TESTING OF LORA MODULE FOR COMMUNICATIONS SYSTEMS IN OPENCAST MINE - VIS-A-VIS SLOPE STABILITY

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Abstract: ***Recently scientific studies on integration of TDR directly with Arduino boards and XBee modules for real-time transmission of slope monitoring data were conducted as a part of Ministry of Mines, Government of India (GOI) sponsored project highlighting the impetus on urgent need of innovative Wireless techniques for mines. This paper presents a critical review of application of various communication systems for transfer of data from sensors deployed for monitoring strata behaviour to various appliances such as desktop /mobile of concerned officials. 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 analysed. In recent scenario power issue is of great concern associated with deploying a real-time monitoring system. This paper also presents the results of range test conducted at NIT-Rourkela on application of LoRa module. Test conducted from 1 m to 2.0 km range showed RSSI of -82 to -127 dBm.***

INTRODUCTION

Slope stability in open-cast mines is the aptitude of the slopes to combat and endure motion. Stability of slope is regulated by shear tension and shear firmness. Main hurdle regarding the slopes is slope collapse or failure – the consequence of slope instability, which is a major natural menace in both local and global aspects. The causes include steeper slopes; excessive water in the slopes which imbalances it by additional weight and reduces cohesion; human modifications like blasting, passage of heavy trucks, cracks formed on the surface of the slope; irregular design of pit; erosion on slope surface and so on. Primarily, the intent of this paper is to have a broad review of various methodologies employed for monitoring the open-cast mines slopes. Secondly, this paper aims to present the amalgamation of WSN and IoT by a detailed study of both the technologies; and how the blend of WSN and IoT can be executed to monitor slopes in open-cast mines.

Various monitoring techniques have been developed and are being developed to monitor any natural activity or change undergoing in open-cast or underground mines. Accurate observation is required which can fetch and provide the sensed data of slope movement in real-time precisely [1]. WSN can capture several mining factors such as vibration of the mines, temperature of mines, gas concentration, movements occurring in areas of mines slope and humidity. This sensing mechanism can be performed by the sensor nodes which is a part of the WSN [2]. The economic concerns and operational problems associated with unstable slopes state the urge of suitable slope monitoring and management measures. The existing Geo-technical sensors include tilt meters, borehole extensometers, wire line extensometers, vibrating wire piezometers, inclinometers; which are implemented to sense the fluctuations in slope conditions. Besides, these sensors are widely used for total station monitoring. The field technicians monitor these geotechnical instruments.

SLOPE MONITORING SYSTEMS-A REVIEW

Recently scientific studies on integration of TDR directly with Arduino boards and XBee modules for real-time transmission of slope monitoring data were conducted as a part of Ministry of Mines, Government of India (GOI) sponsored project highlighting the impetus on urgent need of innovative Wireless techniques for mines, and details presented by the author [22]. This chunk of the paper critically reviews the various related research works carried out in the field of early alert monitoring systems which gives the base of proposing a fresh conception of slope monitoring system for open-cast mines. The intentional objective of this survey is to understand and present the overview of the various existing approaches of monitoring slope stability in open-cast mines. Prior knowledge of the slope failure is crucial information in open-cast mines [3, 4]. Therefore, a stable slope monitoring system is implemented with WSN and ZigBee which has multiple connections and terminals. ZigBee collects data in sleep mode so that it consumes less power [5, 6]. Here a coordinator, a router and an end-device are combined. Data transmission to the host base station via internet is done through the master unit microcomputer which is the coordinator using routers which are basically repeaters. The end-devices bear the sensors where analogue or digital conversion takes place. This system senses all physical values such as acceleration, thermal moisture and pressure of the slope movement. A planar micro-strip antenna is used with crank slits for circular polarization for WSN instead of linear antenna due to the influence of wild animals, rainfall and wind [7]. As this setup is installed at a high position, it is enveloped by a lightening protection cage to protect it [8].

