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Design of Intelligent Monitoring System for Hazardous Chemicals Based on Internet of Things Technology

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The purpose of this study is to realize the safe and reliable storage of hazardous chemicals. To this end, a real-time intelligent monitoring system for hazardous chemicals based on Internet of Things (IoT) technology was proposed and developed in this paper. The intelligent monitoring system is composed of the hazardous chemical information collection system, wireless transmission system and real-time monitoring system. The information collection system uses sensors to complete the collection of monitoring data, and then the collected data is reliably transmitted and exchanged through the wireless transmission system. Finally, the monitoring centre system can display the monitoring information of hazardous chemicals in real time, and conduct comprehensive analysis to classify the hazard level, make timely warning and alarm. Besides, the experiments were carried out on the function, performance, reliability, and environmental adaptability of the system. The experimental results show that the system can perform intelligent monitoring of the hazardous chemicals in real time and accurately so as to ensure the safe storage of hazardous chemicals.

1. Introduction

With the continuous deepening of the industrialization process, chemicals have been the indispensable components of industrial production and residential life. Meanwhile, the types and quantities of hazardous chemicals have been increasing more, the characteristics have been more complex, and the hazard level has been getting higher and higher, the range of hazards has become wider, and the duration of hazards has been getting longer (Sólnes, 2013). Safety and environmental issues involved in the development, testing, production, storage, transportation, sale and use of hazardous chemicals are becoming increasingly prominent (Jansen-Vullers et al., 2013). The storage of hazardous chemicals is in the middle of the life cycle for the hazardous chemicals. Due to its large storage capacity, high concentration and strong time accumulation effect etc., there have existed great potential hazards in the storage of hazardous chemicals (Bingham et al., 2010), which has received attention and research from various industries, academia, and also in different disciplines such as chemical industry, safety supervision industry, and intelligent electronics industry etc.

In recent years, scholars in the electronic computer industry have been committed to using the current advanced technologies in the electronic computers, communication networks, and intelligent monitoring etc. for monitoring and early warning of hazardous chemicals (Beddar et al., 2016; Jothimani et al., 2017; Ourahmoune et al., 2016; Srikanth et al., 2018). Some scholars use real-time and reliable data acquisition and monitoring of chemical plants based on wireless communication technology (Gokulet al., 2017); some scholars based on GPS technology study the real-time tracking and positioning of hazardous chemicals mobile hazard sources (Chi et al., 2014), to ensure the users' monitoring; other scholars established a risk equivalent evaluation model of storage capacity for hazardous chemicals production and storage sites (Lazarescu, 2013), to guide the overall planning and scientific management of inventory at hazardous chemicals production and storage sites. However, the scholars' research above only focuses on one certain aspect, e.g., on collecting and monitoring, tracking and positioning, or risk assessment models. There has been no systematic, comprehensive and hierarchical monitoring management of hazardous chemicals.

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In this paper, the advanced IoT technology was applied to comprehensively and hierarchically study the intelligent monitoring of hazardous chemicals. It not only focuses on the collection, monitoring and location tracking of various status information of hazardous chemicals, but also on the mining, analysis and integration of hazardous chemical status information, so as to provide targeted services to users, and establish risk assessment and risk warning mechanisms.
In this paper, Chapter 2 describes advanced IoT technology, esp., focusing on the three-layer structure of and its key technologies of IoT; Chapter 3 discusses the design of the intelligent monitoring system including three sub-systems: information collection system, wireless transmission system, and real-time monitoring system, which expounds the system composition and functional characteristics in detail; the final chapter makes conclusions.

