This paper presents critical review on available methods and advanced technologies for slope monitoring in opencast mines including SSR, TDR etc besides total station monitoring system for mines, and status of research through the ministry of Mines sponsored S&T project on TDR technique. Critical review of various methods and advanced technologies for slope stability monitoring indicated scope of SSR—which is very costly (about Rs. 4-5 Crores), and recent developments in TDR (About Rs. 20 lakhs) as promising methods for its application to mines besides conventional total station monitoring. Slope stability is one of the leading problems faced by opencast mines. The conventional geotechnical sensors are generally monitored by technicians in the field and the available wireless monitoring systems like SSR, LiDAR are more expensive. The purpose of this paper is to introduce the different cost effective real-time slope monitoring systems. 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 consist of sensor nodes which measure physical quantities and transmit the preprocessed measurement results to a base station wirelessly. Developments in information and communications technology (ICT) support the collection, connection and analysis of data through sensing and monitoring of slopes in mines.

**KEYWORDS:** Slope Stability, Opencast mine, Wireless sensor networks, SAR, Time Domain Reflectometry.

**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 an effective 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 man power required for collection of readings from instruments in mines. 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 take necessary actions accordingly to avoid any types of hazards. To avoid loss of material and damaging of human health, protection system as well as the faithful communication system is necessary mines.

**SLOPE MONITORING TECHNIQUES**

Presently, due to ever-increasing demand of minerals for the country, it is very much required to have the opencast mines at a greater depth. Increasing depth also increased the severity of slope stability problems of the opencast mines. Unlike the previous quarrying practices at shallow depths, now-a-days, study the stability of slopes of working benches and waste-dumps of opencast mines and analyzing their stability has become a challenge for the mining community. For the purpose, besides design of slopes by modeling or analytical methods, it is pertinent to utilize various techniques for monitoring the slopes to understand the status of its stability and early detection of instability of slopes for opencast mines. Many fatal accidents due to slope failures in Indian mines indicate the urgent need of conducting slope monitoring for the working benches as well as dumps. The following methods are reviewed along with its application for slope monitoring in opencast mines:

- Prism monitoring
- Laser monitoring
- Seismic monitoring
Workshop on RADAR TECHNOLOGY FOR SLOPE STABILITY MONITORING, KOLKATA-23-24 MAY 2017

- Digital photogrammetry
- Radar monitoring

**PRISM MONITORING**

Conventional prism monitoring at most open pit mines worldwide is performed by surveyors. Automated theodolites are installed to save time, increase the number of measurements and improve the accuracy and precision. Prisms are installed on the highwalls at a regular spacing, 50 m horizontally and 45 m vertically, and on critical areas throughout the open pits. The Survey Department is responsible for maintaining the theodolites and prisms and for collecting and storing the data. The rock engineers then analyse the data, looking for significant movement, and report any potential areas of slope failure to the mining personnel. The prism positions are measured every 4 hours by the automated theodolites, two of which are permanently set up on beacons on the western and eastern crests of open pit. The GeoMoS system monitors the status of the total stations and allows the user to view the data graphically. The user can filter the data and plot graphs of displacement, velocity and vector movement of one or many selected prisms. There are 3 displacement plots – longitudinal, transverse and height - for the movement along the x, y and z axes. A vector plot combines these 3 movements into an absolute movement. A velocity plot uses the longitudinal displacement to calculate a displacement velocity. The data from the prism monitoring is automatically stored in a customised MS Access database called SS MON. It is linked to the mine’s draughting package, AutoCAD, which displays the movement vectors on cross-sections or 2D plans.

The GeoMoS Analyzer graphs are plotted automatically whenever new data is received which enables quick and easy identification of slope movements. Alarms are set by the rock engineers at site-specific trigger levels and sms’s are sent out to the Survey manager when those levels are exceeded. At PPRust the alarms sound when 30mm displacement or 50mm/2 hours velocity is recorded. If an alarm is sounded, the Survey department will check that it is not a result of survey error while the Rock Engineering department will investigate the area of concern. If slope movement occurs in a working area it will be evacuated until it is declared safe. Laser and radar monitoring will be set in place to improve monitoring until the slope fails. Alternatively failure is induced to remove the risk completely so that operations can continue safely.

