Application of Multidisciplinary – Transdisciplinary Research to Improve Safety in Mining Industry

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Abstract
Know-a-days **trans-disciplinary** utterance is observed to be more apt for more productive and successful application of multi-disciplinary research areas as a solution to any industrial problem than a simple multi-disciplinary axiom. This paper presents field experimental trial of wireless system for online monitoring of sub-surface movements, and blast performance monitoring in typical opencast mines in India. Innovative real time monitoring of ground deformation was accomplished with Time Domain Reflectometry (TDR) to integrate coaxial cables. This study describes the integration of TDR directly with Arduino boards and XBee modules for real-time transmission of slope monitoring data as a part of Ministry of Mines, Government of India (GOI) sponsored project. The TDR system appears to be a reliable measuring system for estimation of the subsurface movements, and an experimental trial of system of Slope Stability Radar (SSR) for online surface movements combined with TDR may be more useful for complete understanding of the slope behaviour for improving safety in opencast mines.

INTRODUCTION

Although efforts are being made in many mining areas to establish strata/ground management cell as per recommendations of various National Conference of Safety in Mines held in India, further modifications are required for its proper organization [1]. Action plan includes detailed geotechnical instrumentation and online monitoring of ground behaviour for underground and opencast workings to improve safety in mines and as a tool for forewarning the disasters. Many experimental trails on ground behaviour monitoring with innovative instrumentation and analysis through Industry and Ministry (Ministry of Coal/Ministry of mines-GOI) sponsored research projects were conducted by the author in various methods of underground extraction and opencast mining of mineral deposits in coal and metal mines [2-6]. Author also emphasized the urgent need of innovative technology with trans-disciplinary research applications of Electronics , instrumentation, Computer science etc., to warn the disasters due to ground movements in the mining Industry. The economic concerns and operational problems associated with unstable slopes indicating the need of suitable slope monitoring and management measures. Available geotechnical sensors include vibrating wire piezometers, wire line extensometers, borehole extensometers, inclinometers; tilt meters etc. for sensing the changes in slope conditions, besides widely practiced total station monitoring. These geotechnical instruments are monitored by technicians in the field. Figure 1 shows the Slope Disaster at Rajmahal opencast mine, Eastern Coal Limited (ECL), India on 29-12-16 and Bingham Canyon Mine [7], southwest of Salt Lake City. The analysis of accident in open pit mine publicized that slope failure and dump failures have upward trends [1]. Few examples of fatal accident involving slope and dump failure are mentioned in Table 1. This paper also emphasizes the urgent need of application of electronics and communication work deals with the elimination of manual slope monitoring in the industry with the help of Wireless Network Infrastructure replacing the need for physical cables.

Fig.1 Typical slope Disasters opencast mines in India, and USA

Vibration monitoring can ascertain motion levels of natural as well as seismic activity. This can provide objective information about seismic effects, in particular when seismic operations are undertaken over sensitive and restricted areas. The monitoring results suggest that three components of ground motion need to be measured, since the PPV in the longitudinal and transverse components could be larger than the PPV measured in the vertical direction [2]. Vibration measurements are fairly simple and straightforward in terms of peak values of particle velocity. However, waveform analysis of ground motion may reveal some further interesting features in the data.

ONLINE MONITORING WITH TDR

Time Domain Reflectometer (TDR) can be called as cable-based radar and consists of two major components which are namely cable tester and coaxial cable. The cable tester works like a Transceiver. The TDR cable tester produces electric impulses which are sent down the coaxial cable. The coaxial cable is grouted into the ground. When these pulses approach a deformed portion of the coaxial cable, an electric pulse is reflected and sent back to the TDR Cable Tester. When the pulse runs across a change in cross-sectional cable geometry (e.g. due to a shear deformation), a portion of the signals is reflected back to the TDR device. The distance between the cable tester and deformity (x) can be accurately determined by the round-trip travel-time (T_R) and propagation velocity (Vp) of the cable.

$$x=VpT_R/2 \quad (1)$$

The TDR is used for finding the ground movement and it requires reading of 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 characteristic impedance and a reflection of energy. This change in the shape of cable can be used to determine the location of shear movement [3].

