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Multi Sensor Energy Harvesting Distributed Energy Collection from Environmental Sensors using Raspberry Pi

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ABSTRACT

To meet the increasing global power demand, various Energy Harvesting Systems (EHS) have been developed, with piezoelectric energy harvesting emerging as a promising approach. This method utilizes piezoelectric transducers to convert unused mechanical energy from natural renewable sources into electrical energy. Over the past decade, numerous analytical models using different piezoelectric materials and configurations have been proposed to enhance energy efficiency and output. This paper presents a comprehensive review of Piezoelectric Energy Harvesting (PEH) systems designed to power small electronic devices. These systems operate on the principle of the direct piezoelectric effect, where mechanical stress, pressure, or vibration induces an electrical response in the transducer. The performance and application suitability of these transducers depend heavily on the type of piezoelectric material, as well as their shape and structural configuration. This review analyzes key performance parameters of various PEH systems and highlights opportunities for further improvement. Researchers have been actively exploring clean energy harvesting from diverse sources including the environment, vehicles, industries, and human motion for over a decade.

INTRODUCTION

The growing global demand for sustainable and clean energy has led to increased interest in Energy Harvesting Systems (EHS). Among the various techniques, piezoelectric energy harvesting stands out due to its ability to convert mechanical energy into electrical energy using piezoelectric materials. This method utilizes vibrations, pressure, and mechanical stress from natural and man-made sources to generate power. Over the last decade, significant advancements have been made in the development of Piezoelectric Energy Harvesting (PEH) systems. These systems are particularly suitable for powering low-energy devices such as sensors, wearable electronics, and wireless modules. The effectiveness of a PEH system largely depends on the material properties, geometric design, and configuration of the transducer. Researchers have proposed various models to enhance the energy output and efficiency of such systems. Energy can be harvested from diverse sources including human motion, traffic vibrations, industrial machinery, and environmental movements. This paper aims to provide a detailed review of existing PEH systems.

LITERATURE SURVEY

Several studies over the past decade have explored the potential of piezoelectric energy harvesting systems for powering low-power electronic devices. Research by Priya et al. (2011) demonstrated the feasibility of using piezoelectric cantilevers for energy generation from mechanical vibrations. Yang and Lee (2014) developed a multilayer piezoelectric harvester to enhance power output and efficiency. Roundy et al. (2016) focused on miniaturized harvesters for wearable and biomedical applications. A study by Kim et al. (2017) analyzed different piezoelectric materials, highlighting the superior performance of PZT over PVDF in high-stress environments. Wang et al. (2018) introduced flexible transducers for energy harvesting from human motion. Singh and Sharma (2019) proposed a hybrid harvester combining piezoelectric and electromagnetic systems for improved energy conversion. In 2020, Zhao et al. optimized harvester geometry for better frequency response. Patil et al. (2021) reviewed advancements in harvesting energy from vehicular vibrations. Gupta et al. (2022) addressed energy storage challenges associated with PEH systems.

EXISTING METHOD

According to the “Centre for Climate and Energy Solutions” (C2ES), renewable energy contributed 26.2% of global electricity generation in 2018, and this share is expected to rise to 45% by 2040. The majority of this renewable energy is derived from sources such as solar, wind, and ocean waves. In recent years, harvesting unused renewable energy using piezoelectric transducers has gained significant attention. One such development involves an energy harvesting device based on a cantilever-type piezoelectric transducer integrated with Shape Memory Alloy (SMA). This system is capable of generating 12.1 microwatts of electrical power from solar energy when the working fluid reaches a temperature of 70°C and flows at a rate of 24 ml/second. Under the same thermal conditions but with a reduced flow rate of 4.8 ml/second, the output power drops to 2.36 microwatts. The

