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An integrated information technology assisted driving system to improve mine trucks-related safety

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ABSTRACT

This paper presents the conceptual model and framework of a novel information technology assisted driving system (ADS) to help improve mine trucks-related safety. The main components of the system include a real-time Google Earth (GE) graphics, GPS, a wireless communication network, a truck driver's fatigue detection system, and an enhanced visibility display to restore degraded images when operating under severe visibility conditions. Mine trucks are traced and proximity warning is provided using GPS, IP addressable radios for wireless data transmission, and the GE graphic interface. Driver's fatigue levels are detected and assessed using face tracing, extraction of eye features, and fatigue recognition algorithms. Development of such integrated information technology assisted driving system has a potential to be applied in coal, metal and non-metal surface mining operations.

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1. Introduction

Trucks are primary means of material haulage in surface mining operations. They are well-suited for hauling different types of material to various destinations. As the size and use of trucks have increased, so has the concern regarding the safety.

The severity and number of fatal and non-fatal injuries involving trucks are higher when compared to all other mining equipment. According to Md-Nor et al. (2008), there were 516 fatal injuries in the United States between 1995 and 2006 attributed to the general category of equipment. A total of 113 fatal injuries or 21.8% were truck-related. Mine Safety and Health Administration (MSHA, 2010) records indicate that additional 15 fatal injuries were attributed to trucks from 2007 through 2009. Kecojevic and Radomsky (2004) have established nine root causes, while Md-Nor et al. (2008) have defined 16 major hazards that contributed to truck-related fatal injuries. Additional analysis of equipment-related fatal and non-fatal injuries for mining equipment in general, and trucks specifically, was conducted by the Groves et al. (2007), and Nieto and Dagdelen (2006). These studies indicated that some of the major contributing factors to fatal and non-fatal injuries involved the lack of visibility, road conditions, truck-driver behavior and operational conditions, and weather conditions.

Mine trucks are massive and extremely large equipment, and driver's cabin occupies just a small upper section of the body. This results in large blind spots in the rear, front, and sides of the truck. Additional factors include lack of truck maneuverability, and the long response time due to the sheer mass-momentum of the vehicle. Mine road conditions include factors such as rolling resistance, curves, grades, and limited road width. Potential accidents are heavily dependent upon driving behavior and the driver's operational condition such as attention, fatigue level, training, experience, and skills. Accidents are also attributed to weather conditions such as rain, snow, and fog. Application of real-time systems with graphic displays providing road and vehicle proximity information, improved driver's awareness, and enhanced visibility during poor-visibility conditions may be one of the approaches to address these problems.

Text that follows describe a conceptual model and framework of an integrated information technology assisted driving system (ADS) that includes real-time Google-Earth graphics, GPS, a wireless communication network, a truck driver's fatigue detection system, and an enhanced visibility display to restore degraded images when operating under severe visibility conditions.

2. Conceptual model and framework of the ADS system

The system consists of four major layers: application, transmission, management, and database. The application layer relates to truck data acquisition component and the Google Earth (GE) 3D

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Interface. The transmission layer is related to the dataflow between truck terminals and the remote server, while the management layer handles the operational database and truck monitoring (data input, data output, data inquiry, and data updates). The database layer is the foundation of the system and is composed of the GPS database, database of truck physical properties, database of road features, mapping information, and the 3D model database.

As shown in Fig. 1, the system consists of GPS hardware used for truck allocation monitoring and mine mapping, the Google Earth (GE) 3D graphics engine for displaying the 3D mine geometry and equipment. Google Earth (GE) is also used as the GIS interface using the Keyhole Markup Language (KML) mapping format, a dashboard-mounted infrared camera for face recognition and fatigue assessment, and external CCD video-cameras for monitoring blind spots and enhancing mine visibility. A charge-coupled device (CCD) is an image sensor used in digital cameras to measure photoelectric charges. The conceptual model and framework of the integrated ADS system is illustrated in Fig. 1.

3. Google Earth and proximity warning

One of the most important features of the ADS system is the user friendly real-time Google Earth (GE) graphics engine. It allows an easy visualization of roads and trucks in the mine. Coupled with the proximity warning feature, ADS tracks the location of trucks and dynamically updates their locations and resolves for proximity in real-time. Roads and truck operational and maintenance data (if the vehicle is equipped with sensors) are geo-tagged and displayed as geographical layer. Fig. 2 illustrates the truck GE 3D interface.

