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Technical Framework Design of Safety Production Information Management Platform for Chemical Industrial Parks Based on Cloud Computing and the Internet of Things

Qin Lele* and Kang Lihua

Hebei University of Science & Technology, Shijiazhuang, China
Mr_qin@163.com

Abstract

As chemical industry is a fundamental strategic sector as well as one pillar industry of our national economy, chemical industrial parks of various scales has been built in many places to facilitate the production of chemical enterprises. However, considering the inflammability, explosibility and toxicity of the raw materials and products of such enterprises, accidents are very likely during the production, transportation and storage, forming major threats to human lives, the environment and property. By making use of key technologies of the Internet of Things such as sensing, accessing and networking, massive information storage, analyzing and processing capabilities of big data technology and the data computing methods of cloud computing technology, this paper designs a safety production information management platform for the daily supervision and emergency rescue of chemical industrial parks, proposes the system communication network framework based on the Internet of Things and the three-layer platform technical framework based on cloud computing, describes the technical structure and function of the sensing layer, the transmission layer, the infrastructure layer, the platform layer and the application layer of the platform, and elaborates key technologies including the design thought of uniform big data analyzing platform, regional collaborative emergency management operating mechanism, the combination of RFID technology and sensor network technology and model design of expert decision-making. The platform can realize logistics management of dangerous articles and key environment parameter monitoring of dangerous chemical enterprises, help enterprises in the safety compliance management to the whole production process, allow red light early warning and start responding early warning mechanism and rescue plan automatically, so as to effectively avoid the occurrence of potential accidents and safeguard and improve the economic and social benefits of enterprises.

Keywords*: Chemical industrial parks, Safety production, Information system, Cloud computing, The Internet of Things*

Chemical industrial parks come into being as modern chemical industry tries to adapt to the transformation of resources or raw materials and to the growing trends such as large-scale, intensification, optimization, internationalization of operation and maximization of benefits. Many developed foreign countries started to build their chemical industrial belt early at the end of WWII, accelerating their postwar economic recovery and growth. Due to the relative concentration of enterprises in the parks, the complex technology, large-scale installation, rigorous operating conditions as well as the large quantity and big density of major sources of danger, there are real and potential serious or extra-serious accidents caused by dangerous chemicals during production. Therefore, emergency management in chemical industrial parks has long been an important disaster reduction and prevention issue of the society and a concern of the government, the public and the academic world. Such condition requires dangerous chemical enterprises to strengthen supervision of the operating state, constantly improve production technology and collect and analyze important environmental parameters such as temperature, pressure and concentration. Hidden dangers to safety production should be eliminated in advance and after the occurrence of accidents, rescue should be carried out orderly by making positive use of on-site supervision data, system information and pre-arranged rescue plans in order to minimize the loss. Therefore, it is essential to design a safety production information management platform for chemical industrial parks based on cloud computing and the Internet of Things, since cloud computing can be employed to realize access to and use of massive data and it has sound cooperative computing power, while the Internet of Things can be used to combine sensor, controller, machine, people and things in a new way.

1. Supervision of Dangerous Chemical Enterprises in the Parks

Currently, safety production is in a grim situation. The non-implementation of main safety production responsibilities in some enterprises, the decreasing supervision strength between management layers and the suspense of many problems underlying safety production lead to the large gross of accidents, the large number of low level accidents due to management defects and the frequent occurrence of accidents in some areas. It's clear that traditional safety production supervision technology and methods have failed to meet the new requirements posed by the rapid development of the society, and a timely, efficient and intelligent management mode is urgently required to tackle new problems arising in safety supervision. In view of the urgency and essential strategic significance of continuous and dependable supervision to each and all key elements during safety production of highly dangerous chemical enterprises, the platform integrates cutting-edge technologies such as cloud computing, the Internet of Things, massive data and mobile communication and various terminals with environmental sensing ability into all links in safety supervision and accident rescue, providing technical support for key data analysis, decision-making, early warning and emergency rescue. The priority among priorities of safety supervision is to update safety supervision method and emergency response mode so as to improve effective normal supervision and emergency rescue and to promote automation control and safety supervision.

