DEVELOPMENT OF EFFECTIVE TECHNOLOGY FOR ONLINE SLOPE MONITORING IN OPENCAST MINES – R&D INITIATIVE

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ABSTRACT

This paper presents overview of accidents due to ground control problems in Indian mines along with the impetus on the need of innovative applications of trans-disciplinary work for improving safety in mines, and need based industry oriented research. Recent disaster on 29.12.2016 at about 7 pm due to slope failure at Rajmahal mines ECL, indicated the lacuna in providing sufficient information to the employees engaged near the working places about the impending danger, which would have saved few lives with effective online data/alarm to the persons engaged below the working benches/slopes at right time. Accidents due to slope instability are one of the primary causes in open pit mining operations, and unpredicted movement of the ground causes the potential to endanger lives, demolish equipment, or destroy property. Time Domain Reflectometry (TDR) is gaining widespread attention as a cost-effective method to monitor ground movements in soil and rock. It has been used successfully for many years to monitor deep-seated failures in soil deposits and for monitoring many different kinds of movements in rock masses.

This article describes the integration of TDR directly with Arduino boards and XBee modules for real-time transmission of slope monitoring data. ***This system is being developed as a part of Ministry of Mines, Government of India (GOI) sponsored project, which is useful for real-time slope monitoring of the slope movements using TDR.*** *Laboratory investigations were conducted using TDR without data logger for real-time transmission of data generated by TDR. For the purpose, interfacing modules, Arduino boards, XBee modules are used and software modules are developed using Arduino-Integrated Development Environment (IDE) Software. The data captured by the TDR was successfully transmitted using developed integrated system.*

Keywords: *Arduino, Time Domain Reflectometry, XBee module.*

INTRODCUTION

The progress of the technology in many branches of engineering is quite rapid in recent years. However, in case of underground mining, the progress is not as expected. It remained a lot with traditional systems, and only a few attempts were made to adopt/absorb recent trends. Although it could be attributed partly to availability and adoptability of the modern mining machinery, but also mainly due to limitations of available strata control technology, be in underground (suitable designs of workings and support systems) or opencast mines (suitable design of pit slopes, and stabilization of high walls/spoil dumps etc).

In olden days, due to lack of proper instruments, qualitative observations with limited possibility of quantification lead to some empirical relations/thumb rules. However, now-days, with improved technology of mining/instrumentation, numerical models - computer applications for analysis of data; investigators gained enhanced satisfaction through observational approaches. Acceptability of such studies by the field personnel may be improved by proper interpretation of the data so generated by experts in the strata monitoring. There is a need to be more innovative in application of the existing instrumentation with proper planning by experienced strata control engineers which may lead to possibility of modification in existing practices for better safety and economy of mining venture. India has large resources of coal deposits for underground mining and lot of coal was blocked in existing underground mines. Safe extraction of these can be made possible by effective strata management. Accidents due to movement of strata in underground coal mines had been a major concern for the mining industry and it is largest contributing factor of underground coal mine accidents. Continuous efforts were being made by all concerned to reduce the hazard of strata movement.

The analysis of the accidents due to strata movement for last two decades revealed that the roof fall and side fall accidents accounted for 59% of all below ground fatal accidents in coal mines. All types of strata were involved in roof and side fall accidents (shale, coal, sand stone, shaley coal, shaley sand stone etc.).Accidents due to fall of roof occurred in almost same proportion in bord & pillar development as well as depillaring districts. The condition of strata and the stress environment around any working place is always dynamic in nature. No two working place are having identical strata condition. It is therefore essential to assess the roof condition of the working places at regular intervals by scientific methods. The analysis of the accidents, observations of the DGMS officers during the inspection of mines revealed that a system of monitoring of strata movement was not in vogue. Most of these accidents can be prevented by effective monitoring the strata movement and implementing SSR. Therefore, it is essential to further emphasis on the issue of strata control mechanism to reduce the accidents due to strata movement (fall of roof & sides). Accident statistics since 1900 as shown in Fig 1 indicates drastically decreasing trend of fatalities since nationalisation of companies in 1970s (DGMS, 2015). However, there was no ostensible change in the trend over five decades signifying importance of new look and trans-disciplinary research to minimise the accidents in mines due to various reasons deliberated in many conferences including National safety conferences conducted from time to time.

