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Energy Generation through Multiple Renewable Sources for Low Power Gadgets: A Review

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Abstract
Energy harvesting has emerged as a promising solution for powering low-power medical devices, offering the potential for sustainable and autonomous operation. This paper explores the application of various energy harvesting techniques, including solar, wind, piezoelectric crystal, and thermal, specifically tailored for powering low-power medical devices. Solar energy harvesting utilizes photovoltaic cells to convert sunlight into electrical energy. It offers a reliable and widely available source of power, especially for wearable and implantable medical devices. Wind energy harvesting harnesses the kinetic energy of air currents to generate electricity. Innovative designs and materials enable the development of compact and efficient wind energy harvesting systems for low-power medical devices. Piezoelectric crystal energy harvesting takes advantage of the piezoelectric effect to generate electrical energy from mechanical vibrations. Thermal energy harvesting utilizes temperature differentials to generate electricity. The integration of these energy harvesting techniques into low-power medical devices presents numerous opportunities, such as reducing the reliance on batteries and enabling long-term, maintenance-free operation. However, challenges related to efficiency, miniaturization, and device integration must be addressed to ensure reliable and sustainable energy harvesting solutions for medical applications. This paper provides an overview of the principles, technologies, and potential applications of solar, wind, piezoelectric crystal, and thermal energy harvesting for low-power medical devices, laying the foundation for future advancements in this field.
Keywords: Solar Energy, Wind Energy, Energy Harvesting, Medical Equipment’s, Thermal Energy, Piezoelectric Energy

1. Introduction

Due to recent advancements in wireless technology and low-power electronics, there is a growing need for wireless sensors in various applications. However, the wireless nature of these systems necessitates the use of self-powered devices. Typically, these devices rely on batteries, which offer a finite power supply [1]. However, batteries can increase the size and cost of the devices, as well as impose the burden of replacement or recharging. Consequently, there is a concerted effort to develop new sources of long-lasting and regenerative power to fulfill the energy requirements of these wireless systems [2]. Energy Harvesting (EH), also known as Power Harvesting or Energy Scavenging, involves capturing energy from a range of ambient sources and converting it into usable electric power. Energy harvesters provide a small but significant amount of power for low-energy electronics.

