Review on low-cost wireless communication systems for slope stability monitoring in opencast mines

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Abstract: Slope stability is one of the primary problems faced by opencast mines. The conventional geotechnical sensors are monitored by technicians in the field and the available wireless monitoring systems like slope stability radar (SSR), light detection and ranging (LiDAR) are more expensive. Critical observations on recent low-cost wireless slope monitoring systems were presented. By deploying the wireless data transmission system using advanced antennas at respective slope instruments in underground or opencast mines, we can collect data without any physical connections. Wireless sensor networks (WSNs) are well suited to monitor the movement, and it consists of sensor nodes which measure physical quantities and transmit the pre-processed measurement results to a base station. Developments in information and communications technology (ICT) support the collection, connection and analysis of data through sensing and monitoring of slopes in mines. This paper gives the detailed review on available low-cost wireless slope monitoring systems for opencast mines.

Keywords: slope stability; opencast mine; WSNs; wireless sensor networks; time domain reflectometry.


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1 Introduction

Sensors are parts of all machines that gather data and have an integral role in subsequent processing and transmission of data. Remote monitoring of slope movement using electronic instrumentation can be of approach for many unstable or potentially unstable slopes. Many options are available for monitoring unstable and potentially unstable slopes. Conventional systems like total station monitoring, extensometer, piezometer, and inclinometers, etc., are difficult for installation and separate manpower required for collection of readings from instruments in mines (Jayanthu et al., 2015; Kane and Beck, 2000). A TDR technology based on XBee communication is proposed. Wireless communication is the burning need today for the fast, accurate, flexible safety and production process in mines. Communication is the main key factor for any industry today to monitor different parameters and takes necessary actions accordingly to avoid any types of hazards. To avoid loss of material and damaging to human health, protection system, as well as the faithful communication system, is necessary mines.

2 Time domain reflectometry

The basic principle of TDR is similar to that of radar. In TDR, a cable tester sends a pulse voltage waveform down a cable grouted in a borehole. If the pulse encounters a change in the characteristic impedance of the cable, it is reflected. This can be caused by a crimp, a kink, the presence of water, or a break in the cable. The cable tester compares the returned pulse with the emitted pulse and determines the reflection coefficient of the cable at that point. Electrical energy travels at the speed of light in a vacuum but travels somewhat slower in a cable. This is called the velocity of propagation. The TDR generates a very short rise time electromagnetic pulse that is applied to a coaxial system which includes a TDR probe for rock mass deformation and samples and digitises the resulting reflection waveform for analysis or storage. The elapsed travel time and pulse reflection amplitude contain information used by the onboard processor to determine quickly and accurately rock mass deformation for slope stability measurement or user-specific, time-domain measurement (Figure 1). A 250-point waveform should be collected and analysed in approximately 2 s. Each waveform should have approximate up to 2048 data points for monitoring long cable lengths used in rock mass deformation or slope stability. TDR for determining ground movement requires reading the cable signature at regular time intervals (Jayanthu, 2014, 2015). Ground movement, such as
slip along a failure zone, will deform the cable and result in a change in cable impedance and a reflection of energy. This change can be used to determine the location of shear movement.

The change in impedance with time corresponds qualitatively to the rate of ground movement. TDR cable readings showed the development of a spike in the cable at 9 m distance indicating movement is as illustrated in Figure 2. Observation of tension cracks in the ground surface verified the fact that some movement had taken place. A cross-sectional view of the installation of the single cable of TDR is shown in Figure 3.

**Figure 1** Basic principle of TDR (see online version for colours)

**Figure 2** TDR cable signatures showing development of a shear zone at 9 m distance (see online version for colours)

3 Optical time domain reflectometry (OTDR)

It works on the principle of the fibre Bragg grating (FBG), and it is a fibre optic sensor recorded with UV laser light reflected wavelength varies with strain and temperature (Figure 4).
3.1 Interrogator

Tunable laser interrogation unit illuminates fibre and measures reflected Bragg wavelengths. Processing Unit converts wavelengths to measure of interest, which is displayed real-time or logged for future analysis. Numerous sensors recorded on a single fibre, mm or km apart. Sensors can measure strain, pressure, temperature, etc. (Figure 5).