2. Internet of Things

2.1 Overview of Internet of Things

The Internet of Things (IoT), as its name implies, is the Internet connected by things. In the ITU Internet Report released by the International Telecommunication Union (ITU), the IoT has been defined as a network in which one thing is connected to the Internet for information exchange and communication according to the agreed agreement by the information sensing devices such as QR code reading devices, radio frequency identification devices (RFID), infrared sensors, global positioning system (GPS), and laser scanners, etc., in order to realize the intelligent identification, location, tracking, monitoring and management (Anisi et al., 2011; Chai et al., 2018). This implies two meanings: First, the basis of the IoT is still the Internet, which is an extension and expansion based on the current Internet; Second, the user end is extended to anything, and the information communication and exchange can be made between any things. The IoT is also seen as the third wave of information technology after computers and the Internet. It will be widely used in industries such as industry, agriculture, logistics, transportation, power grid, environmental protection, security, medical care, and home furnishing etc. In the next 10 years, the market size of IoT-related industries will be as high as $15 trillion.
Like the Internet, the IoT also adopts a layered network architecture. It is divided into a perception layer, a network layer, and an application layer. The first is the perception layer, which realizes the identification and tracking of objects mainly through two-dimensional code reading equipment, RFID, GPS, sensors, infrared sensors, and laser scanners, etc. (Anisi et al., 2011); the second layer is the network layer, mainly applying various network transmission methods, e.g., private network, Internet, wired network, wireless network, etc., for safely and reliably transporting the information data acquired by the perception layer to the application layer. The third is the application layer, which mainly analyses and processes information data and provide users with rich application layer-specific services, such as monitoring, early warning and emergency processing, expert decision making and evaluation of different fields such as intelligent monitoring, intelligent environmental protection, smart home, intelligent transportation, and smart grid etc. (Jiang et al., 2009). There are also many key technologies at each layer or between the layers for the Internet of Things. The hierarchical structure of the Internet of things is shown in the figure below:

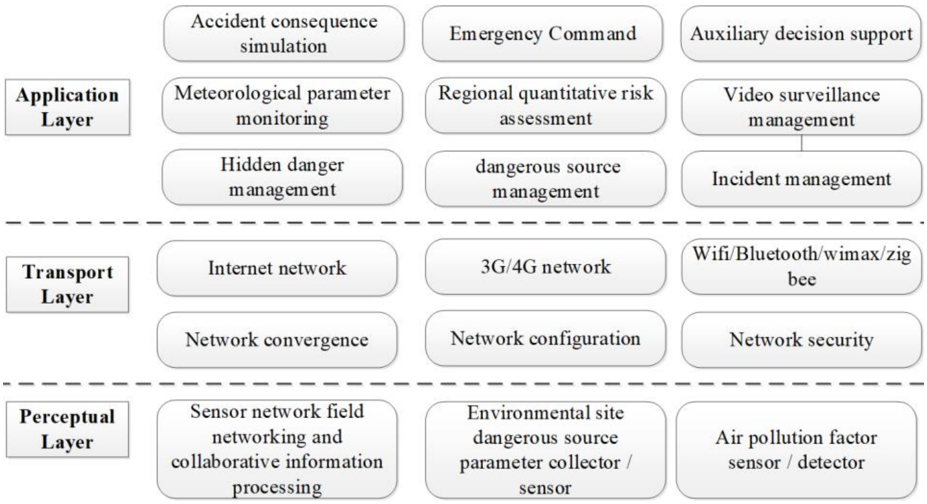

Figure 1: Description of the hierarchical structure of the intelligent monitoring of the Internet of things for hazardous chemicals

2.2 Key technologies of the Internet of Things

The key technologies of the first perception layer are mainly RFID, GPS and various sensor technologies. RFID technology is a non-contact automatic identification technology that automatically identifies targets and acquires information through radio frequency signals, and is composed of electronic tags and readers. The electronic tag consists of a chip and an antenna, and it has a unique identification code for storing the information data of the target; the reader reads the information data in the electronic tag through the radio frequency signal, and when the reader first sends an inquiry signal, the electronic tag senses this inquiry signal within the reachable range and then sends a response signal; the response signal includes the stored information data, and after the response signal reaches the reader, the reader will transmit the valid information. GPS is a satellite positioning and communication technology to quickly and accurately capture the 3D position, velocity and time information of a target. The sensor can sense a device or unit that can be measured and converted into an available output signal according to certain rule, and usually, the physical, chemical, and biological effects are used to convert non-electrical signals such as physical quantity, chemical quantity, and biomass to be easily processed and measured electrical signal. Commonly used sensors mainly include temperature sensor, humidity sensor, carbon dioxide gas concentration sensor, carbon monoxide/methane gas concentration sensor, oxygen concentration sensor, smoke sensor, etc. Sensor technology is the core technology of IoT technology, as an important means of object information digitization, processing, and intelligence.

