Internet of things based 3D assisted driving system for trucks in mines

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***Abstract*—To reduce the surface mining accidents related to low visibility conditions and the truck blind spots, to provide the 3D information for the truck drivers and real time monitored truck information for the remote dispatcher, the 3D assisted driving system (3D-ADS) based on the internet of things, using the GPS, the mesh-wireless networks and the Google-Earth engine as the graphic interface and mine-mapping server was developed. The research results indicate that 3D-ADS system potentially increases reliability and reduces uncertainty in open pit mining operations by customizing the local 3D digital mining map, constructing the truck 3D models, tracking vehicles in real time using a 3D interface and indicating available escape routes for driver safety.**

Keywords-Internet of things; mine safety; assisted driving system; haul truck

I. INTRODUCTION

According to the analysis of surface powered haulage accidents, MSHA reported 1300 fatal accidents from 1990 to 2005. Of these, 163 were considered off-highway truck haulage accidents, and at least 23 involved collisions of an off-highway truck with a neighboring vehicle or a worker on foot. [1] In general, an average of 18 non-fatal accidents and 3 fatal accidents occurred in open pit mining per year when equipment backed over the edge of an embankment, stockpile, or dump point. [2].

The specific problems that need to be solved can be determined by carefully studying the accidents involving haulage trucks. [3] In surface haulage, human performance becomes a critical issue because of the unusual demand the vehicle's places on their human operators. [4, 5]

Driver visibility and communications are key issues to reduce mining truck accidents. [6]Analysis of fatalities and injuries involving mining equipment demonstrates the need to develop new intervention and control strategies to mitigate the risks associated with mining equipment operation. [7, 8]

To reduce the surface mining accidents related to low visibility conditions and the truck blind spots, to provide the 3D information for the truck drivers and real time monitored truck information for the remote dispatcher, the 3D assisted driving system (3D-ADS) based on the internet of things, using the GPS, the mesh-wireless networks and the Google-Earth engine as the graphic interface and mine-mapping server was developed.

II. SYSTEM FRAMEWORKS

The 3D assisted driving system (3D-ADS) datum are acquired by all kinds of wireless sensors, processed by the cloud computing platform, and then broadcasted to the terminals either on PDA or the clients. The 3D-ADS is based on the internet of things (IOT) which is under the security technology and management concept generally. The 3D assisted driving system consists three layers as the sensor layer, the network layer and the application layer. The framework of 3D-ADS is showed in Fig 1.

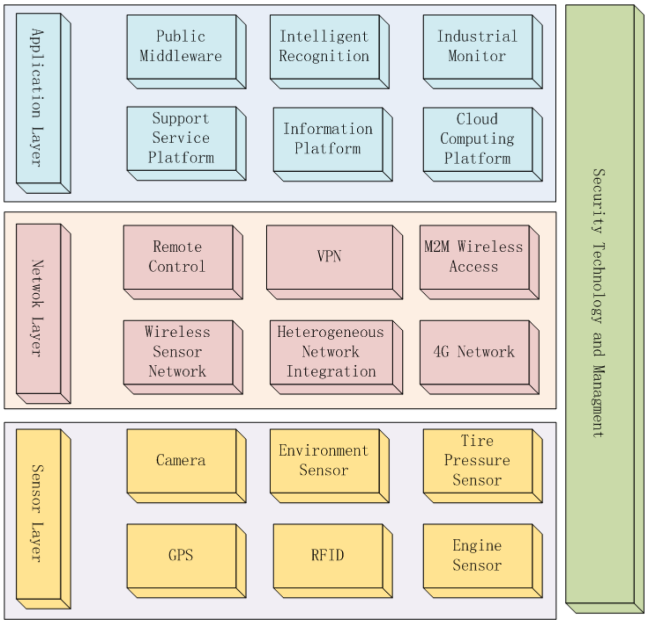


Figure 1. The frameworks of 3D-ADS

A. *The sensor layer*

Sensor layer is the core data acquiring component and the basic layer in the 3D-ADS. Different kinds of sensors, such as the drill hole pressure sensor, water level sensor, deformation sensor etc, are applied to acquire the tailings dam data. The sensors are mostly wireless sensors, which typically consist of a large number of low-cost, low-power, and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are small in size, but are equipped with sensors, embedded microprocessors, and radio transceivers, and therefore have not only sensing capability, but also data processing and communicating capabilities.

