Architecture and Key Technologies of Mine Internet of Vehicles

Yan Junhao¹, Jia Zongpu²

¹College of Computer Science and Technology, Henan Polytechnic University, Jiaozuo, China
²College of Computer Science and Technology, Henan Polytechnic University, Jiaozuo, China

* Corresponding author: yanjh@hpu.edu.cn

Abstract. As the important equipment of mine production, the level of mine vehicles management has a direct impact on all aspects of production, safety and management of mine. The application of IoV (internet of vehicles) to improve the intelligent level of mine vehicle management is an important part of intelligent mine construction. In order to avoid the problems of scattered development, repeated construction and difficult system integration caused by unclear concept, different objectives, different paths, different system architecture and different technical application emphases in the application of IoV in the mine vehicle management, taking the intelligent coal mine as an example, the concept of MIoV (mine internet of vehicles) is proposed, and its system architecture, key technologies and typical applications are analyzed and discussed. Firstly, on the basis of reviewing the development of intelligent mine and IoV, the concept of MIoV is defined and expounded; secondly, referring to the architecture of IoV and MIoT (mine internet of things), the architecture of MIoV is designed, which is composed of sense and control layer, network layer, service support layer and application layer; the key technologies of MIoV and intelligent mine information system are integrated and analyzed key technologies such as positioning and monitoring, intelligent perception and control, wireless communication, collaborative computing. Finally, from the four aspects of human-vehicle-environment-management, mine vehicle and driver monitoring, mine vehicle automatic driving and driverless, mine safety monitoring based on mine vehicles, mine vehicle intelligent scheduling and other typical application of MIoV are discussed. The research results lay a foundation for the construction of MIoV to promote the in-depth and orderly application of IoV in intelligent mine vehicle management, enrich the technical connotation of MIoT, and accumulate experience for the application of other technology branches of MIoT in intelligent mine construction.

1. Introduction

As the important equipment of mine production, the management level of mine vehicles directly affects all aspects of mine production, safety and management. At present, traditional mines are developing from digital mine to intelligent mine, and the construction of intelligent mine has become an inevitable requirement for the industry to cope with a new round of industrial revolution and the transformation as well as the upgrading of the industry[1]. Intelligent management of mine vehicles is an important part of intelligent mine construction. Using IoV technology can improve the management level of mine vehicles and promote the high quality development of intelligent mine.
Intelligent coal mine is an important part and main application scene of intelligent mine. Intelligent coal mine provides the core technology support to adapt to the development trend of modern industrial technology revolution, ensure national energy security and realize the high quality development of coal industry[2]. One of the main tasks in the construction of intelligent coal mine is to realize the intelligent and unmanned operation of the main and auxiliary transportation system in the open-pit coal mine[3]. At present, there is still a long way to go before realizing the goal of "unmanned, less humanized operation" and "intelligent and unmanned operation " in intelligent construction of coal mine. Many industries and enterprises have carried out series of explorations of the application of IoV in intelligent construction of coal mine. In terms of the intelligent management of mine vehicles, domestic coal enterprises have carried out a lot of explorations based on the actual demand. National Energy Investment Group Co., Ltd has constructed vehicle management systems, such as truck dispatching system, vehicle anti-collision warning system, slope stability monitoring system, truck tire on-line monitoring system and fuel monitoring system, in the overall application structure of digital mine. China Coal Pingshuo Group has built GPS intelligent truck dispatching, emulsion explosive vehicle dynamic monitoring, vehicle anti-collision, overspeed alarm and other vehicle management systems in the production information system. In the field of intelligent mining vehicles, enterprises such as NHL, SINOTRUK, SANY and Yutong are all researching on driverless and automatic technology in intelligent mining vehicles[4]. As to the comprehensive application of IoV, Shenhua Group, Huituo Intelligent, Tage Zhixing, Shanyuan Technology and other coal enterprises, solution providers have explored the application of IoV, like the specific scene of IoV, underground IoV.

However, at the same time, the application of IoV in mine vehicle management, owing to the ambiguity in concept, different objectives, different paths, different architectures, different emphasis of technology application, may result in scattered development direction, repeated investment, and difficult system integration. Based on this, we define and expound the concept of IoV by taking the application of IoV in intelligent coal mine as an example. Besides, the key technologies and typical application contents are analyzed and discussed.

