

Kinetic Energy Harvesting Apparel for Sustainable Development in Hilly and Coastal Regions

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ABSTRACT

The rapid growth of IoT devices and wearable electronics has increased the demand for sustainable energy sources. Traditional batteries suffer from limited lifespan, maintenance requirements, and environmental concerns. Human kinetic energy harvesting offers an alternative approach by converting energy generated during walking into usable electrical energy. This project proposes a computer vision-based simulation framework that uses pose estimation to analyze human gait and estimate the kinetic energy available during locomotion. The system demonstrates the feasibility of utilizing human motion as a power source for low-power sensor nodes and wearable devices.

Keyword: Kinetic Energy, Computer Vision, Pose Estimation, MediaPipe Pose, Human Gait Analysis, Wearable Energy Harvesting, Internet of Things (IoT), Sustainable Energy, Artificial Intelligence (AI), Low-Power Sensor Networks.

I. INTRODUCTION

The rapid advancement of wearable devices, portable electronics, and Internet of Things (IoT) applications has created a growing demand for reliable and sustainable power sources. Conventional batteries have limitations such as limited lifespan, frequent replacement, increased maintenance costs, and environmental concerns. Energy harvesting has emerged as an effective alternative by converting ambient energy into usable electrical power. Among the various energy sources, human kinetic energy generated during activities such as walking and running is abundant and renewable. Recent developments in Artificial Intelligence (AI) and Computer Vision enable accurate analysis of human movement through pose

estimation techniques. This project uses MediaPipe Pose to detect body landmarks, analyze walking motion, and estimate the kinetic energy generated during movement. The proposed system provides a cost-effective and simulation-based approach for studying human kinetic energy harvesting without requiring expensive hardware, making it suitable for research, education, and future wearable technology applications.

PROBLEM STATEMENT

The increasing use of wearable devices and IoT systems requires continuous and efficient power sources, but conventional batteries have limited lifespan and require frequent replacement. Existing human kinetic energy harvesting techniques mainly depend on specialized hardware such as piezoelectric and electromagnetic devices, which are expensive and complex to implement. These hardware-based systems also require extensive testing and maintenance, making them less accessible for research and educational purposes. Moreover, there is a lack of affordable simulation tools that can estimate energy generation from human movement. Therefore, there is a need to develop a computer vision-based system that uses AI and pose estimation to analyze human walking and estimate the theoretical kinetic energy generated. Such a system offers a low-cost, flexible, and effective platform for studying energy harvesting potential without the need for physical harvesting devices.

OBJECTIVES:

1. To design and optimize low-cost wearable energy harvesters (e-textiles and footwear) capable of generating 5-50 mW from human motion.
2. To Integrate durable, eco-friendly materials suitable for humid/rugged terrains
3. To Demonstrate capability to power essential devices (LED lights, medical sensors, communication devices)
4. To Establish 10-15 local microenterprises for device manufacturing/maintenance
5. To Provide reliable emergency power during natural disasters
6. To Develop recommendations for government energy subsidies

II. RELATED WORK

1. Chen et al. (2025) proposed a piezoelectric shoe-based energy harvesting system that converts the pressure generated during walking into electrical energy using piezoelectric transducers embedded in footwear. Their experimental results showed that the system could generate approximately 4.5 mW of power during normal walking, which is sufficient for powering low-energy wearable sensors. However, the generated power was relatively low, and the system's performance depended on walking patterns and material efficiency.
2. Li et al. (2025) introduced a Triboelectric Nanogenerator (TENG) capable of harvesting biomechanical energy through contact electrification between different materials. Their study reported higher energy conversion efficiency compared to conventional piezoelectric systems, making TENGs a promising technology for wearable energy harvesting. However, issues such as material degradation, durability, and fabrication complexity limited its practical implementation.
3. Johnson et al. (2023) investigated electromagnetic energy harvesting systems based on Faraday's law of electromagnetic induction. Their work demonstrated

stable electrical power generation through the relative motion between magnets and coils. Although the system produced reliable energy output, the bulky hardware and increased device size made it less suitable for compact wearable applications.

