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LITERATURE REVIEW OF BATTERY-POWERED AND SOLAR-POWERED WIRELESS SENSOR NODE

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ABSTRACT

Nowadays, sensor node networks are designed and increasingly used in various fields and sectors, such as in military (examples Battlefield surveillance, nuclear, biological and chemical attack detection and reconnaissance), in health (examples Tele-monitoring of human physiological data, monitoring patients and doctors inside a hospital), in environment (examples Forest fire detection, flood detection) and in other various applications. However, the power sources and supply of the nodes remains as challenge. Therefore, energy conservation plays an important role for this network. Usually the battery powered is used as power sources for sensor nodes, but energy harvesting offers an alternative, although it not able to avoid from the problem. In this paper, an analysis is performed to compares the use of batteries powered against solar cells powered. The basic parameter and characteristic for both of power supplies are studied in terms of capacity or volume, low self-discharge, shorter recharge time, energy density and power efficiency to generate power for the sensor nodes, the lower cost and also in terms of characteristics such as size and weight.

Keywords: sensor node, power sources, battery powered, solar cell powered.

INTRODUCTION

Today, the use of sensor node seems to grow without limit. Sensor node is a component of larger networks of sensors and it is a node in a Wireless Sensor Network (WSN) that able to perform some of processing in this sensor node is equipped with wireless interfaces, which they can communicate with another to form a network [1]. Besides that, many autonomous sensor nodes are able to establish its self-organizing network to form a Wireless Sensor Network (WSN). The sensor node have different applications likes habitat monitoring, vehicle monitoring, structural monitoring and it is usually intended to monitor, tracking and detect the temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels and vital body functions. It commonly used for health, in daily routine, military, industry, marine, agriculture, environment and others various applications, as shown in Figure-1 below.

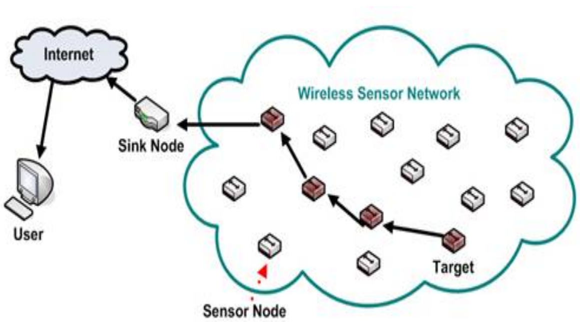

Figure-1. Wireless sensor network.

The sensor node architecture consists of several main components, such as memory, communication, controller, sensor and power supply, as shown in Figure-2. So, the purpose of this project is to examine the sources of power supply and potential for sensor node. Other than that, power supply can provide as much energy as possible at smallest cost, capacity or volume, weight, recharge time, longevity, power efficiency, voltage stability and efficient recharging at low current for sensor node.

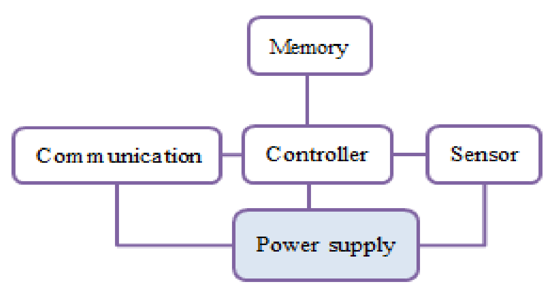

Figure-2. Sensor node architecture.

BATTERY AND SOLAR POWER

The usage of "battery" to describe a group electrical devices dates to Benjamin Franklin, who in 1748 described multiple Leyden jars by analogy to a battery of cannon [3]. Alessandro Volta described the first electrochemical battery, the voltaic pile in 1800 [4]. So according to Volta, this was a stack of copper and zinc plates that was separate by brine soaked paper disks, which is can produce a steady current for a considerable length of time. However, Volta did not appreciate that the voltage was due to chemical reactions and he thought that his cells were an inexhaustible source of energy, [5] and that the associated corrosion effects at the electrodes were

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a mere nuisance, rather than an unavoidable consequence of their operation, as Michael Faraday showed in 1834 [6]. Although, early batteries were of great value for experimental purposes, in practice their voltages fluctuated and they could not provide a large current for a sustained period. The Daniell cell, invented in 1836 by British chemist John Frederic Daniell, was the first practical source of electricity, becoming an industry standard and seeing widespread adoption as a power source for electrical telegraph network [7]. It consisted of a copper pot filled with a copper sulphate solution, in which was immersed an unglazed earthenware container filled with sulphuric acid and a zinc electrode [8]. These wet cells used liquid electrolytes, which were prone to leakage and spillage if not handled correctly. Many used glass jars to hold their components, which made them fragile. These characteristics made wet cells unsuitable for portable appliances. Near the end of the nineteenth century, the invention of dry cell batteries, which replaced the liquid electrolyte with a paste, made portable electrical devices practical [9].

