Analysis of Pressure-Based Energy Harvesting with Intelligent Systems for Crosswalks

By: Vibha Hari, Angelina Mauzy, Tanisha Chatterjee, and Wanruo Wang

COSMOS UC Santa Cruz
California State Summer School for Mathematics and Science

Abstract

In everyday life, there exists a surplus of unused mechanical energy generated through actions like walking or driving. This energy has the potential to power smaller systems within the larger grid. Our project aims to answer the question: Which pressure based energy harvesting method is the most effective to use on medium traffic crosswalks? We will analyze four different pressure-based energy harvesting systems: piezoelectric harvesters, triboelectric nanogenerators, mechanical to electric generation, and pneumatic delayed-release harvesting. They use deformation of material, moving a magnet through a coil of wire, separation of materials (the triboelectric effect), and air compression to form electricity respectively. The methods will be evaluated based on six different criteria: energy output, durability, cost, installation ease, maintenance, and environmental robustness. To complement the chosen energy harvesting method, we will provide recommendations on how embedded smart sensors and machine learning can collect real-time data to determine whether the harvested energy should be stored for future use or immediately released based on current energy availability and demand. Our findings indicate that piezoelectric harvesters are best suited for medium traffic outdoor crosswalks.

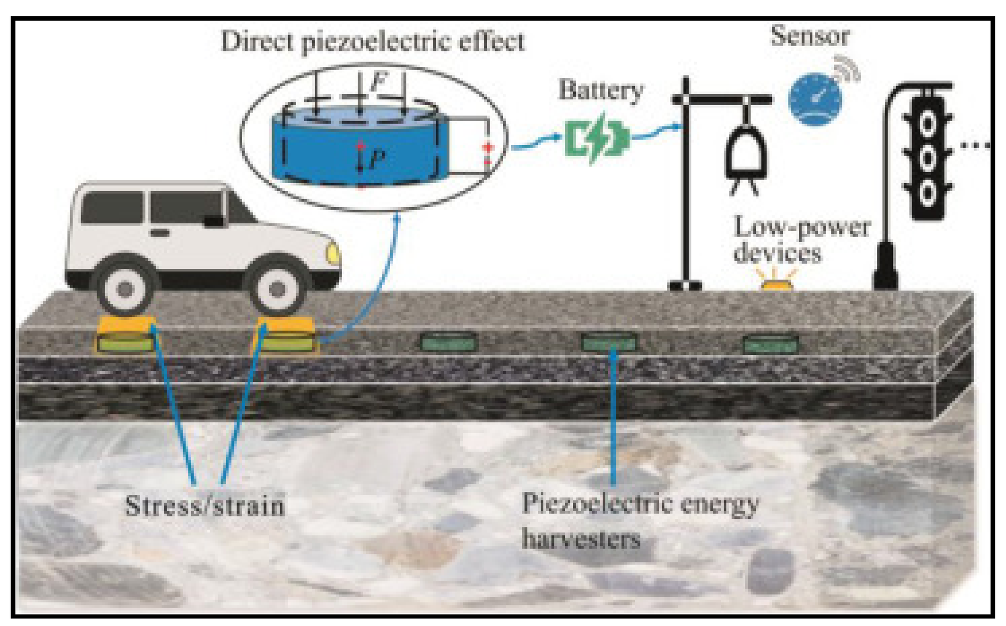


Figure 1: Diagram of Piezoelectric Energy Harvester under a roadway

Introduction

This research supports the development of smart and sustainable infrastructure. We aim to harvest excess mechanical energy that is found in our everyday lives. This energy is generally wasted, but with energy harvesting, it can be repurposed. Although pressure-based harvesting cannot replace conventional power generation, it may provide energy for low-power sensors and help support streetlight and traffic light systems.

Methodology

- Researched each energy harvesting method by reading scientific papers and articles
- Evaluated each method based on the criteria we created
- Used research papers and existing models to create the best Machine Learning and Smart Sensor blueprint
- Compared energy harvesting methods qualitatively and quantitatively to determine the best system

References & Slides

Slides

https://docs.google.com/presentation/d/1GNtauqpgqTDCEnL3bOA5b5EnB7RQgzpkr_p1R_mb6aA/edit?usp=sharing

Sources

https://drive.google.com/file/d/1_wfj1ELJoGtr1EIVUr8GSFlhBdUTL3NR/view?usp=sharing

Results

Piezoelectric Harvester: produced 27.64 mW at 2 Hz (brisk walk) and retained 67.63% of its output after 10 million cycles. It costs about $245.60 per m², requires little maintenance, and mainly needs protection from water.

