

Integrated Solar–Piezoelectric Hybrid Energy Harvesting with IoT-Based Monitoring: A Comparative Analysis of Reported Systems and a Unified Architecture

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Abstract- Hybrid energy harvesting that combines photovoltaic (PV) generation with piezoelectric footstep harvesting promises uninterrupted low-power supply in public spaces, but published prototypes use different tile designs, converters, monitoring schemes and reporting conventions, which makes them hard to compare. This paper critically consolidates three recent studies: an Arduino/ESP8266 solar–piezoelectric system with ThingSpeak monitoring, a footstep floor tile with a closed-loop buck converter, and a tracked-PV plus 48-sensor footstep system for DC loads. Their reported figures are normalised to common metrics (power per unit area, daily energy, and the piezoelectric share of total energy), and inconsistencies in the source data are identified. A unified architecture is then proposed in which a PV string and a piezoelectric tile array feed a common 12 V DC bus through independent converters, with a microcontroller and IoT gateway providing real-time monitoring and fault flagging. Using only values reported in the source studies, an analytical scale-up shows that a 30-tile array (60 Wh over 8 h) can supply a 5.4 W camera for about 11 h, but contributes only about 3–5% of the daily energy of a tracked PV panel of the class reported. The results indicate that piezoelectric tiles are best positioned as a supplementary and sensing-grade source, while PV remains the dominant energy contributor. Experimental validation of the proposed architecture is identified as future work.

Keywords—Hybrid Energy Harvesting; Photovoltaic; Piezoelectric Floor Tile; Footstep Energy; Buck

I. INTRODUCTION

Rising electricity demand and environmental concern have accelerated research into small-scale renewable systems that can power sensors, lighting and surveillance equipment without grid connection[1]–[3]. Solar PV is the most mature of these sources, but its output depends on irradiance, weather and time of day. Piezoelectric transduction, which converts mechanical stress from footsteps, vibration or pressure into electrical charge, can supply a small amount of power at any hour in places with sustained foot traffic, such as entrances, walkways and railway stations [4], [5]. Combining the two sources into a hybrid system is therefore attractive: PV supplies the bulk of the energy in daylight, while piezoelectric tiles contribute opportunistic energy and a measurable proxy for occupancy. However, the literature reports results with different tile geometries, sensor counts, rectifier and

converter topologies, load types, and efficiency definitions. Some reports give instantaneous power in milliwatts, others give daily energy in kilowatt-hours, and several do not state the active area. As a result, claims about the benefit of hybridisation are difficult to compare directly.

This paper makes three contributions. First, it consolidates three recent studies [1]–[3] into a common comparison framework. Second, it normalises their reported data to common metrics and identifies internal inconsistencies that should be resolved before the numbers are reused. Third, it proposes a unified architecture that merges the strengths of the three systems (closed-loop piezoelectric conditioning, tracked or fixed PV, a common DC bus, and cloud monitoring) and © 2015 Author et al. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction

in any medium, provided the original work is properly credited. evaluates its energy balance analytically using only figures reported in the source studies. No new experimental measurements are claimed.

II. LITERATURE SURVEY

1. Solar–Piezoelectric System With Iot Monitoring [1]

Kumari et al. built a hybrid harvester in which a solar panel and piezoelectric sensors charge a 12 V, 7 Ah battery through a buck–boost converter. An Arduino Uno reads voltage sensors on the solar, piezoelectric and battery nodes, drives relays, and shows values on an LCD, while an ESP8266 module uploads the data to a ThingSpeak dashboard.

2. Piezoelectric Floor Tile With Closed-Loop Buck Converter [2]

Selim et al. developed a 455 mm × 405 mm sandwich-style floor tile that uses fourteen 20 mm ceramic piezoelectric diaphragms (brass base, 0.42 mm piezoceramic) pressed by hot-melt-adhesive studs.

3. Tracked Pv Plus 48-Sensor Footstep System For Dc Loads [3]

Hussein et al. combined a pre-programmed (clock-and-table based) tracked PV panel with a footstep array of 12 plates of 100 mm × 100 mm, each carrying four 10 mm piezoelectric discs (48 in total). Sensors are in series within a plate and plates are in parallel; a booster circuit raises the output to 12 V for charging a battery or directly powering DC appliances through automatic transfer switches.

Components

4. Arduino Uno

The Arduino uno is the main control unit of the system. It receives voltage readings from the sensors and processes the collected data. It also controls the connected components according to the program instructions.

5. Solar Panel

The solar panel converts sunlight into electrical energy using the photovoltaic effect. It acts as the primary energy source during daylight hours. The generated

electricity can be used to charge the battery and supply power to connected loads.

6. Piezoelectric Sensors

Piezoelectric sensors convert mechanical pressure or vibration into electrical energy. In this project they can generate electricity from pressure caused by human footsteps. The harvested energy provides an additional source of power for hybrid system.

1. Voltage Sensor

Voltage sensor modules measure the voltage produced by the energy sources. They send corresponding signals to the Arduino Uno for monitoring and analysis. These readings help evaluate the performance of the solar panel and piezoelectric system.

2. 16x2 LCD Display

The 16×2 LCD display shows important system information, such as voltage readings and operating status. The I2C module reduces the number of connections required between the display and Arduino. This makes the circuit simpler and easier to connect.

3. Two channel Relay Module

The two-channel relay module acts as an electrically controlled switch. It allows the Arduino to control connected loads or switch circuits according to programmed conditions. It helps automate the operation of the system.

III. RESULTS AND DISCUSSION

All numbers in this section are taken from the base studies or derived from them arithmetically; they are not new measurements.

