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The Design of Remote Monitoring and Warning System for Dangerous Chemicals Based on CPS

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Abstract

The remote monitoring and warning system for dangerous chemicals is designed with the concept of the Cyber-Physical System (CPS) in this paper. The real-time perception, dynamic control, and information service of major hazards chemicals are realized in this CPS system. The CPS system architecture, the physical layer and the applacation layer, are designed in this paper. The terminal node is mainly composed of the field collectors which complete the data acquisition of sensors and video in the physical layers, and the use of application layer makes CPS system safer and more reliable to monitor the hazardous chemicals. The cloud application layer completes the risk identification and the prediction of the major hazard sources. The early intelligent warning of the major dangerous chemicals is realized and the security risk images are given in the cloud application layer. With the CPS technology, the remote network of hazardous chemicals has been completed, and a major hazard monitoring and accident warning online system is formed. Through the experiment of the terminal node, it can be proved that the terminal node can complete the mass data collection and classify. With this experiment it can be obtained the CPS system is safe and effective. In order to verify feasible, the multi-risk warning based on CPS is simulated, and results show that the system solves the problem of hazardous chemicals enterprises safety management.

Keywords

Cloud Services, Cyber-Physical System (CPS), Dangerous Chemicals, Data Collector, Remote Monitoring and Warning

1. Introduction

Since the 1990s, some technical research has been carried out in China about the identification and some evaluation for the control of major hazard sources, and the major hazard assessment and macro control technology research has been included in the 'Eighth-Five Plan' of the national science and technology research plan. Form the late 1960s, the risk assessment technology represented with the probabilistic risk assessment was studied and developed. Then a series of characteristic risk assessment methods based on probability theory are developed, such as the most commonly used reliability analysis, accident tree analysis, event tree analysis, risk and operability study, initial risk analysis, management failure, and risk analysis, etc. [1-6]. Over the past two decades, various industries in the world have used the term risk assessment or risk assessment. With the advanced security engineering technology, a lot of

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research has been done in China. Through the digestion and absorption of the foreign safety analysis and assessment methods, in many enterprises, the safety checklist and accident tree analysis method have been applied to the production process and the operation position. In addition, some petroleum, chemical or other flammable and explosive enterprises have also applied this method into the chemicals fire and explosion index evaluation for enterprise risk assessment [7]. At present, the supervision of the hazardous chemicals will be strengthened, and the large data urgent platform of the hazardous chemicals need be formed. According to the statistics data, at the end of 2016, the hazardous chemicals companies have more than 12 thousand where have the storage of the major hazardous chemicals. These enterprises are characterized with the wide distribution, large quantity and the potential security risk [8,9]. In recent years, our country has strengthened the safety management and the daily safety management aspects of the major hazard sources. Some areas of the enterprises have established a monitoring system for major hazardous chemicals. But at present there are still the monitoring facilities imperfect, the monitoring and early risk warning level low, and the government safety supervision and management difficult in some enterprises. And especially during accidents the supervision organizations do not timely access the relevant information of major hazardous chemicals [10,11]. So the enterprises need to establish a complete remote monitoring and warning system for the dangerous chemicals [12-14].

The Cyber-Physical System (CPS) is a system with sensing, communication, computation and control function [10]. It is an intelligent control system that includes the computer network technology, the embedded technology and the cloud computing technology. And it is also the calculation system closely combined with the physical world [15-17]. The CPS remote monitoring and warning system for the dangerous chemicals is a remote computer monitoring platform. With the network the CPS system realizes the remote monitoring and the prediction control of the distributed object, and completes the remote management and early warning of the hazardous chemicals [18]. The system can save a lot of manpower and material resources. When the system is deployed in a more remote and the dangerous terrain where it is difficult for people to reach, it can highlight its more advantages [19].

In this paper, the architecture design of the CPS remote monitoring and warning system for the dangerous chemicals has been completed. The architecture of the multi risk early warning and the remote monitoring system is built with the cloud service idea. The overall architecture is divided into three layers: the physical layer, the network layer, and the application layer. The design of the physical layer is completed. At the same time, the data acquisition system is given as a terminal node of the CPS physical layer. The major hazard sources remote monitoring and warning is designed in the application layer. The experiments of the terminal node and the major hazard sources warning are completed in the lab.