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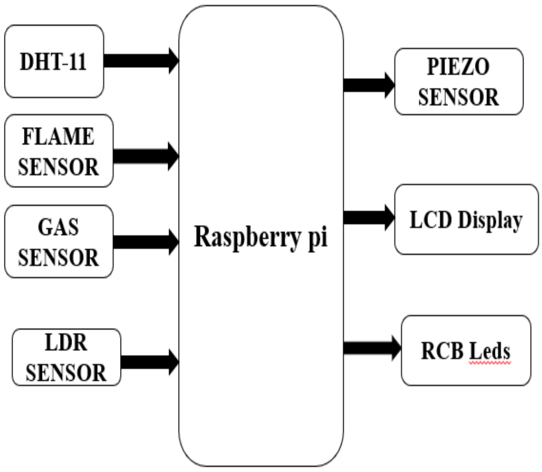
Vol 19, Issue 3, 2025

study by Kang further suggests that increasing the solar input raises the temperature of the working fluid, thereby enhancing energy generation potential.

PROPOSED METHOD

To address the growing global power demand, a variety of Energy Harvesting Systems (EHS) have been developed, with piezoelectric energy harvesting emerging as a promising solution. This approach utilizes unused mechanical energy from natural renewable sources, converting it into electrical energy through piezoelectric transducers. Over time, numerous analytical models have been proposed to enhance the efficiency and output of such systems using different piezoelectric materials and configurations. This paper aims to review the advancements in Piezoelectric Energy Harvesting (PEH) technologies over the past decade, particularly in powering small-scale electronic devices. PEH systems operate based on the direct piezoelectric effect, where mechanical stress, pressure, or vibration applied to a transducer generates electrical energy. The effectiveness of these systems largely depends on the type of piezoelectric material used, as well as the transducer's shape and structure. This review discusses various materials and design configurations and evaluates the performance parameters of existing systems. Additionally, it highlights the current challenges and potential areas for improvement in PEH technology.

BLOCK DIAGRAM



HARDWARE REQUIREMENTS

Raspberry pi

The Raspberry Pi is a low-cost, credit-card-sized single-board computer. It runs on Linux and supports various programming languages like Python and C++. Raspberry Pi is widely used for IoT, robotics, and AI-based projects. It includes USB ports, HDMI output, GPIO pins, and a microSD card slot. Popular models include Raspberry Pi 3B+, 4, and Zero. It supports networking via Ethernet or built-in Wi-Fi and Bluetooth. GPIO pins allow interfacing

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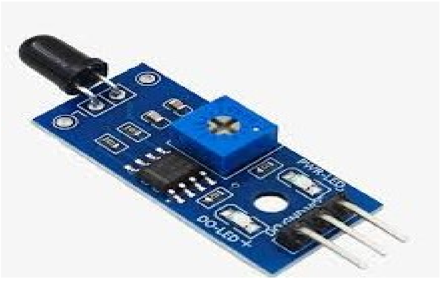
Vol 19, Issue 3, 2025

with sensors, displays, and motors. It can function as a desktop PC, server, or embedded controller. Used in applications like home automation, weather stations, and surveillance. Its versatility and affordability make it ideal for makers and students.

DHT-11

The DHT11 is a basic digital sensor used to measure temperature and humidity. It provides output in digital form, making it easy to interface with microcontrollers. The sensor operates at 3.5V to 5.5V and consumes low power. It uses a thermistor and capacitive humidity sensor for measurement. The data is transmitted serially to the microcontroller. Temperature range: 0–50°C; Humidity range: 20–90% RH. It updates readings approximately every second.

FLAME SENSOR



A flame sensor is used to detect the presence of fire or flame. It senses infrared (IR) light emitted by flames, typically between 760–1100 nm. The sensor provides both analog and digital outputs. It works effectively within a detection range of up to 1 meter. Used for fire detection in safety systems and industrial controls. It is sensitive to light, so shielding or filtering may be needed. Flame sensors are easy to interface with Arduino or Raspberry Pi.

GAS SENSOR

Gas sensors detect the presence of harmful gases in the environment. Common types include MQ-2, MQ-7, and MQ-135, each for specific gases. They use tin dioxide (SnO_2) as a sensing material, changing resistance with gas levels. MQ-2 detects smoke, LPG, CO, methane; MQ-7 detects CO; MQ-135 detects air pollutants. They provide both analog and digital outputs. Operate at 5V with a warm-up time for accurate readings. Used in gas leak detectors, air purifiers, and safety alarms. Gas sensors are key components in environmental and industrial monitoring.