The ADS is able to customize and add vehicle geo-sensorial information as needed. For example, tire pressure, oil temperature, and vibration data can be monitored and tagged to the mine map and make the information available through various online sources as GIS layers. Local mine maps can be updated in 3D, the status of trucks through their ID–IP network addresses can be inquired, the GPS locations for each truck can be checked, and working conditions can be reviewed by selecting trucks displayed on the touch screen server interface. Based on updated mine maps, the 3D mine geometry, and current vehicle locations, the ADS provides pre-recorded vehicle tracking routes, and define new safety routes, mine roads, and mine ramps. In case of low visibility conditions, the truck driver can display his current location with respect to the mine map by simply selecting the 'find truck' button on the screen. The driver can also display safe routes and roads to track the vehicle position automatically. The ADS system alerts the driver when his truck diverts from the pre-defined route with visual and audio warnings.

Another feature of the ADS system is the ability to link to a wireless network. The network link feature enables access to geographic data on both the stand-alone local computer and network based environment. Geographic map information shared by the system is based on the KML format which is the standard format supported by Google Earth. The truck GPS location is updated at the server using the network link, and then it is displayed on the client computer. The network link can automatically refresh or update the information depending on the required operating tasks and conditions.

After starting the ADS real-time GPS tracking function, a digital green dot is used to represent the truck position with respect to the mine map. Real-time latitude, longitude, and altitude are shown on the truck panel. An automatic follow-up view option is also provided. If the driver loses his current location view, this feature helps to quickly regain the current position on the screen. In addition, the system has a GPS data recording function used to store and perform operational analysis based on historic truck records. The entire truck data is stored in digital form in the computer central server for further analysis. Fig. 3 shows the location of a truck following a pre-determined safe route in real-time using the ADS Google Earth as the mapping and computer interface.

In the case of low visibility conditions, truck drivers need to be aware of objects in close proximity to truck including workers, other vehicles and mobile equipment, fixed mining installations, buildings, etc. The objective of a visual aided proximity warning system is to serve as an early warning system. It should be noted that some commercial industries including aviation, transportation and construction have been investigating a potential application of GPS-based proximity warning systems. However, a mining industry operates in a completely different environment and a pioneering research was previously conducted by Schiffbauer (2001), Nieto (2002) and Ruff (2007).

The ADS system proposed here provides a user friendly 3D interface using audible and visual warnings to alert the driver of potential collision with other vehicles or objects. Each truck has a proximity warning zone that is adjusted accordingly to its weight, speed, size, and, resulting blind spots. At the same time, the system measures the driver's response time to the detected

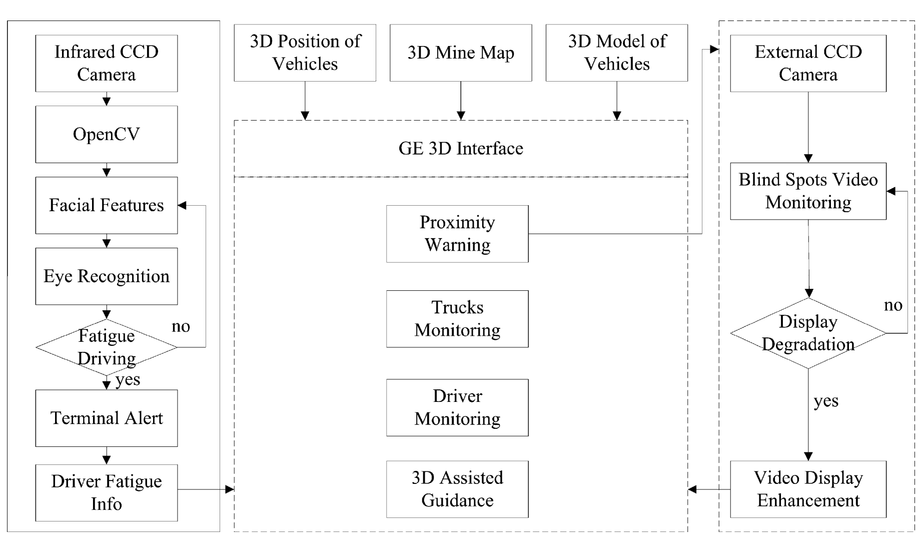

Fig. 1. Framework of the mine truck ADS system.

