A Green and Self-Powered Internet of Things-based Energy Harvesting Nano systems

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The Internet of Things (IoT) is a transformative technology that seeks to establish a network of interconnected items and embedded systems, enabling seamless interaction between countless smart gadgets and basic sensors and controllers. These green and self-governing devices and systems are becoming smaller and smaller, reaching sizes of millimeters and even less. This poses significant difficulties in terms of supplying power to these nano components. This article examines several methods currently used to extract energy from surrounding or outside provided sources, such as radio-frequency, optical, heat, mechanical, atomic, chemical, and biological, to generate electrical power for micro- and nano-systems. The research outlines the primary obstacles in designing IoT devices related to energy and electricity and offers design recommendations for effectively creating green and self-powered IoT gadgets. The potential for implementing these energy conversion methods on a smaller scale is examined, considering both current technology and potential advancements in nanoscience.

Keywords: Internet of Things, Nanosystems, Energy Harvesting, self-powered device.

1. Introduction

Green and Self-sustaining systems at the microscale and nanotechnology that integrate sensors, computing, and wireless information transmission enable revolutionary networks for enhancing health, safety, and quality of life. The Internet of Things (IoT) is transforming several aspects of life, such as home automation, healthcare equipment, manufacturing, facilities, and transportation [1]. There are billions of interconnected IoT devices, with an estimated addition of over 127 new devices connecting to the Internet per second in 2020 [3]. Reducing the size of cyber-physical networks to a millimeter or less is a further development of the IoT [2]. This leads to new features and application areas, thanks to the increased number, volume, and combination of capabilities achievable at these smaller dimensions. The research will apply the term IoT to include all sub-millimeter systems, including nanotechnology and microscale. The functionality of IoT systems is made possible by using several advancements, such as low-power circuitry and heterogeneous connectivity in nanosystems. These green and self-governing gadgets are sometimes called motes since they are a component of the intelligent dust [13].

The emergence of a new research field termed the Internet of Nano Things (IoNT) is driven by recent advancements in nanotechnology and communication science at the micro/nanoscale [4]. Due to their minuscule size, IoNT devices have versatile applications in medical care, the military, safety, detecting, analyzing, actuation, and communications. The IoNT is surgically implanted into a person's body to gather health-related data and then send it to healthcare practitioners over the Internet [6]. Healthcare practitioners choose which actions to carry out, such as producing and dispensing medications [5].

Ensuring the successful operation of autonomous devices relies heavily on providing ample electricity and energy. Multiple options exist for power and energy supply for systems of around centimeters in size and more extensive, including battery-powered structures, direct cable connections, and wireless power supply in nanosystems. Scaling dimensions below one centimeter introduces new obstacles, including a significant decrease in the effectiveness of wireless power transmission at millimeters and more minor scales [15]. Traditional integration methods involving circuit boards, current batteries, and physically available ports for wired links (such as a standard serial bus) are not suitable for the system limitations of IoT gadgets [12]. Energy harvesting offers many ways to supply electricity to the IoT. Energy Harvesting (EH) systems extract energy from several environmental sources, including thermal, tremors, solar, and Radio Frequency (RF) signal energies [7]. This offers a potentially boundless power source for IoT gadgets and substantially enhances the gadget's lifespan. The power density necessary for such structures is around 100 nanowatts per square millimeter, as shown by recent millimeter-scale systems. This paper examines various methods of energy harvesting, offers guidance on designing appropriate green and self-powered IoT gadgets, evaluates the advantages and disadvantages of every energy harvesting method using nanosystems, delves into the specifics of piezoelectric energy collecting supplies and layout for green and self-powered IoT, and concludes by discussing the future obstacles facing green and self-powered IoT [9].

2. Methods

Diverse energy harvesting methods are required for IoT gadgets due to the varying availability of energy sources based on the specific application using nanosystems. The energy source might be obtained from the surrounding environment or deliberately supplied via external stimulation.

2.1 Radio-Frequency

RF energy is collected from the surrounding environment or via a deliberate emission of radiation. RF technologies are the predominant method for implementing IoT technologies [8]. It has been extensively used for years, widespread adoption in many applications, including credit cards, card readers, and medical and security monitoring devices in nanosystems. These RFID applications employ inductive connections to connect with nano chips. They can still connect with coil transmitters with at least one centimeter or more extensive form factors.

