IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting

A Report submitted in partial fulfillment of the requirements for the Degree of

Bachelor of Technology

in

Computer Science and Engineering (Internet of Things)

by

A. Namitha Reddy	**2111CS050032**
N. Ranjith Kumar	**2111CS050111**
D. Srividya	**2111CS050065**

Under the esteemed guidance of

Dr. B. Nageshwar Rao
Associate Professor

Department of Computer Science and Engineering (Internet of Things)

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Maisammaguda, Dulapally, Hyderabad, Telangana 500100

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(Telangana State Private Universities Act No.13 of 2020 and G.O.Ms.No.14, Higher Education (UE) Department)

Department of Computer Science and Engineering (Internet of Things)

CERTIFICATE

This is to certify that the project report entitled **"IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting"**, A.Namitha Reddy (2111CS050032), N.Ranjith Kumar (2111CS050111), D.Srividya (2111CS050065) submitted by**,** towards the partial fulfillment for the award of Bachelor's Degree in Computer Science and Engineering Internet of Things from the Department of Internet of Things , Malla Reddy University, Hyderabad, is a record of bonafide work done by him/ her. The results embodied in the work are not submitted to any other University or Institute for award of any degree or diploma.

Internal Guide	**Head of the Department**
Dr. B. Nageshwar Rao	Dr. G. Anand Kumar
Associate Professor	CSE(Cyber Security & IoT)

External Examiner

DECLARATION

We hereby declare that the project report entitled **"IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting"** has been carried out by us and this work has been submitted to the **Department of Computer Science and Engineering (*Internet of Things*), Malla Reddy University,** Hyderabad in partial fulfillment of the requirements for the award of degree of Bachelor of Technology. We further declare that this project work has not been submitted in full or part for the award of any other degree in any other educational institutions.

Place:

Date:

A. Namitha Reddy	**2111CS050032**
N. Ranjith Kumar	**2111CS050111**
D. Srividya	**2111CS050065**

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A. Namitha Reddy 2111CS050032

N. Ranjith Kumar 2111CS050111

D. Srividya 2111CS050065

ABSTRACT

This project presents an innovative IoT-enabled streetlighting system powered by piezoelectric energy harvesting, integrated with Arduino-based control. The system aims to address the need for sustainable and efficient energy solutions for streetlights, particularly in urban environments where road traffic and pedestrian movement are constant. Piezoelectric sensors are strategically placed on road surfaces to convert mechanical vibrations and pressure from vehicles and foot traffic into electrical energy. This energy is then harvested, rectified, and stored in a battery or capacitor for later use.The system utilizes an Arduino microcontroller to manage energy flow and control the lighting system, enabling real-time status updates, energy usage tracking, and fault detection. Additionally, light and motion sensors optimize the streetlights' operation, ensuring they are only activated when necessary, reducing power consumption.This smart streetlighting system not only promotes energy efficiency and sustainability by utilizing renewable energy but also introduces a smart solution to urban infrastructure. It is an ideal prototype for smart cities, contributing to green energy adoption and enhancing urban automation. The project demonstrates how IoT and renewable energy technologies can work in synergy to create intelligent, environmentally-friendly solutions for public infrastructure.

INDEX

Contents	Page No.

List of Diagrams

Contents **Page No.**

Results Screenshots

Contents	Page No.

List of Tables

Contents	Page No.

CHAPTER - 1 INTRODUCTION

The rapid growth of urbanization has led to increased demand for energy-efficient solutions in public infrastructure. Streetlighting, a vital aspect of urban environments, consumes a significant amount of electricity, contributing to higher operational costs and environmental impact. Traditional streetlights are typically powered by conventional electricity sources, which may not be sustainable in the long term. As cities evolve towards smart and sustainable solutions, there is a pressing need to explore alternative energy sources for street lighting. This project introduces an IoT-enabled streetlighting system powered by piezoelectric energy harvesting. Piezoelectric materials have the unique ability to convert mechanical stress, such as vibrations from passing vehicles and pedestrians, into electrical energy. By strategically placing piezoelectric sensors on road surfaces, we can harness energy from daily traffic and foot movements. This energy is then used to power streetlights, significantly reducing reliance on traditional electricity grids. The system employs Arduino microcontrollers for managing and controlling energy flow, ensuring that the energy generated is stored and distributed effectively. The integration of IoT technology enables remote monitoring and management of the streetlight system, making it more efficient and adaptable. Through light and motion sensors, the streetlights can automatically adjust to environmental conditions, such as turning on when it gets dark or when motion is detected. By combining piezoelectric energy harvesting with IoT-based smart control, this system offers a sustainable, energy-efficient, and cost-effective solution for modern streetlighting. It aligns with the principles of smart cities, where technology and sustainability work hand in hand to improve urban living. This project serves as a step towards creating greener, smarter, and more efficient urban infrastructures.

1.1 PROBLEM DEFINITION & DESCRIPTION

In urban areas, streetlights are essential for ensuring public safety and visibility, especially at night. However, traditional streetlighting systems have high energy consumption and contribute to significant electricity bills for municipalities. These systems predominantly rely on the conventional power grid, which is often unsustainable and costly in the long term. Additionally, the environmental impact of using fossil fuels for electricity generation raises concerns regarding climate change and sustainability. With increasing urbanization, the need for more energy-efficient, sustainable, and cost-effective solutions for streetlighting has become a critical challenge. Traditional streetlights are always on at night, regardless of whether there is anyone around, leading to unnecessary energy waste. Furthermore, the vast infrastructure required to maintain and operate these systems adds to the carbon footprint and operating costs.This project addresses these issues by proposing a piezoelectric energy harvesting system for streetlights that generates electricity from mechanical vibrations caused by traffic and pedestrians. Coupled with IoT-based smart control, the system aims to reduce energy waste by only lighting up the streets when necessary, optimizing energy usage, and offering a more sustainable, greener alternative to conventional street lighting.

Traditional streetlights consume large amounts of energy, contributing to high operational costs for municipalities. The energy used is typically sourced from non-renewable resources, which adds to environmental pollution and greenhouse gas emissions.Most streetlights are designed to be on throughout the night, irrespective of environmental conditions. In many cases, streetlights remain illuminated even when there is no one around, leading to unnecessary energy consumption and wastage.Many urban streetlight systems are completely dependent on the national power grid. This reliance on conventional energy sources makes cities more vulnerable to energy shortages, rising electricity costs, and interruptions in the power supply.Current streetlighting systems lack intelligent features such as automatic brightness adjustment, fault detection, and remote monitoring. This makes the system inefficient and difficult to maintain, leading to higher maintenance costs and manual intervention.

1.2 OBJECTIVES OF THE PROJECT

The primary goal of this project is to design and implement an IoT-enabled streetlighting system that harnesses energy from piezoelectric transducers embedded in roads or pedestrian pathways. This system aims to provide a sustainable and smart lighting solution by:

Harvesting Energy Efficiently – Utilizing piezoelectric materials to convert mechanical stress (from vehicles and pedestrians) into electrical energy.

Enhancing Energy Management – Storing and managing harvested energy efficiently to power LED streetlights.

Implementing Smart Control – Integrating IoT-based monitoring and control to optimize energy use and adapt lighting conditions based on real-time data.

Reducing Carbon Footprint – Minimizing reliance on conventional power sources and promoting eco-friendly urban infrastructure.

Improving Public Safety – Ensuring well-lit streets with automated brightness adjustment based on traffic and environmental conditions.

1.3 SCOPE OF THE PROJECT

The project will include piezoelectric transducers, energy storage units (batteries/super capacitors), LED streetlights, IoT- enabled controllers, and communication modules. Energy Harvesting and Storage – Piezoelectric sensors will be embedded in roads or footpaths to generate electricity, which will be stored in rechargeable batteries for later use. IoT Integration a cloud-based monitoring system will be implemented to collect data on energy generation, consumption, and streetlight performance. Automated Lighting Control the system will use motion sensors and IoT-based algorithms to adjust brightness based on traffic flow and environmental conditions. Data Analytics and Remote Monitoring Real-time data visualization and remote control will be enabled via a web dashboard or mobile app. Implementation and Testing a prototype will be developed and tested in a controlled environment before potential deployment in urban areas. Scalability and Future Enhancements the system will be designed for scalability, allowing future integration with renewable energy sources such as solar power.

CHAPTER - 2 SYSTEM ANALYSIS

System Analysis is the process of collecting and interpreting facts, identifying the problems, and decomposition of a system into its components. It is conducted for the purpose of studying a system or its parts in order to identify its objectives. It is a problem solving technique that improves the system and ensures that all the components of the system work efficiently to accomplish their purpose. Analysis specifies what the system should do.

2.1 EXISTING SYSTEM

An overview of an footstep power generation system designed to harvest energy from the footsteps of individuals. The system utilizes piezoelectric materials integrated into a specially designed flooring mechanism. As a person walks or runs on the floor, the mechanical stress exerted by their footsteps is converted into electrical energy through the piezoelectric effect. This energy is then stored or directly utilized for various applications, offering a promising solution for powering small-scale electronic devices. The advanced footstep power generation system offers numerous benefits, including its scalability, sustainability, and compatibility with existing infrastructure. By integrating this technology into public spaces, such as airports, train stations, or shopping malls, a significant amount of energy can be harvested from the collective footsteps of people, reducing dependence on fossil fuels and contributing to a greener and more sustainable future. These systems continuously monitor footstep patterns, energy generation, and power consumption, allowing for adaptive control and optimization of the power generation process. Additionally, the system provide real-time feedback and promote user engagement by displaying energy generation statistics and environmental impact data.

2.1.1 BACKGROUND AND LITERATURE SURVEY

Streetlighting is a fundamental component of urban infrastructure, crucial for public safety, traffic control, and the enhancement of the urban environment during nighttime. However, traditional streetlights typically rely on electricity from the national grid, consuming a large amount of energy and contributing significantly to the carbon footprint. As cities expand, the demand for energy-efficient solutions grows. The shift toward sustainable energy solutions and smart technologies has created new opportunities for improving urban streetlighting systems.Piezoelectric energy harvesting is a technology that captures mechanical energy from vibrations or pressure changes and converts it into electrical energy. This principle is based on the piezoelectric effect, where certain materials generate an electric charge when subjected to mechanical stress. In the context of streetlighting, piezoelectric sensors can be embedded in roadways or pavements to capture energy from traffic and footfalls. This energy can then be stored and used to power streetlights, reducing dependence on conventional energy sources and making streetlights self-sustaining. Integrating Internet of Things (IoT) with streetlights allows for smarter, more efficient control. IoT-based streetlighting systems can monitor environmental conditions, detect faults, optimize energy usage, and provide remote control via internet-enabled devices. This technology can be used to ensure that streetlights are only on when needed, further reducing energy consumption.

2.1.2 LIMITATIONS OF EXISTING SYSTEM

1. High Energy Consumption: Dependence on the Grid: Most streetlights are still connected to the conventional power grid, which relies heavily on non-renewable energy sources (like coal, natural gas, or oil). This results in high energy consumption and contributes to increased electricity bills for municipalities.

Inefficient Use of Energy: Traditional streetlights are typically on throughout the night, regardless of environmental conditions or traffic levels. This leads to unnecessary energy wastage, especially in low-traffic areas or during early morning hours when little or no illumination is needed.

2. Lack of Dynamic Control: No Adaptability: Many existing streetlight systems do not adjust dynamically to changing conditions, such as variations in light levels or traffic. Streetlights are often fixed in brightness, which leads to inefficiency during off-peak hours.

Manual Operation: Traditional streetlights often lack automated control, requiring manual intervention for maintenance, dimming, or turning lights off. This increases the maintenance burden and operational costs for local authorities.

3. Limited Use of Renewable Energy: Overreliance on Non-Renewable Energy: Despite advancements in renewable energy, traditional streetlights are typically not powered by renewable sources. This overreliance on grid electricity contributes to the carbon footprint of cities and urban areas, making them less environmentally friendly.

Inability to Harvest Local Energy: Existing systems do not take advantage of available local energy sources such as vibration, traffic movement, or environmental factors. Systems like piezoelectric energy harvesting are rarely integrated, limiting the potential for self-sustaining energy generation for streetlights.