2. Current Research

In 2014, Mary and other scientists wrote a paper named *Massive data storing technique of coal mine emergency management in cloud computing* where they designed a massive data storing method of coal mine emergency management based on NoSQL in cloud computing environment and conducted Hadoop benchmark test to the coal mine emergency cloud platform, and the result showed that the coal mine emergency cloud platform built on Hadoop performed well in massive data storing and processing. In the same year, Zhang Yuxue published an article *Supporting Platform Design of Food Safety Data Mining Based on the Internet of Things*. He proposed to construct an ontology library featuring shared concepts and unified regulations. Such ontology library can function as the supporting platform for data mining based on cloud computing and provide decision-making support for data mining efficiency improvement, query, early warning and emergency handling. *Research on the Key Technologies for Developing Internet of Things* wrote by Jia Baoxian in 2012 conducted research on RFID, wireless sensor network, semantic grid and other key technologies and pointed out that the difficulties in the application of the Internet of Things can be solved by combing multiple key technologies. In 2014, in *Application research of technologies of Internet of Things, big data and cloud computing in coal mine safety production*, Ma Xiaoping and other scientists stated the research status of the Internet of Things, bid data and cloud computing and pointed out the relations of the three technologies, namely, the Internet of Things generates big data while big data facilitates the Internet of Things; and big data needs cloud computing while cloud computing adds extra value to big data. By referring to the construction and development history of coal mine integrated automation, the paper studied the respective role of the three technologies in guaranteeing coal mine safety production and proposed their relations therein, i.e., the Internet of Things is the technical framework and roadmap of the coal mine subsystem construction, big data is the outcome of the construction of the Internet of Things and cloud computing is the technological means of big data processing and use. It also pointed out that such coal mine safety production monitoring and controlling system will be an active one combining multiple parameters and possessing early warning function, able to effectively improve safety production of coal mines. In 2015, Zhu Yuanzhong proposed in *Research on Safety Supervision of Dangerous Chemical Enterprises Based on the Internet of Things Technology* a safety supervision system for dangerous chemical enterprises based on the Internet of Things which, by integrating multiple information technologies including sensor, RFID, wireless communication, the Internet and cloud computing, can realize the comprehensive informatization and automation in information sampling, storage, transmission, management and other links of safety production examination, shape a directive and intelligent comprehensive service system where safety production factors possess precognition ability and specific supervision and inspection tasks can be done conveniently and efficiently, as well as maximize information resource sharing, so as to enhance the strength and efficiency of safety supervision.

In view of the current research, the increasingly mature theories of the Internet of Things, cloud computing and big data have been applied in many areas and have gained good results in some ways. The relative concentration of enterprises in the parks, the complex technology, large-scale installation, rigorous operating conditions as well as the large quantity and big density of major sources of danger cause such problems as big data volume, complicated prediction model design, heavy calculated load and big pressure of data transmission network, which, on the other hand, promises the vast development possibilities of an information management platform based on combining the respective theoretical advantages of the Internet of Things, cloud computing and big data.

3. Cloud Computing Technology

Cloud computing is an Internet-based service addition, use and delivery mode, which generally involves the supply of dynamic, extendable and often virtual resources via Internet. Cloud computing in narrow sense refers to the delivery and use mode of IT infrastructure, which is to obtain the required resources on the basis of need and in the extendable way via Internet; and that in broad sense refers to the delivery and use mode of services, which is to obtain the required services on the basis of need and in the extendable way via Internet. Such services may either be pertaining to IT, software and Internet, or others. It means that computing power also can circulate as a commodity via Internet. Actually, cloud is a metaphor for network and Internet. Cloud computing is a combination of multiple technologies, instead of merely one technology, which makes information technology (IT) as a service concept possible and recognized by the public.

Cloud computing emerges after centralized computing, distributed computing, desktop computing and grid computing, as shown in Fig.1.

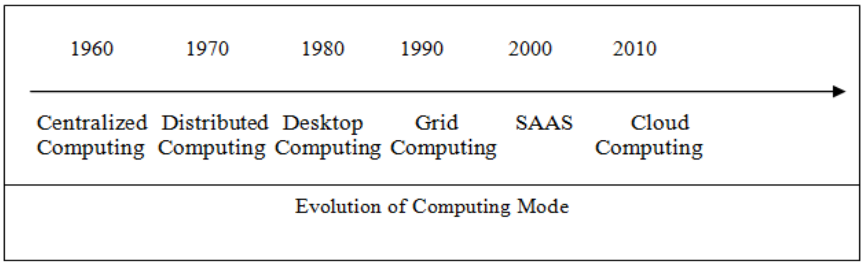

Figure 1. Evolution of Computing Mode

Cloud computing is characterized by: (1) that computing resource integration improves the computing power; (2) that the distributed data center ensures the system disaster tolerance capacity; (3) that separation of software from hardware reduces the device dependence; (4) that platform building block design shows high extendibility; and (5) that virtual resource pool provides users with flexible services.