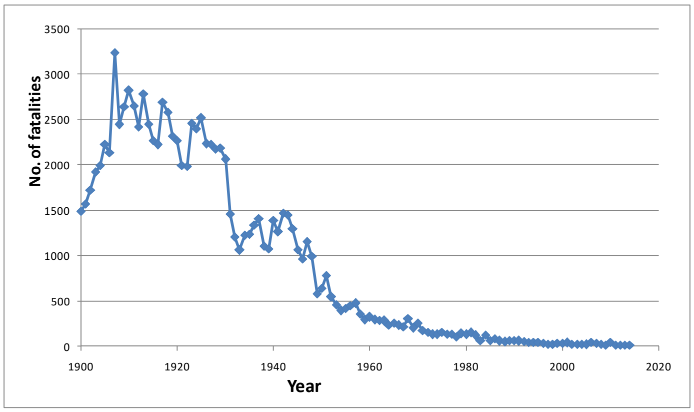

Fig 1: Fatal accidents during years -1900 to 2014 in mines (DGMS, 2015)

In every coal mining company, strata control cell shall be established at corporate and area levels within one year as per recommendations of the 10th National Conference of Safety in Mines held at New Delhi 26-27th Nov, 2007. However, till now strata control cell not establish in all the coal mining areas as required. This may be attributed partially due to lack of proper responsiveness among the officials of some coal mining Industries. Strata control cell in coal mines can assist mine managers, for formulation of Systematic Support Rules, monitoring strata control measures in a scientific way to ensure efficacy of support system and, for procurement/supply of quality supporting materials. This issue can be addressed by proper monitoring of strata and taking adequate control measures in time. Geotechnical instrumentation although has been extensively used in the coal mines, still there is no standard procedures for undertaking the investigation as well as type of instrumentation for monitoring of the strata behaviour. Keeping this in view, two short term courses were held at NIT-Rourkela on “Trends in strata control techniques and instrumentation for enhancing safety in coal mines” during July 28th--31st, 2008, and Nov 19th -22nd, 2009.The Mining Engineering department of NIT-Rourkela also conducted Workshop/ Training programs in coalfield areas of M/s SCCL, SECL, WCL, MCL etc. under the TEQIP sponsored by the World Bank through National Project Implementation Unit during Oct-Dec’08. Strata control technologies have undergone considerable change and it is pertinent that the field engineers must be trained in the state of the art instrumentation for effective implementation of the strata control measures in coal mines.

The economic consequences and operational problems associated with slope instabilities dictate the need of appropriate slope monitoring and management measures. Slope management constitutes anticipation, pre-detecting of likely changes and control of slope behavior. An understanding of the causative factors of slope instability and the expected slope behavior is a prerequisite to successful mining. Available Geotechnical sensors include vibrating wire piezometers, wireline extensometers, borehole extensometers, Inclinometers; tilt meters, for sensing the changes in slope conditions, besides widely practiced total station monitoring. These geotechnical sensors are monitored by technicians in the field. An understanding of the causative factors of slope instability and the expected slope behavior is a prerequisite to successful mining. Failure geometry, strength properties, and monitoring data are important guides in predicting slope behavior. Figure.2a shows the Present Condition of Slopes at DongriBuzurg Opencast Mine, Manganese Ore India Limited (MOIL). Figure.2b shows a typical Slope failure at Bingham Canyon Mine southwest of

Salt Lake City. The analysis of accident in Opencast mine revealed that slope failure and dump failures have upward trends in the recent time [1]. Few examples of fatal accident involving slope and dump failure are as mentioned in Table.1.

