SLOPE STABILITY RADAR FOR MONITORING MINE WALLS

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EXTENDED ABSTRACT

Slope stability is a critical safety and production issue for coal mines. A common technique to determine slope stability is to monitor the small precursory movements, which occur prior to collapse. The “slope stability radar” has been developed to remotely scan a rock slope to continuously monitor the spatial deformation of the face. Using differential radar interferometry, the system can detect deformation movements of a rough wall with sub-millimeter accuracy, and with high spatial and temporal resolution. The effects of atmospheric variations and spurious signals can be reduced via signal processing means. The advantage of the slope stability radar over other monitoring techniques is that it provides full area coverage without the need for mounted reflectors or equipment on the wall. In addition, the radar waves adequately penetrate through rain, dust and smoke to give reliable measurements, twenty-four hours a day.

The prototype system consists of two main parts: the scanning antenna and radar electronics box connected via an umbilical cable (Figure 1). The scanning antenna consists of a 0.92m diameter parabolic dish mounted on a sturdy tripod and controlled by separate motors and gears for azimuth and elevation movement. The beamwidth of the antenna is approximately 2^o. The mechanical pointing accuracy and tripod stability requirements were designed to be within the system accuracy specification. A computer in the radar

Figure 1 – Slope Stability Radar Prototype.

electronics box can position the parabolic dish to anywhere between –15° and 165° in elevation from the horizontal, and between –170° and 170° in azimuth. The 2D scan region is set manually for the application. The scan speed is approximately 25 minutes for 4000 pixels on the wall. The pixel size on the 2D image is determined by the range extent of a 1° angle increment. For a rock slope at 100 metres range, the pixel size will be approximately 2m x 2m. Two-by-two pixels constitute one spatial resolution cell provided by the 2^o beam divergence of the antenna.

The radar source in the radar electronics box produces an intermediate frequency signal that is transmitted via the umbilical and up-converted to an X-band (9.4-9.5 GHz) carrier frequency at the feed of the scanning antenna. Range resolution of 1.5 metres is provided by a stepped-frequency waveform with 100 MHz of bandwidth. The maximum transmitted power from the feed antenna is 30 mW. The received signals are down-converted to the intermediate frequency and sent via the umbilical to the radar electronics box and recorded by the computer. The specifications for electrical stability, signal phase stability and signal-to-noise ratio were set to be within the system accuracy specification of 0.1mm.

Atmospheric disturbances caused by local changes in temperature, pressure and humidity are automatically compensated using the radar data for changes in the propagation velocity. Phase ambiguities occur in the measurements if outward wall movements are greater than $\lambda/4$. As the system has a high repeat rate compared with the time mechanics of slope deformation, phase unwrapping can be performed on a pixel-by-pixel basis through tracking the change over time. A spatial filter is then used to smooth the interferogram, and reduce phase errors caused by signal fades to pixels with a low signal-to-noise ratio.

Because there is no reflection target in the sky, the interferometric phase variation is random and hence is masked in the interferogram. In addition, incoherent phase signals caused by fluctuating vegetation on the slope is masked. Spurious targets caused by moving vehicles that briefly block the view of the radar affects a small region of pixels. These localized effects recover with the subsequent scan and are easily ignored by the software.

A time series of interferograms are combined to make a movie, thereby conveniently displaying the temporal and spatial movement characteristics of the wall surface. The amount of outward or inward movement of each pixel relative to the radar position is indicated by a colour change. The displacement history of selected regions can be displayed by spatially averaging over an unstable region and compared with a stable region. A polynomial regression fit to the data points can be made to measure the outward acceleration of the rock mass. A graphical user interface has been developed to display and compare the interferograms with co-registered images of the reflection amplitude, reflection range, or photographed scene. It also allows regions to be selected for continuous tracking and an adjustment of the various parameters used in the image reconstruction tools. A typical display of the GUI is shown in Figure 2.

The system has been trialed at Drayton, Moura, Callide and Tarong mines, which demonstrated the potential for real-time monitoring of slope stability during active mining operations. These trials showed that outward deformation movements of a rock face could be detected with accuracy around 1 mm (eg. Figure 3). It overcomes the shortcomings of conventional monitoring systems by providing greater coverage of the rock face, hence giving a better understanding of the geodynamics, which should in turn lead to extra warning time. This translates to greater productivity in the sense of lower risk associated with recovery of coal. It would enable direct recovery, where under conventional monitoring conditions the area would be quarantined on grounds of excessive risk.

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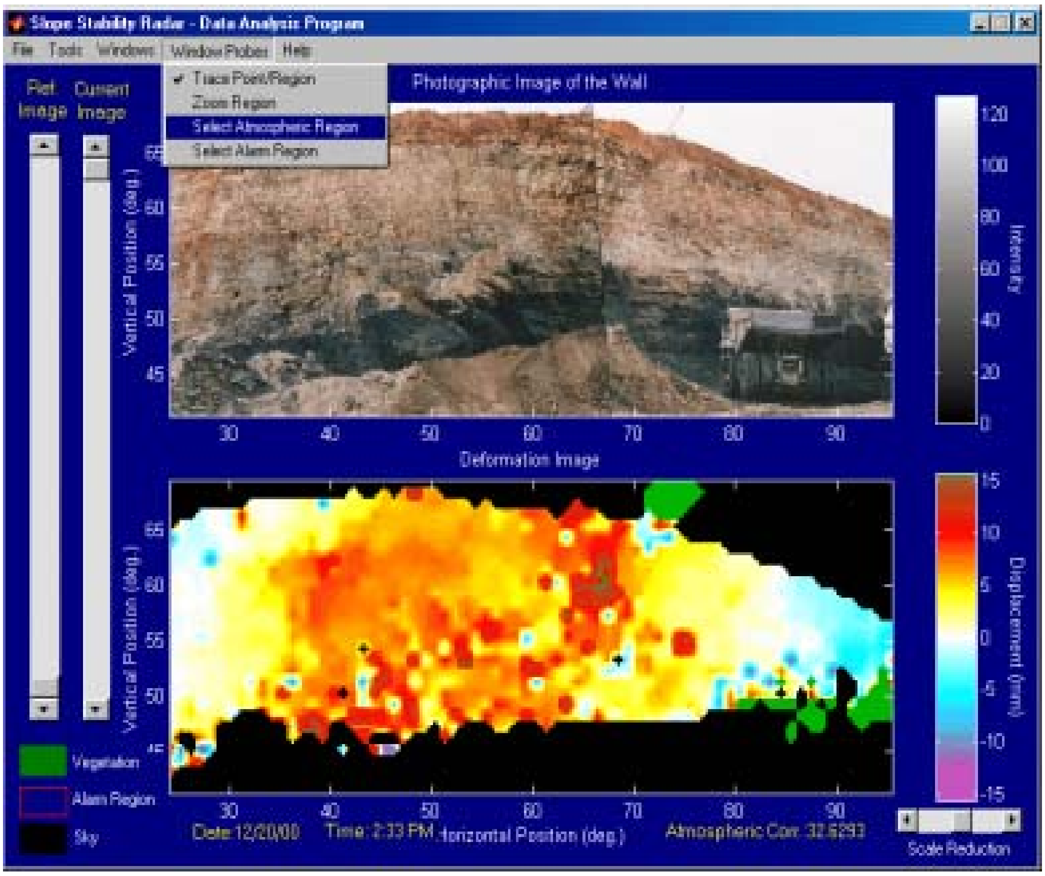
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Figure 2 - Typical GUI display with photograph image of the slope in the top view and radar deformation image in the bottom view (a color scale is used to indicate displacement in millimetres).