Triboelectric Nanogenerator: produced 1.52 mW at 2 Hz and retained 94% of its output after 9,000 cycles. It costs about $158.85 per m² and shows good short-term weather resistance, but sealing and module replacement can be difficult.

Mechanical-to-electromagnetic system: produced 31.94 mW at 7 Hz, higher than typical crosswalk frequencies. Its components cost about $450, and precise alignment, wear and tear, and environmental exposure increase installation and maintenance demands.

Pneumatic delayed-release harvesting: produced about 3,000 mW but costs roughly $3,000 per m². Its pipes, valves, seals, and leakage risks make it the least practical option for crosswalks.

Harvesting Method	Energy 30%	Durability 20%	Cost 20%	Installation Ease 10%	Maintenance Ease 10%	Environmental Robustness 10%	Overall score 100%
Piezoelectric Harvester	8	8	7	7	8	7	7.6
Mechanical to Electromagnetic	7	7	6	4	5	6	6.2
Triboelectric Nanogenerator	7	7	8	7	6	7	7.1
Pneumatic delayed-release	9	7	1	4	4	6	5.7

Overall, piezoelectric energy harvesting provided the strongest balance of performance, durability, cost, and practicality for crosswalks carrying both pedestrian and vehicle traffic. While the frequency of vehicles moving across a crosswalk is easily detectable, pedestrians typically create low frequency when they walk, making it harder to detect. Piezoelectric harvesters are able to detect and generate energy from the low frequency.

