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A Hybrid System and A Wi-Fi System, Involved in the Development of Solar Energy Harvesting Systems

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Abstract

A smart solar energy-harvesting system is suggested to provide consistent and long-term electricity. Solar panels, lithium batteries, and control circuitry make up the system. The system's dependability and stability are enhanced by using hardware rather than software for charge management of the lithium battery. When the sun is shining, it will draw electricity from the solar panels; in cloudy, rainy, or nighttime situations, it will rely on the lithium battery as an additional power source. Using a maximum power point tracking (MPPT) circuit, the system optimizes solar energy use and extends the life of the lithium battery via smart charging that reduces the frequency of the battery's charge-discharge cycle. Internet of Things (IoT) wireless sensor nodes located outdoors are ideal candidates for this system because of its reduced power requirements.

Keywords: Hybrid energy harvesting (HEH), IoT, Solar power

Introduction

This multi-hop an option among the most notable developments in the wireless network testing business is the rise of Networks of Wireless Sensors (WSNs). The reason for this is its possible usage in public fitness management and safety systems, as well as in operational conservation systems. Designing effective power management, localization, monitoring, and communication protocols is of utmost importance in this approach. Hedging systems built on the Solar power production has been positively impacted by the Internet of Things (IoT). Machine learning algorithms and location optimum clustering are only two examples of the many edge-focused approaches that solar investors may use to lessen the little radiation risk they encounter. An R-squared value of 0.841 and a correlation coefficient of 0.917 were achieved by the prediction models that relied on edges. A number of technical priorities, including the need to convert renewable energy sources into usable power, have served as inspiration for WSNs. Most wireless sensor network (WSN) nodes run on batteries.

When all power is gone from a system, it is said to be "empty." Batteries may be refilled or changed with very few uses. The eventual replacement or recharge procedure is sometimes tedious, expensive, and slows down the network. Hence, a number of approaches among the many suggestions made to halt the deterioration of battery capacity are administration of electricity and session-based routing procedures. Technologies that utilize low-current wireless transceivers, which save electricity, are sometimes used in these systems. When turned off, a device's output is much lower than when it's turned on, especially if the gadget is in a power-efficient phase. But while it's asleep, the gadget can't transmit or identify the data packet.

The gadget powers on, waits for a while, and then switches off once with respect to the time, the task loop concludes. Protocols running at a relatively modest power level provide a reasonable and consistent explanation for WSNs that endure for a long time. Obtaining correct responses in a number of calculations, dependable IoT devices are needed. A technique for characterizing IoT dependability measurements was offered by the authors of this research. We use queuing theory to calculate the dependability measures. duration to respond, length of line, duration to delay or wait, and peak hours are all part of the theory.

Better reliability estimates were produced by using the Markov Chain characteristics to account for the dependency of objects in IoT environments. There are many problems with this strategy;

1. Energy efficiency (less duty cycle) and data latency seem to have been balanced.
2. Since WSNs rely on batteries for power, they are ill-equipped to handle the influx of new technologies that need labor-intensive network computing.
3. Despite seldom usage, the batteries are exhausted due to leakage.

Literature Review

Shokoor, *et al*. (2023) [1]. By transforming electrical energy from ambient energy into use in both natural and man-made systems, Research on energy harvesting (EH) has recently undergone a sea change. The potential for EH to power autonomous electronic devices is explored in this study by means of simplified approaches to velocity, heat, wind, and salt gradients. Achievability of this power sources for tiny automated wireless devices used in WSNs is the primary emphasis of the project. Networks of wireless sensors monitor the physical environment by collecting data from a distributed network of high-tech sensors and storing it in a central location. The internet and other technological advancements allow for their widespread use, which in turn allows for efficient computing by virtue of well-managed resources. Key aspects, suggested frameworks, and models are examined in this research to assess EH advancements in minimizing resource use in WSNs. In addition, it delves into the particular energy source productions that WSNs use. Along with discussing the potential of energy storage for WSNs, this section lays the groundwork for future studies in this area by highlighting its feasibility.