These sensors communicate over a short distance via a wireless medium and collaborate to accomplish a common task. Compared with traditional wireless communication networks, for example, cellular systems and MANET, sensor networks have the following unique characteristics and constraints:

- Dense Node Deployment. Sensor nodes are usually densely deployed in a field of interest. The number of sensor nodes in a sensor network can be several orders of magnitude higher than that in a MANET.
- Battery-Powered Sensor Nodes. Sensor nodes are usually powered by battery. In most situations, these sensors are deployed in a harsh or hostile environment, where it is very difficult or even impossible to change or recharge the batteries.
- Severe Energy, Computation, and Storage Constraints. Sensor nodes are highly limited in energy, computation, and storage capacities.
- Self-Configurable. Sensor nodes are usually randomly deployed without careful planning and engineering. Once deployed, sensor nodes have to autonomously configure themselves into a communication network.
- Application Specific. Sensor networks are application specific. A network is usually designed and deployed for a specific application. The design requirements of a network change with its application.
- Unreliable Sensor Nodes. Sensor nodes are usually deployed in harsh or hostile environments and operate without attendance. They are prone to physical damages or failures.
- Frequent Topology Change. Network topology changes frequently due to node failure, damage, addition, energy depletion, or channel fading.
- No Global Identification. Due to the large number of sensor nodes, it is usually not possible to build a global addressing scheme for a sensor network because it would introduce a high overhead for the identification maintenance.

B. The network layer

The network layer includes the remote control, VPN, M2M wireless access, wireless sensor network, heterogeneous network integration and the fourth generation network. The network layer bridges the sensor layer and the application layer.

The network layer is responsible for routing system packets delivery including routing through intermediate routers, whereas the data link layer is responsible for media access control, flow control and error checking. The network layer provides the functional and procedural means of transferring variable length data sequences from a source to a destination host via one or more networks while maintaining the quality of service functions.

The network layer of 3D-ADS makes it possible to monitor the tailings dam in anywhere on anytime. Its networks are partitioned into sub networks and connect to other networks for wide area communications. Networks use specialized hosts, called gateways or routers to forward packets between networks. This is also of interest to mobile applications, where a user may move from one location to another, and it must be arranged the messages. Version 4 of the internet protocol (IPv4) was not designed with this feature in mind, although mobility extensions exist. IPv6 has a better designed solution.

C. The application layer

The application layer is the top level of the 3D-ADS structure. Basically it is based on the support service platform, information platform and the cloud computing platform to accomplish the 3D-ADS functions through public middleware, intelligent recognition and the industrial monitor.

The cloud computing platform deals with the entire sensors layer datum transferred by the network layer, which is a technology that uses the internet and central remote servers to maintain data and applications. Cloud computing allows users to use applications without installation and access personal files at any computer with internet access. This technology allows for much more efficient computing by centralizing storage, memory, processing and bandwidth. The information platform is mainly to promote, share and exchange information on the tailings dam monitoring issues in different regions. The information platform aims to illustrate the tailings dam monitored datum graphically, which are calculated after the cloud computing platform. The support service platform provides the concerned support service to the 3D-ADS users. All the system problems can be solved online on time. Any errors or abnormal behaviors are logged in the server.

III. GOOGLE EARTH BASED GRAPHICAL DISPLAY

The main advantage of 3D-ADS is that it works using commonly available technologies: the GPS as the geo-reference solution to pinpoint truck locations using satellites, and Google Earth graphics engine as a user-friendly, yet powerful 3D graphical interface including basic Geographic Information System (GIS) capabilities.

The 3D-ADS is able to display all kinds of geographical information overlaid on the surface of the virtual mine. It is a web base map client featuring GIS capabilities which are used to store and display any kind of sensorial information produced by the mine equipment. It supports and manages three-dimensional geospatial data using the Keyhole Markup Language (KML), the standard markup language used in GE. KML files are Keyhole Markup Language used by XML language to represent geographic locations which uses a tag-based structure with nested elements and attributes.

The 3D-ADS and its GE interface feature a combination of dynamic zooming based on the GE 3D model of the Earth using surface images taken from satellite imagery and aerial photography. When zooming into a specific mine, system view switches from GE maps to AutoCAD maps previously loaded in the computer server. This process improves and enhances the quality of the graphical information given to the operator and the system manager.

In Fig.2 a mining truck is being tracked using the 3D-ADS based on the GE 3D interface.