3.2 Advantages

There is no necessity of electrical parts. It has reduced the number of components. It has no movable parts. It is tolerant of extremes of the following factors such as temperature, vibration, and electromagnetic radiation, magnetic and nuclear radiations. It has
high-speed, high-resolution, low-cost interrogator. It has a frequency of 2.5 kHz sampling of up to 64 connected sensors and up to 76.9 kHz sampling of each sensor in turn. It is best in class resolution, robustness, and dynamic range. It has ATEX certified variants available (Stanek, 1988). It comprises further details of technology via Smart Scan Lite is a reduced speed (250 Hz) with lower priced variant. Smart Scan Aero is available for harsh environment use. It was flight-tested in 2007 and awarded technology readiness level TRL7, and then further tested in 2013 by an aerospace client.

3.3 Multiplexing

It possesses dozens of multi-parameter sensors on one fibre optic cable. It has fewer instrumentation channels. It integrates different measurands on the same system. It requires lesser connections. It has reduced penetrations and also reduced cost. It is more reliable.

Figure 5 Interrogator system (see online version for colours)

4 Robotic total station

In mines a number of robotic total stations, also known as, the automated total stations are installed, the number being dictated by range, atmospheric conditions, visibility, the design of the optics, the power of laser and resolution of charge coupled device camera. These total stations are usually placed at the top of the pit to identify visibility of as many targets as possible (Figure 6). At least one station stable point is required for rotation orientation and accounting for rotations due to uneven heating and cooling. This is obtained by using a network of total stations to a common prism. The total stations can also be linked to satellite-based positioning systems that provide absolute control.

The total stations are placed in special shelters to protect them from blasting and adverse site weather conditions. Some prisms are installed on the slope at the regular spacing for measuring movements at the monitoring points. The prism installation is risky and time-consuming. There is a possibility that the slope failure would occur during or even before monitoring. The customised software provides a total integration using the wireless communication network to measure movements of slopes in X, Y and Z directions. These data either are recorded in real time or post processed mode. Alarms can low-cost at site specific trigger levels for early identification of slope movements. The major advantages of prism monitoring have increased the precision of the coordinates, continuous measurement in all weather conditions, and accurate
measurement with a distant reference point. The disadvantages of prism monitoring are it requires an open sky view or the system will be affected by insufficiently tracked satellites. The system can be affected by nearby machinery that affects the functioning of the system.

Figure 6  Automatic total station monitoring (see online version for colours)

5 Wireless smart sensor technology

Wireless smart sensors (WSS) differ from traditional wired sensors in significant ways. Each sensor has an onboard microprocessor that can be used for digital signal processing, self-diagnosis, self-calibration, self-identification, and self-adaptation functions. Furthermore, all WSS platforms have thus far employed wireless communication technology. WSS technology has seen substantial progress through interdisciplinary research efforts to address issues in sensors, networks, and application-specific algorithms (Egan, 2005; Stanek, 1988). All commercially available wireless sensors network nodes were designed for low sampling and throughput rate. The WSS nodes can communicate in either single-hop or multi-hop ways with two base-station computers that are remotely accessible via the internet. Intel develops the iMote2 (Figure 7) for structural health monitoring for bridges. Sensor boards (measuring 3-axis acceleration, temperature, humidity, and light). The first deployment of WSS system on the bridge was carried out in 2009 in South Korea. The 70 sensor nodes in the network were divided into two subnetworks: one on the Juido island side and other on the Haenam side. It requires the multidisciplinary research to implement the WSS technology in the mine site for low-cost real-time monitoring of ground movements.
Slide minder wire line extensometer system

With real-time monitoring, the Slide Minder system provides an immediate warning when movement occurs, significantly increasing the safety of personnel and reducing costly damage to equipment (www.campbellsci.com/product-literature, www.slopeindicator.com). Accurate measurements, combined with software that prevents false alarms, allows safe and remote monitoring while reducing production downtime (Figure 8).

Source: www.campbellsci.com/product-literature
6.1 Features
- Stand-alone system operates remotely and requires virtually no maintenance.
- Wi-Fi and FHSS radio technologies do not interfere with existing communications.
- Software utilises web-based graphing engine – can be viewed and controlled on any computer on the network.
- Warnings and alarms can activate strobes and be sent via cell phones, web browsers, and email.
- Complete customisation of alarms allows geotechnical personnel to set user-defined warnings for multiple velocities and displacements for each machine.
- Field proved to withstand rugged conditions and extreme temperatures.
- Allows monitoring throughout a slope failure without damage to the unit.