4. Application of the Internet of Things in the System

According to the definition given by International Telecommunication Union (ITU), the Internet of Things mainly enables the interconnection of Thing to Thing (T2T), Human to Thing (H2T) and Human to Human (H2H). Unlike traditional Internet, however, H2T refers to the connection of Human to Thing through general-purpose devices and that simplifies the connection of Thing to Thing, while H2H refers to the interconnection of Human to Human except that depending on PC. Since the Internet fails to include the connection of Things, the Internet of Things is hence put forward. Just as its name implies, the Internet of Things is the network connecting things. The concept of M2M, as frequently introduced by scholars when mentioning the Internet of Things, can be explained as Man to Man, Man to Machine and Machine to Machine. Fundamentally, the interaction of Man to Machine and Machine to Machine is mainly for the purpose of the information interaction of Man to Man. The three key technologies in the application of the Internet of Things are namely (1) sensor technology; (2) RFID technology; and (3) embedded system technology, a complex technology integrating computer hardware and software, sensor technology, integrated circuit technique and electronics application technology. After evolution in the past several decades, intelligent terminal products featuring embedded system can be found everywhere, from MP3s in our daily life to satellite systems in space flight and aviation. Embedded system is shifting our life as well as promoting the development of industrial production and national defense industry. If the Internet of Things is compared to a human body, sensors are the sense organs like the eyes, the nose and the skin; the network is the nervous system that transmits information; and the embedded system is the brain which conducts classified processing after receiving information.

Based on its features such as all-round sensing, reliable transmission and intelligent treatment, the introduction of the technology of the Internet of Things into safety production supervision can help to meet the requirements of “the interconnection of Things, IntelliSense and smart treatment” in safety production supervision.

Firstly, based on the extensive use of various sensing technologies in the Internet of Things, large numbers of various sensors can be deployed in dangerous chemical enterprises, each sensor as one information source collecting real-time data of critical equipments and key sites.

Secondly, since the Internet of Things is a ubiquitous network built on the Internet, the massive information collected by sensors can be transmitted timely and accurately via various wired and wireless networks, enabling the system to know the safety status of the enterprise, automatically analyze possible hidden dangers, make intelligent decisions, and take preventive measures when possible. Thirdly, by combining sensors and automatic control technology and employing various intelligent technologies including cloud computing and pattern recognition, the Internet of Things can conduct smart treatment, which is of great significance in finding hidden dangers automatically and timely and then nipping accidents in the bud by taking measures such as switching off the valve, disconnecting the power and putting out the fire.

The application of RFID, wireless sensing and GPS enables logistics control and supervision of dangerous chemicals, which helps to completely eradicate accidents during storage, distribution and transportation and conduct recording, storing, tracing and guiding to the whole logistics process. In addition, effective supervision can be done in areas of equipment environment safety, product flow, on-site inspection and occupational hazard prevention so as to improve overall management strength.

Schematic diagram of system communication network is shown in Fig. 2.

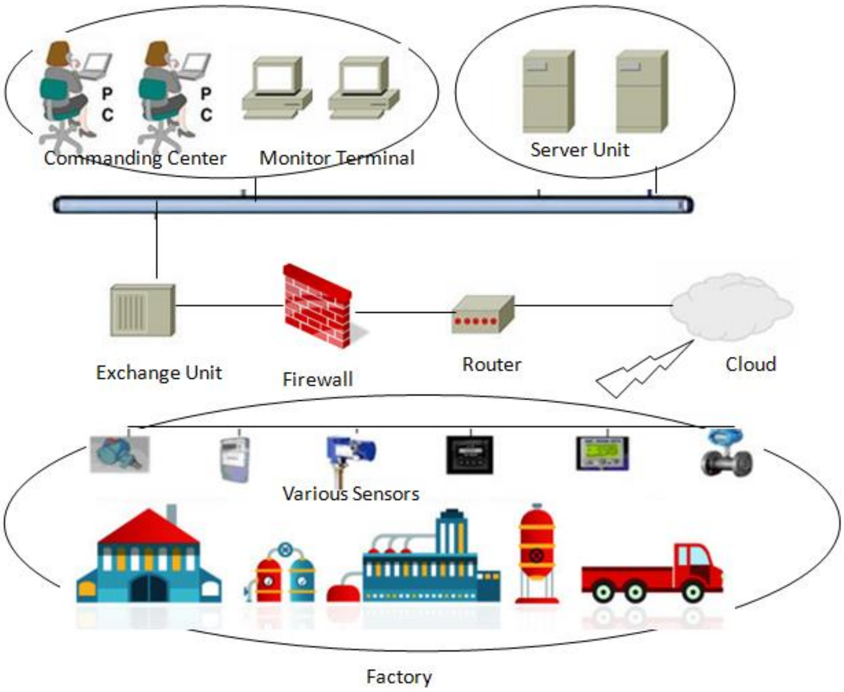

Figure 2. Schematic Diagram of Data Collection and Communication Network of the Platform

5. Framework Design of the Information Management Platform

Based on the definition by National Institute of Standards and Technology, cloud computing service can be generally featured as the following five, namely, providing customized self-service, accessible via network devices of any kind any time any where, resource sharing among multi-users, flexible and rapid redeployment, and monitored and measurable service. The technical framework is shown in Fig. 3 and the overall framework of the platform is shown in Fig. 4.