Fig. 2. Real-time truck monitoring in 3D based on Google Earth (Nieto and Sun, 2010).

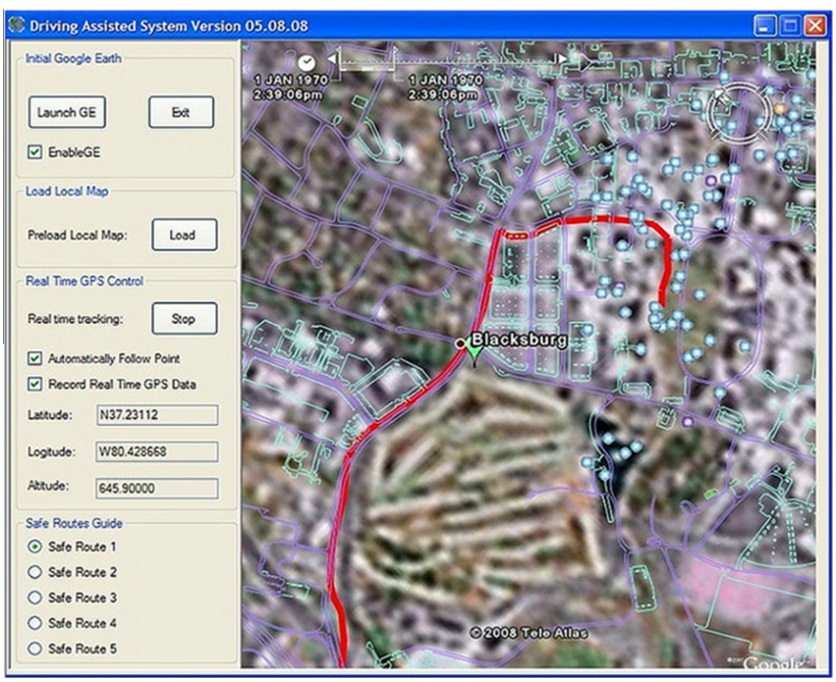

Fig. 3. Real-time truck positioning, local 3D map and safe routes (Nieto and Sun, 2010).

object. If another truck or objects is detected inside the warning zone, information such as 2D location, 3D position, proximity distance, 3D model and ID number will be shown on the screen.

Fig. 4 shows an example where one haul truck is moving in close proximity to another moving truck which has a proximity zone of 60 m radius and a warning zone of 20 m. The system traffic light changes from green to yellow when an object inside the proximity zone is detected and to red when the object is detected inside the warning zone. Alarms signals are generated whenever another vehicle is detected in either zone.

4. Truck driver fatigue detection and warning

Human fatigue was previously studied in transportation industry, and in aviation by Caldwell (2004). However, very little research was conducted in mining industry. Truck driver fatigue or drowsiness is one of the major concerns that can cause truck accidents in surface mining operations (Bartels et al., 2008). Monitoring driver fatigue levels and providing timely warning can help improve truck safety and reduce accidents. However, monitoring fatigue of haul truck drivers is challenging due to complex working

Fig. 4. Simulation of proximity warning for haul trucks in surface mining.

conditions in surface mining operations such as truck vibration, road condition, illumination inside the truck cab which varies as working hours shift between day and night, weather, and atmospheric conditions. The ADS has a capability to determine the position of the driver head and face, and senses eye geometry and movement by the camera in order to detect the driver fatigue. Electroencephalograph (EEG) technology has been also considered to monitor fatigue via an array of small electrodes affixed to the drivers scalp, and examining alpha, beta and theta brain waves to reflect the brain status, identifiable in stages from fully alert, wide awake brain, through to the various identifiable states of sleep (Mabbott et al., 1999). However, EEG monitors are very intrusive and thus not practical if used during normal operations in mining trucks.