**LASER MONITORING**

Prism less laser monitoring was introduced to fill in the gaps where prisms have been lost or where they were never installed. Two Riegl LPM-2K laser scanners for slope monitoring are permanently installed in steel protective houses on the crest of the highwalls. The lasers scanners are battery operated, require no levelling and are eye safe under all operating conditions. A camera is attached to the side of the laser and takes photographs at the start of scanning. The lasers are controlled by 3DLM Site Monitor software which allows the user to specify monitoring points and frequency as well as group certain points. The exact x, y and z coordinates of specified points are programmed into Site Monitor and these points act as ‘virtual prisms’. These points are spaced 5 m apart, both horizontally and vertically across the entire 2 km long and 100 m deep slope. The wall is divided into 10 zones and the laser scans the points one by one and returns to the first point at 6am every morning and 6pm every evening. It takes 9 hours to scan the entire west wall which is 500 m to 1 km from the scanner (depending on the angle). The accuracy is 20-50 mm which is comparable with GeoMoS. The laser transmits the data by radio to a computer in the Survey office where the data is downloaded into Site Monitor Analyser and PolyWorks software where the data can be analysed. The data appears as a point cloud which can be rotated, filtered and colored as required. The data can be exported in ASCII format thus can be brought into AutoCAD and Datamine.

The point clouds are very useful for volume calculations and visually analysing the state of the pit slope. More importantly, the point clouds are compared, point by point, and progressive slope movement is calculated and plotted. A photograph of the scanned region is displayed and the movement is overlaid in various colours. Contour plots can be made of the movement data and alarms can also be set up as with the GeoMoS system. Laser monitoring, however, has the same disadvantage as the prism monitoring in that it cannot provide early warning of failures for evacuation purposes. It is therefore also used for long term monitoring trends and for identifying high risk areas where the GroundProbe radar must be put in place.

**DIGITAL PHOTOGRAMMETRY**

SiroVision is a digital photogrammetry software program that enables safe and comprehensive mapping of dangerous and inaccessible highwalls. Large areas can be quickly mapped and it provides an excellent record of the
changes in pit faces over time. A normal high resolution digital camera is set up on a tripod and its position is surveyed. A photograph is taken of the face in question, which must include a surveyed reference point of some sort. The tripod is moved a certain distance (e.g. 50m) to the left, its position is surveyed and a second photograph is taken of the same face the distance depends on the distance from the camera to the face and the 2 photographs must overlap by 90%. This can be repeated for all the areas on the slope. The photographs are downloaded from the camera and are brought into the software along with the survey readings (Fig 1).

SiroVision is made up of 2 parts – Siro3D and SiroJoint. Siro3D is used to import the images and surveyed coordinates, which are then combined and converted into a 3D image which is accurate to 1 degree orientation. The images are saved and then opened in SiroJoint which is used to interpret the images. Joints, faults, dykes and geological contacts can be easily digitised in SiroJoint and orientations (dip and dip direction) can then be measured off the image. These readings will often be more accurate than ones taken in the field as they average hundreds points on the whole surface. When a geologist takes a reading he measures only a few points on a large surface. Also many of the flat lying joints in a mapping face cannot be reached by a geologist thus the mapping data is biased towards the vertical structures. With SiroVision however, all structures in a face can be measured thus the bias is removed.