Table.1. Details Of Fatal Accident Involving Slope And Dump Failure

Sl. No	**Date**	**Name of Mine**	**Incidence**	**Fatal**
01	24.06.2000	KawadiOpen Cast (OC) Mine of M/s Western Coalfields Limited(WCL)	Slope failure of 31m high OB benches.	10
02	09.12.2006	Tollen Iron Ore Mine of M/s Kunda R Gharse in Goa	Slope failure of 30 to 46m high Dump.	06
03	17.12.2008	Jayant OC Project of M/s Northern Coalfields Limited(NCL)	Failure of Dragline Dump.	05 persons 01 Shovel Buried
04	04.06.2009	Sasti OC Mine of WC.	Dragline OB dumps of 73m height failed and slided down the pit.	02 Persons 02 Excavators Buried
05	25.02.2010	Hansa Minerals and exports Granite Mine.	Granite mass slided along an inclined joint plane and fail from height varying from 10 to 55m.	14 Persons
06	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	2 Persons 1 Dumper 1 Dozer 1 Crane

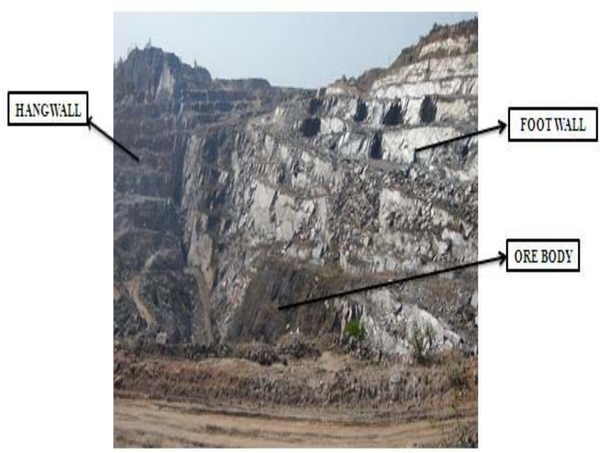

Fig.2a. Present Condition of Slopes at DongriBuzurg Opencast Mine, MOIL

Available electronic instrumentation includes vibrating wire piezometers, wire line extensometers, borehole extensometers, electrolytic bubble Inclinometers and tilt meters for sensing the changes in slope conditions, besides widely practiced total station monitoring. Technicians in the field can monitor These instruments. This research work is focused on the 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. Installing the wireless sensor nodes at respective slope stability points in mines are used to acquiring the data from slope instruments and can be interpreted online. TDR is utilized as a sensor and for sensing the ground movements. The Radio Frequency (RF) module and interfacing unit were integrated with TDR to acquire the data, and data transfer algorithm was developed for the establishment of wireless communication and tested in the laboratory.

Fig.2b.Slope failure at Bingham Canyon Mine southwest of Salt Lake City [2]

TIME DOMAIN REFLECOMETRY

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(Figure.3). 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 [2]. The elapsed travel time and pulse reflection amplitude contain information used by the on-board processor to determine quickly and accurately rock mass deformation for slope stability measurement or user-specific, time-domain measurement. 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 [3, 4]. 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.