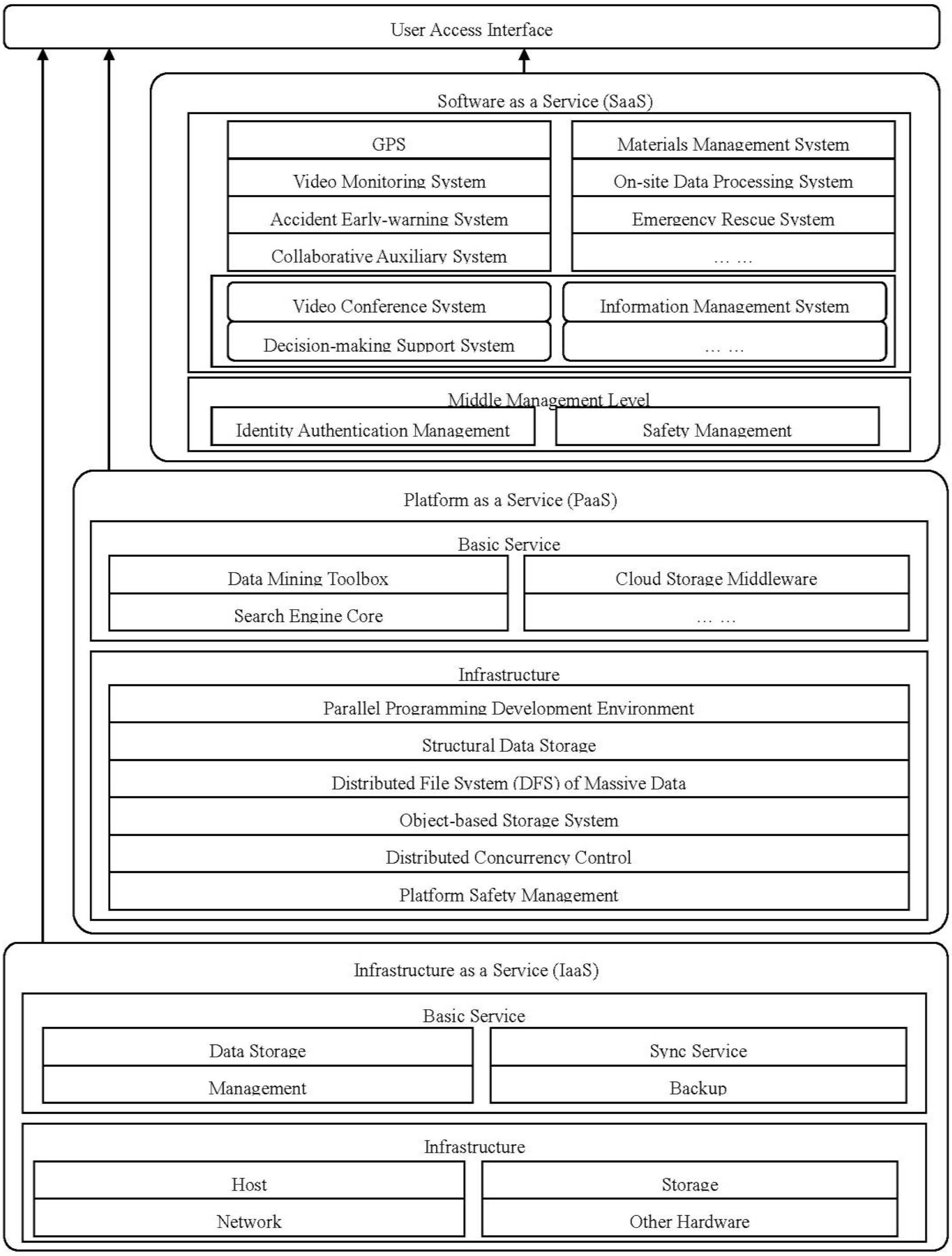

Figure 3. Technical Framework of the Platform

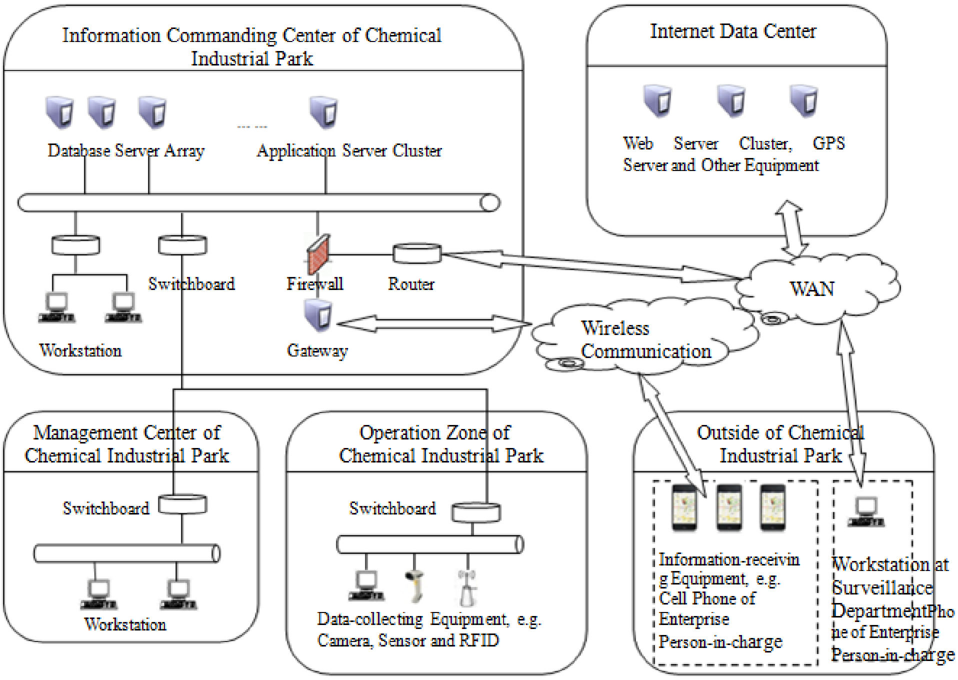

Figure 4. Topological Diagram of Chemical Industrial Park Integrated Information Management Platform

(1) IaaS—the infrastructure layer. As the backbone layer of cloud computing service structure, the infrastructure layer provides the upper layer with cloud computing resources accessible to users. This layer offers computing function and basic storage as standard services in the network.

(2) PaaS—the platform layer. In cloud computing, relevant server platform or development environment is offered to users as a service, i.e. PaaS. As the upper layer over the infrastructure layer, the platform layer is regarded as the core layer of the whole cloud computing system, mainly offering services such as deployment, distribution, supervision management, safety management, distributed concurrency control of the management system and data resource of the Internet of Things.

(3) SaaS—the application layer. The application layer of cloud computing offers uniformly regulated interfaces for end-users to consume cloud computing service. End-users get to cloud computing service center through a dedicated entryway to order and consume needed services; the platform offers dedicated data service interfaces for commanding and management departments, enabling them to monitor and control the operation of all links all the way, be informed of the running conditions of all elements in the park, optimize and integrate the strength of all the subsystems, deploy system resources in a flexible and scientific way, develop coordinated and interconnected commanding and management mechanisms and carry out rapid and efficient supervision and rescue.

6. Functions of the Platform

Based on the analysis above, the comprehensive management information platform of dangerous chemicals for chemical industrial parks mainly has the following functions:

6.1 The Sensing layer

The sensing layer is the carrier through which the application platform collects relevant information and carries out information secure storage and processing. This layer recognizes and then collects the attribute information of objects during the dangerous chemical logistics operation, functioning as the end node for information input and sensing of the application platform. The sensing layer consists of many advanced sensing equipments of the Internet of Things such as RFID, sensors and sensor network, BeiDou Navigation Satellite System (BDS) / GPS and network camera for the purposes of Virtual Identity Electronic Identification (VIEID), alarming sensing, satellite positioning, environment monitoring and video collection.

