

Research on Wireless Sensor Network Technology

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Abstract: A wireless sensor network is a network system that connects numerous sensor nodes scattered within a certain area through wireless connection technology. As a cutting edge field of interdisciplinary integration, wireless sensor networks inherit sensor technology, communication technology, etc., and possess huge development potential. However, due to its large and complex technical system and unclear application scenario boundaries, further research and implementation of this technology are restricted. This paper mainly expounds on the principles, components, key technologies, and applications of wireless sensor networks, analyzes their current advantages and disadvantages, and looks ahead to future development trends.

Keywords: Wireless Sensor Networks, Sensors, Artificial Intelligence

1. Introduction

The popularization of microelectromechanical system technology has given rise to many new types of intelligent sensors. More miniaturized, intelligent, and integrated sensors serve as the foundation for constructing a more complete and efficient wireless sensor network [1]. Wireless sensor networks are an excellent means of achieving information collection and real

time controlling, with promising application prospects in fields such as building smart cities, military reconnaissance and detection, and intelligent industrial production. However, similar to other interdisciplinary fields, this technology faces dilemmas: the theoretical methods and technologies of multiple disciplines are deeply intertwined and mutually reinforcing, increasing the complexity of overall research. The application fields of interdisciplinary disciplines are extremely extensive, and the broad application scenarios also bring a series of problems in different situations. Therefore, this paper aims to provide a brief overview of wireless sensor networks by discussing their composition, summarizing key technologies such as communication protocols and data fusion technology, and summarizing numerous application scenarios of wireless sensor networks and analyzing their advantages and disadvantages under specific application conditions.

2. Principles

A wireless sensor network consists of many sensor nodes. Driven by power sources, they sense the surrounding environment, collect various types of information, and transmit it to other nodes or a central processing unit. Just as a spider web is spread in a certain area and transmits information about the biological activities at various points on the web to the spider through vibrations, a wireless sensor network plays a similar role to the spider web.

2.1. Composition

A wireless sensor network is composed of a sensor module, a processor module, a wireless communication module, a power supply module, and a storage module. The sensor module is responsible for collecting information such as temperature, humidity, air pressure, and altitude. The processor module includes microcontrollers (MCUs), system on chips, and computers. They are responsible for controlling sensor data collection, preprocessing data (removing noise and interference), and feature extraction. The wireless communication module, in accordance with the regulations of the communication protocol, transmits electromagnetic waves through an antenna at specific times to achieve data reception and transmission. The power supply module provides energy for each sensor node in the wireless sensor network. Building a large scale network in a vast area will greatly reduce the stability and increase the cost of wired power supply. Therefore, lithium - ion batteries are usually used for power supply. According to different connection methods of sensors, wireless sensor networks can be divided into several network structures, such as star shaped, tree shaped, mesh shaped, and hybrid types. The construction of a wireless sensor network selects different network structures according to actual requirements.

2.2. Key Technologies

2.2.1. Communication Protocols

A wireless sensor network relying solely on algorithms has issues such as repeated signal transmission and resource waste. When the number of nodes in the network increases, communication protocols become necessary in wireless networks. Communication protocols ensure efficient and accurate data transmission between sensor nodes, including physical layer, data link layer, network layer, transport layer, and application layer protocols. The physical layer protocol stipulates various parameters and characteristics of signal transmission on the physical medium, including the electromagnetic wave frequency band, the modulation and demodulation method of digital signals, the data transmission rate, the types of signal encoding, and the format of physical layer data frames. The data link layer protocol is mainly responsible for encapsulating data into frames based on the raw bit stream transmission service provided by the physical layer to achieve reliable data transmission between adjacent nodes. The network layer protocol is responsible for data path selection and transmission between different nodes, ensuring that data can accurately reach the destination node from the source node through multiple intermediate nodes. The transport layer protocol provides a communication service between processes for application programs. It identifies different application program processes through port numbers, enabling multiple application programs to run simultaneously on the same host and accurately send data to the target application program. The application layer protocol can customize data transmission rules and formats according to the characteristics of specific applications. This protocol also provides a unified interface for upper layer application programs, facilitating subsequent developers to conduct application development and expansion. Communication protocols enable efficient and accurate data transmission between nodes and are key technologies for building sensor networks.

