RECENT INNOVATIONS IN WIRELESS SYSTEMS FOR SLOPE STABILITY MONITORING IN OPENCAST MINES – AN APPRAISAL FOR INDEGINISATION

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ABSTRACT

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 expansive. The purpose of this paper is to introduce the different cost effectivereal-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. This paper gives the detailed review on available low cost wireless slope monitoring systems for mines.

KEYWORDS: *Slope Stability, Opencast mine,Wireless sensor networks,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.

TIME DOMAIN REFLECTOMETRY

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 (Figure.1). 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.

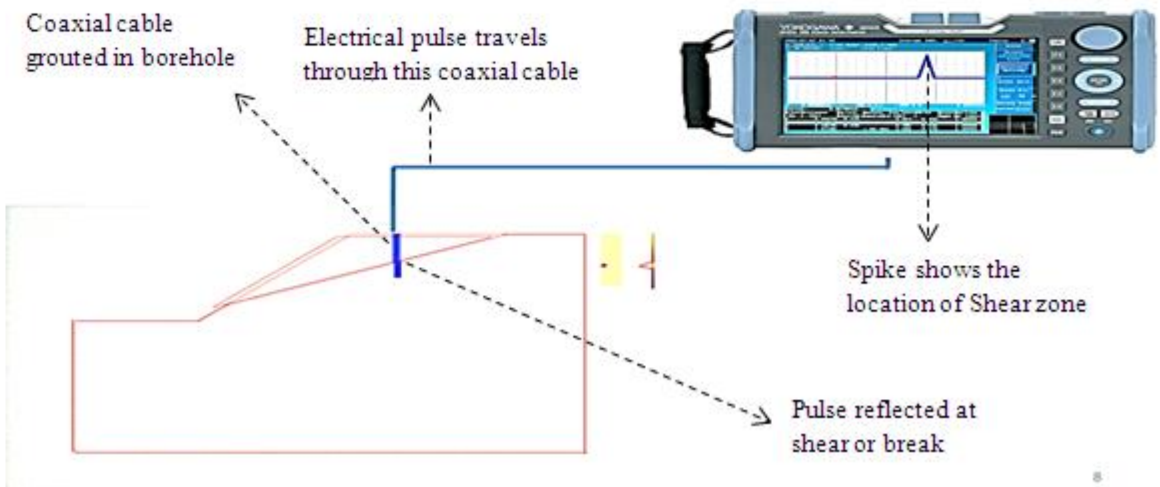

Fig.1. Basic Principle of TDR

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 is as shown in Figure.2. Observation of tension cracks in the ground surface verified the fact that some movement had taken place.