6.2 The Transmission Layer

The transmission layer conducts intelligent treatment and network transmission of the information collected by the sensing layer and it mainly consists of working parts such as the wireless network, the Mobile Internet, the Internet, specialized virtual network of the industry and various network devices.

6.3 The Infrastructure Layer

The virtualization technology enables the construction of IaaS (Infrastructure as a Service) and the infrastructure cloud service. IaaS offers services such as the data center and hardware and software resources of infrastructure including the server, operating system, disk storage, database and information resources.

6.4 The Platform Layer

PaaS (Platform as a Service) can be constructed in accordance with the design thought of business componentization and capability and service orientation of components and based on cloud framework design. Paas can translate scattered functional resources into centralized functional services, maximize function reuse and finally realize the construction, deployment and operation of customized functional service platform as required; meanwhile, it can integrate and invoke resources in the infrastructure cloud, provide an uniform application framework for the application layer and support the daily management of dangerous chemicals and emergency rescue in the parks in an all-round way.

The platform conducts unified allocation and management of hardware resources and provides support for the development, operation, monitoring and safety of upper-layer applications, mainly including:

(1) Distributed service framework

The platform offers a complete distributed service framework for the operation of upper-layer applications. The hard cores of the framework include:

1) Cluster fault-tolerance: offering transparent remote procedure invocation according to interface methods, including multi-protocol support and cluster support such as software load balancing, unsuccessful fault-tolerance, address route and dynamic allocation;

2) Auto-Discovery: based on the directory service of the registration center, users can look up service providers in a dynamic way, the address becomes transparent and service providers can increase or decrease machines smoothly;

3) Telecommunication: offering abstract and encapsulation of multiple long connection based NIO frameworks, including various thread models, serialization and information swap mode in "request-response" pattern.