Table.1. Details of Slope and Dump Failure

Date	Name of Mine	Incidence
24.06.2000	Kawadi Open Cast (OC) Mine of M/s Western Coalfields Limited(WCL)	Slope failure of 31m high OB benches.
09.12.2006	Tollen Iron Ore Mine of M/s Kunda R Gharse in Goa	Failure of Slope 30m to 46m high Dump.
17.12.2008	Jayant OC Project of M/s Northern Coalfields Limited(NCL)	Failure of Dragline Dump.
04.06.2009	Sasti OC Mine of WCL.	Dragline OB dumps of 73m height failed and slided down the pit.
25.02.2010	Hansa Minerals and exports Granite Mine.	Granite mass slided along an inclined joint plane and failed from height varying from 10m to 55m.
22.06.2014	Amlai Opencast Mine, South Eastern Coalfields Limited (SECL).	Dump failure due to sudden development of cracks in the embankment and Unstable Ground Conditions
29.12.2016	Rajmahal OCP of Eastern Coalfields Ltd(ECL)	Dump failure due to development of cracks and Unstable Ground Conditions

DEVELOPMENT OF HARDWARE AND SOFTWARE

Software protocols and transmission algorithms using Arduino-Integrated Development Environment (IDE) Software were developed. RF module was utilized in Transparent Mode (AT) mode along with Arduino at transmitter and receiver side [9]. Data Communication was established between PC to PC wirelessly through Integrated System (Figure 3). 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. 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. As TDR works at a very high baud rate of 57600, so it generates the very large amount of data continuously[5,6].

Though the Xbee PRO module is specified to provide the range of about 1.6 Km by the manufacturer practically it fails to provide it due to various reasons. It includes the environmental condition, rough weather conditions, signal loss (attenuation) while transmission due to Earth Surface. One more serious problem with the RF wireless transmission is the line of sight issue. An observed infield trial carried out at the Dongri Buzurg Mine of MOIL. The line of sight issue occurred while field trial due to increased distance between transmitter and the receiver side increases. The best way to overcome the line of sight issue is to install Router units between the two end devices wherever needed.

EXPERIMENTAL TRIAL – SLOPE MONITORING

The instrumentation was installed to provide a real time monitoring system and to provide quantitative information about ground movements. The locations and range requirements for installation of instrumentation were determined on the basis of field visits; geotechnical investigations and numerical modeling of selected mine. As per the conditions of the mine site, TDR along with three coaxial cables are installed (Figure.5).

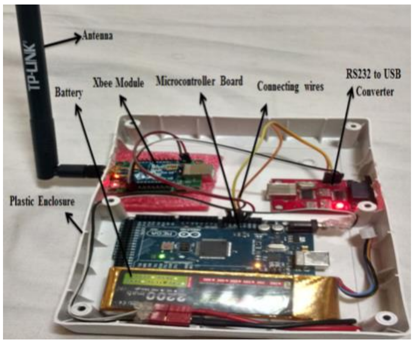

Fig.3. Integrated Master node for real-time monitoring

Each coaxial cable is grouted with cement. RG-6 type coaxial cable used for installation and three coaxial cables connected to TDR100 through SDM8X50 Multiplexer. This cable was used in the field to monitor rock mass deformation with TDR. RG-6 coaxial cable has 75 ohm characteristic impedance and the propagation velocity (VP) of this cable is 0.75. The diameter of the cable RG-6 is 8.43 mm and Operating temperature between the -40^{0}C to +80^{0}C[8]. TDR100 is connected to master node which is developed by scientific team of NIT Rourkela. The generated real time data of TDR100 was directly sent to the mine office through RF module (master node). The TDR measuring system, which was installed at the foot wall benches of DB Mine, MOIL and started operation in August 2017. The Generated real time data of TDR100 was directly sent to mine office through RF module (master node).

Surface monitoring was also conducted with total station measurements at these locations. On the basis of the experimental trial, the TDR system appears to be a reliable measuring system for estimation of the subsurface movements, and an experimental trial of system of Slope Stability Radar (SSR) for online surface movements combined with TDR may be more useful for complete understanding of the slope behaviour. It is also expected to undertake more trans-disciplinary work in application of information technology; mobile communications, Wireless Sensor Network (WSN), Internet of Things (IOT) to mining engineering to give more confidence to the miners about the behaviour of rock, and rock mechanics through innovative field oriented work for solution to the mining industry problems, in near future. Figure.4 shows the Real time data of three coaxial cables using Python Software. Conceptually, it would be possible to create an alarm system based on reflection coefficient (RC) values inferred from TDR measurements. But this would require a more number of days to observe the response from RG6 type coaxial cable in the field and calibration of RC in terms of deformation and further evaluation.

