Design of ZigBee-Based Energy Harvesting Wireless Sensor Network and Modeling of Solar Energy

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Abstract. Traditional wireless sensor networks rely on battery power to operate, but when the node's energy is exhausted, the node loses its ability to operate. To enable wireless sensor networks to achieve continuous working, researchers have turned their attention to energy harvesting wireless sensor networks. The energy harvesting wireless sensor network has the advantages of energy renewable, low maintenance cost, etc., and can achieve permanent use of nodes to a certain extent. However, the energy collected by nodes in such networks will change with the change of environment and time, so the survival of energy-gathering wireless sensor networks in environmental detection needs further study and research. In view of the above problems, we designed a solar energy harvesting wireless sensor network in this paper, and designed energy harvesting and energy consumption related experiments to record the energy and network characteristics under different weather and time, collected under different conditions, and model the solar energy collected under different circumstances, so as to provide basic data for the further research of network reliability and other characteristics.

Keywords: Zigbee · EH-WSN · Energy model

1 Introduction

As a low-cost, small-sized wireless communication computer network, Wireless Sensor Networks (WSNs) can be placed in ridiculous areas for environmental monitoring for a long time [1]. Since the battery energy of wireless sensor networks is limited [2], research on wireless sensor networks is now focused on how to improve the efficiency of energy utilization and extend the service life of nodes [3]. In addition, there are batteries in the wireless sensor network. In a harsh environment, the battery may leak, which is serious for environmental pollution and is not suitable for large-scale deployment [4]. In contrast, energy harvesting wireless sensor networks can collect energy from the environment, enable energy in the battery to be recycled, and use energy sources such as solar, wind, and vibration energy [5]. After the node dies, the energy harvesting

J. Li et al. (Eds.): SPNCE 2019, LNICST 284, pp. 576–584, 2019.
https://doi.org/10.1007/978-3-030-21373-2_47

equipment collects energy from the environment, fills the energy storage device, and restarts the node, achieving the permanent work of the node to a certain extent [6]. In this paper, solar panels are used to collect solar energy and convert it into electrical energy. After the maximum power is tracked, the charging management module supplies power to the rechargeable battery of the wireless sensor node. However there are still some unavoidable problems in energy harvesting wireless sensor networks. The randomness and uncertainty of energy collection seriously restrict the development of energy harvesting wireless sensor networks. How to adjust the working state of nodes based on the collected uncertain energy has become an urgent problem to be solved. In this paper, we mainly design and implement the solar illuminance collection experiment, to collect the illuminance data and model the illuminance data of different time and different weather for the future solar energy collection wireless sensor network.

2 EH-WSN Overall Structural Design

For the whole system, the energy-gathering wireless sensor network platform designed in this paper is composed of solar energy-gathering wireless sensor nodes [7], sink nodes and upper computer (as shown in Fig. 1). Among them, the solar collector wireless sensor node monitors the surrounding environment information as the terminal node and the routing node. The collected information is simply processed and uploaded to the coordinator node. Finally, the coordinator node uploads the information to the host computer through Rs485. In terms of energy use, terminal nodes and routing nodes collect solar energy through solar panels, and the energy comes from clean and pollution-free solar energy in the environment. The power supply of the sink node is supplied by the upper computer without considering the energy loss. ZigBee communication is used between each node. The whole platform realizes the functions of data acquisition, processing, transmission and display.

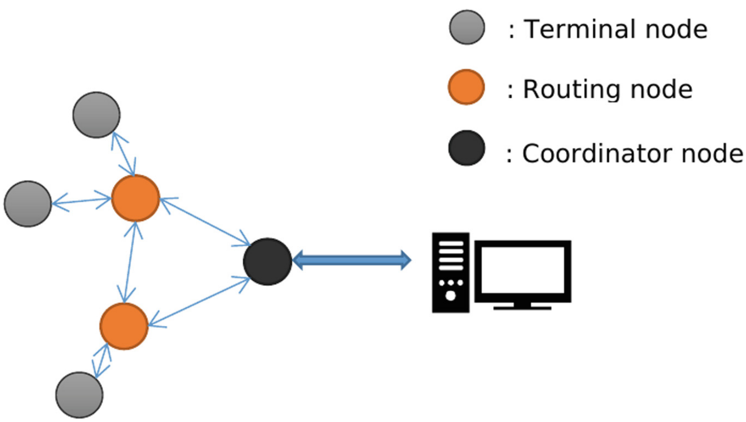


Fig. 1. Energy harvesting type wireless sensor overall structure.