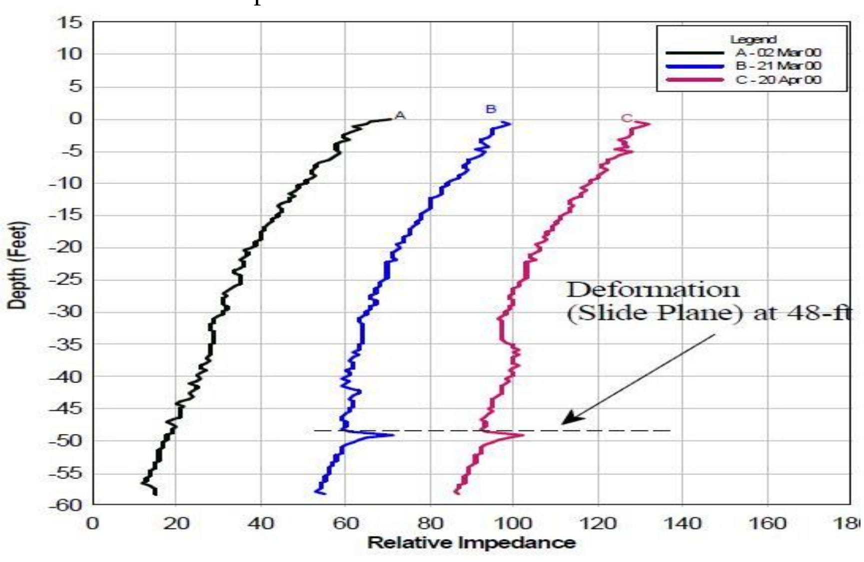

Fig.2.TDR cable signatures showing development of a shear zone

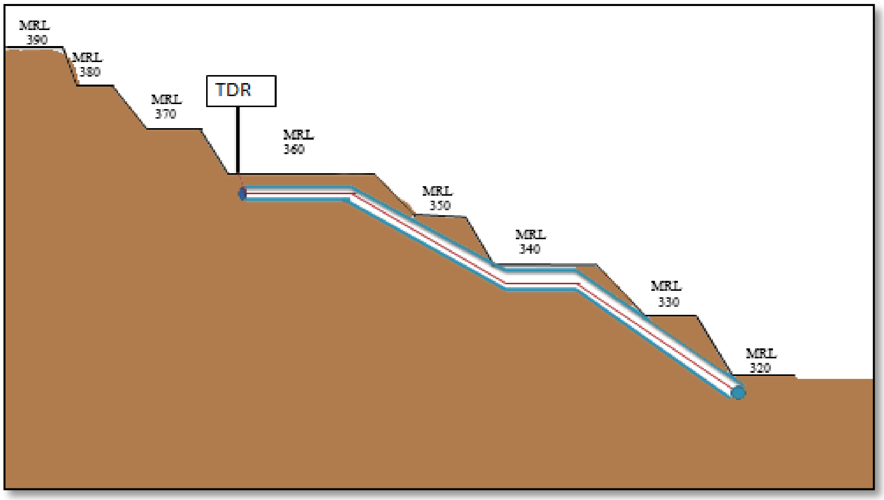

Fig.3. Cross sectional view for installation for single cable of TDR[2]

OPTICAL TIME DOMAIN REFLECTOMETRY (OTDR)

It works with the principle of The Fibre Bragg Grating (FBG) and it is a Fibre optic SensorRecorded with UV laser light Reflected wavelength varies with strain and Temperature (Figure.4).

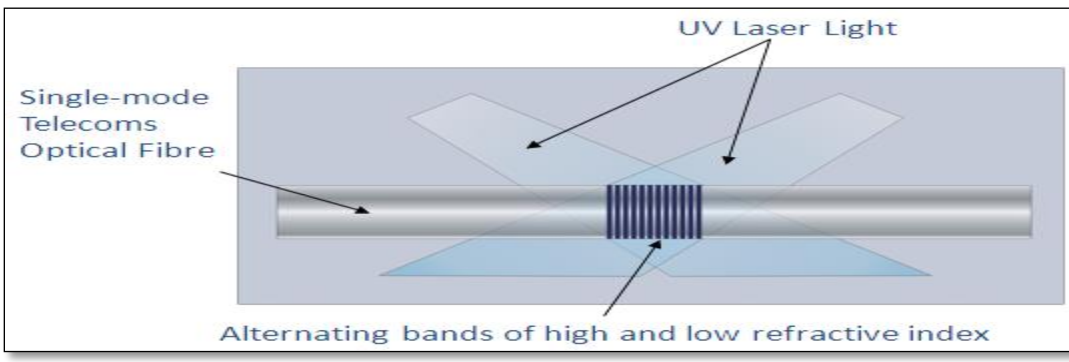

Fig.4. Single mode optical fiber

Interrogator

Tuneable laser interrogation unit illuminates fibre and measures reflected Bragg wavelengths. Processing Unit converts wavelengths to measurands of interest, which are 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).

Advantages

There is no necessity of electrical parts. It has reduced 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 [7].It comprises further details of technology via SmartScanLite is a reduced speed (250 Hz) with lower priced variant.SmartScan 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.

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.

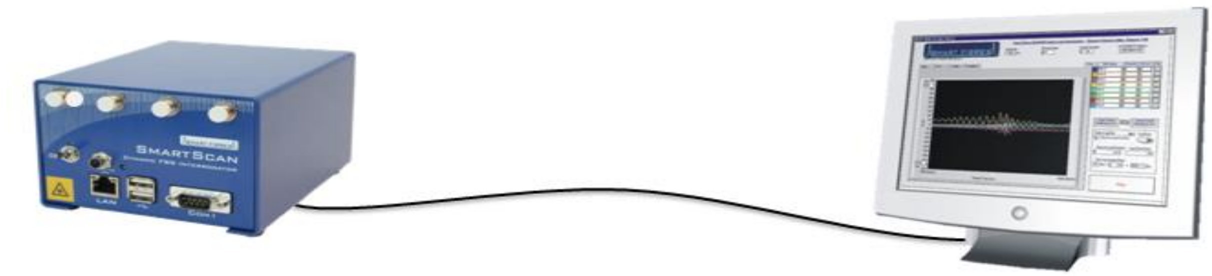

Fig.5. Interrogator system

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 SENSOR TECHNOLOGY

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].

