energy generated by piezoelectric sensors is relatively small, especially in small-scale models. The efficiency of the system depends on the number of vehicles passing over the road.

Large-scale implementation may require proper road design and sensor protection to ensure durability and reliability.

Despite these limitations, the project successfully demonstrates the concept of converting road pressure into electrical energy while detecting vehicle movement using Arduino.

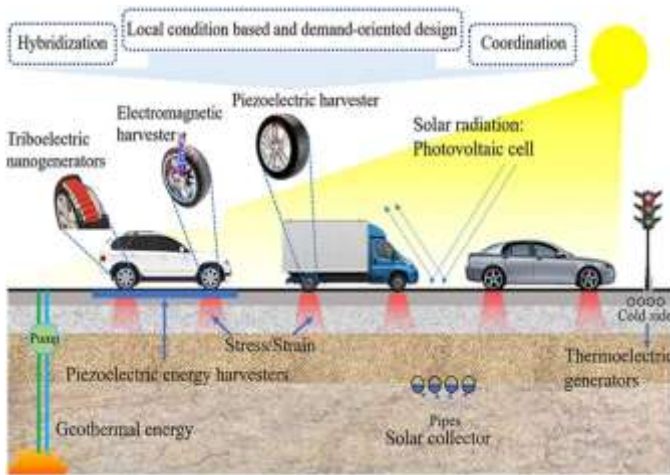


Fig.4: Review and analysis of energy harvesting technologies in roadway transportation

5. CONCLUSION AND FUTURE SCOPE

This chapter summarizes the overall outcome of the project and discusses possible improvements that can be made in the future. The **Smart Road Energy Harvester with Vehicle Detection using Arduino** demonstrates how mechanical energy generated by vehicles moving on roads can be converted into electrical energy and how vehicle movement can be detected using sensors.

The project provides a simple prototype model that shows the concept of energy harvesting and smart road technology.

5.1 Conclusion

The **Smart Road Energy Harvester with Vehicle Detection using Arduino** is a project that focuses on utilizing the mechanical pressure produced by vehicles moving on roads and converting it into useful electrical energy. In this system, piezoelectric sensors are used to generate electrical voltage when pressure is applied to them.

The generated voltage is converted into DC power using a rectifier circuit and stored using capacitors or batteries. The stored energy can be used to power small electrical devices such as LED lights.

The system also includes vehicle detection using sensors connected to an Arduino microcontroller. These sensors detect the presence of vehicles and send signals to the Arduino, which processes the information and controls the output devices.

The prototype model developed in this project successfully demonstrates the concept of converting road pressure into electrical energy while also detecting vehicle movement. The system is simple, cost-effective, and environmentally friendly.

Although the amount of generated energy is small in a prototype model, the concept can be expanded and implemented on a larger scale in real-world applications such as highways, toll plazas, and smart city infrastructure.

5.1 Future Enhancements

Although the proposed system demonstrates the basic concept of road energy harvesting and vehicle detection, several improvements can be made in the future to increase its efficiency and functionality.

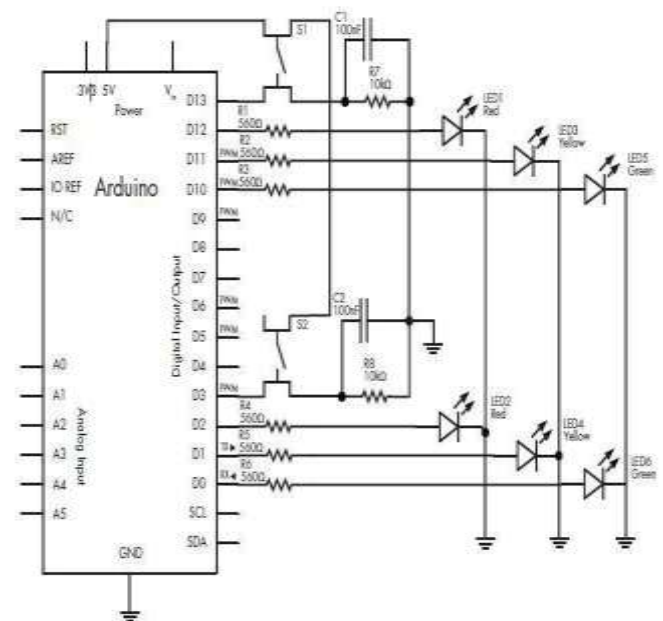
One possible enhancement is the use of a larger number of piezoelectric sensors to increase the amount of generated electrical energy. By installing multiple sensors under the road surface, more energy can be captured from vehicle movement.

Another improvement can be the integration of **energy storage systems such as rechargeable batteries or supercapacitors** to store larger amounts of generated energy.

The system can also be integrated with **smart traffic management systems** to monitor traffic flow and improve road safety. Advanced communication technologies such as **Internet of Things (IoT)** can be used to transmit real-time data to control centers.

Future versions of the system can also include **solar energy systems combined with road energy harvesting** to increase total power generation.

With further research and development, the Smart Road Energy Harvester system can become an important part of **smart city infrastructure and sustainable energy solutions**.



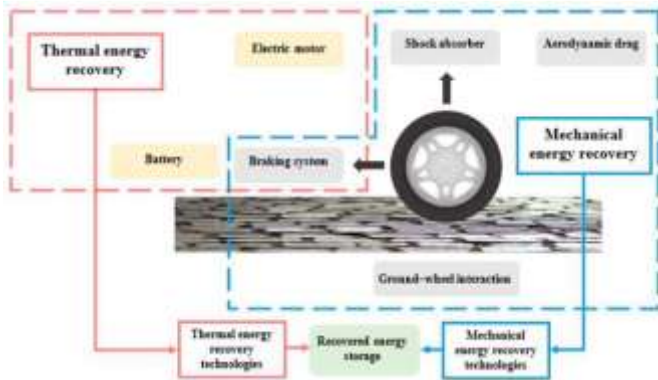


Fig. 6: Flowchart of energy harvesting and vehicle detection

Table 6: Conclusion and Future Scope of the Project

Sr. No.	Aspect	Description
1	Energy Generation	The system successfully converts mechanical pressure from moving vehicles into electrical energy using piezoelectric sensors.
2	Vehicle Detection	The project detects vehicle movement using sensors connected to the Arduino microcontroller.
3	Prototype Demonstration	The developed prototype demonstrates the concept of smart road energy harvesting in a simple and effective way.
4	Environmental Benefit	The system promotes renewable energy and reduces dependency on conventional power sources.
5	Future Improvement	The number of piezoelectric sensors can be increased to generate more electrical energy.
6	Energy Storage Enhancement	Advanced energy storage systems such as rechargeable batteries or supercapacitors can be used.
7	Smart City Integration	The system can be integrated with smart traffic monitoring and smart city infrastructure.

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