2.1 System Hardware Design

The energy harvesting wireless sensor hardware mainly includes the design of terminal nodes, routing nodes and aggregation nodes. For the ZigBee wireless sensor network, it mainly includes the design of routers, coordinators and terminal devices. Among them, the number of terminal devices is the largest, which is an important information collection device and the network component in the whole system. The router device is set as a node with both acquisition and routing functions. The hardware design is the same as the terminal device, and the software configuration is different. The overall hardware design of the terminal node and the router node is shown in Fig. 2. It is mainly composed of a solar energy collection module, an energy storage device, a sensor module, a microprocessor (MCU) module, and a ZigBee communication module. Since the energy harvesting wireless sensor network is adopted in this paper, this paper focuses on the energy harvesting module and energy storage part of the sensor node.

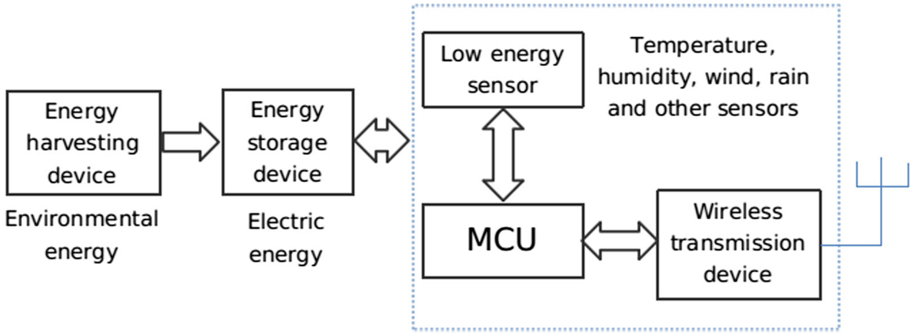
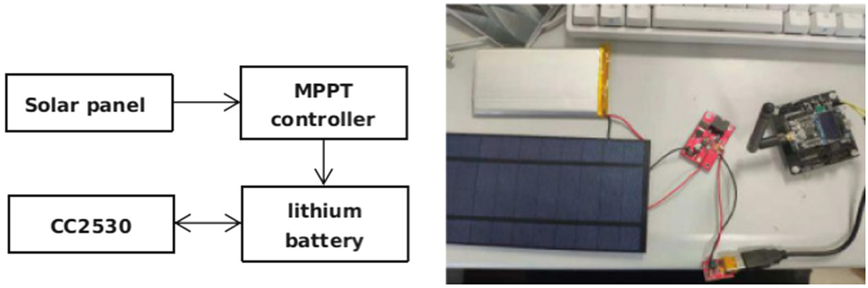


Fig. 2. EH-WSN node.

Energy Storage Device. In the solar collector type wireless sensor network, the most important part is the power supply part. Unlike traditional wireless sensor networks, power modules for solar-collected wireless sensor networks can collect energy from the environment and recycle it [8]. Therefore, in this article, we use a rechargeable battery to replace the ordinary dry battery. Considering that the MCU and ZigBee modules can work normally in the voltage range of 3.7 V to 7 V, the designed terminal uses a rechargeable lithium battery of 3.7 V to 4.2 V for the power supply.

Energy Harvesting Device. This article selects 6 V polysilicon solar panels to charge rechargeable batteries. Since the solar panel voltage output varies depending on the light intensity, the rechargeable battery cannot be directly charged. This paper designs the use of maximum power tracking (MPPT) technology to power rechargeable batteries and other modules. The overall design is shown in Fig. 3. The MPPT controller can detect the generated voltage of the solar panel in real time and track the highest voltage and current values (VI). To allow the system to charge the battery with maximum power output. It is the brain of photovoltaic system used in solar photovoltaic systems to coordinate the work of solar panels, batteries and loads.