The battery powered is a device that consists of one or more electrochemical cells that convert stored chemical energy into electrical energy [10]. In a battery, the overall chemical reaction is divided by two physically and electrically separated processes, such as one is an oxidation process at the battery negative electrode wherein the valence of at least one species becomes more positive, and the other is a reduction process at the battery positive electrode wherein the valence of at least one species becomes more negative. The battery functions by providing separate pathways for electrons and ions to move between the site of oxidation and the site of reduction. The electrons will pass through the external circuit, where it can provide useful work, for example power a portable device such as a cellular phone or an electric vehicle [10]. While, the ions pass though the ionically conducting and electronically insulating electrolyte that lies between the two electrodes inside the battery. Therefore, the ionic current is separated from the electronic current, which can be easily controlled by a switch or a load in the external circuit.

When a battery is discharged, an electrochemical oxidation reaction proceeds at the negative electrode and passes electrons into the external circuit, and a simultaneous electrochemical reduction reaction proceeds at the positive electrode and accepts electrons from the external circuit, thereby completing the electrical circuit [10]. The change from electronic current to ionic current occurs at the electrolyte or electrode interface. When one attempts to recharge a battery by reversing the direction of electronic current flow, an electrochemical reduction reaction will proceed at the negative electrode, and an electrochemical oxidation reaction will proceed at the positive electrode [10].

The photovoltaic effect was first experimentally demonstrated by French physicist A. E. Becquerel. In 1839, at age 19, experimenting in his father's laboratory, he built the world's first photovoltaic cell. However, it was not until 1883 that the first solid state photovoltaic cell was built, by Charles Fritts, who coated the semiconductor selenium with an extremely thin layer of gold to form the junctions. The device was only around 1% efficient. In 1888 Russian physicist Aleksandr Stoletov built the first cell based on the outer photoelectric effect discovered by Heinrich Hertz earlier in 1887 [11]. Panels in the 1990s and early 2000s generally used 5 inch (125 mm) wafers, and since 2008 almost all new panels use 6 inch (150 mm) cells. The widespread introduction of flat screen televisions in the late 1990s and early 2000s led to the wide availability of large sheets of high-quality glass, used on the front of the panels.

Compared to battery power, solar powered operates by converting sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power (CSP) [14]. Concentrated solar powered systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic convert light into electric current using the photoelectric effect [15]. Solar powered can provide higher power densities. Nevertheless, both these power sources will operate differently. Besides that, Solar energy can be converted to electricity in other ways, that is trough the solar thermal or electric power plants generate electricity by concentrating solar energy to heat a fluid and produce steam that is used to power a generator.

RELATED WORKS

The purpose of this paper is to classify the possible methods to provide power to the wireless nodes into three groups, such as energy stores in the nodes (like a battery), distributing power to the node (like wires), and collecting ambient power available at the nodes (such as solar cells). Figure-3 shows the basic stages of a sensor node. The sensor node that only can relay or receive data can skip functions such as sensing and analogue processing.

The sensing block includes one or more sensors. Analogue processing matches the sensor output to the digital processor usually used a lower cost microcontroller and commercial transceivers also are used for wireless communication. Meanwhile, the power supply has to be provided to the different stages.

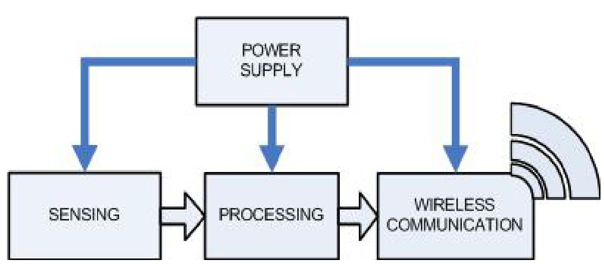

Figure-3. The basic stages of a sensor node.

