VIDEO MOTION DETECTION FOR REAL-TIME HAZARD WARNINGS IN SURFACE MINES

Edward L. McHugh
Spokane Research Laboratory, National Institute for Occupational Safety and Health, Spokane, Washington, USA

ABSTRACT

Digital camera and computer technologies can be used to monitor mine slopes and provide real-time warning of rock falls. NIOSH researchers assembled a surveillance system using low-cost video cameras and computer software from the security industry to test its effectiveness. The system is designed to signal an alarm when motion is detected and to record images of the scene. Masking can restrict motion detection to specific areas within the camera view; sensitivity is adjustable. The time-stamped images provide a record that can help reconstruct and quantify an event. Video motion detection can augment standard monitoring methods to increase safety in surface mines.

INTRODUCTION

Since 1995, 34 miners have died in slope failure accidents at surface mines in the United States. While less than 1% of reported accidents are associated with slope stability problems, slope failure accidents were responsible for about 15% of all fatalities in U.S. surface mines in recent years. Shovel operators and drillers suffered the greatest number of fatalities. Falls of hand-sized rocks weighing only a few pounds can cause fatal injuries to workers away from the protection of large machinery. Large rock falls containing a million cubic yards or more of material can be fatal even for operators inside heavy equipment such as haul trucks, bulldozers, and shovels.

As part of an ongoing study at the Spokane Research Laboratory of the National Institute for Occupational Safety and Health, several remote-sensing technologies are being evaluated as tools to monitor slopes for hazards and to assess slope stability (McHugh and Girard, 2002). Photographic image analysis techniques are being developed as tools to recognize potential hazards at mine sites. One approach is to use video cameras and computer software designed for surveillance monitoring. Video cameras with the standard sampling rate of 30 frames per second can provide real-time motion detection. Video sensors have a much greater range than the more-common radar, infrared, or ultrasonic motion detectors. Real-time monitoring of mine slopes to avoid injuries from falling rocks requires fast response times to provide workers at risk with enough time to get out of the way or find cover. Video surveillance developed in the security industry is designed to signal an alarm and record images of the scene when motion is detected. This technology was adapted for mine slope monitoring.

Development of imaging techniques to assess slope stability has been incremental over several decades. McVey and others (1974) used a 35-mm film camera and carefully positioned reflectors to measure deformation over time in an underground mine. Processed film was used to measure deflection to a resolution of 0.5 mm, but the use of reflectors adds substantial complexity to the installation process and limits analysis to sites with reflectors. Dombe and others (1982) designed a concept for detecting mine slope displacements using a pair of video cameras and computer processing to calculate and monitor slope topology. Allersma (1996) used a monochrome video camera and frame grabber to collect images of an induced dike failure; he was able to measure displacements as small as 10 mm. Collins and others (2000) described development of automated video technologies for real-time analysis of video sensor data. Their work addressed problems with standard video monitoring where an operator sits and watches video images. This method is not only costly, but may be ineffective. At the same time, simple recording of video tape by ubiquitous video cameras provides information only after the fact.

Corthésy and others (2001) described a differencing technique using before-and-after digital images to detect rock displacement in an underground mine. The results were similar to those described here except that the use of artificial illumination underground may simplify noise filtering.

ROCK FALL MONITORING WITH REAL-TIME VIDEO

A basic surveillance system built around hardware and software from Strategic Vista Corp.,[1] Markham, ON, Canada, and GeoVision, Taipei, Taiwan, was tested in the laboratory and in local field trials. The system includes an 8.5-mm (1/3-in) CCD color video camera with 480 lines of resolution, automatic iris, and a 6- to 60-mm (10X) power zoom lens. The camera is connected by means of an external frame grabber to the USB port on a notebook computer. The computer, with a Windows 98 operating system, runs programs (GV100 from GeoVision) that display real-time and re-

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[1] Mention of specific manufacturers or products does not imply endorsement by the National Institute for Occupational Safety and Health.