This paper is organized as follows: in Section 2, we propose the architecture mode of the CPS system. Section 3 discusses the physical layer design mode. Section 4 discusses the application layer design mode. In Section 5, we complete the experiments of the risk warning CPS system. Section 6 concludes this paper.

2. The Architecture Design

Architecture design is one of the important tasks in the initial stage of software development, and it directly influences the follow-up work and the result. The CPS remote monitoring and warning system for dangerous chemicals is very different from the traditional monitoring system, and there is no an example as references. Therefore, it is firstly necessary to design the architecture of the CPS remote monitoring and warning system. After the main functions of the CPS system for dangerous chemicals are analyzed, the architecture is proposed in this paper which designs the cloud service, multi hazard monitoring, and the early warning.

CPS system is a new intelligent system with the computing, the communications and the control technology. And it effectively combines computing resources with physical resources. The embedded system is used as the mass data acquisition entity, and the CPS remote monitoring system includes the collectors, the Internet network, and control technology. The principle block diagram is shown in Fig. 1. The CPS system makes the physical facilities and the network facilities closer. And it has the function of the network communication, the mass data collector and calculation. It can provide the accurate data, timely information, efficient and reliable control for human beings. Fig. 1 shows the schematic diagram of the CPS.

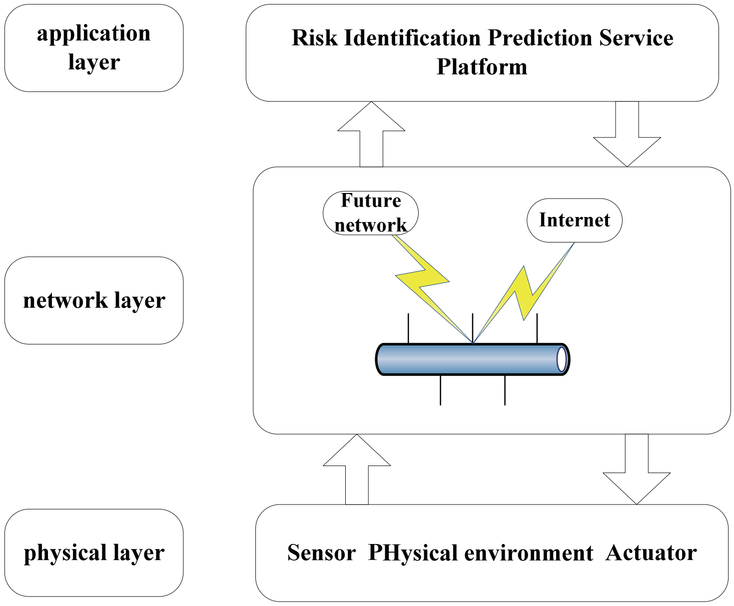

Fig. 1. CPS schematic diagram.

2.1 The System Overall Architecture

The CPS system is divided into three layers: the physical layer, the network layer, and the application layer as shown in Fig. 2. The physical layer includes the acquisition system of the dangerous chemicals, the control subsystem and the corresponding physical environment. In order to obtain accurate information of dangerous chemicals in the physical environment, the CPS deploys a lot of sensors in the physical world. According to the actual situations the sensor type is selected, such as temperature sensor, pressure sensor, flow sensor, component sensor, etc. The sensor data is transmitted to the data collecting system with the enterprise distributed control system (DCS) system with the OPC protocol (Modbus communication protocol, etc.) or 4–20 mA current signal, and it will ensure the real-time data in the system. After processing and compressing the data, the data is finally transmitted to the application layer with the network layer. The decision control unit of the application layer analyzes the physical environment information of the dangerous chemicals according to the semantic rules, and gives the risk warning grade when necessary. The application layer takes the cloud calculation as the technical support. The cloud calculation realizes the analysis and processing of the mass data information from the physical layer, and makes the last decision control.