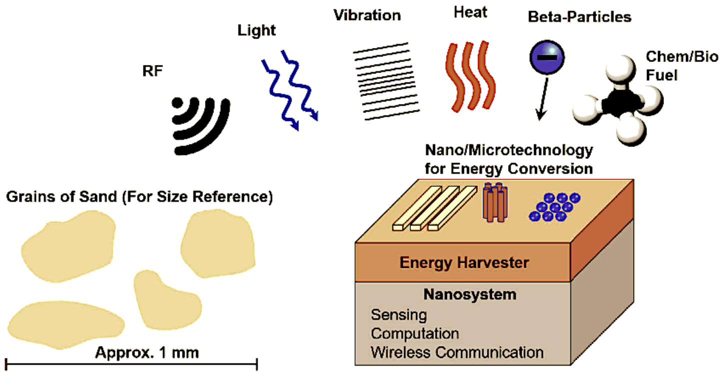


Fig. 1. Structure of the nanosystems

To achieve efficient operation at the millimeter and nanoscale size, it is necessary to raise the frequency and develop new methods for deep subwavelength transmitters. The structure of the nanosystem is shown in Fig. 1. Scaling up to a higher frequency is feasible for specific structures nearby. The impact of propagation loss and the effectiveness of high-frequency circuits must be considered when designing nanosystems.

2.2 Optical

Light is an energy source suitable for being scaled down to the millimeter and nanoscale size. Energy harvesting is easily accomplished using photovoltaic (PV) cells explicitly developed to capture energy from ambient outdoor or indoor lights and other illumination sources [15]. PV cells can produce a voltage of around 0.5 V, based on the kind of light and PV cell technologies in nanosystems. This voltage is raised by connecting several cells in series or using tandem cell layouts.

Reducing the size of a device below 1mm might decrease its conversion efficiency because of non-radiative recombination processes around the perimeter of transistors. To achieve excellent energy conversion rates, it is crucial to protect the exteriors of semiconductors by passivation effectively. Untethered green and self-powered detectors have been successfully shown at diameters of 100 µm while operating at increased power densities. The difficulties in optical energy harvesting lie in the requirement for a line-of-sight system setup and the demand for an optical supply.

2.3 Mechanical

Piezoelectric circuits harness the mechanical power of stray disturbances or moving objects. Piezoelectric energy harvesters are extensively used in many applications, such as monitoring infrastructure detectors, tire pressure detectors, and pacemaker devices. These gadgets often use Micro-Electro-Mechanical Structures (MEMS) technology, which utilizes cantilevers or surfaces with dimensions more significant than a millimeter in nanosystems [10].

The ultrasonic range is a specific category in physical energy harvesting. Ultrasound is a very efficient method for wirelessly transferring power through biological cells and has gained significant interest for its use in biosensor technologies. Devices with scaled measurements at the sub-level have been successfully shown and have considerable potential for developing "neural dirt" used in brain-machine connections in nanosystems. These interfaces need considerably scaled sizes and very short working ranges.

2.4 Thermal

Waste heat is collected using several methods, such as thermal electricity, thermophotovoltaic, and thermoradiative techniques [11]. The thermoelectric method relies on the Seebeck phenomenon, necessitating a temperature differential across the circuit. Thermal electricity thin-film superlattices and quantum dots are very efficient at generating electricity when applied at smaller sizes in nanosystems. Miniaturized devices with an area of $1mm^3$ have been successfully shown to collect 768 $\mu W/mm^3$ when subjected to an external temperature differential of 9K. Scaling downsizes to the sub-mm scale will provide significant challenges, necessitating the complete miniaturization of microreactors or operating the structure in close contact with a high-temperature heating source. Thermoradiative harvesting remains in the early stages of exploration, with just a few modest experimental presentations. This method benefits energy harvesting in specific applications when devices are in close contact with a significant heat flow and an atmosphere with minimal ambient irradiation.

2.5 Nuclear

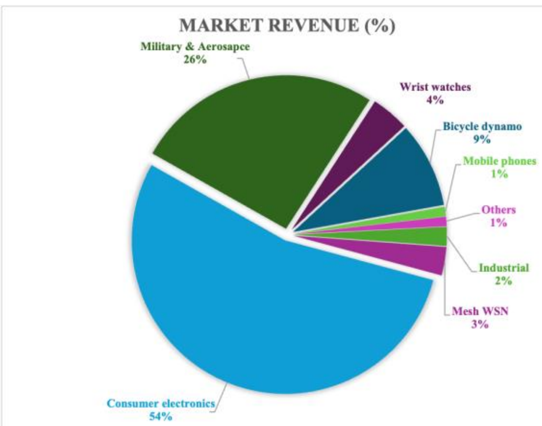
Small-scale nuclear energy produces electricity in the semiconductor junction by absorbing beta particles emitted by radioactive substances [16]. These gadgets, typically known as betavoltaic cells or power sources, rely on internal radioactive substances such as tritium or nickel. Integrated junctions have employed a range of semiconductors, such as silicon, silicon carbide, and gallium nitrate. Betavoltaics provide a reliable and enduring power source, making them suitable for applications like medical implants and military systems needing a secure and tamper-proof nanosystem power supply. The power density provided by Betavoltaics typically ranges in the order of nanowatts per square millimeter, making it appropriate for numerous low-power devices. The primary considerations of betavoltaics include the healthcare and safety risks associated with handling radioactive substances and the need for adequate shielding and isolation measures in equipment.

