Feasibility of Using Intelligent Video for Machine Safety Applications

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***Abstract*—Researchers at the National Institute for Occupational Safety and Health (NIOSH) are studying methods to prevent workers from being entangled in machinery used at mining operations. An analysis of mining accidents in the United States that resulted in a fatality or permanent disability from 2000 through 2005 showed 438 severe incidents that involved contact with machinery or equipment, an average of 73 per year. Researchers determined that the most common machinery involved in these severe accidents was conveyors. Also, a significant portion of the accidents occurred during machine maintenance and repair. Researchers are focusing on improved methods to prevent unintentional machine startup during maintenance activity and methods to detect workers near moving machine components. One new technology that shows promise for this application is intelligent video. Popular in the surveillance and security industries, these systems use cameras and computerized video analysis techniques to automatically detect the presence of people in preset zones within the camera's field of view. A preliminary study has been initiated to determine if this technology could reliably detect the presence of workers in hazardous locations near machinery. Possible advantages of the use of this technology include improved detection zone demarcation and improved ability to distinguish between hazardous and non-hazardous proximity, compared to conventional proximity sensor techniques. Initial tests to detect a person near a conveyor system in daylight conditions showed promising results. A description of the technology, test procedures and results, implementation challenges, and future research needs are discussed.**

I. Introduction

While the total number of mine worker fatalities in the United States has been on a downward trend [1], the proportion of these accidents that involve mine machinery and mobile equipment has consistently been significant. Researchers at the National Institute for Occupational Safety and Health (NIOSH) and other organizations have been concerned with the interaction of workers with machinery and the number of severe accidents classified as struck-by or caught-in [2]–[5]. These accidents include workers entangled in rotating machinery, struck by moving machine components, or run over by mobile equipment. An analysis of accident data available from the Mine Safety and Health Administration (MSHA) [6] was conducted for the purpose of better understanding the problem and the scope of machine-related accidents. Data from the years 2000 through 2005 were collected for underground and surface mines, and 438 accidents that resulted in severe injuries (fatality or permanent disability) fit the search criteria.

On average, severe accidents that involved a worker and machinery or haulage equipment comprised 42% of all severe accidents at mining operations. Fig. 1 shows the top 20 machine types involved in these accidents, with conveyors listed most often (13%). The activity of the worker during the accident was also of interest (Fig. 2)—a significant portion of injuries and fatalities occurred during maintenance and repair of machines (24%). Also of interest was that, in approximately 40% of the fatalities involving stationary equipment such as conveyors and crushers, lockout/tagout procedures either were not followed or were not adequate for the particular machine involved [7].

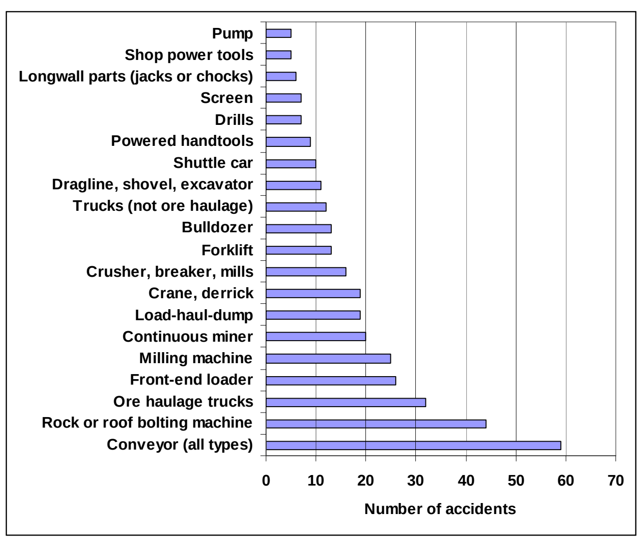

Fig. 1. Mining machinery involved in severe accidents, 2000–2005, n =438 (top 20 machines).