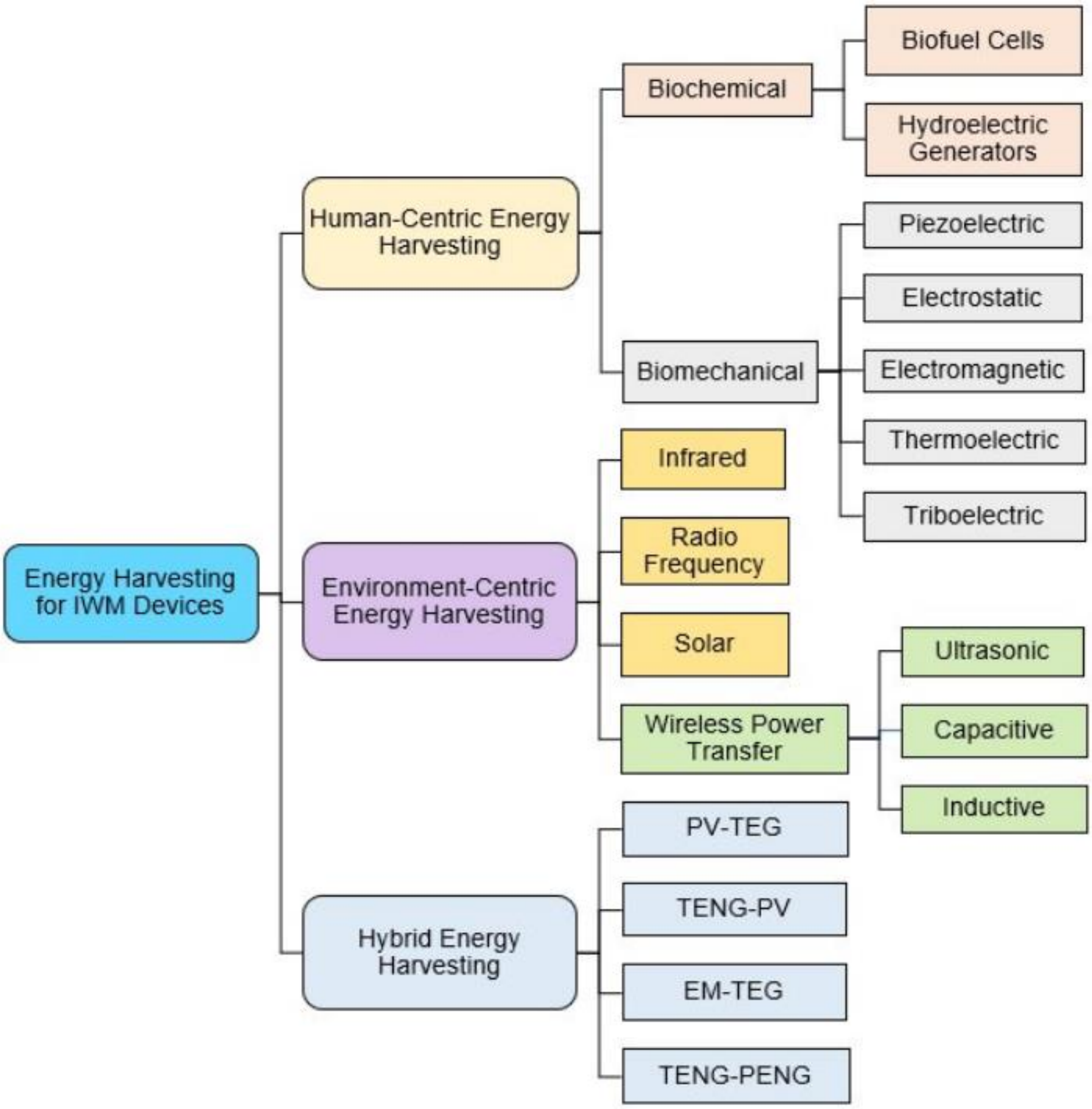

Fig.1: Classification of human-and environment-centric energy harvesting techniques exploited in implantable and wearable medical devices [2].

Energy Harvesting (EH) offers a compelling solution for powering electronics in situations where conventional power sources are unavailable, thus eliminating the need for wires or battery replacements. EH systems typically consist of circuitry that facilitates charging an energy storage cell while managing the power, ensuring regulation and protection [3]. Reliable energy generation, storage, and delivery are crucial for EH-powered systems. Energy storage is essential because EH transducers may not always have a continuous energy source available, such as solar power during the night or motor vibrations when at rest. By harnessing ambient energy, EH can potentially provide an uninterrupted power supply throughout the lifespan of the electronics [4]. Moreover, energy harvesting has the potential to replace batteries in wireless devices, especially in cases where batteries are impractical, expensive, or pose safety risks during replacement.