Such service framework can realize the following three functions:

1) Transparent remote method invocation: when invoking applications or services from remote servers, native applications invoke remote methods in the same way as invoking native methods. This only requires simple configuration, free of any API intrusion and regardless of the problem of developing application program interface implementation;

2) Load balancing and fault-tolerant mechanism of software implementation: defining load balancing strategy based on all-roundly service-oriented application release and invocation. Adopting Round Bin, Least Active and Consistent Hash to set the load balancing strategy of trusted nodes, replacing FS and other hardware load balancer, lowering cost and reducing single nodes;

3) Service automation log-on and discovery: by adopting Zoo Keeper as service, the registration center can inquire the IP address of service provider, and add or delete service providers smoothly.

(2) Shared component service

Shared component service includes basic component service and business component service. The platform carries out abstract and encapsulation of some general functions, forming the basic component service which guarantees the consistency when upper-layer applications invoking relevant services. The platform offers business component service ready for flexible configuration and invocation for some general algorithms and functions to realize the solidification of business logic, consistency of application mode and unification of maintenance.

(3) Data service

Data service provides a uniform data collection, processing and analyzing platform and conducts collection, processing and analysis of all kinds of isomerous data under uniform standards both within and without the platform.

(4) Application operating environment service

Application operating environment service provides relevant operating environment and development and testing environment for the operation and development of application services.

6.5 The Application Layer

Based on the standard business service interfaces offered by the PaaS core business service components, this layer invokes resources in the platform infrastructure cloud and related dedicated infrastructure cloud to construct SaaS, so as to provide end business users with actual responding business applications.

6.6 Operational Management

Operational management service conducts operational management and monitoring of the infrastructure layer, the platform layer and the application layer in the platform framework, so as to guarantee application stability and provide technical support for the dynamic capacity expansion of applications at the same time.

6.7 Safety Management

It provides unified safety management and constructs a unified safety management platform based on the service-oriented framework and modular design in verification management, authorization management, session management, cache management and encryption strategy.

7. Materialization of Key Technologies

7.1 Design thought of Uniform Big Data Analyzing Platform

There are both connections and differences among the Internet of Things, big data and cloud computing. The Internet of Things emphasizes on how to realize correlation and communication of Thing to Thing (Human, Machine, Thing); big data focuses on the storage, analysis and processing of massive data; and cloud computing lays particular emphasis on data computing methods. From the perspective of information flow, the Internet of Things enables the connection of Thing to Thing, and the number of information sources and sinks in the whole information network increase with the enlargement of Internet coverage; the increase of information source and sink number inevitably gives rise to the increase of information volume, i.e., producing big data in the network; to extract and make use of the intrinsic value of such big data requires the technical support of cloud computing equipped with super-large scale and high scalability. Consequently, the relations of the three technologies can be summarized as: the Internet of Things generates big data while big data facilitates the Internet of Things; and big data needs cloud computing while cloud computing adds extra value to big data. Therefore, in the platform, the concept of big data is proposed and introduced into cloud computing. The strategic significance of big data lies not on the acquirement of huge data information but on the specialized processing of such meaningful data. Technically, big data and cloud computing are inseparable just like the two sides of a coin. Big data can definitely not be processed by a single computer, and distributed framework must be adopted. It features distributed data mining of massive data, but only feasible on the basis of distributed processing, distributed database, cloud storage and virtualization technology of cloud computing. The purpose is to complete the mining, storage and processing tasks of massive data in the parks through the design of a uniform big data analyzing platform.

(1) Software framework

Application programs connect to the database through the master host and multi-node segment hosts via the Internet. Application programs visit data through the master host, and each storage node in the network is a standalone database without data sharing. Data switching is conducted between multiple storage nodes and the master host.

The segment servers in each node are connected via the Internet to perform a same task, seen as a server system by users.

The basic characteristic is that the system is based on the interconnection of segment servers (each segment server as a node) via the Internet, each node visiting the local resources of its own, including internal storage and storage, forming a completely share-nothing structure which guarantees the best scalability. Theoretically, the system can be unlimitedly scalable; current technology allows the interconnection of 512 nodes and thousands of CPUs. Each node can run its own database and operating system while one node cannot visit the internal storage of another, and the information switching between nodes is conducted via the node internet. Such process is called data redistribution. See Fig. 5.