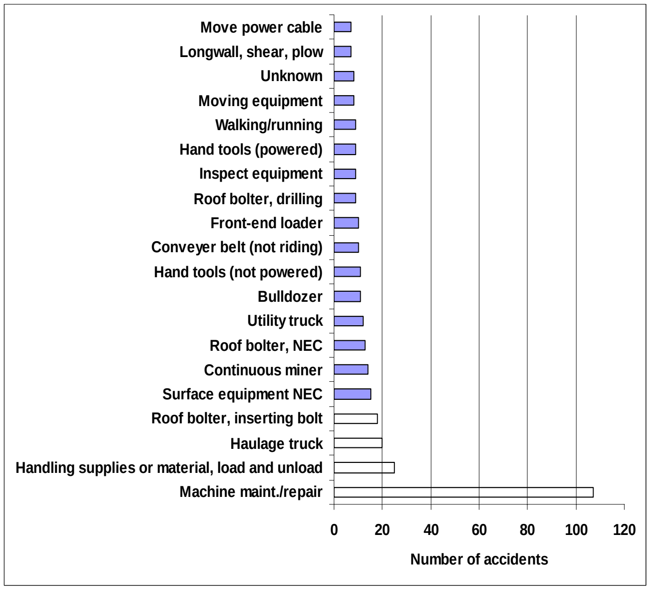

Fig. 2. Worker activity at the time of the accident, 2000–2005, n=438 (top 20 activities).

While many factors contribute to machinery accidents, one possible approach to preventing caught-in and struck-by accidents entails better methods of detecting hazardous situations. Guarding, emergency stop devices, and safe control system design have all contributed to a decrease in accidents, but improvements are still needed. Active and intelligent sensing technology that can better detect human presence in hazardous areas could decrease these accidents further.

NIOSH researchers have identified intelligent video systems (IVS) as a potential tool that could reduce accidents involving machines. IVS is used by the security and surveillance industries [8] and in some safety applications, such as detecting a distressed person in a public pool [9]. These systems use standard video cameras connected to a computer to automatically analyze the video signal and provide notification if a person enters a predefined zone within the camera's field of view. Other functionality includes the detection of items left behind, the removal of items, a worker down, etc. IVS employs familiar and accepted camera technology. It may eliminate the need for additional sensing systems, and it may reduce false alarms when compared to other sensor-based technology [2], [3].

II. Intelligent Video Systems

An IVS uses a computer to perform sophisticated analysis of video camera images. The main motivation for its development was to provide automatic recognition of certain events (intrusion, loitering, theft) for surveillance and security applications, thus reducing the work load associated with the constant observation of video monitors by security personnel [10]. Analytic functions available on most commercial IVS include detection of intrusion, loitering, and abandoned or removed objects, as well as vehicle/person tracking and vehicle counting. The detection of personnel entering or leaving a specified zone is a common function of these systems, and it is the application that prompted NIOSH researchers to study the use of this technology for machine safety.

IVS analyzes video frame-by-frame to detect changes in the scene or image [11]. For instance, a baseline or non-event video image for a particular camera is taught to the analysis system (this is a dynamic process, and recalibration is constantly occurring at intervals specified by software parameters). If a person then walks into the scene, the system detects this as a change in the baseline image. Boundaries can be defined within the image to limit detection to a certain perimeter. When detection occurs within this perimeter, alarms can be activated and/or control signals generated. Parameters can be set to alarm only on objects of a certain size and shape. Filters can be employed to ignore events of short duration or the effects of shadows. Thermal imaging and low-light cameras can be used if needed for nighttime operation.

The following summarizes the potential advantages of intelligent video systems for machinery applications. Tests have been designed by NIOSH researchers to verify these features. IVS may offer

- a relatively low cost, low maintenance, stand-alone detection system that uses available camera technology.
- vision-based object recognition with increased ability to discriminate between hazardous and non-hazardous situations.
- well-defined hazardous zone demarcation.
- the ability to monitor large areas with a single camera.
- increased difficulty in circumventing, disabling, or ignoring (does not depend on worker compliance).
- many alarm output options, including a simple audible alarm in an operator's station to prompt a check of the video, remote on-site alarms or beacons, generation of machine control signals, and/or personnel paging and email.
- the capability to digitally record video footage of alarm events.

