Harnessing energy for wearable technology: a sustainable approach

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ABSTRACT

Recent advancements in electrical sensing and electronics have notably propelled the progress of wearable fitness and medical technology. Key to these applications is the mobility of wearable nodes, essential for remote patient monitoring. However, the limited lifespan of wearable devices, particularly in biomedical applications, poses a significant challenge to their widespread adoption. Energy harvesting technology emerges as a promising solution to this issue, despite the inherent challenges of size, weight, and cost restrictions for wearable devices. This study presents three innovative strategies for harnessing solar and thermal energy at wearable sensor nodes, offering new pathways to overcome the longevity constraints of wearable technology.

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1. INTRODUCTION

Wearable sensors are becoming more common in our society, including smart watches and wristbands for measuring our fitness and health. The rapid expansion of this industry introduces new applications to the market on a regular basis that follow the trend of miniaturization while also including an increasing spectrum of monitoring applications. This trend is being aided by flexible and printable technologies, which are boosting wearer comfort and lowering the form factor of wearable gadgets [1]. Energy collected from things like shaking, solar radiation, temperature differences, or radio frequency waves has become a popular and practical way to power an IoT node. Solar energy is often used to power an IoT node instead of other types of energy because it has a high power density and can be found everywhere. Solar energy gathering has come a long way in the last 20 years, from lighting spaceships to keeping people going in their daily lives. The key to collecting solar energy is how well the photovoltaic (PV) panel converts light into electricity. Many maximum power point tracking (MPPT) methods have been developed to turn more solar energy into electricity. Because the power from PV is not always the same, designing DC-DC converters for solar energy gathering is another technical point. Energy storage is also needed because the energy sources in the environment are unreliable and stop and start [2]–[4]. The human body constantly emits heat. Through the use of thermogenerators, devices in close contact with the human body may capture this squandered energy using thermoelectric energy generators (TEGs). The thermocouple module (based on the seebeck effect) provides an electrical voltage proportionate to the temperature difference between hot and cold junctions. In our scenario, the TEG generates electrical energy by using the temperature differential between the hot (body) and cold (ambient) sides [5]–[7]. In this study, we present three different and effective energy harvesting systems for wireless sensor networks (WSN) nodes, as well as a method for tracking the MPPT. The goal of the study is to compare three overall harvesting systems by battery voltage and battery state of charge (SoC). The energy harvester system for this module was built, and iterative simulations were done in MATLAB/Simulink. The following portions of this work are organized as follows: The methods used to collect energy in the three systems described in this article are discussed in section 2 of the article. In section 3 of the proposed design will address three model systems, each of which contains energy-harvesting technology in the sensing devices to aid in energy autonomy. In section 4 describes the simulation outcomes for the three model systems. Lastly, section 5 summarizes the conclusions.

2. ENERGY HARVESTING SYSTEM

Energy gathering is the process of turning energy that is easy to get from the world into useful electrical energy. This gives you a useful way to keep power going to a wide range of loads. There are a number of natural and man-made things in the world that can be used to make energy. Some of these are motion, light, heat, electric force, and many others [8].

2.1. Light energy harvesting

Photovoltaics is the best way to turn energy from the sun into power. Solar cells are machines that turn sunlight into power by using the photoelectric effect [9]–[13]. For many years, solar energy has been utilized to power everyday objects like watches and calculators. It is one of the most frequently utilized energy sources due to the quantity of energy collected. When exposed to sunlight, PV cells, which are nonlinear semiconductor devices, produce electricity. The substances in them deteriorate as a result of exposure to sunlight or light. The efficiency of solar cells is dependent on the material used [14], [15]. PV cells are commonly made of three materials: amorphous, monocrystalline, and polycrystalline silicon. Amorphous PV panels are photovoltaic cells made of thin layers that are mounted on plastic or stainless-steel sheets. It is appropriate for use in low-power gadgets like watches and mobile devices. Another kind of solar cell is the monocrystalline PV module. It is composed of monocrystalline solar cells built of high-grade cylindrical silicon alloy that has been divided into many chips. This kind of cell has the highest efficiency rates, ranging from 15-20%, since it is made of silicon. Several crystals from various silicone sources are combined to create polycrystalline panels. Despite being less costly, these cells are less efficient than monocrystalline ones [16]. Depending on the type of cell, PV panels turn between 15% and 20% of the sun’s energy into electricity. The rest of the energy is turned into heat, which makes the temperature of the photovoltaic cells rise [17]. Temperature increases have a greater impact on PV cells, resulting in a decline in the electrical power generated [18].

