Chapter 36
Wireless Sensor Energy Harvesting and Management

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Abstract This paper analyzes the energy harvesting and management of wireless sensor network nodes and studies the principle, technology and method of energy collection of wireless sensor network nodes. Energy management of wireless sensor network nodes should be solved from two aspects of energy saving and energy supply. The harvesting principles and methods of various energy sources in the environment, including solar energy, wind energy, sound energy, vibration energy, thermoelectricity and electromagnetic field energy, are analyzed. Sensor nodes should absorb energy from the environment in as many ways as possible to ensure long-term, stable and reliable operation of sensor nodes.

36.1 Introduction

Wireless sensor network (WSN) is self-organizing, miniaturized and aware of the outside world. It integrates many new technologies, such as sensors, embedded systems, communication and power supply. Wireless sensor network nodes are usually composed of sensors and communication circuits and can be placed in factories, farmland or battlefield and other dangerous or inconvenient places to complete positioning, measurement, control and other functions. Can at any time, any place through data collection, processing, analysis, dissemination to provide a new information channel, so that people get more detailed and reliable information, in industrial control, traffic management, environmental monitoring, space exploration and other fields has a potential and extensive application needs [1].

Wireless sensor network node is stationary and, possibly in the wild environment, is not allowed to change the battery; therefore, wireless sensor network node is the energy management problem for prolonging the lifetime of wireless sensor

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network application and reduce the cost of the key, to become one of the core problems in the research of wireless sensor network, involves two aspects, namely energy consumption and energy problems. Therefore, in order to solve the problem of energy management of wireless sensor network nodes, it is necessary to conduct in-depth and detailed research from these two aspects. At present, there are many researches on solving the problem of energy consumption. For example, in order to effectively utilize the existing energy resources and extend the life cycle of the network, various optimized routing communication protocols are studied. It is impossible for wireless sensor network nodes to work normally for a long time only by various optimization and consumption reduction methods. When the energy consumption has been reduced to a certain limit by various measures, no matter how hard people try, they will not get a better effect. Therefore, we must study from the perspective of energy supply and take effective methods to provide continuous energy supply for wireless network sensors. Wireless sensor network nodes can also obtain and store energy from their environment, so research on how to effectively collect and store energy from the environment and energy collection methods have attracted more and more researchers' attention [2].

36.2 Requirements for Energy Harvesting

Wireless sensor networks generally consist of a large number of sensor nodes scattered over a certain area, usually powered by batteries. However, due to the limitations of node size, the configured battery can provide very limited energy. At the same time, because the sensor nodes are often in harsh environments or inaccessible environments, and the number of sensor nodes is very large, it is not possible to replace the battery for each node. In order to prolong the life of sensor nodes, it is necessary to take various methods to replenish the energy of sensor nodes. The sensor nodes harvest energy from the environment, known as energy harvesting. Wireless sensor nodes collect all available energy from the environment and store it. When the node needs energy, the energy is taken out of the storage unit and transformed to get the energy needed on the node [3].

According to the environment of sensor nodes, the energy collected in the environment is also different, so the energy collection method of a single energy is difficult to ensure that all nodes in the wireless sensor network can reliably obtain the required energy. Therefore, it is necessary to set up two or more energy collection methods for each sensor node, which requires that a comprehensive energy collection power supply should be configured as far as possible in a wireless sensor network node with limited space according to the possible energy types in the working environment of the node [4].

36.3 Analysis of Energy Harvesting Technology

There may be a variety of potential energy available in the physical space we live in, such as solar (light) energy, wind energy, heat energy, mechanical vibration energy, sound energy, electromagnetic field energy and so on. How to collect and store the energy in small sensor network nodes is one of the focus problems that many scientists have studied hard in recent years, and some progress has been made at present. Among them, the energy harvesting technology using mechanical vibration and light energy is more studied, and the products of related devices appear, which has a good application prospect.

36.3.1 Solar (Light) Energy Collection

New advances in optoelectronic materials make light energy collection, a new method of power source for wireless network sensors. The installation and operation cost of optoelectronic components can also be greatly reduced with large-scale applications. The basic principle of photoelectric acquisition is to use photoelectric materials to absorb a large number of photons. If enough photons can activate the electrons in the photocell, electrons can be obtained after proper structural design. Photoelectric components act as decoders, generating voltages under light irradiation, which, combined with the corresponding adjustment and storage circuits, can supply power to the load. The amount of electric quantity is a function of the collected light energy. To obtain more electric quantity, the photoelectric element is usually placed in a well-lit environment and the area of illumination is increased. Usually photovoltaic cells can produce voltage DC 0.5 V, but the actual voltage output varies with the operating temperature. Generally speaking, the lower the temperature, the higher the output voltage, the stronger the light, the greater the current output. Optoelectronic technology has evolved from the initial manufacture of silicon crystals to today's deposition of tiny particles on photosensitive substrates. This new material can be used indoors or outdoors; it is easy to install in weight, and is less affected by ambient temperature, making it ideal for powering small, remote sensors. Solar collection power sources using super capacitors as energy buffers are a universal and representative model that is well suited for a wide range of sensor network applications, as shown in Fig. 36.1.