The key technologies of the second network layer mainly are mainly the integration and expansion of the existing Internet, mobile communication network and satellite communication network. It can be sub-divided into access layer and transport layer. At present, the mainstream access technologies include: 4G/LTE-V technology that can be applied to the Internet of the vehicle with a bandwidth greater than 10 Mbps and high power consumption; eMTC/GPRS to be applied to the smart wearing with bandwidth of less than 1Mbps; NB-IoT technology applicable to remote meter reading and positioning acquisition with the bandwidth less than 100Kbps and a wide range of coverage. Network layer technologies include mobile communication networks, IP telecommunications networks, Wi-Fi and WiMAX, Bluetooth, ZigBee, and the like.

The key technology of the third application layer can integrate the massive information resources transmitted by the network layer and then provide users with rich services. It includes technologies such as massive database storage, search engine indexing, data mining and machine learning, data security and privacy protection etc.

3. Design of intelligent monitoring system

According to the design concept of the three-layer hierarchical structure in the Internet of Things, the intelligent monitoring system for safe storage of hazardous chemicals is also designed, including 3 sub-systems: information collection system, wireless transmission system, and real-time monitoring system, which corresponds to the perception layer, network layer, and application layer of the Internet of Things respectively. The network topology of the intelligent monitoring system is shown in the following:

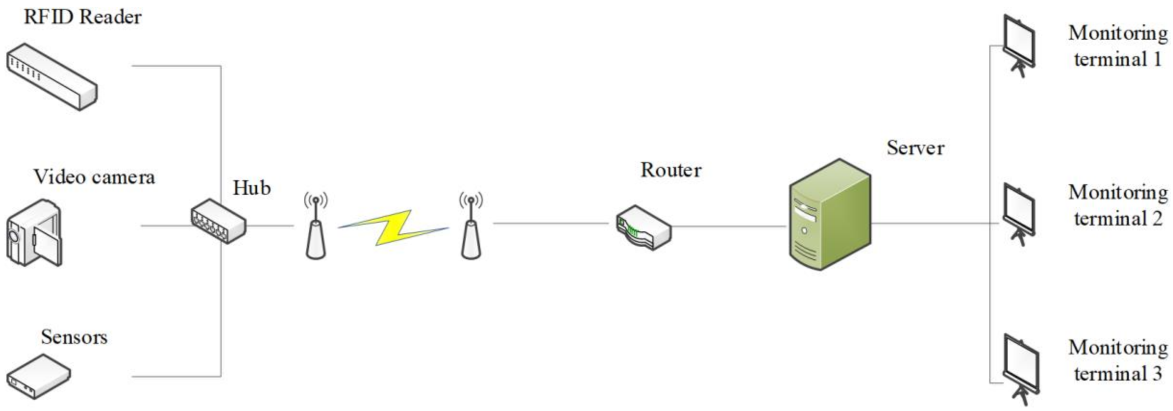

Figure2: Network topology diagram of intelligent monitoring system

3.1 Information collection system

There is very much state information of hazardous chemicals, and various states can influence each other under the accumulation effect of time, e.g., long-term drying and low humidity can cause an increase in temperature, leading to the spontaneous combustion and explosion of flammable and explosive chemistry; the excessive high chemical liquid level for a long time will cause the pressure of the container to be excessively deformed, resulting in leakage and other hidden dangers. Therefore, the information collection system of hazardous chemicals needs to collect a large variety of information data, and it needs to be always online and continuously monitored in real time, which poses a great challenge to the design of the information collection system.

In view of the characteristics of different hazardous chemicals and the necessary requirements for storage, the state data is mainly collected by video surveillance and meteorological monitoring, combustible gas monitoring, toxic gas monitoring, and fire detection etc. Among them, the combustible gas monitoring is to monitor the concentration of combustible gases or that formed by vaporization of Class A and Class B combustible liquid. Toxic gas monitors are mainly for gases or vapours that can cause acute or chronic toxicity through skin contact. Common toxic gases are hydrogen cyanide, hydrogen sulfide, benzene, ammonia, nitrogen dioxide, acrylonitrile, vinyl chloride, chlorine, and phosgene, etc. Fire detection includes various fire alarm detectors such as temperature sensor fire detectors, flame detectors, smoke detectors, carbon monoxide fire detectors, and also the fire extinguishing facilities-related fire water pressure, and fire foam inventory monitoring etc. Video surveillance mainly makes real-time monitoring of each entrance, storage, and channel, and the use of explosion-proof cameras for explosion hazardous areas. Meteorological data monitoring mainly includes monitoring of common environmental temperature, humidity, air pressure, wind direction, and wind power.