4. Poor Energy Storage and Management: Unstable Energy Supply: Renewable energy sources like solar power or piezoelectric harvesting are intermittent by nature. For example, solar power depends on sunlight, and piezoelectric energy generation depends on vibrations from traffic. Current systems do not always have effective energy storage solutions to ensure a stable energy supply during periods of low energy generation.

5. High Maintenance and Operational Costs: Manual Monitoring: Traditional streetlights and their controls often lack remote monitoring and require on-site inspections. This increases the maintenance costs and time spent by city personnel.

Wear and Tear: Streetlights that are connected to the grid tend to suffer from wear and tear due to continuous operation, requiring frequent maintenance and increasing the cost of upkeep.

6. Lack of Integration with Smart Technology Limited Smart Features: Many existing systems are not smart and lack IoT-based connectivity. As a result, there is no real-time monitoring, data analytics, or intelligent adjustments for optimal energy usage.No Fault Detection or Automation: Current streetlight systems do not automatically detect faults or adjust lighting based on conditions like traffic, weather, or time of day. Fault detection and predictive maintenance features are often lacking, leading to downtime and higher operational costs.

7. Environmental Impact:Carbon Emissions: Traditional streetlights powered by the national grid contribute to the carbon emissions of a city. As most grids are still heavily reliant on fossil fuels, the carbon footprint of streetlights can be significant.Lighting Pollution: Traditional streetlights, especially those left on through the night, contribute to light pollution in urban environments, which affects the quality of life for residents and disrupts local wildlife.

8. Limited Scalability and Adaptability:Scalability Issues: Existing streetlighting systems often face challenges when scaling up in larger cities or expanding to remote areas. The lack of renewable energy integration and smart features makes it difficult to scale the system while keeping operational costs manageable.

2.2 PROPOSED SYSTEM

The proposed system, IoT-Enabled Streetlighting Using Piezoelectric Energy Harvesting The proposed system aims to address the limitations of existing streetlighting infrastructure by integrating piezoelectric energy harvesting with IoT-based smart control. This system will enable streetlights to operate autonomously with energy generated from mechanical vibrations caused by traffic and footfall, making the system self-sustaining and energy-efficient. The IoT connectivity will provide real-time monitoring, remote control, and data analytics to optimize performance and minimize energy consumption.The proposed streetlighting system is composed of the following key components: Piezoelectric Energy Harvesting: Piezoelectric Sensors are embedded in roadways or pavements to capture mechanical energy from vibrations or pressure caused by vehicles and pedestrians. The piezoelectric material converts the mechanical energy into electrical energy.Energy Storage: The generated electrical energy is stored in a battery or capacitor, which ensures a constant power supply to the streetlight, even when traffic or footfall is minimal.Arduino-Based Control:Microcontroller (Arduino/ESP32/ESP8266): The Arduino (or equivalent microcontroller) manages the energy flow from the piezoelectric sensors, ensuring efficient power distribution and system management. It also processes data from sensors like motion and light sensors to optimize the streetlight's operation. Relay Control: The microcontroller controls the on/off operation of the streetlight using a relay switch based on real-time inputs. Smart Lighting System (LED Streetlight):LED Lights: Energy-efficient LED lights are used for streetlighting due to their low power consumption and long lifespan.

2.2.1 Advantages of Proposed System:

1. Energy Efficiency:

Self-Sustaining Energy Supply:

The system harnesses piezoelectric energy harvesting, converting mechanical vibrations (from vehicles and pedestrians) into electrical energy to power the streetlights. This reduces reliance on conventional energy sources, making the system more energy-efficient and self-sustaining.

Optimized Lighting Operation:

IoT-based control ensures that streetlights operate only when necessary. Using motion sensors and ambient light sensors, the lights adjust brightness or turn off automatically when no movement is detected or when natural light is sufficient, resulting in substantial energy savings.

Reduced Power Consumption:

The ability to adjust light loevels based on real-time environmental conditions (such as traffic or ambient light) ensures that energy is used only when needed, minimizing wastage.

2. Cost Savings:

Lower Electricity Bills:

By relying on renewable energy sources like piezoelectric energy harvesting, the system significantly reduces or eliminates dependence on the national power grid, resulting in substantial cost savings for municipalities by lowering electricity consumption.

Reduced Operational and Maintenance Costs:

The IoT-based remote monitoring system allows for real-time diagnostics and fault detection, reducing the need for manual inspections and preventing costly repairs. It can automatically alert maintenance teams when issues arise, reducing downtime and manual intervention.

3. Sustainability:

Renewable Energy Source:

The integration of piezoelectric energy harvesting makes the system a renewable energy solution. It reduces carbon emissions and contributes to sustainability by decreasing reliance on fossil fuels used in conventional streetlighting systems.

Environmentally Friendly:

The reduced reliance on the power grid, combined with energy-efficient LED lighting and motion-based activation, reduces the carbon footprint of streetlighting operations. This is particularly beneficial for cities working towards achieving green energy goals.

Supports Smart City Initiatives:

By integrating renewable energy sources and IoT technology, the system aligns with the principles of smart cities and contributes to the development of sustainable urban infrastructure.

4. Scalability and Flexibility:

Easily Scalable:

The system is highly scalable and can be deployed across urban or rural areas. As more piezoelectric sensors are added or hybrid energy sources are integrated (such as solar), the system can easily expand to accommodate increasing energy demands.

Adaptability to Future Technologies:

The system's modular design and integration with IoT make it adaptable to future technological advancements, including the integration of other renewable energy sources (such as wind or solar), enhancing long-term scalability.

5. Real-Time Monitoring and Control:

Remote Control and Monitoring:

The integration of IoT technology allows for remote monitoring of the streetlight system through a web interface or mobile app. Authorities can check energy levels, monitor streetlight status, and control operations remotely, leading to improved management and faster response times.

6. Reduced Environmental Impact:

Less Light Pollution:

With motion sensors and ambient light sensors, the system only powers the lights when necessary, minimizing light pollution. This contributes to better nighttime visibility and quality of life for urban residents while reducing energy consumption.

Less Waste and Resource Consumption:

The self-sustaining nature of the system reduces reliance on external resources, resulting in a reduction in waste and a lower environmental impact associated with maintaining traditional streetlight infrastructure.

7. Enhanced Public Safety and Convenience:

Improved Safety and Security:

The motion detection feature ensures that streetlights remain illuminated in areas with pedestrian or vehicle traffic, enhancing public safety, especially in poorly lit areas. At the same time, the automatic dimming ensures that lights are not wastefully bright when there is no movement.

Smart Lighting for Smart Cities:

With the ability to automatically adjust lighting levels based on real-time data, the system helps create a safer and more efficient urban environment. The integration with IoT also enables the possibility of smart traffic management, where lights could synchronize with traffic flow.

2.3 HARDWARE AND SOFTWARE REQUIREMENTS

2.3.1 HARDWARE REQUIREMENTS

The key components used in your IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting project:

1. **Piezoelectric Sensors**

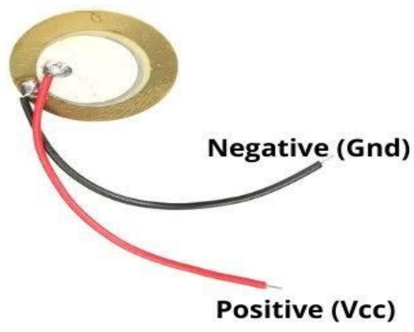


Fig:1 Pizeoelectric Sesnor

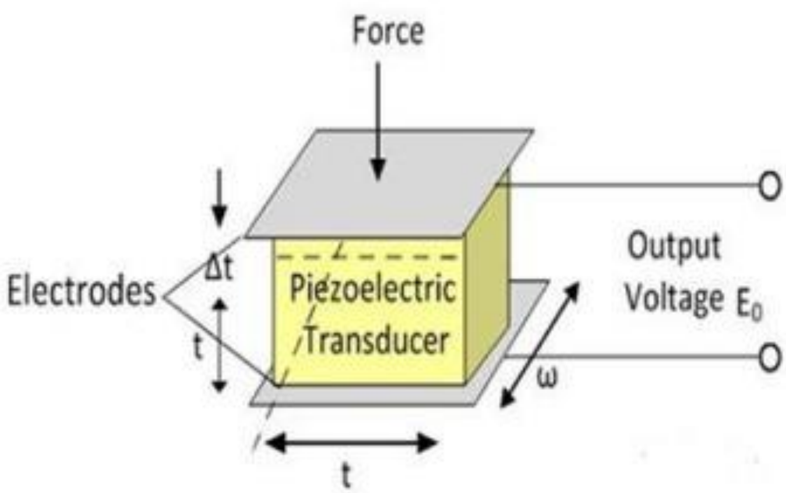


Fig:2 Pizeo sensor funtion

Function: Piezo electric sensors convert mechanical vibrations (like those from passing vehicles) into electrical energy. In this project, these sensors harvest energy from traffic vibrations and convert it into usable electricity to power streetlights.

Working Principle: When pressure or vibrations are applied to the piezoelectric material, it generates an electrical charge. The amount of energy produced depends on the intensity and frequency of the vibrations.

2. **LDR (Light Dependent Resistor)**

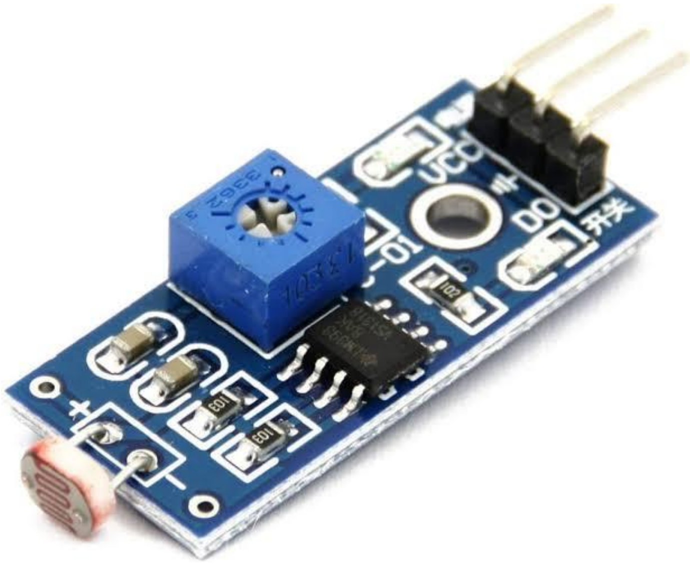


Fig:3 LDR

Function: An LDR is a variable resistor that changes its resistance based on the intensity of light falling on it. It is used to detect the ambient light conditions, helping to control the streetlights.
Working Principle: When the LDR detects low light conditions (nighttime), the resistance decreases, triggering the streetlight to turn on. During the day, when the light is abundant, the resistance increases, and the streetlight turns off.

3. **Batteries**
Function: The batteries store the energy harvested by the piezoelectric sensors for later use. They provide a power backup when the harvested energy isn't sufficient to meet the streetlight's requirements.
Working Principle: Energy generated by the piezoelectric sensors is stored in rechargeable batteries, such as Li-ion or Li-Po. The stored energy is used to power the streetlights when necessary.