Mushtaq, *et al*. (2025) [2]. Research on improving the performance and lifetime of sensor networks deployed in areas with limited resources seems to be focused on energy harvesting wireless sensor networks (EH-WSNs). This article reviews recent developments in the subject and focuses on the most important components including EH methods, physical layer security (PLS), cognitive radio applications, energy management strategies, and routing protocols. In a methodical examination of these aspects, the paper elucidates the significant technological advances, draws attention to the obstacles that have recently emerged, and asks what the future holds in terms of revolution. The article begins by taking a close look at several devices that collect energy from several sources, including the sun, heat, motion, and radio frequency. The effectiveness of each approach is evaluated under different operating conditions. In order to ensure the network's operability, it also examines cutting-edge energy management approaches that optimize energy usage and storage. In addition, cognitive radio's ability to enhance spectrum efficiency and address related technical issues is highlighted via its integration into EH-WSNs, which is thoroughly evaluated.

Shi, Ronghua. (2015) [3]. To ensure reliable and sustainable power generation, it is recommended to install a sophisticated technique for capturing solar energy. Solar panels, a lithium battery, and a control circuit make up the bulk of the system. By controlling the charge of the lithium battery using hardware rather than software, the stability and dependability of the system are improved. Electricity is drawn from the solar panels while the sun is shining; when it's overcast, raining, or dark, it makes advantage of the lithium battery to provide more power. An MPPT circuit, which is built into the system, uses solar energy to its fullest potential. Plus, it prolongs the life of the lithium battery significantly since it charges it appropriately, reducing the frequency of the charge-discharge cycle. This technology is ideal for usage with Internet of Things (IoT) wireless sensor nodes situated outdoors since it needs less power equipment to execute.

Javaid, M. *et al*. (2024) [4]. This thesis presents a mechanism for controlling and collecting energy from WSNs. Similar to routers, nodes in a WSN collect data wirelessly. Nevertheless, due to their compact size, wireless sensor networks are unable to afford huge batteries. These gadgets quickly use up the available energy when left on. The battery is hard to change and charge since it isn't easily accessible. Installing these devices might be challenging in places with rough terrain, such as mountainous regions, or in more distant locations. One possible approach to this problem might be to take advantage of the unequal distribution of energy here on Earth. It is impossible to predict when this energy will be available. One tried and true way to harness the power of the sun is solar energy harvesting. We lay forth a workable strategy for managing wireless sensor networks, complete with a suitable model for energy management. The suggested methodology for solar energy harvesting and management does more than just save costs; it also guarantees network connectivity and communication via efficient use of energy and management of both collected and stored power.

León Ávila, *et al*. (2024) [5]. Energy harvesting offers a promising approach to address problem with wireless sensor networks (WSNs), whose batteries are the main source of their lack of autonomy and sustainability. Current approaches and developments in energy harvesting for WSNs are reviewed in this work, which is a systematic literature review (SLR). The examination covers every part of the system architecture, from power management to energy storage. From 2014 to 2023, a total of 196 peer-reviewed publications were examined and analyzed using bibliometric tools. Using a wide range of sustainable power sources, this publication offers a comprehensive review of several systems, methodologies, and technologies for powering wireless sensor node devices. These might originate from biological, mechanical, thermal, light, radio frequency, chemical, or any combination of these. Transducers, energy sources, and energy types have all been defined and clarified to lay the framework for an organized system of analysis and categorization. In addition to outlining current trends, difficulties, and potential avenues for further study, the paper focuses on the urgently needed area of battery-less systems that use capacitors and supercapacitors.

Solar Energy Harvesting

Results from both online and offline testbeds show that the suggested architecture might improve energy savings and extend the life of the network, and maintain data throughput in various energy harvesting situations. The results show that traditional energy management strategies are outperformed by optimization based on machine learning, offering a scalable and dependable solution for sustainable WSN operations. By showing that ML algorithms can be easily integrated into energy harvesting devices, this work tackles the pressing issue of intelligent energy management in WSNs operating in environments with limited energy resources.

