Pioneering Green Technology: Energy Harvesting Through Piezo – Speed Breakers

N. Harathi[1], N Hari Keerthana[2], S Sanjay Kumar[3], G Bhavathi[4] and G Vinay[5]
{nimmalaharathi@gmail.com[1], harikeerthana0810@gmail.com[2], sanju770244@gmail.com[3], bhavathigali23@gmail.com[4], vinaygunji2001@gmail.com[5]}

Electronics and communication engineering, Siddharath Institute of Engineering & Technology, Puttur, Andhra Pradesh, India[1]
Electronics and communication engineering, Mohan Babu University (Erstwhile Sree Vidyanikethan Engineering college) Tirupati, Andhra Pradesh, India[2, 3, 4, 5,]

Abstract. This paper presents a novel system for the generation of sustainable energy from vehicles using wasted kinetic energy. The system employs six piezoelectric sensors placed on speed breakers to convert the mechanical energy to electrical energy as vehicles move over them with Arduino acting as a system supervisor. This energy collected can be used to power the automatic streetlights and electric vehicle (EV) charging stations-this helps in conserving energy and decrease carbon footprints as well. The third is to use LDR sensors in ambient light detection, the light turn-on-off setting of street lights also manages the energy output. This is followed by the connection to the street lights and EV charging system via a relay module. Transmission of the data is done wirelessly to The Cloud with a NodeMCU (ESP8266 — ESP12E) communicating to the Ubidots IoT platform for real-time monitoring and analytics. An optional wireless circuit coil transmitter and receiver are available and we assume included in FCA's purchasing agreement expand the system's functionality even further. It also allows for the generation of power that can be used to drive LED indicators, which are good ways to provide a system status feedback. This project illustrates that piezoelectric energy harvesting is possible on a larger scale and provides an example that this could be done in conjunction with other elements of smart city infrastructure to help build a greener, more sustainable urban environment.

Keywords: Pioneering green technology, Arduino Uno, Kinetic energy, Node MCU(ESP8266), LDR Sensor, Smart City Infrastructure, Ubidots IOT platform, Electric Vehicle (EV)Charging Stations, Automatic Street Lights.

1 Introduction

Web applications, driven by a need for faster and more responsive web apps are outpacing the capabilities of conventional cloud accelerations. In today's world, with users expecting feedback in milliseconds, latency and server load continue to represent major performance bottlenecks (Sheikh et al., 2025). To mitigate this shortcoming, Edge computing is an appealing solution because it positions the computation near to the end user and reduces latency for better user experience (Andriulo et al., 2024). Nonetheless, to date, most approaches have limited their focus to optimizing individual pieces of the web stack with little practical impact on end-to-end performance. This work (along with other future works) investigates a holistic edge computing model taking into account the front-end, back-end, and edge performance optimization together to meet the significantly increasing performance demanding of today's web users in distributed settings (Ju et al., 2021).

ICITSM-Part I 2025, April 28-29, Tiruchengode, India

DOI 10.4108/eai.28-4-2025.2357861

1.1 Current Challenges in piezo power technology

The Low energy conversion: Piezoelectric materials often have low energy conversion efficiency, meaning that while they can generate electricity, the amount of energy produced may be insufficient to justify the cost of implementation [7].

Fluctuating power output: The power output is heavily dependent on traffic volume and vehicle speed. On low- traffic roads, the energy generated may be negligible, limiting the system's usefulness [12] [13].

Degradation over time: The piezoelectric materials used can degrade under constant mechanical stress from vehicle traffic. Prolonged exposure to heavy loads can result in a decrease in their ability to generate power efficiently.

Harsh environmental conditions: The outdoor environment can expose the system to factors such as extreme weather, temperature fluctuations, dust, and water, which can affect both the piezoelectric material and the mechanical components of the system.

Material sustainability: The piezoelectric materials themselves often consist of materials like lead, which can have negative environmental impacts if not properly disposed of. Research into alternative, more sustainable piezoelectric materials is still ongoing

Energy storage issues: The electricity generated from speed breakers must be stored or converted for use. Storing small amounts of energy from irregular sources can require specialized and expensive storage systems.

1.2 Statistics on piezo power generation - speed breaker

Typical Power Generation: On average, a single piezoelectric device embedded in a speed breaker generates about 1 watt. Peak Power: In some cases, when a heavy vehicle (like a truck) passes, the power output can be higher, reaching up to 3-5 watts for that individual vehicle. The amount of power generated can vary greatly depending on factors like vehicle weight, speed, and the piezoelectric material used [2].