Driver's sight and hearing senses play a crucial role in trucks safety. It is estimated that between 80% and 90% of the information needed to drive and operate a truck is obtained through the driver's eyes (Cohen, 1978). Human eyes carry a wide variety of information related to potential fatigue by physiological signals, such as the response of the retina to external light stimuli, or by eye movement, including the frequency, interval and speed of eyelid blinking and pupil gazing. These signals or movements change with the driver's fatigue level, and they can be used to as indicators of driver's fatigue level such as whether a truck driver is vigilant or drowsy. Generally, human physiological signals can be used to provide information about immediate fatigue level, whereas eye movements are more suitable for determining the driver's global state such as vigilance or drowsiness (Larue et al., 2009).

The haul truck driver's fatigue detection and warning methodology is shown in Fig. 5. It involves a three-stage process. First stage relates to acquisition of data on driver facial features. An infrared CCD camera is mounted on the mine truck dashboard to capture and record the driver during the both day and night shifts. The second stage is pattern recognition of the driver's face and eyes. The AdaBoost algorithm (Sochman and Malas, 2004) can be used to separate the driver's head and face from the background of truck cab. To reduce computational burden and improve

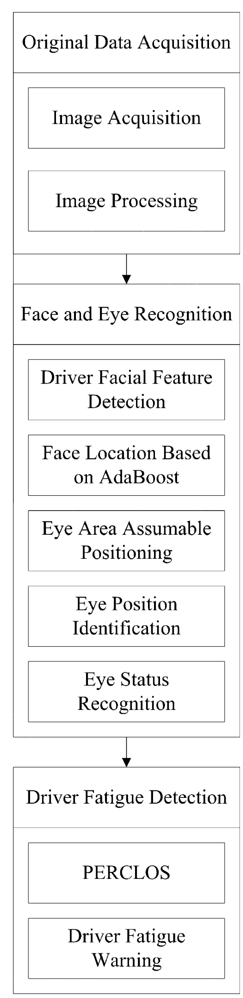

Fig. 5. Methodology for truck driver fatigue detection and warning.

real-time monitoring efficiency, the template matching algorithm can be applied to search possible eye areas in the head and face boundary. The precise eye locations can be tracked by the sub-block complexity algorithm and the status of eye openness or closeness can be judged by the Snake algorithm (Sakalli et al., 2006). Finally, truck driver's fatigue level is recognized and warning signals are given out. The PERCLOS algorithm, which is considered by the US Department of Transportation as a reliable indicator of driver drowsiness and fatigue, can be used in this stage (Wierwille et al., 1994).

Real-time detection of truck driver's facial features includes determining the driver's face location, size, and shape. The human face is a highly variable visual recognition target. Face appearance, facial expression, and skin color varies significantly for each driver. Sometimes a driver may wear glasses, beard or carry other accessories. Cab light intensity and illumination are always changing. All those factors affect the accuracy of detection.

The AdaBoost algorithm, a learning algorithm sensitive to noisy data and outliers, can be adopted to extract the head boundary and face location. In the process of sampling driver's images, the monitored data includes driver's face images with different angles of head and face orientation, left- right or up–down, in addition to those samples used as face patterns. The AdaBoost cascade classifier is useful to reject most of the non-face patterns and reduce computational burden with improved real-time monitoring efficiency (Sochman and Malas, 2004). The process of reducing the number of unwanted non-face patterns is shown in Fig. 6.

Similarly, the template matching algorithm can be used to roughly detect the eye region. This algorithm is used to recognize and differentiate the unknown patterns from known patterns in the image and uses both left and right eye templates to search for the driver's eye regions in drivers face (Strickland et al., 1990). In addition, the sub-block complexity algorithm can be used to track the precise eye locations as shown in Fig. 7. The initially detected eye regions are divided into blocks using a pre-determined fixed block size. Each block is analyzed to determine the exact eye location.

To detect and judge driver fatigue, it is necessary to recognize the status of the driver's eyes. The snake algorithm, can be used to recognize the contour of eyes and judge the degree of eye's openness or closeness (Sakalli et al., 2006). The haul trucks driver eye contour detection is shown in Fig. 8.

