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Using a case study fatality to depict the limits of proximity detection systems for articulating, underground machinery

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ABSTRACT

Proximity detection systems are actively being marketed to the underground mining section as a way to provide enhanced information for operators of large underground machinery. To date, many of the systems are lacking the reliability and validity ratings that researchers would like to see them have. Due to this, they may not interact in a predictable way to always improve operator awareness. In fact, Burgess-Limerick (2011) noted that in many fatalities that occurred on underground machinery, the operator was aware of the location of the victim, or they were the victim themselves. This work recreates one of the accidents from that review in a computer simulation environment, models a video-based proximity detection system and then evaluates the capacity of the system to improve operator line of sight. Results demonstrate that there was only a small window of time during which the operator may have been able to see the victim's location even with a hypothetical camera system installed. The work points to the importance that mine design and machine design have with respect to improving safety of the worker, as well as the downfalls of existing proximity detection systems that rely on video feeds mounted to the machinery.

1. Introduction

The worldwide mining industry continues to report a concerning number of fatalities and severe accidents related to line of sight or visibility concerns on large, underground machines (Burgess-Limerick, 2011; Chirdon, 2009; WSN, 2012). Thus, the mining industry has debated the appropriateness of collision avoidance versus proximity detection systems (Horberry, 2012). Collision avoidance systems remove the control from the operator with a machine shut-down function when the machine travels within a given distance from a known and identified hazard. Proximity detection systems simply provide additional situational awareness, in the form of visual or auditory cues, when the machine is in close proximity to a perceived risk. The logistics for effective implementation of any such system has been noted by Horberry (2012). There are many human-centered design principles, policy and procedure issues that need to be considered prior to widespread implementation of any new technology in the industry (Horberry, 2012).

Burgess-Limerick (2011) completed a review of the fatalities in the US Coal Mining Industry with a case study focused around whether existing proximity devices would have prevented the accidents in question. In some of the fatalities, the operator was unaware of where the victim was positioned, suggesting that a proximity detection system could have improved situational awareness for the operator and prevent the accident. In many other cases, the operator was the victim or knew where the victim was located just prior to the accident (Burgess-Limerick, 2011). In these cases, the role of proximity devices is less clear, and the design of the system becomes an important consideration.

In above-ground situations, many open pit mines have successfully implemented GPS-based devices that function as proximity detection or collision avoidance systems. Underground, companies are relying on technologies like RFID tags, electromagnetic technology, and radar (Ruff, 2007). Most systems include proprietary software and customized hardware that enhances how the information is presented to the operator. Numerous entrepreneurial companies are designing and selling more complex systems, with driver-alert options in the form of audio tones or visual displays. A variety of technologies are being used to generate inner and outer zones that can reliably detect pedestrians, light vehicles and other hazards (Chirdon, 2009; Ruff, 2007). These systems vary in price drastically, depending on how much supporting infrastructure (WiFi, Leaky Feeder, and other communication and tracking protocols) is needed for the basic proximity detection system. For

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this reason, many smaller companies can only afford a stand-alone system.

An affordable stand-alone system that can provide enhanced situational awareness for the operator of underground machinery is the closed circuit television system (CCTV). Small and robust (usually infrared) cameras are mounted in protected spots around the machine and directly feed to a viewing screen, or screens, in the cab. These systems are similar to those being implemented in numerous passenger vehicles as rear-view back up aids. In an effort to evaluate what potential impact a CCTV system would have on improving line of sight for the operator of a load-haul-dump (LHD), this work will quantify LOS for the operator in an actual, reported fatality as well as quantify the additional LOS that may have been provided if the machine in question had a quad-camera system installed.

2. Methods

The 3D auto-CAD file of a common, large (7.5yd^3 bucket) load-haul-dump (LHD) machine was imported into Siemens JACK software (v8.0) and a 50th percentile, for height and weight, male avatar was positioned in the cab seat. A monocular test point was chosen between the two eyes to calculate LOS for the operator in that position. Since LHDs are driven using bi-directional movement with the operator sitting perpendicular to the line of travel, the trunk and neck of the avatar were rotated moderately to represent a typical driving position (Eger et al., 2008). This provides a reasonably unobstructed view to the mine tunnel on the same-side as the operator, as indicated by Burgess-Limerick (2011), but very little view to the opposite-side tunnel wall.

