Overview of Miniature Energy Harvesting Technologies

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ABSTRACT

Wireless Sensor Networks (WSN) are expected to be the key to enabling Ubiquitous Sensor Networks (USN). Some examples of potential early adopters of WSN applications include smart buildings, environmental monitoring, and physical security. However, a key issue for the wireless sensor is the power supply. Currently wireless sensors are powered by small batteries that under proper management can provide power up to five years. However, such systems are inefficient and relatively expensive in the concept of ubiquitous sensor networks. Energy harvesting draws attention as an alternative to solve the power supply problem. Energy harvesting is the technology to generate energy from the environment and promises to enable inexpensive wireless sensors. This paper presents an overview of the current state-of-the-art of such technologies and applications. This paper also presents thoughts on potential successful business models for energy harvesting technologies.

Keywords: wireless sensor networks, energy harvesting, MEMS

1 INTRODUCTION

A Wireless Sensor Network's (WSN's) goal typically is to transmit a variety of information to and from central servers and other devices and components through a distributed network of intelligent wireless sensors. Numerous configurations for the optimal operation of WSNs are a major topic of research and development, and depend a lot on the application. As batteries can operate wireless sensors and transmit data through wireless communication, it is easy to install them anywhere. WSNs have the potential to significantly impact industry and society through the realization of ubiquitous sensor networks (USNs), yet another concept of major research and development worldwide. Some examples of potential WSN applications include smart buildings [1], environment monitoring, vehicle monitoring, and physical security. However, a key issue for wireless sensor is the power supply. Currently wireless sensors are powered by small electrochemical batteries that under proper management can provide power up to five years. At the current rate of development in battery technology, it cannot be hoped that a small battery will power a wireless sensor over its life time. This results in the need to maintain the batteries and thereby adds cost to the operation of a WSN. Ideally, a WSN should have minimal or no hardware maintenance cost. A WSN may involve many wireless sensors. Therefore, the cost of replacing batteries and management will be not small. Thus, such systems are inefficient and relatively expensive in the concept of ubiquitous sensor networks. Energy harvesting devices have been drawing attention as an alternative to solve the power supply problem for the past few years. Energy harvesting is the technology to generate electricity from waste or excess energy in the surrounding environment. It is also referred by some as "Power Harvesting," or "Energy Scavenging." Energy sources exist not only in nature but also in artificial objects such as machinery, buildings, transportation, etc. Energy harvesting is also expected to play a major role in energy conservation and efficiency, and will draw more and more attention in the near future. This paper focuses on miniature Energy harvesting devices which are fabricated using MEMS technology (Micro Electro Mechanical Systems) mainly.

2 ENERGY HARVESTING TECHNOLOGY

2.1 Overview

Research and development of Energy harvesting devices has been popular over few years. PowerMEMS is the international workshop on micro and nanotechnology for power generation and energy conversion applications. PowerMEMS itself started as a category of MEMS in 2000 and has included energy harvesting as a category. The graph in Figure 1 shows the number of papers presented in this workshop related to energy harvesting. The total number of papers is increasing yearly perhaps indicating a general increased concern about global environmental issues. Of specific interest is that the number of Energy harvesting papers have also increased rapidly in the past few years with nearly half of all the papers in this category last year. It is an indication of growing interest in this area of technology for various reasons that will be explained below. .

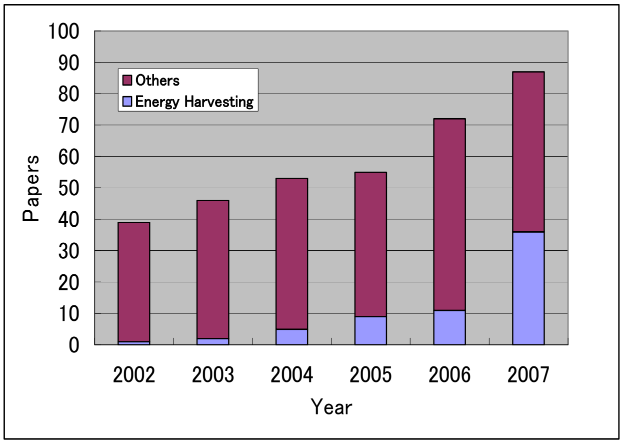

Figure 1: Number of papers PowerMEMS

There are heat, vibration, acoustic, light and others forms of energy that can be harvested from the environment. Most the current research and development are addressing Energy harvesting utilizing heat and vibration. This paper as well will address these two areas of energy harvesting as they are the “low hanging fruit” for both technology development as well as market penetration.