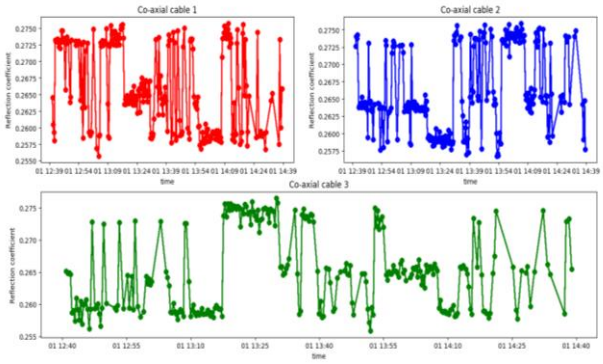

Fig.4. Representation of Real time data of three coaxial cables using Python Software

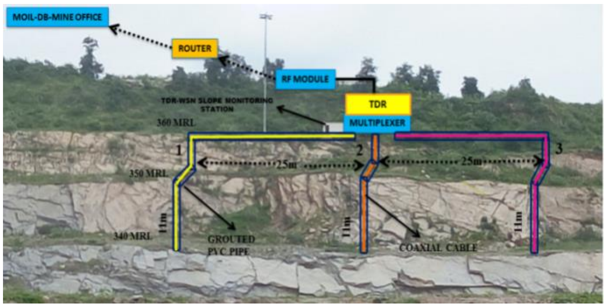

Fig.5.The Coaxial Cables installed in TDR-WSN trial at Dongri Buzurg Mine-MOIL-India

EXPERIMENTAL TRIAL – BLAST VIBRATION MONITORING

Minimate Blaster was preferred due to following advantages for blast monitoring at various sites in and around mine (Figure 6). Table 2 shows details of the instrument used for the study.

- Small, rugged package for portability and easy setup. Simple menu driven operation. Easy one button download and reporting with Instantel® software
- Continuous monitoring
- Integral monitoring log records time and duration of monitoring jobs.
- Auto Record™ mode allows for continuous recording as long as activity cycles about the trigger level.
- Fully compliant with the International Society of Explosives Engineers (ISEE) "Performance Specifications for Blasting Seismographs" requirements with the ISEE Linear Microphone and an ISEE Geophone (2250Hz).
- Fully compliant to the DIN 456691 Standard with optional DIN Geophone (1315Hz).

Figure 6: Minimate Blaster, an Instrumentation installed at a typical blast site

Table 2: Details of the instrument used for the study

Key Features	Easy to use Auto Record/ Record Stop
Channels	Microphone and Triaxial Geophone
Available Memory	30 events
Record mode	Manual and Continuous
Available sample rate	1024 to 4096 S/s per channel
Unit Dimensions	81mmx 91mmx160mm
Unit weight	1.4 kg
User Interface	8 domed tactile keys
Product rank	Low cost

Totally eleven Trial blasts were conducted at quarry number 6 and quarry number 5 during. Experimental blasts were conducted during 25th to 27th Feb'16 and 12th to 19th Mar'16 at Dungri mine, ACC (Figure 7). The blast result was also assessed in terms of ground vibrations, its frequency, air over Pressure produced and fly rock. The vibro-graph was installed at a predetermined distance in the range of 150 to 750 m from blast site to the monitoring station to monitor the ground vibrations generated from blast. The fly rock, fragmentation and muck pile tightness was also assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for experimental blasts with respect to the distance from the blast site to the monitoring station with varying charge per delay for various experimental blasts.

ANALYSIS OF GROUND VIBRATION

Experimental blasts were conducted with explosive charge per delay in the range of 30 to 55 kg, and total number of holes per blast in the range of 15 to 130. At 750 m and 150 m distance from the blast site, maximum PPV observed was about 0.191 mm/s, and 8.6 mm/sec, respectively.

