ROLE OF TRANS-DISCIPLINARY TRANSLATIONAL INDUSTRY ORIENTED RESEARCH FOR IMPROVEMENT OF SAFETY IN MINING

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ABSTRACT

This paper presents overview of a few innovations by the author as scientist of CSIR-CIMFR, NIRM-Ministry of Mines, and Professor of NIT Rourkela through various industry oriented trans-disciplinary research activates over 37 years to improve safety in mines. Various innovative attempts made including application of Information and Communications Technologies (ICT) through more than 130 industry/Ministry sponsored projects for development of new concepts, designs and implementation in the field of opencast and underground mines in India. Mining evolves the cycle of stages which is started from exploration continuing through production and ends with closure of the mine facing lots of risk, hazards to environment and mankind. So minimizing the riskiness of the job and hazards technological innovations are coming forward in the mining industry. Renewal of the innovations is driven by the growth of the demands of the minerals with respect to communities and the environment. Adopting the technological innovations like geophysical methods for exploration of minerals, global positioning system, geographical information system, 3-D models using software etc makes the mining process more productive and reliable. So technological innovations shape the future. Attempts made on development and experimental trials of innovative systems for the first time in India for online-real-time slope stability monitoring with TDR, WSN, IoT, LoRa, Cloud/Fog computing etc for opencast mines is also presented with emphasize on urgent need of Trans-Disciplinary Translational industry oriented Research and Academics (TTIORA) for improving safety in mines, including fatigue monitoring.

Keywords: Mine Safety, WSN, TDR, IoT, LoRa, Cloud/Fog computing, Transdisciplinary research

INTRODUCTION

Mining is considered as the backbone of the economy and also an old industry. So as an old industry does not mean to adopt traditional methods. In general, we observe the mining industry is less technologically advanced in comparison to other industries like biotechnology, communication etc. But the reality is different. Mining has the scope of innovation which brings the better efficiency, safety and environmental and social integration in any adverse situation. Innovations in mining are difficult and challengeable because we mined the non-renewable resources which are present beneath the surface where unknown and unreceptive conditions get in the way of exploration and extraction. Technological innovations in mining industry provide the smarter exploration of the minerals, more efficient mining, safer working conditions and more environmentally responsible industry. The smarter exploration methods help in identifying the minerals, chemical and physical properties of minerals in the field and detecting the depth of the mineral deposit and modeling the mineral deposits. Mining methods based on the data which is more suitable for the extraction of mineral. The technological innovations improve the underground communication system and also provide the sophisticated mineral transport system and emergency response. It also minimizes the impact on the environment.

Innovation represents the changes in ongoing process for mining industry that draws the areas of knowledge. Innovation does not limit itself in the field of technology it can be based on social and environmental aspects. From the mining point of view social and environmental aspects are playing the vital role. So technological advancements consider these factors while renewing the technology. Attempts have been made by the author since 1990's about field oriented research and in line with NEP2020, also on Transdisciplinary Translational Industry Oriented Research and Academics (TTIORA) as scientist and Professor above three decades. Some of the recently developed systems through projects related to TTIORA are presented below besides critical review and emphasis on urgent need of TTIORA for sustainable development of mining industries.

Adopting a huge fleet of machinery, with massive capacities of shovels and dumpers became quite common in the Mining Industry. Despite the technologies and methods, the human element plays an important role in maintaining the whole system safely and efficiently. manner. As most of the mining accidents are caused due to the operator's negligence / Heavy earthmoving machinery, there is a need to monitor the operator's efficiency, and alertness while operating the machinery. Drowsiness or sleepiness, and the accompanying physical and mental state of employees is one of the major factors contributing to accidents in the mining industry worldwide. This paper presents some of the technologies (Artificial Intelligence and Machine learning) used to monitor and assess the fatigue levels of the work personnel working in various capacities as vehicle drivers, hauler/conveyor operators, pump operators, or any moving machinery operators etc both in underground as well as surface mining conditions in the Mining Industry. Although AI/ML algorithms can assist fatigue monitoring, true reasons can only be understood by using studies using technology like biomarkers.