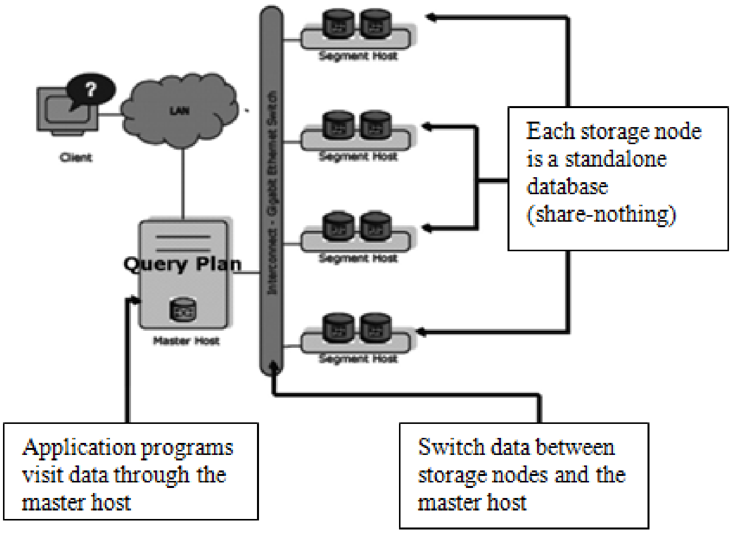

Figure 5. Data Software Framework of Uniform Big Data Analyzing Platform

(2) High availability analysis

The master host and standby master synchronizes with each other in the form of "one master and one standby" while the master host connects with multi-node segment hosts via GE network, with each node segment host containing two sets of data, namely the primary segment data and mirror segment data, so as to guarantee the high availability of the whole system framework. See Fig. 6.

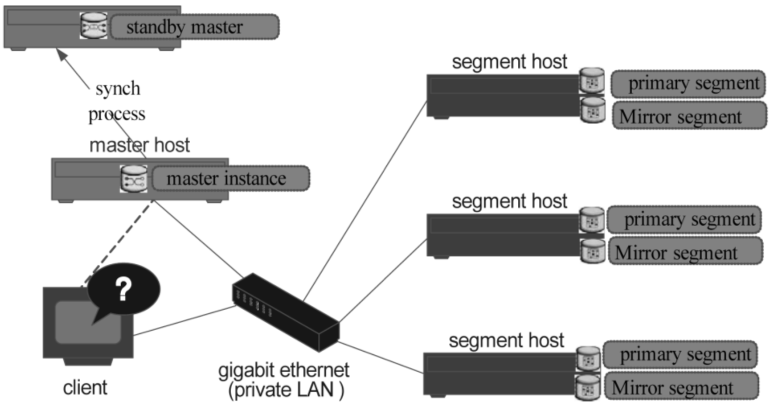

Figure 6. High Availability Framework of Big Data Platform

7.2 Combination of RFID and Sensor Network Technology

The combination of RFID and sensor network technology is of crucial significance in platform design. The application of RFID is limited by its low anti-interference and short effective distance of less than 10m. Wireless sensors have an effective radius of as long as 100m, and when they are combined with RFID, a wireless sensor network is formed, and such network has an immeasurable future. The sensor network generally puts no emphasis on the location of nodes and doesn't adopt overall marking of nodes consequently; however, RFID technology has its exceptional advantage in marking nodes. A network based on the combination of the two can offset their respective defects and concentrate the vigor of the network on data. When the information of a specific node is required, such node can be located by taking advantage of the marking function of RFID.

In the Internet of Things, interaction occurs constantly between Machine and Machine, Man and Man and Man and Machine, making it difficult to exchange and share the complex cost information. The construction of ontology enables the common understanding and cognition of the organizational structure of information between users and agents. Professional knowledge can also be adopted to clarify hypotheses in professional field and such knowledge can also be analyzed. Meanwhile, the ontology can act as the medium of communication to assist the acquisition, expression and operation of knowledge. Such assistance is realized by providing a core with uniform basic concept and language structure. At the same time, the ontology can also help construct and organize a knowledge base, and explain the input and output of knowledge processing tool modules. The construction of ontology is most important in the realization of ambiguity-free interaction.

In P2P framework, information resources are oriented to man rather than machines. The information in the nodes is chaotic data rather than knowledge. The integration of ontology into P2P can form semantic P2P. Semantic P2P equips information with structuring feature, easing the query and understanding of users. Information is stored in the nodes in the form of ontology. Ontology can be defined as a definition which provides the basic terms and relations of the vocabulary of a domain as well as rules that regulate the denotation of such vocabulary constituted by such terms and relations.

In addition, semantic P2P also removes the maintenance difficulty brought about by centralized framework. In dispersive environment, different nodes conduct knowledge processing and management tasks during information exchange. Semantic P2P relieves the management burden of participants and simplifies knowledge sharing and information retrieval. It takes advantage of the Internet of Things to accelerate network speed and realize semantic sharing of resources, so as to provide strong technical support for data monitoring and emergency rescue of the chemical enterprises in the parks.