2. Concept of mine Internet of vehicles

2.1. Related concepts

Traditional mine is developing to be intelligent mine, which is automatic, intelligent and unmanned after experiencing the stages of manpower mine, mechanical mine and digital mine[5]. Intelligent mine is based on the digital mine and the MIoT. The construction of intelligent mine is a process of rebuilding the production and management based on digital mine and mine IoV, a process of refining information into decision wisdom, and transforming decision wisdom into execution ability based on perception and digitization[6]. The intelligent development of coal mine always leads the development of intelligent mine[7-9]. Some scholars have carried on the thorough research and exploration of the coal mine intelligence, the standard system frame of intelligent coal mine construction and the construction thought, the intelligent coal mine classification, the classification appraisal index system. With regard to mining vehicles, for well-working coal mine production, it mainly includes monorail cranes, electric locomotives, rubber wheel trucks and so on, which undertake important underground transportation tasks such as transporting gangue, materials, coal and people. For open-pit coal mine production, mining vehicles include not only transporting vehicles, but movable mining machinery and equipment use in, say mining, transportation, discharging soil and blasting. In a broad sense, all movable mining machinery and equipment belong to mine vehicles. Intelligent management of mine vehicles is the symbol of intelligent coal mine and the important content of intelligent coal mine construction.

IoV is a derivative concept of IoT after its application in the field of intelligent transportation. Because of its clear service object and application demand, relatively centralized application technology and field, unified implementation and evaluation standards, as well as more determined social application and management needs, it has attracted the general attention, been regarded as the most successful application field and important branch of IoT, and has become a hot issue in current
research\cite{10}. In theory, some domestic scholars, like Liu Xiaoyang\cite{11}Li Jinglin\cite{12} have carried out the thorough research on the concept of IoV, the architecture and the key technology. In the field of industry, many automobile manufacturing enterprises and related supporting enterprises have carried out deep layout.

2.2. Definition of mine Internet of vehicles
MIoV is the application of IoV in intelligent mine. It not only needs to meet both the actual needs of intelligent mine construction, and the development trend of IoV to be applied in industrial field. With the rapid application and exploration of vehicle networking technology in intelligent mine, it is necessary to define and expound the concept of MIoV.

Combining with the actual needs of intelligent mine construction and the consensus of the concept of general IoV, we believe that MIoV is a derivative concept of IoV in intelligent mine, an important branch of MIoT. It regards mine vehicles (including other movable mining machinery and equipment) as the main object, aims to improve the management level of mine vehicles, meet the needs of production, safety, operation and management in mine, realize intelligent mine by using perception technology, control technology, wireless communication network technology and intelligent information processing technology. It finally builds a perceptible, controllable, manageable and credible open fusion system, where human, vehicle, environment and management are cooperative.

To promote the orderly application of IoV in intelligent mine, it is necessary to define the concept of MIoV and analyze architecture, key technologies and typical applications of MIoV.

3. Architecture of mine Internet of vehicles
About the architecture of IoV, Yang Fangchun\cite{13} has proposed an architecture which includes four levels: vehicle network environment sense and control layer, network access and transport layer, coordination computing control layer and application layer. Mine is the application scene of MIoV, so it is necessary to design and transform mine environment and business requirements on the basis of general IoV architecture. IoV is an important branch of IoT, and the MIoT is the concrete application of IoT in the construction of intelligent mine. Therefore, MIoT architecture can be used as an important reference model for MIoV architecture. Zhang Shen\cite{14,15}, Ding Enjie\cite{16,17}, Yuan Liang\cite{18} have made a profound research on the main characteristics, key technologies and specific applications of MIoT, and designed the MIoT architecture with four levels: perception layer, transport layer, data processing layer and application layer.

Synthesizing the hierarchical design and concrete content of IoV and MIoT architecture, we design the MIoV architecture into four levels: perception control layer, network layer, service support layer and application layer, as shown in figure 1.

3.1. Sense and control layer
Sense and control layer realizes information perceiving and feedback control of mine vehicles. This layer is able to perceive position and condition of vehicle, vehicle loading object, drivers and passengers, as well as mine environment element through the sensor. In addition, it also offers automatic feedback to the perceived information through vehicle control devices or execute management operation instruction and control action to realize vehicle control.

3.2. Network layer
The main function of this layer is to realize the network access, data processing, data analysis, and data transmission of various MIoV elements. It can realize V2V(vehicle-to-vehicle) communication through short-range wireless communication, V2I(vehicle-to-Infrastructure) communication through WAN/Intranet/private network, and V2N(vehicle-to-network) communication through the mobile telecommunication network.
3.3. Service support layer
Service support layer of MIoV provides collaborative computing and public service support for application layer. Collaborative computing includes computation collaboration, service collaboration and communication collaboration. Public service capacity includes computation support and general support. Computation support includes computing capacity such as vehicular computing, edge computing, cloud computing and big data processing. General support offers services including M2M control, GIS services, information push services and the other related.