Slope stability is one of the major geological concerns in open-cast mines. The mining area slopes needs to be regularly monitored to detect occurrence of any slope failure prior to any catastrophe. An early warning system solves this purpose preventing loss of significant mass of human lives as well as property. This is a critical scrutiny which renders various techniques and methodologies regarding Slope monitoring of open-cast mine. Wireless sensor network has been standing out as a productive competent tool for monitoring the tangible environmental structures by sensing the differences, processing this raw data and finally communicating the result to the web from where it can be referred for researches and predicting mechanisms. Internet of Things comes into picture for communicating the sensed and processed data from the sensors to the application where it can be further analyzed. In recent scenario power issue is of great concern associated with deploying a real-time monitoring system. This review depicts how WSN can be adopted and preferred to any other technologies used in slope monitoring due to its advantages it brings. Moreover, collaborative operation of WSN with IoT results in a more systematic, robust, energy-efficient, cost-effective real-time monitoring approach.

TELE MONITORING FOR MINE SAFETY

Automatic monitoring system is one of the main means to ensure the safety of underground engineering construction. At present, the study of construction safety of underground engineering mainly adopts the traditional manual monitoring methods whose data collection process are cumbersome and time-consuming. (Fig 1). The typical underground engineering monitoring system is composed of four parts: data acquisition, data transmission, data analysis and processing, and security state early warning. The typical underground engineering monitoring system is composed of four parts: data acquisition, data transmission, data analysis and processing, and security state early warning (Fig 2). The data acquisition terminal mainly uses sensors and cameras. Data transmission adopts wired and wireless modes; data analysis and processing adopt a variety of intelligent algorithms and early warning system forecasts security status based on the processing results.

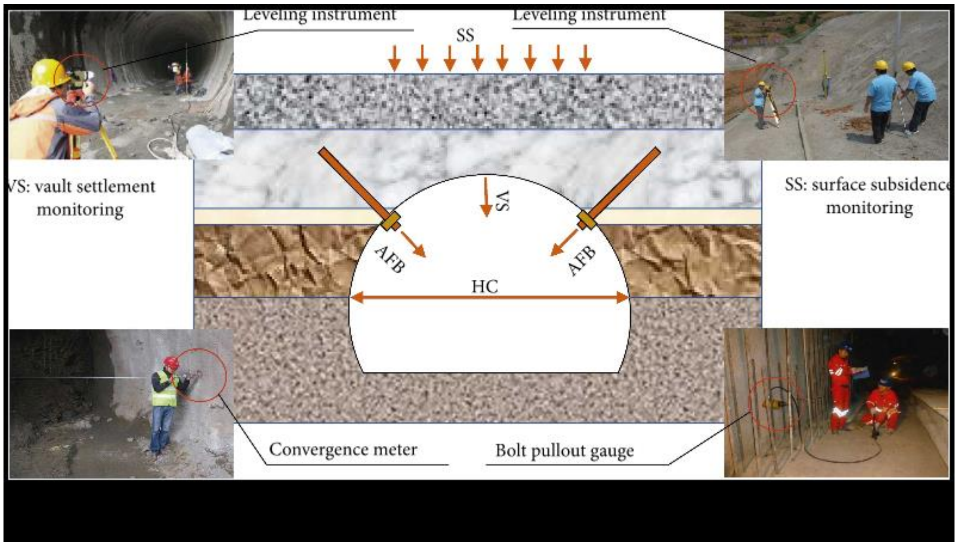

Fig 1: Traditional monitoring data acquisition (11).

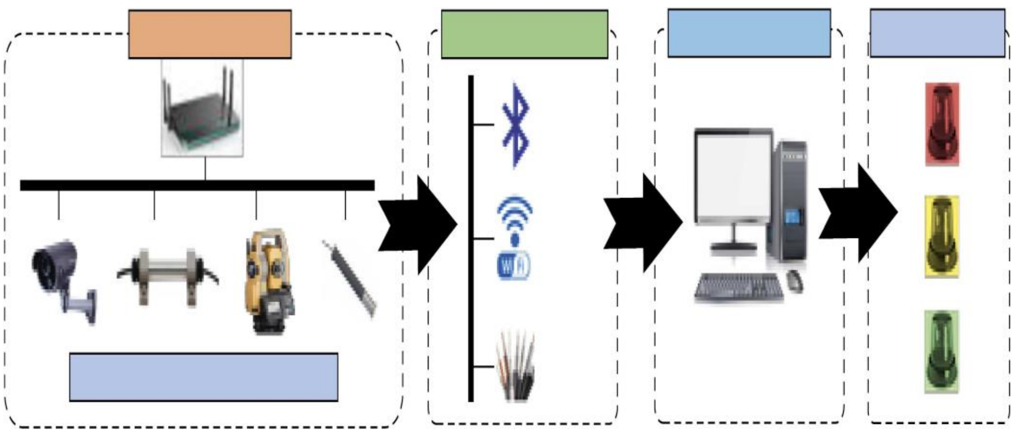

Fig 2: Architecture of the monitoring system (11).

