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Research and Application of Comprehensive Control Platform for Open-pit Mines Based on Cloud Architecture

Congrui Liu*
Power Station Information and Monitoring Technology Department
Xi'an Thermal Power Research Institute Co., Ltd.
Xi'an, China
* Corresponding author: liuocngrui@tpri.com.cn

Jinsong Zhao
Power Station Information and Monitoring Technology Department
Xi'an Thermal Power Research Institute Co., Ltd.
Xi'an, China

Xiao Liu
Electric Power Infrastructure Network Security Research Center
Xi'an Thermal Power Research Institute Co., Ltd.
Xi'an, China

Yue Liu
Yimin open coal mine
Huaneng Yimin Coal and Electricity Co., Ltd
Xi'an, China

Wenming Tian
Yimin open coal mine
Huaneng Yimin Coal and Electricity Co., Ltd
Xi'an, China

Yongquan Gu
Power Station Information and Monitoring Technology Department
Xi'an Thermal Power Research Institute Co., Ltd.
Xi'an, China

***Abstract*—In the process of informatization construction, the number of application systems is increasing, and this has led to many issues, such as the data format not uniform, system module duplication construction, lack of data sharing. To solve these issues, the comprehensive control platform is established. This article analyzes the overall architecture of the open-pit mine industry PaaS platform, and adopts technologies such as cloud computing, big data, and containers to establish the comprehensive control platform that meets the concept of intelligent open-pit mine management. It covers container platform, development platform, and data center, achieving unified management of open-pit mine data, continuous development and deployment of business systems, application resource management, and operation and maintenance monitoring functions.**

Keywords-PaaS; open-pit mine; Kubernetes; data center; control platform

I. INTRODUCTION

Intelligentization of coal mines can integrate modern techniques such as artificial intelligence (AI), interenet of things (IOT) [1], big data, and cloud computing [2] with the coal mining. It can achieve intelligent operation of coal mine development, mining, transportation, and other processes, thereby improve the level of coal mine safety production, and ensure stable coal supply. However, the intelligence level of most open-pit mines is still in the development and initial stage at present. In the process of informatization construction, the number of application systems is increasing, and this has led to many issues, such as the data format not uniform, system module duplication construction, lack of data sharing. To solve these issues, open-pit mines need to establish an intelligent comprehensive control platform as the information technology foundation. The platform can fully utilize underlying data, and break down barriers between business modules to achieve unified data management and application resources management.

II. PLATFORM ARCHITECTURE

A. Overall Architecture

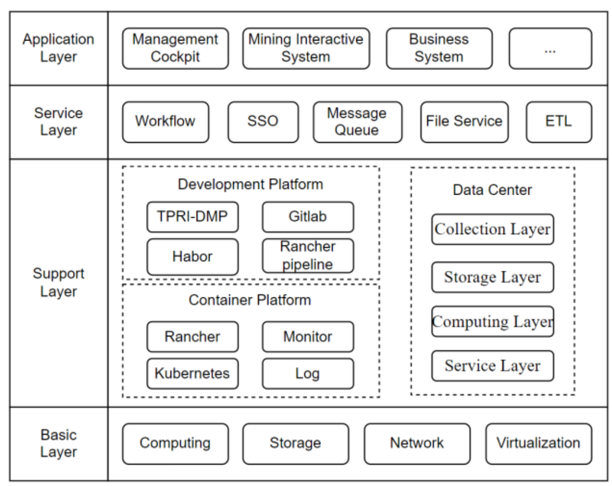

Figure 1. Structure of the comprehensive control platform.

Based on the current mainstream technology of industrial Internet, the comprehensive control platform is established by intergrating container cloud, DevOps tools, application services, data center. As Fig.1 shows, the structure of the platform can be dandevided into basic layer, support layer, service layer, and application layer. The basic layer is a complete virtualization environment composed of hardware facilities and virtualization

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software [3]. The support layer is an industrial PaaS platform, which includes three parts: container platform, development platform, and data center. The service layer includes the basic services required by the application, such as workflow, single sign on (SSO), message queue, file service, and Extract-Transform-Load (ETL) tools. The application layer is composed by various business systems that support open-pit mining production operations, including management cockpit, mining interactive system, production management, equipment maintenance management, intelligent safety management, coal full process management, mobile app, etc.

B. Network Architecture

The network environment of open-pit mines is complex, and business systems are distributed across multiple network regions. According to the guidelines of cyber security protection for electric power system supervision and control, the network area of open-pit mines is usually divided into production control zone (PCZ), management information zone (MIZ) [4], and wireless intranet zone (WIZ), as shown in Fig. 2. Each zone is isolated by security protection tools such as network gates and firewalls. The PCZ mainly covers the management and control systems related to production equipment, such as truck scheduling system, power supply and distribution system, and drainage centralized control system. The PCZ and the MIZ are isolated through a one-way gateway, and data can only be transmitted from the PCZ to the MIZ. The MIZ is the main zone used by staffs, so the main functions of this platform and the data center are deployed in this zone. The WIZ is an internal network area based on 5G mobile signals, and it covers the systems that require wireless transmission, including vehicle positioning system, personnel positioning system, slope monitoring system, and mobile applications. The WIZ and the MIZ can achieve bidirectional data exchange. All the data in PCZ and WIZ are collected in the data center.