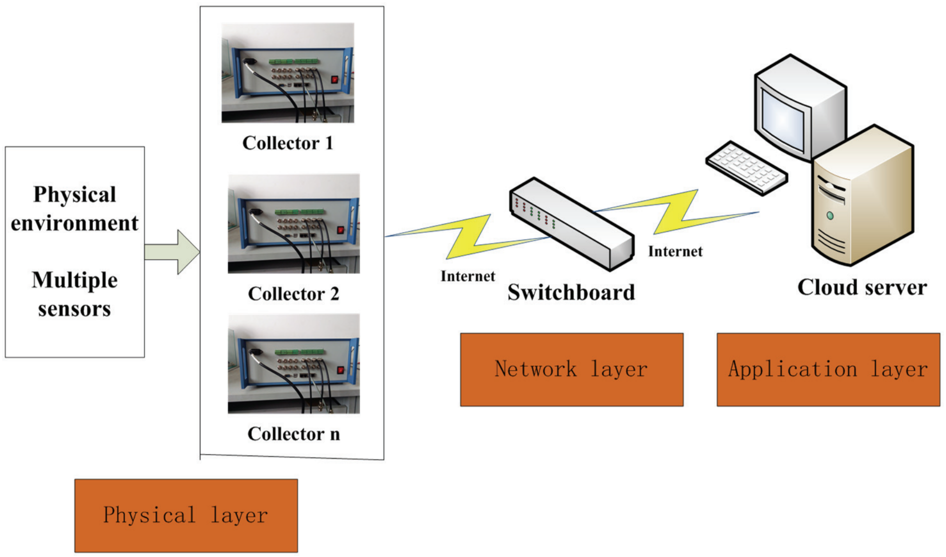

Fig. 2. The overall scheme of CPS.

2.2. The System Technology Architecture

In accordance with the overall scheme of Fig. 2, the technology architecture for the CPS remote monitoring and warning system of dangerous chemicals is proposed with the main purpose of the remote monitoring and the major hazard sources identification. It is shown in Fig. 3.

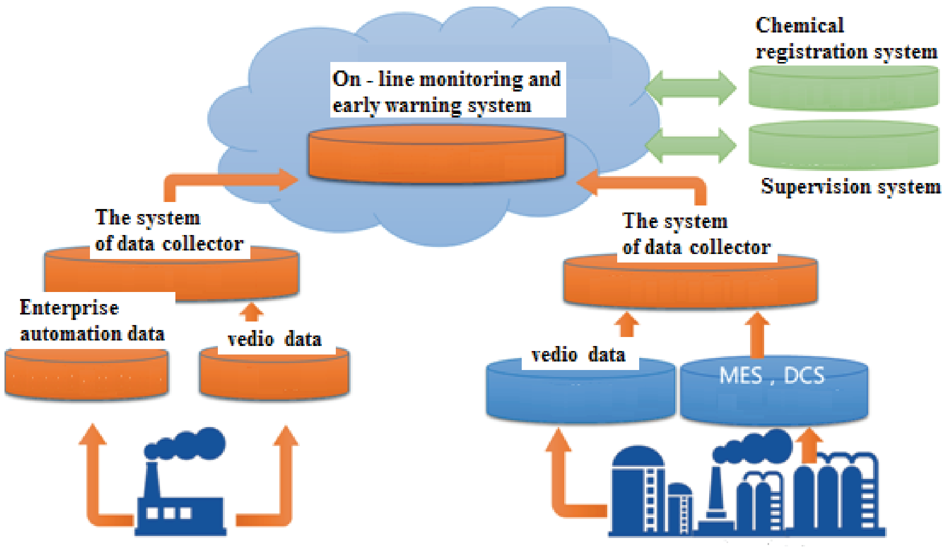

Fig. 3. System architecture diagram based on CPS.

The main duty of this design is to design the identification and warning of major dangerous chemicals. The CPS remote monitoring and warning system for the hazardous chemicals not only may realize the traditional system monitoring and alarm function, but also can solve the centralized management, monitoring and the risk prediction problems about the distributed hazardous chemicals. The specific functions are as follows:

- The massive data acquisition: The CPS system of the hazardous chemicals may implement the real-time data acquisition, the real-time data transmission and the real-time monitoring. The collection of environmental parameters of the hazardous chemicals mainly depends on the sensor network and communication network.
- The massive data storage: In the traditional monitoring system, the data is usually stored on the local database server. Thus, when the data reaches a certain amount, the processing ability of the system will be reduced, and some historical data will have to be transferred or deleted directly. The CPS remote monitoring system is not only for an object, but for thousands of objects, and in this case, the amount of data generated is mass. Therefore, the CPS system may store the data on the cloud server computer, and realize the mass data storage.
- Mass data processing: Simple data processing is not of great value to researchers in related fields, and the analysis of the mass historical data results in immeasurable value. For example, to the early warning of major hazard sources, the data at a fixed location for a period of time is not significance to us, but the distributed data of hazardous chemicals throughout the country is of great value. Through the analysis and processing these data, the distribution of major hazards and potential risks, estimates, investigation and so on are effectively reached.
- Filing and gathering: Data are filed, classified, and gathered on the cloud server computer for the dispersive hazardous chemicals. The data classification and collection of major hazards chemicals are very convenient for managers on the cloud server computer.