36.3.2 Wind Energy Harvesting

The wind energy collection device consists of a rotating shaft and a number of blades. One end of the blade is fixed on the rotating axis and radially extends to all sides along the rotating axis. The blades form an oblique Angle to the shaft. When the wind

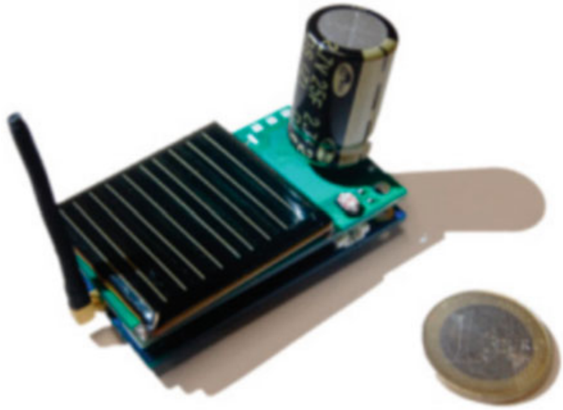

Fig. 36.1 Energy harvesting sensor node

blows head-on against the blade, the blade rotates on its axis under the action of the wind. The shaft rotates, collecting energy from the wind. The wind energy collecting effect is related to the wind side. The effect of wind from different directions is very different. The wind force also has a big impact on wind harvesting.

36.3.3 Harvesting of Thermoelectric Energy

Research on thermoelectric technology began in the 1940s and reached its peak in the 1960s with the successful realization of long-term power generation on spacecraft. The thermoelectric generator has the characteristics of small size, light weight, no vibration, no noise, reliable performance, less maintenance and can work for a long time in extreme harsh environment. It is suitable for small power supply of less than 5 W, for a variety of unsupervised sensors, small short-range communication devices and medical and physiological research instruments. At present, the relevant products have entered the practical stage. In recent years, thermoelectric generator has also shown a good application prospect in civil use. Through the in-depth study of thermoelectric conversion materials and the development of new materials, it has become the core content of thermoelectric technology research to continuously improve the thermoelectric performance and improve the electric output power under the condition of constant heat source. Scientists have invented a new type of battery that uses human temperature differences to generate electricity, which could provide long-term power for portable miniature electronic instruments, eliminating the trouble of charging or replacing batteries. As long as there is a temperature difference of 5 °C between the human skin and clothes, you can use this battery to provide enough energy for an ordinary watch.

36.3.4 Collection of Sound Energy

Sound energy is a form of energy. Its essence is the transfer and transformation of mechanical energy through the media and in the form of wave after the object vibrates. Conversely, the transfer and transformation of other energies can also be reduced to mechanical energy to produce sound. The change can be reversed. To convert sound energy into electricity when sound waves encounter obstacles, it is possible to design and build resonators that collect sound when the input noise energy they collect is converted into electricity storage.

Conventional engines are limited by thermodynamics and engine complexity. The most efficient engines are typically giant turbines used in power stations. Small sound-energy engines are up to 10% more powerful than the largest, most efficient turbines and have no moving parts and no maintenance.

36.3.5 Magnetic Energy Harvesting

In the magnetostatic case, electric current and magnetic field always exist together. Thus,Therefore, the magnetic energy can be regarded as related to electric currents and stored in the magnetic field. However, scientific practice has proved that magnetic field is a special form of matter, which can exist without electric current. The changing electric field can also produce a magnetic field, which also has energy and its field energy density is the same as that of magnetostatic. In general, changing electromagnetic fields propagate in the form of waves, accompanied by energy transfer.