Energy Produced Per Day: If placed in an area with high traffic volume, such as a busy urban road, a speed breaker can generate anywhere between 5-20 kWh per day.

However, in low-traffic areas, the output may be negligible. Storing the generated energy from speed breakers has been another hurdle. The conversion from mechanical to electrical energy, coupled with the challenges of energy storage, reduces the overall efficiency of the system [3] [4]. Capacitors and batteries are typically used for storing small amounts of harvested energy. However, there have been challenges related to the cost-effectiveness of these storage systems for low-output piezoelectric devices. Piezoelectric power generation through speed breakers is an emerging technology, and while there isn't an exhaustive global dataset or standardized statistics on the exact performance of these systems, there are some key data points and examples of projects that give us insight into its potential and limitations. Below are some general statistics and findings from various pilot projects and studies on piezoelectric power generation via speed breakers [5] [6].

1.3 Impact on piezo generation and EV battery

The interaction between piezoelectric power generation and EV batteries is still in the experimental phase. While piezoelectric systems have potential as a supplementary, low-power source of energy in urban environments or as a small energy contributor to the smart grid, their impact on EV battery charging remains minimal due to their low energy output. However, with advancements in material science and energy storage solutions, piezoelectric systems could play a larger role in creating sustainable, decentralized energy networks in the future, complementing EV infrastructure. Transmission of infectious diseases in closed settings

- Direct impact on EV battery charging is minimal at present due to low energy generation.
- Complementary energy source rather than a primary one.
- Potential future integration into smart cities and sustainable transport networks, especially in high-traffic zones.
- Regenerative braking in EVs remains far more efficient than piezoelectric systems in terms of energy recovery.

Moreover, Supplementary Power Source: Piezoelectric systems can provide a small, supplementary source of energy to charge EV batteries, especially in locations where both EVs and high traffic volume coexist (such as highways, urban centers, or busy intersections). However, the energy generated by piezoelectric systems is currently minimal.

For instance, a typical piezoelectric system under a speed breaker might generate around 5-20 kWh per day in areas with heavy traffic, which is far less than the energy needed to charge an EV. To put this in perspective, an average EV requires around 30-80 kWh for a full charge, depending on the model. As such, piezoelectric power generation can only act as a complementary source of energy to other methods, such as grid charging or solar power, rather than being a primary charging solution.

Battery Charge Management: Since piezoelectric systems generate low amounts of power, any contribution they make to EV battery charging would likely have a negligible effect on battery lifespan. However, a small additional charge could theoretically be useful in off-grid or urban charging environments where quick top-ups are needed.

2 IoT Technology in Piezo EV Battery

The combination of IoT (Internet of Things) technology and piezoelectric energy harvesting systems/ EV (Electric Vehicle) batteries can improve the efficiency, management and performance of both energy harvesting and usage. We are now at the point that piezo systems can be linked to IoT devices, allowing us to build smarter and more sustainable ecosystems for energy and performance monitoring and predictive maintenance. Some applications for IoT in piezoelectric systems and EV batteries include the following:

In piezoelectric energy harvesting and EV battery management, the IoT-enabled technology can build smarter piezoelectric harvesting and EV battery management system which can gather, analyze and act on real-time data: Set the stage for energy transformation.

Improve the surveillance and capacity of piezoelectric construction as well as Maximize energy freedom in-between piezoelectric devices, stations and EV batteries. Predict maintenance and minimize downtime and revenue loss. Enhance sustainability and energy efficiency in transportation [8].

Although the power output of piezoelectric energy harvesting may not currently compare with that of other types of renewable energy, by integrating IoT into the system, the power output can be increased which could be useful into a smart move to a greener and smarter transportation ecosystem GI Fig 1 [10].