3. The Design of the Physical Layer

In the remote monitoring and warning system for hazardous chemicals based on CPS, the physical layer is at the bottom of the whole system, and it is responsible for the real-time data acquisition, storage and transmission. The system functions can not only be realized by sensors, but also need processor module, power supply module, communication module and so on. In this part, according to the composition structure of the physical layer terminal node, the sensor access mode, communication module, and processor module are introduced.

3.1. The Terminal Node Composition Structure

In the architecture design of the CPS remote monitoring and warning system for hazardous chemicals, the physical layer includes the monitoring objects, the sensor units, the network and the collectors. A sensor unit can complete the measurement of hazardous chemicals parameters, when with the OPC of DCS, it can be regarded as multiple sensor nodes. When using Modbus protocol, it can be regarded as a sensor node. With the AD converter, the same can be regarded as a node. Sensor nodes are called the terminal nodes.

The structure diagram of a sensor terminal node is shown in Fig. 4. It mainly includes the power supply, the sensors, the processor module, and the communication module. The arrow in Fig. 4. indicates the direction of the data flow.

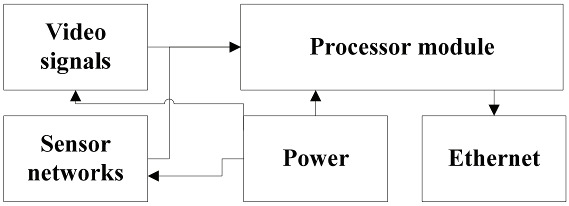

Fig. 4. Terminal block diagram.

3.2. The Analog Signal Collection and the Video Signal Acquisition

In the storage area of dangerous chemicals, the sensors have been deployed and installed. There are three ways to acquire the sensors data by the OPC of the DCS devise, the Modbus or the AD card. When the DCS device is used, all sensors are connected to the DCS device and the massive data from the sensors can be obtained only by the DCS with the collectors. When there is no DCS device, the collectors may collect the sensor massive data with the Modbus protocol or directly the AD converter card.

An important function of the CPS remote monitoring and warning system for dangerous chemicals is that it can complete video data acquisition, storage, and transmission. Through the analog video collection card, the collector completes the analog video data capture, compression, and storage, and the data is uploaded to the cloud server computer with the Internet network. At the same time, the digital video data can also be collected with the collector. The CPS remote monitoring system collects the distributed video surveillance data, and finally uploads it to the cloud server computer. And the CPS system realizes the real-time monitoring for the large range dangerous chemicals.

3.3. The Design of Data Acquisition and Processing Unit

The core part of the collector module is the microcontroller, which uses the Freescale i.MX6 processor and the Cortex-A9 core, and its maximum frequency is 1 GHz. The used Linux embedded system has the very good scalability, portability and stability, and the chip and system software upgrade is convenient. The sensors connected to the terminal node collector include the temperature sensors, the pressure sensors, the flow sensors, the liquid level sensors, etc., and the data types include temperature, pressure, flow, level, video, and other sensor data.

4. The Design of the Application Layer

In the CPS prototype architecture, the top layer is defined as the application layer. The targets of the CPS are to process the mass data, so it is more reasonable to build the system on the cloud services platform. The main tasks of the application layer include: (i) the major hazard sources identification of dangerous chemicals, (ii) the classification of the major hazard sources for hazardous chemicals, (iii) the monitoring and warning of the major hazards sources, and (iv) the risk control of the major hazards sources. The risk assessment and early warning system of major hazards sources is shown in Fig. 5. The cloud services platform is not only because of the cloud computing ability, but it can provide a wide range of estimates to the hidden risks warning of the dangerous chemicals.