The electromagnetic energy recovery system is mainly composed of receiving antenna, rectifier circuit and energy management module, among which the performance of antenna and rectifier circuit is the key factor affecting the performance of the whole system. In this system, the receiving antenna determines how much electromagnetic energy can be collected, and the rectifying circuit determines how much direct current energy can be converted into electromagnetic energy that can be directly used. On the one hand, the electromagnetic energy distributed in the environment has location, frequency uncertainty and power inhomogeneity, and the current design of electromagnetic energy recovery system mainly uses single-frequency or multi-frequency high-gain directional antenna to solve the recovery problem. However, this scheme often requires high alignment of the receiving and receiving antennas, and the actual relative position between the energy source and the receiving antenna is often uncertain. On the other hand, there are two main problems in the existing rectifier circuit schemes: impedance matching, secondary rectification and impedance compression are adopted to improve the conversion efficiency, but the input power is too high when the optimal rectification efficiency is achieved; The nonlinear action of diodes makes the input power range of the rectifier circuit narrow when efficient rectification. Therefore, for the practical application scenarios with uncertain electromagnetic energy, the existing recovery schemes still fail to solve the current problems well [5].

36.3.6 Comprehensive Harvesting of Energy from Various Sources

We live in an environment in which there are many forms of energy. Energy takes different forms in different environments. In order for each sensor node to obtain as much energy as possible from its environment, it is necessary to design such an energy collection system, which cannot collect energy from only one kind of energy, otherwise, the node will not work reliably for a long time once the environment is short of this kind of energy. Therefore, it is necessary to integrate multiple energy harvesting methods on each node. Of course, the difficulties are not difficult to imagine, mainly manifested in the following aspects: (1) various energy recovery technologies and methods are not mature at present, and researchers need to carry out a lot of innovative research; (2) Various energy harvesting components must meet the stringent size requirements of sensor network nodes; (3) Ensure that the various energy harvesting components work in concert and that the collected energy is effectively stored.

36.4 Energy Management

The energy collected must be managed effectively so that it can be continuously and effectively supplied to the sensor, otherwise the energy collected will be useless. Power management is a hot topic in energy utilization. Dynamic power management is a potential method to save power. The storage element of power supply is battery or capacitor. Chemical battery has become the first choice in network sensor because of its stable and effective storage. The limitation of collecting energy into the battery is the battery life problem. How to make the battery life meet the user's acceptable expectation and adopt the correct charging method to extend the battery life is the key problem. Dynamic power management and dynamic voltage dispatching are adopted in power management of networked sensors, which is an effective design method to reduce the energy consumption of the system. Dynamic power management (DPM) is a design method to reduce power consumption by dynamically allocating system resources and completing system tasks with the least components or the least workload.

Dynamic power management technology includes a series of methods to enable the system to achieve efficient energy saving. These methods control the "power management" of whether system components enter a low-power state when they are idle. The basic premise of the application of dynamic power management technology is that the system components have different workload during the working time. This is true of most systems. Another premise is that fluctuations in the workload of systems and components can be predicted with some degree of confidence. In this way, it is possible to switch between states of energy consumption, and the system cannot consume excessive energy within the observed and predicted time of the workload. In the network sensor power management, its working characteristics are very suitable for dynamic power management. Because the nodes of the sensor network are not working all the time, they spend a lot of time in sleep mode, which requires low power consumption. When the sensor collects the data, the controller processes the data and carries on the data communication, the system power consumption increases. When entering idle, the device can be shut down and enter the low-energy sleep state; when the request is received again, the device is evoked [6].

In a dynamic power management system, the working states of different components must dynamically adapt to different performance requirements. Only in this way can the energy wasted in idle time or in useless components be minimized. For the judgment of power management time, it is necessary to use a variety of prediction methods, such as static prediction method and dynamic prediction method. It is necessary to predict the coming workload according to the historical workload and decide whether to change the working state. The main principle of dynamic voltage scheduling is to adjust the supply voltage dynamically based on the load state to reduce the power consumption of the system, which has been applied in portable personal mobile devices. Sensor nodes on the embedded operating system is responsible for scheduling request to receive services from different task queue, and real-time monitor the processor utilization and task queue length, the load observer based on the sequence of these two parameters value computation load of nominal value, DC/DC converter with reference to the value of the output amplitude of voltage, support the work of the processor. This actually constitutes a closed-loop feedback system, and the method of control theory can be used to design each module.

36.5 Conclusion

Wireless sensor network is widely used. In order to prolong the life cycle of sensor nodes, improving the energy efficiency of sensor nodes has always been an important research topic. In this paper, the energy collection and management of wireless sensor network nodes are analyzed and discussed. Solar energy, wind energy, sound energy, magnetic energy and so on are introduced and analyzed. In order to make the sensor nodes work stably and reliably for a long time, the most effective method is to adopt various methods to obtain energy from the environment and reduce energy consumption and improve energy efficiency through energy management.

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