2.1 Benefits of IoT for Remote piezo power EV Monitoring

The implementation of IoT (Internet of Things) into remote piezoelectric power generation and EV (Electric Vehicle) battery monitoring greatly improves the efficiency, re liability and user interaction [9] [11]. For piezoelectric energy harvesting systems as well as for the performance of EV batteries, it enables constant and real-time data gathering and processing. Here are a few of the main advantages that IoT brings for remote piezo power and EV monitoring:

Real-time Monitoring: By making use of IoT-based sensors, generation of piezoelectric power and EV battery status can be monitored in real time. As such, you can gather data on a rolling basis regarding:

- Piezoelectric energy generation (e.g., power output, vehicle load, traffic density, and efficiency).
- EV battery status (e.g., state of charge, temperature, voltage, and health).
- This continuous monitoring helps ensure that both systems are functioning optimally and provides a comprehensive overview of energy generation and consumption.
- In piezoelectric systems, sensors can detect wear and tear, reduced efficiency, or malfunctioning components and alert technicians before a system failure occurs.
- In EV batteries, sensors can detect temperature spikes, voltage imbalances, or signs of degradation, allowing for early intervention to prevent breakdowns or reduce battery lifespan.

2.2 Key Components of IoT-Based piezo power for EV

n IoT-based piezoelectric power system for EVs should combine many critical components to catch, supervise, store, and supply energy properly [12] [13]. This is to ensure that the vestige of piezoelectric energy derived from sources such as speed breakers, road or other active surfaces to charge or power the EV batteries is optimally used, and that the whole system remains fail proof. Following are the important aspects in this IoT system:

- Function: These sensors are used to collect and monitor various parameters in real time, including energy production, battery status, traffic patterns, and environmental factors. IoT sensors help in:
- Monitoring Piezoelectric Output: Sensors track the energy produced by piezoelectric systems, measuring voltage, current, and power.

- Monitoring EV Battery Health: Sensors on the EV battery track metrics like state of charge, voltage, temperature, and battery health to ensure proper functioning and prevent overcharging or degradation.
- Environmental Sensors: Measure external factors such as temperature and humidity, which may affect piezoelectric efficiency.

2.3 Architecture of IoT-Based Piezo power Systems for EV

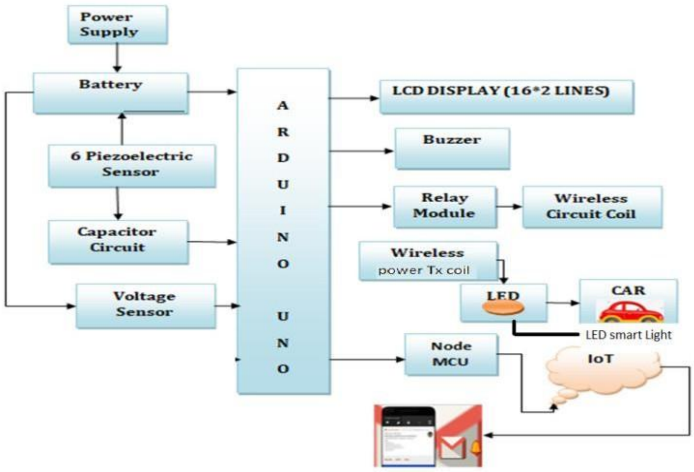

Fig. 1. Architecture Diagram.

This project aims to implement an IoT based piezoelectric power supply for electric Vehicles (EVs) using ATMega328, NodeMcu and Piezeo Electric sensors. The aim is free-form energy harvesting, real-time monitoring, battery management and cloud communication architecture.

An IOT based piezoelectric power system for Electric Vehicles harvest energy effectively and manage them wisely. The system consists of ATMega328, NodeMCU and piezoelectric sensors which harvest and manage energy to charge Electric Vehicle with potential battery health monitoring[14].

3 Sensor Network and Data Collection

In an IOT-PCPS posed for EVs, the heterogeneity of the structure integrating diverse sensors that controls different parameters allows efficient piezoelectric energy harvesting, battery charging and decision processes in real time. The sensor mesh records information such as energy generation, battery state, or environmental conditions and sends such information to a cloud platform or user interface for analysis.

- The high-performance microcontroller board which can handle multiple sensor interfaces at the same time is ideal for collecting data from EV batteries, and the Arduino ATMega328 is a perfect example.
- Piezo sensor: piezoelectric sensor is to harvest mechanical energy from the

environment. These sensors generate electricity when subjected to mechanical stress, such as vibrations from passing vehicles on speed breakers or road surfaces.

