Development of blast-induced ground vibration wireless monitoring system

Ragam Prashanth & Nimaje D.S.
National Institute of Technology, Rourkela, India

ABSTRACT: In recent decades, the ground vibration induced by blasting is an inevitable outcome and severely damages surrounding structures. Hence, it is essential to monitor the ground vibration to evaluate and control the adverse consequences of blasting. Several conventional instruments were widely adopted to measure vibration in terms of Peak Particle Velocity (PPV). The major limitation of the conventional system is wire-based, expensive, and cannot transfer real-time seamless information. To mitigate, proposed a novel real-time, low-cost wireless vibration system. In this context, design and implement an economical wireless system to monitor PPV effectively. Further, discuss the overall architecture, integrating of hardware, and implementation of software protocols in the process of making the wireless system. Developed prototype having an accelerometer, Radio Frequency (RF) module, and microcontroller unit. The system was installed at different locations in Mine-A, India and obtained results ensure that PPV values are varied from 0.191 to 8.60 mm/sec

1 INTRODUCTION

Drilling and Blasting (DAB) are the most pervasive excavation operations for rock fragmentations in the mining industry. Explosives are a valuable source of energy used to breakage, excavation, and displacement of the rock mass. During the time of explosive detonates, a large quantity of energy was realized. Only 20% of energy can be utilized for fragmenting the rock and remain wasted away in the form of ground vibration, air blast, fly rock, and back breaks (Ragam 2018a). The adverse effects of blast-induced ground vibration are the collapse of nearby trees and live hood, get cracks in mine office buildings, and chances to failure overburden dumps. Recently, the complaints are rapidly increased given by mine resident people owing to the effects of ground vibrations due to blasting. Thus, it is necessary to monitor and control ground vibration. Usually, ground vibration can be expressed in terms of peak particle velocity (PPV) and the units are an mm/s. Limit values for Blast-Induced Ground Vibration (BIGV) are recommended in the standard by Directorate General of Mines Safety (DGMS) circular No.7 of 1997 in India. The permissible PPV of ground vibration at a sensitive structure should be below 5 mm/s (Ragam 2018b). Researchers, academicians, and scientists are widely used conventional type seismographs to measure the PPV in various mine case studies. The conventional systems such as Instantel Blast mate-III, Minimate Plus, Minimate Pro, UVS1500, MR 202-CE etc. are installed to evaluate ground vibration levels (Nimaje 2019) in open cast mines (Fig. 1). The presently used conventional instruments have one to three geophone sensors to measure PPV (mm/sec) and one microphone sensor for air blast measurement (dB). The prices of the available systems are starting from US $4500- 7000 dollars.

1.1 *Limitations of existing systems*

The conventional devices like Instantel Blast mate-III, Minimate Plus, Minimate Pro, UVS1500, MR 202-CE used for measuring the PPV are cable-based communication system type and have limitations such as (Ragam 2018c):

- Susceptible to failure due to breakage in the wire;
- Wire impedance owing to the length of wire not possible to extend;
- Cannot transfer the measured data in real-time;
- Expensive systems;
- Limited storage memory;
- Need an expert to operate;
- Tedious and time-consuming process.

Figure 1. Various types of seismographs installed in mines

To mitigate the aforementioned limitations, proposed and developed an economical and reliable wireless sensor network (WSN)-based system. In recent years, Information and Communication Technologies (ICT) has been used extensively and inexpensive Micro-Electro-Mechanical-System (MEMS) technology has enabled in the applications of environmental and industrial monitoring. In addition, these sensors are embedding within the WSN. As a result, the embedded of both MEMS sensors and RF modules were enhanced transmission abilities for the application of BIGV monitoring with novel methods such as the utilization of WSNs for the realization of low-cost monitoring systems. The main objective of integrating various MEMS sensors within the WSN has initiated by researchers in the new millennium. Moreover, the price of a MEMS accelerometer sensor may be just 10% or less over the commercially available conventional accelerometer along with the signal condition unit. MEMS accelerometer has become a ubiquitous part of everyday life owing to their small dimension (currently even less than 2mm), easy to integrate with any electronic devices, high shock-resistance, high reliability, high accuracy, low power consumption, and low cost (Luczak 2017).