Figure 7: A view of a trial blast at Dunguri mine, ACC

Blast monitoring observations shows that explosive charge of 50 kg per delay would induce PPV less than 5 mm/sec beyond 200 m distance from the blast site with the present blasting practice in the mine. To predict the safe charge per delay for reducing the damage potential for various distances from the blast site, regression analysis was done [6]. In majority of the observations, the maximum air over pressure recorded was within 140 dBA, which is within the safe limits. The dominant frequency of ground vibration was observed to be in the range of 2 to 34.3 Hz for distances from 150 m to 750 m in the experimental trials. Since the structures with normal civil construction may have a natural frequency of about 20 Hz, it is suggested to meticulously design the blasts with explosive charges considering both PPV and frequency content. Predictor equation in terms of the scaled distance (x) and PPV (Peak particle velocity) developed to represent the data to keep the vibration level within the safe limits can be expressed by the equation(2):

$$PPV = 489.21(\text{Scaled distance})^{-1.4} \qquad ---(2)$$

Since the PPV levels should be within safe limits of damage level criteria (< 5 mm/sec) for any type of structures other than sensitive structures, the blasting pattern may be followed with the respective explosive charge per delay for containing the PPV of ground vibration within damage limit for various distances from the blast site.

WIRELESS MONITORING SYSTEM

Sensor networks are crucial components of many applications as the data they gather are fundamental for the services. Wireless Sensor Networks (WSNs) are especially important as they can be built by relatively cheap and small sensors with low power consumption and maintenance cost whose ability to transmit data remotely allows their deployment at a large variety of locations. Multi Sensor Network is the Network created by the sensors which will be connected to a controller. The controller reads the data of all the sensors. Each sensor has a unique Identity or the address so that the controller will identify which data belong to which sensor location-wise [11-16]. A multi-sensor arrangement will help provide an exact data map of specific application area with respect to the specific parameter being sensed without sacrificing the homogeneity of readings. In contrast, a single sensor approach to gather data at different geographical points will produce only an approximation of the map through the data being collected from uncorrelated events producing heterogeneous readings.

A WSN consisting of multiple sensor nodes that are connected wirelessly to a sink node (central node) is shown in (Figure 8). Kim *et al*. developed a vibrating wire WSN to monitor the tunnel construction with ZigBee protocol [8].The proposed system suggested is equipped with a 3-axis acceleration sensor, an A/D converter, Atmega microcontroller and ZigBee-based communication system. The sensor module forms part of a Zigbee based wireless sensor network having an XBee radio in the PCB on-board so that the data can be wirelessly received and transmitted among each other. The above Wireless monitoring system is proposed to be experimented in subsequent blasting monitoring studies in various opencast mines.

CONCLUSIONS

TDR along with developed RF module measurements proved to be reliable and cost effective for real time slope monitoring at the experimental site of a typical opencast metal mine in India. In the TDR time series, no measurable deformations are visible and only a slight characteristic noise could be seen. An experimental trial of system of Slope Stability Radar (SSR) for online surface movements combined with TDR may be more useful for complete understanding of the slope behaviour for improving safety in opencast mines. An alarm can be created based on reflection coefficient (RC) values inferred from TDR measurements in the field and calibration of RC in terms of deformation and further evaluation.

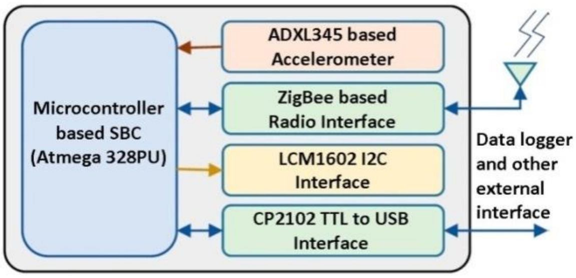

Figure 8:3-axis Accelerometer node in the development of a WSN based monitoring system

Scientific experimental studies on blasting of benches in Dunguri open cast limestone mine with blasting parameters; 4.0 – 5.0 m spacing, and 2.5 – 3.5 m burden for bench heights of 10 m were conducted with Aquadyne explosive of 50 kg of charge/delay indicated that vibration levels are within damage criteria beyond 200 m distance from the blast site. The dominant frequency of ground vibration was in the range of 2 to 34.3 Hz for distances from 150 m to 750 m in the experimental trials. It is recommended to use the respective explosive charge per delay for containing the PPV of ground vibration within damage limit (within 5 mm/sec) for various distances from the blast site as per the equation 2. Involvement of experts from Electronics/Computer science disciplines from the conceptual stage to field experimental trials and necessary modifications while implementation as a part of transdisciplinary research effort is required, instead of mere fulfillment of modular objectives of multi/inter-disciplinary research activities for improvement of safety stratus of mining industry.

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