The orientation readings can be plotted on stereonets in SiroJoint and grouped into joint sets. At PPRust, this is used for joint set identification, kinematic failure analysis and geotechnical zoning. The structures can be extrapolated and overlaid over pit designs in SiroJoint or exported into design and draughting packages. It greatly improves the rock engineer’s ability to identify potential failure planes in 3D space and to predict where they will cause failure on the benches below. This is particularly effective on the west wall at Sandsloot open pit where there is no access to faces and mapping the accessible faces is dangerous. Also the size of the exposed failure planes ensures reliable readings and allows for accurate extrapolation. The west wall is regularly mapped with SiroVision and each failure plane and potential failure plane is exported into Datamine. The planes are then extrapolated laterally and down slope to provide an idea of where failures may occur on lower benches. This enables better identification of where prisms must be installed, laser point cloud density must be increased and radar monitoring must be focused. It also provides a qualitative method of monitoring failures. By taking photographs of the same place on a regular basis comparisons can be made and failures that have been missed by other monitoring techniques can be identified. SiroVision analysis also aids the planning department in designing around the failures and incorporating the cost of cleanup and secondary blasting into their economic analysis. It is therefore important for the Rock Engineering department to work closely with the Survey, Geology and Planning departments to get the maximum benefit out of the system.

**VISUAL MONITORING**

Visual monitoring, like SiroVision, plays an important role in identifying high risk areas and subsequently implementing the correct monitoring systems. A system is only as good as its user and without inspections by geotechnical staff and operational staff the monitoring equipment would be incorrectly used. Inspections are also a basic form of monitoring and are especially important in areas that do not warrant high-tech monitoring devices. The geotechnical department at PPRust performs 4 types of inspections which are stored in a MS Access database. Daily
inspections on operational areas are done by the geotechnical assistant and any hazards that are identified are reported immediately to the mining personnel who are then responsible for taking action to remove the risk. These are very simple inspections which the pit foremen can also perform. Detailed inspections are done on areas that are high risk or where failure has occurred. These provide good understanding of the causes of failure and enable the geotechnical engineers to select the correct monitoring devices for the hazardous area. Comprehensive monthly inspections of all areas in both pits are done by a rock engineer who uses the data to determine risk ratings for each area. A monthly hazard plan is produced which is displayed in all shift change and line up areas so that all pit personnel are aware of the risk levels in their area. Mitigating actions are also specified and the pit superintendent is responsible for implementing them. Presplit inspections were designed to measure the success of the presplit and trim blast designs. The blast design parameters and the condition of the highwall are combined to calculate a rating out of 10 for the presplit wall. This enables the rock engineers and blast engineers to determine the cause of damaged final walls and remedy the problem ahead of further blasts. The ratings are also automatically overlaid on bench plans in AutoCAD which are accessible to all mining personnel. Thus at any time, a user can check up on the status of the highwalls. Presplit and trim designs are thus regularly checked and improved.

SEISMIC MONITORING

Seismic monitoring aims to predict slope deformation by measuring micro seismic events caused by brittle movements within a rock slope. Analysis of micro seismic events using multiple geophones enables the location of source and therefore the discontinuity on which movement is occurring. Seismic monitoring systems are the norm in underground gold mines but have only recently been implemented at open pits by ISSI. These systems consist of a number of geophones installed in the pit slope, which record all micro seismic movements down to 0.001 mm. The data is stored on a hard disk on surface and collected or sent to an office computer via radio link. The data is then interpreted by seismologists and reports are produced. Increased seismic activity can provide early warning of slope failure and trends in the data can potentially identify weak failure planes. It is therefore a long-term monitoring system for which aids in the understanding of weaknesses in a rock mass.