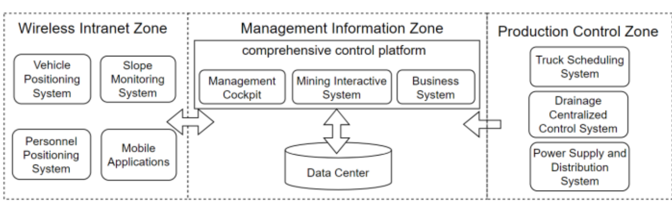

Figure 2. Network Architecture of the comprehensive control platform.

III. CONTAINER PLATFORM

Container is a software encapsulation method that packages applications and their dependencies together. Through containerized deployment, cloud native applications [5] can achieve rapid deployment, elastic scaling, and resource isolation, reducing the hardware and maintenance costs of the platform. However, with the continuous increase of cloud native applications for open-pit mines, the deployment of containers has greatly increased, so the platform need a container orchestration management tool to achieve automated deployment and support large-scale scalability. The comprehensive control platform uses Kubernetes to achieve centralized container orchestration and dynamic resource scheduling, and continuously integrates and deploys programs through Gitlab, Harbor, and Rancher. The structure is shown in Fig. 3.

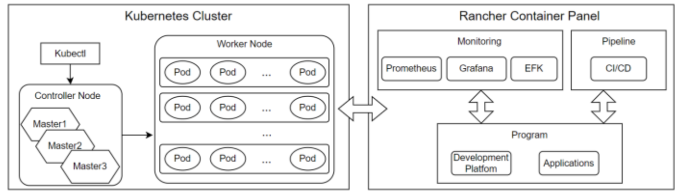

Figure 3. Structure of container platform.

A. Kubernetes Cluste

Kubernetes cluster is the core of container platform. It controls the usage of computing resources through workloads and uses horizontal pod autoscaling (HPA) to achieve automatic container expansion. Kubernetes can automatically expand Pods within the allowed range after the resource utilization reaches the threshold. In this platform, the expansion range of pod replicas is 1 to 5, and the threshold for average CPU utilization is 75%. When the resource utilization reaches the threshold, it automatically expands by 1 Pod at a time. Pod automatic expansion can simplify operations and improve service high availability.

B. Rancher

The native deployment and operation method of Kubernetes is to orchestrate containers through resource files (YAML or JSON) in a Linux environment, and this limits the use of non professionals. To avoid this, the platform use Rancher to achieve visual orchestration and data display of Kubernetes clusters. Rancher is an open-source multi cluster Kubernetes management platform that provides visual management capabilities for deploying, operating, and accessing Kubernetes. It can control multiple Kubernetes clusters, and its control side corresponds one-to-one with Kubernetes clusters.

C. Monitoring of Container Platform

In order to monitor the status and faults of Kubernetes clusters, Prometheus, Metrics-Server, and Grafana is used in the platform. Prometheus and Metrics-Server are used to collect monitoring data. Prometheus mainly focuses on business-related metadata, such as deployment and pods. Metrics Server mainly focuses on resource usage, such as CPU and memory. The collected data is stored in Prometheus' built-in time-series database InfluxDB and can be alerted through Prometheus' Altermanager. Grafana can query monitoring data in InfluxDB and display it through a visual panel.

D. Auto Scaling

Auto scaling is a highlight feature in Kubernetes. When the load is high, applications can be expanded to increase the number of replicas in the pod to cope with large amounts of traffic. When the load is low, applications can be scaled to avoid resource waste. By comparing the test results of different POD quantities, the performance improvement brought by auto stretching can be intuitively reflected from the parameters. This paper conducted performance tests on the platform under different concurrent user counts of 100, 300, and 500 in the states of 1 Pod and 2 Pods. As listed in Table. 1, the test results show that the performance improvement brought by multiple Pods is not very significant in environments with low user concurrency, but in environments with 500 or more concurrent users, the performance improvement of multiple Pods is more significant. In addition, there is a certain improvement in throughput and sample collection in multi Pod environments, with performance increasing by up to 20%.