III. Preliminary Tests

A preliminary evaluation of intelligent video technology was conducted by NIOSH researchers during a 2007 pilot project. A small rock conveyor was used as a test platform (Fig. 3). An 8-channel intelligent video system manufactured by Arteco Vision Systems and three different types of outdoor cameras were purchased for evaluation. Several different scenarios were tested: perimeter protection to detect the presence of a worker near the conveyor; monitoring small areas on the conveyor to detect the presence of fingers, hands, and arms in hazardous areas; monitoring the removal of machine guards or enclosure lids; and detecting a worker lying motionless on the ground. The tests described here were primarily conducted using an inexpensive outdoor color camera (420 lines of resolution, 4.3 mm lens).

At the time of this report, only tests conducted with a stationary belt during daylight conditions in fair weather were completed. Tests in dark or stormy conditions and tests with moving material on the belt were still pending. The tests during daylight were conducted at different times of the day and with different degrees of cloud cover in order to determine the effects of sun position and cloud shadows. Tests to detect the presence of a worker near the perimeter of the conveyor were conducted to determine the reliability of the system as a proximity warning device. Another intrusion test was conducted to determine the ability of the system to detect appendages or limbs in hazardous areas.

Fig. 3. Test conveyor at NIOSH Spokane Research Laboratory.

Detection zones were drawn by simple point-and-click actions to define the corners of the detection area in a particular camera's video window. Detection zones are indicated by green boundaries (Fig. 4). If a person entered a zone, the boundary turned red, indicating an alarm event. At the same time, an audible alarm was activated and a control signal was generated by use of a relay interface. Tests were conducted in the morning (9 a.m.) and again just after noon (1 p.m.) to observe the effect of different sun positions and resulting shadows. Each test was conducted with the same test subject, first in light-colored clothing, and then in dark-colored clothing to determine the effects of differing clothing contrasts against the asphalt background. The test subject entered the zone several times and at several different locations for each test. The IVS also remained activated between the morning and afternoon tests to see if false alarms were generated.

A. *Whole Body Detection*

With high sensitivity settings, the system reliably detected a person entering either the left or right zone (Fig. 4), regardless of clothing color. No missed detections occurred during approximately 80 test events at various points along the detection zones. This detection reliability was seen for both the morning and afternoon tests. Consistent detection occurred when at least half of the test subject's body was in the zone. There were no false alarms during the tests, but there were 10 false alarms in the 4-hour period between the tests because of birds and insects flying directly in front of the camera lens. Sensitivity settings were lowered and filter adjustments were made to decrease false alarm rates, and the test was repeated on another day.

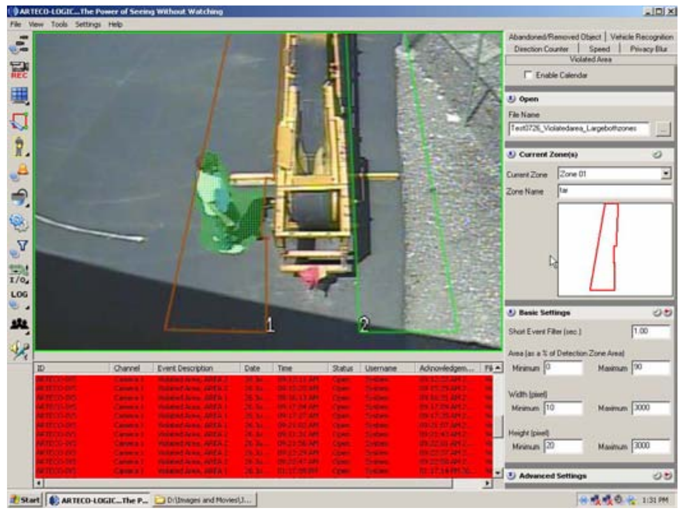

Fig. 4. Detection zones for whole body detection tests.

With the new settings, detection of a person was not as reliable. Clothing color seemed to be a factor—dark clothing was detected 55% of the time and white clothing 90%. No false alarms were seen between or during tests. A trade-off exists between reliable detection of a person and false alarm rates. Fine tuning of the filters could have resulted in better results. However, these tests showed that the system, as configured, could probably not be used to directly control the machine—e.g., automatic shutdown when someone gets too close. Settings that allowed high reliability also produced false alarms that would not be tolerated if they resulted in frequent interruptions in production. However, the proximity warning functions may be useful in providing an alert to control room operators or other personnel to indicate the presence of workers in hazardous areas. The alert could prompt a plant operator to check the video monitor, and the operator could then make a decision to ignore the event, shut down the machinery, or warn the worker via loudspeaker or other communication.