The circuit receives its input voltage generated by the solar cells. Changing the input voltage to about 5 volts, regulator TCTL 431 compares the new voltage to the old feedback value. The output is sent to the triggering location of the IC555. After being guided to fullness mode by a positive pulse, the two transistors begin to transfer output to the battery. A standard NIMH battery has an output voltage of 0.50 volts at startup. The findings demonstrate that after 10 minutes of charging, the voltage increases to around 0.8 volts. The voltage rises to 1.8 volts after 30 minutes, and it reaches 1.2 volts after 20 minutes. The findings showed that the NiMH battery is wasteful when the energy is required quickly and charges slowly. We propose a different kind of battery that can be charged more quickly to address this issue.

These sensor nodes use around 0.92 Wh/day and include a Devices for measuring temperature, pH, and dissolved oxygen levels; ZigBee module; and ARM-cortex-MO microcontroller. The System is capable of delivering 5V of output voltage over a standard USB port. A lithium polymer battery, a control circuit, and the system itself (from which five different types may be chosen), and a solar panel. We went with this battery because of its load capacity—roughly 4000 mAh. To manage the charging and over-discharging safeguards, hardware is used rather than software. To put this into action, RS triggers are used. It will not turn on until the battery voltage falls below the limit; it is disabled while I have completely charged the battery. If U12(ST2301) detects that there is an imminent danger of it from being overdischarged.

Developing A System for Harvesting Solar Energy

Collecting energy from the sun encompasses a wide range of useful tools.

1. Solar energy system,
2. DC-DC converter,
3. MPPT,
4. Energy forecasting tool,
5. Categories of energy storage,

An additional component of the inter energy management unit is this

Light-harvesting photovoltaic module Solar cells are an essential part of photovoltaic (PV) systems. Energy harvesting from the sun requires a number of processes, including the solar cell does not need any intermediate transformation processes. Photons hitting a solar panel often arrive in bundles, and there is a limit on how much energy each photon in the bundle may hold. When free-holes are formed, however, two assumptions are made: that electrons are negatively charged and that holes are positively charged. This is how the solar cell converts the energy of the sun into usable power. Energy conversion efficiency in EH-WSNs is conditional on many parameters.

Power storage categories Energy storage plays an essential role in the mechanism for collecting sunlight as it determines the operating state of the load, the network, the routing, the node coverage, and many other processes. Two primary energy sources are available storage that nodes may employ: rechargeable batteries and super-capacitors. Battery and supercapacitor interactions may take several forms when used together in a harvesting device known as hybrid storage. Due to its higher capacity for charging cycles, rechargeable batteries are often preferred for extended usage in EH-WSNs. The portability and good performance at low temperatures of super-capacitors are their primary advantages.

EH-WSN Stands For "Wi-Fi Energy Harvesting System."

The Reasons behind Wireless Energy Harvesting: There Wireless sensor networks, or WSNs, have been all the rage lately. Their extensive usage is shown by the proliferation of quickly expanding domains such as the internet of things and cyber physical systems. When the system must operate continuously for extended durations, energy becomes a big concern. In order to measure how efficient a wireless network is, two important metrics are its lifespan and energy performance. There have been a number of new proposals for methods that aim to increase the lifespan of networks while decreasing their energy use.

Because of their inaccessible locations, WSN nodes cannot be easily recharged or replaced when their batteries die. Unless the power source is refilled or a harvesting device is put in place to bridge the energy deficit, a dead node will disappear and stop being used by the network. Battery life is reduced even while not in use owing to current leakages; moreover, environmental problems may arise from packaging flaws caused by long-term usage. Sensor node lifetimes could be months or even years long, depending on the demands of the application. There are three states that the sensor node may enter: active, idle, and sleep.

The more nodes there are in a sensor network, the longer it will last. The amount of time a node may go between charges is heavily dependent on its data processing, sensing, and communication frequencies. The adoption of harvesting and energy conservation methods is therefore necessary to restrict power use and lengthen the life of the network. More than one article has addressed the question of how to increase the lifetime of sensor nodes that run on batteries. The low power consumption of SMAC and BMAC is well-known among these MAC protocols. There are other protocols that are more energy efficient for routing and data dissemination. Also proposed were methods for duty rotation. The combined effect of these techniques aims to reduce electricity use while increasing the lifespan of the sensor node. But there is still a time restriction and a lifetime limit. The aforementioned solutions help extend running time of the app and/or duration between battery changes, but they can't get beyond energy-related limitations.