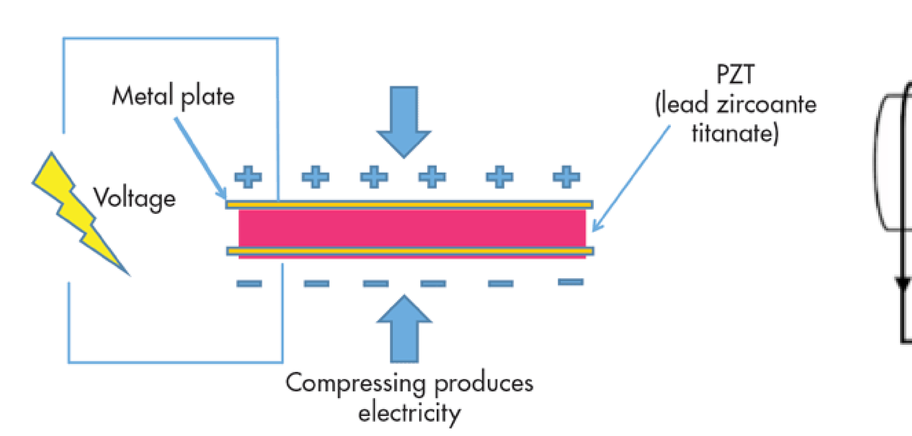


Figure 2: Piezoelectric Energy Harvesters

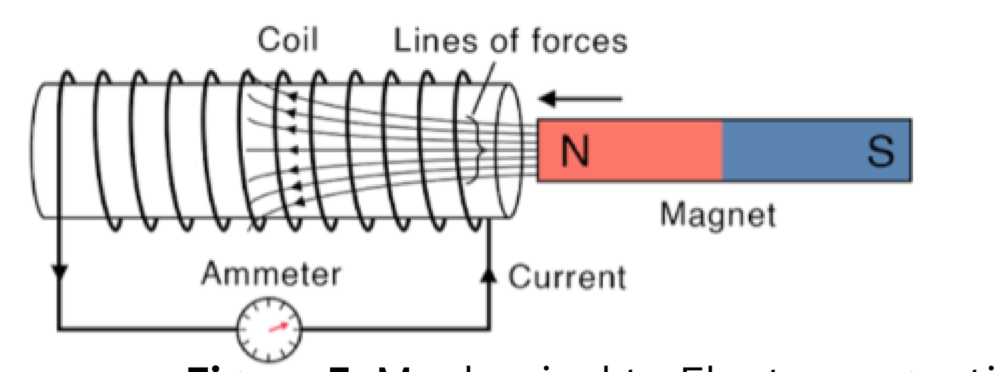


Figure 5: Mechanical to Electromagnetic

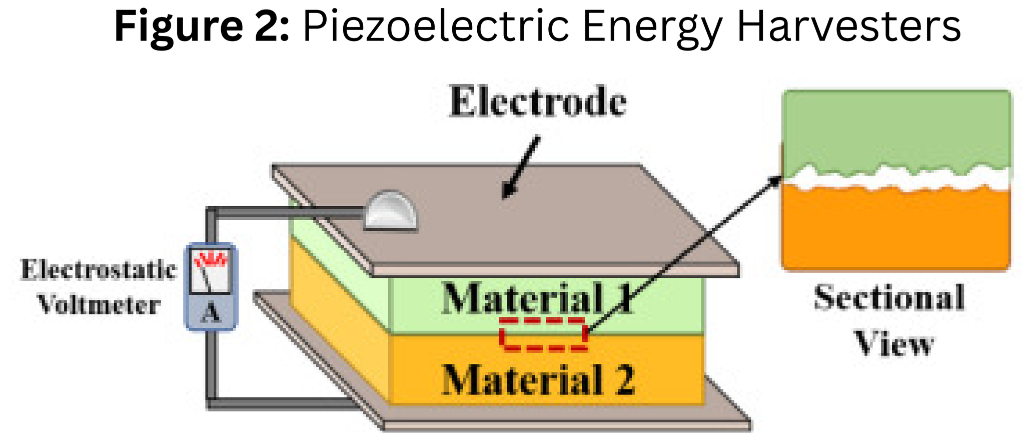


Figure 3: Triboelectric Effect

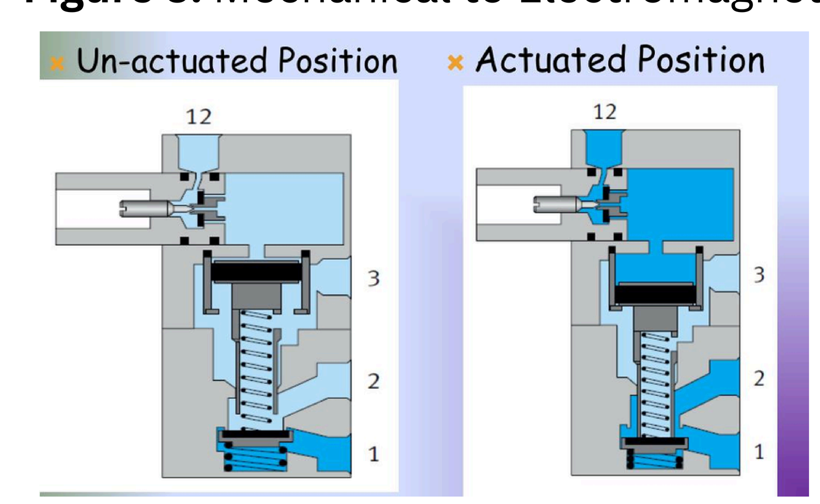
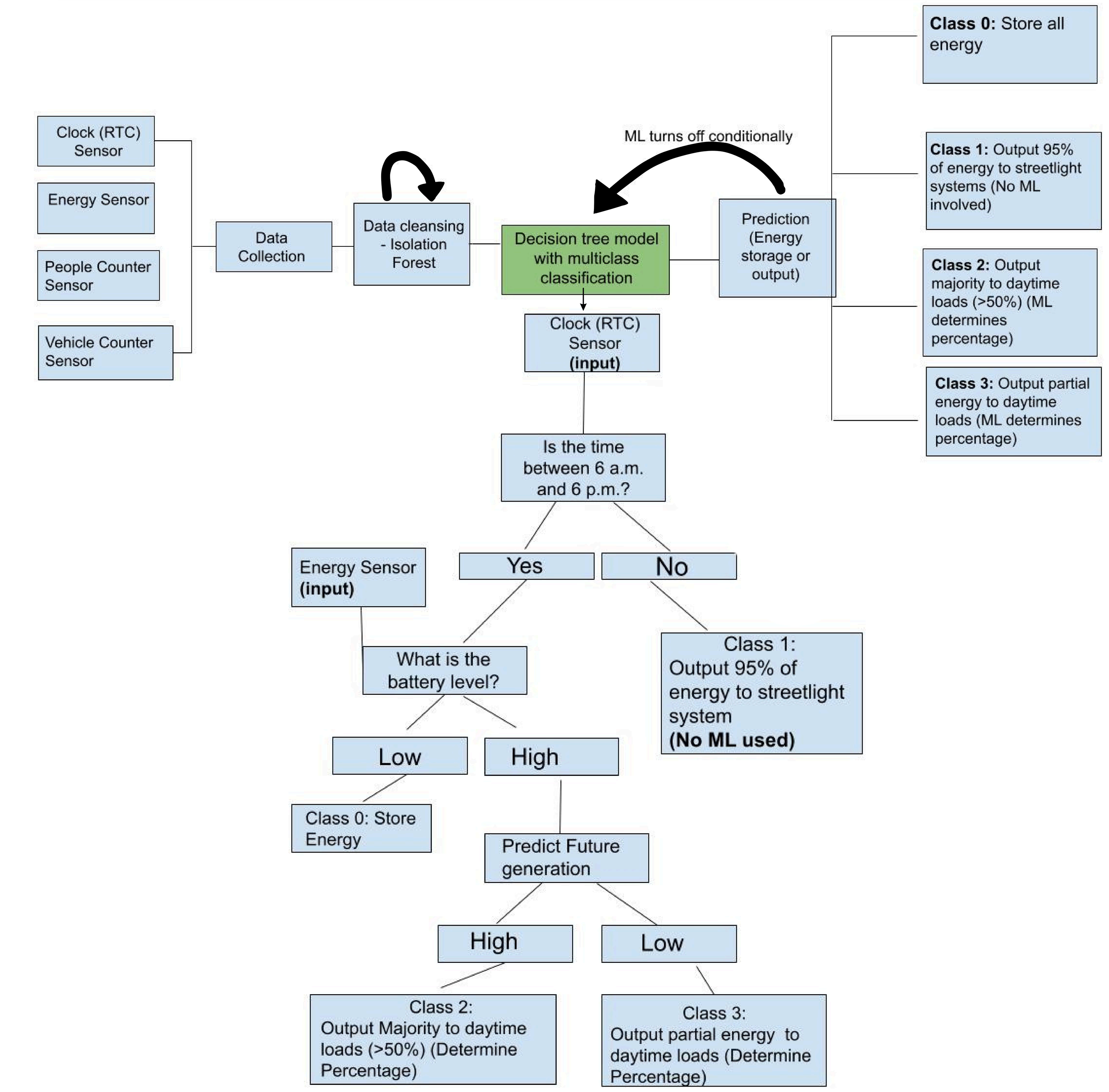