B. *Appendage Detection*

The next test was to determine the reliability of the video system in detecting smaller portions of the body encroaching on critical areas of the conveyor—e.g., the belt and pulley areas. Fig. 5 shows the detection zone drawn over the tail pulley area. This detection analytic could only be active when the conveyor was not running—the moving material and belt would constitute constant changes within the detection perimeter and would result in false alarms. Thus, detection and alarming would be activated during maintenance, when the conveyor was motionless. If a worker's hand, arm, or body was detected in this scenario, an alarm control signal would be provided to the main conveyor controls to prevent startup. In this way, the system could not be restarted if a worker was performing maintenance, or if maintenance was completed but not all personnel were clear of the area. False alarms in this scenario could be tolerated. Tests showed that false alarms were short in duration and the cause was evident in the video, allowing quick correction and resulting in only short delays in the execution of machine startup.

Tests were conducted in the morning and afternoon at several different locations along the detection area. Sensitivity settings were set high to detect small objects in the detection zone. Tests were run to detect fingers, a hand (to the wrist), an arm (past the elbow), and head/shoulders leaning over the belt (Fig. 5). For each body part, ten detection tests were conducted in the morning and ten in the afternoon. Fingers were detected with 80% reliability in the morning test and 60% in the afternoon. A hand was detected with approximately 60% reliability in the morning and afternoon (sporadic detection occurred at some locations, but was considered unreliable detection for these calculations). An arm over the belt, or head/shoulders leaning over the belt, was detected 100% of the time in both tests. Fig. 6 shows the "blob" view that the computer is analyzing during the arm detection test. In this view, black indicates areas that have not changed from the baseline, while white areas indicate new features or changes in the scene.

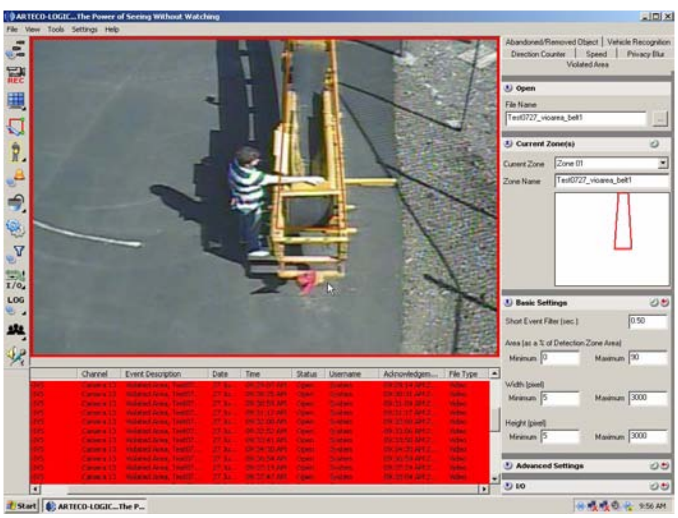

Fig. 5. Tail pulley zone for appendage detection tests.

Sometimes the test subject's shadow was detected prior to the subject's body entering the zone. This occurred about 10% of the time, most often during the morning tests when shadows were longer. This was not seen as a substantial deficiency—the presence of moving shadows was usually associated with a true alarm condition. If a person's shadow generated a false alarm that prevented startup, the video monitor could be checked to verify the source of the alarm. Twelve false alarms occurred during the 4-hour period between the two tests, and the alarms were most often caused by birds or insects flying directly in front of the camera. These false alarms were of short duration and could be minimized by adjusting the short event filter on the video analysis system. Again, further adjustment of the software settings could improve detection of fingers and hands, but most likely at the cost of increased false alarms. Detection of larger portions of a person's arm was more reliable. That and whole body detection may be all that is needed for reliable prevention of machine startup.

