

Analysis of the Application and Popularization Strategies of Physical Sensors in Smart Home Systems

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Abstract: With the rapid development of science and technology, the smart home system has gradually become an important part of modern family life, bringing users a more convenient experience. As a key part of a smart home system, Physical sensors can sense environmental information in real time and convert it into electrical signals, which are crucial for enabling the system's functions. This paper mainly discusses the use of physical sensors in smart home systems and how to encourage more people to use them. First of all, this paper briefly introduces physical sensors, including what they are, their types, how they work, their development process and current status, and how to integrate them into smart homes. Then it discusses the application scenarios in detail and gives some examples. Additionally, it points out some problems encountered, such as inaccurate sensors, poor equipment coordination, data privacy and security risks, and relatively expensive prices. Finally, it put forward several solutions, including optimizing sensor algorithms, popularizing unified standards, strengthening data encryption and security protection, and reducing hardware costs. The purpose of this research is to provide theoretical support and practical guidance for the broader application of physical sensors in smart home systems, thereby facilitating the healthy development of the smart home industry.

1. Introduction

1.1. Research Background

With the deep integration of 5G technology and artificial intelligence, smart home system is rapidly developing in the direction of multi-scene and high interconnection, and gradually becomes the core carrier of modern life and the perception center of smart home [1]. With the characteristics of miniaturization, low power consumption and high sensitivity, physical sensors promote the realization of environmental monitoring and security protection. The temperature sensor can adjust the indoor temperature in real time to improve the living comfort, while the image sensor combined with remote monitoring technology effectively strengthens the family security system. The Chinese smart sensor market has been growing at an average annual rate of 16%, reaching a market size of 133.62 billion yuan in 2023. It demonstrates great market potential. The typical information-physical integration system of smart home relies on devices such as voice assistants and smart cameras to collect data on the physical environment, and then processes it in the cloud to generate instructions. However, the chain faces risks such as data privacy leakage, insufficient sensor accuracy, poor device compatibility, and high hardware costs, which seriously hinder the increase in market penetration rate. At the policy level, the country is promoting the popularization of smart home through measures such as financial subsidies and standard system construction. However, the gap between technological research and development and user demands still needs to be bridged.

1.2. Research Significance

Upgrading smart home systems has two main benefits from physical sensor research. In academics, studying cyber-physical systems (CPS) for technology integration and safety gives examples for research [2]. When studying user behavior using sensor data, we should also consider

privacy protection and the feasibility of the technology. In fact, this algorithm enhances the accuracy of sensor data, which in turn helps address challenges in environmental monitoring. Adopting unified standards further breaks down technical barriers between devices, enabling seamless connectivity across different systems. Meanwhile, mass production and cost control of local sensors, combined with government support, will expand access to sensor technology for more users. In practical applications, these advancements empower green, intelligent smart homes to achieve energy efficiency and improved security. Embedded sensor devices, designed to be hidden, maintain high performance while preserving the aesthetic appeal of living spaces. Overall, this research provides a scientific basis for technological innovation, standard formulation, and government decision-making.

2. Overview of Physical Sensors

2.1. Definition and Classification of Physical Sensors

A physical sensor is a device that can measure specific actions. They convert these measurements into output signals that we can use in accordance with the rules. The main function of a physical sensor is to detect changes in a physical quantity. These physical quantities include force, heat, light, electricity, and sound. Based on their working principles and measurement content, physical sensors can be divided into many types.

Mechanical sensors are widely used to measure mechanical quantities, including force, pressure, and displacement. For example, the pressure sensor in an electronic scale uses thermal sensors to measure thermal parameters such as temperature and heat. Optical sensors detect information such as light intensity, color, and position, while electrical sensors measure voltage and current. Electrical sensors can measure electrical quantities such as resistance. Acoustic sensors can detect parameters such as sound intensity and frequency, just like a microphone in an intelligent voice device. Various physical sensors play their respective roles in the smart home system, enabling our home to achieve intelligent control.

2.2. Working Principle of Physical Sensors

Physical sensors work according to different physical phenomena and natural laws. A common example is the piezoresistive pressure sensor. This device makes use of the piezoresistive properties of semiconductor materials. When external pressure acts on the sensing part of the sensor, its resistance value will change. By measuring the change of resistance, we can know the pressure indirectly.

Thermocouple temperature sensor works according to thermoelectric effect, which is a closed loop composed of two different metals. When there is a temperature difference between the two ends of the loop, a thermoelectric potential will be generated in the loop. By measuring this voltage value, the temperature difference can be calculated. The photoelectric sensor works according to the photoelectric effect: when the light shines on the photosensitive element, its electrical characteristics will change, thus converting the optical signal into an electrical signal. Physical sensors can accurately capture physical data and convert these data into electrical signals that can be processed, providing necessary basic data support for our smart home system.