7.3 Model Design of Expert Decision-making

Expert system is an intelligent computer program system which contains a large number of professional knowledge and experience of some domain and can solve problems in such domain by making use of the knowledge and trouble-shooting methods of human experts. That’s to say, expert system is a program system featuring large numbers of specialized knowledge and experience. It makes reasoning and judgment, imitates the decision-making process of human experts and then solves complex problems requiring processing of human experts based on the knowledge and experience provided by one or more experts of a domain by employing artificial intelligence technology and computer technology. In short, expert system is a computer program system which imitates the trouble-shooting methods of human experts. The utilization of expert system in the platform enables analysis of key data collected, automatic decision-making and early warning as well as provides strong technical support for emergency rescue. It can also provide decision makers and regulators with training, testing and simulation environment.

As shown in Fig. 7, the expert decision-making system connects into the cloud server side via the Internet of Things real-time data such as temperature, concentration and pressure coming from sensors in the factories as well as the location data of current logistics vehicles and dangerous articles, and integrates such data with the basic data, mathematical model and expert model preset in the system. By making use of the basic principles and technologies of expert system, the system summarizes and collects large numbers of experience and knowledge of safety experts, studies and analyzes the information resources, data and background information provided by the system and offers the danger level of the current factory, early warning, initial plan for accident rescue,

rescue commander and other data by means of simulation and intelligent simulation, so as to provide technical support for the decision-making of regulators.

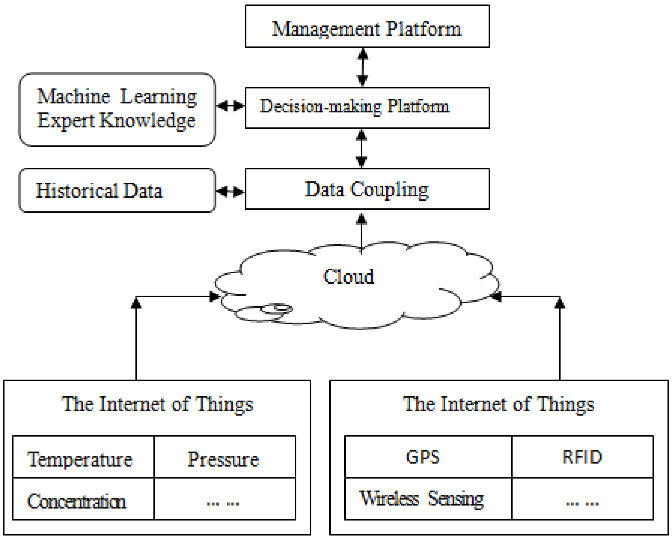

Figure 7. Model Framework of Expert Decision-making

8. Conclusion

The development of chemical industrial parks shows such features as concentrated sources of danger and large scale, and it has become a problem attracting increasing concerns of governments of all levels, constructors of the parks and regulators to make reasonable supervision, prevent and control potential serious and extra-serious accidents, reduces losses and limits the influence, so as to guarantee production safety and social stability and realize benign and sustainable development of enterprises in the parks. In order for reasonable safety production supervision and emergency rescue in the parks based on multiple technologies, technical framework design of a safety production information management platform based on cloud computing and the Internet of Things is proposed by making use of key technologies of the Internet of Things such as sensing, accessing and networking, massive information storage, analyzing and processing capabilities of big data technology and the data computing methods of cloud computing technology. The design flow confirms the working procedure of on-the-spot supervision, realizes a long-effect management mechanism including real-time parameter monitoring, high-sensitivity precise localization, accident risk grade warning, accident simulating and forecasting, expert system and pre-arranged accident rescue plan, and proposes the application of regional collaborative emergency management operating system in daily production and emergency rescue. The platform can realize logistics management of dangerous articles and key environment parameter monitoring of dangerous chemical enterprises, help enterprises in the safety compliance management to the whole production process, allow red light early warning and start responding early warning mechanism and rescue plan automatically, in order to effectively avoid the occurrence of potential accidents and safeguard and improve the economic and social benefits of enterprises.

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Authors

Qin Lele, male, Associate Researcher,was born in Zhangjiakou, Hebei, China on March 19, 1978. He earned a Master Degree of Engineering from Nanjing University of Science and Technology, China in 2006.His major field of study is the analysis and design of management information system.

He has been in the research of management information system, and is now dean of Teaching Operation Management, Office of Teaching Affairs in Hebei Univesity of Science and Technology. He has been teaching more than 10 courses at various levels including Management Information System, MIS Curriculum Design, and Database Principle. He has published "A Case of Environmental Engineering CAD Application" (Beijing, China: Chemical Industry Press, 2005) , "A Case of Water Treatment Engineering CAD Application" (Beijing,China: Chemical Industry Press, 2002) . He has published more than 20 articles, 15 of which were indexed by EI. His research interests are the analysis and development of MIS.

Kang Lihua, female, lecturer, was born in Hengshui.Hebei, China on Dec 25,1985.She earned a Master Degree of Engineering from Hebei University of Technology in 2011.Her major field study is seismic design of buildings.

She has published more than 10 articles, some of which were indexed by EI.