4. Recent developments in Artificial Intelligence (AI), Machine Learning (ML), and Computer Vision have significantly improved human motion analysis. Zhang et al. (2024) evaluated the MediaPipe Pose Estimation framework for real-time human pose tracking. The framework accurately detected 33 human body landmarks and enabled detailed gait analysis without requiring specialized motion capture equipment. However, its performance was affected under poor lighting conditions and when body parts were occluded.

5. Kumar et al. (2025) proposed an AI-based gait analysis system using deep learning algorithms and computer vision techniques. Their model accurately estimated walking patterns, stride length, and movement characteristics, demonstrating the effectiveness of AI for biomechanical analysis and healthcare monitoring. Similarly, Wang et al. (2024) developed a deep learning model for predicting kinetic energy generation from human movement data. Their approach improved prediction accuracy but required large training datasets and high computational resources.

6. Singh et al. (2024) focused on wearable energy harvesting technologies for IoT applications and concluded that harvesting human kinetic energy could significantly reduce battery dependency in future wearable devices. Ahmed et al. (2024) proposed a self-powered sensor network driven by biomechanical energy, demonstrating its suitability for healthcare monitoring systems. Patel et al. (2024) developed a biomechanical energy estimation model that accurately calculated energy generation using gait parameters, although the computational model was relatively complex.

RESEARCH GAP

From the literature survey, several limitations have been identified:

1. Most existing systems require dedicated hardware components such as piezoelectric sensors and triboelectric materials.
2. Hardware-based systems increase cost and maintenance requirements.
3. Existing studies primarily focus on physical energy generation rather than energy estimation.
4. Limited research has been conducted using computer vision techniques for kinetic energy estimation.
5. Few systems combine Artificial Intelligence and biomechanical analysis for energy harvesting simulations.
6. Real-time energy estimation based on pose tracking remains relatively unexplored.

III.METHODOLOGY

The methodology begins with **video acquisition**, where a webcam or a pre-recorded video captures the user's walking activity. The captured video is divided into individual frames for further processing. Each frame is then analyzed using the **MediaPipe Pose Estimation** model, which detects and tracks 33 human body landmarks such as the shoulders, hips, knees, and ankles.

After detecting the body landmarks, the system performs **gait analysis** by tracking the movement of the lower body joints across consecutive frames. From these landmarks, important gait parameters such as stride length, displacement, walking speed, and body movement are calculated. These parameters provide the information required to estimate the user's walking velocity.

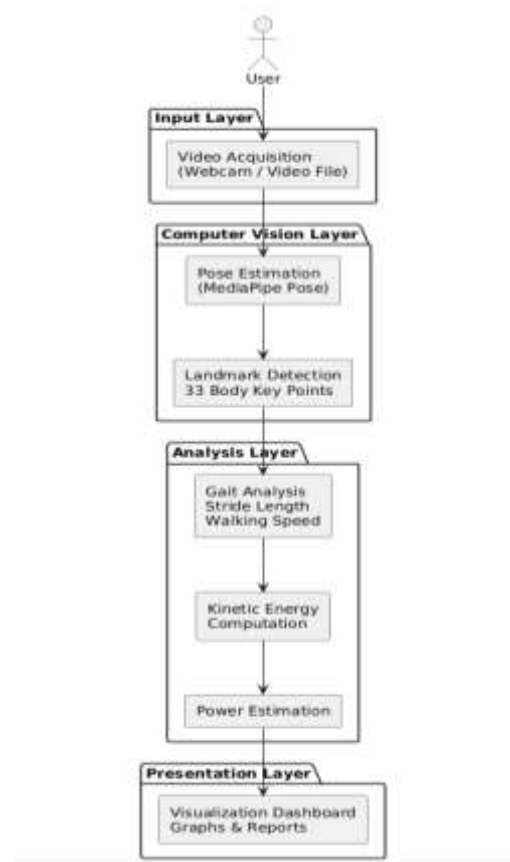
The user enters their **body weight (mass)**, which is used along with the calculated walking velocity to estimate the kinetic energy generated during walking. The system applies the classical kinetic energy equation:

$$KE = \frac{1}{2} mv^2$$

where **KE** is the kinetic energy (Joules), **m** is the body mass (kg), and **v** is the walking velocity (m/s).