SLOPE STABILITY RADAR TECHNOLOGY

Conventional modern monitoring methods for predicting pit slope failures normally depend on visual inspection and regular EDM surveys using reflecting prisms at specified locations. Some typical slopes failures in iron ore mines presented in Fig 2. This may be augmented by detailed recording of movements at known problem sites by use of extensometers, tension crack monitors, or other types of instruments. Apart from visual inspection, these instruments provide displacement information only for a single site or nearby sites. If the monitored sites are wide apart or displacement occur between the sites, it is difficult to predict early indication of slope failure. Slope stability radar has some advantages than other monitoring methods in its ability to cover large surface areas for 2-monitoring round the clock in any weather condition. Such a scanning radar system was designed and developed by researchers at University of Queensland, Australia (2002) specifically for monitoring mine slope failures using differential interferometry. The GroundProbe SSR is a technique for monitoring mine walls based on differential interferometry using radar waves. The system scans a region of the wall and compares the phase measurement in each region with the previous scan to determine the amount of movement of the slope. An advantage of radar over other slope monitoring techniques is that it provides full area coverage of a rock slope without the need for reflectors mounted on the rock face. The system offers sub-millimetre precision of wall movements without being adversely affected by rain, fog, dust, smoke, and haze. The system is housed in a self contained trailer that can be easily and quickly moved around the site. It can be placed in the excavation, or on top of a wall or on a bench to maximize slope coverage whilst not interfering with operations. The scan area is set using a digital camera image and can scan 320 degrees horizontally and 120 degrees vertically. The system provides immediate monitoring of slope movement without calibration and prior history. Scan times are typically every 1-10 minutes. Data is uploaded to the office via a dedicated radio link. Custom software enables the user to set movement thresholds to warn of unstable conditions. Data from the SSR is usually presented in two formats. Firstly, a colour “rainbow” plot of the slope representing total movement quickly enables the user to determine the extent of the failure and the area where the greatest movement is occurring. Secondly, time/displacement graphs can be selected at any locations to evaluate displacement rates. Additional software can also be installed to allow the data to be viewed live at locations remote to the SSR site such as corporate offices and at the offices of geotechnical consultants.
Use of SSR in Identifying Mine Slope Hazards

One of the primary roles of the SSR is identifying unstable slopes [4]. The broad area coverage and near real time scanning means that large expanses of slope (e.g., 500,000 m^2) can be scanned and results obtained in less that 10 minutes. After a relatively short time, areas of stable slope can be identified, as well as those areas that are showing greater deformation than expected (providing they show deformation greater than one tenth of a millimetre). This increased deformation may represent areas of slope instability, possible leading to collapse. Some mining operations have used the SSR as a campaign monitoring tool where the portability of the system is used to scan regions of the slope for several days before moving onto the next region of the slope [5]. The results of the slope survey are then used to target further geotechnical investigations and instrumentation. For example, additional survey prisms or wireline extensometers will then be located at ‘hot spots’ areas where deformation rates are considered excessive.

Another frequent application of the SSR in identifying instabilities is in monitoring highly hazardous rock walls with adverse geological structures. The SSR has seen widespread adoption in these situations because the broad area coverage and fast scan mean that such failures can be identified quickly. Small bench failures can develop rapidly in hours. In these cases it is prohibitive to mount survey prisms at such high densities to guarantee that the failure would be identified on survey. As a result, SSR systems are employed to provide monitoring coverage and early warning of rapid failures to protect production crews.

In everyday usage, risk is often used synonymously with the probability of a known loss. Mining risk can involve people, equipment, reserves or company profile. The mining risks that the SSR can help ameliorate are naturally associated with slope failure. Many practitioners consider risk as a product of the likelihood of a negative event occurring and the consequence of this event if it does occur. Both the likelihood and consequence of slope failure can be modified by the application of an SSR system with some examples given below.

The likelihood of failure can sometimes be reduced by modifying the geometry or properties of the slope. SSR systems have often been used in buttress operations during both removal and creation. During the development of slope stabilizing toe buttresses, the SSR system has been deployed to monitor the real-time velocity of a slope while material is added to the toe of the slope to stabilise it. As well as monitoring the stabilization effect of buttressing on the slope (works cease when slope velocity drops below a target level). The SSR is also used to monitor and alarm for an increase in slope velocity or disintegration of the slope, so that the construction team can be safely evacuated.

Use of the SSR systems to monitor removal of a buttress is particularly common in the coal mines where failures on the high wall often occur due to coal excavation (coaling). The SSR has been utilized in known unstable areas of the high wall during production. This requires near real time monitoring data over the expanse of the rock slope, for which the SSR is well suited. In addition the SSR can also be used in waste dump monitoring.