WIRELESS SENSOR NETWORK BASED MONITORING SYSTEM FOR MINE SAFETY

Wireless Sensor Networks (WSNs) are a new kind of ad hoc network, which consist of hundreds to thousands of WSN Nodes that communicate with each other, and can monitor areas from small to huge (9). WSNs have emerged as a powerful technology. In recent years, with the rapid development of mobile communication, micro-electro-mechanical-systems (MEMS) and high-speed electronic devices, sensors with characteristics of low power consumption, programmability, multi-parameter sensing or multi-sensor modules and low power consuming wireless communication infrastructure have provided practical wireless solution to real-life problems in variety of domains. With outstanding advantages of ease of configuration, flexibility to shrink or expand the monitoring range, strong fault-tolerance and mobility, WSNs can play an important role in monitoring and analyzing dynamic, hostile and unfamiliar environments. Conceptual structure of a typical WSN is shown in Fig-3.

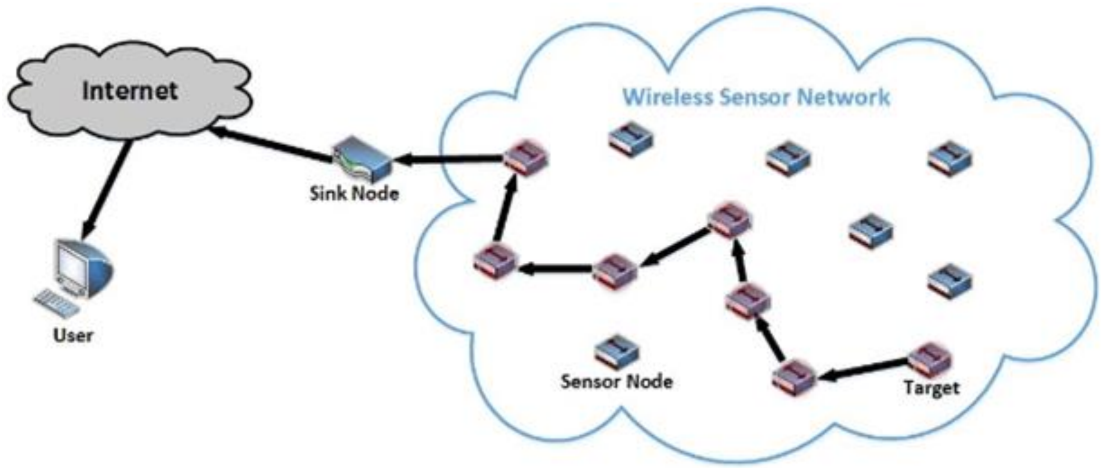

Fig 3: Conceptual Structure of a Wireless Sensor Networks (WSN)

FATIGUE MONITORING FOR IMPROVING SAFETY

Fatigue is a complex state characterized by a lack of alertness and reduced mental and physical performance, often accompanied by drowsiness (1999 U.S. DOT Operational Definition). Fatigue is increasingly recognized as a problem affecting the workforce. Research shows 13% of workplace injuries (National Safety Council) can be attributed to fatigue, a dangerous byproduct of a society that operates 24 hours a day.

The majority of the accidents occurred due to Heavy Earth Moving Machinery, in which the human element is the main contributing factor. Round the clock working operations, monotonous and repetitive duties are directly influencing the worker fatigue levels. Fatigue is a serious symptom that is prevalent across a variety of occupations and industries (World Health Organization, 1990). The U.S. Centers for Disease Control and Prevention, (CDC, 2015) estimates that one in three adults does not get enough sleep, labeling fatigue as a public health problem. Quantifying and analyzing the fatigue levels for each operation is essential for safely doing work.Symptoms of "extreme tiredness" and "reduced functional capacity" are two of the main factors to be assessed for each worker. Fatigue can manifest physically, mentally, and/or emotionally. Monitoring operator fatigue and distraction are the key factors in minimizing the incidents at the workplace. Mining environment associated fatigue is commonly due to operating machinery during night time, improper lighting at the workplace, poor design of lighting systems, bad temperature settings at the workplace, noise, and highly repetitive tasks resulting in boredom.