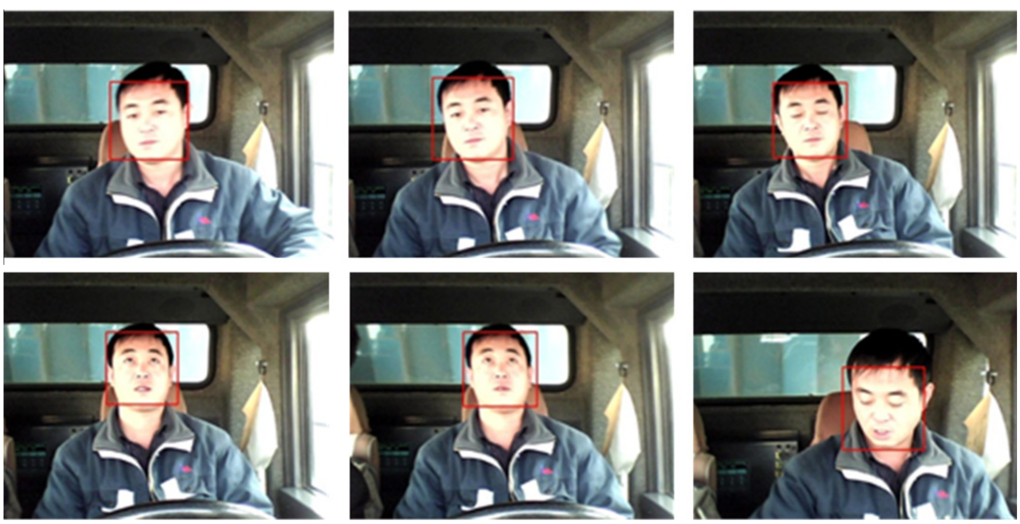

Fig. 6. Reduction of non-face patterns.

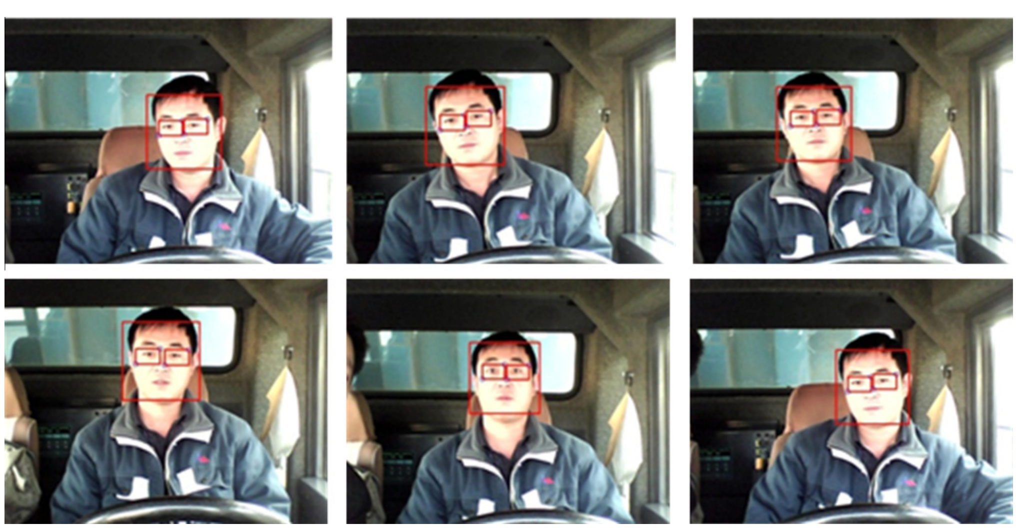

Fig. 7. Tracking of eye locations.