Usually the issue of slope failure in open-cast mines is caused due to unregulated and undisciplined treatment of illegally unpermitted mines and impacts of weather conditions in those areas like rainfall intensity, soil parameters etc. Slope monitoring requires the knowledge of geomorphologic and geological factors such as strength, structure and type of material, geometry of slope etc [9]. This technique also focuses on WSN that is energy efficient [10]. An algorithm is formulated which predicts Landslide or slope failure from the sensed data of areas where slope failure occurs. This is implemented in LabVIEW. This system comprises of 4 operational units such as measurement nodes, relay nodes or Cluster heads, Gateway node and database equipment to store data. All the nodes work in a mesh topology. LabVIEW presents, and analyses real-time data collected from database [11, 12, 13].These factors have a decisive impact in regulating the failure types which can occur and have an impact on stability threshold upon which the stability factors also operate. WSN effectively helps in monitoring slope failure in real-time which is desirable [14, 15]. WSN is preferred for it helps in sensing data from wider areas which are prone to slope failures. WSN is capable of streaming useful live data onto the web or IoT. WSN includes the design and implementation of the network services, the sub-networks involved within and their inter-communication, data management facilities, power management, retasking and node management [16, 17].

Sensor nodes can be incorporated with WSN which helps in performing networking and general-purpose computations. These sensor nodes perform sensing in a timely manner and report data as per the requirement of the system or application. These features come encapsulated with SMARTCONE system [18] which monitors slope movements with minimum standby power consumption still actively detecting events. It is comprised of a sensor which continuously senses the movements in different operating modes and a server which analyses data obtained from the SMARTCONE placed on the slope.   Remote sensing-based approach to assess slope is another technique applied in Jazan province in the Red Sea hills of Saudi Arabia. [19]. This technique consisted of 5 steps firstly, the Geographical Information System (GIS) with web interface is developed to analyse sensed data; secondly the satellite datasets identified inventory of movements and a subset of it was also field verified then spatial analysis were done in a GIS surrounding; fourthly there was construction, optimization and validation of an Artificial Neural Network (ANN) and Logistic Regression (LR) Model and lastly these models produced movement susceptibility maps. These models produced mostly accurate prediction results. Here a statistical model is adopted monitor the slope movement because it is well suited for regional-scale applications, it is built on actual cases rather than expert knowledge and these models promptly allow cross validation and evaluation independently [22].

Engineered slopes also need to be monitored because they are also prone to failure and instability because of the faulty materials used while constructing these structures. To assess these structures, a strategy combining remote sensing and numerical modelling is used which are automated. Most of the approaches of monitoring slope movements or landslides fall into one of the three categories such as statistical, deterministic or heuristic [19-21]. The approach of monitoring engineering slopes falls in to the deterministic category and it uses Air-borne Laser Scanning (ALS) data and multi-spectral aerial imagery to extract the influences on slope stability. This can also be extended to monitor slopes of open-cast mines. But this is an expensive method. Ground based synthetic aperture radar interferometry (GB-InSAR) is another monitoring technique developed in order to understand the dynamics of landslides and its response to the external stimulating factors such as rainfall and get an early alert. Bradar in Brazil newly developed this system which consists of a closely packed irregular X-band GB-InSAR. The ground-based radars are flexible to operate in all weather conditions for monitoring. It is able to remit continuously a thick network of quantification with respect to space and time. It has its own set of advantages like robustness, transportable, simple and self-sufficient operation, having a Graphical User Interface (GUI) for envisioning the 2D or 3D results, measurement of slope movement with accuracy of less than 1cm and having a coverage range of

1km. But when it comes to determine minimal information needed along with the radar data a cost-effective system is very difficult to build.

Modern open-pit slope management programs include Slope Stability Radar (SSR), ground level control point by use of geo-technical instruments, Global Positioning System (GPS) and observations resulting from these components. To minimize personal risk of mining staff resulting due to slope failure and maximize mines production is the conclusive aim of these programs thereby reducing the inactivity of mines. The SSR periodically monitors the slopes by using a scanning disc antenna which locates and measures the range and nature of the slope movements. Detecting landslide failure is the role of the geo-technical engineer through scanning of land surface . Preventive measures regarding slope failure can be followed by design of safe and efficient slope structures. This includes monitoring elements such as hydrological conditions, rock mass properties and geological structures in an effective manner. Sometimes even carefully designed slopes become prone to failure because of unexpected weather changes, earthly activities and change in geological structure of the surroundings . Signs of instability in slopes include visual information which can be cracks formed on the bench floor or on the wall surface of the mines. The usage of precision equipment gives a clear indication of a failure soon.