A study published in the American Journal of Health Promotion stated employees that "almost always" felt tired during the day missed an average of 2.7 times more days of work and had 4.4 times more productivity loss than those who reported "almost never" feeling tired. Fatigue of any kind poses a workplace hazard, as well as reduced productivity. According to the National Safety Council, the challenge costs employers $1,200 to $3,100 per employee annually, due to absenteeism, health care, and other related costs.

Smart Technologies for Fatigue Monitoring

Artificial Intelligence (AI) is the ability of computers and robots to sense, reason, and perform tasks that are usually done by humans. Machine Learning (ML) is a subset of AI that are algorithms that improve over time through exposure to more data. Deep Learning (DL) is a subset of Machine Learning that uses artificial neural networks, algorithms inspired by the human brain, learn from massive amounts of data. Natural Language Processing (NLP) is a branch of AI that helps computers understand, interpret, and manipulate human language. Advances in AI and ML have brought us many applications that were previously unimaginable.

Machine Learning has brought recommender engines that suggest the products we may be interested in buying, a movie we may want to watch, or a news article that we may want to read. Advances in Natural Language Processing have made it possible to translate between two languages in real-time enabling communication between two remote teams and pushing productivity higher. Deep Learning advances brought us autonomous and self-driving cars, identify a specific type of cancer, and even dancing robots[2].

Artificial Intelligence and Machine Learning are prime technologies that could help the mining industry, due to the remote mine sites, the hazardous nature of the work, and the high costs of labor and transport. Indeed, AI & ML have found uses in mineral exploration, smart sorting of minerals and ores, demand forecasting, autonomous machinery, etc. Applications of AI & ML are relatively new in mining, and the full potential of these advances need to be realized. Artificial Intelligence, especially computer vision and deep learning techniques, just started to appear in the realm of driver safety monitoring and fatigue management systems. For example, Dotnetix.ai's Nexus employs an in-cabin camera and sensors suite monitoring distracted driving conditions, and streaming data to the control center. Hexagon mining uses a combination of visual analytics, collision avoidance system, and body clock models.

As explained in the introduction sections <insert section number here> fatigue is a result of many factors: work schedule, nutrition, sleep, personal habits, circadian cycles, long and monotonous work, tiredness, medical and psychological causes. To truly monitor the drivers and the operators for any fatigue, a holistic view of all the causes of fatigue needs to be adopted. However, a holistic view requires the ability to merge and understand data from personnel's medical, social, behavioral, and physical records. Doing this manually is an impossible task. In addition, the data is typically in silos, and most likely in a non-automatable format. Moreover, a real-time monitoring system is needed to alert the driver of any possibilities of incidents and accidents. Artificial Intelligence has excelled at places where human capabilities have met their limits, especially when it comes to consuming streams of data and analyzing for actionable insights. We now present a couple of approaches to monitoring fatigue, and driver safety using AI. Figure 4 shows A typical driver safety monitoring system. Figure 5 represents the Road Monitoring using Deep Learning.

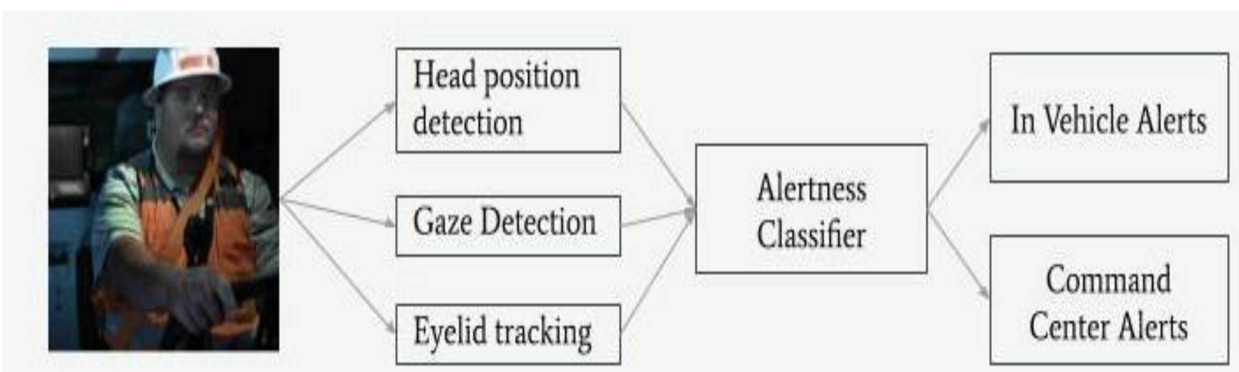

Figure 4: A typical driver safety monitoring system

Technology 1: In-cabin camera to monitor the driver's physical state.
Technology 2: Road monitoring system, with optimal location predictor
Technology 3: Ambient sensing technologies
Technology 4: Driver's physical measurements
Technology 5: Combine operator's medical records with the approaches above