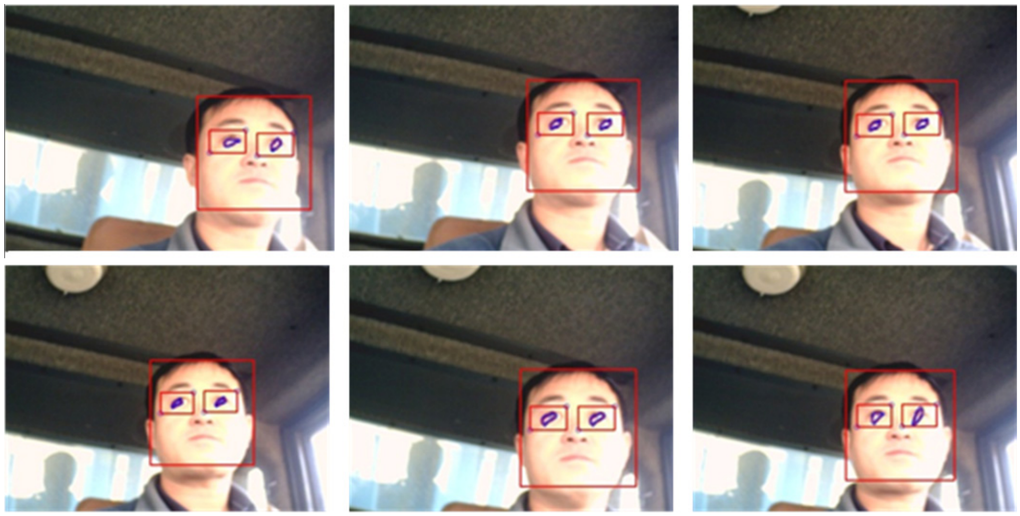

Fig. 8. Extraction of eye contours.

Table 1
Relations between the truck driver fatigue level and PERCLOS value (Wierwille et al., 1994).

Fatigue level	Classification	PERCLOS value (f)
0	Awake	$0 \leqslant f < 0.075$
1	Questionable	$0.075 \leqslant f < 0.15$
2	Drowsy	$0.15 \leqslant f$

The PERCLOS drowsiness indicator can be used to recognize the fatigue level of drivers (Wierwille et al., 1994). According to the research by the Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA), the PERCLOS value was considered to be a valid psycho-physiological measure of alertness as assessed by psychomotor vigilance and among the most promising known real-time measures of alertness for in-vehicle drowsiness detection systems (Wierwille et al., 1994). The principle of PERCLOS value is to use the time percentage of eye closing as the indicator of driver fatigue level. Mathematically, the PERCLOS value is described as follows:

$$f = \frac{t_3 - t_2}{t_4 - t_1} \times 100\%$$

where f is the PERCLOS value, $t_3 - t_2$ is the time difference between two consecutive instants at which the eye size is 20% or less of the maximum eye size, and $t_4 - t_1$ the time difference between two consecutive instants at which the eye size is 80% or less of the maximum eye size.

Based on the ranges of PERCLOS value, the level of mine truck driver fatigue can be classified into three categories of drowsiness (“awake,” “questionable” and “drowsy”). The relation between the truck driver fatigue level and PERCLOS value is given in Table 1 (Wierwille et al., 1994).

The level of driver fatigue is increased with the PERCLOS value. If the detected data result in a PERCLOS value falling to Level 0, it means that the driver is alert or vigilant, and in a normal state of driving; a PERCLOS value in Level 1 means that the driver is turning in a state of quasi-fatigue or in the onset of fatigue and alert messages in either light or voice signals are to be sent. The PERCLOS value at Level 2 means that the driver is drowsy with the clear presence of fatigue and signals warning on dangerous driving.

The fatigue system described here would be able to identify and measure fatigue events. This system can be further enhanced by an additional feature that would alert the truck driver and the warning messages would also be sent to the to the mine control headquarter.

5. Driving visibility enhancement

In addition to driver’s fatigue, truck haulage safety is closely related to truck’s blind spots and driver’s visibility. Enhancing driver’s visibility by developing visual information aids may help improve truck haulage safety in adverse mine climate conditions. To this end, various devices such as cameras, radio-frequency identification (RFID) and radar, and emerging algorithms for image processing can be adopted to acquire road images, reduce blind spots, restore degraded images and eventually improve truck driver’s visibility.

One of possible approaches to the enhancement of truck driver visibility is to reduce the blind spots. Various monitoring devices have been tested to assist truck drivers in monitoring blind spots in surface mines (AMT, 2010; Acumine, 2010). Fig. 9 illustrates positions of the cameras at the front, rear and off side of the truck driver (Faul, 2007).

The driver gets visual information from the mirrors which are mounted on both sides of the truck. If the truck is near the edge of dumping spots or the driver gets proximity warning from the terminal client screen, the monitoring cameras and video devices will be able to provide assisted wider views than the regular mirrors.