Risk models to assess movement of land contributing to landslide have been developed. Particularly it pays attention to the risk which people face due to this. Risk model which is based on both statistical and deterministic approach is considered to be more efficient because it takes both prior set of data to determine probability in case of statistical strategy as well as the measurement of physical factors obtained from the sensor network in case of deterministic strategy. Here the sensor network monitors the events which triggers landslide. The same approach can be applied to monitor mine slopes. Besides, here zone-wise monitoring can be performed with the help of clustering algorithm and the data for each zone is provided by its respective sensor monitor. Finally, a consolidated map can be represented by grouping data of all the zones.

This area of the paper reviews a wide range of methodologies used for monitoring open-cast mines. One can have a better understanding of how slopes are monitored after having the knowledge of several strategies of this implementation. To determine consequential results relevant to the prior action of strata, geotechnical instrumentations in analysis of slope play a vital role during mining activities and operations. Besides monitoring, these instruments are also helpful in surveillance, monitoring safety of a structure or construction activity, confirming whether designing inferences shall be feasible, observing on-site changes and determine initial conditions. The geotechnical instruments while measurements for strata behaviour is done, these measurements also involve a certain amount of inaccuracy and flaws. Inadequacy in instruments includes inherent erroneous designs, inferior quality of craftsmanship and raw materials to make it cost-effective and so on. Through experience and correct judgment these gaps of instrumentation and measurement should be filled which is important because it has impact on the performance of the project where it is implemented. These techniques can be advantageous and beneficial only when each phase of instrumentation planning and execution is considered precisely. Instrument organization blueprints are commonly adapted to deliver one or most of the following functions like (a) determininghow stable the mine structures are; (b) checking assumptions of present data and then creating the probable future data; (c) developing and evaluating new schemes, approaches and protocols; (d) settling lawful conflicts.

The number of instruments required, least count and their capacity are decided based on the quality and standard of the mines site. The behaviour of rock mass chooses the range of the instrument. A comparison of different low-cost open-cast mines slope monitoring system is shown in table 1. Some slope monitoring systems are expensive while some are cost effective. But keeping aside cost factor, all the monitoring techniques developed so far have their own set of pros and cons. Nevertheless, at times the methodologies which are expensive also prove to be efficient depending upon some of the circumstances in the mines site. This section reviews critically numerous slope monitoring techniques giving a brief idea about each.

Table 1. Comparison of Some Low-cost Open-cast Mines Slope Monitoring Systems

Technology	Slope Coverage	Update Rate	Range	Deployment	In all weather conditions
Automated Total Station Networks	Discrete Points	Twice/day	2 km	Difficult	No

LIDAR	Broad	~Seconds	900m	Easy	No
SSR	Broad	~Minutes	850m	Easy	Yes
GPS	Discrete Points	~Seconds	N.A.	Difficult	Yes
TDR	Discrete Points	~Seconds	N. A	Difficult	Yes
Photogrammetry	Broad	Hours	<150	Moderate	No
Micro Seismic	Broad	Continuous	300m	Easy	Yes
Inclinometer	Discrete Points	Daily	N. A	Difficult	Yes
Piezometers	Discrete Points	Daily	N. A	Difficult	Yes
Crack Meters	Discrete Points	Daily	N. A	Easy	Yes
OTDR	Discrete Points	~Seconds	N. A	Difficult	Yes
String Potentiometer	Discrete Points	~Seconds	N. A	Moderate	Yes
Shape Accel Array	Discrete Points	~Seconds	N. A	Difficult	Yes

WIRELESS SENSOR NETWORKS

This section illustrates the basic operation of WSN; the flexible architecture due to which it is the most preferred technology to build any system; the guidelines of designing an effective WSN and challenges encountered while designing it and lastly it explains the standards and applications of WSN. In past decade there has been emergence of many technologies. Particularly, the onset of low-power and low-cost transceivers combined with the growth of compressed and open standard stack has put WSN in tech-trends. Today, optimal consumption of power and resource is the focal point of any technology to improve productivity. Therefore, WSN has come to the spotlight in the field of research and is suitably an integral part of many environment monitoring and industrial based applications.

WSN is an assortment of base stations and smart sensor nodes which can perceive the tangible and intangible stuffs and pass that data through network. Originally the idea of "smart sensors" came from the defence and military applications to perform vigilance of battle arena. But now this has become the basis of data transmission in WSN (Fig. 1) in many application domains. The core part of WSN is the web of around 10 to 1000 disposable and low power tiny nodes called sensor nodes. These sensors wirelessly share or communicate information in the WSN. These smart sensors also bear some power to post-process the raw data aggregated to extricate helpful information.Furthermore, WSN eliminates cost of cabling and provides low cost wireless connectivity, less cost of installation.