The estimated kinetic energy is further used to calculate the **theoretical electrical power** that could be harvested by assuming an energy conversion efficiency. Finally, the computed results are displayed through graphical dashboards showing walking speed, stride length, kinetic energy, and estimated power generation. This methodology provides a simple, low-cost, and efficient platform for studying human kinetic energy harvesting without requiring expensive hardware components, making it suitable for research, educational, and wearable technology applications.

ARCHITECTURE DIAGRAM



IV.HARDWARE AND SOFTWARE REQUIREMENTS.

HARDWARE REQUIREMENTS

Component	Specification
Processor	Intel Core i5 / i7
RAM	8 GB Minimum
Storage	256 GB SSD
Webcam	HD Camera
GPU	Optional NVIDIA GPU
Display	15-inch Monitor or Higher

SOFTWARE REQUIREMENTS

Software	Purpose
Python	Programming Language
OpenCV	Video Processing
MediaPipe	Pose Estimation
NumPy	Numerical Computation
Pandas	Data Analysis
Matplotlib	Data Visualization
Flask	Web Interface
VS Code	Development Environment

V.RESULTS



Figure: capacity stored

Human Kinetic Energy Harvesting System that detects a person's movement and estimates the amount of electrical energy generated from walking.

1. The **left panel** displays a live computer vision feed where a person is walking, and the system detects motion, as indicated by the **"Movement Detected"** status at the top.
2. The **right dashboard** shows real-time telemetry, including the **stride count (77)** and the **total energy generated (346.5 J)**, calculated from the person's walking activity.
3. The **cell accumulator load matrix (36% capacity)** represents the current charge level of the energy storage unit, indicating how much harvested energy has been stored.
4. The **"Store Session Log"** and **"Clear Meters"** buttons allow the user to save the current walking session data or reset the measurement values for a new session.
5. The **historical accumulation records** at the bottom maintain a log of previous walking sessions, including the file name, number of steps, energy generated (in joules), and timestamp for performance tracking and analysis.

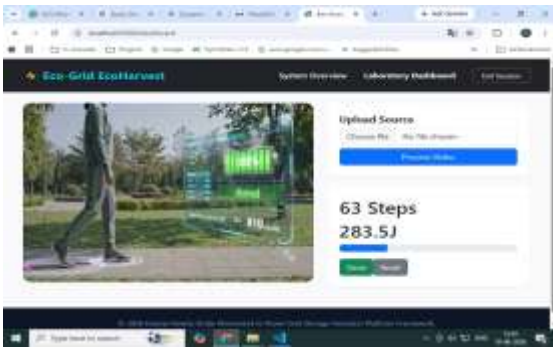


Figure: with upload source

1. This interface represents the **Eco-Grid EcoHarvest** system, which processes a walking video to estimate the amount of electrical energy that can be harvested from human footsteps using computer vision and kinetic energy calculations. The uploaded video is analyzed after clicking the **"Process Video"** button.

2. The **left panel** displays the walking video, where the system tracks the person's footsteps and movement in real time. The holographic overlay shows the energy storage status, indicating that the harvested energy is being accumulated in a virtual storage unit.

3. The **right panel** presents the processing results, showing that the user has taken **63 steps** and generated approximately **283.5 Joules** of energy. These values are calculated based on the detected walking motion and the energy harvesting model.

4. Overall, this dashboard demonstrates a **Human Kinetic Energy Harvesting Framework** that combines **computer vision, step detection, energy estimation, and energy storage visualization** to monitor walking activity and estimate the renewable electrical energy that could be generated from human movement.

VI.CONCLUSION

The proposed Human Kinetic Energy Harvesting System successfully estimates energy generated from human walking using computer vision and pose estimation. It integrates motion detection, gait analysis, and energy calculation into a single software-based framework. The system demonstrates the potential of human movement as a renewable energy source for low-power electronic devices. It provides a cost-effective platform for research, education, and sustainable energy

applications. The framework can be further enhanced by integrating real energy harvesting hardware and IoT-based smart systems.

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