The scope of the column includes IoT technological achievements that have social impacts and/or incorporate social factors. Each column will provide knowledge and insights in the most recent developments, cutting-edge applications, latest deployments, and conceptual innovations, and of course, their implications on our society. I hope the columns will be meaningful in understanding how our society interacts, adopts, adapts to, and changes with IoT technological advancements.

INTRODUCTION

COLUMN EDITOR
Jun Zhang

How IoT technology and autonomous vehicle technology integrate for advancing vertical industrial applications? This article may provide an example of such enormous potential in the mining industry.

IoT Based Automation of Mine Transportation: From Conception to Realization

by Yu Gao, Feiyue Wang, Yunfeng Ai, Dongpu Cao

ABSTRACT

The application of automated driving technology will become a concentrated demand for enterprises in 2019. As autonomous driving on public open roads cannot be realized in a short time, the commercialization on closed areas and fixed routes such as mining sites, parks, ports, logistics distribution, and sanitation sites are the first choice for all parties. In this article, we explain how autonomous driving in mining areas will be the most reliable and fastest application area to develop. An IoT mining system has been designed and simulated and is described in the paper.

The field of autonomous driving has been an area of much investment over the last decade, attracting the largest industrial players in technology, automobile manufacturing, tires, and many start-ups. However, after several years of rich enthusiasm for fast results, autonomous driving has entered a period of calmer development and drawbacks on expectations. In addition to concerns on profitability and development expectations, autonomous driving related asset valuation in the capital market have declined by varying degrees. Profitability and commercialization has become inevitable choices and strong demands for autonomous driving industry. Startup companies seek to attract more developmental funds by technology application, including road testing or commercial use,while large companies seek to capture market segments by immediately delivering technology implementation.

Normally the autonomous driving capability is divided into five levels; however, there might be decades before it finally and completely comes to reality. There are many barriers to success for full commercial adoption of driverless vehicles on public roads. Complex traffic conditions and signs, unpredictable behavior of road participants, and unstable hardware-software systems are all obstacles for driverless cars to move to urban and public roads. Thus, with these barriers in open and public areas, commercialization on private and closed areas with fixed routes becomes the most desirable alternative that can advance.

AUTONOMOUS MINING: THE MOTIVATION

There are abundant motivations for adopting autonomous driving in the mining industry:

1. Labor intensity and a harsh working environment raise challenges for human performance, such as long shifts and repetitive operation of large equipment which can cause fatigue and safety risks, leading to higher rates of workplace accidents.
2. Employment shortage and a lack of skilled heavy machinery operators for the mining industry emerge as a major problem for this industry.
3. In terms of labor cost, salary and accommodation of mining vehicle operators and drivers account for 30 to 60 percent of the whole mine expenditure.
4. Due to inexperienced operational skills and poor driving habits, human driving could cause severe wear and tear of mining equipment, high fuel consumption and other issues.

As a result of these factors, automated driving technology has a strong fit with the mining industry to address such challenges, improve efficiency and decrease operational risk.

IoT BASED AUTONOMOUS MINES

In the last decade, the emergence of integrated communications and control systems has enabled the development of much more complex autonomous systems. Recently, Internet of Things (IoT) technology has also been incorporated to improve the safety of personnel and equipment, reduce the cost of mining operations, and enhance production capacity.

Roads in mining sites are normally highly undulating with impacts of dust and sand, which greatly reduces the effective perception range of sensors. Even if advanced sensing technology is equipped in an autonomous truck, poor perception ability may still be an issue with high costs and low reliability. Therefore, it is merely impossible to rely on just one single mining vehicle's perceptual results to make safe and efficient decisions in complex mine traffic scenarios.

As a mine site has a very strict management system, all equipment and personnel entering the operation area are closely monitored. IoT technology enables the mine management and control center to receive all perceptual results, such as vehicle localization, status information and surrounding environment perception information, by V2X communication, which is a type of communication with vehicle to everything. As a benefit from IoT based management and control, the sensor configuration for each autonomous truck is reduced, with significant cost savings.

The networked multi-vehicle autonomous driving system mainly includes three modules: the center-side, the transmission-side and the equipment-side. Among them, the center-side includes the management and control center, and the remote take-over system. The transmission-side includes the V2X wireless communication system and real-time kinematic Global Positioning System (RTK-GPS). The equipment-side includes the truck autonomous driving system, the excavator cooperative management system, the bulldozer cooperative management system, manned vehicle management system and roadside awareness system.