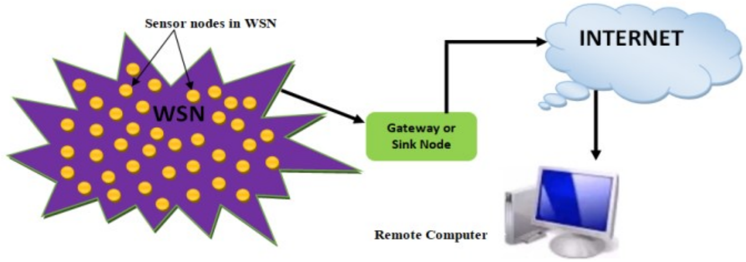

Fig. 1. An overall interpretation of WSN

Standards and Applications of WSN

Protocols based on IEEE standards address different applications depending on the adaptability of the WSN. The following are the different protocol standards which operate in the physical layer and Media Access Control (MAC) layer. These protocols either belong to IEEE 802.15.4 or IEEE 802.15.4e as illustrated in table Mainly the WSN applications commonly use Zigbee and 6LoWPAN as their standard. Both are based on IEEE 802.15.5 standard which specifies the physical layer and MAC layer features for WPAN with low data rates. Table 3 shows various protocols and WSN standards.

Table 3. Various protocols and WSN standards

WSN Standard and Protocol	Institute/ Research body/ Work group	Support for multiple topologies	Access scheme	Channel access	Size of network	Base standard	Operation between IP and Internet	Green Motes support	Data rate (in kbps)
WirelessHART	HART Communication Foundation	Available	Direct sequence spread spectrum (DSSS)	TDMA	2^{16}	IEEE 802.15.4	No	No	250
Zigbee	Zigbee alliance	Available	DSSS	CSMA/ CA	2^{16}	IEEE 802.15.4	Yes (Zigbee IP)	Yes (Zigbee Pro)	250
ISA100.11a	ISA100 Wireless Compliance Alliance	Mesh routing	DSSS channel hopping	Transport layer – TDMA, MAC layer – CSMA	IPv6 address-ing	IEEE 802.15.4	Yes (IPv6)	No	250
6LoWPAN	Internet Engineering Task Force (IETF)	Available	N/A	CSMA/ CA	IPv6 address-ing	IEEE 802.15.4	Yes (IPv6), 802.15.4 compliance	No	20-250

Merger of WSN and IoT for Slope Monitoring of Open-cast Mines

In the first phase, the sensing devices are evenly distributed along the mines slope area to be observed thereby forming multiple wireless links which are ubiquitous in nature. In such craggy and rugged areas wired communication is unsuitable. This forms a sensor network which provides data assets in the form of analog data. These data assets are the measure of various factors contributing to slope movement. These measured data is sent to the central processing unit or the microcontroller through a sensor communication signal (Fig 2). The second phase or the communication phase the sensed analog data is sent to the CPU for processing and converting the analog data into digital data. Here a local database is also involved which stores the intermediate processed data. At this phase a GUI could also be linked to the CPU for analysing the signals and data. Depending upon the threshold values the alarm signal is generated. Then through the wireless transmission module, the sensed data is communicated to the wireless receiver module of the receiving unit through a single or multiple gateways. ZigBee, Long Range (LoRa) are some of the efficient communication standards which performs this communication wirelessly in the transmission and receiver modules. At this stage the data is converted to useful information to be sent to the Base station. The analytical and statistical computations are performed in the base station and the results are stored in the server where IoT comes into picture.

RANGE TEST OF LORA

range test was conducted at NIT-Rourkela on application of LoRa module during November 2018 for understanding the strength of signal for communication of data in open space. Test was conducted with the transmitter at a distance of 1 m to 2.0 km range from the receiver. Received Signal strength Indicator (RSSI) observed was in the range of of -82 to -127 dBm for the corresponding distance between the transmitter and receiver (Table 4). Fariis open space propagation model was applied for prediction of the RSSI. Theoretical RSSI values obtained by the model are found to be having wide variation with the measured RSSI values. Therefore, it is also proposed to test with other models such as Hata model.