While optimizing a WSN, it is not possible to focus on just one performance metric. A greater footprint is indicative of a larger, heavier, and more costly battery. Having a low duty-cycle decreases the sensor's dependability. A greater transmission range requires more power, whereas routing strategies that use shorter transmission lengths consume more power at each hop.

A lot of research is going into energy collecting to address the issue of insufficient node lifespan. There is a lot of hope in this approach, which is one of the newest innovations in communications systems. Without energy harvesting, eliminating the need for batteries or wiring All forms of communication systems that get their power from either the surrounding environment or an external power transmitter are included under the term "wireless communication.

Table 1: How much power do commercially available sensor motes consume?

Sensor mote	Operating voltage	Sleep	Processing	Receive	Transmit	Idle	Expected lifetime
IRIS [19]	2.7 V-3.3 V	8 µA	8 mA	16 mA	15 mA	-	216 hrs [20]
MICAz [21]	2.7 V	15 µA	8 mA	19.7 mA	17.4 mA	-	187 hrs [20]
TELOSB [22]	1.8V-3.6 V	5.1 µA	1.8 mA	19.7 mA	17.4 mA	-	241 hrs [20]
SunSpot [23]	5V (±10%)	33 µA	104 mA	40 mA	40 mA	24 mA	-

The capacity to collect energy from the environment, whether it natural or artificial, enables wireless devices to continually get power. Wireless networking stands to benefit greatly from this, as it allows for energy independence, practically endless operation, less reliance on traditional energy sources and their associated carbon footprint, untethered mobility (no need to replace batteries or connect to power grids), and the possibility of deploying these devices in inaccessible places, such as inside people or in faraway rural areas.

Hybrid Energy Harvesting

Although we have covered various methods Regarding energy harvesting for sensors discussed before, a hybrid system combining the two approaches is the most effective. This is due to the fact that although individual approaches have their limits, we may overcome these issues and achieve optimal energy harvesting results by combining them. proposed a new ultrathin integrated module for gathering energy from the sun, wind, and rain, which might be used by IoT devices to power make them last longer. Indium tin oxide (ITO) sandwiched between two layers of fluorinated ethylene propylene (FEP) forms the Rain TENG, a component of the UHM. The Wind TENG is composed of PTFE material that is sandwiched between two aluminum electrode plates that are fitted with neodymium magnets. A solar cellule made of amorphous silicon.

The increasing demands of the industrialized world's population and economy are putting a strain on conventional energy sources like biomass energy sources. Energy that is both renewable and sustainable, such as solar, wind, waves, vibration, rotation, etc., provide a viable and practical solution to the world's energy crisis. Scientists and programmers have poured a lot of energy onto improving and expanding existing techniques of environmental energy collecting. Power on a macro scale (>W level) is provided by various energy sources to compensate for the area's power outage, which families and businesses may utilize.

Simultaneously, research into energy harvesting has seen a spike in attention, specifically the elimination of the need for batteries in wireless sensor networks (WSNs) and portable/wearable devices by centering on microscale power (<W level, typically nW to mW). This may pave the way for intelligent WSN systems that can power themselves and for gadgets that can charge themselves. Energy harvesters provide sustainable and renewable power solutions by collecting solar, thermoelectric, piezoelectric, electromagnetic, triboelectric, and other forms of energy transduction that harness the power of the environment and transform it into electrical current.

Most energy harvesters could only handle a single kind of energy source until quite recently. Light, sunlight, thermal gradients, fluctuations, kinetic energy, and so on may be harvested by many kinds of energy harvesters, for example, electrostatic, solar, thermoelectric, and pyroelectric models. Still, it's not out of the question that the vast majority of our renewable and sustainable power sources immediate vicinity aren't always available or dependable. Due to its production being reliant depending on how easily the power source may be reached, only one harvester cannot constantly satisfy the power demands of electronic devices. One sustainable energy source that is often used is solar electricity. When it's overcast, dark, or pouring, solar harvesters don't work very well. Kinetic energy may be found in many forms in the natural world, including the movements of people and machinery, the tremors of wind and water, and so on. The fact that people need downtime, that machines aren't always on, and that kinetic energy sources like wind and water waves don't always materialize are all reasons why kinetic energy could be unreliable and insufficient. Under these circumstances, kinetic energy harvesters are not usable. The same would hold true for thermal energy harvesters in the event of unforeseen temperature gradients or shifts.