A series of straight wall sections were positioned in the environment to replicate the mine tunnel described in a fatality reviewed (Case Study #2) by Burgess-Limerick (2011). In that particular incident, at the time of collision, the pedestrian was positioned on the opposite side tunnel with respect to the operator's compartment, which is a known blind spot for LHD operators. Based on the diagram provided, the machine was articulated at the time of collision (Burgess-Limerick, 2011). The description of the operator's field of vision was "a small opening between the canopy and the top of the scoop" (Burgess-Limerick, 2011, pg.). The recreated fatality from Burgess-Limerick (2011) is displayed in the JACK software environment in Fig. 1. A total of 12 planes of varying sizes were needed to create the relevant accident area. Descriptors used to define the area include the straight tunnel section (where the machine was driving from), the cross-cut tunnel (the intersection that the machine crossed to enter the tunnel where the incident occurred), and the accident area (the tunnel section where the victim was located). The results and discussion refer to areas on the "same-side" as the operator and the "opposite-side". Scooptrams, loaders or load-haul-dumps (LHD) as these machines are termed in the mining industry almost always have a sideways-seated operator position. In this case, the operator is offset from the center of the machine and is seated perpendicular to the line of travel. They must rotate their head to look forward and backward down the tunnel for navigation. Rather than confuse the reader with left and right perspectives, we define tunnels or walls on the operator's left-hand side going forward (or right-hand side when traveling backward) as the "same-side" and areas that are located on the far side of the machine as "opposite-side" tunnels and walls. The tunnel wall sections, and the floor areas were created from JACK coverage planes that have the capability of recording nodal points with and without LOS using red and green dots. Using this tool, researchers can determine what percentage of area around the machine is visible from the operator's seated position in the cab (Eger et al., 2010). Percentage of visible area for each plane was recorded during analysis of the scenarios.

Camera views were simulated using a separate nodal analysis from a theoretical "eyepoint" located at the typical mounting locations for a PROVIX system (Godwin, 2014). These site positions in the simulation environment were restricted with blinders to provide the correct fields of view (FOV) for typical PROVIX cameras. The camera locations were Front Camera (FC) forward facing and located on the overhang of the cabin, the Front Right Camera (FRC) located on the back body of the machine and pointing forward and the Back Right Camera (BRC) located on the front half of the machine near the wheel well and pointing backward. In this work, a robust, waterproof camera with a horizontal and vertical FOV of 96° was simulated. The LOS percentage available to the operator, as well as the LOS percentage provided by individual cameras (FRC, BRC, FC) were recorded for the relevant planes only (Table 1). For instance, the FC provides no LOS to the planes located behind it so these were not calculated or presented.

LOS results were calculated in three different positions. The reference position is depicted in Fig. 1 and represented a straight section of tunnel. A second assessment was done at the critical stopping distance from the victim location when the machine was slightly articulated and moving into the opposite tunnel. The

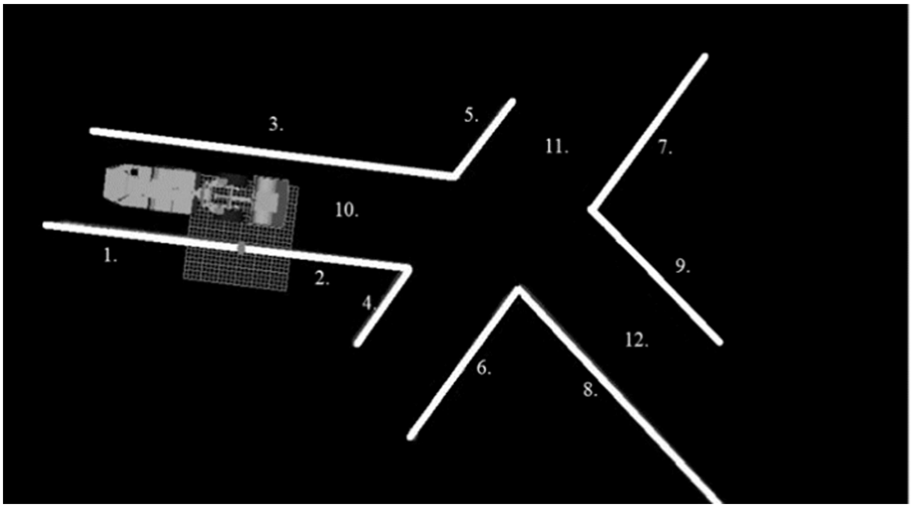

Fig. 1. Schematic to match described outline of fatality from Burgess-Limerick (2011) with planes labelled to match analysis and Table 1 information.