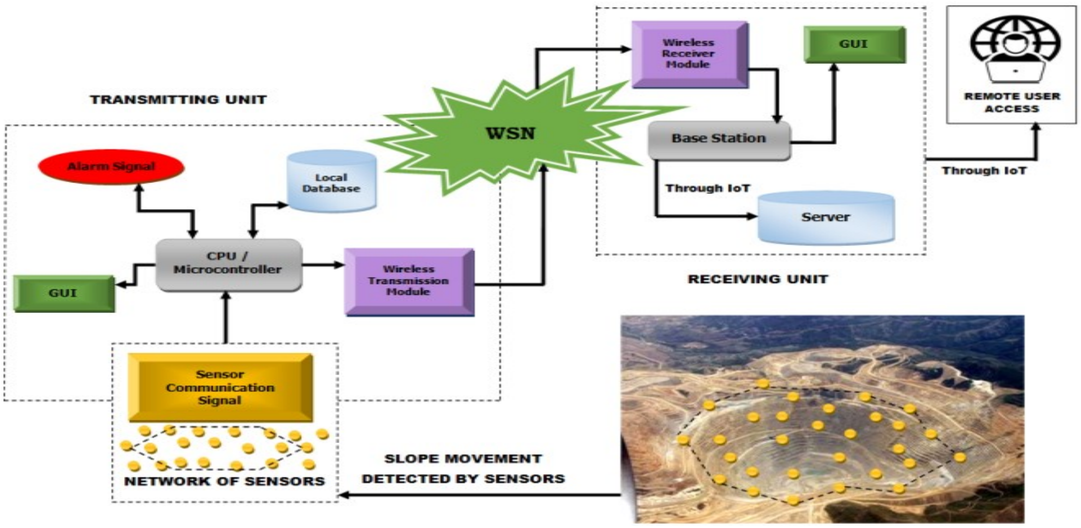

Fig. 2: Mechanism of Slope Monitoring with the union of WSN and IoT

Table 4: result of range test on Lora module for mine communication

Position	Log d	Mean RSSI	Theoretical RSSI
1	0	-82	-18.61476819
100	2	-82	-58.61476819
200	2.30103	-99	-64.63536811
300	2.477121	-120	-68.15719329
400	2.60206	-105	-70.65596802
500	2.69897	-89	-72.59416828
600	2.778151	-116	-74.1777932
700	2.845098	-102	-75.51672899
800	2.90309	-128	-76.67656793
900	2.954243	-90	-77.69961838
1000	3	-86	-78.61476819
1100	3.041393	-127	-79.4426219
1200	3.079181	-89	-80.19839312
1300	3.113943	-127	-80.89363524
1400	3.146128	-126	-81.53732891
1500	3.176091	-100	-82.13659338
1600	3.20412	-127	-82.69716785
1700	3.230449	-127	-83.22374662
1800	3.255273	-124	-83.7202183
1900	3.278754	-88	-84.18984021
2000	3.30103	-93	-84.63536811

CONCLUSION

A comparative study and review has been performed regarding the techniques implemented for slope monitoring in open-cast mines site. Many approaches have already been applied for monitoring the slopes and each approach has its own pros and cons. WSN forms a basic solution to measure the activities or parameters which control the slope stability. On the other hand, IoT also acts as a key factor for making required data available anytime and anywhere. Therefore, a composite solution is proposed mixing both WSN and IoT so that open-cast slope failures in mines can be avoided. Test conducted from 100 m to 2.0 km range showed RSSI of -82 to -127 dBm.

This mechanism shall monitor the slopes and movements occurring in it. WSN is energy efficient and cost effective and easy to set up in irregular zones without any physical links. It also has low maintenance cast as compared to other monitoring techniques. Sensing of the slope motion could be sent to the base station and then the processed data is stored in the server through IoT. Here IoT plays an important as every sensor node associated with the network of WSN and IoT will provide accurate data of the zone in which it is placed. Such accuracy is possible because everything (here the sensor nodes) in the WSN will have its own IP address which will be accessed by the IoT architecture. This will minimize the time of computation and taking the average results. Appropriate computational algorithms could be applied to extract predictions and use this to generate early alarms. Even if the WSN monitoring systems are left unattended for a month's time still it continues to operate in real-time continuously. Hence it is more stable. This will help IoT to have a stable communication in the network layer and have automatic feeding of data to the base station through the gateway. Thus, an effective monitoring and early warning system could be developed.

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