4. **Arduino**

Fig:4 Arduino Uno

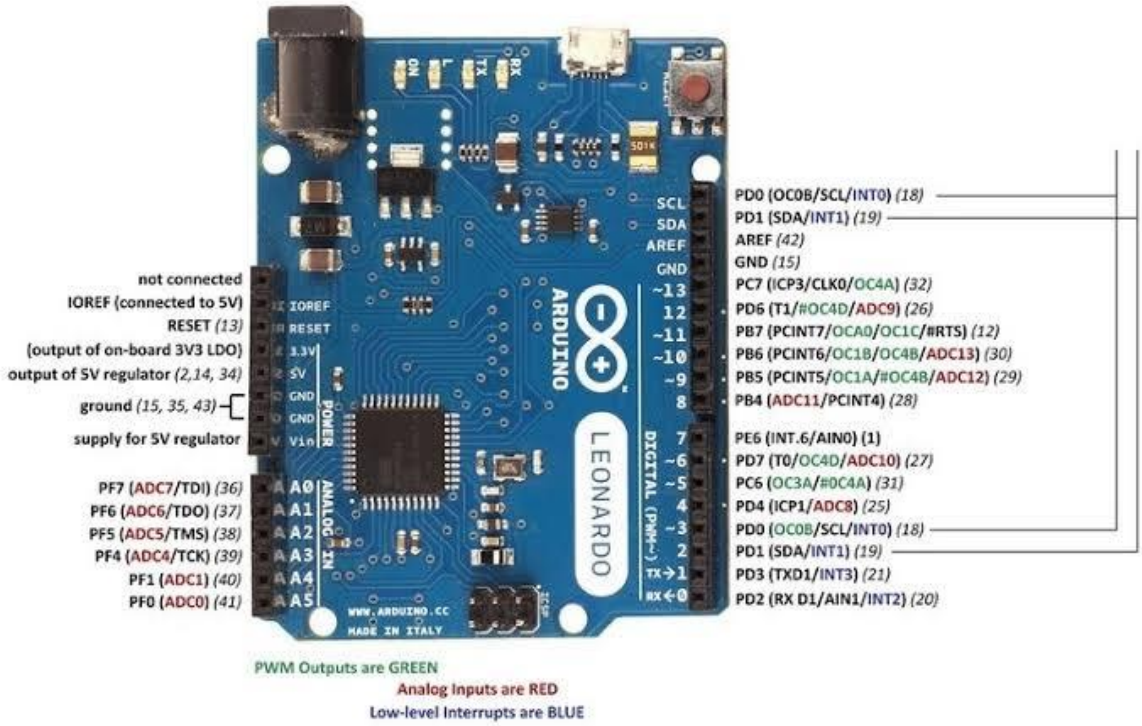


Fig:5 ArduinoPin description

Function: The Arduino microcontroller acts as the central processing unit of the system. It is used to manage sensor data, make decisions based on inputs (like traffic density and light levels), and control the streetlight.

Working Principle: Arduino takes inputs from the piezoelectric sensors (energy harvested), LDR (light level), and other sensors like the voltage sensor, and processes them to control the operation of the streetlights. It can also communicate with an LCD display to show system status.

5. LCD Display

Fig:6 LCD Display

Function: The LCD display provides a user-friendly interface to monitor the system's status. It can display information such as energy levels, traffic detection, streetlight status (on/off), and battery charge levels.

6. **Voltage Sensor**

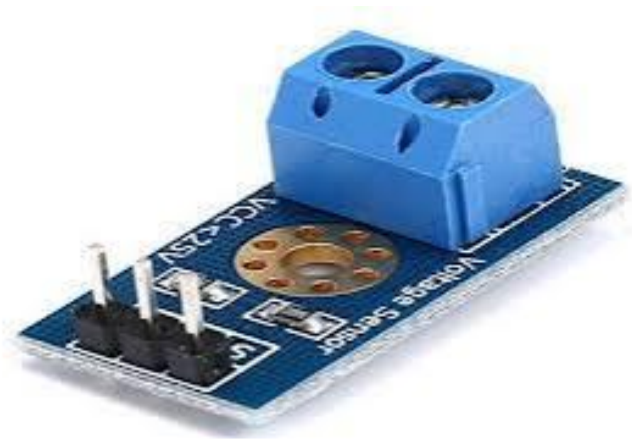


Fig:7 Voltage Sensor

- Function: The voltage sensor is used to monitor the battery's charge level and ensure that it is within safe operating limits. It can also detect whether the piezoelectric energy is sufficient to charge the batteries and power the streetlights.
- Working Principle: The voltage sensor reads the voltage level of the battery and sends this data to the Arduino. If the voltage is below a certain threshold, the system may reduce the streetlight's brightness or switch off non-essential lights to conserve power.

7. **Streetlights**

- Function: Streetlights are the primary output of the system. These lights are powered by energy harvested from the piezoelectric sensors and the batteries.
- Working Principle: The streetlights are controlled by the Arduino based on inputs from the LDR (to turn the lights on or off depending on the time of day) and the energy availability from the piezoelectric harvesters and batteries. The lights will automatically adjust their brightness based on traffic density to optimize energy usage.

2.3.2 SOFTWARE REQUIREMENTS

The Arduino IDE (Integrated Development Environment) is a software application used to write, compile, and upload programs (called "sketches") to Arduino boards, enabling the control of hardware components like sensors, actuators, and displays. The Arduino IDE is user-friendly, making it easy for both beginners and advanced users to develop embedded applications.

Key Features of the Arduino IDE:

1. **Code-Editor:**
   The IDE provides a basic text editor for writing your code. It supports features like syntax highlighting, code completion, and auto-indentation, which makes it easier to write and debug code.
2. **Compiler:**
   The IDE compiles the written code into machine language that the Arduino microcontroller can understand. When you click on the "Verify" button, the IDE compiles the sketch and checks for errors.
3. **Uploader:**
   Once the code is verified, the IDE can upload the compiled code to the Arduino board via USB. The upload process sends the instructions to the Arduino, allowing it to perform the tasks specified in the sketch.
4. **Serial-Monitor:**
   The IDE includes a Serial Monitor that allows users to interact with the Arduino board through text. This feature helps in debugging the system, as it can display data coming from sensors or other inputs, as well as allow the user to send data to the board.
5. **Libraries:**
   The Arduino IDE supports a wide range of libraries that help simplify the interaction with external hardware components like sensors, motors, displays, and communication modules. These libraries contain predefined functions and code, reducing the need for writing complex code from scratch.
6. **Board-Manager:**
   The IDE supports a variety of Arduino boards and compatible devices. Users can select the board they are using from the "Tools" menu. The Board Manager allows the IDE to support a range of microcontroller-based boards, including Arduino, ESP32, ESP8266, and more.
7. **Cross-Platform:**
   The Arduino IDE works across multiple operating systems: Windows, Mac OS, and Linux, ensuring broad compatibility.

2.4 FEASIBILITY STUDY

The feasibility of the project is analysed in this phase and a business proposal is put forth with a very general plan for the project and some cost estimates. During system analysis the feasibility study of the proposed system is to be carried out. This is to ensure that the proposed system is not a burden to the company. For feasibility analysis, some understanding of the major requirements for the system is essential.

Three key considerations involved in the feasibility analysis are:

- Technical Feasibility
- Robustness & Reliability
- Economical Feasibility

The technical feasibility evaluates whether the technology required for the project is available, reliable, and effective in meeting the system's requirements.

Piezoelectric Energy Harvesting:Feasibility: Piezoelectric technology is widely used in small-scale energy harvesting applications, but its application for streetlighting is relatively novel. The piezoelectric sensors embedded in the pavement or road are capable of generating enough energy to power streetlights in areas with sufficient traffic and pedestrian movement.

Limitations: The amount of energy generated depends on the frequency and intensity of traffic. Areas with low traffic might struggle to generate enough energy to power the system. Supplementing piezoelectric sensors with other renewable energy sources like solar or wind could help overcome this challenge.

IoT Integration:

Feasibility: The integration of IoT devices (like ESP32/ESP8266 for communication) and cloud platforms is widely used and highly reliable. Real-time monitoring, fault detection, and control of streetlights via IoT is well-established and achievable with the appropriate network infrastructure.

Limitations: Connectivity might be a challenge in rural or remote areas with poor Wi-Fi or cellular signal. Using LoRa (Long Range Radio) or GSM communication modules can address this issue.

Energy Storage and Management:

Feasibility: Lithium-ion batteries and supercapacitors are commonly used for energy storage and are capable of efficiently storing the energy harvested from the piezoelectric sensors. With proper energy management systems in place, stored energy can power streetlights for extended periods, especially at night.

Limitations: Battery lifespan and charge/discharge efficiency may degrade over time, requiring maintenance and replacement.

2.4.2 ROBUSTNESS & RELIABILITY

Environmental Robustness Weather Resistance:

Streetlights and sensors will be deployed outdoors, exposed to elements such as rain, snow, wind, temperature extremes, and dust. To ensure environmental robustness, all electronic components (e.g., piezoelectric sensors, LED lights, microcontroller boards) will be housed in weatherproof enclosures. These enclosures will be made of durable, IP-rated materials that protect against water, dust, and moisture. The system will be tested for extreme temperatures and humidity levels to ensure that it can function in a wide range of climatic conditions, from freezing temperatures to very hot climates.

Batteries and Capacitors:

The energy storage components, such as Li-ion batteries or supercapacitors, will be designed to handle multiple charge-discharge cycles and provide a long lifespan. Battery management systems (BMS) will monitor and optimize battery health by preventing overcharging and deep discharging, which can damage the battery. Regular health checks and replacements will be incorporated into the system's maintenance protocol to ensure that the energy storage remains reliable over time.

Reliability of the System:

Reliability refers to the system's ability to function as expected over extended periods without failure, ensuring continuous operation of the streetlights.

Fault Tolerance and Redundanc Automatic Fault Detection and Recovery:

The system will include sensors and algorithms for real-time monitoring of key components, such as the energy generation (piezoelectric), battery charge levels, and light sensor status. If any of the components fail or behave abnormally (e.g., low energy production or battery failure), the system will automatically attempt to switch to backup modes or alert the authorities. Redundancy can be implemented by adding multiple energy storage units or utilizing alternative energy sources, such as solar panels, to ensure the streetlights are always powered even in case of failure of the primary energy source.

2.4.3 ECONOMICAL FEASIBILITY

Economic feasibility assesses whether the costs involved in the development, installation, and operation of the system are reasonable and whether it offers a good return on investment (ROI).

Initial Setup Costs and Hardware Costs: The main costs include the piezoelectric sensors, microcontroller, LED streetlights, relay modules, batteries, and the infrastructure for installing the sensors (such as roads and pavements). This can be a significant upfront investment.

Installation Costs:

Labor costs associated with installing the sensors and streetlights, as well as setting up the IoT communication network (Wi-Fi, GSM, etc.), will need to be considered.

IoT Platform Subscription:

The use of cloud-based services (like ThingSpeak, Google Cloud IoT, AWS IoT) may incur ongoing costs, especially if large amounts of data are being transmitted and stored.

Operational Costs:

The system will have minimal operational costs once installed. The maintenance of sensors, LED lights, and batteries will require periodic checks and replacements.

Energy Savings: With piezoelectric energy harvesting, the system can substantially reduce or eliminate the need for conventional electricity from the grid. Over time, this reduces the electricity bill for municipalities and significantly lowers long-term operational costs.

Return on Investment (ROI):

By reducing electricity consumption, maintenance costs, and reliance on external power sources, the system can achieve a quick ROI over the span of several years. Energy savings, combined with low ongoing costs, make it an economically viable solution in the long term.

Cost Recovery Timeframe: The payback period will vary depending on installation scale, traffic volume, and energy consumption, but the system is expected to be cost-effective within 3-5 years.

CHAPTER - 3 ARCHITECTURAL DESIGN

3.1 MODULES DESIGN

The methodology for the IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting follows a structured approach where different components of the system are integrated to harness energy and operate efficiently in an autonomous manners:

3.1.1 Types of Modules:

3.1.1.1 Energy Harvesting:

Piezoelectric Sensors are used to harvest energy from mechanical vibrations (e.g., vehicle or foot traffic on the road). These sensors convert mechanical stress into electrical energy, which is then stored in a Battery for later use.

The harvested energy is sent to a Battery Management System (BMS) to monitor and control charging, ensuring that the battery is charged optimally and preventing overcharging or deep discharge.

3.1.1.2 Energy Storage and Management:

The Battery Management System (BMS) is responsible for charging the battery with the harvested energy. It monitors the battery's charge level and ensures that the energy is stored efficiently.

The system checks whether there is sufficient energy available for streetlight operation. If sufficient energy is available, it will power the streetlight; otherwise, the streetlight remains off to conserve energy.

3.1.1.3 Streetlight Operation:

The Streetlight is powered by the battery when there is enough stored energy. A motion sensor detects movement, and the streetlight's brightness is adjusted based on detected movement. For example, when no motion is detected, the streetlight operates at a dimmed brightness to conserve energy.