Figure 1.—Video motion-detection system showing camera, electronics enclosure, and 12-V battery on a tripod.

corded video images. All of these off-the-shelf components are powered from a 12-V, 100-amp-hour, deep-cycle battery by way of a 140-W dc-ac inverter. The computer, camera controls, and power connections were installed in a fiberglass environmental enclosure. The enclosure and a mount for the camera were attached to a 2-m-long, 38-mm diameter steel mast screwed into a three-legged base (figure 1). The camera was mounted near the top of the mast in its own weather enclosure.

The system can be set to record video frames and sound an audio alarm when motion is detected. Detection is accomplished by algorithms that monitor the intensity value of each pixel in the scene. When sufficient change is detected, video frames containing the motion are recorded to the computer's hard drive, and the alarm is activated. Sensitivity of the trigger is adjustable. Video images can be viewed and captured at several resolutions; for these tests, resolutions of 640 by 480 or 320 by 240 pixels were used. A mask function allows the user to select an area within the image frame where motion in the field of view will not trigger the record and alarm functions; this allows motion to occur in parts of the image without unwanted alarms. The system can also be configured to view the scene remotely through an Internet connection and dial a designated telephone number upon a triggering event. In addition to setting up capture of video clips of motion, the surveillance software provides a viewer that will run the video clips at various speeds, stop the video at any selected frame, and save frames as time-stamped digital images (.jpg or .tif).

Video clips can also be examined using commercial imaging software. Animation software (e.g., Windows Media Player, Jasc Animation Shop) makes it possible to view clips in real time or other speeds, forward or backward, or step through the frames individually. Additional analyses can be applied to frames saved to digital images. Images from succeeding frames can be compared using any of several relatively inexpensive programs that provide layering or mathematical operators for image manipulation (e.g., Adobe Photoshop, Jasc Paintshop, PictureWindowPro). In a subtraction or differencing operation between two nearly identical images, intensity values for corresponding pixels from each image are subtracted, resulting in a low value (dark) if the pixels are the same in the two images. For any pixels that have different intensity values between the two images, i.e., if there is a change, the result will be a bright image.

Laboratory tests of the system showed that motion is readily detected and recorded. Calibration tests included dropping markers of different sizes and color values against a white board marked with a 25-mm grid as a background. In a typical test shown in figure 2, a black square 25 mm on a side was dropped, triggering the system when it had moved about 10 mm. That change represents about 100 pixels (10 by 10) within the 76,800 pixels in the image (320 by 240 pixels), or about 0.13% of the image. Other tests were used to evaluate stability and file size. For example, the system was left to monitor routine laboratory activity continuously over a 40-hour period. During that test, more than 100 individual events triggered the system, capturing a total of 15.6 minutes of video at about four frames per second. Individual events ranged from less than 1 second to more than 3 minutes. The resulting files totaled 26.7 Mb of hard drive memory. The system manages available hard drive space by writing over the oldest files when storage resources reach a defined level. Other tests showed that very slow motion within the detection area would not trigger the alarm, and recording and alarm functions would stop when motion within the area stopped, even though elements within the view had changed from the original image.

Field tests in a local rock quarry showed that rock falls could be captured. Exterior change detection is based on a wider range of variables than are used in a more-controlled laboratory setting. To evaluate motion detection in the field, the system was set up in a rock quarry to monitor highwalls between 10 and 17 m high at ranges of 30 to 82 m. Rocks at least 15 cm across were dropped from the top of the slopes to generate

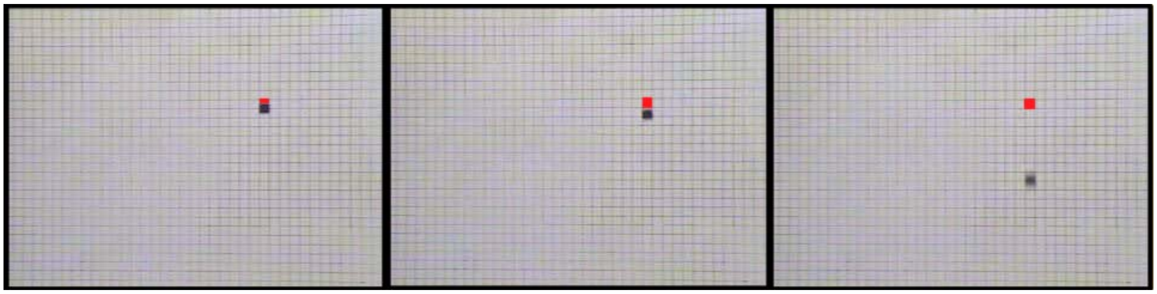

Figure 2.—Laboratory test of video motion detection. The grid in the background is at 25-cm spacing; a 25-cm marker falls after release. The colored box shows the location of the original marker. At the left is the first frame captured after motion detection, the second frame (center) was captured at 0.81 seconds, and the third frame (right) at 0.86 seconds.