**System Specifications:** Key technical details of the SSR are:

- Measurement precision ±0.1 mm
- Maximum range of 1,400m (SSR-T) or 2,800m (SSR-XT)
- Scans up to 270° horizontally and 100° vertically
- Scan rate of 1min-30min (varies according to scan area)
- Resistant to vibration and local mining equipment
- Unaffected by wind speeds up to 88km/h
- Trailer towing weight approximately 1,800kg
- Radio frequency exposure (<0.02mW/cm²) is at least a factor of 50 below the acceptable limit for general population (1mW/cm²)

A less direct application of the SSR in reducing the likelihood of failure involves using the data obtained in geotechnical analysis and design, which is then used to modify operational activity. For example, at one mine site the sub-millimetre response of a rock slope during blasting was monitored by the SSR for a number of different blasting trials, to select the best limit blasting procedure to reduce damage to the rock slopes. Monitoring and feedback is an essential part of the design process and the large quantities of data produced by the SSR are useful for this purpose.
Whether an area is evacuated in time prior to a failure obviously has major implications to the resulting consequence of that failure. Although loss of access and productivity may not change, an effective evacuation should mean a slope failure without loss of life and with a minimised cost to equipment. The near wide area coverage and real-time nature of monitoring with the SSR systems has meant increasing confidence of operators to evacuate operations with a minimised loss to production. When a failure does occur, it usually destroys surface mounted equipment such as survey prisms or extensometers. The advantage of SSR systems is that we can continually monitor through the failure process and after collapse has occurred. SSR and its real time monitoring are shown in Fig 3 and 4, respectively. In this way, minutes after the collapse occurs, we can determine whether the area is continuing to move and what implication this has on rehabilitation of the area or disaster recovery if required.
Rampura Agucha- A Case study with SSR

The Rampura Agucha Mine (RAM) is situated 220 kilometres south-west of Jaipur, in the district of Bhilwara, Rajasthan, India. It is a world class zinc-lead deposit, owned by Hindustan Zinc Ltd, Vedanta Resources Plc, with an estimated geological reserve of 107.33 million metric tonnes. Hindustan Zinc Ltd is the only integrated zinc producer in India. It operates three underground mines and one open cast mine, Rampura Agucha Mine, which is considered one of the most cost-efficient zinc mines in the world. It has rich ore grade which allows the mine a high recovery and overall low cost of production. The mine was commissioned in 1991 for the designed capacity of 0.9 Mtpa ore production and its beneficiation. Eight years later it expanded to 1.35Mtpa and more recently, in 2005 and 2007, its capacity was further enhanced to 3.75Mtpa and 5Mtpa, respectively. Shortly it is poised for further expansion to 6Mtpa in 2010-11. Sustainable development and safety management is an integral part of Hindustan Zinc’s business philosophy and is committed to continue to improve its performance inline with their HSE & social policy. After comparing the different slope monitoring instruments, RAM opted for the Slope Stability Radar (SSR) as a commitment by management to safety of its people and the mine.

Rampura Agucha is the first mine in India to use Slope Stability Radar for improvement in its productivity and safety. “RAM is proud to be the first mine in India to have an SSR on site, especially because the SSR goes hand-in-hand with RAM’s policy of minimisation of slope hazards. Utilising the SSR fits perfectly with the company’s culture of always being one step ahead in safety and production. Thus, Hindustan Zinc Ltd is leading the way with the highest Safety Standards for mining in India. Fig.5 shows SSR visual of the Rock Fall.