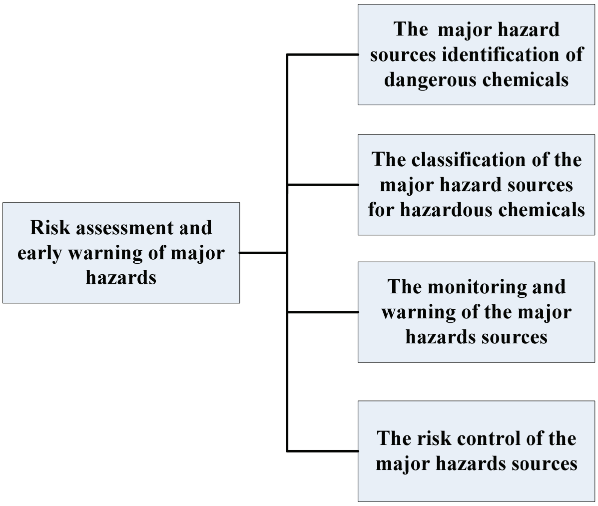

Fig. 5. The monitoring and early warning system diagram.

4.1. The Risk Identification Design of the Major Hazard Sources

The identification of the major dangerous chemicals is based on the national standard GB18218 [20], and the hazardous characteristics and quantitative data of the hazardous chemicals are used to calculate and identify the hazardous chemicals. On the basis of mass data acquisition, the risk identification is carried out. Using the hazardous chemicals information database, such as video data, name, quantity, concentration, status, distribution and other data information, the hazardous factors of the major hazard sources are identified through qualitative analysis and empirical judgment. The identification and analysis of hazardous and harmful factors for the major hazard sources include some analysis of physical and chemical characteristics for the hazardous chemicals existing. The analysis and judgment of their dangerous characteristics are completed, such as combustion, explosion and poisoning. Combined with the production process conditions, natural environment, surrounding social environment and other conditions, the contents of the comprehensive analysis include the possible types of accidents, the causes of occurrence and the law development.

4.2. The Risk Prediction Design of the Major Dangerous Chemicals

4.2.1 Classification index

The calculation method of the classification index R for the major hazard installations is shown in the expression (1):

$$R = \alpha(\beta_1 \frac{q_1}{Q_1} + \beta_2 \frac{q_2}{Q_2} + \cdots + \beta_n \frac{q_n}{Q_n}) \tag{1}$$

where $q_1, q_2, \cdots q_n$ are the actual quantities of each hazardous chemical, $Q_1, Q_2, \cdots Q_n$ are the critical values of each hazardous chemical, $\beta_1, \beta_2, \cdots \beta_n$ is the correction factors of each hazardous chemical, α is the correction factor of outside exposed persons.

4.2.2 Classification standard

According to the calculated R, the grade of major hazard sources is determined according to Table 1.

Table 1. The grade of major hazard sources

	First level	Second level	Third level	Forth level
The R value (m)	≥100	≥50 and <100	≥10 and <50	<10

4.2.3 Risk assessment

The quantitative risk assessment (QRA) principle is applied to estimate the potential risk of hazardous chemicals. QRA is also called probabilistic risk assessment. With the risk quantification and the risk accident impact assessment of hazardous chemicals caused by the surrounding environment acceptability, the relevant security measurements are suggested to take for the effective reduction of the risk. At present, many European Union countries adopt the QRA method to determine the risk increment caused by the major risk sources. The potential risk assessment of the hazardous chemicals includes the individual risk estimation and the social risk assessment. The personal risk refers to the accident area of a fixed position. The individual death probability is due to the leakage of hazardous chemicals, the potential fire and explosion of major risk sources and the toxic gases. The personal risk contours curve shows the personal risk. The social risk is the cumulative accident frequency (F) that can cause death greater than the death of N persons. The social risk curve (F-N curve) is used to show the social risk.