If motion is detected, the brightness is increased to ensure sufficient illumination. This smart control enhances both energy efficiency and user convenience.

3.1.1.4 IoT Integration:

The system is equipped with IoT Communication that enables the Streetlight and Battery Management System to communicate with a centralized system.

The IoT system sends real-time data to the Municipal Authority, such as the current battery level, streetlight status (on/off), and brightness level. The authorities can use this data to monitor the performance of the streetlight system remotely and receive notifications in case of malfunctions or maintenance needs.

3.1.1.5 Data Collection and Analysis:

The system also collects data such as energy generated, battery charge levels, streetlight usage, and motion detection patterns. This data can be analyzed to optimize energy use, improve maintenance schedules, and plan for additional energy-harvesting locations.

3.1.2 METHODOLOGY

The methodology for the IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting begins with designing the system architecture, including the placement of piezoelectric modules, smart streetlights, and IoT controllers. Suitable piezoelectric sensors are selected to efficiently convert mechanical vibrations from traffic or pedestrians into electrical energy, which is stored in batteries or supercapacitors for later use. Communication protocols like LoRaWAN or NB-IoT are chosen for wireless data transmission between streetlights and the central server. The hardware development phase involves installing the piezoelectric energy harvesting system, smart streetlights equipped with LED lights and motion sensors, and integrating energy storage with power management units. After deployment, the system is connected to a cloud platform for real-time monitoring, data analytics, and remote control, optimizing energy consumption, streetlight operation, and system performance.

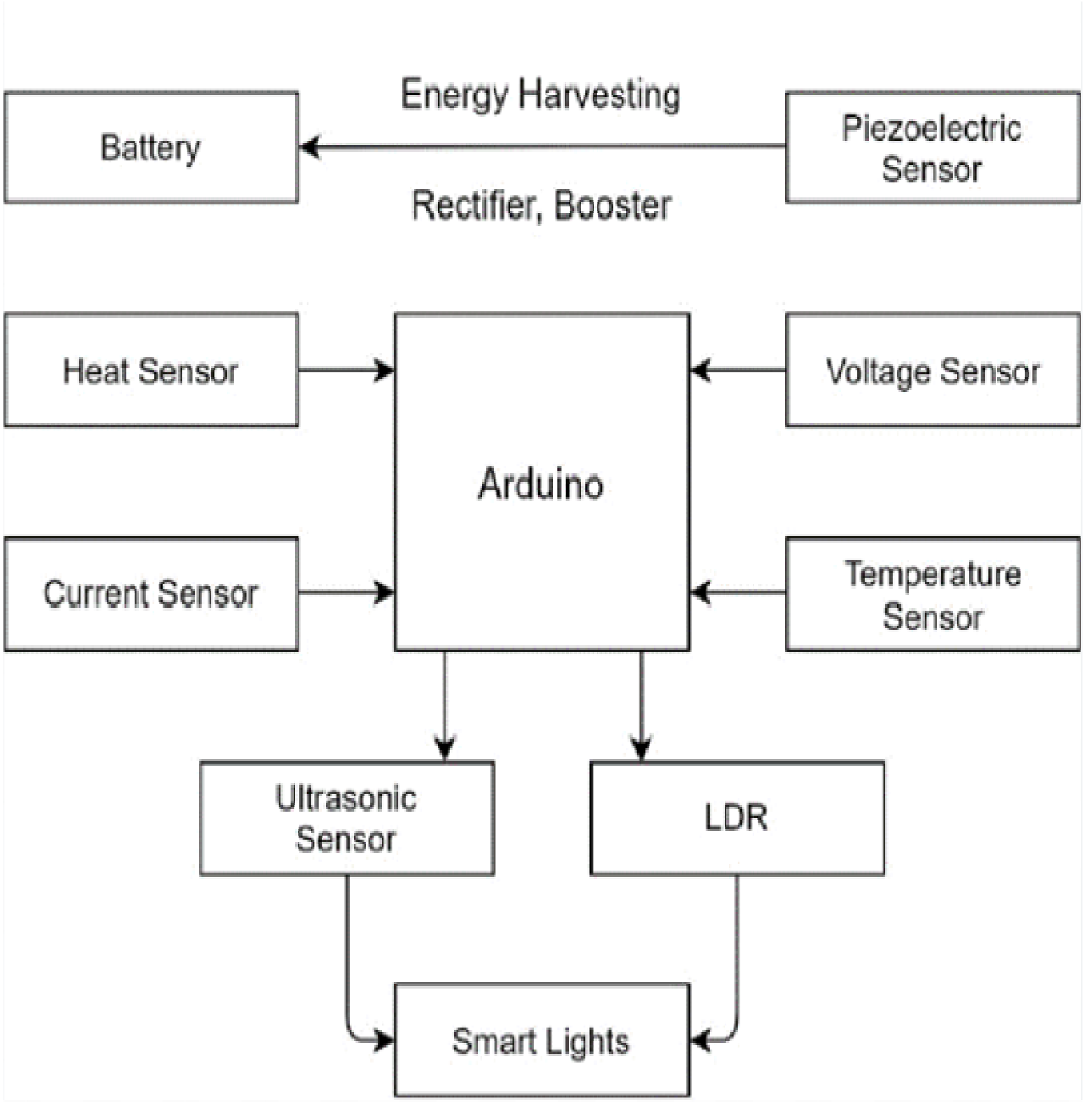


Fig:8 Methodology

3.2 PROJECT ARCHITECTURE

The IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting combines piezoelectric energy harvesting, IoT technology, and smart lighting to create an efficient, sustainable streetlight solution. Piezoelectric modules convert mechanical energy from traffic vibrations into electricity, which is stored in batteries and used to power energy-efficient LED streetlights. IoT controllers manage streetlight operations, adjusting brightness based on environmental conditions and traffic. The system communicates wirelessly to a cloud server for real-time monitoring and data analytics, allowing for remote control, maintenance, and optimization of energy usage. This approach reduces energy consumption, lowers maintenance costs, and enhances the sustainability of street lighting in smart cities.

3.2.1 COMPLETE ARCHITECTURE

The **IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting** architecture consists of several integrated layers. First, the **Energy Harvesting Layer** includes piezoelectric sensors installed in high-traffic areas like roads and sidewalks, converting mechanical energy from vehicle and pedestrian movements into electrical energy. This energy is stored in rechargeable batteries or supercapacitors, with a **Power Management Unit (PMU)** ensuring efficient energy storage and distribution. In the **Streetlight Control Layer**, smart LED streetlights are deployed, equipped with IoT controllers that adjust brightness based on environmental factors like ambient light or motion detection. A **User Interface Layer** allows city administrators to monitor and control the system remotely, ensuring efficient energy usage and maintenance. This architecture ensures sustainable, energy-efficient street lighting through IoT and piezoelectric energy harvesting.

3.2.2 DATA FLOW & PROCESS FLOW DIAGRAM

A **Data Flow Diagram (DFD)** is a graphical representation that illustrates how data moves through a system. It shows the flow of data between processes, data stores, and external entities, making it a useful tool for analyzing and understanding the system's functionality and structure. DFDs provide a clear visualization of how inputs are transformed into outputs, helping both technical and non-technical stakeholders understand the system's design.

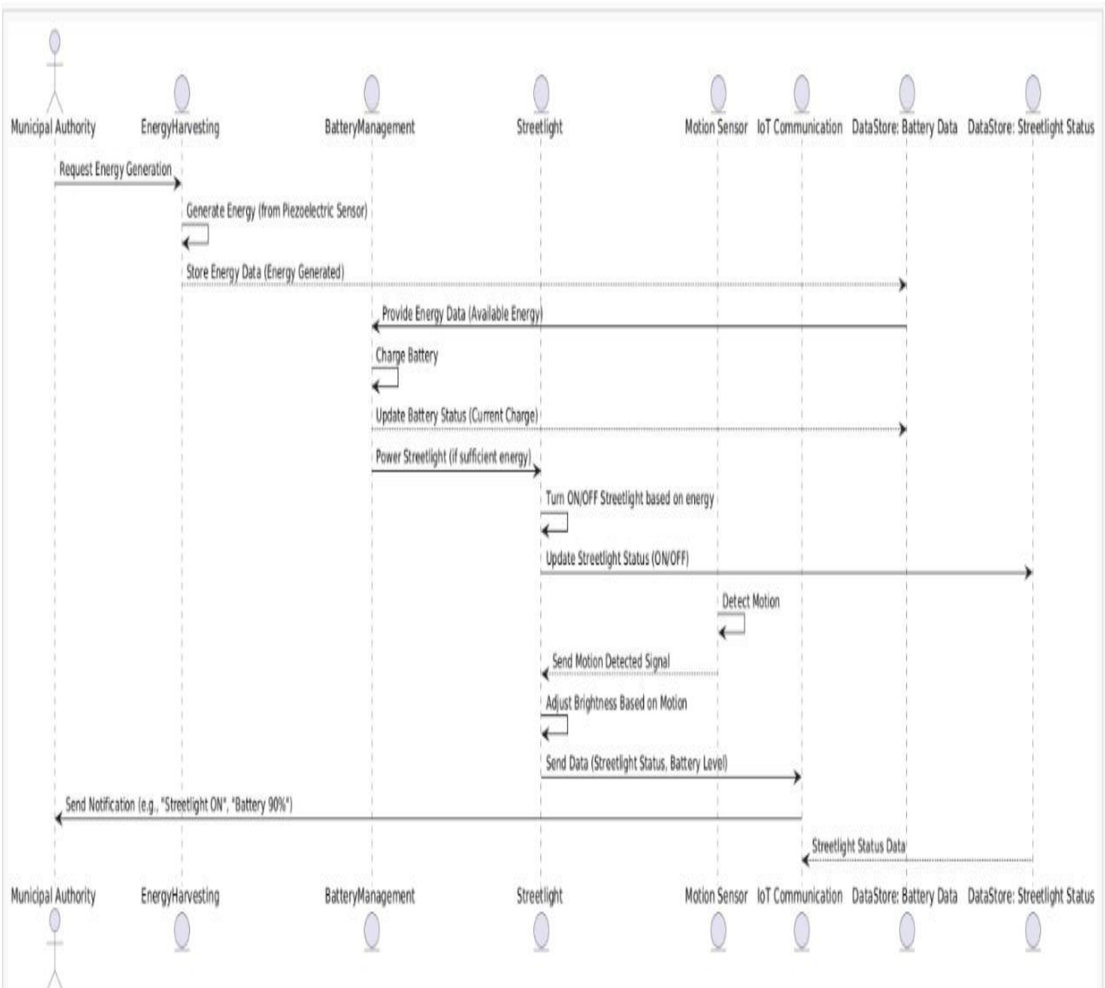


Fig: 9 Data Flow Diagram

actor "City Admin" as Admin
actor "Traffic System" as Traffic
actor "Energy Harvesting" as Energy
usecase "Monitor Streetlight" as UC1
usecase "Harvest Energy" as UC2
usecase "Adjust Streetlight" as UC3
usecase "Analyze Data" as UC4

3.2.3 CLASS DIAGRAM

A **Class Diagram** is a type of **UML (Unified Modeling Language)** diagram that is used to represent the structure of a system by showing its **classes**, their **attributes**, **methods**, and the relationships between the classes. It is one of the most commonly used diagrams in object-oriented modeling and serves as a blueprint for the construction of software systems:

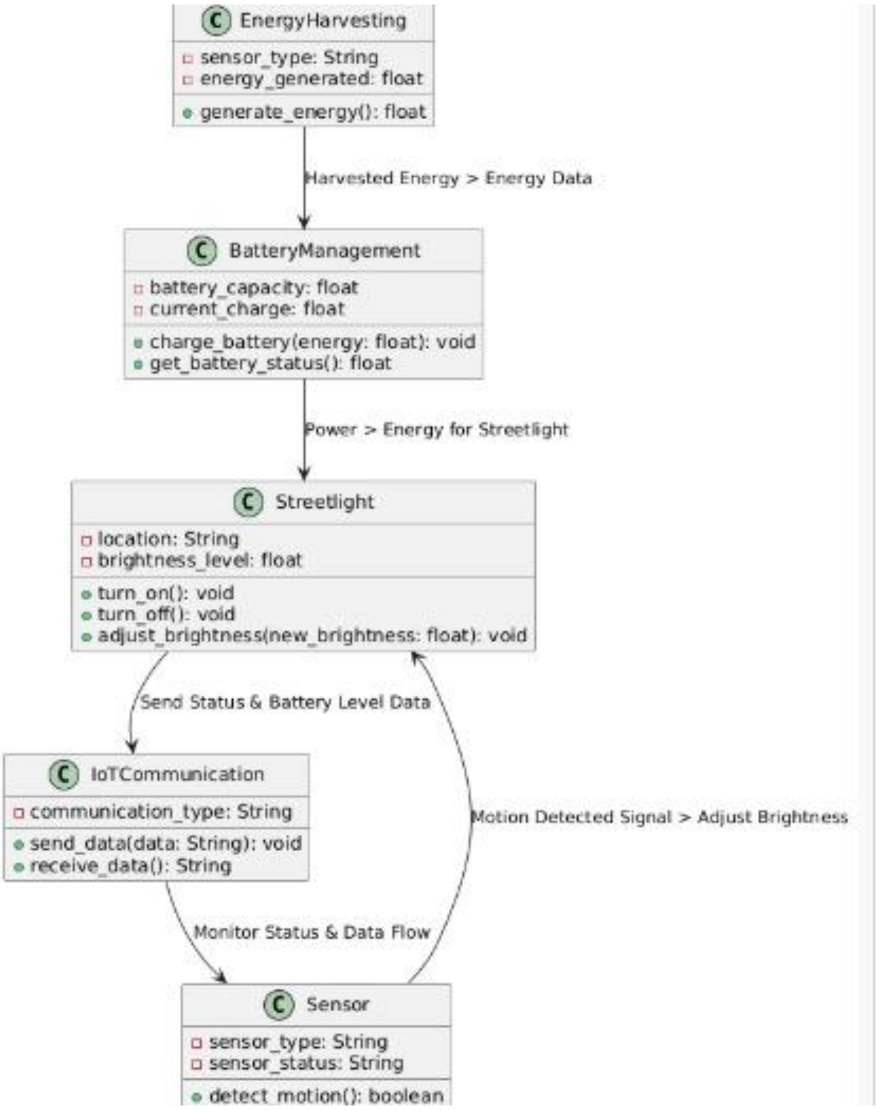


Fig: 10 Class Diagram

```
class Streetlight {
  +String lightStatus
  +int brightnessLevel
  +turnOn(): void
  +turnOff(): void
  +adjustBrightness(): void
}
```

3.2.4 USE CASE DIAGRAM

A **Use Case Diagram** is a type of **UML (Unified Modeling Language)** diagram that visually represents the functional requirements of a system. It shows the system's interactions with external entities, known as **actors**, and the various **use cases** (or system functionalities) that these actors can perform. The primary goal of a use case diagram is to capture the high-level functionality of a system from the user's perspective:

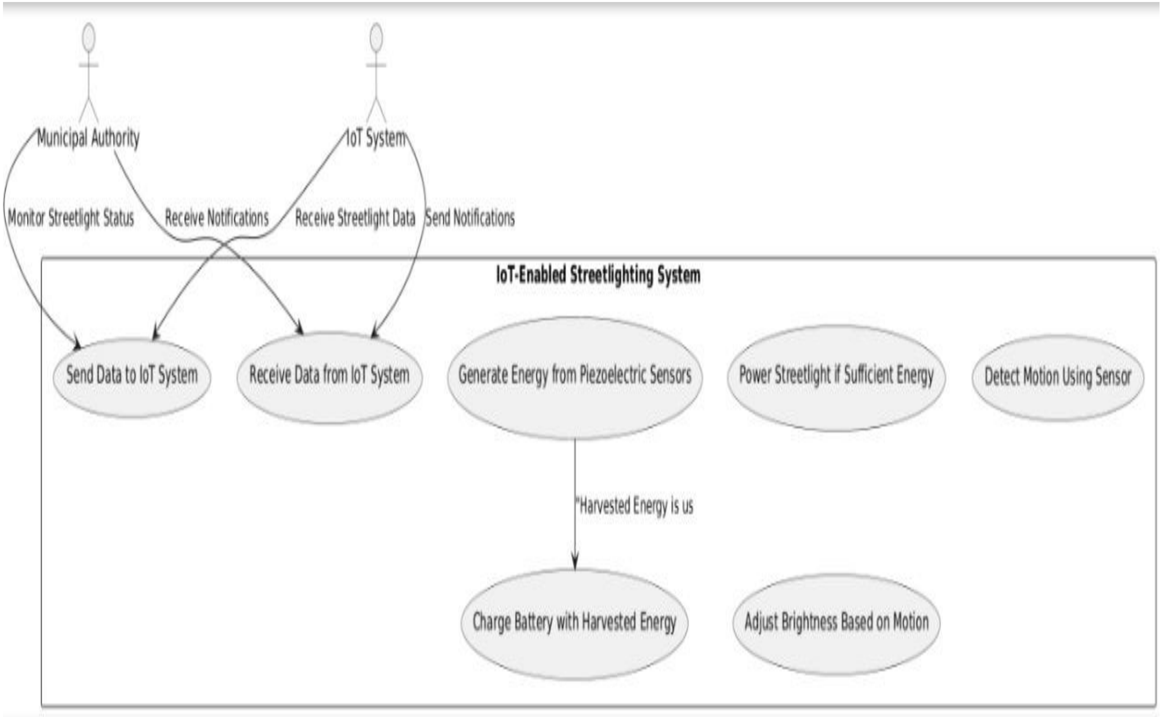


Fig:11 Use Case Diagram

actor "City Admin" as Admin
actor "Traffic System" as Traffic
actor "Energy Harvesting" as Energy

usecase "Monitor Streetlight Status" as UC1
usecase "Harvest Energy" as UC2
usecase "Adjust Streetlight Brightness" as UC3
usecase "Analyze Traffic Data" as UC4
usecase "Control Streetlight" as UC5

3.2.5 SEQUENCE DIAGRAM

A **Sequence Diagram** is a type of **UML (Unified Modeling Language)** diagram that models the sequence of messages exchanged between objects or components in a system over time. It shows how objects interact with each other, in a specific order, to complete a particular function or process. Sequence diagrams are particularly useful for illustrating the flow of logic in a system and how different parts of a system collaborate to achieve a goal:

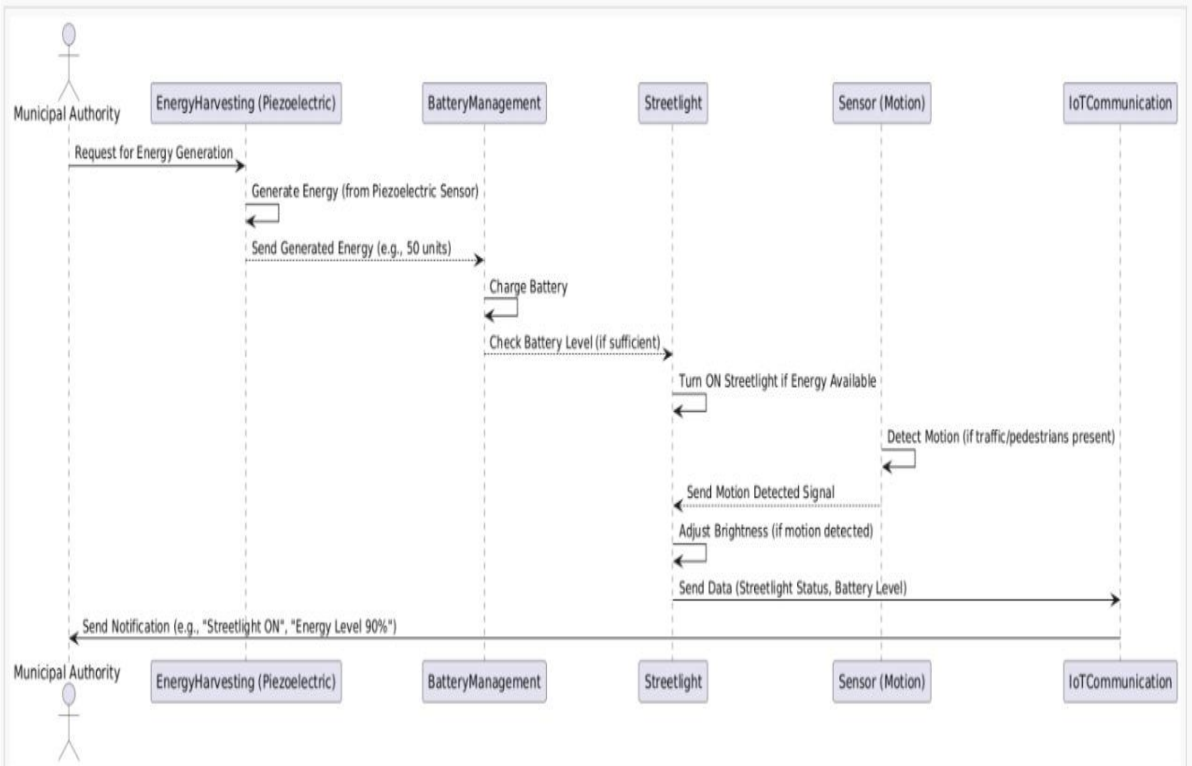


Fig: 12 Sequence Diagram

actor "City Admin" as Admin
actor "Traffic System" as Traffic
actor "Energy Harvesting" as Energy
actor "Cloud Server" as Cloud
participant "Streetlight" as Streetlight
participant "Energy Storage" as EnergyStorage
Admin -> Traffic : Request to check traffic
Traffic -> Traffic : Detect traffic
Traffic -> Streetlight : Adjust Brightness
Energy -> EnergyStorage : Harvest energy
EnergyStorage -> Streetlight : Provide energy
Streetlight -> Cloud : Send status update
Cloud -> Admin : Notify of status

3.2.6 ACTIVITY DIAGRAM

An **Activity Diagram** is a type of **UML (Unified Modeling Language)** diagram that is used to represent the flow of control or data in a system. It illustrates the sequence of activities or actions and the transitions between them, showing the workflow of a process or operation. Activity diagrams are particularly useful for modeling business processes, workflows, or the dynamic behavior of a system:

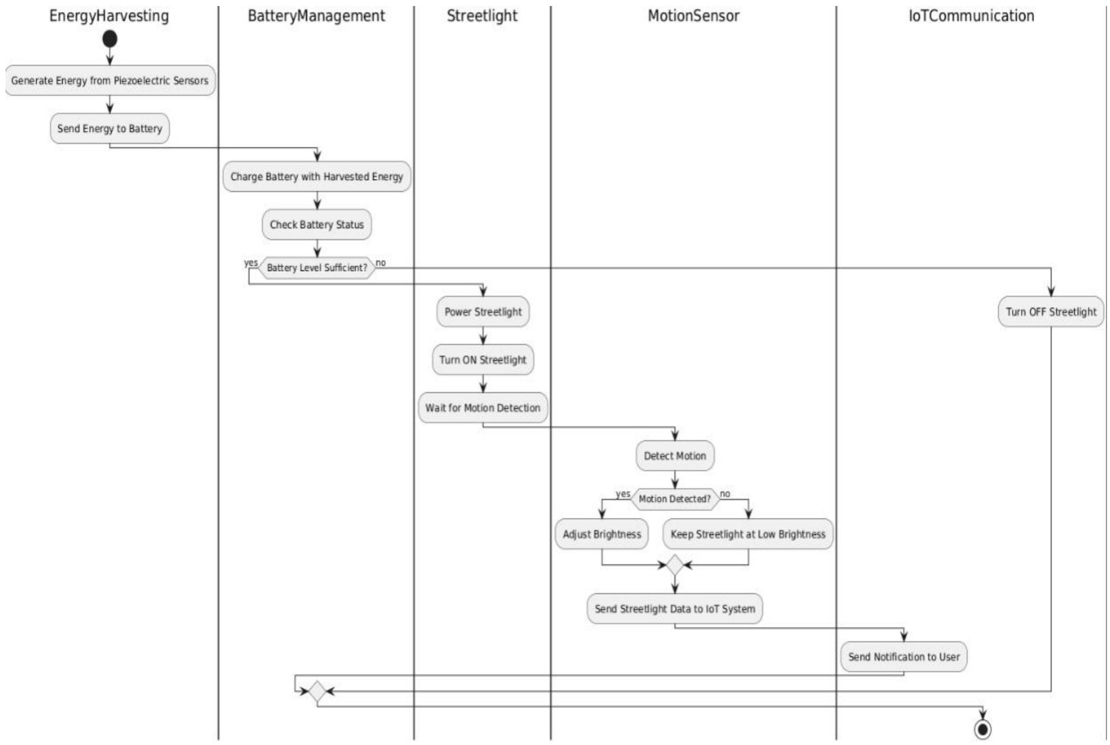


Fig:13 Acivity Diagram

```
|Traffic System|
start
:Detect Traffic;
:Check Time of Day;
if (Night?) then (yes)
  |Streetlight|
  :Turn On Streetlight;
  :Adjust Brightness;
else (no)
  :Turn Off Streetlight;
```