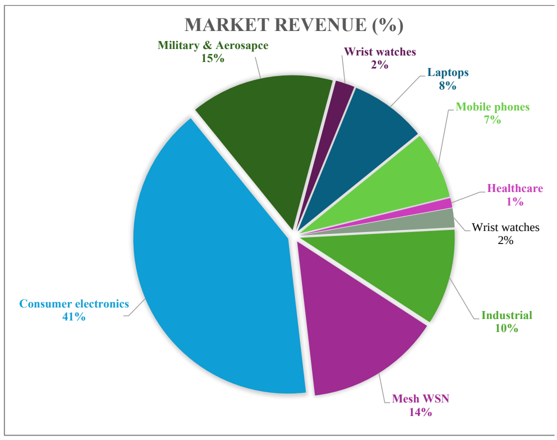
2.6 Chemical and Biological

Scaled fuel cells use biochemical and biological sources to produce power in micro and nanosystems. Methanol and alcohol frequently serve as fuels in proton-exchanging membrane energy cells, which were successfully commercialized in devices of centimeter dimensions [13]. The microreactors in such structures are often manufactured using MEMS equipment, which imposes limitations on scaling down to smaller dimensions due to challenges in controlling gas flow and accommodating a fuel cartridge. Microbial fuel cell technologies have been demonstrated to be effective in the field of biosensors for real-time monitoring of wastewater in nanosystems. The scalability of microbial fuel cell technology, like chemical-fueled cells, will depend on the need to regulate fuel flow. Another factor to consider while using microbial fuel sources is the time it takes for colonization by bacteria to begin, which usually takes a few days.

3. Results

The cumulative quantity of IoT devices will reach 50 billion by 2030. Only a few of these devices are intelligent cell phones and laptops. At the same time, the rest are dedicated to doing essential functions such as detecting and sometimes transferring a tiny quantity of data. Significant businesses will install integrated intelligent sensors to collect data from equipment, enabling more efficient inventory tracking and machine management. This will significantly enhance efficiency, generate more money, reduce expenses, and save lives in nanosystems. The global population of IoT device designers now stands at around 12.6 million individuals, with an annual growth rate of approximately 4%. According to Intel, the worldwide value of IoT technology is estimated to be over USD 8.6 trillion. The healthcare sector is expected to account for USD 4.9 trillion, while the manufacturing sector is projected to contribute USD 4.5 trillion.





In 2020, the worldwide energy harvesting marketplace had a value of $970 million, which increased to $2.1 billion in 2030. It is projected to expand to $5.8 billion by 2030. Figures 2(a) and 2(b) correspondingly depict the energy harvesting marketplace in 2020 and 2030. Consumer goods dominate the majority of the worldwide EH marketplace. Figures 2(a) and 2(b) demonstrate that the Industrial and Wireless Sensor Networks (WSNs) sectors are seeing the most rapid development among energy harvesting industries. This results from miniaturized gadgets such as factory automation and tracking, architectural health surveillance, environmental surveillance, and residential automation in nanosystems. The widespread use of energy harvesting methods in IoT applications has led to a more significant portion of the energy harvesting industry being dedicated to IoT-related sectors, such as industrial and WSNs. The proportion of medical services in the EH market is projected to grow significantly due to the widespread use of IoT solutions in the healthcare sector.

4. Conclusion

There are several ways to gather energy for the future growth of nanosystems, either from the surrounding environment or by supplying a third-party source. The cost, environmental impact, and complexity of the entire system will be the main factors influencing the best choice of energy harvesting method. Most energy harvesting methods for small-scale systems have focused on devices around one centimeter in nanosystems. These devices can support various IoT applications and circuitry linked wirelessly. When academia and the media mention micro- and nano-technology, they usually talk about chip-scale and more extensive systems, as well as the nanotechnology that has made these more enormous structures possible. More research is still needed on effectively using energy harvesting gadget techniques to provide power for IoT devices on a nanoscale, namely below one millimeter. A practical approach involves using energy harvesting methods to extract power from the surrounding environment and provide sufficient power to the devices for daily use in nanosystems. This would significantly enhance the longevity of the gadget and reduce the need to use the battery as a power source. This survey provided many energy-collecting systems and examined the advantages and disadvantages of each methodology.

Because of the substantial transmit power of most Low Power Wide Area Networks (LPWAN) methods, which are anticipated to have significant roles in delivering extensive IoT features, batteries will continue to be essential components of IoT devices running over LPWANs. Energy harvesting solutions will be crucial in prolonging the gadget's lifespan by offering a sustainable method for recharging nanosystem batteries.

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