Few researchers (Kim 2013) already remarked the advantages of WSN technology over conventional monitoring systems. It covers a wide range of objects from various embedded operating systems and micro-controller units to wireless protocols. The intelligent internet-based network connects ubiquitous devices to the internet to exchange seamless data and communicating via sensing devices according to agreed protocols. It accomplishes the aim of intelligent identifying, locating, tracking, monitoring, and managing things. It is used to establish communication from person to person as well as things and things. In this WSN paradigm, various things surrounding us should be attached to networks in one form or another. WSN has three main characteristics and as follows (Chen 2014):

A. Comprehensive perception

Sensor devices, radio frequency identification (RFID) tags, and barcode are providing the information of objects at any time and anywhere which will be a great opportunity. By using it, sensing information and communication system can be invisibly embedded in the environment. Wireless sensor network enables us to interact with real-world remotely. Objects and locations are identified using identification technologies. Identification and recognition of the physical world is the basic foundation of developing overall perception.

B. Reliable Transmission

Sensing object information can be available at any time through multiple radio networks, telecommunication, and the internet. Communication technology includes wire, wireless transmission, switching, and gateway technologies. Further, WSN provides an interactive platform among the real physical world, the digital world, and the machine to machine (M2M). The important technology of networks of things is established and communicated between M2M as well as machine to human.

C. Intelligent Processing

After receiving the information, it stores in the database including computing technology like cloud computing. The available network service providers process the billions of messages immediately using cloud computing technology. Thus, this technology is the main promoter of WSN applications.

In this context, the main aim of this study is to help mine administrations, blast experts, and nearby residing community to obtain real-time information such as BIGV data from an end user (sink node) through wireless sensor nodes. A Global System for Mobile (GSM) RF module has been placed in the sensor node as an RF protocol conversion in between blasting point to end users such as mine managers, experts of blasting as well as rural peoples who live in and around the mine area. The designed wireless system was installed successfully at different locations in Mine-A, India and monitored the vibration levels (in terms of PPV) over a period of eleven days.

2 SYSTEM ARCHITECTURE

Usually, ground vibration due to blasting is a low frequency and low amplitude waves. Thus, it is very difficult to capture. An accelerometer sensor is used as a sensing device which captures the vibration as well as earthquake waves. It is essential to measure low frequency and low amplitude signals, choose high sensitivity and low noise density MEMS-based accelerometer sensor. The proposed system consists of three layers and depicted in Figure 2. The layers are (Akyildiz 2002):

1. Sensing Layer
2. Network layer
3. Application layer

The first layer of the proposed system is the sensing layer and the main role of it is to collect the physical characteristics data. Sensor nodes are deployed in the unmanned dynamic environment in and around the blasting site at different vulnerable distances. Sensor nodes are configured by a star/mesh topology network to exchange information in a network layer section.

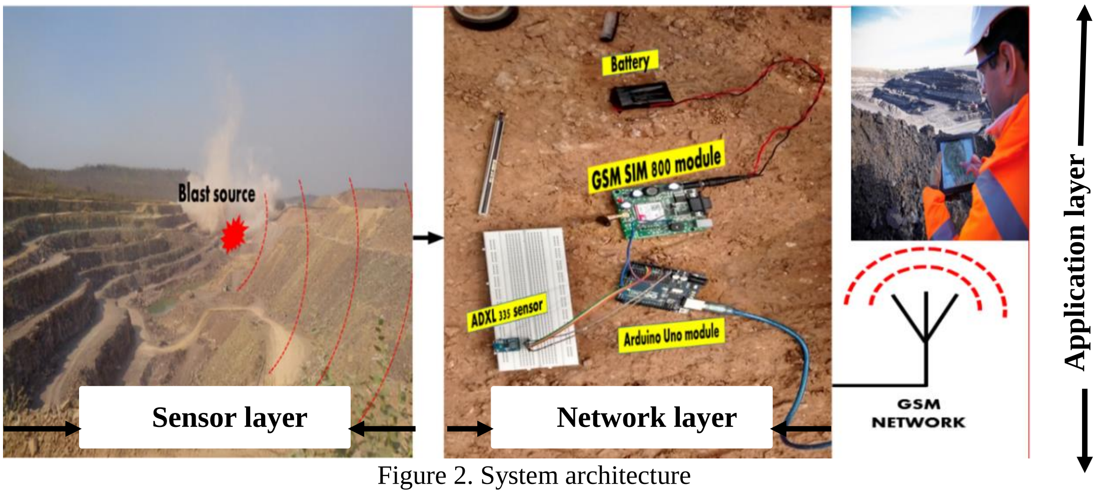

Figure 2. System architecture

2.1 *Sensor node*

Sensor node consists of a microcontroller unit (MCU), an analog-to-digital converter (ADC), RF module along with an accelerometer sensor shown in Figure 3. Each sensor node has to be placed at various distances from the blasting point. For instance, sensor node 1 is deployed at a 100m distance from the blast source. Similarly, Sensor node 2 and node 3 might be placed at other distances (200m, 250m, and 300m. etc.). After blasting, the generated waves are captured by each accelerometer sensor of respective sensor nodes and converts into appropriate electrical (voltage) signals. Every sensor node is to collect and send the sensed data to the Global System for Mobile communication (GSM network layer) RF module.