- Voltage Sensor: The voltage sensor measures the voltage across the energy storage system (battery or supercapacitor). It ensures that the voltage stays within the safe operational range for charging and discharging the battery, preventing overcharging or deep discharging.
- Current Sensor: The current sensor measures the current flowing into and out of the battery or energy storage system. This sensor is critical for managing charging rates and ensuring that the energy stored from piezoelectric devices is used effectively and efficiently.
- LDR Sensor: The LDR (Light Dependent Resistor) is used to monitor ambient light conditions. It detects changes in light intensity, which can affect the efficiency of piezoelectric systems (e.g., by causing changes in the surrounding temperature or impacting solar power charging if integrated). Fig 2 shows Piezoelectric material placement inside the synthetic speed breaker.

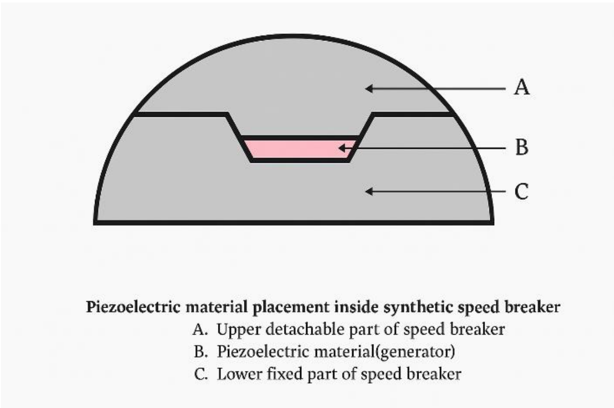

Fig. 2. Placement of piezoelectric material inside the synthetic speed breaker.

3.1 Circuit Configuration

The Arduino ATMega328 is a high-performance microcontroller board that can interface with multiple sensors simultaneously, making it ideal for gathering data related to EV battery management.

- Piezo Sensor: Connected to I2C pins (SDA and SCL).
- Voltage Sensor: Analog output connected to one of the analog input pins (e.g., A0).
- Current Sensor: Output connected to another analog pin (e.g., A1).
- LDR Sensor: Connected to a separate analog pin (e.g., A2).

3.2 Software Implementation

The Arduino IDE was used for programming the microcontroller. Libraries specific to each sensor were utilized for efficient data acquisition. The primary tasks included:

- Initializing the sensors.
- Reading data from each sensor in real-time.
- Displaying the collected data via the Serial Monitor for preliminary analysis.

3.3 Data Collection Protocol

Data collection over a period of several minutes for each sensor, with readings taken every second. Each reading was timestamped for further analysis.

3.4 Edge Computing and Local Processing

To address the challenges of processing large volumes of piezo data in real-time, we've implemented an edge computing layer in our architecture. This approach allows for local processing of sensor data, reducing network latency and improving response times for EV alerts.

The layer of the edge computing is the microcontrollers and Arduino board are embedded in every EV. First-level processing and features computation: These are the devices that deploy wirelessly collected data, and include:

- Filtering and conditioning of raw sensor data
- Aggregation of health EV information across multiple sensors.
- Anomaly detection of vital signs
- Activating immediate alerts on possible emergencies

Through edge computing, we are able to compute the instantaneous rolling risk, in terms of the speed, as well as the status, of the parameters 9. This functionality is essential in order to guarantee efficient medical assistance during train travels.

Where edge computing manages immediate data processing, we also involve cloud integration for holistic EV health monitoring and analysis. Processing of the edge device data is securely transmitted to the cloud via cellular or satellite communication. Our cloud-based platform leverages Apache Spark to handle read in data on the distributed server, which offers the scalability and capability to handle mass amount of data effectively 10. The collaboration between on-board power systems and remote healthcare providers facilitates the interchange of information, and timely interventions when needs arise.

To improve the data security and privacy, we incorporate the Privacy-Preserving Searchable Encryption (PPSE) mechanism into our cloud framework 7. This guarantees the protection of sensitive EV health information, and at the same time, the authorized persons are able to get access to the necessary data. Our sensor networks and edge computing technology in combination with cloud integration represent an end-to-end solution for EV BMS health monitoring Our IoT system for piezo power.

4 Key Features of real TIME- System

Our IoT-based remote piezo power system includes several important functionalities which enable efficient high-power generation and charging, and timely use case assistance while charging and discharging. Let's examine each of these features in more detail.