3.4. Application layer
Application layer realizes some particular applications of mine vehicle management, which fall into four types in accordance with human-vehicle-environment-management of mine management. Human-oriented applications include personnel positioning and information interaction and so on. Vehicle-oriented applications include vehicle positioning, driver-less transportation, transportation safety and so on. Environment-oriented applications include environmental monitoring, safety monitoring. Management-oriented applications include production scheduling, transportation management, equipment management. Those applications can also be divided into closed applications and open applications. Closed ones are used within vehicle management systems. While, open ones can be opened to external applications and systems as encapsulates services.

4. Key technologies and typical applications of mine Internet of vehicles

4.1. Key technologies of mine Internet of vehicles
The construction and application of MIoV need relevant technological support, some of which play a key and primary role. Based on the studies of intelligent mine Information system platform\(^{19,20}\) and information systems\(^{21}\), and reference to the key technology of general vehicle networking, we arrive at the key technologies of MIoV as follows.

4.1.1. Positioning and monitoring of mine vehicle: The studies are about realizing the accurate vehicle positioning in open-pit mine and wireless monitoring in underground mine. The former is developed on
the basis of GPS, RFID, GPRS, 5G and the latter one is on the basis of Wi-Fi, RFID, UWB, ZigBee technology.

4.1.2. Intelligent sense and control of mine vehicle: The studies are about the methods realizing environmental perception and autonomous control of mine vehicles. It includes the equipment and methods of detection and identification under harsh mine conditions, the information collection and fusion transmission of human, vehicle and environmental parameters to meet the requirements of IOT and ubiquitous perception, as well as vehicle management and automatic control systems and devices aiming at autonomous driving and driver-less vehicle.

4.1.3. Wireless communication of mine vehicle: This refers to the study of V2X (vehicle-to-everything) networking and communication in different scenarios. It includes V2V which is mainly for anti-collision and coordinated transport, V2N which is mainly for autopilot, line planning, remote control, V2P (vehicle-to-person) which is mainly for driving and monitoring security and V2I which is mainly for production management and environmental perception.

4.1.4. Collaborative computing of MIoV: It studies the cooperative control mode of cloud computing, edge computing and vehicle computing in MIoV in order to reasonably allocate the vehicle and non-vehicle computing resources needed for intelligent mine vehicle and mine vehicle management. It includes the establishment of cloud computing platform and computation offloading system[22] of MIoV, as well as the computing coordination mode of cloud-edge-vehicle, the scheduling strategy of computing resource allocation and the design of computing migration strategy.

4.2. Typical applications of mine Internet of vehicles
In line with the goal of mine information construction, the systematic planning of MIoV application construction around four aspects of human-vehicle-environment-management can guide the relevant industries and enterprises to make clear the research and development direction and investment focus in the application development of MIoV. The reference framework for MIoV application development is shown in figure 2.

![Reference Architecture of MIoV Application](image)

In view of the four aspects of "human-vehicle-environment-management", some typical applications of MIoV should be focused on.

4.2.1. Monitoring system of mine vehicles and drivers: The monitoring system of mine vehicles and drivers is the basic application scene of intelligent mine vehicle management. The goal is to realize the global, dynamic and accurate management of all mine vehicles and drivers. With the support of MIoV, it can, by monitoring not only the dynamic position, working condition and state information of mine vehicles and drivers, visualize the mine vehicle management so as to harness vehicles and drivers.
4.2.2. Driverless and autonomous driving of mine vehicles: Driver-less and autonomous driving accords with the development trend -- the mine production scene with few even no people, and it is the most typical and popular application scene of MIoV at present. Whether in open-pit mining or underground mining, compared with the general traffic environment, mine operation scene is closed with simple traffic condition and small number and less types of traffic participation elements. There is the best condition and prospect to realize driverless and autonomous driving.

4.2.3. Mine safety monitoring related to mine vehicle: With relevant perception equipment and monitoring equipment, mine vehicles, during its usual production operation can perceive and monitor the relevant factors of production environment and natural environment, such as slope monitoring of open-pit mine, deformation of underground roadway, and so on. Thus, it can eliminate monitoring blind spots and reduce the input of equipment and personnel which costed by traditional monitoring methods and means. At present, intelligent patrol vehicle, intelligent patrol robot and other related application are being researched.

4.2.4. Intelligent dispatching system of mine vehicle: MIoV, with transparent, visual and operable mine vehicles, can not only support fine-grained and delicacy management of transportation system management and scheduling, but also realize the rapid iterative optimization of vehicle scheduling model and strategy, thus promoting the development of mine vehicle scheduling from traditional digitization to automation and intelligence, and improving the efficiency and economic benefit of mine production management.