6.2 Measurement
- **Wireline**: 600 ft. or 1000 ft. (183 m/305 m)
- **Sensitivity**: 0.01 in. or cm.
- **Encoder resolution**: 4096 CPR
- **Operating temperature**: –40 F to 140 F (–40°C to 60°C).

6.3 Communication
- **Frequency**: 902–928 MHz FHSS (Standard) or 916–927 MHz FHSS (International).
- **Range**: 2 miles (3.2 km) with 5 dB antenna or 5 miles (8 km) with 6 dB antenna.
- **Broadcast power**: 1 W.
- Repeaters available for extended coverage.
- Wi-Fi option.

7 Wireless slope monitoring-string potentiometer
Specto Technology’s automated, wireless slope monitoring system combines unique hardware and software technologies to provide customers with a simple and effective solution for unattended slope monitoring (Figure 9). By leveraging the power of the simple, rugged data logger along with reliable String Potentiometer sensors, slope movement may be monitored remotely and automatically. Time spent on site is virtually zero thanks to the simplicity of the data logger and the fact that system configuration and management is done remotely through a simple web portal. The data logger records data from the sensor at intervals determined by the user (as often as every minute). Data is sent to the web over the cellular network each day (or when a threshold is exceeded). Data is available for viewing in a web-browser (through the ARGUS software).
7.1 Features and benefits

- String potentiometer sensor accurately measures slope movement (displacement).
- Rugged sensor housing.
- Sensors come in various forms, sizes, measuring ranges and prices.
- Data logger collects data and transmits to the web once per day
- Read up to 4× sensors per data logger.
- 5-year battery life (with daily upload).
- Fully potted electronics protect data logger from water ingress.
- Setup, configuration and automated download done via web portal.
- Plug-and-play installation (no onsite setup required).
- Proven technology.
- Low subscription cost.
- Compatible with ARGUS Monitoring software.

Figure 9 Installation setup of string potentiometer in slope (see online version for colours)

8 Wireless tiltmeter

Wireless tiltmeter was designed which could be specially tailored to the needs of monitoring hazardous rock bodies in both surface and underground mines. By recording angles of any slope, either in a surface mine or underground, over extended periods of time, changes in readings can infer instabilities in the rock mass underlying the slope being measured. By placing many tiltmeters in a mesh on a surface slope or underground roof, rib, or other face, the entire surface can be monitored (Chan, 2010). Compared to the measurements of a single point using one instrument, a dense network can be extremely useful in detecting rock movement. Many monitoring techniques are in use
already in mines. Traditional methods of monitoring, though undeniably useful, are often time-consuming. By utilising wireless devices that transmit data back to a single location, data acquisition and analysis time can be minimised, saving the mine employee hours as well as down time.

9 Shape Accel Array

The Shape Accel Array/Field (SAAF) consists of an articulated chain of sensor elements (segments) each 0.305 m or 0.500 m long. The segments are joined in such a manner that they can move in relation to each other in all directions except for twisting (Figure 10). Each segment contains a multi-axial MEMS chip accelerometer. This makes the segment act as an extremely accurate inclinometer that determines the angle of inclination in both $X$- and $Y$-direction. Due to its articulated construction, the SAAF is capable of following the deformation of the soil very precisely.

Figure 10  Shape Accel Array on shipping reel (see online version for colours)

The diameter of the SAAF is only 25 mm. Therefore, it can be installed in a flexible PVC-pipe with an outside diameter of only 32 mm. The SAAF operates in any desired position, so vertical or horizontal or at any angle in between. As not only the $X$- and $Y$-coordinates but also the $Z$ coordinates are determined, the SAAF provides the complete three-dimensional picture of the deformation. The SAAF is delivered with free-of-charge visualisation software packages for real-time monitoring and measurement at time intervals. The data can be readily exported to common software as MS-Excel and MS-Access.

10 Conclusions

A critical review on various recent low-cost wireless slope monitoring techniques was presented for the understanding stability of slopes. It is also indicated that monitoring of slope movements remotely with TDR techniques is a feasible alternative to more labour-intensive methods like using survey monuments or inclinometers. One of the main
drawbacks in TDR, compared to the use of a tiltmeter, is the inability to determine the orientation of the movements. To overcome this problem TDR can also be compatible with tiltmeter to install along with TDR cables. In OTDR number of sensors required is more and monitoring area is less. By installing wireless sensor nodes at respective slope stability monitoring stations in mines, data from slope instruments can be acquired and interpreted online. It is very much required the multidisciplinary research to implement the WSS network technology in mines for slope stability monitoring.

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