Fig.6. Automatic Total Station Monitoring

Sensor boards (measuring 3-axis acceleration, temperature, humidity, and light)**.**The first deployment of WSSsystem on the bridge was carried out in 2009 in SouthKorea. 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.

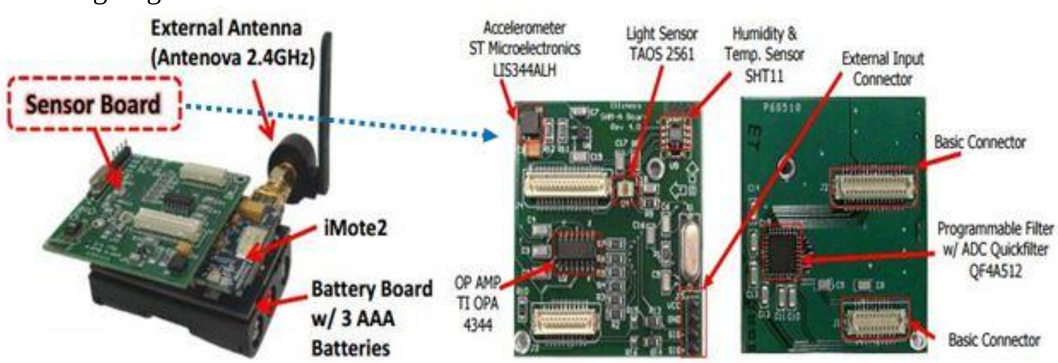

Fig.7.Wireless Smart Sensor Node [8]

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).

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

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

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 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.By leveraging the power of the simple, rugged WASP datalogger along with reliable String Potentiometer sensors, slope movement may be monitored remotely and automatically (Fig 8a). 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

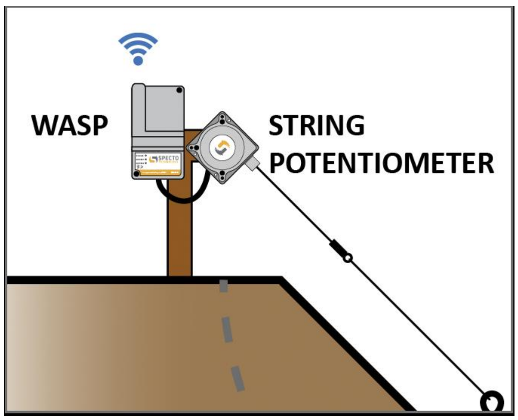

Fig.8a. Slide Minder Wire line Extensometer System [10]

SHAPE ACCEL ARRAY

The Shape Accel Array/Field (SAAF) consists of an articulated chain of sensor elements (segments) each 0,305m or 0,500m long. The segments are joined together in such a manner that they can move in relation to each other in all directions except for twisting (Figure.8.). 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. The diameter of the SAAF is only 25mm. Therefore it can be installed in a flexible PVC-pipe with an outside diameter of only 32mm.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 visualization 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.

WIRELESS ADVANCED TILTMETER-PROPOSED SYSTEM

Arduino is an open-source single-board microcontroller. This paper is about interfacing accelerometer to Arduino. The MEMS IC is a low cost, Tri-axis thermal accelerometer capable of measuring tilt, acceleration, rotation, and vibration with a range of ±3 g. These Micro-electro-mechanical systems

(MEMS) IC based accelerometers have an advantage over the conventional laboratory accelerometers that they are capable of measuring the acceleration due to gravity (represented by dynamic acceleration).
The accelerometer sensor to be interfaced with Arduino based GSM module. Coding is going to be done by using the Arduino Integrated Development Environment - or Arduino Software (IDE) which contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino and other hardware to upload programs and communicate with them. The Block Diagram of proposed system shown in Figure.9.