To address the issue of energy shortage caused by single energy harvesters, a growing body of opinion is in favor of hybrid energy harvesting methods. The term "hybrid" refers to materials, structures, and mechanisms that can increase the efficiency of energy conversion while also making use of multiple energy sources simultaneously. In a broad sense, this means that Power may be generated from a variety of sources via a variety of transduction techniques. Thus, two main categories of hybrid energy harvesters may be established: those that utilize a single source in conjunction with many mechanisms, and those that employ a combination of mechanisms from two or more sources. A combination of energy sources often operates in a loop or tandem. To illustrate the point, it is not uncommon for machines or people to generate thermal energy in addition to vibrational energy.

Control of maximum power points in solar energy systems

Solar photovoltaic (PV) systems and different types of renewable energy are starting to make a big splash as a potential remedy for the world's growing energy needs and growing environmental consciousness. But ever-changing environmental factors like temperature, shadow, and light irradiation significantly impact PV systems' efficiency. Slow convergence, steady-state oscillations, and inadequate performance in complicated situations are common problems with conventional Maximum Power Point Tracking (MPPT) systems like P&O and Incremental Conductance (INC) are two methods.

Researchers have been investigating ANNs and FLCs, two forms of artificial intelligence (AI), as well as hybrid approaches to the most efficient power point tracking (MPPT) method in an effort to overcome these challenges. Some of these methods are computationally too expensive to be used in real-time, and there is a lack of research that comprehensively assesses them in a range of long-term settings, even if these techniques increase tracking efficiency and flexibility. To address these shortcomings, researchers are creating a dynamic MPPT controller that combines FLC with LSTM neural networks. Less oscillations, quicker settling, and improved tracking efficiency are the goals of this approach in many contexts.

The potential performance Adding a platinum complex (F-Pt) to the acceptor layer was studied as a potential enhancer for Layer-by-Layer (LbL) all-polymer solar cells (APSCs). Adding 0.2 wt% F-Pt to the PY-IT layer increased the power conversion efficiency (PCE) from 15.86% to 17.14%, as shown in the study. The efficient transmission of energy from F-Pt to PM6 and PY-IT led to this enhancement. This energy transfer mechanism was confirmed by measurements of increased photoluminescence lifetime and spectral overlaps involving F-Pt's photoluminescence spectra and PM6's and PY-IT's absorption spectra. The PCE was enhanced from 17.57% to 18.29% after adding F-Pt to the PY-DT layer, further demonstrating that the F-Pt inclusion method may be used in any location in PBQx-TCl/PY-DT-based LbL APSCs.

Polymer solar cells (PSCs) are at the forefront of scientific breakthroughs in this industry due to efforts in order to boost the efficiency of their power conversion (PCE). Applying an improved ternary donor layer of PM1:D18 and a L8-BO acceptor layer allowed the sequentially spin-coated polymer solar cells (SS-PSCs) to attain a power conversion efficiency (PCE) of 19.13%. The improvement in charge recombination losses was a result of enhanced photon harvesting, more effective usage of excitons, and greater vertical phase separation. The addition of D18 to Donor materials were able to transmit more energy and the open-circuit voltage (VOC) was raised by the donor layer.

Conclusion

With the help of an MPPT circuit, we were able to create a whole new intelligent solar energy-harvesting system. The charging management of the lithium battery is implemented using hardware rather than software, which significantly improves the system's reliability. For WSN nodes in IoT, analyses are conducted according to power supply needs. The system is able to access a reliable power source with a 5-volt output voltage via a regular USB port. A further clever way to prolong the life of a lithium battery is to charge it in a way that minimizes the charge-discharge cycle. The results of the experiments show that the system is capable of automatically switching the power supply branch. A lithium battery can be charged correctly when its voltage falls below a certain threshold. Stability, safety, great efficiency, minimal power loss, and a simple composition characterize the system's performance.

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