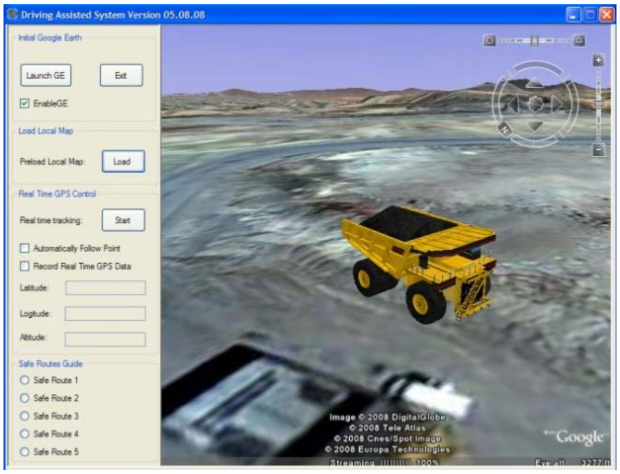


Figure 2. 3D display of real time tracked truck

A. 3D map customization and uploading

The key issue behind the local 3D map conversion is to accurately adjust the AutoCAD mine map to the GE coordinate system to ensure that the local 3D mine model precisely overlays and displays the GE geographic model.

The 3D-ADS internal coordinate system is based on geographic coordinates (latitude and longitude) projected from the 1984 World Geodetic System (also known as the WGS84). If local mine maps are based on UTM coordinates (Universal Transverse Mercator) or local state coordinates. The UTM mine maps must be converted into WGS84. According to the transform formula showed below:

$$\begin{bmatrix}X\\ Y\\ Z\end{bmatrix}_D = \begin{bmatrix}X\\ Y\\ Z\end{bmatrix}_G + \begin{bmatrix}\Delta X\\ \Delta Y\\ \Delta Z\end{bmatrix} + \begin{bmatrix}0 & -Z & Y & X\\ Z & 0 & -X & Y\\ -Y & X & 0 & Z\end{bmatrix}_G \begin{bmatrix}\xi_X\\ \xi_Y\\ \xi_Z\\ K\end{bmatrix} \tag{1}$$

It includes seven transformation parameters which are three rotation parameters ($\Delta X \Delta Y \Delta Z$), three translation parameters ($\xi_X \xi_Y \xi_Z$) and one scale factor K_0. If there are more than three public points, the seven transformation parameters could be solved from the adjustment by method of points. According to the transformation parameters, all the point coordinates can be transformed into WGS84 by the formula one.

To generate and import 3D mine map in 3D-ADS, a geo-reference point consistent with both maps (UTM and Geodetic) must be defined according to an equivalent point in the WGS84 coordinate model. From the 3D-ADS map-conversion window, the user selects a point in the AutoCAD DWG map (X, Y) and then defines the geodetic location with its equivalent longitude and latitude.

To adjust terrain elevations with respect to the GE model in the original mine map, the user can compensate both maps by fine tuning the relative vertical position to ground level, sea level, or by draping the mine map over the GE model. The system manager gives offset values by defining north-south, east-west, and elevation.

The 3D-ADS map keeps all original requested AutoCAD information and its attributes, such as color, lines.

B. Uploading the local 3D mining map

After the system manager has preprocessed the local 3D mining map, the next step is to upload the local 3D mine map to the system server and to each vehicle. There are two approaches to upload files according to the host receiving the data (maps, roads, etc). One is to locally upload the mine map to the local server using the networked intranet. The second approach is to remotely upload the mine map to every equipped vehicle in the mine using the wireless network.

The map is renamed with an extension KMZ format. KMZ are KML files which have been compressed or zipped. When a KMZ file is unzipped, a single KML file is decompressed along with any overlay and icon images referenced in the KML geographic map.

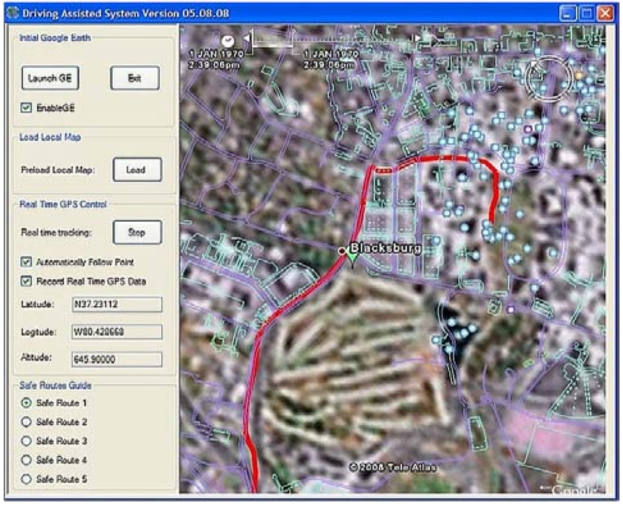
C. Real-time tracking and monitoring

The objective of the 3D-ADS is to provide guidance to mine vehicle operators and truck drivers by displaying safe routes when low visibility is present if the driver or operator requests it. If the 3D-ADS system is turned on, a line representing the safe route is shown on the mine map as an added roadmap layer. From the touch screen onboard computer the driver selects the safe route according to the truck's current location. The driver can choose between different path alternatives using the computer interface. Besides having full control of the assisted driving system from inside the vehicle's cab, the system manager can remotely load and turn the safe routes and maps to provide route information if requested by the operator.