TABLE I. TEST RESULT OF AUTO SCALING

Quantity of Pods	*Concurrency*	*Sample size*	*Average response time(ms)*	*Failure rate*	*Throughput*
1	100	62062	566	0.00%	61.40423
	300	80875	1773	0.00%	81.67416
	500	104898	2857	0.00%	118.36998
2	100	69931	480	0.00%	80.41152
	300	90211	1633	0.00%	108.4582
	500	127313	2806	0.00%	140.60076

IV. DEVELOPMENT PLATFORM

To achieve rapid development and iterative updates of applications, the comprehensive control platform has built a development platform that supports rapid development and continuous delivery. The development platform consists of TPRI-DMP development tools [6], Gitlab code hosting platform, Harbor container repository service, and Rancher pipeline. Developers can use TPRI-DMP for application development and submit code to Gitlab. After submission, Rancher pipeline will pull the code from Gitlab and offline build tools from Harbor for code construction, followed by testing. Finally, the code will be packaged into an image and pushed to Harbor. After the packaging work is completed, the Kubernetes cluster pulls the image from Harbor and deploys the application to the specified namespace.

TPRI-DMP is a self-developed industrial application software development platform. It consists of front-end module code development and back-end API low code development tools, with various components and services such as business flow engine, permission control service, and workflow engine, suitable for rapid development of complex business systems.

Gitlab is a code repository for the platform that enables code management and version control when multiple people collaborate. The platform connects Gitlab and Rancher through the Rancher interface. When projects are updated in Gitlab, they will be automatically synchronized to Rancher and then proceed to the pipeline.

The comprehensive control platform uses Habor as the image repository to push and pull container images. The images stored in Habor include the basic images of Kubernetes clusters, Kubernetes clusters related third-party images, TPRI-DMP platform related images, and business application images. To ensure data security and high availability, Habor adopts a master-slave architecture and achieves master-slave mirror synchronization through scheduled tasks.

The comprehensive control platform integrates Jenkins with Rancher and Kubernetes to build the pipeline, and the pipeline includes four steps: build, test, package, and deploy. In the build step, the pipeline will pull the code submitted to the master branch for construction. In the test step, the pipeline conducts complete testing of the code based on test cases and Maven tools. After that, the pipeline packages the code into an image using Dockerfile and publishes it to the Harbor in the package step. Finally, in the deployment step, the pipeline creates workloads in the Kubernetes cluster, pulls the image from the Harbor repository, and deploys it to the specified namespace.

V. DATA CENTER

The data center is the foundation for the centralization, integration, and sharing of open-pit mining data resources. The data center consists of collection layer, storage layer, computing layer, and service layer, and it collects different types of data from various network areas. Through the data center, the platform can achieve unified storage, management, mining, and analysis of mining operation management, business execution, and equipment operation data. The architecture of data center is shown in Fig.4.

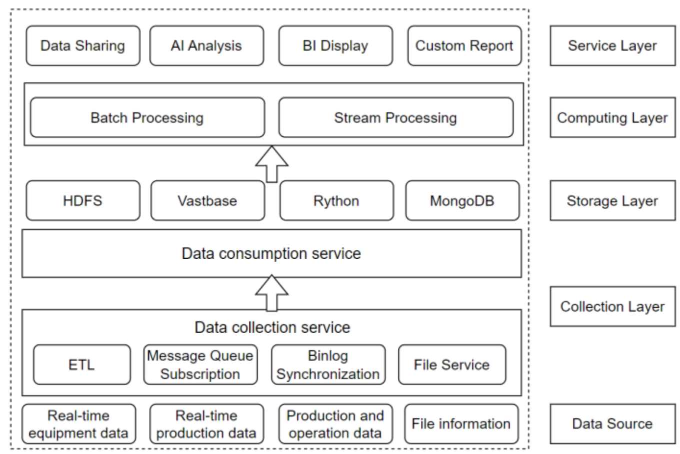

Figure 4. Architecture of data center.

The data generated by the open-pit mining information system includes:

- Real-time equipment data, including real-time operation data of various production equipment such as trucks, shovels, and continuous systems, usually collected by wireless sensors with a collection frequency of seconds or milliseconds.
- Real-time production data, including production data, positioning data, and fuel consumption data, is mainly used in truck scheduling systems, usually in the form of minute level relational data.
- Production and operation data, such as equipment maintenance records, equipment defects, and shift handover records.
- File information, including equipment drawings, alarm photos, videos, and other file data.

Based on the characteristics of the above data, the collection layer uses microservices to achieve scheduled and real-time collection of data through interface calls, message queue subscriptions, binlog monitoring [7], protocol communication, and database reads. In addition, due to the isolation devices between network areas in the open-pit mine, the collection layer deploys data collection services in each area, and provides data consumption services on the data center side to receive data returned by each area. At the same time, Kafka message queues are set up on both sides of network isolation devices to ensure data caching and consistency during high concurrency transmission and network disconnection.