2.3. Development History and Current Status of Physical Sensors

The development of physical sensors has gone through several stages. At first, the sensor was simple and had limited functions. Their accuracy and stability are not too high. With the ongoing advances in materials science, microelectronics, and manufacturing technology, sensors have become smaller, more integrated, and more intelligent.

Over the past few decades, the performance of physical sensors has greatly improved. The sensor's accuracy is continually improving, and it has captured subtle changes in physical quantities [3]. Response speed has also increased, and environmental information can be fed back immediately. Moreover, energy consumption is reduced, helping prolong the sensor's service life. Physical

sensors have been widely used in all walks of life. It plays a key role in a smart home system. There are various types and brands of physical sensor products in the market. They face problems such as inconsistent product quality and a lack of unified standards, which urgently need to be standardized and optimized.

2.4. Integration Methods of Physical Sensors in Smart Homes

In smart homes, there are three main ways to connect physical sensors. The first is wired connection. It connects the sensor to the control center of smart home system by cable. Wired signals are stable and reliable, and are not easily disturbed. The problem is that the wiring process is very complicated and the installation cost is relatively high. This method is suitable for new houses or places that need ultra-stable systems.

The second method is wireless connection. By using wireless communication technologies such as Wi-Fi, Bluetooth and ZigBee, the sensor can be connected with the control center [4]. The advantages of wireless connection include simple installation and strong adaptability. It does not need complicated wiring, and is especially suitable for those places where installation is convenient and important. The problem is that its signal is easily disturbed and its transmission distance is limited.

The third method is hybrid integration. It combines the advantages of wired and wireless methods. Those sensors that need reliable data transmission are connected by wires, while those sensors that are flexible in location or have a small amount of data are connected wirelessly. This integration method can be flexibly adjusted according to the requirements, making the whole smart home system run more efficiently.

3. Application Scenarios of Physical Sensors in Smart Homes

3.1. Environmental Monitoring Applications

Physical sensors play a core role in the environmental monitoring of smart homes. The temperature sensor can monitor the indoor temperature in real time, and cooperate with the intelligent air conditioner to automatically adjust the room temperature to a comfortable range, which not only improves the living comfort, but also realizes energy saving. Indoor humidity monitoring is equally important. The humidity sensor will continuously track the environmental changes: when the humidity is too high, the dehumidifier will be automatically started; When the humidity is too low, turn on the humidifier to maintain the stability of indoor humidity.

The light sensor can automatically adjust curtains and lights. These sensors can detect the brightness of indoor and outdoor light. During the day, when the outdoor light is bright enough, the curtains will open automatically, so we don't have to pull them ourselves. At night or when the light is dim, it will automatically turn on and adjust to the appropriate brightness. Air quality sensors monitor harmful gases and fine particles in the air. If air quality worsens, the air purifier will automatically improve indoor air quality.

3.2. Security Applications

Physical sensors are particularly important in a smart home security system. When the indoor smoke concentration rises abnormally, such as in the event of a fire, the smoke sensor will immediately detect the change. Once a high smoke concentration is detected, the alarm system will be triggered. The system will also send an alert to the user's mobile phone. This can help users to take action quickly and reduce the damage caused by fire.

Door and window magnetic sensors are installed on doors and windows. If someone opens a door or window illegally, the sensor will detect it and trigger an alarm. This can remind users and help prevent burglary. Additionally, infrared sensors can detect people's movements. If an intruder enters the surveillance area, the camera will automatically start recording. These data will be sent to users, thus improving home safety. Water immersion sensors are placed in kitchens, bathrooms and other places where water damage is easy to occur. Once water is detected, the sensor will give an

alarm immediately to avoid property damage.

3.3. Health and Convenience Applications

Physical sensors in smart homes can help us to be healthier and make life more convenient. The pressure sensor in the mattress can record our sleeping habits, how our body moves, how fast our heart beats, and the rhythm of breathing. Smart algorithms will analyze these data and then make a sleep quality report. In this way, we can know more about our sleep and find ways to live better every day.

The pressure sensor can accurately measure people's weight in the intelligent weighing scale, and it can record the curve of weight change by connecting with the mobile APP, which provides data support for our health management. In the smart home system, voice sensors and smart speakers work together. As long as we talk, we can control the switch of household appliances, adjust the volume, check information and so on, without doing it ourselves at all, which greatly improves the convenience of life. Gesture sensors can recognize the movements of our hands, so that we can control the equipment quickly.