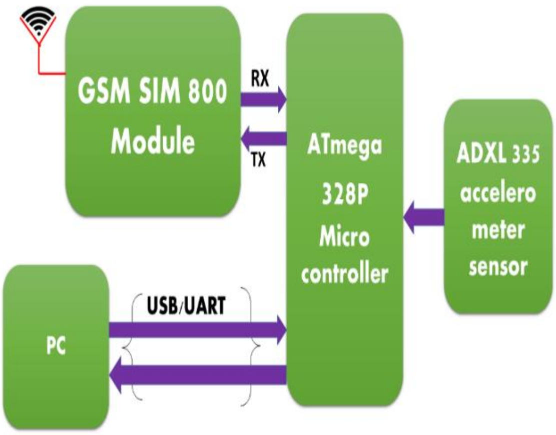

Figure 3. Architecture of the sensor node(mote)

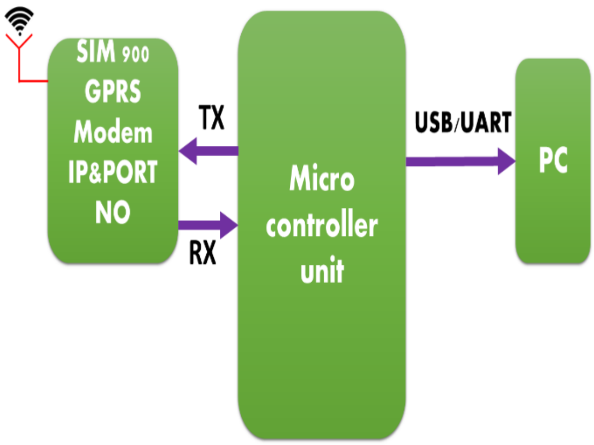

Figure 4. Architecture of receiver node

Similarly, the main function of the network layer is to transmit the information from the sensor layer to application layer using GSM module receives the sensor nodes 1, 2 and 3 data sequentially and convey to end user using AT commands (Fig. 2). In the end, the end user can retrieve the information to analyze in the application layer. Finally, the sensed data from sensor node 1,2 and node 3 must be displayed in the system (PC) as well as tablet/phone (if required) using SMS (Fig. 4).

3 DEVELOPMENT OF WIRELESS SENSOR SYSTEM

The system consists of MEMS accelerometer (ADXL 335), RF module (GSM), and Arduino Uno microcontroller board as shown in Figure 5. ADXL 335 is inexpensive 3-axis accelerometer having moderate sensitivity range lies between 270-330 mV/g and low noise density varies from 150-300 µg/√Hz rms. It was used to measure tilt, acceleration, rotation, and vibration with a range of ±3 g. These MEMS-based accelerometers have an advantage over the conventional accelerometers that they are capable of measuring the acceleration due to gravity (Manjiyani 2014). Arduino Uno is an open-source single-board using ATmega328P microcontroller considered as a processing unit**.** It provides sets of digital and analog I/O pins that can be interfaced to various expansion boards and other circuits. The boards feature serial communications interfaces, including USB on some models, for loading programs from personal computers. For programming, the microcontrollers, the Arduino platform provides an integrated (IDE) based on the processing project, which includes support for C, C++ and Java programming languages.

GSM 800 device is used as an RF module to establish wireless communication. Three outputs of the accelerometer sensor are plugged into the standard expansion headers on the Arduino Uno development board represented in Figure 5. The software program was implemented in the Arduino Integrated Development Environment or Arduino Software (IDE) which contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus. The testbed has been designed and developed by interfacing Arduino Uno with triaxial accelerometer ADXL 335 and GSM module SIM 800. The accelerometer needs a power source of 5 V and Grounding. GSM SIM 800 RF module requires a power supply of 9-12 volts along with proper grounding. The transmitter (Tx) section of Arduino Uno board is connected to the receiver of GSM module so that Arduino can send the accelerometer readings to GSM module and therefore the GSM 800 shall send the data obtained from Arduino to any displaying device i.e, mobile phone or personal computer (PC).