Figure 4: Pneumatic Delayed-Release

Acknowledgements

Thank you to our professors Dr. Yu Zhang and Dr. Yihsu Chen for helping us develop our interest in sustainable power and teaching us about renewable energy and the importance of understanding the energy market. We would also like to thank Elena Vindrola and Caleb Lin for providing us with hands-on learning and a deeper understanding of renewable energy and programming. Lastly, thank you to our cluster fellow Hassan Afify for supporting our project throughout the creation process.

Recommendations



- Two machine learning models: Isolation Forest (anomaly detection) and Decision Tree (supervised multiclass classification)
- Decision Tree uses labeled data from the RTC clock, energy sensor, people counter, and vehicle counter
  - Determines whether the harvested energy should be stored or output at different levels (partial, majority, or 95%)
    - Predicts upcoming energy generation based on upcoming pedestrian and vehicle traffic
- Why a Decision Tree?
  - Simple, rule-based decision making with conditional statements
  - Easy to interpret
- Machine learning is disabled between 6 pm and 6 am
  - During this period, 95% of the harvested energy is automatically directed to streetlights.

Discussion

- Piezoelectric harvesters are currently the most practical energy harvesting option.
- Pneumatic delayed-release and mechanical-to-electromagnetic systems had greater total power outputs but their cost, installation complexity, and limited available data reduced their suitability.
- Triboelectric nanogenerators were the closest in performance: they had higher energy output per unit cost, but its usable energy remained lower.
- Piezoelectric harvesters were very durable, easy to install, and had a reasonable cost which outweighed the limitation of lower power output compared to pneumatic and electromagnetic systems.
- All four methods scored above 5/10, but piezoelectric harvesters provided the best balance of criteria.
- **We have evaluated piezoelectric harvesters to have the best overall performance across the criteria, making it the best to implement under medium traffic crosswalks.**