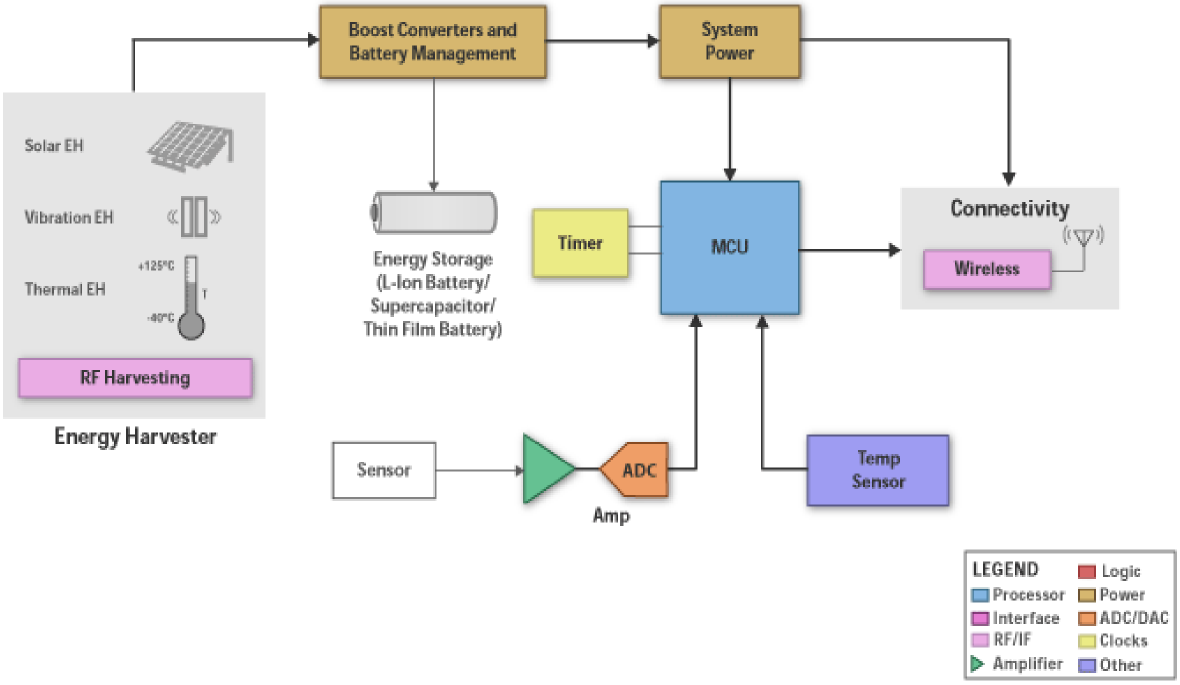

Fig.2: Energy Harvesting Block Diagram.

Energy Harvesting (EH) technology utilizes ambient energy sources to generate electrical power for small electronic and electrical devices. An Energy Harvesting Module is designed to capture milli-watts of energy from various sources such as light, vibration, thermal gradients, and even biological processes. Another potential energy source is radio frequency (RF) signals emitted by cell phone towers [5]. Once harvested, the captured energy is conditioned and stored using efficient methods like batteries, quick-charging capacitors, or thin film batteries. The EH system is programmed to trigger at specific intervals to take sensor readings using low-power systems. The collected data is then processed and transmitted to a base station or receiver. By implementing such an EH system, the reliance on battery power is significantly reduced, eliminating the need for frequent battery replacements or servicing [6]. This enables a more sustainable and maintenance-free operation of the system.

2. Sources of Energy

Energy harvesting uses unconventional sources to power circuitry. There are various sources of renewable energy are available excluding fossil fuel. For example, Sound Energy, RF Energy, light energy, natural energy, mechanical energy, thermal energy and many more.

Wind energy: Wind energy is a renewable source of power derived from the natural movement of air, primarily caused by the uneven heating of the Earth's surface by the sun. Wind turbines, consisting of large rotating blades mounted on tall towers, are used to capture the kinetic energy of the wind and convert it into electrical energy through generators. Wind energy is a clean and sustainable alternative to fossil fuels, as it produces no greenhouse gas emissions or air pollutants during operation, contributing to a reduction in carbon dioxide emissions and mitigating climate change. Wind farms, consisting of multiple wind turbines grouped together, can harness the power of wind on a larger scale, generating significant amounts of electricity to power homes, businesses, and even entire communities. Wind energy has the potential for further growth and development, as advancements in technology and increased efficiency continue to make it a cost-effective and reliable source of renewable energy worldwide [8].