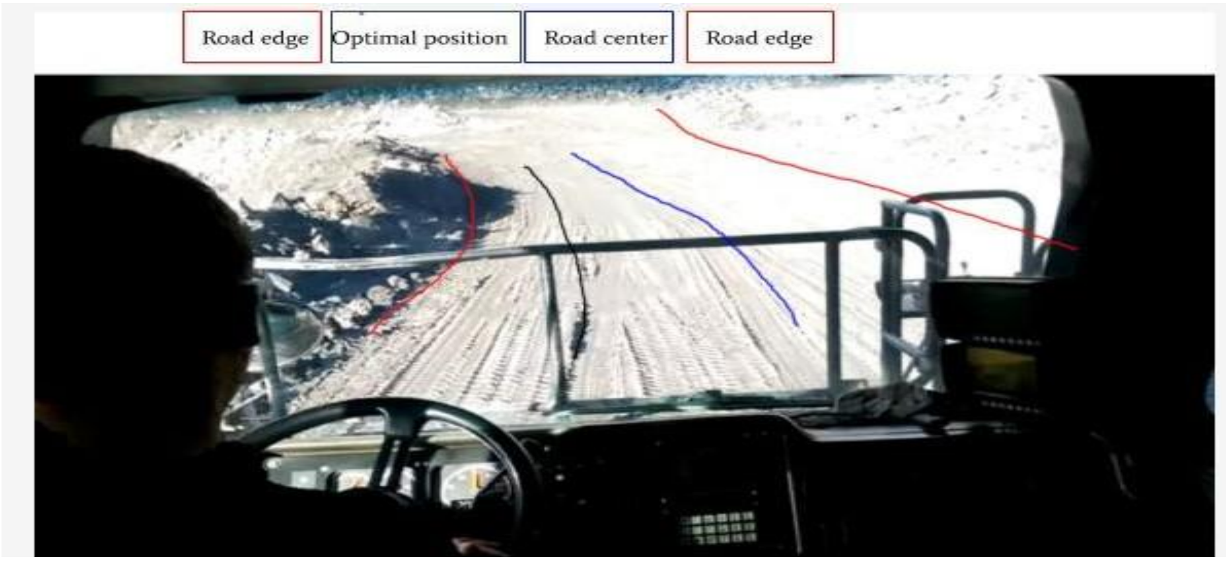

Figure 5 represents the Road Monitoring using Deep Learning

No matter which approach is chosen, the data collected, and the incidents averted must be reviewed by the safety manager of the mining site, along with the operator(s) involved in the incident. To achieve this, videos and the data from the sensors are stored for later analysis and review. In addition, mine-wide analytics of the incidents, along with where and when they happened, and who were involved are extremely important to maintain the safety of the operations, and to make improvements on it.

Biomarkers for Understanding Underlying Reasons

The official National Institute of Health (NIH) definition of a biomarker is: "a characteristic that is objectively measured and evaluated as an indicator of normal biologic processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention." (Biomarkers Definitions Working Group, 2001). Fatigue is a complex construct of symptoms that emerges from alteration and/or dysfunction in the nervous, endocrine, and immune systems. Identifying biomarkers of Chronic fatigue (CF) is an important part of this effort. Chronic fatigue (CF) in combination with a minimum of 4 of 8 symptoms and the absence of diseases that could explain these symptoms, constitute the case definition for chronic fatigue syndrome/myalgic encephalomyelitis (CFS/ME). Inflammation, immune system activation, autonomic dysfunction, impaired functioning in the hypothalamic-pituitary-adrenal axis, and neuroendocrine dysregulation have all been suggested as root causes of fatigue. Although AI/ML algorithms can assist fatigue monitoring, true reasons can only be understood by using studies using technology like biomarkers.