Fig.8. Shape Accel Array on shipping reel

Operation

- The data is first obtained from the accelerometer sensor.
- The obtained data is then processed using Arduino.
- Thereafter the processed data is sent to GSM module.
- Thus, user can receive the data from GSM through any displaying device.

Advantage of this Arduino based system with other existing system

- High Processing speed.
- Coding is simpler.
- Arduino is compatible with every microcontroller, even with the Intel board.
- It is a cost-effective system.

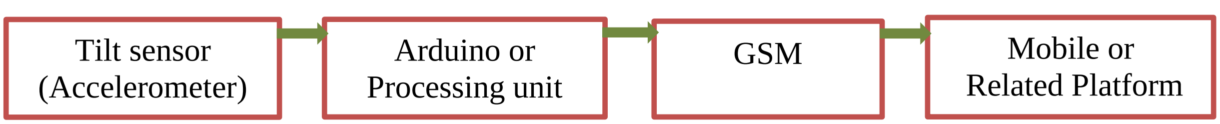

Fig.9.Block Diagram of proposed system

TRIAXIAL ACCELEROMETER (ADXL345)

In this method for inclination sensing with three axes is to determine the angle individually for each axis of the accelerometer from a reference position. The reference position is taken as the typical orientation of a device with the x- and y-axes in the plane of the horizon (0 g field) and the z-axis orthogonal to the horizon (1 g field).The ADXL345 is a small, thin, low power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16g. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I2C digital interface (Figure.10.). The ADXL345 is well suited for mobile device applications. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock [11]. Its high resolution (4 mg/LSB) enables measurement of inclination changes less than 1.0°. Several special sensing functions are provided. Activity and inactivity sensing detect the presence or lack of motion and if the acceleration on any axis exceeds a user-set level. Tap sensing detects single and double taps.

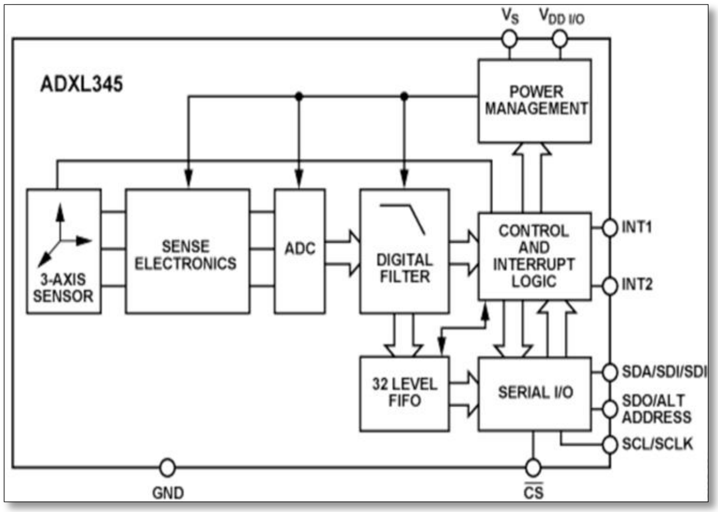

Fig. 10 Circuit Diagram of triaxial Accelerometer(ADXL345)

Free-fall sensing detects if the device is falling. These functions can be mapped to one of two interrupt output pins. An integrated, patent pending 32-level first in, first out (FIFO) buffer can be used to store data to minimize host processor intervention. Low power modes enable intelligent motion-based power management with threshold sensing and active acceleration measurement at extremely low power dissipation.The ADXL345 is supplied in a small, thin, 3 mm × 5 mm × 1 mm, 14-lead, plastic package.

ARDUINO

Arduino is an open-source computer hardware and software company, project and user community that designs and manufactures microcontroller-based kits for building digital devices and interactive objects that can sense and control the physical world. The project is based on a family of microcontroller board designs manufactured primarily by Smart Projects in Italy, and also by several other vendors, using various 8-bit Atmel AVR microcontrollers or 32-bit Atmel ARM processors. These systems provide sets of digital and analog I/O pins that can be interfaced to various expansion boards ("shields") and other circuits (Fig 11). The boards feature serial communications interfaces, including USB on some models, for loading programs from personal computers. For programming the microcontrollers, the Arduino platform provides an integrated (IDE) based on the Processing project, which includes support for C, C++ and Java programming languages. The first Arduino was introduced in 2005, aiming to provide an inexpensive and easy way for novices and professionals to create devices that interact with their environment using sensors and actuators. Common examples of such devices intended for beginner hobbyists include simple robots, thermostats, and motion detectors. Arduino boards are available commercially in preassembled form, or as do-it-yourself kits.