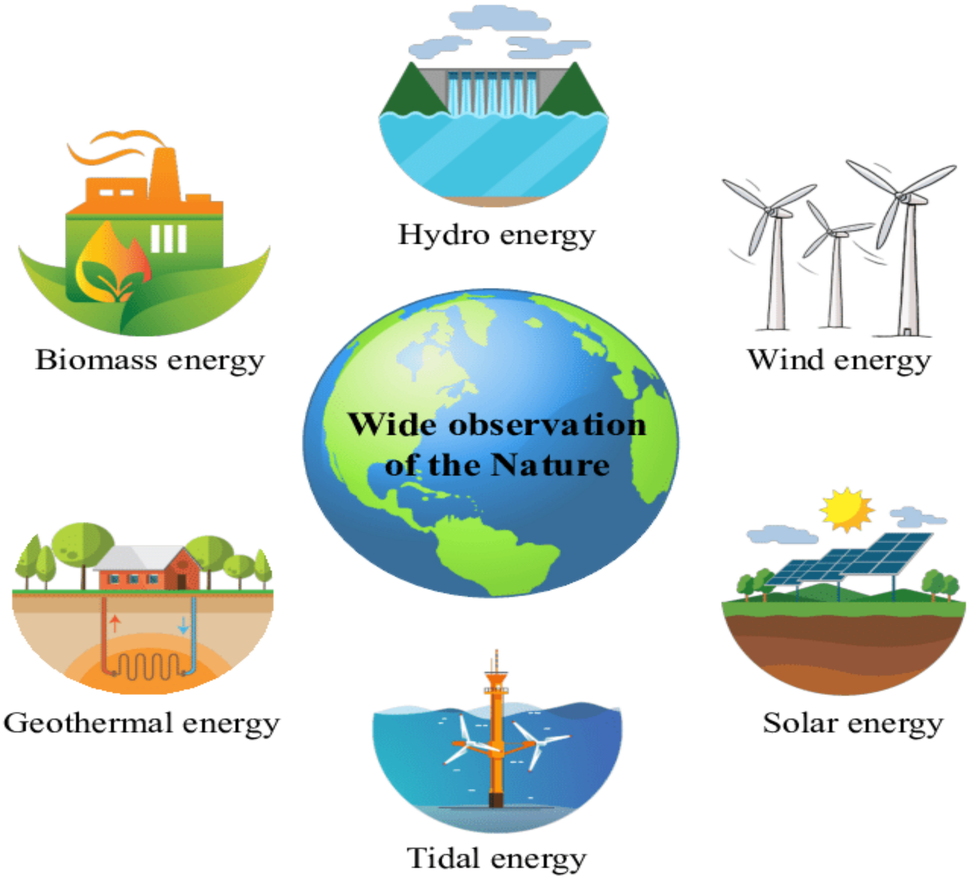

Fig.3: Various Energy Sources [5].

Thermal energy: Waste heat energy generated by furnaces, heaters, and friction can serve as a valuable source for energy harvesting. Thermal energy can be obtained from the heat present in the environment or from heat generated during various processes. The conversion of this thermal energy into usable electric power can be achieved through either thermoelectric or pyroelectric effects. Thermoelectric effects, such as the Peltier effect, Seebeck effect, and Thomson effect, have the capability to generate power as long as there is a heat source available. The extraction of energy from a thermal source relies on the existence of a thermal gradient. The efficiency of conversion mainly depends on the temperature difference between the heat source and the environment, specifically the cold and hot sides. A larger temperature difference leads to a more efficient output [9]. The conversion efficiency is primarily influenced by the temperature gradient between the heat source and the surrounding environment, with a greater temperature difference resulting in improved power generation.

Mechanical energy: Mechanical energy sources offer a compelling opportunity for energy harvesting, with vibration sources being particularly advantageous. Vibration, in various scenarios such as civil structures like tall buildings, railroads, ocean waves, and even human movements, can generate substantial power output. To convert vibration energy into electrical energy, different methods can be employed, including utilizing electrostatic effects, magnetic fields, or the strain on a piezoelectric material. These techniques enable the conversion of mechanical vibrations into usable electrical power [10]. Capturing vibrations from machinery, mechanical stress, and strains caused by high-pressure motors, manufacturing machines, and rotating equipment presents an opportunity to harness ambient mechanical energy sources for power generation. By effectively harvesting energy from mechanical sources, we can tap into previously untapped resources, contribute to sustainable power generation, and reduce our reliance on traditional energy sources.