2.2.2. Data Fusion Technology

In a wireless sensor network, the signals received by a single sensor node are often affected by interference, noise, and measurement errors, resulting in a large deviation between the sensor measurement results and the actual values. Data fusion technology uses specific techniques and algorithms to comprehensively process data from multiple sensors and relevant database information, achieving the transformation from observed signals to abstract concepts, in order to determine the

position, characteristics, identity, etc., of entities, and interpret them in combination with the environment and relationships with other entities. Data fusion can be carried out at different levels, such as the raw data level, feature vector level, or decision - making level. If the sensor data is similar, the raw data can be directly fused; if the data is highly diverse, fusion is required at the feature vector or decision making level. The JDL data fusion process is a functional oriented data fusion conceptual model. It divides the data fusion process into multiple levels, covering various functions and technologies, enabling in depth processing and analysis of data step by step. In the JDL data fusion process model, different levels use different algorithms. Level 1 algorithms are used to achieve an accurate representation and understanding of a single object, including data alignment algorithms, data/object association algorithms, position/kinematic and attribute estimation algorithms, and object identity estimation algorithms. Level 2 algorithms are used to analyze the relationships between objects and events in the current environment, interpret the meaning of data, and provide support for decision making, including knowledge representation algorithms, logical reasoning algorithms, and intelligent learning algorithms. Level 3 algorithms are used for threat assessment and future situation prediction, mainly using algorithms such as neural networks, blackboard systems, and fast time engagement models. Level 4 algorithms are used to monitor and optimize the data fusion process. Performance evaluation algorithms use evaluation metrics, performance metrics, and utility theory to evaluate the performance of the data fusion system from different perspectives. Process control algorithms use methods such as multi objective optimization, linear programming, and goal programming to adjust the data fusion process in real time according to the performance evaluation results, achieving rational allocation and utilization of resources.

3. Applications

3.1. Agricultural Management

Wireless sensor networks can extract crop growth information, conduct real time monitoring of crop growth, and play an important role in ensuring crop safety, reducing resource waste, and improving crop quality and yield.

Sanchez et al. proposed an integrated wireless sensor network that uses infrared motion sensors to detect intruders and camera sensors for identification, thereby protecting crops from damage. However, it has issues such as high energy consumption and end to end delay [2]. Zhang et al. utilized WSNs, embedded, and image processing technologies to non invasively monitor plant vitality. If abnormal plant behavior is detected, the system will send a warning message to the end user and use wireless sensor nodes to reduce planting resource waste [3]. Zhu et al. developed a monitoring system with good environmental adaptability. In scenarios such as greenhouses, open field farmland, and orchards, it can achieve reliable communication between sensor nodes, reduce the data packet loss rate, and effectively monitor the crop growth environment [4]. Srbinovska et al. designed a vegetable greenhouse monitoring system that analyzes environmental parameters such as temperature, humidity, and light to create optimal conditions for crop growth and improve crop yield and quality [5].

3.2. Healthcare

Wireless sensor networks can collect information on people's physiological, psychological, cognitive, and behavioral processes by embedding sensors in people's living spaces or having them worn on the body. This enables real time monitoring of personal physical health. With the increase in age, changes in modern social living habits, and the intensification of social aging, people face multiple health challenges. Diseases such as diabetes and asthma are difficult to monitor and treat. By wearing wireless sensors, personal health related information can be collected in real time and comprehensively, and comprehensively analyzed in combination with social and environmental

backgrounds [6]. Based on this information, these intelligent aids can provide long term, real time, and scientific feedback to users and their caregivers. These devices can also adjust their physical characteristics according to the environment and specified training or rehabilitation programs [7]. However, as sensors are more deeply applied in people's daily lives, the risk of user privacy leakage also increases.