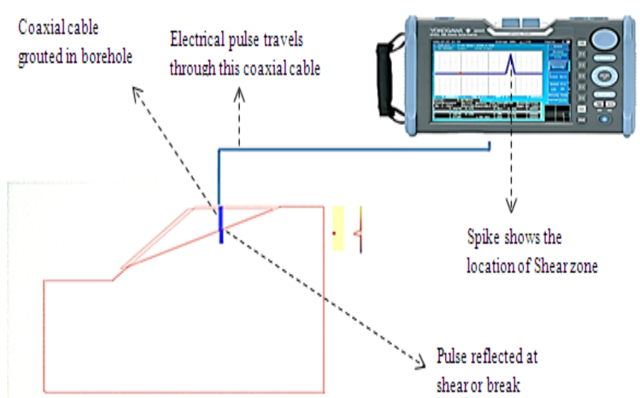

Fig.3. Basic Principle of TDR

RS232 TO USB CONVERTER

The TDR is having the RS232 communication port for data logging using communication cable. This port is the only source for communicating the data which is captured by the TDR, so using the RS232 to USB breakout board along with simple Arduino UNO, the data generated by the TDR was observed in a Serial monitor in Arduino IDE software instead of Logger Net software which is supplied by the Campbell Scientific Ltd. By this simple test, it is noted that establishment of wireless communication is possible from TDR to PC. Figure.4. Shows the schematic diagram of RS232 to USB converter.

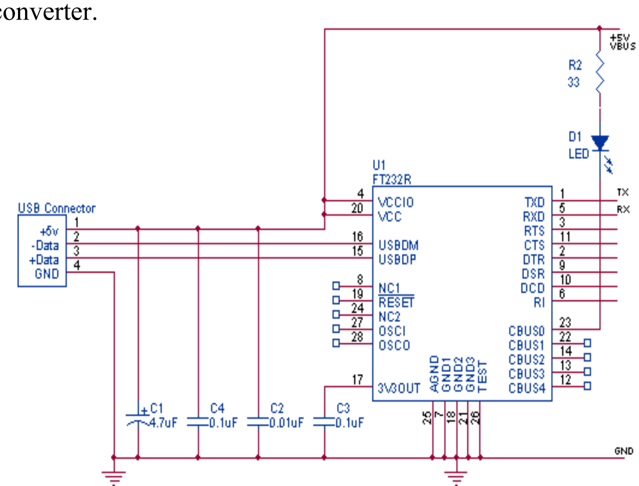

Fig.4.Schematic diagram of RS232 to USB converter

ARDUINO MEGA

The Arduino Mega is a microcontroller board based on the ATmega1280. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [5, 6]. Itcontains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts, and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board(Figure.5)

The recommended range is 7 to 12 volts. The ATmega1280 has 128 KB of flash memory for storing code (of which 4 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM and the Arduino Mega can be programmed with the Arduino software. The Arduino Mega has some facilities for communicating with a computer, another Arduino, or other microcontrollers. The Arduino Mega is designed in a way that allows it to be reset by software running on a connected computer. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

ARDUINO SOFTWARE

The Arduino Integrated Development Environment or Arduino Software (IDE) is used for the programming the Arduino Boards. It 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 Genuino hardware to upload programs and communicate with them. Programs written using Arduino Software (IDE) is called sketches. These sketches are written in the text editor and are saved with the file extension. The editor has features for cutting/pasting and for searching/replacing text [7, 8]. The message area gives feedback while saving and exporting and also displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information. The bottom right-hand corner of the window shows the configured board and serial port. The toolbar buttons allow you to verify and upload programs, create, open, and save sketches and open the serial monitor.