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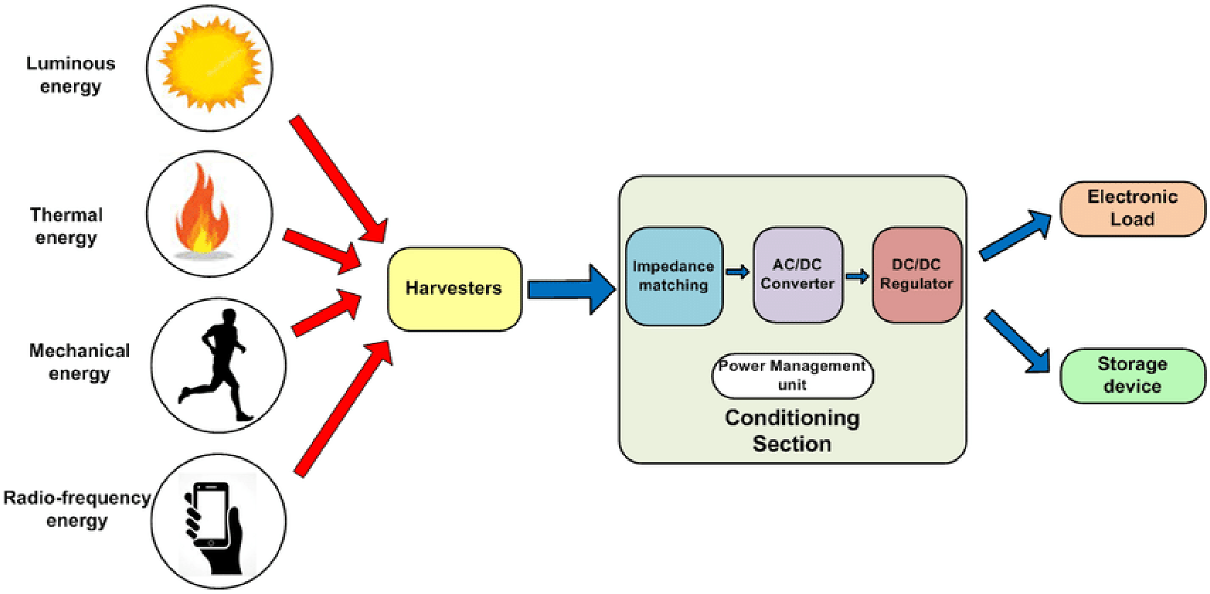

Fig.4: Block diagram of a generic energy harvesting system Diagram

Table 1 Characteristics of Typical Energy Harvester

Energy Source	Characteristics	Efficiency	Harvested Power
Light	Outdoor Indoor	10-25 %	100mW/cm^2 100uW/cm^2
Thermal	Human Industrial	0.1 %	70uW/cm^2 10mW/cm^2
Vibration	Hz Human KHz machines	3 %	4uW/cm^2 850uW/cm^2
Radio Frequency	GSM 900MHz	25-50 %	0.1uW/cm^2 0.01uW/cm^2

3. Energy Harvesting Applications

Wireless Network: Energy harvesting has proven to be a valuable concept with numerous applications in the field of wireless communication and networks. In certain cases, ad hoc sensor networks employ minimum energy paths to optimize energy consumption at each node, enabling more efficient utilization of limited resources. While using a low-energy path frequently can lead to a depletion of energy along that specific route and potentially cause network partition, the utilization of energy-aware routing protocols occasionally allows for the incorporation of sub-optimal paths. This approach aims to enhance performance with the assistance of energy harvesting. By implementing energy harvesting techniques, the need for battery replacement and maintenance is eliminated, resulting in an extended lifespan for sensor nodes [11]. Energy harvesting technology plays a significant role in addressing the challenges of energy management and sustainability in wireless sensor networks, ultimately contributing to enhanced network performance and prolonged operation. Figure 5 depicts a wireless sensor network as an example.