The collection of the above information is mainly done by various sensors and signal conversion equipment. A general gas sensor needs to be equipped with a conversion device to gain and filter the collected signal, because the gas concentration value initially collected by the sensor is a relatively small weak voltage signal or current signal, then converted into a digital signal by analog/digital conversion, and finally transferred to the centralized acquisition module. Meanwhile, the collection time of sensor monitoring data for hazardous chemicals needs to be very accurate. Therefore, in order to ensure the time accuracy, the system uses two sets of clocks: local clock and network clock.

3.2 Wireless transmission system

The information collection system is part of the IoT perception layer, and the data collected by the information collection system requires the network layer to instantiate the network at the network layer. In this paper, the wireless transmission node is formed by setting up a wireless transmission module and a processing module, which constitutes a wireless network of transport layer. The transmission node is the core network element of the wireless transmission network, and each of the transmission nodes gather the state information collected by the connected sensors, RFID, and GPS etc. into the data frame according to the wireless transmission protocol, and then transmits the data at the set frequency. The functional block diagram of wireless sensor network nodes is shown below:

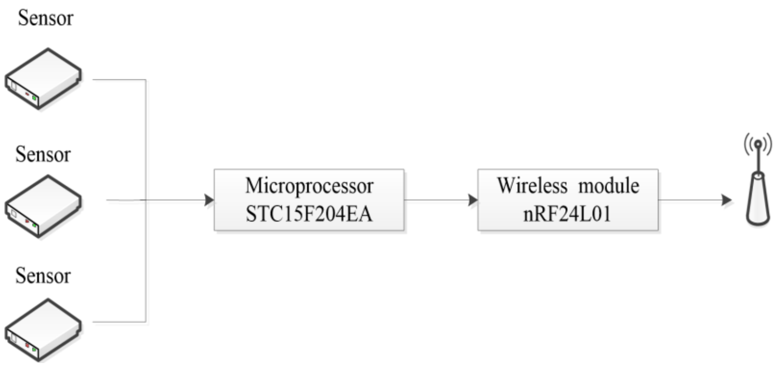

Figure 3: Functional block diagram of wireless transmission node

In the wireless transmission module, the nRF24L01 single-chip wireless transceiver chip produced by Nordic is adopted. The working frequency range is 2.4GHz-2.5GHz ISM frequency band, including frequency generator, enhanced mode controller, power amplifier, crystal oscillator, and modem, etc. (Ruizgarcia et al., 2009). The nRF24L01 wireless transmission module has extremely low power consumption, with a current consumption of 11.3mA and a receive mode of 12.3mA at a transmit power of 0dBm. It has a wide voltage operating range of 1.9V-3.6V, and the input pin can support 5V voltage input; the operating temperature range is industrial grade, at -40℃-80℃; the data transmission rate supports 1Mbps, 2Mbps; data packet can

transmit data frames of 1 to 32 bytes at a time; 126 communication channels and 6 data channels can meet the needs of multipoint communication; the processor can directly configure the nRF24L01 chip through the SPI interface or the GPIO interface to simulate the SPI communication protocol, applicable to multiple environments.
For the processor chip, STC15F204EA single-chip microcomputer is used, which can support 8-channel 10-bit A/D conversion with a rate of up to 300,000 times per second, low operating voltage and good stability. Bus operating frequency is up to 35MHz, and on-chip program memory erasing times is up to 100,000 times, with 256-byte on-chip data memory; with 26 GPIO, each IO pin drive capacity is up to 20mA; advanced instruction set structure is compatible with the 8,051 instruction set with hardware multiplication and division instructions. STC15F204EA is widely used in such fields as industrial control, consumer electronics, and Internet of things for its low cost, low power consumption, easy learning and operation, rich instruction set, and versatile functions. Transmission test results of wireless network transmission nodes are shown in the following:

Table 1: Wireless transmission node test part of the results

Testing time / min	Tx packets	Rx packets	Transmission accuracy / %	Testing result
30	50000	49987	99.97	pass
30	50000	49981	99.96	pass
30	50000	49991	99.98	pass
30	50000	49986	99.97	pass

3.3 Real-time monitoring system

The real-time monitoring system is a user-oriented system that aggregates, analyses, compares, monitors, alarms, and directs and controls the status data of each hazardous chemical collected and transmitted at various time points. Once an emergency occurs, it can start the rescue dispatch and take remedial measures in time. For accidents that have already occurred, the pre-accident status information of hazardous chemicals can be inquired, so as to analyse the cause or direct cause of the accident. This shall provide sufficient evidence for the accident investigation, and also the basis for the warning rectification of the subsequent hazardous chemical's storage.
Based on the B/S mode, the real-time monitoring system is developed, and equipped with a web server, a database server and other various types of application servers. It takes the monitoring and early warning of hazardous chemicals as the core. When the status information of hazardous chemical reaches dangerous values, the warning is turned on, and the overall status of hazardous chemicals can be evaluated according to the data mining and integrated technology, to improve the utilization efficiency of hazardous chemicals. The real-time monitoring system also divides different access control rights, and adopts hierarchical permission control for different users to ensure the security of monitoring. The software design block diagram of the real-time monitoring system is shown below:

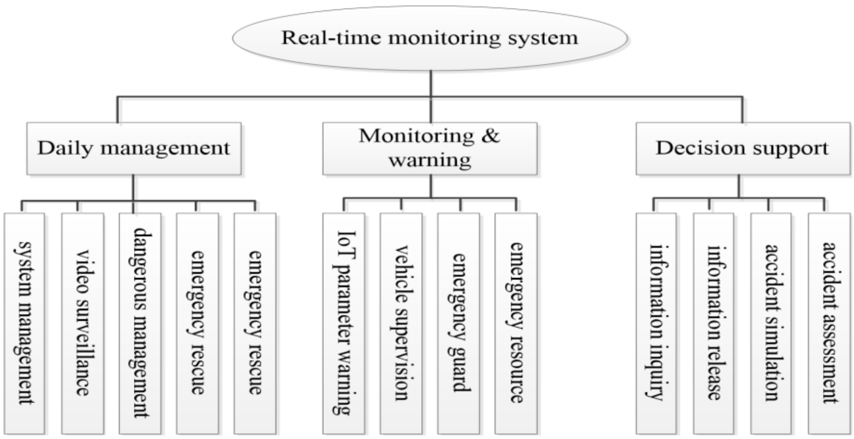

Figure 4: Functional block diagram of real-time monitoring system software design

The real-time monitoring system consists of the foreground and the background. The foreground includes the display interface, control operations, hierarchical visual query and monitoring. The background includes massive data statistics and analysis, big data mining, office automation database, logistics data database, daily monitoring information database, and network-related network optimization, network testing, network management, as well as dangerous processing-related expert decision-making assistance systems, warnings system, emergency response system, and disaster recovery system, etc. The foreground and background application functions of real-time monitoring system can be used by users as needed. Some functions can also be added according to actual needs, with the flexible configuration.

4. Conclusions

The intelligent monitoring system based on the advanced IoT technology for hazardous chemicals can accurately monitor the status information of hazardous chemicals in real time, reduce the risk factor in the storage process, and improve the management efficiency and safe production ability of chemical enterprises. With the user-oriented design concept. It promotes the informationized and professional management level of the chemical industry, and generates considerable economic and social benefits. In addition, this system can also reduce certain functional options of the application layer according to actual needs, and extend it to several fields such as environmental meteorological monitoring, community security, and urban management. However, there still exist some problems in the construction and application of the system. The primary problem is the network security problem of wireless transmission technology. The 2.4GHz-2.5GHz ISM working frequency band is a global frequency band. The wireless electromagnetic signal is easily stolen and tampered during the transmission and reception process, causing system monitoring errors and hidden dangers such as monitoring system to be taken over by hackers. This network security problem can be greatly improved by sending and receiving data encryption, digital signature authentication, security protocols, network heterogeneity, and elimination of co-channel interference.

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