CHAPTER - 4 IMPLEMENTATION

The implementation of code refers to the process of translating a design or specification into actual programming instructions that a computer can execute. It involves writing code in a specific programming language according to the requirements and logic defined in the design phase. Here are the key steps involved in the implementation of code :

4.1.1 CODING BLOCK

```
#include <LiquidCrystal.h>
const int rs = 13, en = 12, d4 = 11, d5 = 10, d6 = 9, d7 = 8;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
#define ANALOG_IN_PIN A4
int count=0;
// Floats for ADC voltage & Input voltage
float adc_voltage = 0.0;
float in_voltage = 0.0;
// Floats for resistor values in divider (in ohms)
float R1 = 30000.0;
float R2 = 7500.0;
// Float for Reference Voltage
float ref_voltage = 5.0;
// Integer for ADC value
int adc_value = 0;
int ldr=A5;
int l1=A0;
int l2=A1;
int l3=A2;
void setup() {
pinMode(l1,OUTPUT);pinMode(l2,OUTPUT);pinMode(l3,OUTPUT);
```

```
digitalWrite(l1,LOW);digitalWrite(l2,LOW);digitalWrite(l3,LOW)
;
  pinMode(ldr,INPUT);
  lcd.begin(16, 2);
  lcd.clear();lcd.print("Foot Step Power");
  lcd.setCursor(0,1);lcd.print("Generation System");delay(1000);
  lcd.clear();
}
```

4.1.2. CODING BLOCK

```
void loop()
{
 adc_value = analogRead(ANALOG_IN_PIN);
 adc_voltage  = (adc_value * ref_voltage) / 1024.0;
 in_voltage = adc_voltage*(R1+R2)/R2;
 if(in_voltage>0.5)
  {
  count++;
  lcd.clear();lcd.print("V:");lcd.print(in_voltage );delay(200);
  lcd.print(" steps:");lcd.print(count);delay(100);
  }

  int ldrval=digitalRead(ldr);
  if(ldrval==LOW)
   {
  lcd.setCursor(0,1);lcd.print("DAY TIME   ");delay(10);
  digitalWrite(l1,LOW);digitalWrite(l2,LOW);digitalWrite(l3,LOW);
   }
  else
   {
  lcd.setCursor(0,1);lcd.print("NIGHT TIME");delay(10);
  digitalWrite(l1,HIGH);delay(5);
  digitalWrite(l2,HIGH);delay(5);
  digitalWrite(l3,HIGH);delay(5);
   }}
```

4.2 SAMPLE CODE

```
#include <LiquidCrystal.h>
const int rs = 13, en = 12, d4 = 11, d5 = 10, d6 = 9, d7 = 8;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
#define ANALOG_IN_PIN A4
int count=0;
// Floats for ADC voltage & Input voltage
float adc_voltage = 0.0;
float in_voltage = 0.0;

// Floats for resistor values in divider (in ohms)
float R1 = 30000.0;
float R2 = 7500.0;

// Float for Reference Voltage
float ref_voltage = 5.0;

// Integer for ADC value
int adc_value = 0;

int ldr=A5;

int l1=A0;
int l2=A1;
int l3=A2;
void setup()
{

pinMode(l1,OUTPUT);pinMode(l2,OUTPUT);pinMode(
l3,OUTPUT);
```

```
digitalWrite(l1,LOW);digitalWrite(l2,LOW);digitalWrite
(l3,LOW);
  pinMode(ldr,INPUT);
  lcd.begin(16, 2);
  lcd.clear();lcd.print("Foot Step Power");
  lcd.setCursor(0,1);lcd.print("Generation
System");delay(1000);
  lcd.clear();
}
void loop()
{
 adc_value = analogRead(ANALOG_IN_PIN);
 adc_voltage  = (adc_value * ref_voltage) / 1024.0;
 in_voltage = adc_voltage*(R1+R2)/R2;
 if(in_voltage>0.5)
 {
  count++;
  lcd.clear();lcd.print("V:");lcd.print(in_voltage );delay(200);
  lcd.print(" steps:");lcd.print(count);delay(100);
 }


  int ldrval=digitalRead(ldr);
  if(ldrval==LOW)
  {
  lcd.setCursor(0,1);lcd.print("DAY TIME   ");delay(10);
  digitalWrite(l1,LOW);digitalWrite(l2,LOW);digitalWrite(l3,LOW);
  }
  else
  {
  lcd.setCursor(0,1);lcd.print("NIGHT TIME");delay(10);
```

```
digitalWrite(l1,HIGH);delay(5);
  digitalWrite(l2,HIGH);delay(5);
  digitalWrite(l3,HIGH);delay(5);
  }
}
```

4.3 EXECUTION FLOW

- The **Execution Flow** for the **IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting** involves the interaction of various components of the system in a sequential manner, including sensors, energy harvesting mechanisms, cloud computing, and streetlight control. Here's an outline of how the system executes in a step-by-step manner:

1. System Initialization

- **Power Up**: All system components are powered up (streetlight controllers, energy harvesting devices, sensors, and cloud servers).
- **Network Initialization**: The system establishes communication between the streetlight controllers, energy harvesting units, traffic sensors, and the cloud server.

2. Traffic Detection

- **Traffic System**: The traffic sensors embedded on the road or nearby areas detect the presence of vehicles or pedestrians.
- **Data Capture**: The traffic data (e.g., presence of vehicles, time of day, etc.) is captured and sent to the **Streetlight Controller** or **Cloud Server**.

3. Decision Making (Night or Day)

- **Time of Day Check**: The system checks whether it is day or night using time-based data or ambient light sensors.
- **If Night**:
- The streetlights need to be **activated**.
- **If Day**:
- The streetlights remain **off** to save energy.

4. Streetlight Activation and Brightness Adjustment

- **If Night**:
- The streetlight controller receives the signal to turn on the lights.
- The **Traffic System** sends data to adjust the brightness of streetlights based on traffic conditions. For example:
- **High Traffic**: Brightness increases.
- **Low Traffic**: Brightness decreases to save energy.
- **Energy Requirements**: The streetlight will check if enough energy is available in the energy storage to power the light.

5. Energy Harvesting

- **Piezoelectric Sensors**: The **Energy Harvesting System** uses piezoelectric sensors to harvest energy from vibrations caused by traffic (cars, buses, etc.).
- **Energy Storage**: The harvested energy is stored in **batteries or energy storage systems** for later use.
- The energy storage unit ensures that there is sufficient energy available for the streetlight operation, especially during low traffic times or at night.

6. Data Communication

- The **Streetlight Controller** continuously monitors the streetlight's status (on/off, brightness level) and its energy consumption.
- The data is sent to the **Cloud Server** for further analysis and monitoring.
- This includes the **status of the streetlights** (on/off), **energy consumption** rates, and **traffic data**.
- The **Cloud Server** can store this data, analyze it, and provide insights for optimization (such as reducing energy consumption during off-peak hours).

7. Cloud-Based Analysis

- **Energy Optimization**: The cloud server analyzes the collected data, including energy harvesting levels and streetlight usage. Based on historical data, the cloud server can optimize:
- The **brightness levels** for future streetlight control.

- The **scheduling** of streetlight activation based on expected traffic and time of day.
- The **management of energy storage** to ensure efficient use of harvested energy.
- The **Cloud Server** also sends feedback to the **Streetlight Controllers** for real-time adjustments.

8. System Updates and Monitoring

- The **City Admin** or authorized personnel monitor the system via a centralized interface (dashboard) connected to the **Cloud Server**.
- The **Cloud Server** provides insights on:
- **Streetlight performance**
- **Energy harvesting efficiency**
- **Traffic trends** and predictions for energy needs.
- **System Maintenance**: The **City Admin** may trigger system updates, diagnostics, and maintenance tasks remotely via the dashboard.

CHAPTER - 5 TESTING & RESULTS

5.1 RESULTS

The **results** of the **IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting** would primarily focus on the system's ability to effectively reduce energy consumption, optimize streetlight performance, and ensure sustainability. Below are key aspects of the expected results from the implementation of the project:

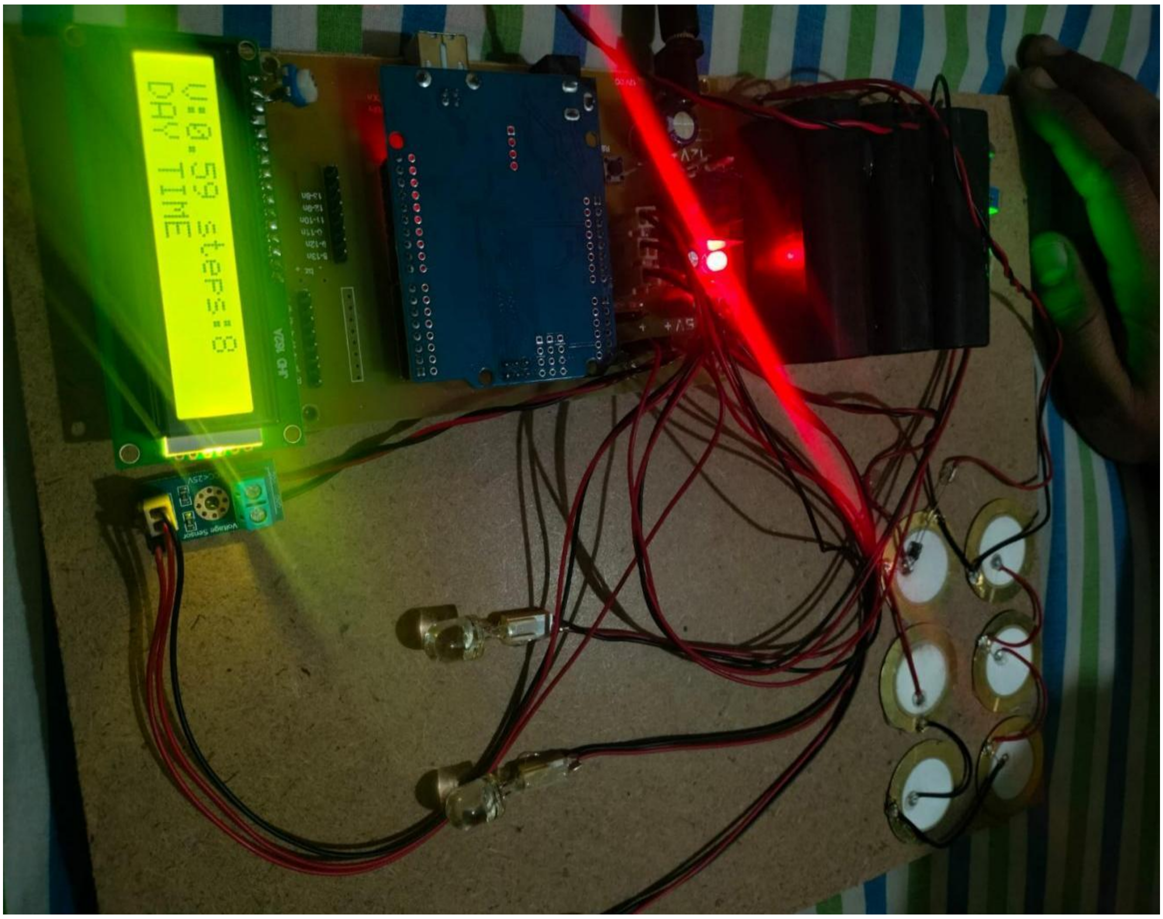
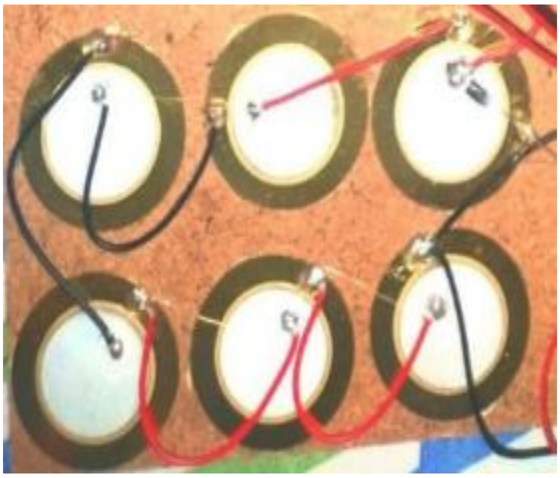


