

Smart Walkway for Rainwater Harvesting and Hydrogen Gas Generation Using Piezoelectric Energy

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Abstract—This paper presents the design and development of a sustainable smart walkway system that integrates rainwater harvesting, hydrogen gas generation via electrolysis, and renewable energy production through piezoelectric sensors. The proposed solution promotes water conservation and clean energy generation while enabling intelligent automation using sensor data and fuzzy logic control. The system uses permeable concrete for water percolation, piezoelectric materials to generate electricity from foot traffic, and a monitored electrolysis chamber to produce hydrogen and oxygen. The project demonstrates an interdisciplinary approach combining civil, electrical, and computer engineering to address modern energy and environmental challenges.

Index Terms—electrolysis, fuzzy logic, hydrogen generation, piezoelectric energy, Rainwater harvesting, smart walkway, Sustainable systems

I. INTRODUCTION

In the modern era of smart cities and sustainable development, the quest for alternative energy sources has become more vital than ever. With the rapid increase in urbanization and the associated energy demands, researchers are focusing on innovative technologies that can harness energy from everyday activities. Among various renewable sources, piezoelectric energy harvesting has emerged as a promising solution that taps into ambient mechanical vibrations, pressure, and motion to generate electrical energy. Urban walkways and roadways witness constant foot and vehicular traffic, making them ideal candidates for converting mechanical stress into usable power. This project introduces the Smart Walkway for Rainwater Harvesting and Hydrogen Gas Generation Using Piezoelectric Energy, which

capitalizes on the mechanical stress exerted by pedestrian footsteps. The energy is harvested using piezoelectric discs embedded beneath a pervious concrete surface capable of allowing water percolation up to 98%, thus supporting dual functionality – energy harvesting and effective rainwater management.

This Project not only focuses on energy harvesting but also incorporates an intelligent control algorithm that manages energy routing and storage efficiently. This enhances the viability of integrating piezoelectric pavements in real-world urban scenarios where power can be used for low- energy streetlights, environmental sensors, or stored in battery banks. The adaptability and modular nature of project make it scalable and cost-effective for deployment in different infrastructure settings such as parks, sidewalks, and metro platforms.

II. LITERATURE REVIEW

Pervious concrete plays a central role in the proposed design. Research by Khankhaje et al. shows that incorporating industrial waste like fly ash improves strength and sustainability, while Costa et al. provide design benchmarks for porosity and compressive strength. Akkaya et al. demonstrated its effectiveness in road applications using aggregate sizes of 10–15 mm. For energy harvesting, Kim et al. established that piezoelectric sensors can accurately measure static footstep forces, enabling effective energy conversion. In terms of water sourcing for electrolysis, Simoes et al. found grid and treated water as ideal sources, although our system opts for rainwater to minimize environmental impact.

III. METHODOLOGY/EXPERIMENTAL

1. Construction of Pervious Concrete Walkway

The first step involved designing and casting a pervious concrete road segment.

- A mixture of cement, coarse aggregates, and minimal fine aggregates was used to create pores in the concrete, making it permeable.
- This pavement allows efficient percolation of rainwater through its surface, directly into the underlying water collection system.
- The slab was cured and tested to ensure it retains strength while maintaining high permeability (~98%).

2. Design of Piezoelectric Energy Harvesting System

The second step focused on harvesting mechanical energy from footsteps using piezoelectric materials:

- 18 piezoelectric discs were strategically placed underneath the concrete slab, where foot pressure is most likely.
- When a pedestrian steps on the slab, the piezo elements generate electrical energy via the piezoelectric effect.
- The generated voltage is passed through a rectifier circuit and used to charge a battery.
- This stored energy powers the electrolysis chamber and sensors, enabling off-grid operation.

3. Electrolysis Chamber Development

In the third step, a system was constructed to convert rainwater into hydrogen and oxygen:

- The water from the pervious pavement was guided into an underground storage tank, then pumped or channelled into the electrolysis chamber.
- Inside the chamber:
 - The water undergoes basic filtration or distillation.
 - An electrolyte is added to improve conductivity.
 - Graphite electrodes act as anode and cathode for the electrolysis process.
 - Upon powering the chamber, water is split into hydrogen (collected at the cathode) and oxygen (at the anode).
 - Hydrogen is collected for storage or future use; oxygen is either stored or released into the environment.

4. Fuzzy Logic-Based Water Level Control

To ensure safe and efficient operation, a HC-SR04 ultrasonic sensor was installed inside the electrolysis chamber:

- It continuously monitors the water level in the chamber.
- A fuzzy logic controller is implemented on an Arduino Uno, which makes intelligent decisions based on:
 - If water level is below 25% → Stop electrolysis.
 - If water level is above 75% → Start electrolysis.
 - If water level is in between → Maintain previous state (hysteresis logic).
- This prevents dry running and optimizes resource use.

5. Integrated System Assembly

All components were integrated into a working prototype:

- The piezoelectric output was connected to a battery, which powered the electrolysis chamber.
- The ultrasonic sensor fed data to the Arduino running the fuzzy logic code.
- Water harvested via the concrete pavement was directed to the chamber through PVC piping and a mechanical setup (or gravity-fed where possible).
- The system was housed in a durable structure and tested for synchronization and functionality.

IV. SIMULATION RESULTS AND DISCUSSION

Simulations using data from existing literature estimate a percolation rate of 0.45 cm/s for the selected concrete mix, with an annual rainwater yield of around 10,000 liters per square meter in moderately rainy climates. The average adult footstep exerts a force of about 700 N, converting into 0.42 joules of electrical energy per step. With approximately 2,000 steps daily over the walkway, the system can store around 840 joules of energy—sufficient for limited electrolysis operations. Given an electrolysis efficiency of 70%, producing 1 kg of hydrogen (which requires 52 kWh) would be feasible with daily foot traffic from about 500 users. The fuzzy logic controller consistently maintains the tank level above 50%, ensuring electrolysis occurs only under safe and efficient conditions.

V. CONCLUSION

This research project successfully demonstrates the design and functionality of a smart walkway system that combines rainwater harvesting, hydrogen gas generation through electrolysis, and renewable energy harvesting using piezoelectric sensors. The system was designed to address two major sustainability concerns—water conservation and clean energy production—within a single integrated infrastructure. By employing permeable concrete, the walkway effectively allows water percolation and collection into an underground storage system. The stored water is later utilized for hydrogen and oxygen gas generation via electrolysis. The unique aspect of the system is the use of piezoelectric sensors, which harness mechanical energy from foot traffic to power the electrolysis process, thus eliminating dependence on non-renewable power sources. The inclusion of ultrasonic sensors for water level monitoring and a fuzzy logic controller for smart automation ensures that the electrolysis process operates only under optimal conditions. This not only maximizes system efficiency but also enhances operational safety and energy conservation.

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