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, design of the optics, power of laser and resolution of charge coupled device camera. These total stations are usually placed at the top of 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. A number of prisms are installed on the slope at 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. Customized software’s provide a total integration using wireless communication network to measure movements of slopes in X, Y and Z directions.[1] A vector plot combining the above three movements into absolute movement is obtained. These data either are recorded in real time or post processed mode. Alarms can be set at site – specific trigger levels for early identification of slope movements. The major advantages in prism monitoring are increased 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 insufficient tracked satellites. The system can be affected by nearby machinery that affects the functioning of the system.
Wireless smart sensors (WSS) differ from traditional wired sensors in significant ways. Each sensor has an on-board 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. 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. The iMote2 (Figure 7) is developed by Intel for structural health monitoring for bridges [8]. 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 sub networks: 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, greatly increasing the safety of personnel and reducing costly damage to equipment. Accurate measurements, combined with software that prevents false alarms, allows safe and remote monitoring while reducing production downtime (Figure 8).

Features

- Stand-alone system operates remotely and requires virtually no maintenance
• Wi-Fi and FHSS radio technologies do not interfere with existing communications
• Software utilizes 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 e-mail
• Complete customization of alarms allows geotechnical personnel to set user-defined warnings for multiple velocities and displacements for each machine
• Field proven to withstand rugged conditions and extreme temperatures
• Allows monitoring throughout a slope failure without damage to the unit

Fig.8. Slide Minder Wire line Extensometer System [9]

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

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: 1W
• Repeaters available for extended coverage
• Wi-Fi option

WIRELESS SLOPE MONITORING- STRING POTENSIOMETER

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. By leveraging the power of the simple, rugged WASP datalogger along with reliable String Potentiometer sensors, slope movement may be monitored remotely and automatically (Figure.9). Time spent on site is virtually zero thanks to the simplicity of the WASP and the fact that system configuration and management is done remotely through a simple web portal. The WASP 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).

Features & Benefits
• String Potentiometer sensor accurately measures slope movement (displacement)
• Rugged sensor housing (IP67)
• Sensors come in various forms, sizes, measuring ranges and prices
• WASP data logger collects data and transmits to the web once per day
• Read up to 4 x sensors per WASP logger
• 5 year battery life (with daily upload)
• Fully potted electronics protect WASP from water ingress
• Setup, configuration and automated download done via web portal
• Plug-and-play installation (no on-site setup required)
• Proven technology (more than 5000 WASPs already deployed worldwide)
• Low subscription cost
• Compatible with ARGUS Monitoring software

LASER SCANNING-QUARRYMAN PRO

Quarryman Pro is a 3D laser-scanning system (Figure 10), which is easily operated by one person, with very little training needed to use the system or associated, intuitive software. Light and portable; coming in a single Peli case, the tripod-mounted Quarryman Pro system can quickly be moved around site and between sites by operators. Operators can choose between a manual point-and-shoot mode, and an automatic laser-scanning mode (250 points per second). Entire rock faces can be scanned in minutes. Quarryman Pro measures and records millions of data points directly to a USB drive and does not require external PDAs or computers in the field. The collected data can then be processed to create detailed 3D models, which can then be edited, analysed and exported to specialist packages or other CAD software. Quarryman Pro is intuitive to use, portable and rugged: carefully designed and tested to ensure it is robust enough to operate in the toughest conditions [10].

GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS (GSM)

GSM (Global System for Mobile Communications, originally Group Spécial Mobile), is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile phones, first deployed in Finland in July 1991. As of 2014 it has become the default global standard for mobile communications - with over 90% market share, operating in over 219
countries and territories. Designed for global market, SIM800 is a quad-band GSM/GPRS module that works on frequencies GSM 850MHz, EGSM 900MHz, DCS 1800MHz and PCS 1900MHz. SIM800 features GPRS multi-slot class 12/ class 10 (optional) and supports the GPRS coding schemes CS-1, CS-2, CS-3 and CS-4.