Another approach to enhance the visibility of mine truck drivers is to improve the quality of monitored video by restoring the degraded images due to adverse mine climate conditions. Such bad weather conditions can include fog, mist, haze, smoke, dust, sand, snow, rain, and other suspended particles in the air. With such conditions, the visibility of mine air diminishes and the appearance of video will be degraded. Fig. 10 shows two examples of degraded images for trucks operating under rain and fog conditions in surface mining (Kloos, 2007). In such cases, visibility enhancement algorithms can be used to restore the degraded images and enhance the visibility of mine drivers to help improve truck haulage safety.

The enhancement of driver visibility with adverse mine climate conditions can be achieved by processing and restoring degraded video images. According to the theory of atmospheric physics, a particulate in the air scatters lights as they shine onto it. With adverse climate conditions, there are more fine particles suspended in the air and they affect light transmission and image quality

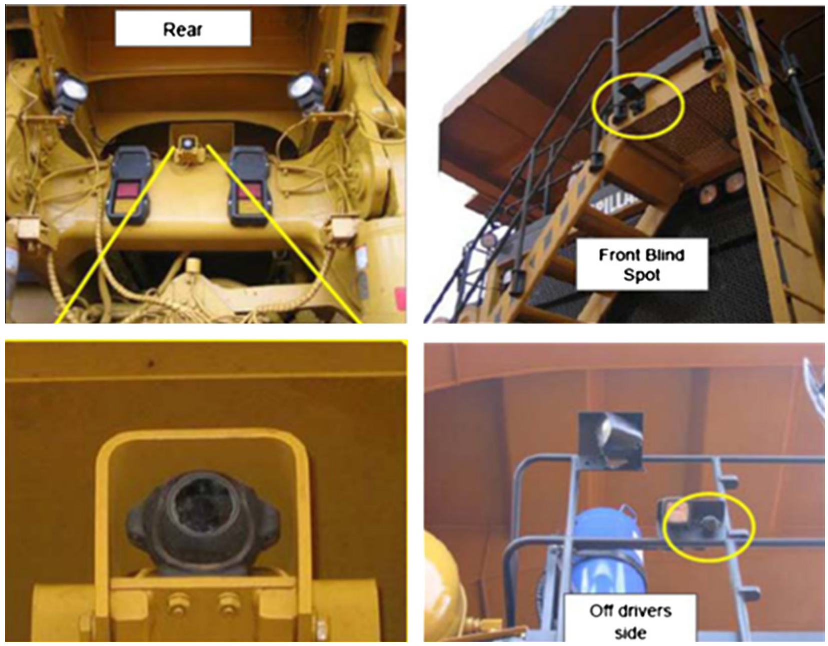

Fig. 9. Camera installations on mine truck (Faul, 2007).

Fig. 10. Mine truck images degraded by rain and fog (Kloos, 2007).

negatively, causing monitored images to be degraded. To help truck driver identify obscured objects under such adverse climate conditions, the degraded images can be restored by using image restoring algorithms. The atmospheric scattering models and algorithms proposed by Narasimhan and Nayar (2001) can be used to restore the degraded images from Kloos (2007). Fig. 11 illustrates the results of restoring the mine truck images degraded by bad weather as shown in Fig. 10. This type of image processing algorithms may be helpful for recognizing obscured objects due to low visibility and severe weather conditions.

6. Conclusions

Many of the haul truck-related accidents result from a combination of factors involving truck, driver, road, and weather. An integrated information technology assisted driving system may significantly contribute to control truck-related accidents. This system should include Google-Earth graphics engine to display roads and objects in close proximity, a truck driver fatigue detection system, and an enhanced visibility display that can be used when low visibility weather conditions are encountered. The entire system

Fig. 11. Restoration of weather degraded images results.

will require a heavy-rugged hardware embedded into the trucks such as a computer-displays, radio data transmitters, CCD cameras, etc. since trucks operate in harsh working conditions. The next phase of the research should include cost analysis (capital and operational) of suggested system, installation and testing in specific surface mine operations.

References

Advanced Mining Technologies Pty, Ltd., 2010. Collision Avoidance System. <http://www.advminingtech.com.au/> (2.01.10).