4.1 Real-Time battery Monitoring

The key element of our platform is battery monitoring, in-real time. We have added multiple sensors to each of our speed breakers- voltage sensor, piezo sensors, LDR monitors. These devices monitor the most important data from the battery constantly, to enable early detection of any abnormal situation. Fig 3 Benefits of IoT in piezo power System

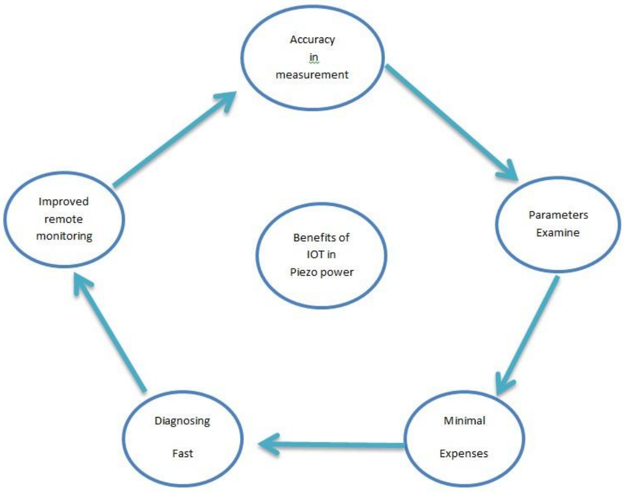

Fig. 3. Benefits of IoT in piezo power System.

Our system is based on Arduino and microcontrollers in order to process the sensors data acquired. When any of the vital signs cross the predetermined threshold levels, the assistive support buzzer alert is initiated by the controller.

4.2 Automated Emergency Response

In piezoelectric power generation (speed breaker) application an automatic emergency response system like safety, stability and best service has been designed in case of faults or abnormal conditions. The system combines real-time monitoring, sensor data analytics, and automated decision-making to respond rapidly, prevent damage to the energy harvesting infrastructure, and the EV charging systems.

Further, there is a safety and system optimization in an AER with piezoelectric power generation system, especially along with speed breakers. By relying on real-time reading and processing of information, anomaly detection and automatic decision systems, the system can respond promptly to faults, for instance sensor malfunctioning, abnormal voltage or irregularities in a battery. The system's cloud connectivity and mobile interface provide remote monitoring and control, empowering users to manage their energy systems efficiently and safely, while also reducing downtime and maintenance costs.

3.3 Communication with Professionals

Safety and performance combined with automation in piezoelectric power generation system including speed breakers having automated emergency response therapy. It can react quickly to faults, e.g., sensor failure, abnormal voltage, or even battery problems, through real-time data, anomaly identifying and automated decision making. Cloud-connected and with a mobile app, users can remotely monitor and control their energy system, so they can use and store energy when it's needed to best suit their lifestyle, saving and reducing energy costs in the process.

When a fault or emergency occurs in a piezoelectric power generation system (e.g., problems with the sensors, problems with the voltage, failures in the battery management, etc.), through the system, alerts can be automatically issued to professionals. This reporting system helps to notify the appropriate people in a timely manner and allows for a rapid response.

5 Implementation Challenges

Despite its promising prospect for generating power, speed breaker or electric vehicle charging using piezoelectric has its own set of challenges such as energy ratio and cost effectiveness, sustainability and environmental impacts, maintenance etc. Solving these problems involve the development of new designs and technologies in fuse, detonator, and system. After solving these challenges by jugging high engineering, engineering and construction strategic planning and cooperation between solution providers, real-estate and grid-operator, the piezoelectric system could be integrated in the sustainable energy infrastructure of the future.

5.1 Technical Hurdles

Addressing the technical hurdles associated with piezoelectric power generation from speed breakers requires innovative solutions and multidisciplinary expertise. From improving energy conversion efficiency to ensuring system durability and reliable data transmission, overcoming these challenges is crucial for the widespread adoption of piezoelectric energy systems. By investing in advanced materials, smart storage solutions, and integrated systems, piezoelectric systems can play a significant role in the future of sustainable energy harvesting and EV charging. Fig 4 shows Implementation Model

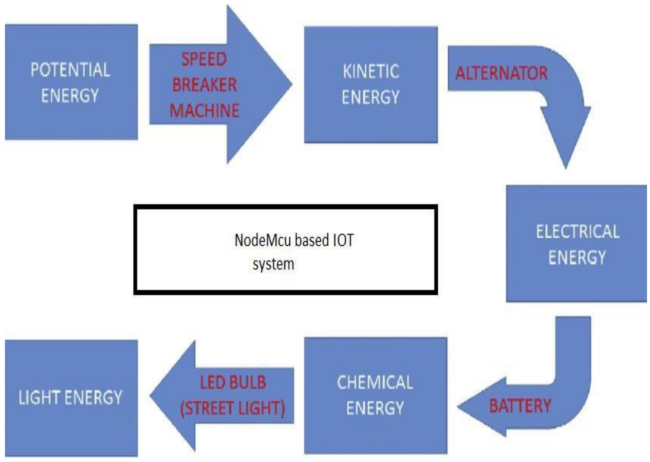

Fig. 4. Implementation Model.