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(Figure.12).

Fig.11. Arduino UNO

Fig.12. GSM Module (SIM800)

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)

PROPOSED FIELD INVESTIGATIONS

On the basis of detailed geotechnical studies carried out in the field, application rock mass classification system, numerical modeling etc, it is proposed to install the above wireless tilt meter in one of the MOIL mines (Fig 13) [12]. Dongri Buzurg Mine of Manganese Ore mine of M/s. MOIL is located in the

Bhandara district of Maharashtra is an opencast mine that produces manganese dioxide ore used by dry battery industry.

Assessment of the stability of slopes in open pit mines at different stages of mining is important for the safe and economic mining operations. Slopes are generally designed based on the geotechnical data and physico-mechanical properties of rock/soil. From geotechnical data, the rock mass quality is assessed, and from this, the rock mass properties are estimated. Using the rock mass properties stability of the slopes is evaluated from empirical, analytical and numerical techniques. In homogenous, isotropic ground conditions, the factor of safety can be determined for predefined failure modes using limit equilibrium. Similarly, using analytical solution, flexural breaking of rock mass can be determined. Design charts can be developed using limit equilibrium method. Some design charts are available for plane, wedge, circular modes of failure, and for toppling failure. The field engineer can use them if the basic geotechnical properties are known. These charts are useful to analyse only simple types of predetermined failures, but not for determining the slope angle which depends on the rock mass stability [13]. Surface exposures were mapped to get the discontinuity data. Within the footwall strata, there are four sets of discontinuities including the schistocity. They are:

a) Schistocity - its general trend is 50^0 dips due 170^0 (striking roughly E - W).

b) Joint Set no. 1 - these are inclined joints, with roughly E-W strike (dip amount 35^0, and dip direction 345^0). The mean spacing is 40 cm, and the joint surfaces are smooth, planar.

c) Joint Set no. 2 - this set is a westerly dipping set (dip amount 40^0, dip direction 270^0). The joint surfaces were smooth and undulating, and the joint spacing is 1 to 3 m.

d) Joint Set no. 3 - this set has 50^0 dip amounts and dip direction is 220^0. The joints in this set have rough, planar surfaces, and the joint spacing is 2 m.

The hangwall strata also contain three sets of joints: one $75^0/060^0$ (planar, smooth surfaces) with a spacing of 10 to 50 cm; the second one $43^0/325^0$ (planar, rough surfaces) spaced at 15 cm; and the third set $55^0/135^0$ (rough, irregular), which occurs at 3 m interval. In addition, the schistocity has a prominent trend of $50^0/175^0$. Due to tendency of slope failures in footwall it is proposed to monitor with various instruments in footwall side in addition to monitor with total station. Joints are also observed to be favorable for instability in footwall side compared to hang wall [13-16].

Fig.13. Proposed location of wireless tilt meter in Footwall of the Dongri Buzurg Mine, MOIL.

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CONCLUSIONS

Critical review on various recent innovations related to wireless monitoring techniques for understanding stability of slopes indicated that monitoring slope movements remotely with TDR techniques is a feasible alternative to more labor intensive methods like using survey monuments or inclinometers. TDR can also be compatible with tilt meter to install along with TDR cables fro measuring the direction of the movement. In OTDR, number of sensors required is more and monitoring area is less. Using wireless sensor nodes at respective slope stability monitoring stations in mines, data from slope instruments and Data Acquisition System can be acquired and interpreted online.

It is very much required the trans-disciplinary research to implement the wireless smart sensor network technology in mines for slope stability monitoring. In the proposed model the data will be processed using Arduino, Thereafter the processed data is sent to GSM module. The user can receive the data from GSM through any displaying device and it is a cost-effective system compared to the available wireless tilt meters. Advancements as such would allow mining operators to continually monitor the slopes, in real-time, areas of interest using dense meshes created of multiple wireless tilt sensors. The use of wireless sensors to monitor slope stability would help to improve the understanding of rock behavior, as well as increase predictability of failure(s).

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