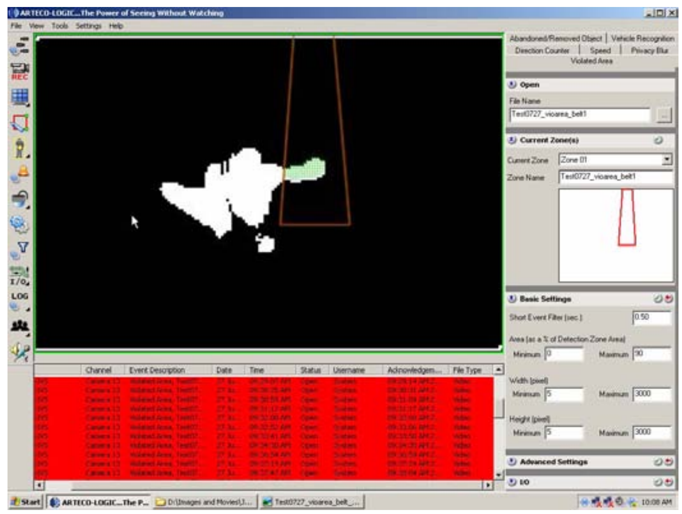

Fig. 6. Corresponding "blob" view after processing.

C. *Missing Machine Guards and Worker-Down*

Finally, limited tests were conducted to determine if the IVS could detect the removal of a machine guard or an electrical enclosure cover (removed object analytic) and an injured worker on the ground (abandoned object or worker down analytic). Reliability of detecting a missing machine guard or an open electrical enclosure was low in most circumstances. Background contrast issues and false alarms when a person stood in front of the machine guard or enclosure contributed to the low reliability. Furthermore, a separate camera would need to be dedicated to monitoring the guarded area in order to provide enough detail—i.e., the same camera could not be used for overall perimeter protection and for missing machine guards. Reliability did increase when high-contrast placards were attached to the machine guard to provide more positive detection. But problems were still seen when a worker stood in front of the machine guard, effectively making the system think the guard was not visible and thus missing.

Detection of a motionless person lying on the ground was possible, but false alarms were common when a person stood still in the same detection area. Different camera angles and adjustment of software parameters resulted in better performance, but false alarms still occurred because of changing light conditions or similar-sized objects left in the detection area. It is possible to define the shape and size of the object to be detected so that a person's body lying on the ground can be distinguished from someone standing upright. Such refinement requires much experimentation, and reliability could still be questionable in congested work areas.

IV. Conclusion

NIOSH researchers are studying methods to reduce struck-by and caught-in accidents involving machinery at mining operations. This is a challenging problem—in many circumstances workers must be near moving machinery in order to perform their jobs. Innovative safety interventions are needed to further decrease accidents without adversely affecting productivity. Monitoring hazardous areas near machines by using IVS may be one possible solution, but limitations must be understood and anticipated during implementation. While more tests are needed, some general conclusions can be drawn about the possible applications of intelligent video for stationary machine safety:

- One promising application may be the use of IVS to supplement lockout/tagout procedures during maintenance—i.e., monitoring disabled machinery and preventing startup if someone is detected in a hazardous area.
- Current systems could be used to detect the presence of workers in hazardous locations near operating machinery, but implementing automatic machine controls would have to be done with caution and only for functions that could tolerate occasional false alarms. Providing alarms that increase situational awareness during production for plant operators may be a more beneficial and realistic application.
- Detection of missing machine guards or other safety equipment will require more sophistication and intelligence than what was possible with the IVS tested here.
- Worker-down detection may be possible with IVS if false alarms are tolerated. This analytic is typically applied to a large field of view, resulting in low object resolution and making human body recognition difficult.
- Reliability of many IVS applications may be increased with the use of multiple cameras to provide different views of the same scene or, as in the case of stereovision, to provide 3-dimensional information.
- More tests are needed to determine the effects of rain, snow, fog, dust, and dark conditions on the reliability of IVS for all the above applications. Outdoor operation of the system has been reliable in security and surveillance, but reliability requirements increase for safety applications, and environmental effects must be well-understood. Additional tests will also be needed to conduct a thorough comparison with alternative sensor-based technologies.

Note: The findings and conclusions in this article have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy. Mention of a specific company or product does not imply endorsement by the National Institute for Occupational Safety and Health.

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