However, power can also be dominated by the sensor stage [16]. So, new low-power sensors and

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electronic interfaces can help in the reduction of the power consumption of a sensor node. Furthermore, the power supply stage must be able to provide both the total energy demanded during the expected lifetime and the instant power at the activation time [17]. Figure-4 shows a block diagram of the power supply of a sensor node. The load accounts for the sensing, processing and communication stages as shown in Figure-3.

The left three blocks will sense by solar cell powered from the harvesting energy or either the battery powered is used likes in dashed blue box. After that, the ensuing power conditioning stage will provides the appropriate power supply to the load. In addition, the batteries with the appropriate amount of energy must be used to avoid their replacement [16].

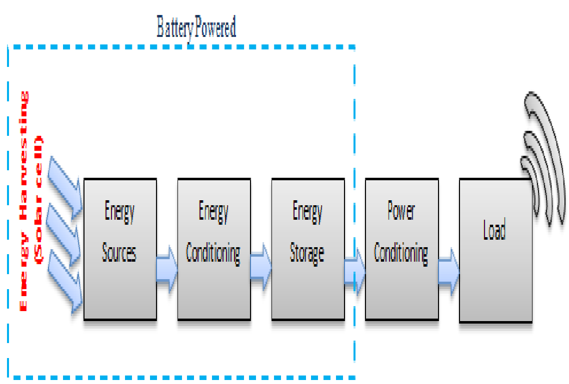

Figure-4. Block diagram of the power supply of sensor node.

Commonly, energy harvesting and the solar cell power required the storage systems to help and provide power when the solar power cannot operate. The storage can provide and also store the power for sensor node. The rechargeable batteries are the common choice of energy storage for sensor node design [16].

The rechargeable battery is a storage cell that can be charged by reversing the internal chemical reaction. A few popular rechargeable technologies like Sealed Lead Acid (SLA), Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH) or Lithium Ion (Li-ion). So, regarding to Table-1, Lithium-ion batteries have highest output voltage, energy density, power density and charge-discharge efficiency along with low discharge rate. While, the NiMH and Li-based, emerge as good choices for using by solar powered of sensor nodes.

Table-1. The Comparison of rechargeable batteries of storage system.

Battery Type	Nominal Voltage (V)	Capacity (mAh)	Weight Energy Density (Wh/kg)	Power Density (W/kg)	Efficiency (%)	Self Discharge (%/month)	Memory Effect?	Charging Method	Recharge Cycles
SLA	6	1300	26	180	70-92	20	No	Trickle	500-800
NiCd	1.2	1100	42	150	70-90	10	Yes	Trickle	1500
NiMH	1.2	2500	100	250-1000	66	20	No	Trickle	1000
Li-ion	3.7	740	165	1800	99.9	<10	No	Pulse	1200
Li-polymer	3.7	930	156	3000	99.8	<10	No	Pulse	500-1000

Furthermore, the other storage system that used for solar cell powered like ultra-capacitor bank or also known as supercapacitors storage, as shown in Figure-5. The supercapacitor has energy density hundreds of times greater than electrolytic capacitors and the long life, with little degradation over hundreds of thousands of charge cycles. It is very higher rate of charge and discharge. The benefit of Supercapacitor compare to rechargeable batteries is when power sources full charge, not have any overcharge danger, not any full detection needed and safe.

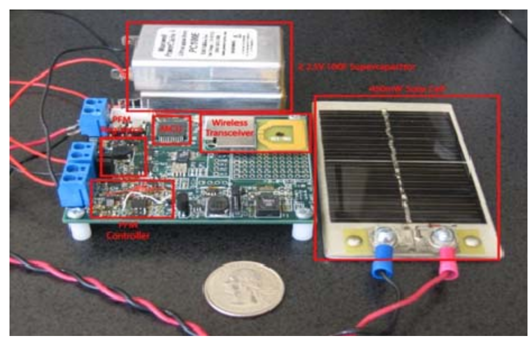

Figure-5. Supercapacitor storage system for solar powered sensor node.