A notable challenge in data management is the issue of data overload and accuracy. The data generated by the piezoelectric system, including energy output, system health, and performance metrics, needs to be collected, processed, and transmitted to monitoring systems for analysis. However, data transmission reliability and data integrity can be challenging, particularly in remote locations or areas with poor network connectivity.

5.2 Regulatory Considerations

The implementation of piezoelectric power generation with speed breakers requires careful consideration of a wide range of regulatory requirements related to safety, environmental impact, grid compatibility, and construction. Collaboration with local authorities, adherence to safety and environmental standards, and ensuring compliance with national and international regulations are essential to ensuring that these systems can be deployed effectively and safely. By navigating these regulatory challenges, piezoelectric energy harvesting systems can contribute significantly to the development of sustainable energy solutions.

6 Result and Future Development

The Piezoelectric power generation in speed breakers offers a promising path toward sustainable energy harvesting from everyday activities. However, the development of new features and technologies is key to overcoming challenges such as low energy output, maintenance, and integration with existing infrastructure. Future directions could focus on:

- Refining piezoelectric materials for greater efficiency and sustainability.
- Developing intelligent energy management systems to optimize energy storage and distribution.
- Integrating advanced sensors and IoT platforms for remote monitoring and automated maintenance.
- Exploring hybrid systems that combine piezoelectric energy with other renewable sources.

By improving both the results and features of piezoelectric systems, we can create more robust, scalable, and efficient systems that help meet the growing energy demands of smart cities and contribute to green energy solutions worldwide.

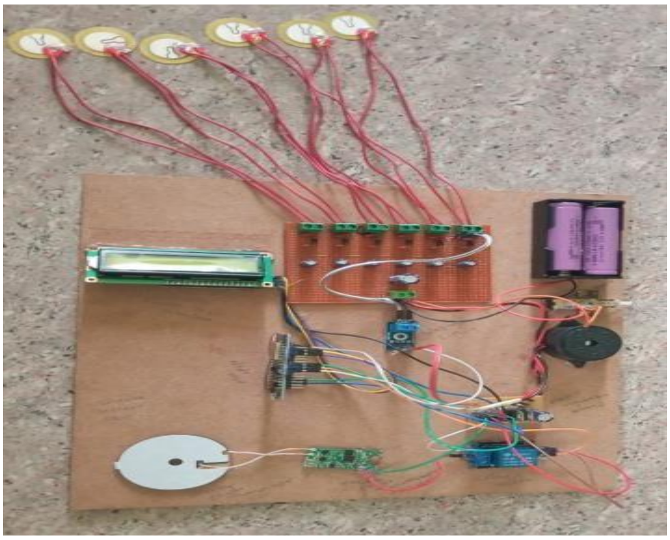

Fig. 5. Hardware implementation

Data collection and server Integration: The data collection and server integration aspects results. Fig 5 shows Hardware implementation

Table 1. Power generation parameters

Piezo Sensor	50 kg	60 kg
1	0.520	0.680
2	0.612	0.650
3	0.560	0.680
4	0.540	0.645
5	0.560	0.680
6	0.600	0.654
7	0.582	0.680
8	0.546	0.684
9	0.522	0.654
10	0.510	0.645
11	0.558	0.680
12	0.552	0.680
Average	0.555	0.668

Expansion of Monitored EV health Parameters: By expanding the monitored health parameters of an EV integrated with piezoelectric power systems, vehicle owners, fleet managers, and maintenance personnel can gain deeper insights into the vehicle's overall performance, energy efficiency, and longevity. Monitoring these parameters provides a comprehensive understanding of both vehicle health and energy generation systems, ensuring that the vehicle operates efficiently while also optimizing the power harvested from piezoelectric energy sources. Using machine learning, data collected from various parameters can be analyzed to predict when certain components (like the battery, motor, or piezoelectric harvesting system) may require maintenance or replacement. Table 1 shows Power generation parameters