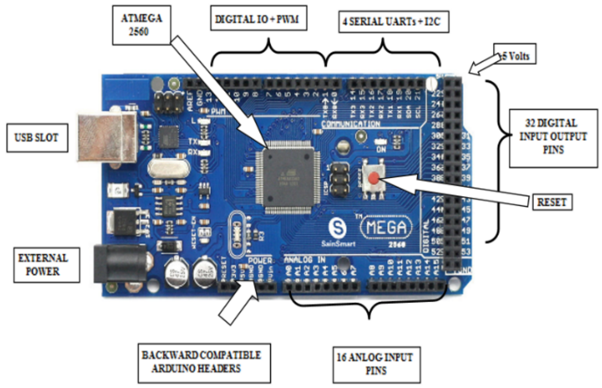

Fig.5. Arduino Mega Board

ZIGBEE PRO-RF MODULE

ZigBee is a high-level communication protocol used for creating PAN (Personal Area Network). ZigBee builds on the physical layer and control defined in IEEE standard 802.15.4 for low-rate WPANs. It is the most simpler and less expensive than the other wireless Personal Area Networks like Bluetooth or Wi-Fi. The data transmitted through the ZigBee is secured with 128-bit symmetric encryption keys [8, 9]. ZigBee operates in the Industrial, Scientific and Medical (ISM) radio band around 2.4 GHz worldwide. XBee is the RF wireless transmission module developed by Digi Internationals. This module works on the ZigBee wireless communication protocol. XBee is popular for its various features like acknowledgment based transmission. So that next data is to be sent only after the successful transmission of the previous data. If such not happens, data is retransmitted automatically avoiding loss of data [10, 11]. Configuration process of XBee is much simpler using XCTU software provided by Digi internationals. After configuration, wireless communication can be checked between two X-Bee module using console tools in XCTU software (Figure.6.).

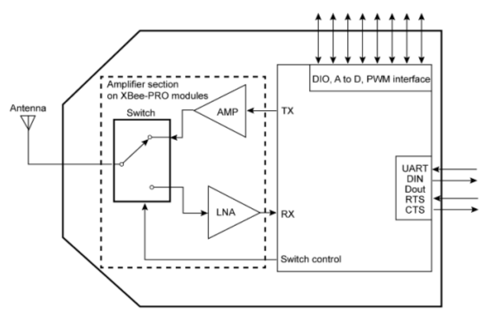

Fig.6. XBee module with Pin diagram [8]

DEVELOPMENT OF HARDWARE AND SOFTWARE MODULES

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.7 shows the Connection Diagram of the Developed System. Figure.8. Shows the flow chart of the software module.

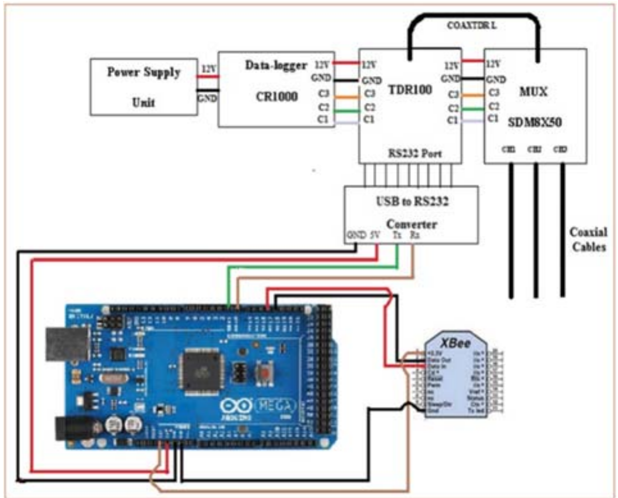

Fig.7. Connection Diagram of the Developed System

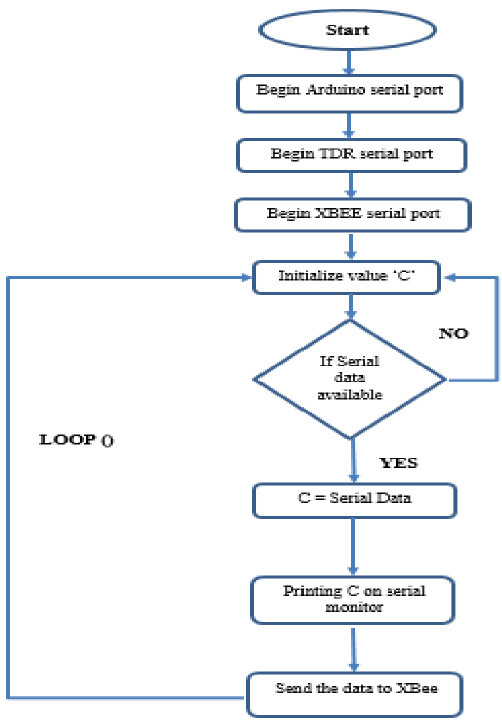

Fig.8.Flowchart for Software Module

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. 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. 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 Figure.9. 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.