The management and control center is the core system developed for the management and dispatching of machineries at open-pit mines. Taking into account the efficiency, fuel

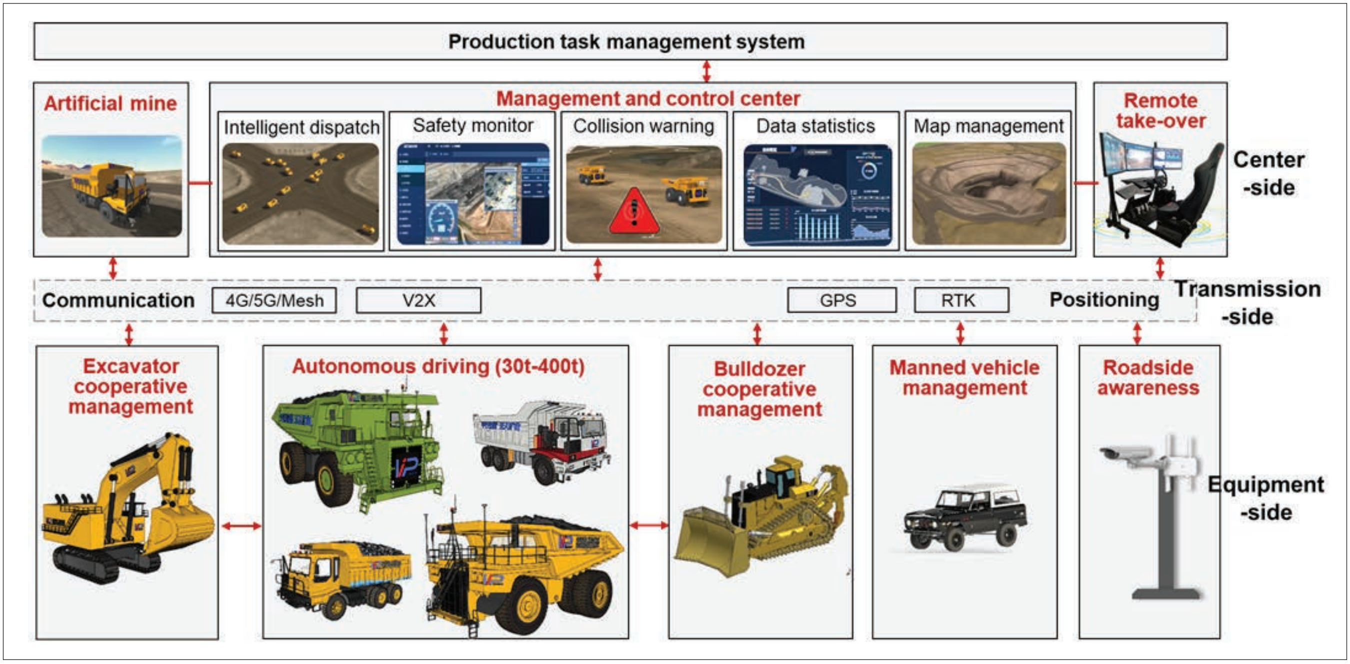

FIGURE 1. The architecture diagram of parallel mine.

economy and sensor life, a computing engine is built within the management and control center for mine production activities through continuous calculation, planning and management.

Through receiving dispatching and operation instructions issued by the center, the autonomous driving truck and excavator work together for the integrated operation process of collaborative loading, unmanned transportation and automatic unloading. The bulldozer cooperative management system is responsible for guiding the autonomous driving truck into the dump site, so as to realize the automatic dumping operation. The remote take-over system is responsible for monitoring the production and operation of the autonomous driving truck, and conduct remote take-over actions in case there is the need for an operator management intervention or recognition of an emergency situation.

An artificial mining system is established in the computing facilities as a parallel imaging of the real mining system. Through the IoT link, state information of the autonomous vehicles in the real world are reproduced in the artificial systems. A large number of possible operational scenarios are constructed in the artificial system, based on which decisions and strategies are synthesized for intelligently managing vehicle dispatching and autonomous driving. The communication facilities of the mining system adopts V2X architecture, which can realize network connection of vehicle to vehicle (V2V), vehicle to road (V2I), vehicle to pedestrian (V2P) and vehicle to service center (V2N).

Up to now, the autonomous driving trucks in the system have run more than 50,000 kilometers, and moved more than 800,000 tons surface materials. At present, the overall efficiency of unmanned transportation is close to that of human drivers, while it saves the costs of drivers, solves the problem of labor shortage in mining enterprises, and avoids the occurrence of safety accidents.