(a) Solar collector equipment structure (b) Physical display

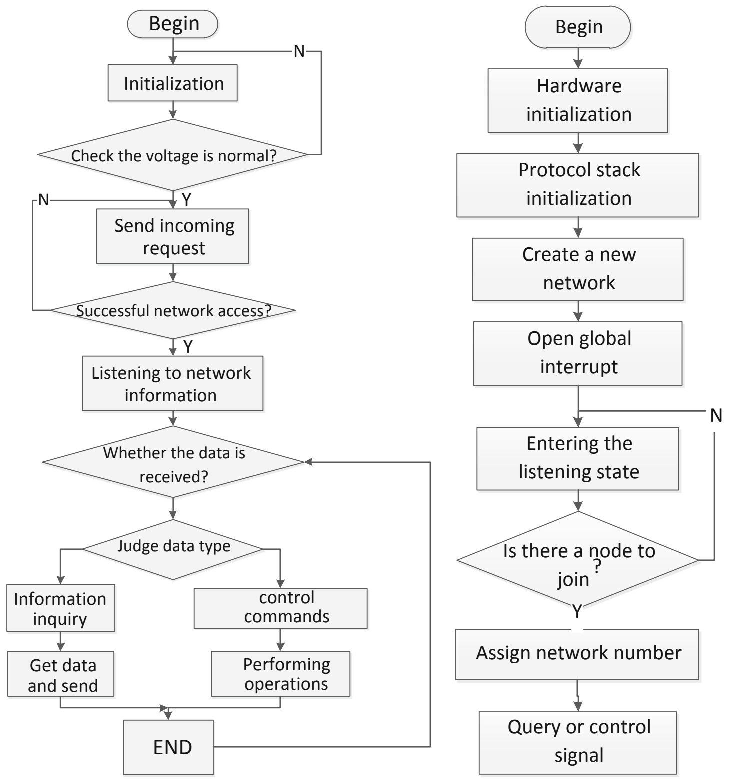
Fig. 3. Energy harvesting equipment

Microprocessor (MCU) Module. This paper uses a microprocessor module that is an enhanced 8051 integrated on the CC2530 chip, with lower power consumption, 8 kB of RAM, and optional 32/64/128/256 KB flash. Since the ZigBee stack Z-Stack is required to run, 256 KB of flash memory is selected.

Sensor Module. The sensor module is mainly responsible for collecting information such as ambient temperature, humidity and illuminance, directly using digital sensors or converting analog quantities into digital quantities by A/D conversion.

2.2 System Software Design

The software used in this paper uses the Z-Stack protocol stack provided by TI. The Z-Stack protocol stack is a polling task scheduling management system, using OSAL (Operating System Abstraction Layer) [9]. ZigBee protocol stack is a communication protocol formed by ZigBee Alliance, which standardizes the network layer and application layer on the physical layer and media access control layer defined by IEEE802.15.4. In order to make each layer of the protocol stack work independently, a hierarchical structure is adopted, the protocol stack is modified appropriately, and the application layer is programmed to meet the different needs of users. In this paper, the coordinator and terminal nodes respectively design software programs according to the Z-Stack protocol stack (see Fig. 4), which realizes the networking requirements of the system.

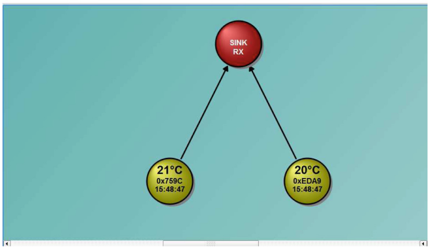


(a) Terminal node software flow chart. (b) Coordinator node software flow chart.

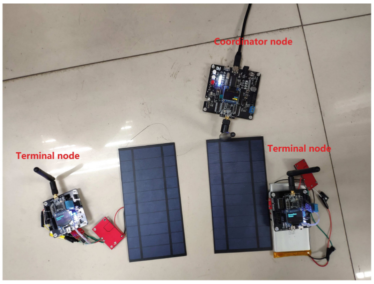
Fig. 4. Software flow chart.