2.2 Thermoelectric Conversion

Thermoelectric conversion is the conversion of heat (a temperature difference) to electricity. It utilizes the Seebeck effect of semiconductors or metals to generate current [2]. Advantages of thermoelectric conversion are solid-state operation with no moving parts. That’s why relatively high reliability and long life can be achieved. The drawbacks of thermoelectric conversion are low efficiency and relatively large devices [3]. The current trend of research is to improve efficiency of thermoelectric conversion by optimizing the materials. There is one issue to be considered in the production of commercial devices – the whole device package would be potentially exposed to high temperature and strong heat shocks and has to be robust enough to sustain this over its lifetime. While thermoelectric devices can be highly reliable because of having no moving parts, there needs to be effort in the development of reliably packaging these devices for industrial use.

2.3 Vibration Conversion

Next Energy harvesting devices utilizing vibration from the surrounding environment are discussed. There are currently three main types of harvesting devices using vibration energy. They are piezoelectric, capacitive and electromagnetic energy conversion devices.

2.2.1 Piezoelectric Conversion

Popular piezoelectric devices used widely include microphones, sensors, etc. Piezoelectric conversion principle generates an electric potential in response to an applied mechanical stress [4]. As stress converts to voltage directly, piezoelectric conversion is the most efficient in a theoretical sense. However, efficiency of piezoelectric conversion decreases when miniaturized. The main cause of the lowered efficiency is that the resonant frequency of piezoelectric film is very high to convert the vibration to electricity. Frequency of vibration from environment is usually less than a few hundred Hz. Therefore, it is necessary to decrease the resonant frequency of the piezoelectric film. Furthermore, while there is lot of evidence with bulk piezoelectric material devices, there is limited experience with thin film piezoelectric devices. The current trends in research are to improve the efficiency, and to decrease the resonant frequency of piezoelectric film and to establish the thin film fabrication process. In addition, the thin film piezoelectric material is fragile generally. It is necessary to improve the strength of piezoelectric film for production of industrial level harvesting devices.

2.2.2 Capacitive Conversion

Capacitive conversion generates electricity by the principle of changing capacitance of variable capacitor during motion (vibration) [5]. It utilizes electrostatic induction and generates a voltage. The architecture of capacitive conversion is relatively simple. Therefore, it is easy to fabricate capacitive conversion using conventional MEMS fabrication processes. One of the issues is in the controlling the frequency of the moving parts in such a device. Frequency of vibration from environment is usually less than a few hundred Hz. On the other hand, resonant frequency of silicon used in MEMS devices is around several kHz. Therefore, it is necessary to decrease frequency of the moving parts of a capacitive conversion device. Many researchers are developing such devices utilizing polymer film as the moving part [6].

2.2.3 Electromagnetic Conversion

Applications of electromagnetic principles are well known for driving motors and mechanical relays. Electromagnetic generation of electricity in general involves the motion of a magnet in an electric field [7]. It utilizes electromagnetic induction to generate current. There are some efforts to miniaturize electromagnetic principle devices for Energy harvesting. The current trend of research is to reduce the size of the electromagnetic devices.

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3 POTENTIAL APPLICATIONS

Table 1 shows comparison of Energy harvesting devices which are shown in previous section.

Conversion	Output	Efficiency	Size	Reliability
Thermo	Current	Low	Big	Good
Piezo	Voltage	High	Smallest	Poor
Capacitive	Voltage	Lowest	Small	Good
EM*.	Current	Very High	Biggest	Very Good

* - EM = electromagnetic

Table 1: Comparison of Energy Harvesting Devices

Each energy harvesting device has certain advantages and drawbacks depending on the application and construction of the device. It is important to find applications to meet the feature by considering the feature of each device. For example, when used for operating wireless sensors, a voltage output is required. Piezoelectric and capacitive devices offer momentary high output voltage relatively, and are suitable as a power supply to operate wireless sensors. If the conversion efficiency is further improved, these devices are well suited to replace batteries in a wireless sensor. On the other hand, thermoelectric and electromagnetic conversion is suitable for charging battery because their main output is current. Hybrid systems of such devices with batteries where such devices can charge the battery are very appropriate. The role of energy harvesting in this case is to extend the operating time of charging the battery.

