HYBRID FOOTSTEP ENERGY GENERATOR FOR SMART CAMPUS AND PUBLIC UTILITY APPLICATIONS

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Keywords:

Piezoelectric Energy Harvesting, Footstep Power Generation, Hybrid Energy System, Rack and Pinion Mechanism, IoT Monitoring

Introduction:

The increasing demand for sustainable and eco-friendly energy solutions has led to the exploration of alternative energy harvesting techniques. In urban environments, a significant amount of mechanical energy generated from human footsteps is wasted. This project aims to harness this unused energy using a hybrid footstep energy generation system.

The proposed system utilizes piezoelectric sensors embedded in stair structures to convert mechanical stress into electrical energy. Additionally, a mechanical rack-and-pinion mechanism coupled with a generator is proposed to enhance energy extraction. The harvested energy is rectified, regulated, and stored for powering low-power devices such as IoT modules and lighting systems.

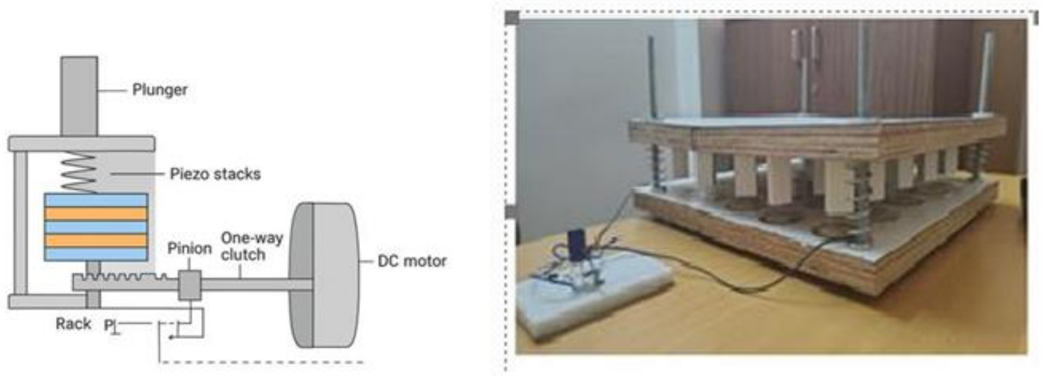
This approach contributes to the development of smart and sustainable infrastructure, particularly in high-footfall areas like educational institutions, malls, and transportation hubs.

Objectives:

1. To design a hybrid mechanical-piezoelectric energy harvesting system using a plunger mechanism, piezo stacks, and a rack-pinion-driven generator to convert human-applied force into electrical energy.
2. To stabilize and optimise energy generation by incorporating a flywheel-based smoothing mechanism and independent rectification for both piezo and generator outputs.
3. To develop an efficient power-conditioning and storage unit using bridge rectifiers, supercapacitor/battery storage, and a DC-DC boost regulator to deliver a stable regulated voltage.
4. To integrate and evaluate an IoT module (ESP32) powered by the harvested energy, demonstrating real-time monitoring and validating the system’s practical usability.

Methodology:

1. The proposed system follows a hybrid approach combining mechanical and piezoelectric energy harvesting.
2. Initially, mechanical energy from footsteps is applied to a plunger mechanism. This force compresses the piezoelectric stack, generating electrical energy. Simultaneously, the linear motion is intended to drive a rack-and-pinion mechanism, converting it into rotational motion.
3. The rotational motion will be coupled to a flywheel and generator to ensure smoother and continuous energy generation. Both piezoelectric and generator outputs will be processed independently through rectification circuits.
4. The generated electrical energy is then passed through filtering, voltage boosting, and regulation stages to obtain a stable DC output. This energy is stored in a battery or supercapacitor and used to power an IoT module (ESP32) for real-time monitoring.
5. System performance is evaluated based on voltage output, energy storage capability, and ability to power practical loads.



(a) (b)

Figure 1: (a) Prototype Design of the overall system; (b) Hardware Implementation of Piezo Stack

Result and Conclusion:

1. The developed piezoelectric module successfully generated peak voltages above 20 V, with rectified output reaching approximately 40 V DC. A usable voltage of around 15 V DC was obtained after filtering and storage, confirming effective energy conversion.
2. The mechanical rack-and-pinion mechanism and generator integration are currently under development and have not yet been incorporated into the prototype. The inclusion of this hybrid mechanism is expected to enhance overall energy output and provide smoother and more consistent power generation.
3. In conclusion, the present work successfully demonstrates the feasibility of piezoelectric-based energy harvesting, while the complete hybrid system is expected to significantly improve performance and enable practical deployment in smart and sustainable infrastructure applications.

Project Outcome and Industry Relevance:

1. The project demonstrates a practical approach to generating renewable energy from human motion. It contributes to the development of sustainable and energy-efficient systems suitable for smart cities.
2. The system can be implemented in high-footfall areas such as malls, metro stations, railway stations, and educational institutions to generate localized power. It can be used for powering LED lighting, sensors, and IoT-based monitoring systems.
3. Industries focused on smart infrastructure, renewable energy, and IoT applications can benefit from this technology. The project also promotes energy awareness and efficient utilization of otherwise wasted mechanical energy.

Working Model vs. Simulation/Study:

The project involves the development of a physical working model. The piezoelectric energy harvesting module has been successfully implemented and tested, while the mechanical integration is in progress.

Project Outcomes and Learnings:

1. Gained practical knowledge of piezoelectric energy harvesting
2. Understood power conditioning and energy storage techniques
3. Learned system integration of mechanical and electrical components
4. Developed skills in circuit design and IoT implementation
5. Gained experience in testing, measurement, and performance evaluation

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Future Scope:

The future scope of this project includes:

1. Integration of rack-and-pinion mechanism for enhanced energy generation
2. Optimization of system efficiency and output performance
3. Scaling the system for deployment in high-footfall areas
4. Implementation of IoT-based real-time monitoring and smart applications