3 Network Experiment and System Test

This paper uses a PC, a coordinator and two terminals to form a star network for temperature acquisition networking experiments. The coordinator receives the data of each node, and the serial port is connected with the host computer, and the accepted data is displayed through the upper computer, and the power is supplied by the upper computer USB port. The terminal equipment is distributed in the area that needs to be collected and monitored. The energy collection type equipment designed in this paper is used for power supply, which is responsible for collecting data and transmitting it through wireless radio frequency signals. The terminal sends a data to the coordinator every 20S, and the experimental data is as shown in the Fig. 5.



(a) Terminal node software flow chart.



(b) Coordinator node software flow chart.

Fig. 5. Software flow chart.

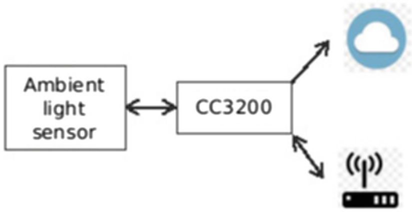
4 Solar Illuminance Collection Experiment

The collection efficiency of solar energy is affected by many factors, such as geographical location, different seasons, different time of day, the placement of solar panels, etc. According to the formula for calculating the solar altitude angle [10]:

$$sinh = sin\phi sin\delta + cos\phi cos\delta cos\omega. \tag{1}$$

Where h is the solar elevation angle, ϕ is the time angle under the system of the local star, δ is the current solar declination, and ω is the local latitude. According to the formula, regions at different latitudes will have different solar elevations in different seasons. The higher the angle of the sun is, the more solar energy is collected. Therefore, in the same latitude area of the Northern Hemisphere, the solar energy height angle is large in summer, and the solar radiation collected is the largest, while in winter, the opposite is true. During different periods of the day, the amount of radiation collected during the day is large, and at night the solar radiation is basically 0. In addition, weather is also one of the factors affecting solar energy collection. Cloud thickness, haze and strong wind will affect the collection efficiency of sensor-less nodes. Therefore, the energy supply of solar energy harvesting wireless sensor networks are very unstable. We need to study the law of solar energy collection under different conditions. We use the CC3200 and B-LUX-V30B environmental light sensors as shown in the Fig. 5 to collect the illumination information under direct sunlight, and upload the AP to the cloud through the WiFi module on CC3200, and draws a line graph. The experimental site was selected as Hohhot City, with a latitude of 40.48° north latitude, 111.40° east longitude and an altitude of 1023 m. The climate type is mid-temperate and semi-arid with a collection interval of 50 s.

We measured solar illuminance for different weather in August and December, respectively. In Fig. 6, we measure solar illuminance data for two types of weather on a sunny day and a cloudy day in August, and use the method of changing the position of the sensor to simulate the data after the illuminance



(a) Illumination data collection experiment design structure

(b) Physical display

Fig. 6. CC3200 collects illuminance data

sensor is blown by the wind. From the figure, we can see that on a sunny day, the illuminance value starts to rise from the morning, and reaches about 10000 Lux around noon. As the sunlight shifts, the illuminance value drops again, and after sunset, the illuminance value drops to zero. On cloudy days, the illuminance data is relatively stable. It floats between 20000 Lux and 40,000 Lux after 8:00 in the morning. The highest value of the data appears at 12 noon, and the illuminance value drops to 0 after sunset. On a sunny day, we changed the angle of the sensor so that the sensor angle was facing east. It was found that the illuminance reached a maximum of 90000 Lux at the beginning of 9 o'clock. The illuminance was slightly higher than the normal sunny day, and it began to drop after 11 o'clock. At 12 o'clock, the illuminance is similar to that in the case of cloudy days, and then the illuminance data is similar to that collected on cloudy days. In general, in the sunny summer of Hohhot, the average maximum illuminance per hour can reach 10WLux, while on cloudy days, from 7:00 am to 4:00 pm, the illuminance fluctuates between 2 W and 4WLux, the specific illuminance value not only related to time, but also related to the thickness of the clouds. When the clouds are thick, the illuminance is low, and when the clouds are thin, the illuminance is high. The illuminance data is similar to that on a cloudy day when the sensor is not obscured and the illuminance is greatest when it is perpendicular to the sun. When the sensor is in shadow, the illuminance data is similar to that on a cloudy day.