1. Piezoelectric power levels across studies

Fig. 2 compares the reported power of piezoelectric tiles and modules. Using the comparison table in [2] together with the module in [1], the 249.6 mW tile of [2] is roughly an order of magnitude above the other tile designs, which ranged from 1.24 mW to 35 mW. The piezoelectric module in [1] (35 mW) is comparable to the best of the earlier tile designs, but its area is not stated. Two factors likely contribute to the higher figure in [2]: the use of fourteen diaphragms per tile with an

explicit pressing mechanism, and the use of low-forward-drop Schottky diodes in the rectifier.

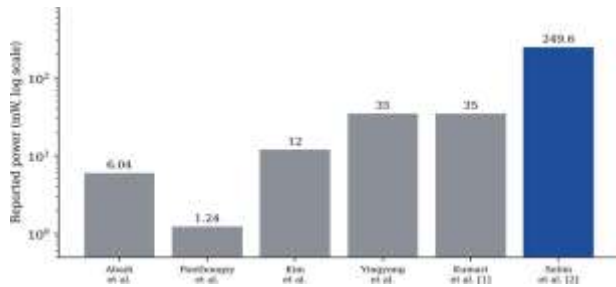
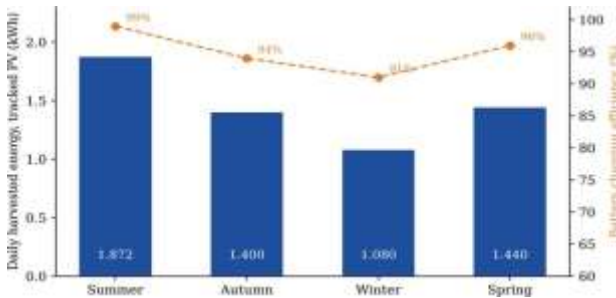


Chart -1: Reported piezo electric power

2. Solar Contribution And Seasonal Behaviour

Fig. 3 shows the seasonal daily energy and battery charging efficiency reported in [3] for a tracked panel in Baghdad. Daily energy ranges from 1.08 kWh in winter to 1.872 kWh in summer, a summer-to-winter ratio of about 1.7, while battery charging efficiency falls from 99% to 91% over the same range. Fig. 4 shows that, in all four seasons, a 30° tilt gave the highest tracking efficiency among the three tested angles, with the largest sensitivity in winter (89–91%).



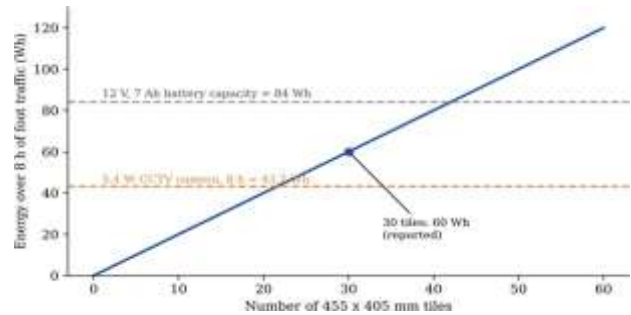
A. Normalised comparison and data consistency

Table II normalises the piezoelectric results. The tile of [2] has an areal power density of about 1.35 W/m² (249.6 mW over 0.184 m²), or about 17.8 mW per diaphragm. The 8 h energy of 2 Wh per tile corresponds to about 10.9 Wh per square metre. By contrast, the footstep energy of 0.125–0.42 kWh per day reported in [3], taken together with the stated plate geometry (12 plates of 100 mm × 100 mm, 0.12 m² in total), implies 1.0–3.5 kWh per square metre per day, about two orders of magnitude above [2]. Since [3] also quotes instantaneous plate output of the order of 10 W for a single 10 cm × 10 cm plate (approximately 1000 W/m²), the footstep figures in

[3] should be regarded as unverified until the measurement method and the counting of steps are clarified. For this reason the scale-up in Section V-D uses the tile energy of [2] rather than the footstep energy of [3]. Two further points need care. The piezoelectric voltage in [1] is stated both as 0.7 V (Table 1 of that paper) and as 2–6 V (text). The 100% power-transfer efficiency claimed in [3] for the DC chain is not physically attainable once converter, switch and wiring losses are included, and it is best read as meaning that no DC–AC inversion stage is required.

3. Energy-Balance Scale-Up Of The Unified Architecture

Using (2), the energy of an array of N tiles over 8 h is 2N Wh. Fig. 5 shows this against two reference levels: the 84 Wh capacity of the 12 V, 7 Ah battery in [1] and the 43.2 Wh required by a 5.4 W camera over 8 h. Twenty-two tiles are sufficient to meet the camera energy over 8 h, and the 30-tile entrance estimated in [2] (60 Wh) would power the same camera for about 11 h. A 42-tile array would match the full battery capacity of 84 Wh.



Result:



IV. CONCLUSION

Three recent hybrid and footstep-harvesting studies were consolidated and normalised. The tile of [2] provides the highest reported piezoelectric power (249.6 mW, about 1.35 W/m²), the tracked PV system of [3] gives 1.08–1.872 kWh per day depending on season, and the monitoring scheme of [1] provides a low-cost route to remote supervision. A unified architecture with independent source conditioning, a shared 12 V bus and cloud monitoring was proposed. On an analytical basis, a 30-tile array can supply a 5.4 W camera for about 11 h but adds only about 3–5% to the daily energy of a tracked panel of the class reported, so its main value is as a supplementary source and an occupancy sensor. Inconsistencies in the source data, particularly the footstep energy in [3] and the piezoelectric voltage in [1], should be resolved by direct measurement before the figures are used for design.

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