Main features
- Bands: GSM 850MHz, EGSM 900MHz, DCS 1800MHz, PCS 1900MHz
- Coding schemes: CS-1, CS-2, CS-3, CS-4
- Tx power: Class 4 (2W), Class 1 (1W)
- Small package: 23 * 23 * 3mm
- Power supply voltage: 3.4 - 4.4V
- Lowe power: down to 1mA in sleep mode
- TCP/IP TCP/IP AT firmware
- Operating temperature: -40C do +85C
- Support up to 5*5*2 Keypads
- One full function UART port, and can be configured to two independent serial ports.
- One USB port can be used as debugging and firmware upgrading.
- Audio channels which include a microphone input and a receiver output.
- Programmable general purpose input and output.
- One SIM card interface.
- Support Bluetooth function.
- Support one PWM.
- PCM/SPI/SD card interface, only one function can be accessed synchronously. (default function is PCM)

TIME DOMAIN REFLECTOMETRY OR CABLE BASED RADAR

The basic principle of TDR is similar to that of radar. In TDR, a cable tester sends a voltage pulse 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 digitizes the resulting reflection waveform for analysis or storage. The elapsed travel time and pulse reflection amplitude contain information used by the onboard processor to quickly and accurately determine rock mass deformation for slope stability measurement or user-specific, time-domain measurement (Figure11 and .12).

![Fig.11. Basic Principle of TDR](image)

A 250-point waveform should be collected and analyzed in approximately two seconds. Each waveform should have approximate up to 2,048 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.
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 a depth of 48-ft indicating movement. Observation of tension cracks in the ground surface verified the fact that some movement had taken place. Figure 13 shows the Cross sectional view for installation for single cable of TDR.

Fig.12. TDR cable signatures showing development of a shear zone

Fig 13. Cross sectional view for installation for single cable of TDR[2]

COMPLETE SYSTEM DEVELOPMENT

Developed the virtual communication system and tested in the laboratory. Software protocols and transmission algorithms using Arduino-Integrated Development Environment (IDE) Software was developed. RF module was utilized in Transparent Mode (AT) mode along with Arduino at transmitter and receiver side. Data Communication was established between PC to PC wirelessly. Figure 14 shows the Connection Diagram of the Developed System.
No packet loss was observed during the transmission. In the final communication model Arduino Uno board is replaced with Arduino Mega board and the RF module is replaced with advanced RF module. The upgraded Arduino Mega controller system succeeds to transmit the data wirelessly directly from the TDR to the system through RF module. Thus it successfully removes the need for the PC from transmitter side of the RF transmission system. Field tests were conducted in typical opencast metal mines to ascertain the range for the transmission of the packets without loss \[7\]. Single coaxial cable location in a particular bench and its associated system components for transmission of real time data from the instrument site to a typical mine office is represented schematically in Fig 15. In practice, many coaxial cables may be required based on the site conditions which will be connected to a multiplexer for real time monitoring of more number of locations. Fig. 16, and 17 shows the location of site and field test of the developed wireless transmission system with PC and Xbee at Panna Diamond Mine-NMDC.

TDR data is transmitted wirelessly to the developed system with three coaxial cables connected to three different channels of Multiplexer (MUX). TDR generates three strings successively one for each of the channel of MUX continuously one after other. Each of the string contains 240 points representing the reflection coefficients along the length of the particular cable. As TDR works at a very high baud rate of 57600, so it generates the very large amount of data continuously.

**COMMUNICATION TEST IN LABORATORY**

After complete development of the wireless transmission system a communication test is carried out in the model preparation laboratory using console tool of Xctu software. Two Xbee Pro modules are connected to two different PCs, message type in the window of the one Xbee is then displayed in the others window and vice versa. This shows that Xbee modules are configured successfully and are ready for the real time data transmission from the sensor. Another communication test was also carried out in the lab for testing the real time wireless transmission of the TDR sensor data. Arduino mega board along with Xbee module forms a communication node each one on the transmitter and receiver side. Output can be observed using the serial monitor screen of the IDE software. Both of the tests in the lab provided the wireless transmission between two Xbee modules successfully.
COMMUNICATION TEST IN FIELD

First field test of the developed system was carried out at the NMDC Panna Diamond Mine, M.P. Complete set up of the developed system including TDR sensor unit, Power supply and the wireless transmission unit including Xbee.
Pro modules and Arduino mega microcontroller board taken at the mine site. Mine office is approximately 1 Km far from the location selected for the implementation of the TDR system. Developed system transmitted the wireless sensor data up to 400m successfully and encountered a line of sight issue with increasing distance further more. Hence it is proposed to add router between two end nodes to minimize the line of sight issue. Also one more solution is to elevate the Xbee modules from base as high as possible to reduce the attenuation of transmitted energy due to earth surface.