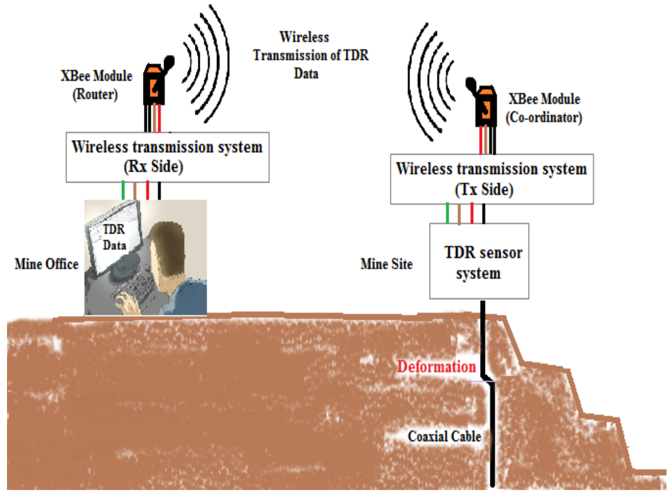

Fig.9.Schematic representation of the developed system

FIELD EXPERIMENTAL TRIAL-COMMUNICATION TEST

First field test of the developed system was carried out at the National Mineral Development Corporation Ltd, Panna Diamond Mine, MadyaPradesh. 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 took at the mine site. Mine office is approximately 1Km 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 a base as high as possible to reduce the attenuation of transmitted energy due to the earth surface. One of the XBee modules generates 100 no. Of packets (signals), one by one and transmits it wirelessly. XCTU software continuously updates the information after transmission of each packet. Receiver XBee provides the acknowledgment signal after receiving each of the packets. In the Range test 100 packets are sent from the transmitter XBee from which 99 are received successfully, and one packet is missed during wireless transmission. Also, it shows the change in the RSSI value during packets transmission. RSSI is the Received signal strength indicator value which shows the measurement of the power present in received radio signalFigure.10 shows the RSSI value is varied during the packets transmission during the range test. At some points RSSI value is decreased to some extent, this is due to the line of sight issues encountered at the mine site.

Fig.10. Graphical representation of the variation of RSSI values during Range test.

COMMUNICATION TEST AT THE LABORATORY

Range test is carried out at different floors and the different distances in the Mining Engineering Department of the NIT Rourkela. The Transmitter XBee module (Co-ordinator) is kept fixed at the model preparation lab (1st floor), and Receiver side is moved from one place other as mentioned in Table.2. Figure.11 and Figure.12 shows the laboratory set up including transmitter side and receiver side along with TDR setup. Figure.13. shows the Different locations in the department for the range test.

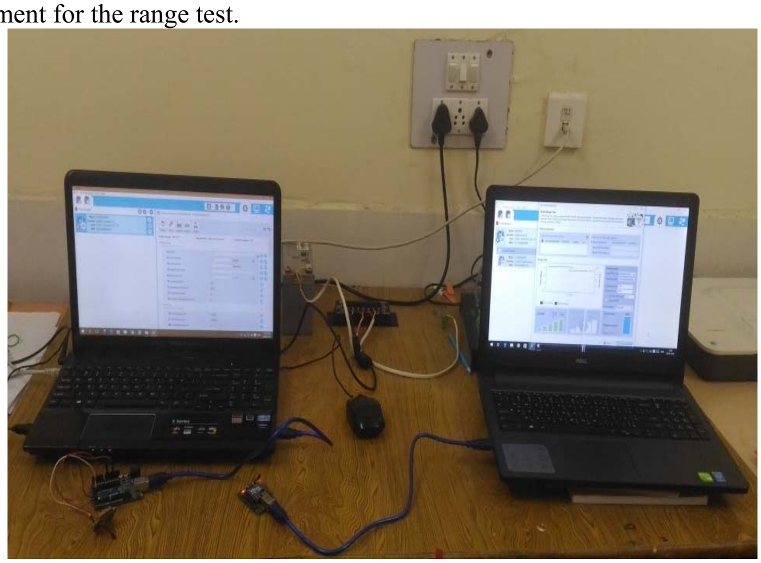

Fig.11 The lab set up including transmitter side and receiver side.