The storage layer uses Hadoop Distributed File System (HDFS), Rython, Vastbase, and MongoDB for data storage and management. HDFS is used for storing the raw data collected by various systems, which is mainly used for batch processing, data mining, and data exchange. Rython is used to store real-time data with high collection frequency. Vastbase stores data that are frequently applied and modified, such as positioning data and production data, and MongoDB is used to store unstructured data and small files.

The computing layer processes data through batch and stream processing, providing support for BI display and AI analysis.

The service layer provides basic service functions for data applications, including data sharing tools and analysis tools. The data sharing tool is based on the TPRI-DMP platform and provides two ways to share data: message queues and data interfaces. At the same time, the API gateway module is used to manage and monitor the entire lifecycle of API interfaces, including API registration, permission control, logging, and other functions. The analysis tools include AI analysis, BI display, and custom report, supporting users to implement reports, BI, and data modeling through low code methods.

VI. Platform Application

A. *Management Cockpit*

The management cockpit (Fig.5) is a comprehensive statistical and display of open-pit mine data, used for the monitoring screen in the dispatch room. It includes production, equipment maintenance, and alarm data, helping management staffs monitor, schedule, and analyze production situations.

Figure 5. Management cockpit.

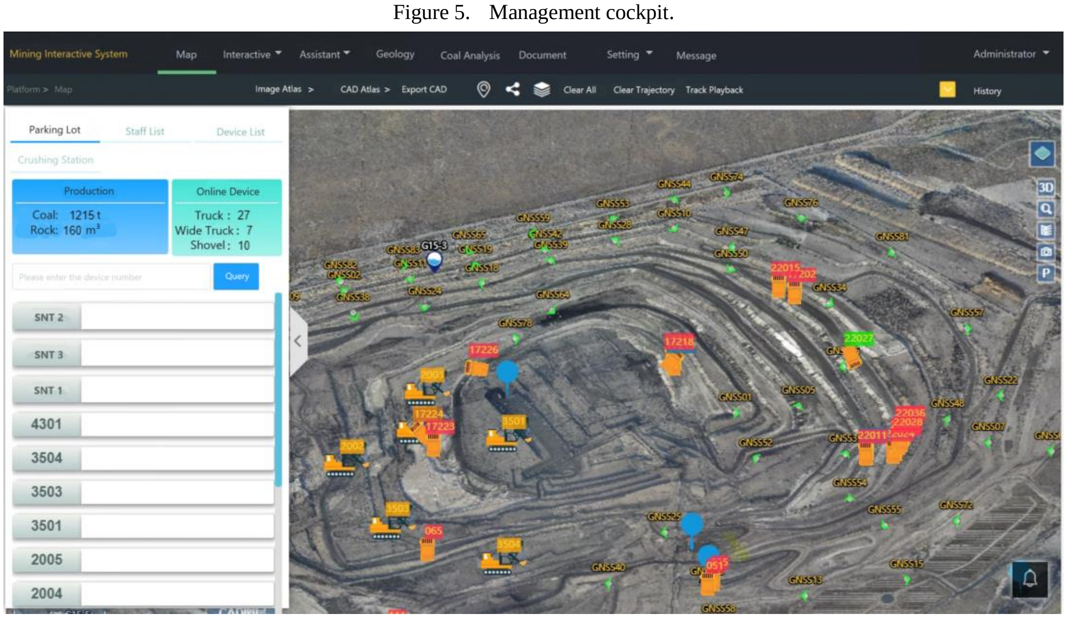

Figure 6. Mining interactive system.

B. *Mining Interactive System*

The mining interactive system (Fig.6) digitizes information related to spatial location in the mine, such as surface topography, hydrogeology and geological structure, geological reserves of the mine, development and mining plans, completed mining projects, etc., and organizes them into a digital mine according to three-dimensional coordinates, comprehensively and detailedly depicting the overall appearance of the mine. On this basis, the system integrates operational data such as truck scheduling, personnel positioning, and equipment information, achieving integrated digital analysis of mining design, production scheduling, and safety monitoring.

C. *Business System*

The business system includes production control, mining design, equipment control, salary management, and safety and nvironmental control, with a total of more than 230 functions. It provides on-demand services to different business departments, realizing intelligent control of the entire process of production management, equipment maintenance, safety supervision, etc. It breaks the drawbacks of human intervention in multiple production processes, promotes the production efficiency and management level of coal mining enterprises, and forms a series of implementation standards and operational norms for collection, calculation, evaluation, maintenance, etc.

VII. CONCLUSIONS

Digitization, informatization, automation, and intelligence are the necessary paths for the development of industrial enterprises in China. This paper takes the comprehensive control platform of open-pit mines as an example to introduce the composition and application of industrial PaaS platform. The platform adopts an open architecture, supports high load elastic scalability and continuous integration and deployment capabilities, and can achieve system self construction, self operation and maintenance. It realizes centralized information management, full sharing, and meets the needs of intelligent management.

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