A solar energy gathering system is made up of a solar panel, a DC-DC converter, a reusable battery, a battery charge safety circuit called a battery management system (BMS), and a DC-DC converter control unit. The solar panel collects the sun’s light energy and turns it into electricity. Before sending the voltage to the recharged battery, the DC-DC boost converter lowers and changes the amount of voltage that was gathered. The MPPT sensor checks the power and current coming from the solar cell. Lastly, the wireless sensor node is charged by the battery’s energy. The WSN does detection, computing, and talking to other nodes with similar traits [19]–[21].

2.2. Thermal energy harvesting

The seebeck effect may be used to extract energy from thermal sources via the thermoelectric effect. The temperature difference T between a person’s skin and the surrounding air may be converted into voltage by placing TEGs, which have thermoelectric material properties, on the wearer. To create a TEG, an n-type material is connected in series with a p-type material. Heat electrons travel from the hotter thermoelectric material to the cooler substance when the temperatures of these materials vary. Electric potential is created during the process, causing current to flow in a closed circuit. High electrical conductivity and low heat conductivity are characteristics of a good thermoelectric material. Examples of frequently used thermoelectric materials are calcium manganese oxide, lead telluride, and bismuth telluride. By switching the metal contact pads on various n- and p-type semiconductors, a thermopile may be created with a higher voltage output [22]–[25].

3. PROPOSED ARCHITECTURE

In this part, we will describe three model systems in which the sensing devices are outfitted with energy harvesting technologies to aid in energy autonomy. In the first case study, solar energy was harvested using a single PV panel. In the second case study, solar energy was harvested using two PV panels. The third case study included hybrid energy harvesting, which consisted of one PV panel and one TEG.

3.1. Case I: Energy harvesting by one photovoltaic panel

A block diagram of the PV energy harvesting system integrated into the wearable sensor node is shown in Figure 1. Two major parts make up the system block diagram: the PV energy harvesting system, which includes a PV panel to detect light and a DC-DC boost converter to regulate the voltage generated by a rechargeable battery used as a fallback power source when the sun isn't shining. The node MCU board and a pulse oximeter sensor make up the second part. The heart rate (HR) and blood oxygen level (SpO2) from the sensor are collected and analyzed by a microcontroller on the node MCU board.

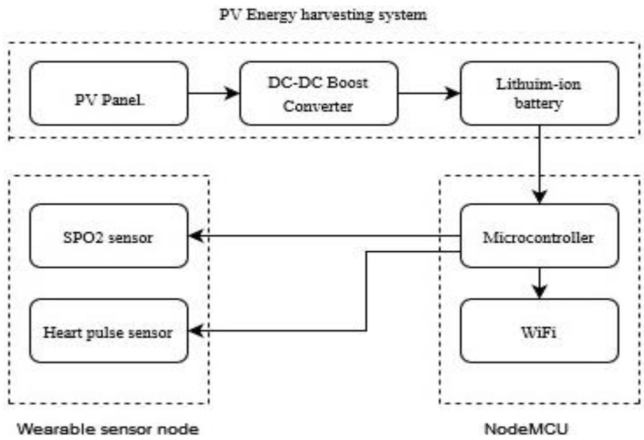

Figure 1. Block diagram of wearable sensor node with one PV energy harvesting system

3.2. Case II: Energy harvesting by two photovoltaic panel

The suggested system's architecture is shown in Figure 2. This architecture is split into two parts. The first component is an Internet of Things wearable sensor node that detects and records patients' vital data. There is a pulse oximeter sensor and a node MCU board included. The pulse oximeter sensor keeps track of two physiological variables: HR and SpO2. A microcontroller on the node MCU board gathers and analyzes sensor data. The second component that will power the IoT wearable sensor node is the solar energy harvester. It is made up of two parallel-connected PV panels, a charging controller, and a lithium-ion (Li-ion) battery. PV panels are used to generate power from the sun. In order to charge the Li-ion battery, the charging controller adjusts the voltage of the PV panels. During the night, this battery functions as a backup.