Conclusions

The IoT based autonomous vehicle system for mining applications has enormous potential for increased adoption, and 24-hour continuous mining operation is made possible. Labor costs are decreased due to reduced expenditures on drivers,

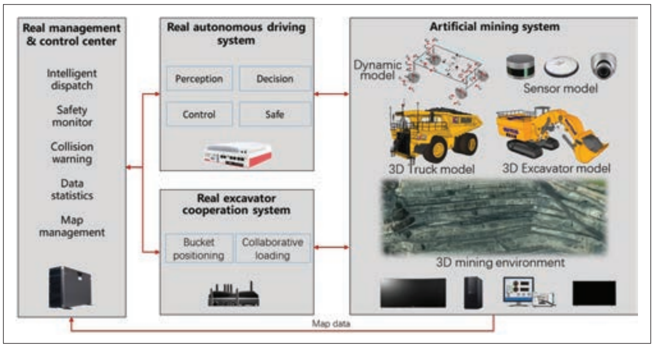

FIGURE 2. Artificial mining system for simulation.

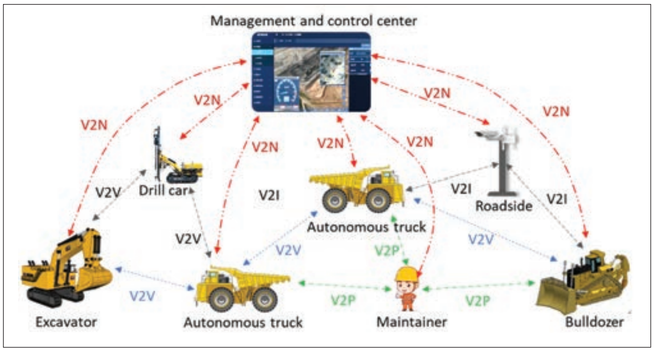

FIGURE 3. Schematic diagram of network transmission structure.

and mining process safety is improved due to fewer potential accidents from human driver error or fatigue. Operational costs are reduced due to precise operation of machinery and reduced fuel costs. The adoption of IoT based mines may also decrease insurance costs, leasing and maintenance of vehicles, leading to higher rates of return for mine owners.

IoT based autonomous mines have recently entered into a partnership with XCMG Group, Aerospace Heavy Industry Co., Ltd., Inner Mongolia North Hauler Joint Stock Co., Ltd., and LGMG Group, to build unmanned mining systems. These systems were then deployed at various sites in China, including three vehicles placed into operation in Wushan (China Gold Group), five trucks at the Shenbao Coal Mine (China Energy Investment Corp.), and six trucks at the Baoli coal mine (China Datang Corp. Ltd.). Each of these engagements were made with parallel mine autonomous systems (PMAS), and will further promote the use of IoT in the mining industry, and serve as examples of development to promote IoT intelligent networked industrial systems.

Biographies

Yu Gao is the Deputy Director of the Institute of Technology and a Project Director at the Institute of Engineering, Vehicle Intelligence Pioneers Inc., Shandong, China. He received his Ph.D. Degree in mechanical engineering from the University of Science and Technology Beijing, China, in 2018. He worked as a visiting scholar in the Center for Automotive Research at the Ohio State University, Columbus, OH, USA, from 2016 to 2017. His research interests include parallel autonomous mining, planning and control for autonomous vehicles, modeling of off-road vehicles, and vehicle dynamics control.

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Dongpu Cao is an associate professor at the University of Waterloo, Canada. He received his Ph.D. degree from Concordia University, Canada, in 2008. His research focuses on vehicle control and intelligence, automated driving and parallel driving, where he has contributed more than 180 papers and two books. He received the ASME AVTT'2010 Best Paper Award and 2012 SAE Arch T. Colwell Merit Award. He serves as an associate editor for *IEEE Transactions on Vehicular Technology*, *IEEE Transactions on Intelligent Transportation Systems*, *IEEE/ASME Transactions on Mechatronics*, *IEEE Transactions on Industrial Electronics*, *IEEE/CAA Journal of Automatica Sinica*, *ASME Journal of Dynamic Systems, Measurement and Control*, and the *International Journal of Vehicle Design*. He has been a member of the SAE Vehicle Dynamics Standards Committee and the Co-Chair of the IEEE ITSS Technical Committee on Cooperative Driving. He was a Program Co-Chair for IEEE IV 2018.

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