3.4. Application Cases

Take a smart home pilot project as an example, this project vividly shows the advantages of physical sensors in practical application. In the aspect of environmental monitoring, intelligent adjustment of indoor environment is realized by arranging temperature, humidity, illumination and air quality sensing equipment. When the temperature is too high in summer, the air conditioner will automatically start and adjust the temperature to a comfortable range; In winter, the system will concentrate on maintaining indoor warmth. The function of the humidity sensor is to ensure that the indoor humidity is always kept in a comfortable range of 40% to 60%.

In the field of security, smoke detectors and door and window magnetic controllers play a key role. When there was a fire in the kitchen, the smoke detector immediately started the alarm system and sent a notice to the residents and the property, which successfully stopped the fire from spreading. The door and window magnetic controller also effectively prevented a burglary attempt. When the thief tried to open the window, the device immediately alerted and contacted the police.

In terms of health and convenience, pressure sensors can track our sleep and give personalized advice. Voice and gesture sensors allow users to easily control home devices. You can play TV programs with voice commands, and you can open or close curtains with a wave of your hand. These applications have greatly improved the quality of life and overall happiness of residents.

4. Problems in the Application of Physical Sensors in Smart Home Systems

4.1. Lack of Sensor Accuracy Affects Stability

Smart home technology is unreliable, and the key depends on whether its physical sensors are accurate. In environmental monitoring, if the temperature reading is incorrect, our indoor temperature will not be adjusted to the desired state [5]. For example, if you set the air conditioner to a comfortable 25°C but the sensor is not allowed, the actual temperature will fluctuate between 23°C and 27°C. Humidity sensors can also play this trick. When the readings of these devices are incorrect, it disrupts the home's humidity balance.

When it comes to fire safety, the reliability of smoke alarm is the most important. If these gadgets are not accurate enough, they may sound the alarm when there is no real danger, or worse, they will say nothing when there is an emergency. False alarm will bring trouble to the owner, but failure to detect the real fire will turn a small flame into a catastrophe with terrible consequences. Moreover, the performance of these sensors will deteriorate with time and different environmental conditions. After long-term use, their readings may start to make mistakes, which will weaken the consistency and credibility of smart home systems and eventually make users lose confidence.

4.2. Poor Device Compatibility Causes Connection Problems

The smart home market is developing very fast. Now there are many brands and all kinds of

smart sensors, all of which want to share a piece of cake in this growing market. Although this expansion has brought a more convenient and efficient new era, it has also made a big problem more serious: the compatibility problem. Devices produced by different companies often use different communication protocols and data formats, which makes it difficult to successfully add these sensors into the existing smart home system or make them work with other smart devices.

For example, a window door magnetic sensor using ZigBee protocol can't directly talk to the intelligent gateway using Wi-Fi protocol. In this way, the status of doors and windows cannot be correctly transmitted to the control center [6]. Even if two devices use the same protocol, different companies may design in different ways, which will make them not cooperate well. Poor compatibility will make system assembly more difficult and expensive, and will also reduce the overall efficiency of smart home. When we buy and install equipment, we must spend extra time and energy to check whether the equipment can work together, which makes it more difficult to popularize smart homes.

4.3. High Risk of Data Privacy and Security

Physical sensors are used throughout smart homes, generating substantial user data. These data include private information such as our behavior and the environment at home. Therefore, data privacy and security become particularly important [7]. When sensors are always on, they will keep collecting and sending information. If data is not encrypted during transmission, hackers can steal or change it.

If hackers steal users' health data or daily activity information, they may use it for malicious purposes. Smart cameras and microphones in smart homes are also in danger of being attacked by hackers. Bad guys can use them to peek at our family life, which seriously infringes on personal privacy. Some smart home devices lack strong security protections and can easily become targets of attack. Once a device is compromised, the entire system may fail, causing significant economic losses and security problems for users.

4.4. High Costs Limit Market Expansion

In smart home system, the application cost of physical sensors is relatively high, which has become an important reason to limit their popularity [8]. This is because the development and production of sensors need to invest a lot of money. In order to meet the standards of high precision and high performance, sensors must use powerful materials and manufacturing technology, so their prices are relatively expensive. Some sophisticated sensors used to detect air quality may cost several hundred yuan.

The total cost of a complete smart home system is very high because it includes not only the cost of a single sensor but also a lot of supporting things, such as smart gateways, control hubs, routers, and various communication devices, which are essential for the seamless connection and operation of the whole home equipment. In addition, we have to pay a lot of installation and system setup costs, which usually require the help of professionals to ensure the equipment is installed correctly, adjusted properly, and connected to achieve the best results. This will cost an extra sum of money. For many people, although they know that smart home technology can bring convenience and security benefits, these large upfront and follow-up expenses make them hesitate to buy smart home products. Moreover, smart home technology is updated rapidly, which means equipment may soon become obsolete, forcing everyone to replace or upgrade components regularly to maintain compatibility, security, and functionality. As a result, the cost of long-term ownership has further increased.