Fatigue monitoring is a necessary step in maintaining the safety of the mining operation, to safeguard the operators, and maintain high levels of efficiency. Mining operators can readily start to gain an advantage by deploying fatigue monitoring systems. Gaussian Solutions LLC has worked with clients to custom design solutions for their needs. With the advances in mobile processing, it is possible to quickly start deploying solutions using mobile phones. However, this solution is not robust. Dedicated cameras, and edge computing devices that are ruggedized to work in the mines are needed to achieve the reliability and availability needed in the mining industry. Good connectivity and real-time analytics are needed for the safety managers to monitor and take corrective actions when a driver's lack of attentiveness is detected. Mining operators should approach the problem with agility, and be able to quickly deploy solutions, test, and improve on the deployments. A rapid development, deployment, test, monitor, and redo mantra should be adopted. All the data analyzed, and insights gained should be shared with the mining community to improve the overall state of the safety measures in a mine. Finding good analytics and machine learning partner will help a mining company progress faster and achieve greater results.

APPLICATION OF TDR-WSN-IOT FOR SLOPE MONITORING

Laboratory Experiment

A laboratory test was carried out on the TDR system to check the response of the TDR with the applied deformation. RG-6 type of co-axial cable is selected, and the reading is taken in the PC-TDR software. Laboratory set-up used to test the response of the TDR to applied deformation is shown in Figure 6, and 7. The response of TDR is then to be determined with deformation applied precisely mm by mm using the open cast model. RG-6 is used for the test with the specifications. RG-6 is used for the test with the specifications:

(I) Velocity of propagation (V_P) = 66% = 0.75
(II) Maximum Operating Frequency = 1 GHz
(III) Diameter(mm) = 6.5 mm
(IV) Operating temperature(C) = -40^0 to $+80^0$
(V) Characteristic Impedance(Ω) = 75

In the first test, RG-6 type of co-axial cable was deformed by model, and the TDR response was checked. This Open Cast (OC) mine model was designed using a Plexiglas and represents the open cast mine with three numbers of benches. The arrangement is done so that middle bench can move forward representing the bench movement. The model was having the arrangement of scale so that displacement can be measured. Table 1. Shows the reading of the reflection coefficients taken by TDR system when deformation applied by model. Same results are represented in graphical form in **Figure 8.**

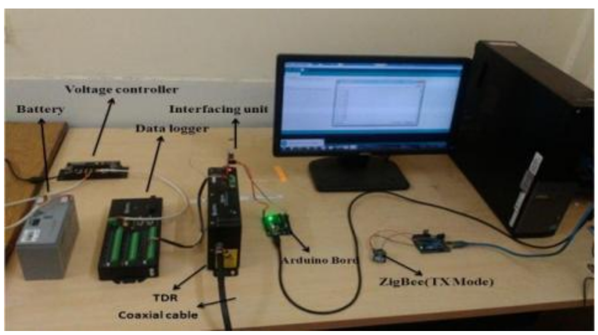

Figure 6. Electronic instruments used for a laboratory experiment

The reflection coefficient is a parameter that describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium. It is equal to the ratio of the amplitude of the reflected wave to the incident wave (Dowding *et al.*, 1988; Kane *et al.*, 2001; Lin, 2009). The impedance of the coaxial cables changes with the applied deformation, so a higher value of the reflection coefficient at the length where deformation is applied compared with other points of the cable. It can be concluded from the results of the above test that TDR senses the deformation occurring along the coaxial cable sensitively. It can be used successfully for the slope stability monitoring of the open cast mines. Changes in reflection coefficient caused by deformation of the cable are best modeled regarding changes in impedance and expressed as follows:

$$\textbf{Reflection Coefficient } (\rho) = (Z1 - Z0)/(Z1 + Z0) \quad (2)$$

Here, $Z1$ = characteristic impedance of the deformed section of cable and $Z0$ = characteristic impedance of the unreformed cable. Changes in ρ caused by deformation in the cable. The characteristic impedance increases due to the applied deformation so that reflection coefficient also increases.From the reflection theory, the applied deformation changes the shape of the cable results in the variation of impedance in the cable at a particular location (Kane, 1996; Kane *et al.*, 2004). So some of the energy is reflected back from the shear zone, and after capturing the reflected wave, TDR analyses both signals and gives the output in the form reflection coefficient values. The change in capacitance and characteristic impedance at the location of cable deformation gives the change in the reflection coefficient also. A linear relationship between reflection coefficient and deformation was observed (Dowding *et al*., 1989; Dowding and Kevin, 2000). This result was considered encouraging because it suggests that, for a given type of cable, there is a direct, linear, and measurable relationship between the cable signal and shear deformation. In laboratory shear testing, the setup was simulated to know the intensity of slope movement. The TDR senses the slope movement of the coaxial cable injected into the slope. Two types of coaxial cables were employed here—RG-6 and RG-213. For RG-6 cable, the average highest magnitude of coaxial cable deformity by shear failure was 11 mm, equivalent to RC of 0.49 beyond which the cable breached as shoen in table 1. For RG-213, the average highest magnitude of coaxial cable deformity by shear failure was 14 mm, equivalent to RC of 0.050 beyond which the cable breached as shown in table 2. fter concluding the experimental results of laboratory testing, it was also observed that RG-6 cable is more responsive as compared to other coaxial cables used in this research work and it is cost-effective too. Due to this, RG-6 can be preferably used for installation in mine site for slope monitoring.

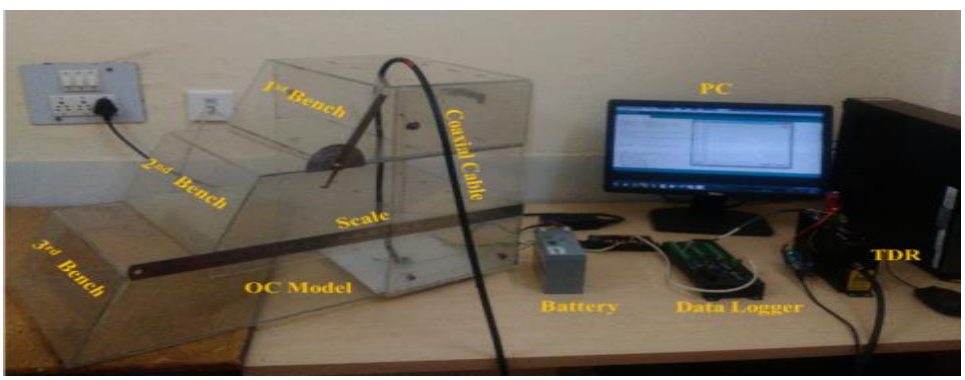

Figure 7. Set up used for the laboratory test

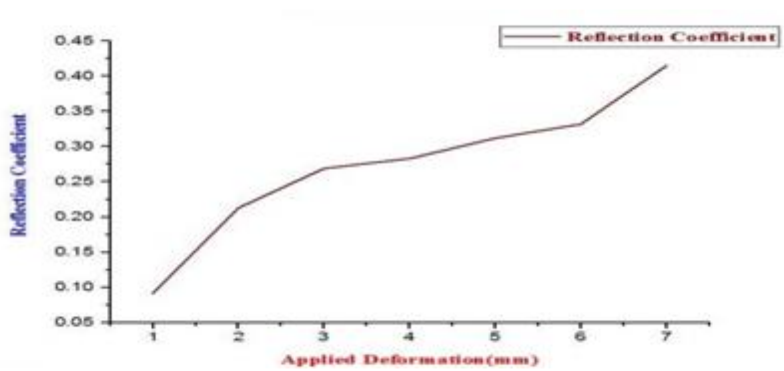

Figure 8. Reflection Coefficient Vs. Applied Deformation

LORA Test

The LoRa module used here for surveillance is from Pycom and its version is Lopy 1.0r. The antenna used at the transmitting and receiving end is 6 dBi with 900 MHz. Both the antennas were mounted at a height of 6 meters above the ground throughout the testing phase. The temperature during the testing was 29 °C whereas the humidity was 67%. The power consumption of these LoRa modules while data transmission was 14 dBm. The experiment in Rourkela was performed within the distance range of 1 m to 2000 m in the case of SF-6. For SF-6, the average RSSI value ranges from -50 dBm to -130 dBm whereas the average SNR value ranges from 6 dB to -8 dB as shown in figure 9.