minor rock falls. The dropped rocks and rock falls were sufficient to trigger the detection system, sounding an audio alarm and recording images of the rock fall. In one 13-minute interval of continuous monitoring, seven motion events were detected, including four manual triggers and each of three induced rock falls. The rock fall events lasted from 3.1 to 4.0 seconds; event times and durations are shown in figure 3. By recording video clips only when a threshold of motion was exceeded, storage resources (e.g., computer media) were reserved only for significant events, and time spent in reviewing recorded activity was minimized.

MINE EXPERIMENTS

Field tests of video motion-detection technologies were conducted at mines in Montana and Wyoming. The prototype single-camera, battery-powered system, as well as a multi-camera wireless unit in development, were set up and operated at the Yellowstone talc mine (Luzenac America, Inc.) near Ennis, MT, and at the Black Thunder Mine (Thunder Basin Coal Company, LLC) near Wright, WY. Three days were spent at each mine monitoring slopes for rock movements. In each system, video cameras were trained on a mine slope where rock falls might be expected; computer-detected changes in the video image triggered recording of video clips to capture the rock fall event. Later, the surveillance software viewer program and third-party animation software (Jasc Animation Shop) were used to analyze the video clips. The experiments were intended to provide data for determining optimum range, resolution, and sensitivity settings for video slope monitoring and for improving and simplifying the configuration, set-up, and operation of the system.

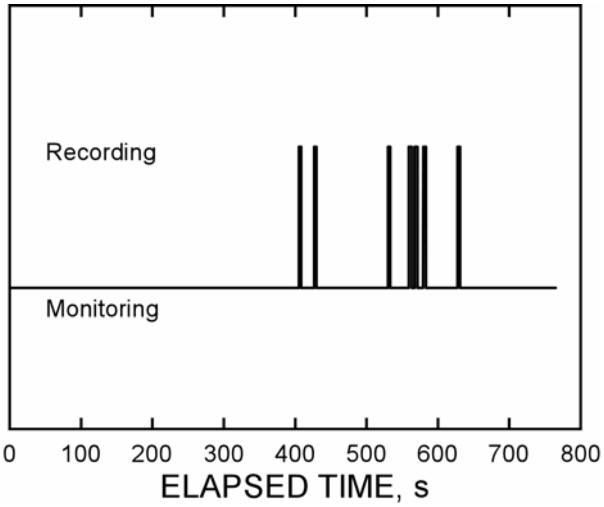

Figure 3.—Video clip recordings triggered by motion detection. During this 13-minute interval, about 25 seconds of video were recorded in seven motion events, including three rockfalls, each lasting less than 4 seconds.

Yellowstone Mine

At the Yellowstone Mine, the motion detection camera was trained on a portion of the highwall, at a range of 134 m, where rockfall had occurred recently (figure 4). No rockfall activity was detected over a 2-day period, but rocks were dropped from above into the image area to generate rockfalls. Each of these was captured in two events totaling 220 frames. Figure 5 shows a video frame that includes the impact of a dropped rock. The rock in motion (blurred) and a small cloud of dust were sufficient to be detected by the system.

On the third day, the system was moved to the floor of the active pit to monitor rock faces at different ranges and settings. In the first configuration, the camera was directed toward a blasted but otherwise undisturbed rock face on the floor of the pit; range was

Figure 4.—Highwall at the Yellowstone Mine showing area monitored by video camera (white box).

Figure 5.—Video frame captured during detection of a rockfall. Box shows where rock impact was detected. Inset shows where in the box differencing with a previous frame revealed changed pixels.