5. Strategies for Promoting the Use of Physical Sensors in Smart Home Systems

5.1. Optimizing Sensor Algorithms to Improve Data Accuracy

Optimizing the sensor algorithm can greatly improve the accuracy and reliability of data. We can use advanced filtering technology, such as Kalman filter. This method can remove the noise in the

sensor data and make the measurement result closer to the real value [9]. For example, using Kalman filter can reduce the influence of environmental factors on temperature readings. It can provide more accurate indoor temperature data, so that the smart home system can control the room temperature more accurately.

Machine learning technology can also be used to analyze and integrate the data collected by sensors. It can flexibly adjust the measurement settings of sensors and improve the accuracy of measurement under different conditions. For example, by deeply studying the data of a large number of light sensors, the system can automatically adjust the measured light intensity according to the time and weather changes, providing accurate reference for the lighting control of smart homes. Optimizing the sensor algorithm can improve the performance, make the smart home system more stable and improve user satisfaction, which can promote the technology to be used and applied more widely.

5.2. Promoting Unified Standards to Enhance Device Compatibility

Integrating the body sensor into the current smart home system will encounter a major problem, mainly because many devices do not interoperate. This restriction makes the system less smooth and less appealing to users. To address this problem effectively, we must promote the formulation and adoption of unified standards that overcome fragmentation across manufacturers. Trade associations and government agencies play a key role in this matter. Therefore, these organizations need to work closely with private companies to reach an agreement on standardization plans.

One of the primary strategies for improving compatibility is standardizing communication protocols. It is very important to establish the same standards for those common wireless connections, such as ZigBee, Wi-Fi and Bluetooth. These connections are the backbone of the whole smart home sensor network, which enables devices to transmit information. Establishing interoperability standards for these protocols can ensure that sensors and smart devices produced by different companies can communicate smoothly and be combined into a unified system.

It is also very important to unify the data format and interface rules. In this way, when different devices exchange information, they can recognize and understand the data from the other side [10]. Clear data recording and transmission rules can help intelligent gateway accurately collect and process information from different sensors. Establishing a unified standard can reduce the difficulty and cost of system assembly and make the whole smart home system perform better.

5.3. Strengthening Data Encryption and Security Protection

Physical sensors are widely used in smart home systems. However, data privacy and security issues are becoming increasingly serious. To protect our users' rights and improve smart homes, it is crucial to strengthen data encryption and security measures. When transmitting data, we should use strong encryption methods, such as the AES algorithm. In this way, the sensor's collected data can be encrypted to prevent theft or tampering [11]. For example, when the door and window sensors send the switch information to the intelligent gateway, even if hackers intercept the data, they can't solve it.

For device security, smart devices and sensors should implement strict access controls and identity checks. We can use fingerprints or face recognition to unlock and operate the smart home system, ensuring only authorized people can use and control these devices. We also need to regularly check and fix the system's security vulnerabilities. Updating security patches can make the whole system safer. Strengthening encryption and protection measures can make people feel more at ease, helping physical sensors be more widely used in smart home systems.

5.4. Reducing Hardware Costs to Promote Consumer-Level Use

In order to effectively control the hardware cost, we can do several things. In the production process, the company can improve production technology and expand production scale to reduce costs. Using more advanced chip manufacturing technology can improve chip performance and reduce manufacturing investment

In terms of supply chain management, companies should establish closer relationships with

suppliers and strengthen procurement networks to reduce material costs. It is also crucial to promote scientific and technological innovation, and to develop cheaper and more practical sensor materials. We can study new sensor materials, which can not only reduce the cost, but also maintain good performance. Once the hardware cost comes down, smart home products will become cheaper. This will encourage consumers to buy and use physical sensors and promote their popularity in the consumer market.

6. Conclusion

This article points out that physical sensors are the basic pillar and core driving force for building smart home systems. In key application scenarios such as environmental monitoring, safety protection, and health and comfort, sensors play an indispensable role and are a prerequisite for realizing home automation and intelligence. The research shows that there are four obstacles to the application of sensors: insufficient accuracy undermines system stability, poor equipment compatibility hinders interconnection, data privacy and security threats are increasingly prominent, and high cost limits market adoption.

To better solve the problem and make those physical sensors more widely used, this paper proposes a systematic, universal method. First, we can make the algorithm more powerful and make the data more accurate and reliable. Second, it is also necessary to formulate uniform rules for everyone to use, so that devices will not "quarrel" and can communicate well. Third, through technological innovation and mass production, the price of hardware will be reduced, opening the market to ordinary people. As long as we think comprehensively and consider many aspects together, we can solve the current problem and fully leverage the potential of physical sensors.

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