5. Conclusion

With the coming climax of intelligent coal mine construction, it will become an important content of intelligent mine construction, as well as a hot field for mine enterprises and equipment manufacturing industry to apply IoV in mine vehicle management to construct MIoV. Elaboration, design, research and discussion of the concept, architecture, key technology and typical application of MIoV will lay a foundation for the wide application of MIoV in the mining industry. The research and exploration of MIoV and the construction of MIoV can focus on intelligent coal mine, taking into consideration of the technical conditions and production environment of coal mine production, and making use of the existing research results of intelligent coal mine and MIoT, and carry out the further research on the application of MIoV from four aspects: human, vehicle, environment, management. MIoV has the characteristics of clear service object and application demand, relatively centralized application technology and field, easily unified implementation and evaluation standard. So, MIoV is likely to be the first important field to obtain application and breakthrough in the construction of intelligent MIoT.

References

[1] ZHANG Ruixin, MAO Shanjun, HONGZE Z. Framework and structure design of system construction for intelligent open-pit mine[J]. Coal Science and Technology. 2019, 47(10): 1-23.
[2] WANG Guo'ai, LIU Feng, PANG Yihui. Coal mine intellectualization: The core technology of high quality development[J]. Journal of China Coal Society. 2019, 44(02): 349-357.
[3] WANG Guo'ai, LIU Feng, MENG Xiangjun, et al. Research and practice on intelligent coal mine construction(primary stage)[J]. Coal Science and Technology. 2019, 47(08): 1-36.
[4] LI Honggang, WANG Yunpeng, LIAO Yaping. Perception and control method of driverless mining vehicle[J]. Journal of Beijing University of Aeronautics and Astronautics. 2019, 45(11): 2335-2344.
[5] CUI Yazhong, BAI Mingliang, LI Bo. Key technology and development research on big data of intelligent mine[J]. Coal Science and Technology. 2019, 47(03): 66-74.
[6] JIANGUO H. Key technology research and demonstration of intelligent mines in Shenhua Group[J]. Journal of China Coal Society. 2016, 41(12): 3181-3189.
[7] WANG Guofa, WANG Hong, REN Huaiwei, et al. 2025 scenarios and development path of intelligent coal mine[J]. Journal of China Coal Society. 2018, 43(02): 295-305.

[8] WANG Guofa, PANG Yihui, LIU Feng. Specification and classification grading evaluation index system for intelligent coal mine[J]. Coal Science and Technology. 2020, 1: 1-13.

[9] WANG G, DU Y. Coal mine intelligent standard system framework and construction ideas[J]. Coal Science and Technology. 2020, 48(01): 1-9.

[10] Wang Qun, Qian Huanyan. Architecture and Key Technologies for Internet of Vehicles[J]. Telecommunications Science. 2012, 28(12): 1-9.

[11] LIU Xiaoyang, WU Minyou. Vehicular CPS: an application of IoT in vehicular networks[J]. Journal of Computer Applications. 2012, (04): 900-904.

[12] LI Jinglin, LIU Zhihan, YANG Fangchun. Internet of Vehicles: The Framework and Key Technology[J]. Journal of Beijing University of Posts and Telecommunications. 2014, (06): 95-100.

[13] Yang, Fangchun, Li Jinglin, Lei Tao, et al. Architecture and key technologies for Internet of Vehicles: a survey[J]. Journal of Communications & Information Networks. 2017, 2(2): 1-17.

[14] ZHANG Shen, ZHANG Tao. Discussion of structured platform and service platform of mine Internet of things[J]. Industry and Mine Automation. 2013, 39(01): 34-38.

[15] ZHANG Shen, HU Qingsong, WANG Gang. Consideration about construction of standards for mine Internet of things[J]. Industry and Mine Automation. 2018, 44(01): 1-5.

[16] DING Enjie, ZHAO Zhikai. Research advances and prospects of mine Internet of Things[J]. Industry and Mine Automation. 2015, 41(05): 1-5.

[17] DING Enjie, SHI Weizhu, ZHANG Shen, et al. Top-down design of mine Internet of things[J]. Industry and Mine Automation. 2017, 43(09): 1-11.

[18] YUAN Liang. Framework and key technologies of Internet of things for precision coal mining[J]. Industry and Mine Automation. 2017, 43(10): 1-7.

[19] QIU Shuohan, TAN Zhanglu. Study on index system of intelligent mine construction degree in coal enterprises[J]. Coal Science and Technology. 2019, 47(10): 259-266.

[20] YIHUI P, GUOFA W, HUAIWEI R. Main structure design of intelligent coal mine and key technology of system platform construction[J]. Coal Science and Technology. 2019, 47(3): 35-42.

[21] TANG Hailong. Interpretation of general technical specifications for smart mine information systems and discussion on its key technologies[J]. Coal Science and Technology. 2018, 46(S2): 157-160.

[22] ZHANG WenLi, GUO Bing, SHEN Yan, et al. Computation Offloading on Intelligent Mobile Terminal[J]. Chinese Journal of Computers. 2016, 39(05): 1021-1038.

J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.