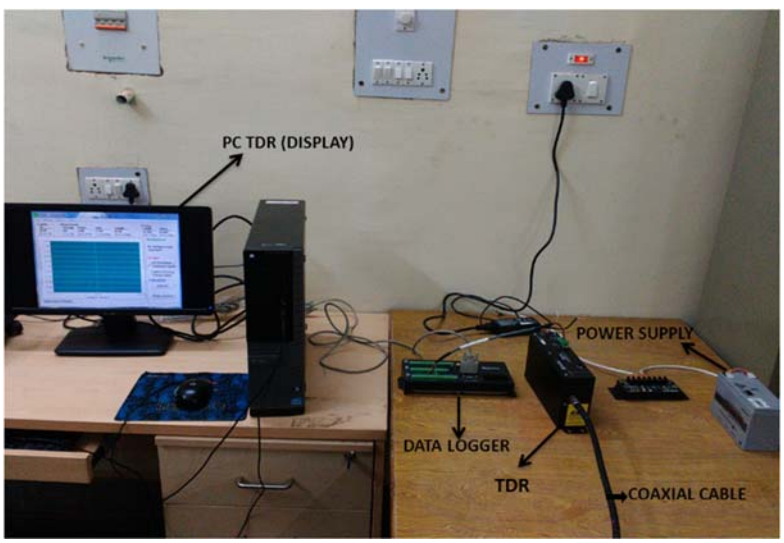

Fig.12 The lab set up including TDR.

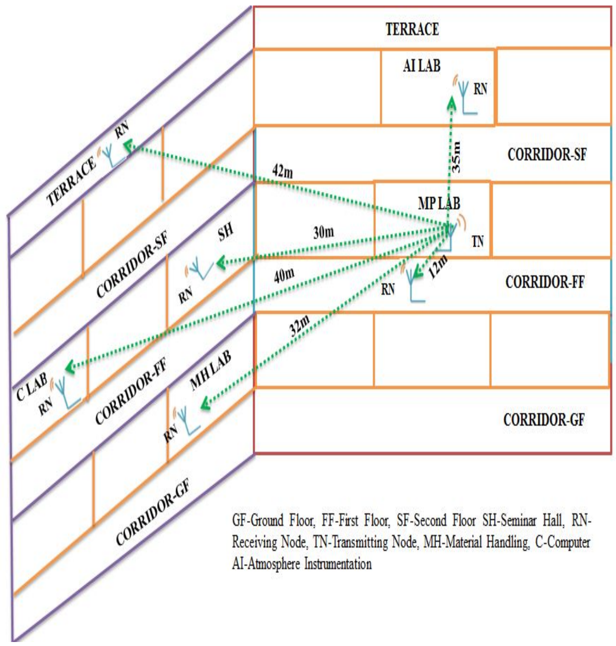

Fig.13.Different locations in thedepartment for the range test.

Table.2 Results Of The Range Test At Different Places In Mining Department

Sl.No.	Position	Height from transmitting Node	Depth from transmitting Node	Point to point distance from transmitting Node	RSSI Values (dBm)
1	In front of Model Preparation Lab	0	0	12 m	-31
2	in front of Seminar Hall	0	0	30 m	-36
3	In front of Computer Lab	0	0	40 m	-59
4	In front of Atmosphere Instrumentation Lab	10 m	0	35 m	-82
5	At the Terrace of Mining Department	10 m	0	42 m	-87
6	In the Material Handling System Lab	0	9 m	32 m	-87