Fig. 17. A view of various benches in a typical opencast metal mine for field test of the developed system

Fig. 18. Field test of the developed wireless transmission system with PC and XBee

SCOPE OF MIMO TECHNOLOGY BASED SAR SYSTEM FOR SLOPE STABILITY MONITORING

The recent prominent research and development in MIMO (Multiple-Input-Multiple-Output) technology for enriching radar and wireless communication systems is found to be attractive for SAR (Synthetic Aperture Radar) imaging. The most attractive MIMO features are microwave radar antenna array beamforming and beam steering to serve the purpose of scanning an area for slope stability monitoring involvement. The existing GB-SAR (Ground Based-SAR) system for landslide measurement Linear SAR (LISA) which is available in market, uses a costly equipment vector network analyser (VNA) for stepped frequency continuous wave (SF-CW) for transmit signal generation [23]. The other VNA based SFCW GB-SAR systems available in market are IBIS-L/M [24] and FastBGSAR [25]. Furthermore, the BG-SAR systems available in market need to move and precisely place antenna along a rail using extremely accurate controller and hence, are costly. On contrary the GB-MIMO-SAR system does not require such mechanical movement of antenna and can use frequency modulated continuous wave (FMCW) generated by low-cost direct digital synthesizer (DDS), analog/digital-to-digital/analog (ADC/DAC) to replace VNA. Therefore, the cost of GB-MIMO-SAR system may be devised at a cost which is 50% of the existing GB-SAR systems available in market. Moreover, the recent research outcomes of MIMO radar technology on statistical detection and estimation of static or moving target have ample scope of achieving precise measurement. Therefore,
GB-MIMO-SAR may be used for obtaining high resolution images to monitor slope stability in various mine applications.

CONCLUSIONS

Critical review of various methods and advanced technologies for slope stability monitoring indicated scope of SSR—which is very costly (about Rs. 4-5 Crores), and recent developments in TDR (About Rs. 20 lakhs) as promising methods for its application to mines besides conventional total station monitoring. The SSR is the state-of-the-art development for monitoring slope movement in open pit mines and non-vegetated slopes. It offers the unprecedented advantage of sub-millimetre precision and broad area coverage of wall movements through rain, dust and smoke. The real-time display of the movement of rock faces has allowed continuous management of the risk related to slope instability. The SSR technology has enabled a radical change in the management of risks in open cut mining operations, resulting in over 80 open pit mining operations around the world adopting its use. At a large number of mines, the SSR is now an integral part of the mine providing major contributions to the mine’s future plans. It is also believed that the SSR will contribute significantly to safety and mine design by providing accurate, reliable deformation data that may be later reviewed to further develop our understanding and analysis of failure mechanisms in open pit mines, eventually leading to improved slope design.

Attempts made to develop indigenous wireless system in typical mining conditions for transmission of real time data generated from the TDR sensor indicated successful transmission of data without any packet loss up to 400 m. The developed system gives new approach for Arduino and RF technology based real time slope stability monitoring from the remote location. Wireless transmission system integrated with the XBee pro RF modules and Arduino Mega microcontroller board provides a low cost solution for the monitoring of the sensor data remotely. Use of general purpose electronic components have made the wireless communication system universal and can be used with different kind of sensors like tilt-meter, accelerometer etc. as per future need. Range of the transmission can be increased by adding the routers between two end nodes as per need. Acknowledgement based wireless system operation provides higher reliability for secure data transmission without loss of information.

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