3.3. Industrial Process Monitoring and Control

Wireless sensor network technology shows great potential in industrial production applications. In process monitoring and control, process data such as pressure, humidity, temperature, liquid level, and viscosity can be collected through various sensor nodes and transmitted via radio waves to the control system for operation and management. Process monitoring and control is a combination of architectures, mechanisms, and algorithms used in industrial plants to monitor and control specific process activities to achieve goals [8]. Compared with traditional wired systems, wireless sensor networks have significant advantages: there is no need to consider the limitations of movement and space caused by wiring, and the system has high expandability and flexibility; maintenance is simple, and device migration and addition are more convenient; the cost is lower, eliminating wiring and installation costs, and some nodes can also save energy; the performance is better, with faster data transmission speed, the ability to conduct multiple wireless communications simultaneously, and allowing more sensors to be connected for a wider range of monitoring [9]. At the same time, the large scale application of wireless sensor networks also brings some challenges. Industrial plants need to consider the energy supply and distribution of each sensor node. As the number of connected sensor nodes increases, the interference and noise in information extraction also increase, and the huge amount of data will increase the burden on the processor, resulting in a reduction in information accuracy and data transmission delays. Scheduling tools and priority methods are required to meet real time requirements, and an appropriate network topology structure needs to be selected.

4. Prospects

4.1. Wireless Sensor Networks Will Become the Foundation for Building Industry 4.0

With the in depth application of advanced technologies such as the Internet of Things, big data, and cloud computing in the manufacturing industry, the Fourth Industrial Revolution, led by intelligent manufacturing, has received much attention in recent years and has become a key force in the transformation and upgrading of the global manufacturing industry. Wireless sensor networks are the foundation for achieving collaborative operation among production equipment in Industry 4.0, information transmission between factories and the market, and collection and feedback of consumer data. Sensors installed on various production equipment can collect various engineering parameters during the production process, monitor the process flow, and provide a decision making basis for automated production [10]. Sensors in product and user activity areas can collect massive data generated by users, which is used to test product performance and help manufacturers make targeted improvements. At the same time, wireless sensor networks can also achieve scientific scheduling in the logistics and transportation links, optimize resource allocation, and improve the operational efficiency of industrial systems.

The challenges of applying wireless sensor networks in Industry 4.0 mainly come from signal transmission, energy supply, positioning, and security issues [11]. Various metal devices in factories can interfere with the signal transmission between sensors. When wireless signals encounter metal products, most of the energy is scattered, and a small part is reflected, causing changes in the signal propagation direction and a weakening of the signal intensity, resulting in unstable signal transmission and signal transmission errors. If there are large scale metal structures between sensors,

they will block the signal transmission, causing network node interruptions. Smart wearable devices collect users' location, physiological characteristics, and various physical indicators, posing risks of infringing on personal privacy and leaking user sensitive information. Sensor nodes have limited computing power, memory, energy, and communication bandwidth, making it difficult to adopt complex security mechanisms to resist attacks. The open wireless channels of wireless networks, a large number of unattended sensor nodes, and dynamic network topologies make them vulnerable to illegal intrusion, resulting in service interruptions or loss of confidential information.

4.2. Wireless Sensor Networks Will Develop in - Depth Integration with Artificial Intelligence

Distributed artificial intelligence consists of multiple intelligent agents and emphasizes communication and collaboration among nodes. By distributing computing resources and target tasks to each node, it can efficiently and flexibly handle large and complex tasks. A wireless sensor network is a network system composed of multiple nodes with certain computing capabilities and can be regarded as a distributed artificial intelligence system composed of multiple intelligent agents. The application of artificial intelligence makes sensors intelligent, enabling self calibration, self verification, and compensation. Self calibration means that sensors can monitor measurement conditions to determine whether new calibration is required. Self rectification applies mathematical modeling of error propagation and error isolation or knowledge based techniques. Self compensation uses compensation methods to achieve high precision. With the development and wider application of artificial intelligence, people can use artificial intelligence to solve the constraints of wireless sensor networks, create new algorithms and applications, optimize resource management and task allocation, thereby promoting the further development of wireless sensor networks [12].

5. Conclusion

This paper discussed the composition and related technologies of wireless sensor networks and summarized their applications in scenarios such as agricultural management, healthcare, and industrial monitoring. With the update of sensor technology, wireless sensor networks will become the cornerstone of Industry 4.0 and develop rapidly with the iteration of AI.

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