ISSN 2454-9940
www.ijasem.org
Vol 19, Issue 3, 2025

LDR SENSOR

An LDR (Light Dependent Resistor) detects the intensity of ambient light. Its resistance decreases with increasing light intensity. Used for automatic lighting, streetlights, and solar trackers. It is an analog sensor and requires an ADC for digital systems. LDRs operate at low voltage and are highly energy-efficient. They are simple, affordable, and easy to use in DIY projects.

PIEZO SENSOR

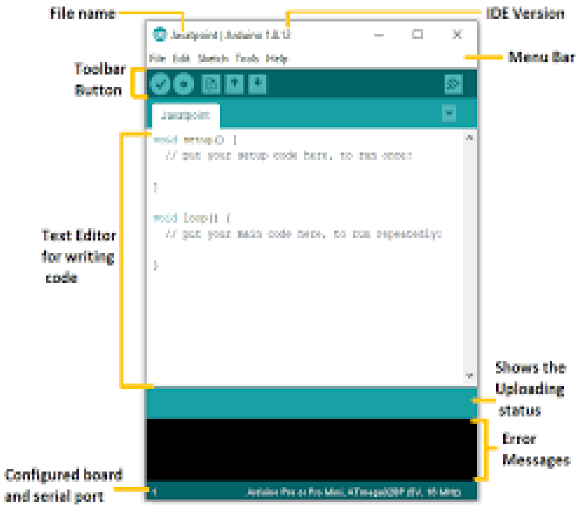
A piezo sensor generates voltage when subjected to mechanical stress. It is used to detect vibrations, pressure, or impacts. Common applications include knock sensors, security systems, and musical instruments. It works on the piezoelectric effect, converting mechanical energy into electrical energy. The output is an analog signal, often requiring signal conditioning. Piezo sensors are highly sensitive and have a fast response time. They are compact, durable, and consume very low power. Used in touch-sensitive systems, alarms, and smart wearables. They can also be used in energy harvesting circuits. Integration with Arduino allows real-time detection of motion or force.

LCD DISPLAY

An LCD (Liquid Crystal Display) shows characters or data in embedded systems. The most common modules are 16x2 and 20x4 character LCDs. They operate at 5V and can be interfaced using parallel or I2C communication. Each character is displayed using a 5x8 pixel dot matrix. Used for displaying sensor values, system status, or menus. Equipped with backlight and contrast control for visibility. Widely supported with Arduino and microcontroller libraries.

SOFTWARE REQUIREMENT

Arduino Software (IDE)



The Arduino IDE (Integrated Development Environment) is a simple yet powerful platform used to program Arduino boards. It supports C and C++ programming languages with an easy-to-understand syntax tailored for microcontroller applications. The IDE provides a clean and intuitive interface where users can write, compile, and upload code directly to Arduino hardware. It includes a rich set of built-in libraries, making it easy to perform common tasks such as reading sensors, controlling LEDs, or operating motors. The integrated Serial Monitor allows real-time communication and debugging between the Arduino and the computer. Compatible with Windows, macOS, and Linux, the IDE is accessible across multiple platforms. Users can extend its functionality using the built-in Library Manager, which offers access to numerous community-developed libraries. As an open-source tool, the Arduino IDE can be customized to fit specific development needs.

CONCLUSION

The shift of small electronic devices from battery-powered to self-powered systems has been made possible through the use of energy harvesting technologies. Among these, piezoelectric transducers are widely employed due to their simple fabrication, cost-effectiveness, and high energy density. However, their broader application is limited by certain challenges, such as low output energy, the need for efficient power extraction, rectification, high voltage regulation, and system-level optimization. Addressing these limitations is essential to improve the overall performance and efficiency of Piezoelectric Energy Harvesting (PEH) systems. Among various vibration sources, traffic-induced vibrations have shown significant potential for PEH applications. Roadway energy harvesting, particularly in densely populated regions, offers a promising solution to meet the increasing energy demands in the post-pandemic era and deserves greater research and development focus.

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