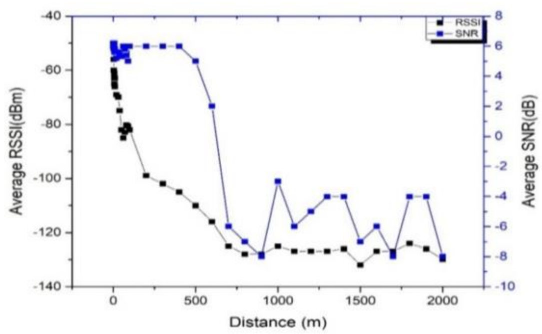

Figure 9. Average RSSI vs distance and average SNR vs distance with SF-6 in Rourkela

FIoTSM

The FIoTSM system. Initially, the prototype of the proposed system was tested with the open-cast mines model as shown in figure 10.The results of TDR behavior with the RG-6 coaxial cable under different test conditions strongly suggest that TDR can be used to determine the rate of ground movement of the slope failure along the TDR cable locations, provided calibration curves are obtained for each location. Testing of the coaxial cable with TDR and OC model indicated the reflection coefficient of 0.0916 - 0.415 vis-à-vis increase in the deformation from 0mm-7mm. Testing of coaxial cable with TDR and press machine indicated the reflection coefficient of 0.135 – 0.89 vis-à-vis change in the diameter of the cable 0mm-4.4mm. These encouraging results were considered for implementing the above TDR system of slope monitoring in the opencast mines in India as a part of Ministry of Mines, Government of India (GOI) sponsored the project. This result suggests that small shear Displacements and loads the TDR can be detected the signal reflections may be sufficient to quantify rock or soil movement. This graphic procedure allows visual determination of the cable deformation directly from the reflection amplitude. Rock/soil shear deformation can be effectively quantified when TDR reflections are sufficient amplitude to allow reliable quantification. Recommendations are given for continuing implementation by TDR for slope monitoring.

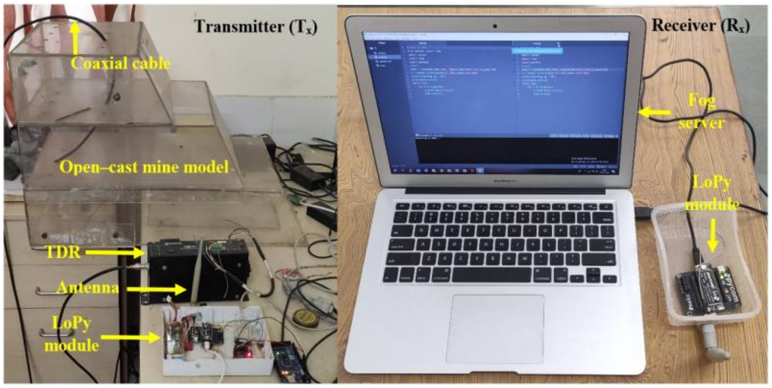

Figure 10 Prototype of the FIoTSM system

CONCLUSIONS

The mining industry should pay more attention to improve the productivity by upgrading the technology. Without changing technology, the allied industry has lagged behind the productivity to be achieved as per demand. Some of the recently developed systems through projects related to TTIORA emphasizes on urgent need of TTIORA for sustainable development of mining industries. Fatigue affects all of us, regardless of our skills, training, and knowledge. It influences your physical and mental abilities needed for even the simplest of tasks. As there is myriad of factors that can contribute to fatigue, there is no one single way to eliminate fatigue. A holistic approach to reduce fatigue that encompasses physical, mental, situational and ambient factors is necessary. Integration of multiple systems that exist today to monitor each of the factors is necessary. Machine Learning and data analytics have been proven effective to collect data from different sources and find actionable insights from them. Although AI/ML algorithms can assist fatigue monitoring, true reasons can only be understood by using studies using technology like biomarkers.

Applying such techniques to fatigue monitoring can benefit the operator, mining operations, and overall productivity. Emphasize is made for urgent implementation of transdisciplinary translational industry oriented research and academics with some of the technologies (Artificial Intelligence and Machine learning) used to monitor and assess the fatigue levels of the work personnel working in various capacities as vehicle drivers, hauler/conveyor operators, pump operators, or any moving machinery operators etc., both in underground as well as surface mining conditions in the Mining Industry. Benefits of Fatigue Monitoring results in increased operator productivity and reduction in incidents and accidents. The results of TDR behavior with the RG-6 coaxial cable under different test conditions strongly suggest that TDR can be used to determine the rate of ground movement of the slope failure along the TDR cable locations, provided calibration curves are obtained for each location. Recommendations are given for continuing implementation by TDR for slope monitoring, ans also TTIORA with various departments including DGMS, academic and research organizations in collaboration with the industry for improved safety.

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