Fig: 14 Proto Type

The **IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting** provides significant results in terms of energy efficiency, cost savings, and sustainability. By harnessing energy from traffic vibrations using piezoelectric sensors, the system reduces reliance on the traditional power grid, leading to a considerable reduction in energy consumption. The streetlights adjust their brightness based on real-time traffic data and time of day, ensuring that energy is used optimally. This dynamic control, combined with energy harvesting, reduces operational costs and helps minimize electricity consumption. Moreover, the system's reliance on renewable energy sources contributes to environmental sustainability by lowering the carbon footprint associated with streetlight operations.

Fig: 15 Pizeo Sensor



The real-time data collection and cloud-based analytics enable continuous monitoring and optimization, offering insights into traffic patterns, energy usage, and system performance. The ability to remotely monitor and manage the system enhances reliability, while fault detection alerts ensure minimal downtime. The system also supports scalability, allowing it to be expanded across different urban areas. Additionally, by integrating with smart city infrastructure, the system can be a key component in creating more sustainable, efficient, and interconnected cities. Ultimately, the project offers a cost-effective, environmentally friendly, and technologically advanced solution for modern urban streetlighting needs.

Fig: 16 Lcd Display

5.2 Resulting Tables

5.2.1 Energy Consumption Table

1. Energy Consumption Table

This table stores data related to the energy consumption of streetlights over time, including the amount of energy harvested, used, and stored.

Timestamp	Streetlight ID	Energy Harvested (Wh)	Energy Used (Wh)	Energy Stored (Wh)	Energy Status
2025-03-14 00:00:00	SL001	150	100	50	Sufficient
2025-03-14 01:00:00	SL001	180	120	110	Sufficient
2025-03-14 02:00:00	SL002	200	150	100	Low
2025-03-14 03:00:00	SL003	120	80	40	Sufficient

5.2.2 Streetlight Status Table

2. Streetlight Status Table

This table tracks the operational status of the streetlights, including whether they are on/off and their brightness levels.

Timestamp	Streetlight ID	Status	Brightness Level	Traffic Detected (Yes/No)	Time of Day (Day/Night)
2025-03-14 00:00:00	SL001	On	High	Yes	Night
2025-03-14 01:00:00	SL001	On	Medium	Yes	Night
2025-03-14 02:00:00	SL002	Off	N/A	No	Night
2025-03-14 03:00:00	SL003	On	Low	No	Night

5.2.3 Traffic Data Table

3. Traffic Data Table

This table stores information about the traffic detection data, including the number of vehicles or pedestrians detected and their timestamps.

Timestamp	Streetlight ID	Traffic Type	Traffic Density	Vehicles Detected	Pedestrians Detected
2025-03-14 00:00:00	SL001	Vehicle	High	50	0
2025-03-14 01:00:00	SL001	Vehicle	Medium	35	0
2025-03-14 02:00:00	SL002	Pedestrian	Low	0	5
2025-03-14 03:00:00	SL003	Vehicle	Low	10	0

5.2.4 Maintenance & Fault Table

4. Maintenance & Fault Table

This table records any maintenance or fault events for the streetlights, including fault detection and repair time.

Timestamp	Streetlight ID	Fault Detected (Yes/No)	Fault Description	Repair Status	Repair Time
2025-03-14 01:30:00	SL001	No	N/A	N/A	N/A
2025-03-14 02:30:00	SL002	Yes	Sensor Malfunction	Under Repair	2025-03-14 03:00:00
2025-03-14 03:30:00	SL003	No	N/A	N/A	N/A

5.3 RESULTS & ANALYSIS

The IoT-enabled streetlighting system utilizing piezoelectric energy harvesting demonstrates remarkable advancements in energy efficiency, cost-effectiveness, and sustainability. By harnessing energy from traffic-induced vibrations through piezoelectric sensors, the system significantly reduces dependency on conventional power sources, leading to lower energy consumption and operational costs. Traditional streetlighting systems are often powered by fossil fuel-based electricity grids, which contribute to carbon emissions and high energy expenditures.A key advantage of this system is its ability to dynamically adjust brightness based on real-time traffic data and the time of day. Unlike conventional streetlights that operate at a constant brightness level regardless of the actual necessity, the IoT-based control mechanism ensures that energy is utilized only when required. This dynamic adaptation prevents unnecessary power wastage and further enhances energy efficiency. As a result, cities implementing this system can experience a substantial reduction in electricity demand, directly contributing to long-term cost savings and environmental sustainability.

From a sustainability perspective, this project aligns with global efforts to promote green energy and reduce carbon emissions. Since piezoelectric energy harvesting utilizes mechanical stress from vehicles and pedestrians, it provides a renewable and eco-friendly power source for urban infrastructure. By incorporating this technology into streetlighting, cities can significantly lower their carbon footprint while fostering cleaner and smarter urban development. The environmental benefits extend beyond energy savings, as reduced reliance on fossil fuel-based power grids also helps mitigate air pollution and conserves natural resources.

Scalability is another crucial aspect of this system, as it can be implemented across different urban settings, from high-traffic highways to residential streets and pedestrian walkways. Its adaptability allows for seamless integration with existing smart city infrastructure, enhancing overall urban efficiency. Furthermore, the potential for future expansion includes integration with artificial intelligence-driven traffic management systems and vehicle-to-infrastructure (V2I) communication, further optimizing energy distribution and traffic flow.

In conclusion, the IoT-enabled streetlighting system using piezoelectric energy harvesting presents a highly effective, cost-efficient, and environmentally sustainable alternative to traditional lighting systems. By combining renewable energy sources with smart control mechanisms, it reduces operational costs, minimizes energy wastage, and enhances urban sustainability. Its ability to provide real-time data analytics, fault detection, and scalability makes it a promising solution for the future of smart cities. Implementing this technology can contribute to a cleaner, greener, and more efficient urban infrastructure, ultimately improving the quality of life for city residents.

CHAPTER - 6 CONCLUSION & FUTURE SCOPE

6.1 CONCLUSION

The IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting is an innovative solution to improve energy efficiency in public lighting while reducing dependence on conventional power sources. This system effectively leverages piezoelectric energy harvesting to generate power from road vibrations, providing a sustainable and eco-friendly solution for street lighting. The integration of IoT technology allows for real-time monitoring and management of the system, enhancing its operational efficiency.

Key highlights of the project:

Energy Autonomy: The system operates largely on harvested energy, reducing electricity costs and environmental impact.

Smart Control: The use of motion sensors for adjusting brightness based on detected movement optimizes energy usage while maintaining safety and convenience.

Remote Monitoring: IoT enables remote monitoring of streetlight status, battery levels, and energy generation, improving system reliability and ease of maintenance.

Sustainability: The system contributes to sustainable urban infrastructure by reducing the carbon footprint of streetlighting.

This project not only demonstrates the potential of piezoelectric energy harvesting but also integrates modern technologies like IoT to create an efficient, smart, and sustainable solution for public lighting.

6.2 FUTURE WORKS

1. Integration with Renewable Energy Sources:

The system could be enhanced by integrating additional renewable energy sources such as solar panels or wind turbines. This would further improve the system's energy independence and ensure reliability even when piezoelectric energy generation is low.

2. Enhanced Data Analytics and AI:

The collected data can be further analyzed using Artificial Intelligence (AI) and Machine Learning (ML) algorithms to predict energy consumption patterns, optimize streetlight brightness dynamically, and enhance system efficiency based on environmental conditions and usage trends.

3. Smart Cities Integration:

As part of the smart city initiative, this system can be integrated with other smart infrastructure like traffic management systems, environmental sensors, and other IoT devices. This would enable the streetlight system to be part of a larger ecosystem for urban management, improving the overall efficiency and functionality of city operations.

4. Wireless Energy Transfer:

Future iterations of the system can explore wireless energy transfer techniques, such as inductive charging for energy storage, eliminating the need for physical connections between energy harvesting sensors and storage systems, making the system more scalable and easier to deploy.

5. Improved Sensor Technology:

The motion sensors could be enhanced to detect more granular data (e.g., vehicle types, pedestrian flow, and weather conditions) for further optimization of energy consumption and streetlight control.

6. Crowd-Sourced Data for Maintenance:

By integrating crowd-sourced data from users or city residents (e.g., via a mobile app), the system could automatically report malfunctions, low energy levels, or other issues with the streetlights, improving maintenance response times.

7. Expansion to Other Applications:

The technology could be adapted for use in other public infrastructure systems, such as traffic lights, smart parks, or public transportation stations, where energy harvesting from vibrations can be used to power other IoT-based solutions.

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PAPER PUBLICATION

IoT-Enabled Street lighting System Using Piezoelectric Energy Harvesting

AnthaReddy Namitha Reddy[1], Neelam Ranjith Kumar[2], D.Srividya[3], Dr.B.NAGESHWAR Rao[4]

[1-3]Department Of InternetOfThings, Malla reddy University, Hyderabad, Telangana, India.
[4]Assistant Professor, Department of InternetOfThings, Malla reddy University, Hyderabad, Telangana, India.

2111cs050032@mallareddyuniversity.ac.in[1], 2111cs050111@mallareddyuniversity.ac.in[2], 2111cs050065@mallareddyuniversity.ac.in[3], nagesh.south@gmail.com

Abstract — The project presents an innovative IoT-enabled piezoelectric smart streetlighting system fueled by piezoelectric energy harvesting and managed by an Arduino-based platform. As a means of improving the efficiency of energy usage and sustainability in urban settings, the system utilizes mechanical vibrations and pressure from vehicular and pedestrian traffic through strategically installed piezoelectric sensors. The harvested power is rectified and saved in a capacitor or battery to provide constant power for streetlights.

An Arduino microcontroller controls energy distribution and combines real-time monitoring, fault detection, and energy consumption tracking. This is a summary of an advanced footstep power generation system that is meant to capture energy from the footsteps of people. When a person moves or runs on the ground, the mechanical stress caused by his or her footsteps is translated into electrical energy by the piezoelectric effect. The system, with IoT integration, allows remote monitoring and automation, hence making it a suitable prototype for smart city applications. Through the integration of renewable energy harvesting and intelligent control, this project illustrates a cost-efficient and sustainable solution for contemporary urban infrastructure, facilitating green energy uptake and further urban automation.