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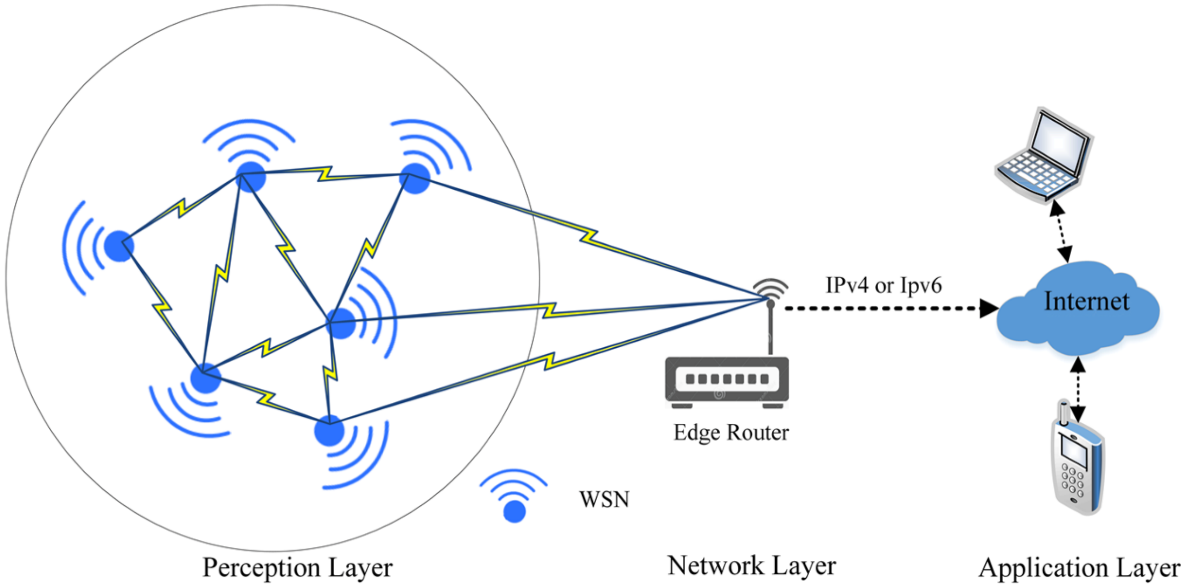

Fig.5: Wireless sensor networks

Biomedical Applications: The concept of energy harvesting has been extended to the field of portable medical devices. These devices are designed to be compact, lightweight, and often wearable (such as a sphygmomanometer) or implanted inside the body (such as a pacemaker). Due to their small size, these devices have lower energy consumption requirements. Although smaller batteries are sufficient to meet these demands, the operational time and performance of portable medical devices are limited as these batteries need to be periodically replaced or recharged [12]. For example, individuals with pacemakers powered by lithium batteries typically require surgery to replace the battery approximately every 8 years. This need for periodic battery replacement can be burdensome and may affect the overall convenience and efficiency of the medical device. By implementing energy harvesting techniques in portable medical devices, the reliance on batteries can be reduced or eliminated, thereby alleviating the need for frequent battery replacements or recharging. This can significantly improve the overall performance, lifespan, and user experience of these devices, providing more convenience and peace of mind for patients and healthcare providers.

Table 2 Medical Device and their Power Requirements

Medical Equipment	Power requirement (W)
Pacemaker	5.6 W
Arterial Pressure Monitor	3 W
Glucose Level Monitor	0.5 W
Insulin Infusion Pumps	12 W
Blood Coagulation Monitor	0.5 W

Photo of a Pacemaker with battery is shown in Figure 6. Likewise, implantable neurostimulator & infusion pumps have a reduced lifespan of 3 to 5 years. Thus, dependence on batteries needs to be reduced in this field giving rise to energy harvesting as an alternative solution. Piezoelectricity, thermal energy & electromagnetic energy w. r. t to human body are mainly considered for biomedical EH. Thermoelectric devices are an attractive source of energy as it directly converts temperature gradients in to power. Though thermoelectric generators (TEG) were available for quite some time, it is only recently that low power medical implants have been researched & developed.