39 m and resolution was 640 by 480 pixels. For 16 events at this resolution, nine were manual triggers during set-up and testing, five were apparently wind induced, and two captured small-scale sloughs on the slope. In a second configuration, the camera was focused in on a part of the rock face, and resolution was changed to 320 by 240 pixels; rocks were dropped or thrown onto the slope (figure 6). Three artificially induced rock falls totaling 252 frames were captured. In one event, three sequential rock impacts were followed by sloughing over a total of 72 frames and an elapsed time of 39 seconds (figure 7).

In additional settings, the camera was redirected at other parts of the broken rock face and at the talc highwall at a minimum range of 29 m. Small sloughs on the broken rock face were captured in three events totaling 542 frames. Weather played a role in generating false triggers during this interval, capturing snow and rain both in the air and on the camera enclosure window. Fast-moving clouds and brief periods of bright sun caused illumination fluctuations too great to be compensated for by the automatic iris of the camera and exceeded its dynamic range. Resulting video clips include periods of camera bloom (whiteout) where nearly all detail was lost in the images.

Wind was found to present difficulties by shaking both the mast assembly and the camera mount and generating false triggers. More than 250 apparently wind-induced events were recorded over about 17 hours of monitoring. Stiffening the mast by attaching ratcheting nylon straps to the base legs helped substantially, but wind-induced shake in the single-point camera mount continued to be a problem.

Black Thunder Mine

The video system was initially positioned at the crest of the spoil pile above an active coal face to monitor the highwall above a shovel and truck loading operation; range to the highwall was about 168 m. Small-scale rock falls and sloughing were common along the highwall, especially from broken zones near the crest or part way down the face. Seeping moisture on the face was associated with these rock falls. The camera was first positioned with a wide-angle lens setting to include the highwall from its crest to the top of the coal. At this setting, 19 events were recorded over a period of 2 hours; rock movement was detected in three events accounting for 62 frames (22 frames per event). The remaining 16 events were apparently wind induced, resulting in 138 frames recorded (9 frames per event).

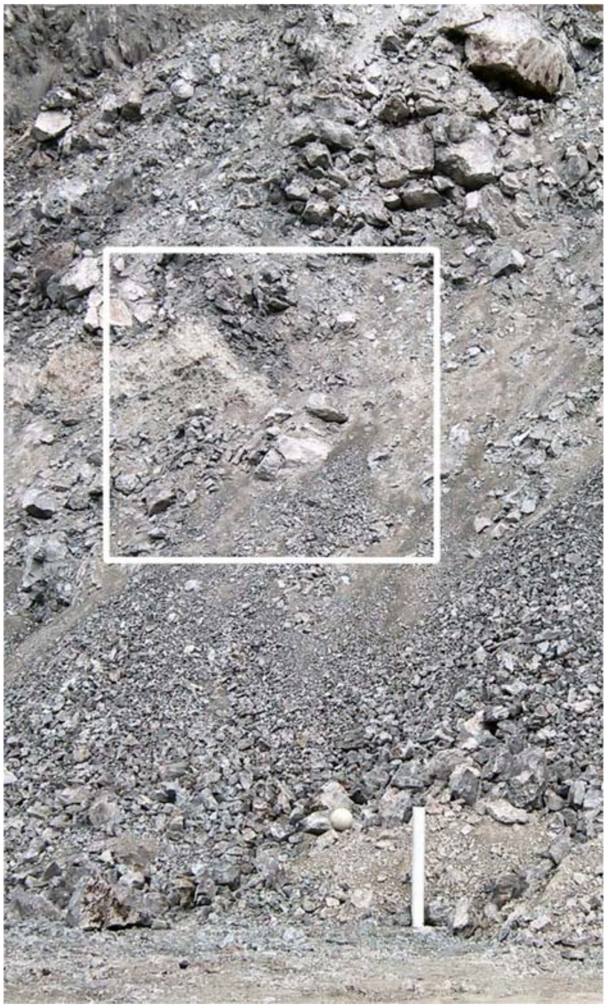

Figure 6.—Broken rock in Yellowstone Mine main pit. Box shows area monitored by video system. White rod is 1 m long.