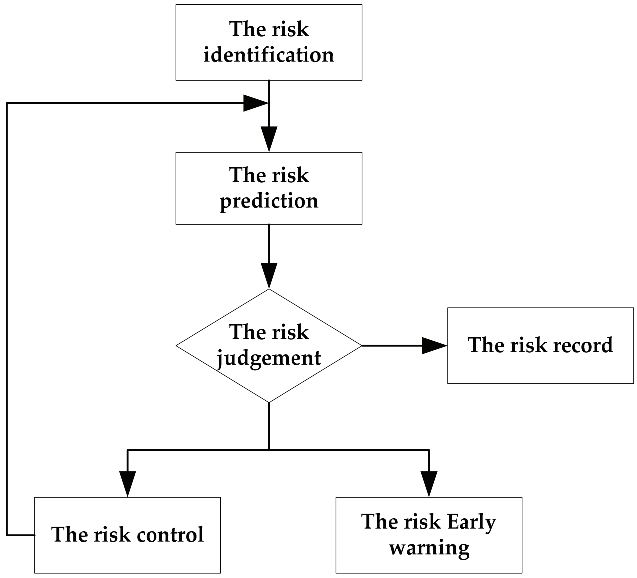

Fig. 6. The flow diagram of major hazard risk assessment.

4.2.4 Risk early warning and risk control

The evaluation and grading results are explained, the risk assessment results are obtained, and the results are compared with the safety target value, and the risk control and management according to the risk results takes the preventive measures to reduce the risk. Using the conclusion of risk assessment, risk early warning and risk control are realized for the major hazards chemicals. Risk control is an important part of the CPS monitoring and early warning system, effective control of major hazard sources can reduce the accident rate and the degree of damage to the surrounding. The risk feedback control algorithm can select fuzzy control algorithm, neural network control algorithm or adaptive control algorithm, etc. The flow diagram of major hazard risk assessment is shown in Fig. 6.

5. Discussions and Experiments

The experimental work is divided into two parts: one is the terminal node experiments and the other is the CPS system experiments. In the laboratory the communication test platform is built with the DCS, the data collector terminal node, the network communication and the server computer. The collector terminal node and the communication network are test in the first part. At the same time, the collector acquires the real-time sensors data connected the DCS system and multiple cameras data. The data collected is transmitted to the cloud server computer by the Internet network, and the identification and early warning risk of major dangerous chemicals are realized in the second part.

5.1. The Terminal Node Test in the Physical Layer

The test of the terminal node mainly includes the hardware test, the data acquisition and the sending test. Hardware testing includes the DCS, the cameras, a collector, a switch and a notebook computer. The connection diagram of the test is shown in Fig. 7.

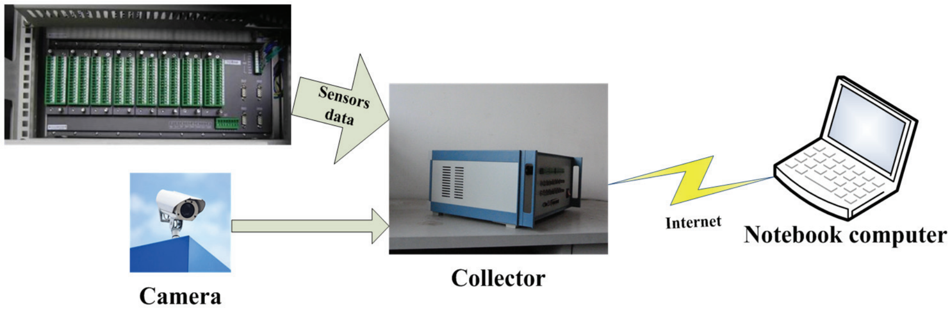

Fig. 7. Terminal node test connection diagram.

The Internet communication test software is developed to verify the correctness of data acquisition and communication. The terminal node test software is developed with C language in development environment of Visual Studio 2010. The terminal node collector compresses the DCS data and the video data into a data packet, and successfully sent the data packet to the host computer as shown in Fig. 8.

Fig. 8 shows a subsystem of the CPS remote monitoring and warning system, the video data is good and the frame rate meets the requirements. The DCS data can be collected and displayed with the voltage form in the notebook computer screen. The Modbus data can also be collected and displayed with the voltage form in this screen. Through the experiment of the terminal node, it can be proved that the data acquisition terminal can complete the mass data collection and classify. The terminal node by Internet can transmit the data to the cloud server computer.

Fig. 8. Terminal node test platform.