Fig.6: Pacemaker with battery

Besides these some of domains of application are listed below:

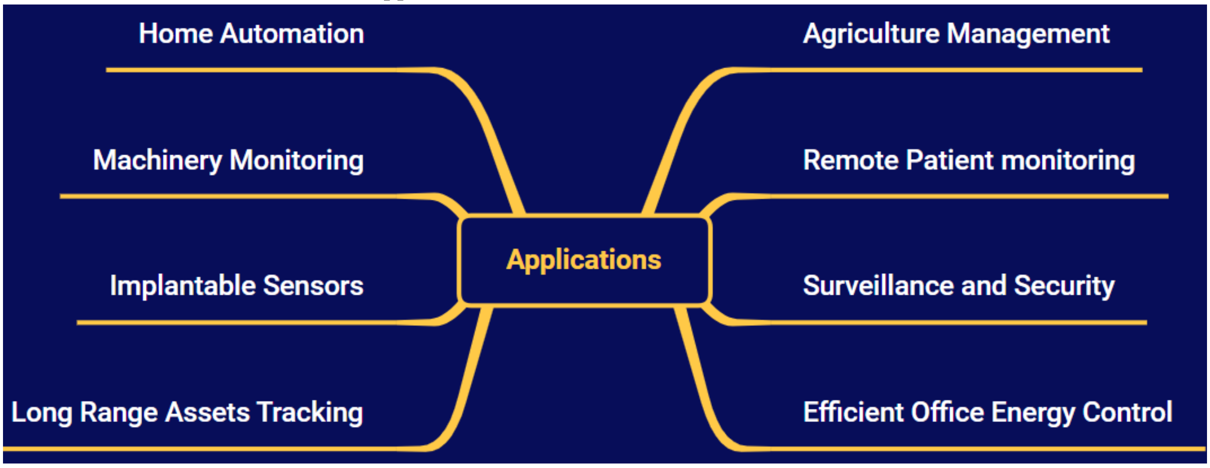

Fig.7: Application for Low Power Devices

4. Energy Storage Devices

Various simulation tools are readily available to cater to the diverse energy-harvesting scenarios that necessitate an energy storage element or buffer. Even if an embedded application has extremely low voltage and current requirements that can be directly powered by energy captured or scavenged from the environment, the flow of such power would not be constant. Hence, the inclusion of storage elements or buffers becomes crucial. Typically, energy storage elements take the form of capacitors, standard rechargeable lithium batteries, or emerging technologies like thin-film batteries [14-15]. The choice of energy storage greatly depends on the specific application requirements. Some applications may only require power for brief periods, comparable to the discharge rate governed by the RC time constant of a capacitor. On the other hand, certain applications demand substantial power for extended durations, leading to the adoption of traditional AA batteries or rechargeable lithium batteries. Understanding the energy needs of an application and selecting the appropriate energy storage solution is essential for achieving optimal performance and functionality in energy-harvesting systems.

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Table 3 Various Storage Devices Specification

Sr. No	Parameters	Super capacitor	Thin Film Battery	Li-Ion Battery
1	Capacity	10-100 µAH	12-1000 µAH	0.3-2500 mAH
2	Charge Time	Sec-Minutes	Minutes	Hours
3	Recharge Cycles	Millions	Thousands	Hundreds
4	Environment Impact	Minimal	Minimal	High
5	Physical Size	Medium	Small	Large
6	Self - Discharge	High	Negligible	Moderate

5. Conclusion

To enhance the reliability of energy harvesting compared to battery-based and plug-based connections, improvements in storage efficiency are necessary. This paper focuses on reviewing various energy sources for harvesting and exploring potential applications in wireless sensor networks (WSNs), biomedical devices, and other relevant areas. It is observed that only a few sources have contributed significantly to the development of efficient energy harvesting architectures. Some applications have even combined multiple sources, such as human and vibration energy. In the future, an intriguing concept would be to combine multiple energy sources using a feedback mechanism from the load to meet power requirements. This approach, known as Feedback Energy Harvester, would involve selecting energy sources based on criteria such as required output power, potential output at any given moment, and the efficiency and speed of the conversion module, among others. By continuously exploring and advancing energy harvesting techniques, we can strive towards a more sustainable and self-sufficient power generation paradigm.

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