Figure 7.—Video frame captured during detection of rockfall in area of box shown in figure 6. Bright areas show where change was detected.

In a second setting the camera was zoomed in on a zone of broken rock and water seepage about a third of the way down the highwall from the top (figure 8). In this position over a period of 10 hours of monitoring, rock movements were observed in 32 events resulting in 1073 frames recorded (33 frames per event). No rock movement was apparent in an additional 101 events that were likely caused by wind shake of the camera, averaging seven frames per event.

On day 3 at Black Thunder, the video system was positioned on the highwall side of the pit to view the spoil slope above a ramp intersection with the pit floor; range was 154 m. The view includes a spoil face where large-scale sloughing had occurred in recent weeks (figure 9). The video monitor was positioned to include a portion of the haul road along the pit floor so that vehicles using the road could trigger recording if no mask was used. The left video frame in figure 10, where the first parts of the haul truck are barely visible at the left edge, shows that even a very small change in the image can trigger recording. The right frame shows a mask within the image that would avoid vehicle-triggered alarms. Rock movement was detected in none of the 355 events recorded; moving vehicles (haul trucks, graders, loaders, scrapers, pickup trucks) accounted for 132 events, averaging 212 frames per event. Nine events were manual triggers during setup and testing (1,014 frames or 112 frames per event). The weather on this day was very windy and wet; 214 events are attributed to wind-induced camera shake or rain in the air or splattered on the camera enclosure window. In these events, 978 frames were recorded (five frames per event).

DISCUSSION

Changes in light and shadow in natural and mine environments make edge recognition a primary factor for detecting change within an image. Rock exposures that are relatively uniform in color make change detection difficult; for example, a brown rock moving against a brown background can be detected only by the shadows that shift as it falls. For that reason, the camera cannot differentiate between actual movement and changes in illumination such as when a cloud passes in front of the sun. In addition, wind can result in false alarms both by moving objects within in the image, especially vegetation, and by moving the camera itself, which causes the whole image to shift.

The single-camera, battery-powered prototype system used in these experiments operated well in mine environments. The camera and power-zoom lens provided sufficient resolution to frame problem areas for monitoring without difficulty. Rock fall events were readily detected, although no estimate was made of undetected events. The system is relatively portable and

Figure 8.—Highwall at Black Thunder Mine. Box shows area of broken rock and water seepage monitored by video system. Inset shows video frame captured during detection of rockfall; area in oval shows where change was detected

Figure 9.—Slump area in spoils at Black Thunder Mine. Box shows area covered by video monitor.