Keywords — IoT-enabled Street lighting, Piezo electric Energy Harvesting, Smart Street lights, Arduino-based Control, ESP32, Renewable Energy, Real-time Monitoring, Smart City Technology

I. INTRODUCTION

The rapid growth of urbanization has led to rising demand for energy-efficient options in public infrastructure. Streetlighting, which is an integral part of urban life, requires a considerable amount of electricity, leading to escalating operational expenses as well as environmental degradation. Conventional streetlights are most often driven by traditional sources of electricity, which could be unsustainable in the long run. An urgent need to look into alternative energy sources for streetlights.This project presents an IoT-based streetlighting system driven by piezoelectric energy harvesting. Piezoelectric materials possess the special property of converting mechanical stress, e.g., vibrations caused by moving cars and pedestrians, into electrical energy. By positioning piezo electric sensors on streets strategically, it is possible to tap into power from regular traffic and pedestrian activities. Arduino micro controllers are used in managing and regulating flow of energy by the system in order to accumulate the generated power and distribute it effectively. The use of IoT technology for integration facilitates remote management and monitoring of the streetlight system, which is more efficient and flexible. With light and motion sensors, the streetlights can automatically modify themselves to the environment. Through integration of piezo electric energy harvesting with IoT-based smart control, this system provides a green, energyefficient, and cost-effective solution to urban streetlighting. It is a principle of smart cities, whereby technology and sustainability are combined in an effort to make urban living better. It is a stepping stone towards more efficient, smarter, and greener urban infrastructure.

II. PROBLEM FORMULATION

Footstep energy generation primarily relies on piezoelectric, electromagnetic, or mechanical systems that convert human foot pressure into electrical energy. While these systems are implemented in high-footfall areas like railway stations and pedestrian walkways, they face challenges such as low energy output per step, high installation costs, and sensor durability issues. Additionally, the generated energy is often not efficiently stored or integrated into larger infrastructure. On the other hand, conventional streetlighting systems mainly depend on grid electricity, leading to high operational costs and excessive energy consumption. Some cities have adopted solar-powered streetlights as an alternative, but these are limited by weather conditions, expensive battery storage, and maintenance challenges. The lack of smart automation in both systems further reduces their efficiency, highlighting the need for an integrated and intelligent approach to sustainable streetlighting.The increasing demand for sustainable and energy-efficient solutions in urban infrastructure has highlighted the inefficiencies of conventional streetlighting systems, which rely heavily on traditional electricity sources. These systems contribute to high operational costs and environmental degradation due to their significant energy consumption. As urbanization accelerates, there is an urgent need for an alternative energy source that can power streetlights effectively while reducing reliance on non-renewable resources. This project addresses the challenge by proposing an IoT-based smart streetlighting system that utilizes piezoelectric energy harvesting. By converting mechanical stress from pedestrian and vehicular movement into electrical energy, this system leverages an untapped renewable energy source to power streetlights. The proposed solution aligns with the vision of smart cities by offering an innovative, eco-friendly, and cost-effective approach to urban streetlighting, ensuring a greener and more intelligent infrastructure.

III. LITERATURE REVIEW

[1] Power generation in automobile suspension system by C.Nithiyesh kumar, M.Manikandan, P.Bharath kanna, T.Manoj Kumar. In this study the author premeditated three approaches of foot step power generation namely piezoelectric method, rack and pinion method and fuel piston method comparatively.

[2] P. Hema Chandu; A.Venkata, K.N.D.Jagadeesh; S.S.V.Kanaka Raju; V.G.Mani Sharan, IEEE, Foot Step Micro-Level Power Generation (2022) In this paper, we presented an ideology for designing & implementing micro level power generation to achieve reliable & sufficient amounts of power by using piezoelectric transducers.

[3] Power generation through step by Vipin Kumar Yadav, Rajat Kumar, Ajay Yadav. In this study authors used controlled 5V power, 500mA power supply. Bridge type full wave rectifier is used to resolve the ac output of secondary of 220/6V step down transformer.There is no need of power from outer sources (mains) and there is significantly less pollution in this source of energy.

[4] Sanjit.V.K; Nirmitha.S; Ramya Jaya chandran; Vijaya durga.P; Yashaswini G.Y, IEEE, Parametric Analysis of Piezoelectric-Sensor Array In Foot Step Power Generation System (December 2022) The footstep power generation system using different configurations of piezo sensors are analyzed in this paper.

[5] A literature survey on footstep power generation systems highlights the significant role of Arduino micro controllers in optimizing these technologies. For instance, research (2018) demonstrated Arduino's effectiveness in managing piezoelectric sensors to accurately measure and process energy data.

IV. METHODOLOGY

Research Design:

The design methodology of the IoT-Enabled Street lighting System Using Piezo electric Energy Harvesting starts with system architecture design, such as the location of piezoelectric modules, smart streetlights, and IoT controllers. The appropriate piezo electric sensors are chosen to effectively transform mechanical vibrations from traffic or pedestrians into electrical energy, which is stored in batteries or super capacitors to be used later. Hardware development phase is where the piezo electric energy harvesting system, smart streetlights with LED lights and motion sensors, and energy storage coupled with power management units are installed. Upon deployment, the system is connected to real-time monitoring, data analysis, and remote control, maximizing energy usage, streetlight operation, and system performance.

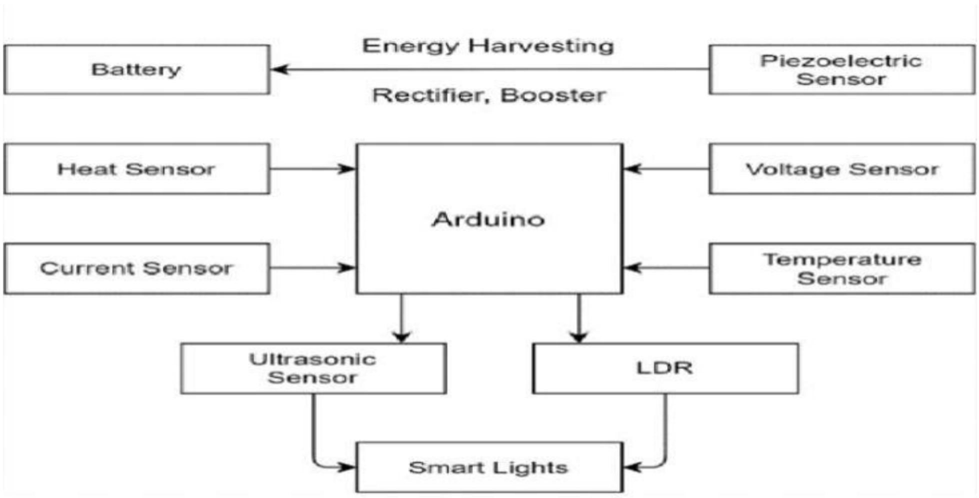

Figure:1 Methodology

Systematic Testing:

Systematic testing guarantees the dependability and effectiveness of the street lighting system. The individual hardware components are tested to ensure sensor accuracy, energy harvesting efficiency, and LED functionality.

Individual Functionality Testing:

Piezoelectric energy harvesting: The testing starts with the assessment of the piezoelectric energy harvesting system, where mechanical pressure due to pedestrian footfalls and vehicular movement is induced on the sensors.

Monitoring of electrical signals: The electrical output generated is determined to ensure voltage and current levels are verified, efficient energy conversion from the bridge rectifier and voltage regulator.

Energy storage: The energy storage component (battery or capacitor) is also tested to ensure it can store and provide power efficiently to the streetlights. Then, the photoelectric and motion sensors are checked for automatic light control.

Controlling Streelights: The photo electric sensor is subjected to varying light conditions to verify if the streetlights turn ON in the evening and OFF during the day.

V. RESULT DISCUSSION

The IoT-enabled piezoelectric street lighting system successfully demonstrates an energy efficient and smart lighting solution by utilizing piezoelectric energy harvesting and Arduino based control mechanisms. The system was tested under various conditions to evaluate its performance in terms of energy generation, lighting automation, and IoT integration. During testing, the piezo electric sensors effectively converted mechanical pressure from foot traffic and vehicle movement into electrical energy. The generated energy was rectified, regulated, and stored in a battery or supercapacitor, providing a stable power source for the street lights. The Arduino micro controller efficiently managed energy flow and controlled the lighting system based on real-time sensor inputs. The LDR sensor ensured that the streetlights turned ON automatically in low light condition. It is an ideal solution for smart cities, promoting green energy adoption and efficient urban infrastructure management.

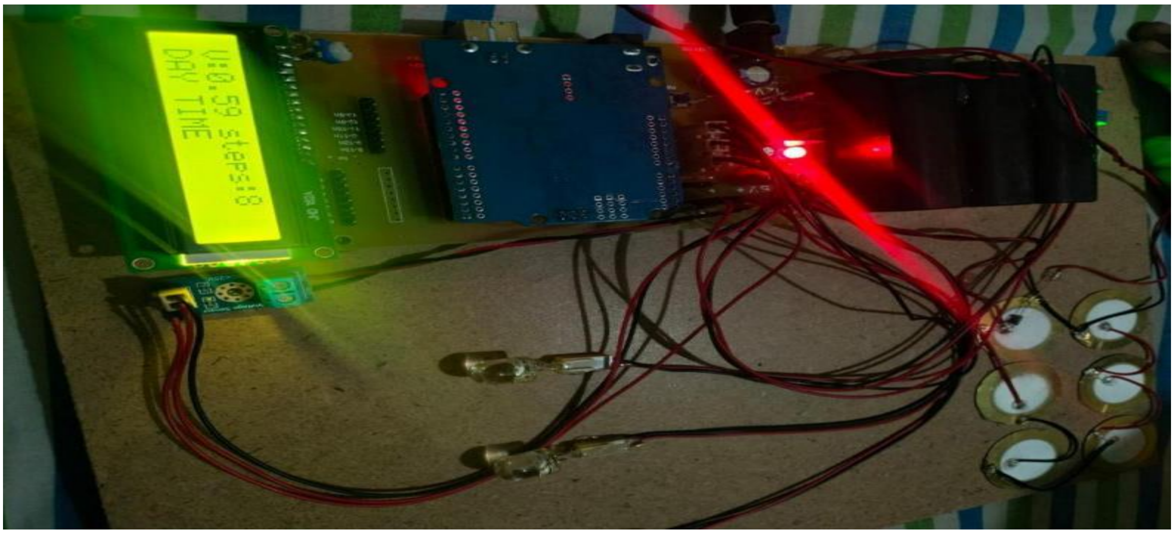

Figure:2 Proto Type

VI. SUGGESTION AND RECOMENDATIONS FOR FUTUREWORK

The piezoelectric IoT-based street lighting system has high potential for further development, which makes it an effective solution for smart cities and green urban growth. One such improvement would be the incorporation of sophisticated AI and machine learning software to study traffic flow and make energy usage more efficient. Further, hybrid energy harvesting systems using piezoelectric, solar, and wind power could make power generation more efficient, guaranteeing continuous operation of streetlights. Additional developments can also involve wireless power transmission to dispense with the use of wires, enhancing system reliability and minimizing maintenance costs. Utilizing high efficiency energy storage devices, Additionally, expanding the IoT network with cloud-based analytics can allow for predictive maintenance, minimizing downtime and maximizing system lifespan. With the increasing use of 5G and edge computing, real-time processing and decisionmaking can be enhanced. Moreover, the use of blockchain technology could provide security and transparency in energy transactions for decentralized smart grid applications.

VII. CONCLUSION

The IoT-Enabled Streetlighting System Using Piezoelectric Energy Harvesting is an innovative solution to improve energy efficiency in public lighting while reducing dependence on conventional power sources. This system effectively leverages piezoelectric energy harvesting to generate power from road vibrations, providing a sustainable and eco-friendly solution for street lighting. The integration of IoT technology allows for real-time monitoring and management of the system,enhancing its operational efficiency. The proposed IoT-based smart streetlighting system powered by piezoelectric energy harvesting presents a sustainable and innovative solution to urban lighting challenges. By utilizing the mechanical stress generated by pedestrian and vehicular movement, the system efficiently converts wasted energy into a renewable power source for streetlights. The integration of IoT technology enhances its effectiveness by enabling remote monitoring, automated adjustments, and optimized energy distribution. Compared to traditional streetlighting systems that rely on grid electricity or solar power, this approach significantly reduces energy consumption, operational costs, and environmental impact. This project serves as a stepping stone toward smarter and greener urban infrastructure, aligning with the vision of sustainable and energy-efficient smart cities. By adopting this technology, urban areas can achieve improved energy management, reduced carbon footprints, and enhanced public infrastructure for a more eco-friendly future.

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