Acumine. 2010. Collision Avoidance Safety System (ACASS). <http://www.acumine.com/_Products/Proximity.php> (8.01.10).

Bartels, J.R., Ambrose, D.H., Gallagher, S., 2008. Analyzing factors influencing struck-by accidents of a moving mining machine by using motion capture and DHM simulations. In: The 2008 SAE Digital Human Modeling for Design and Engineering Conference and Exhibition.

Caldwell, J.A., 2004. Fatigue in aviation. Journal of Infection and Public Health 3 (2), 85–96.

Cohen, A.S., 1978. Eye Movement's Behaviour While Driving a Car: A Review. Zurich, Swiss Federal Institute of Technology, Department of Behavioural Science. Grant No. DAERO-78-G-018. Progress Report No. 1.

Faul, H., 2007. Collision Avoidance Systems. Anglo-American Technical Report No: 2007 CAS1.

Groves, W., Kecojevic, V., Komljenovic, D., 2007. Analysis of fatalities and injuries involving mining equipment. Journal of Safety Research 38 (4), 461–470.

Kecojevic, V., Radomsky, M., 2004. The causes and control of loader and truck related fatalities in surface mining operations. Injury Control and Safety Promotion 11 (4), 239–251.

Kloos, G., 2007. Radio-frequency Signal Strength Based Localisation in Unstructured Outdoor Environments. PhD thesis, University of Sydney.

Larue, G.S., Rakotonirainy, A., Pettitt, A.N., 2009. Predicting driver's hypovigilance on monotonous roads: literature review. In: 1st International Conference on Driver Distraction and Inattention, Gothenburg, Sweden, September 28–29, 2009.

\Mabbott, N.A., Lydon, M., Hartley, L., Arnold, P., 1999. Procedures and Devices to Monitor Operator Alertness Whilst Operating Machinery in Open-cut Coal Mines. Stage 1: State-of-the-art Review. ARRB Transport Research Report RC 7433.

Md-Nor, Z.A., Kecojevic, V., Komljenovic, D., Groves, W., 2008. Risk assessment for haul truck-related fatalities in mining. Mining Engineering 60 (3), 43–49.

MSHA, 2010. Equipment Safety and Health Information. <http://www.msha.gov/equipmentsafety/equipmentsafetyhome.asp> (2.01.10).

Narasimhan, S.G., Nayar, S.K., 2001. Removing weather effects from monochrome images. In: Proceedings of 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, pp. 186–193.

Nieto, A., 2002. Development of a Real-time Proximity Warning and 3D Mapping System Based on Wireless Networks, Virtual Reality Graphics, and GPS to Improve Safety in Open-pit Mines. PhD thesis, Colorado School of Mines.

Nieto, A., Dagdelen, K., 2006. 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 320, 11–20.

Nieto, A., Sun, E., 2010. Real time assisted driving in open pit mining operations using Google Earth. Mining Engineering 62 (2), 21–26.

Ruff, T.M., 2007. Recommendations for Evaluating and Implementing Proximity Warning Systems on Surface Mining Equipment. NIOSH Report of Investigation, RI 9672, pp. 1–78.

Sakalli, M., Lam, K.M., Yan, H., 2006. A faster converging snake algorithm to locate object boundaries. IEEE Transactions on Image Processing 15 (5), 1182–1191.

Schiffbauer, W.H., 2001. An Active Proximity Warning System for Surface and Underground Mining Applications. Preprint # 01-117, SME Annual Meeting, pp. 1–8.

Sochman, J., Malas, J., 2004. AdaBoost with totally corrective updates for fast face detection. In: Proceedings of Sixth IEEE International Conference on Automatic Face and Gesture Recognition, pp. 445–450.

Strickland, R.N., Draelos, T., Mao, Z., 1990. Edge detection in machine vision using a simple L_1 norm template matching algorithm. Pattern Recognition 23 (5), 411–421.

Wierwille, W.W., Ellsworth, L.A., Wreggit, S.S., Fairbanks, R.J., Kirn, C.L., 1994. Research on Vehicle Based Driver Status/Performance Monitoring: Development, Validation, and Refinement of Algorithms for Detection of Driver Drowsiness. National Highway Traffic Safety Administration Final Report: DOT HS 808 247.