ANALYSIS

This paper analyzes about the potential power sources for sensor nodes. Analysis between power sources, such as batteries power and Solar cell power from energy harvesting for sensor node. In order to provide a general understanding of the various sources of power, the following metrics will be used for comparison in terms of energy and power density efficiency to generate power for the sensor nodes, the lower cost and also in terms of characteristics such as size and weight. Based on analysis and researches from other journal, the batteries have been the dominant form of power storage and delivery for electronic devices over the past 100 years, thus their consideration for use in sensor node is natural [17]. So, the batteries are the main solution at present, but unless they can provide very long lifetime while not dominating the size or cost of the nodes, the battery will be a significant deterrent to widespread adoption of these technologies.

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The primary batteries are perhaps the most versatile of all small power sources. Table-2 shows the energy density for a few common primary battery chemistries. Meanwhile, in Figure-6 shows the average power available from these battery chemistries versus lifetime. So, in many type of primary battery, zinc-air batteries have the highest energy density from others, although the battery lifetime is very limit and short.

Table-2. The energy density for primary batteries.

Primary battery	**Zinc-air**	**Lithium**	**Alkaline**
Energy density (J/cm^3)	3780	2880	1200

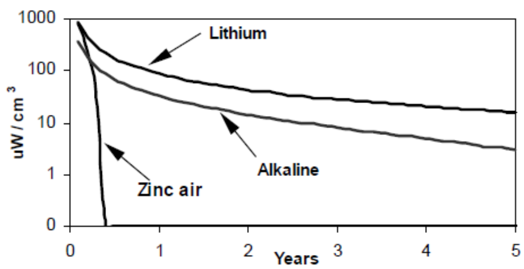

Figure-6. The average battery powered versus lifetime.

The secondary or rechargeable batteries are commonly used in consumer electronic products such as cell phones, PDA's, and laptop computers. The rechargeable batteries also used as power sources in sensor node. Sometimes, the energy harvesting source on the node itself, such as a solar cell powered, would be used to storage power and recharge the battery. Table-3 gives the energy density a few common rechargeable batteries powered. One item to consider when using rechargeable batteries is that electronics to control the charging profile must often be used. These electronics add to the overall power dissipation of the device [16]. Nevertheless, like primary batteries, the voltages are stable and power electronics between the battery and the load electronics can often be avoided [16].

Table-3. The energy density for rechargeable batteries.

Rechargeable battery	**Lithium**	**NiMHd** (nickel metal hydride)	**NiCd** (nickel - cadmium)
Energy density (J/cm^3)	1080	860	650

Meanwhile, we know that Solar cell powered is energy harvesting, which is the process by which energy is derived from external sources. The energy harvesting reference design contains a thin film battery used to recharge the wireless sensor node through solar cell powered. Power solar cells can provide higher power density and energy through photovoltaic conversion vibration. Sensor node uses on the order of several mW of power and energy. There are two situations that used solar powered will be considered, such as use in outdoors (solar energy) and use in indoors (artificial light). Table-4 shows the analysis by using solar cell powered in outdoor and indoor with the daily energy and average power densities in December, at the area of Barcelona (Spain) has done. These data have been summarized together with the output of a solar cell with 10% efficiency [18].

Table-4. Energy and power densities from a solar cell powered.

Location	**Irradiation** (mW/cm^2)	**Hours** (h)	**Daily energy** (mWh/cm^2)	**Power** (mW/cm^2)
Outdoors	100	3.4	34	1.42

Table-5, compares the size that required of both the batteries powered and solar cells powered in order to power sources of the sensor node. Based on research, we found that the lithium primary batteries with an energy density 3 of 0.8 Wh/cm^3. Meanwhile, a lifetime of 5 years is considered, which results in an average power of 18 $\mu W/cm^3$ for the batteries and while, the sizes are given in square centimetres for solar cells and in cubic centimetres for batteries.

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Table-5. Primary batteries versus solar cell.

Energy source	Power density	Power supply size	
		Continuous operation	Periodical operation
Battery	0.018 mW/cm^3	5913 cm^3	6.1 cm^3
Solar outdoors	1.42 mW/cm^2	76 cm^2	0.078 cm^2
Solar indoors	0.017 mW/cm^2	6480 cm^2	6.7 cm^2

Moreover, the power densities are similar for indoor solar cells and batteries. On the other hand, outdoor solar cells provide 80 times more power and then provide the minimum size solution.