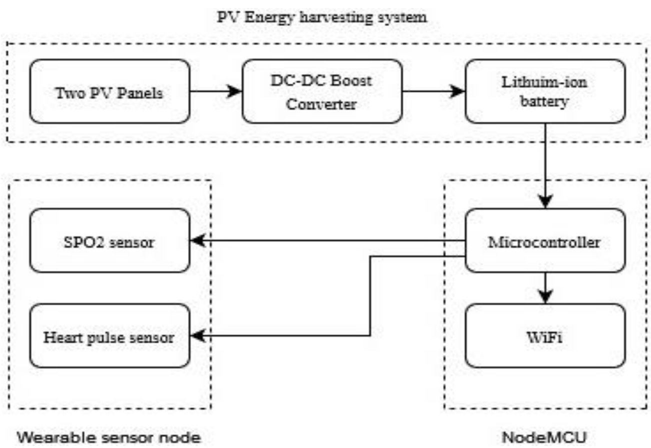

Figure 2. Block diagram of wearable sensor node with two PV energy harvesting system

3.3. Case III: Hybrid energy harvester system

Figure 3 depicts the hybrid energy harvester design with sensor system that is proposed. This design integrates a solar panel for detecting solar irradiance with a TEG module for monitoring human body temperature. There are parallel connections between the PV panel and the TEG module. Together, the PV panel and TEG module acquire rapid, sufficient, and consistent energy from the sun and a source of body heat. TEG, on the other hand, is a useful energy source for the medical system because human body heat is an inherent property. Consequently, thermal energy is utilized. This architecture also includes a DC-DC boost converter, which functions as the third component of the energy harvester. This converter increases the DC output voltage of the photovoltaic or thermoelectric module. In addition, a microcontroller unit (node MCU) is utilized to manage vital sensor inputs, such as HR and SpO2.

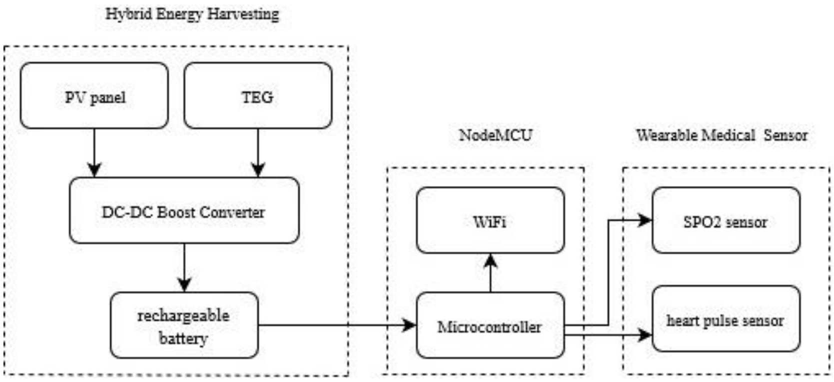

Figure 3. Block diagram of hybrid energy harvester system

4. SIMULATION RESULTS

For the simulation of the three model systems, MATLAB Simulink 2017 was utilized. This section presents the results of simulating the proposed system. The focus is on the battery SoC and battery voltage.

4.1. Case I

Table 1 displays the simulation parameters for this scenario of energy harvesting equipment. Figure 4 depicts the simulation results of the battery SoC in this proposed paradigm. A battery SoC for a simulated time of 200 seconds is provided. The SOC of the battery ranges from 0% to 3.066%. The battery voltage simulation findings in this proposed paradigm. The battery voltage is reported for a 200-second simulation. The voltage of the battery reaches 18.91 volts.

Table 1. Simulation parameters for case I

Parameters	Value
Irradiance (W/m^2)	1,000 Watts/m^2
Temperature (T)	25-degree celsius
Rechargeable battery type	Nickel-cadmium
WSN load model	10-ohm resistor
Battery voltage	20 volts

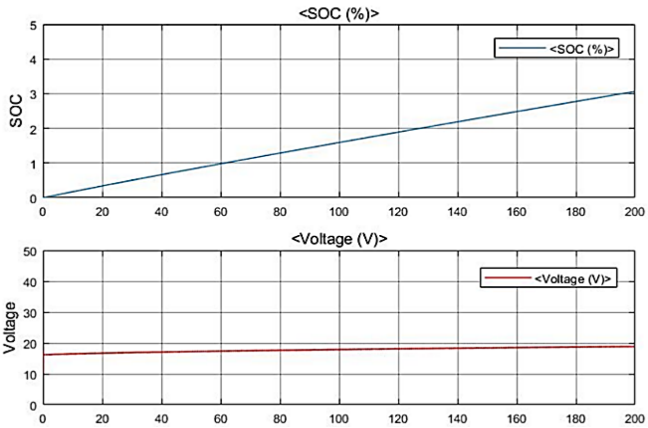

Figure 4. Battery state of charge and battery voltage for energy harvesting system by one photovoltaic panel

4.2. Case II

Table 2 shows the simulation settings for this scenario of an energy harvesting system with two PV panels linked in parallel. Figure 5 depicts the simulation results of the battery SoC in this proposed paradigm.