INSTALLATION METHOD OF DEVELOPED SYSTEM

Technically one deep hole of 80m and other two holes of 20m-25m length shall be provided as it is anticipated that this will give a correct data for Insitu rock condition and slope monitoring data. One 80m deep hole is suitable for measuring the displacement or shifting of rock structure due to induced stresses up to the bottom of the query. Further, two more short holes of 20m-25m length can be drilled after stabilization of lower benches in footwall side. After installation of TDR, data will be collected at TDR Room. Proposed site of installation of TDR system in a typical opencast mine is shown in Figure.14.

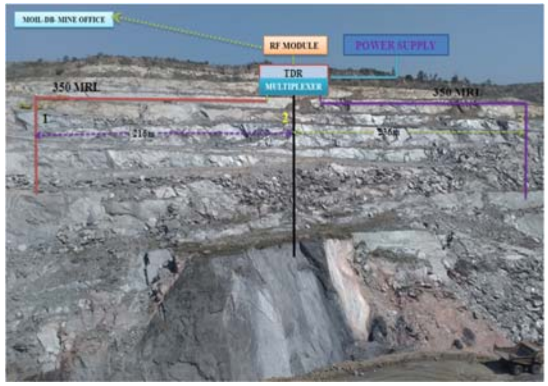

Fig.14.Proposed site of installation of TDR system in a typical opencast mine.

CONCLUSION

Attempts made to develop the indigenous wireless system in typical mining conditions for transmission of real-time data generated by the TDR sensor indicated successful transmission of data without any packet loss up to 400 m. The developed system gives the new approach for Arduino and RF technology based real time slope stability monitoring from the remote location. Wireless transmission system integrated with the XBeePRO-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. The range of the transmission can be increased by adding the routers between two end nodes as per need. Acknowledgment based wireless system operation provides higher reliability for secure data transmission without loss of information.

REFERENCES

[1] Available at:http://dgms.gov.in
[2] Available at:https://en.wikipedia.org/wiki/Bingham_Canyon_Mine.
[3] Prof. S. Jayanthu, Guntha Karthik G. Manekar "Slope Monitoring by TDR-A Low cast system "Published in The Indian Mining Engineering Journal (IMEJ) pg.29-32, volume-54 No.9, September-2015. ISSN 0019-5944.
[4] Prof. S. Jayanthu, and Guntha Karthik “Innovative Application of Time Domain Reflectometry for Real Time Slope Monitoring– An Experimental Trial” 6th Asian Mining Congress 23–26 February 2016, The Mining Geological and Metallurgical Institute of India (MGMI)Kolkata, India.pp.153-158
[5] Cortez, Edel R., et al. Simplified User’s Guide to Time-Domain-Reflectometry Monitoring of Slope Stability. No. 0877 1804—SDTDC. 2009.
[6] Kane, William F, and Timothy J. Beck, 2000, Instrumentation practice for slope monitoring. Engineering geology practice in Northern California. Association of engineering geologists Sacramento and San Francisco sections.
[7] S Jayanthu, 2014, Interim Report on Development of TDR-Based Wireless System For Slope Stability Monitoring In Opencast Mines" S&T Project sponsored by the Ministry of Mines-Govt of India (unpublished), 33p.
[8] X-CTU Configuration and Test Utility Software: User’s Guide, Digi International Inc., Aug. 2008.
[9] XBee/XBee Pro OEM RF Modules: Product Manual v1xEx 802.15.4 Protocol, Digi International, Inc., Sep. 2009.
[10] L. Ruiz-Garcia, P. Barreiro, and J. Robla, “Performance of ZigBee-based wireless sensor nodes for real-time monitoring of fruit logistics,” Journal of Food Engineering, vol. 87, no. 3, pp. 405–415, Aug. 2008.
[11] ZigBee Wireless Networking by Drew Gislason, Newness ZigBee Alliance pp 1-50.