Next, some of the potential applications of energy harvesting are shown from the view-point of the energy source.

Structural Health Monitoring

Structural health monitoring with WSN is recently of significance and is discussed next. One example is where sensor nodes which include energy harvesting devices are attached on the surface of liquefied natural gas (LNG) pipelines [8]. Each sensor node collects and transmits data wirelessly to a base station. Power supply for the sensor node is supplied by an energy harvesting device that generates power from the vibrations in the pipeline induced by the flowing LNG. Another example of structural health monitoring is in aircraft where sensor nodes are built in the bulkhead of the jet or the blades of the helicopter. In this case, smaller and lighter sensor nodes are required. Miniature energy harvesting devices enable such a monitoring system. Similar monitoring systems will have applicability to buildings, bridges and other structures.

Automobile

There are two energy sources that can be harvested from an automobile. One is the waste heat from the engine, the other is vibrations from the motion of the vehicle.
Waste heat from engine is one of the most appropriate applications for thermoelectric energy harvesting because the temperature of the engine can reach up to 1000 deg C. By taking advantage of the vibrations from the motion energy harvesting devices can replaced the battery of a TPMS (Tire Pressure Monitoring System).

Portable Electronics

As portable electronics such as lap-top computers and cellular phones become more functional, their power consumption is on the increase. On the other hand, the progress in chargeable battery technology, such as Li-ion batteries, is not keeping pace. In this case, the role of energy harvesting is to extend the operating time of the chargeable battery. Energy sources of portable electronics are waste heat from the CPU (Central Processer Unit), and vibrations from typing (keyboard) and transporting the portable device. Energy harvesting from the vibrations of the keys while typing has been demonstrated by, T. Wacharasindhu, et al. [9].

Other Electronics

The new energy policy bill passed in the United States requires not only automobile to average 15 kilometers per liter by 2020, but also sets tougher efficiency requirements for electric appliances (home electronics) such as refrigerators, freezers, and dishwashers, and a 70 percent increase in efficiency of light bulbs. It will be necessary to reduce power consumption of the internal components in order to improve efficiency of electric appliances. If target efficiency goals are unattainable directly, then energy harvesting devices will have to play a role to fill in the gap. In this case, the ease of installation and product cost of such devices are important. The new energy bill provides a significant push to the development of energy harvesting technologies and devices.

4 BUSINESS MODEL

In the previous sections, many potential applications of energy harvesting have been described. . However, energy harvesting is yet to achieve commercial success in many of these applications. The common issue with all energy harvesting devices is that the power generated by the energy harvesting device is much lower than that of a conventional battery. For instance, a cellular phone requires 0.9 W to operate. Power output of the current energy harvesting is sub-mW at most. Some WSN applications require only about 0.2 W for power. Initially energy harvesting devices will be accepted in the low power applications. Then the number of applications will increase as the efficiency is improved. And the ease of installation is also important for mass adoption. . Therefore, it is necessary to establish standards for energy harvesting devices.

5 CONCLUSION

An overview of miniature energy harvesting devices is presented in this paper. These devices are the key to the success of Wireless Sensor Networks. Energy harvesting can be the replacement for a battery in a wireless sensor. As energy harvesting becomes more feasible and is incorporated widely, the Wireless Sensor Networks will also grow bigger from the synergy. There are various types of energy harvesting devices. The characteristics and features of each device will dictate the application where it can be used.. In other words, each application will have an optimal energy harvesting solution. Energy harvesting technologies are also expected as an alternative to reduce power consumption of electronics components that hope to realize energy conservation for various regulatory, technical and commercial reasons. The widespread use and commercial realization of energy harvesting devices rests on the development of more efficient and smaller devices. However, given the rapid pace of development in materials and engineering due to advances in nanotechnology, MEMS and CMOS technologies, the future where Wireless Sensor Networks powered by energy harvesting devices is not far away.

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