In December, due to the continuous sunny days, we collected data for three consecutive days of sunny days, as shown in Fig. 7. It can be seen that in winter, the solar irradiance data starts from 8:00 in the morning and reaches a maximum of 60,000 Lux at noon. Lower, gradually drop to 0 after 5 pm. In the clear summer, the light level reached 60,000 Lux at 9:00 am and 60,000 Lux above 3 pm. Also in the clear winter, it did not reach 60,000 Lux when the light was the highest at 1 pm, and the winter illuminance data were significantly lower than the summer. On the whole, on the one hand, the solar irradiance intensity in December is lower than that in August. On the other hand, solar energy can be collected in December shorter than August.

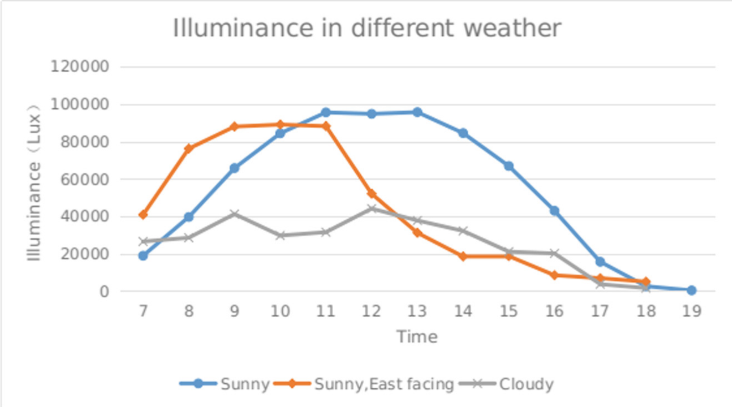


Fig. 7. Illuminance data for different weather in August.

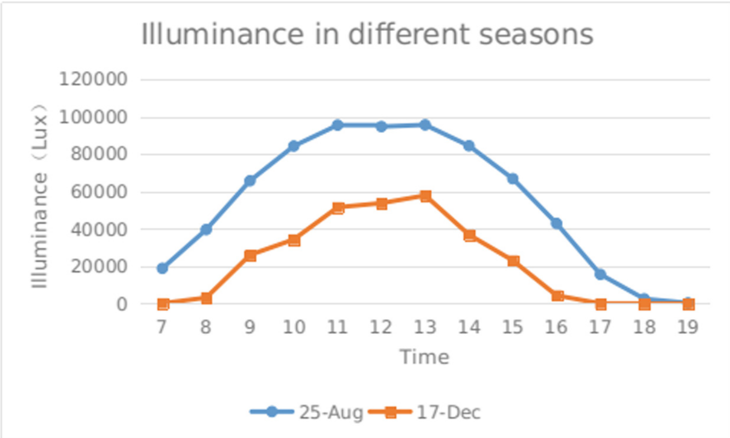


Fig. 8. Illumination data for sunny days under different months.

In summary, solar energy collection has great instability, which is very different in different weather and seasons. In the subsequent research process, we need to adopt different energy management and transmission schemes in different seasons and weather to ensure the reliability of the entire wireless network (Fig. 8).

5 Conclusion

This paper introduces the design and implementation of a solar collector type wireless sensor network based on ZigBee. The designed node has low cost, low power consumption, and can collect energy from the environment. The use time is long, and the node can be charged after the sleep, complete the recycling of energy, avoid using the disposable dry battery, and reduce the pollution to the environment. Reduce the design and development time of the EH-WSH platform with versatile development tools and modules. In addition, this paper designs an illuminance acquisition experiment, analyzes the illuminance data of different weather, different time and different angles, and obtains the illuminance information under different conditions, which provides a reliable design for the future solar energy collection wireless sensor network. Actual data support.

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