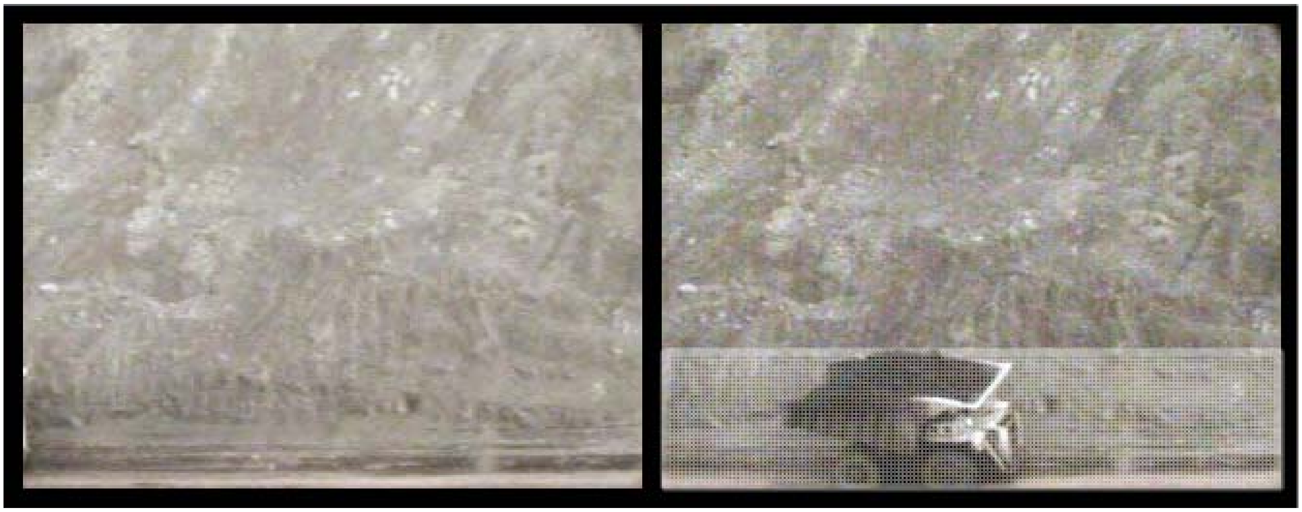

Figure 10.—Two frames from video clip of spoils pile. Each frame covers about the area shown in figure 8. In left frame, haul truck just entering at left edge was sufficient to trigger recording. Right frame shows masked area that would prevent machinery from triggering system.

easy to set up. The power system operated without problems, and a simple solar charging system could be easily added to charge the 12-V battery. Reviewing recorded video clips showed that changes on the mine slopes were readily observable. Video clips of rock fall events provided a valuable database of slope activity, showing sources of fallen rock and just how and where material moved on the slope.

The system, however, failed to prove its usefulness in providing real-time warning of rock falls. Excessive false alarms generated by wind and weather would make the present configuration unreliable. Modifications to stiffen the supporting mast and to stabilize the camera mount would likely solve the wind shake problem. Problems with rain and snow obscuring the camera enclosure window could be partially alleviated by adjusting the size and shape of the enclosure shroud, but triggers caused by the motion of falling rain and snow are more difficult to avoid.

The minesite experiments also provided an opportunity for first-time testing of a multi-camera video system (figure 11) that represents a next generation from the original prototype. Still in development, the system includes an embedded modular computer to run upgraded surveillance software and radios to provide wireless Internet protocol access. The wireless access will allow remote program control and will provide real-time video feed from each of four cameras to any notebook, hand-held, pocket, or other wireless-equipped computer within 90 m of the base station. Multiple cameras will allow the system to monitor several areas simultaneously using different resolution, zoom, and mask settings. In addition to slope monitoring, this system could be adapted to a wide range of other monitoring tasks.

Both prototypes relied on notebook computer LCD screens for pointing cameras and adjusting focus, zoom, and aperture settings. A problem shared by both systems is that the LCD screens were difficult to see in bright outdoor light. Brighter, higher-contrast screens, available on some hand-held and specialty computers, need to be incorporated for more effective outdoor use, although a light shroud to shield the screen would be an inexpensive short-term solution.

Control of the cameras themselves also presented problems. Although the single camera system included powered zoom, focus, and aperture controls, the camera still needed to be manually tilted and aimed to frame the desired zone on the slope for monitoring. Lenses in the multi-camera system had manual zoom and focus settings. Setup would be greatly simplified if each camera had remote pan, tilt, and zoom controls along with an autofocus lens.

CONCLUSIONS

Video motion detection was shown to be effective in identifying small changes in the video image. Relatively minor rock falls were recorded in active mines at ranges greater than 160 m. Video cameras need to be absolutely steady to provide motion detection; wind and precipitation during the mine experiments resulted in an excessive number of false triggers.

In addition to the potential for warning workers in the vicinity of hazardous rock slopes, recorded video images can allow shift bosses and safety investigators to reconstruct the rock fall and help identify areas of unstable ground. Archived video images can also pro-