7 Conclusion

The work offers a new strategy toward energy challenges in an urban environment via exploiting the un-cornered kinetic energy of car movement. With the use of piezoelectric sensors, Arduino, IOT and wireless energy transmission, the system showcases a promising alternative that can be utilized to power important urban infrastructure like streetlights and charging stations for electric vehicles. Through the use of LDR sensors and Ubidots platform based real-time lighting control of SGWSL, streetlighting automation achieved and thereby reduces power consumption and ensures sustainability of the system. This project shows the potential for generating renewable energy with piezo electrics and in the future could be applied to the inside of a shoe. Such a solution, with scalability and replicability, has the potential to be realized in different urban contexts, including part of sustainable development over the long term. Should the project be successful it could also set a trend for other smart green solutions as we strive to create a culture of sustainability and responsible energy use.

Acknowledgment.

I owe a great debt to so many who have informed and inspired this project of sustainable generation of energy using vehicle rush kinetics. This has significantly contributed to furthering our understanding of energy harvesting systems, and where they can be integrated in urban infrastructures for sustainable developments.

References

[1] Chu, Steven, and Arun Majumdar. "Opportunities and challenges for a sustainable energy future." nature 488.7411 (2012): 294-303.

[2] "Smartprivacy for the smart grid: embedding privacy into the design of electricity conservation." Identity in the Information Society 3.2 (2010): 275-294.

[3] Willems, P. A., G. A. Cavagna, and N. C. Heglund. "External, internal and total work in human locomotion." Journal of Experimental Biology 198.2 (1995): 379-393.

[4] Madhushree, M., Utkarsh Kumar Rawat, And K. Internal Guide. Design And Fabrication Of Footstep Power Generation By Crankshaft Mechanism. 2017

[5] K. Thandapani, P. Nagarajan, C. K. Pappa and N. Ashokkumar, "MEMS Sensor Based V2V Communication Using Li-Fi Technology," *2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS)*, Coimbatore, India, 2023, pp. 1370-1374,.

[6] P. Gupta, D. Agrawal, J. Chhabra and P.K. Dhir, IoT based smart healthcare kit. In Computational Techniques in Information and Communication Technologies (ICCTICT), 2016 International Conference, IEEE, March 2016, pp. 237-242.

[7] S. Asthana, A. Megahed and R. Strong, A recommendation system for proactive health monitoring using IoT and wearable technologies. In AI & Mobile Services (AIMS), 2017 IEEE International Conference, June 2017, pp. 14-21.

[8] N.A. Khan, M. Hai, M.A. Sawand, A. Khuzema and M. Tariq, Real Time Monitoring of Human Body Vital Signs using Bluetooth and WLAN. IJACSA) International Journal of Advanced Computer Science and Applications, 7(10), 2016.

[9] N. Ashokkumar, V. Arun, S. Prabhu, V. Kalaimagal, D. Srinivasan and B. Shanthi, "Monitoring and Warning of Flooding Conditions Using IoT Based System," *2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS)*, Coimbatore, India, 2023, pp. 1199-1203
[10] H.B. Patil and P.V.M. Umale, Arduino Based Wireless Biomedical Parameter Monitoring System Using Zigbee. International Journal of Engineering Trends and Technology (IJETT), 28(7), 2015, pp.316- 320.
[11] J. Madhu, and N. Rao, IoT based remote patient health monitoring system, 2017.
[12] S. Misbahuddin, J.A. Zubairi, A.R. Alahdal, and M.A. Malik, IoTBased Ambulatory Vital Signs Data Transfer System. Journal of Computer Networks and Communications, 2018.
[13] Nagarajan, Ashokkumar, A. Kavıtha, and S. Devı. "Wireless Sensor Data Fusion Techniques in Estimating Temporal Resource Attributes in Scenarios of Intermittent Connectivity." *El-Cezeri* 9.2 (2022): 413-423.https://www.kajeet.com/en/blog/advantages-of-iot-in-remote-patient- monitoring
[14] Vijayakumar, P., et al. "IOT based wireless smart shoe and energy harvesting system." International Journal of Innovative Technology and Exploring Engineering (IJITEE) 8.7 (2019): 2685-2689.
[15] Kavitha, A., Kumar, N. A., & Revathy, M. (2018). Automatic Identification of Maritime boundary alert system using GPS. International Journal of Engineering & Technology, 7(3.1), 20-22.