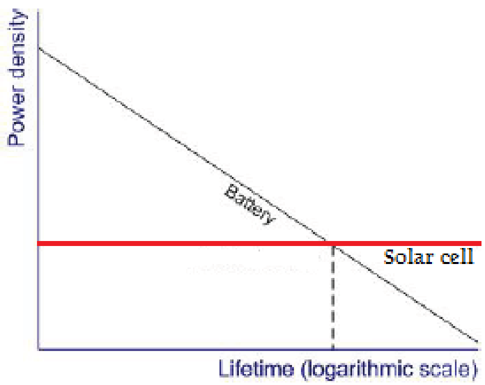

Figure-7. Power density versus lifetime battery and solar cell powered.

Regarding to Figure-7, the lifetime intersection point is slightly more than 23 days and 5 years when comparing the selected primary battery technology with the considered solar cells at respectively outdoors and indoors. For continuous operation, both indoor solar cells and battery sizes are too large to fit respectively on the top (face of 100 cm^2) and within the given enclosure [18]. While, for periodical operation all the solutions fit in the required space. So, other criteria such as cost and circuit complexity also will be included.

In Figure-7 above, the considered primary battery powered or solar cell powered will be respectively the best option for lifetimes lower or higher than the intersection point between graphs (dashed line). At the other hand, primary Batteries have a maximum lifetime (shelf-life) due to self-discharge and chemical decomposition [19]. Lifetime of energy solar cell can also be limited by the storage unit. As can be seen, power density of batteries decreases linearly with lifetime because of their limited energy. Energy density mainly depends on battery technology but also on battery size and manufacturer [18]. On the other hand, solar cell has average and a constant power density that depends on the specific ambient source. At a specific time, the alternative with the highest power density will provide the best option in terms of size and weight [18].

In general, energy harvesters or solar cells powered in particular need an energy storage system, as shown in Figure-3 above. In this research, the researchers were assume that the storage system has to power the sensor node for 5 days in darkness. In Table-6 shows the resulting sizes for lithium and NiMH of rechargeable batteries and supercapacitors. The energy density of batteries is two orders of magnitude higher than that of supercapacitors. As a result, supercapacitors are not feasible when the node is operating continuously.

Table-6. Energy density and required sizes of storages.

Storage system	Energy density (mWh/ cm)	Storage unit size (cm^3)b	
		Continuous operation	Periodical operation
Lithium	416 (195-532)	31	0.032
NiMH	260 (151-410)	50	0.051
Supercapacitor	(3.8-6.4)	2700	2.7

Table-6 (a). Advantages and disadvantages of battery powered.

Battery	Advantages	Disadvantages
Primary (not rechargeable) battery	High energy density Wide availability of standard products Best alternative for low cost	fixed and limited energy rating (limited lifetime) High cost of continuous replacement Dangerous and lead to fire, explosion, and chemical

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		pollution
Rechargeable battery	Cost is paid back quickly for high utilization applications Increased economic and environmental benefits Flat discharge curve	Cost of charger - for low cost applications the charger can cost much more than the actual product Lower energy density overcharging can damaging the battery

Table-6(b). Advantages and disadvantages of solar cell powered.

Advantages	Disadvantages
solar power not only be used for outdoor applications, but can be used for indoor applications Solar energy does not cause pollution. Low electricity bills Unlimited supply of solar batteries Can use storage device to storage the energy	High Cost Require a battery charge, to use solar power at night.

Table-6(a) and (b) show, the advantages and disadvantages of battery-powered and solar-powered sensor nodes.

FUTURE WORK

The next stage of the research work is to focus on developing an energy-efficient routing protocol to enhance the network lifetime of the sensor nodes. Then, the research work will deploy and analyze real-time implementation of wireless sensor network with both types of power source to determine which power source is better between the two. Analysis will cover the throughputs, packet drops, delay and network lifetime.

CONCLUSIONS

In this paper, we have analyze and compared the use of primary batteries against energy harvesting, in particular with solar energy. The parameters and characteristics of power sources sensor nodes have also been outlined. In this paper also reviews of each energy density and power efficiency to generate power for the sensor nodes. At a certain time, the highest power density is the best alternative that will provide the best option in terms of size and weight. So, for power density of batteries powered mainly depends on size, manufacturer and also type of battery technology. Meanwhile, the solar cell powered has constant power density and that is depends on the specific ambient external sources.

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