5.2. The Major Hazard Sources Identification and the Potential Risk Warnings in the Cloud Service Layer

In the laboratory, using alcohol storage simulates the storage of the reservoir area. With an alcohol distillation unit, a small amount of alcohol is as the dangerous source storage. The alcohol risk warning experiment is to be completed in the lab with the designed CPS system. The alcohol risk warning results will compare with water risk warning experiment. The sensors connected to the DCS system include the flow sensors, the temperature sensors, the pressure sensors, and the liquid level sensors. There are 8 cameras which are form of 2 analog cameras and 6 digital cameras. The system is shown in Fig. 9. The DCS data and camera data are collected by the collector, and then the data is transmitted to the cloud computer by the Internet. The cloud computer will complete the data calculation and risk prediction with the big data.

Fig. 9. The experiment system of the DCS.

To the experiment the expression (1) only has the q_1 and q_2, the q_1 is the alcohol and the q_2 is the water. In GB18218, the critical value of ethanol is 500 T, and the Q_1=500 T. The water is not a hazard chemical, and the Q_2=0. With the video data, there are three students which works in this storage area for 8 hours in one day, and it can obtain the $\alpha_1 = 3\times 8/24 = 1$. The surrounding temperature is 25°C and the pressure is 1 atmospheric pressure. The alcohol β_1 is 1. With the level data, the q_1 value is less than 1 T. So the R is calculated and R << 10 m. The alcohol risk level is the forth level. The results are shown in Fig. 10.

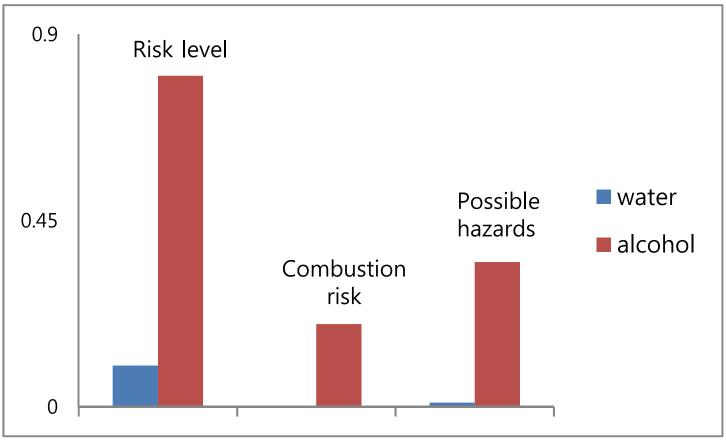

Fig. 10. The results of the cloud calculation.

Fig. 10 shows that the risk of alcohol is far higher than the risk level of water. The risk level of the alcohol is higher than water. The alcohol has a certain degree of combustion risk, and then the water has not. The possible hazards of the alcohol have the combustion risk and the blast risk. The possible hazard of the water may only have the flooding equipment and laboratory risk. In the laboratory a higher level chemical goods may not be stored for the CPS experiment test, but through the alcohol risk warning experiment, the CPS remote monitoring system can identify the hazard and give the risk level.

It can be obtained the collector lying in the physical layer can complete the mass data collecting by the terminal node experiments. Meanwhile the network layer may better complete the mass data communication. The terminal node experiments have confirmed the excellent performance of the collector, and the collector may competent the data collects and transmission jobs to this 'CPS remote monitoring and warning system for dangerous chemicals'. It can obtained the application layer can complete the alcohol identification and the potential risk warnings with the sensors data and video data collected by the physical layer. So the 'CPS remote monitoring and warning system for dangerous chemicals' already has some better effects and performances by the experiments.

6. Conclusion

A remote monitoring and warning system for dangerous chemicals is designed by using CPS technology. With the overall architecture and technical framework of the system, the overall design steps are realized. By the design of the physical layer and the application layer, the CPS monitoring and warning system for dangerous chemicals have been established. In the physical layer the collectors complete the field data acquisition, data transmission and data local storage of hazardous chemicals. The real-time data through the network layer is sent to the application layer, in the application layer the major hazard identification and risk warning work of dangerous chemicals is completed, and finally the whole results are shown in the cloud server computer. The interchange and the flexible configuration of the CPS system greatly improve the supervisor reliability, and the system failure may affect as little as possible. In the laboratory, the 'CPS remote monitoring and warning system for dangerous chemicals' has proved that it has the ability of identifying hazard sources and predicting potential risks. At the same time, the CPS safety information system has reached the unified standards and the unified deployment, to ensure the overall performance and enhance the scalability and maintainability of the supervisor platform. In the future, this CPS system will be used to some safety supervision and management system of petrochemical enterprises.

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