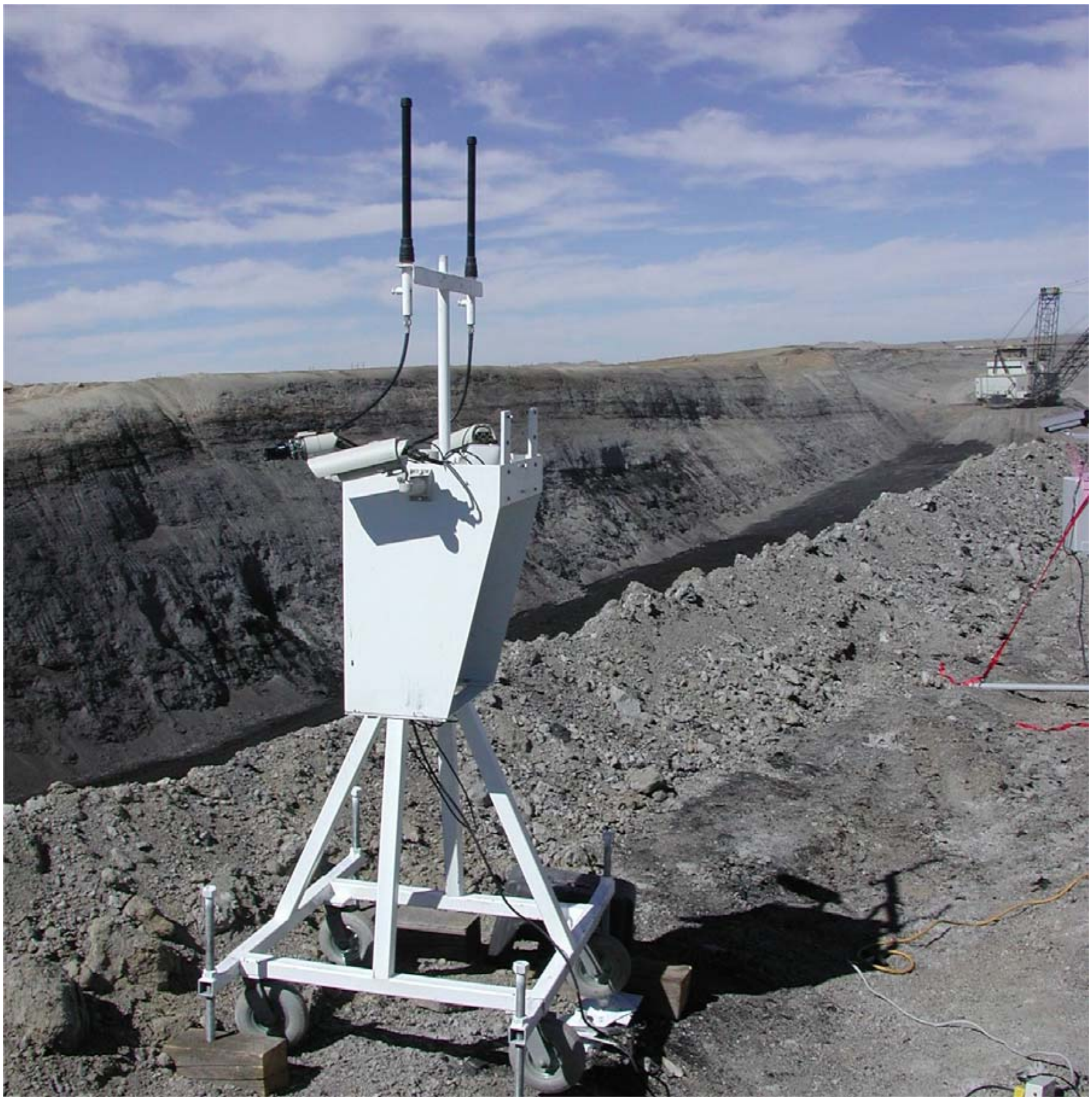

Figure 11.–Multi-camera, wireless-access video monitoring system at Black Thunder Mine.

vide quantitative information on the size and frequency of rock falls. One significant advantage of motion-triggered monitoring is that only short intervals of video are recorded, conserving storage media resources and making scenes of interest easier to find.

Digital and video cameras have proven valuable for recording mine slope conditions. Computer tools using time-lapse and motion-sensing methods can provide means to document slope failures and warn workers of rock falls. Basic development should focus on ways to streamline framing, capturing, and processing digital images and overcoming false alarms caused by wind, rain, and lighting.

ACKNOWLEDGMENTS

Access to mining operations and assistance in the mine site experiments provided by Mike Cerino, Luzenac America, and Mike Hannifan, Thunder Basin Coal, are greatly appreciated. The contributions of Rich Rains, Spokane Research Laboratory, in assembly of the prototypes and in the mine experiments were invaluable.

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