One of the most powerful features within GE is the network link. The network link enables users to access geographic data on a local machine, or on an internet networked computer. This geographic information is based on the KML file which is the standard format supported by GE. The 3D-ADS running at the server uses the network link function to update the truck's GPS coordinates. The truck's GPS location is then displayed by the 3D-ADS client. The network link can automatically refresh or can be updated on demand by the user depending on operating conditions.

After starting the real-time GPS tracking function, a green dot is used by the 3D-ADS to represent the truck position. Real-time latitude, longitude, and altitude are displayed on the panel as seen in Fig 3.

The truck driver can change the interface view by tilt, altitude, and angle setting. The tilt determines the vertical angle of the virtual camera relative to the vertical axis. The automatic follow-view option is another useful camera view function. If the driver loses the current view, this feature helps the driver to quickly regain his current position. This system provides a GPS data record function useful for historic operational data analysis. The entire vehicle data is stored in the central server for further analysis. Safe routes are calculated based on the entire set of historic GPS data using updated mine maps as the main geographic reference.



☑ EnableGE

Preload Local Map:

Real time tracking:

☑ Automatically Follow Point

☑ Record Real Time GPS Data

Latitude: N37.23112

Logitude: W80.428668

Altitude: 645.90000

● Safe Route 1

○ Safe Route 2

○ Safe Route 3

○ Safe Route 4

○ Safe Route 5

Figure 3. Real-time truck positioning (dot in green) and safe route (line in red)

IV. CONCLUSIONS

The 3D Assisted Driving System (3D-ADS) is the first system proposed for mining and earth moving operations that integrates GE with dynamic equipment GPS positioning, using local AutoCAD maps to augment graphic information in GE. It is a reliable safety and warning complement in mining and construction operations. It potentially increases safety reliability and reduces decision-making uncertainty when low visibility conditions exist (due to snow, rain, dust, etc.) in open pit mining operations.

The research results indicate that 3D-ADS system potentially increases reliability and reduces uncertainty in open pit mining operations by customizing the local 3D digital mining map, constructing the truck 3D models, tracking vehicles in real time using a 3D interface and indicating available escape routes for driver safety.

The system is being tested and under continuous development in the future. A Real-time map loading function should be developed to improve map-server reliability. Usability of this system can be expanded to include the collection of different types of sensors (such as vibration, temperature, humidity, etc.), displaying real-time map layers according to the sensor's data.

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REFERENCES

[1] SUN En-ji, Antonio Nieto, LI Zhong-xue, Vladislav Kecojevic. "An integrated information technology assisted driving system to improve mine trucks-related safety". Safety Science.2010, vol. 48,10, pp 1490-1497.

[2] ZHANG Xing-kai, WANG Qi-ming, XIANG Gui-sheng. "Analysis of current safety situation of metal and non-metal tailing pond. Journal of Safety Science and Technology". 2006, vol. 2, 2, pp 60-62.

[3] Nieto A, Dagdelen K. "Development of a Dump Edge and Vehicle Proximity Warning System Based on GPS and Wireless Networks to Improve Safety in Open Pit Mines". SME Transactions, 2006, vol. 320, pp 11-20.

[4] M. Ricoa, G. Benitob, A.R. Salgueiroc, A. Díez-Herrerod and H.G. Pereirac. "Reported tailings dam failures: A review of the European incidents in the worldwide context". Journal of Hazardous Materials [. 2008, vol. 152, pp 846-852.

[5] Shigeyasu Okusa,So Anma. "Slope failures and tailings dam damage in the 1978 Izu-Ohshima-Kinkai earthquake". Engineering Geology. 1980, vol. 16, 3, pp 195-224.

[6] Pyles J, Woodrome M., South J, Zenone M, Blanton A, Fredland J, Skrabak R, Vamossy S, Conrad D. "Report of Investigation—Fatal Powered Haulage Accident. Mine Safety and Health Administration". 2003, vol. 9, pp 25-26.

[7] Ruff T. "Evaluation of a radar-based proximity warning system for off-highway dump trucks. Accident Analysis and Prevention". 2006, vol. 38,pp 92-98.

[8] Groves W A, Kecojevic V, Komljenovic D. "Analysis of fatalities and injuries involving mining equipment". Journal of Safety Research. 2007, 38(4) ,pp 461-470.