A battery SoC for a simulated time of 200 seconds is provided. The SOC of the battery ranges from 0% to 2.005%. The battery voltage simulation findings in this proposed paradigm the battery voltage is reported for a 200-second simulation. The voltage of the battery reaches 36.93 V.

Table 2. Simulation parameters for case II

Parameters	Value
Irradiance (W/m^2)	1000 Watts/m^2
Temperature (T)	25-degree celsius
Rechargeable battery type	Nickel-cadmium
WSN load model	10-ohm resistor
Battery voltage	40 volts

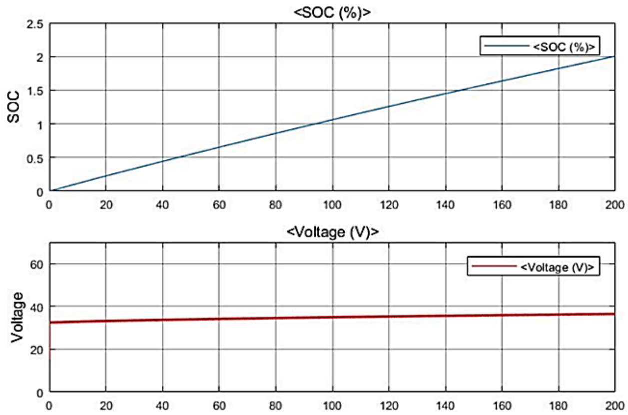

Figure 5. Battery state of charge and battery voltage for energy harvesting system by two photovoltaic panel

4.3. Case III

Table 3 displays the simulation parameters for this hybrid energy harvesting system instance. Figure 6 depicts the battery SoC simulation results in this proposed paradigm. A battery SoC for a simulated time of 200 seconds is provided. The SOC of the battery ranges from 0% to 0.9277%. The battery voltage simulation findings in this proposed paradigm. The battery voltage is reported for a 200-second simulation. The voltage of the battery hits 36.41 V.

Table 3. Simulation parameters for case III

Parameters	Value
Irradiance (W/m^2)	1,000 Watts/m^2
Temperature (T)	25-degree celsius
Rechargeable battery type	Nickel-cadmium
WSN load model	10-ohm resistor
Battery voltage	42 volts

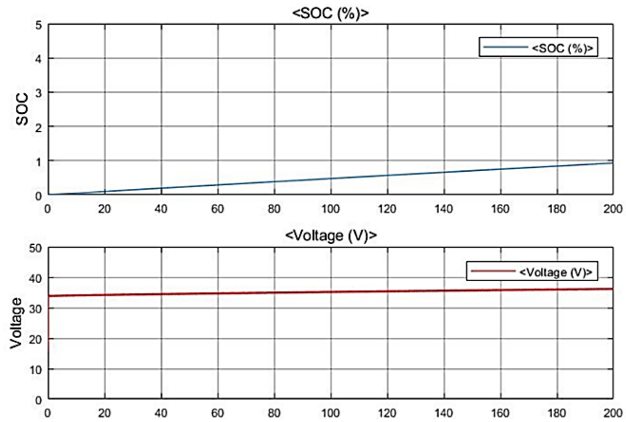

Figure 6. Battery state of charge and battery voltage for hybrid energy harvester system

5. CONCLUSION

In light of the presented results, the dual PV panel model emerges as the most efficient for battery charging. However, the increased size due to the use of two PV panels positions it as a larger model compared to others, which may limit its applicability in certain wearable designs. Energy harvesting undeniably provides a potent solution for powering autonomous wearable devices, yet the path to optimal design involves a careful balancing act considering various other factors. Creating wearables with a prolonged lifespan demands more than simply selecting an appropriate energy source. It must also take into account the power and communication requirements of the device. This includes the integration of energy-efficient routing methods and the selection of suitable energy storage solutions. Ensuring these components work harmoniously is crucial to maximizing device performance. In conclusion, the journey towards perfected wearable technology is multifaceted. It requires an interdisciplinary approach, marrying advancements in energy harvesting with a deep understanding of design ergonomics and user interface. The potential benefits of this technology, from promoting personal wellness to revolutionizing healthcare, make this journey an exciting frontier of exploration and innovation.

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