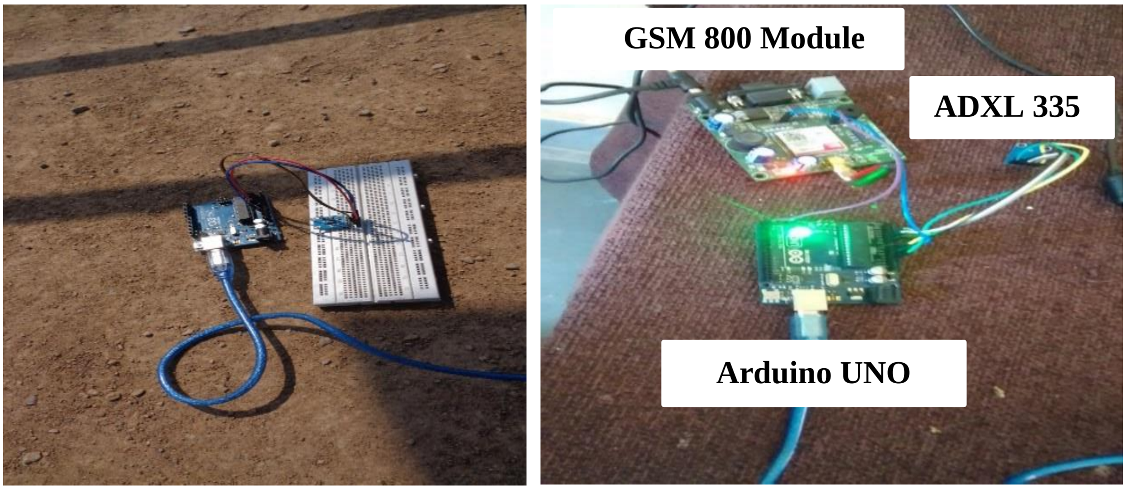

Figure 5. Integration of ADXL 335 accelerometer with Arduino microcontroller board and GSM

4 FIELD EXPERIMENT

The designed system has been installed at different vulnerable and strategic locations from the blast site as depicted in Figure 6. The investigation has been carried out in Mine-A with a longitude of 83°32’57.4” and latitude of 21°41’24” located in India. It is fully mechanized limestone mine operated by DAB to primary breakage and rock fragmentation. Atlas Copco makes D50 and Sandvik make TITON 500 drill machines are widely used for DAB operations with around 9 to 10 m bench height. Burden varies from 3-3.5m, the spacing between 4-5m, and quantity of charge per hole between 40-60 kg for 115 mm hole diameter. Accordingly, the stemming column in the blast holes also varies between 2.5-3m. Staggered pattern and the square grid pattern of holes are drilled. The blast hole depth is 10 meter including 10% subgrade drilling.

The non-electric (NONEL) system of initiation (TLDs 17/250ms and 25/250ms) is being used for blasting work in combination with ANFO and cast booster weighing 150 gm. In case of watery hole during the rainy season and in the lower bench, large diameter slurry explosive cartridges (Aquadyne and super gel) were used for blasting. Each blast is monitored for ground vibration and fragmentation and necessary care has been taken based on the report obtained. Minimate plus device is used for measurement of ground vibration in the field survey. In blasting, two to three rows of holes are blasted at a time and maximum of 60 holes are blasted at a time with proper initiation, charging pattern and charge per delay. Delay is set in such a way that each hole gets the adequate free face and blasted at a time. Hence optimum fragmentation with reduced ground vibration is achieved. So practically the charge per delay is only the amount of explosive placed in a single hole, i.e. 40-60kg.

Figure 6. Installation of test bed in Mine-A

The developed system was installed in Mine-A. Eleven PPV values were captured at each measured point using a test bed along with Minimate Plus seismograph. The obtained PPV values are varied owing to the distance between the blast point and the monitored location and other parameters such as a charge per hole, number of holes, spacing, burden, and hole depth. The test setup was placed at different monitoring locations (distances) every day to detect blast event PPV while blasting operation. On the first day, the testbed was installed at a 125m distance from blast face and the observed PPV as 6.02 mm/s. Similarly, the next day the PPV was observed 8.25mm/s at 150 mm distance. Each of the recorded PPV value is plotted in MATLAB 12(b) software as shown in Figures 7-8. The same process had been carried out for remaining days (total of eleven recorded values) and depicted in Figure 9. The obtained results are plotted in MATLAB software to easily analyze and observation of PPV ranges.

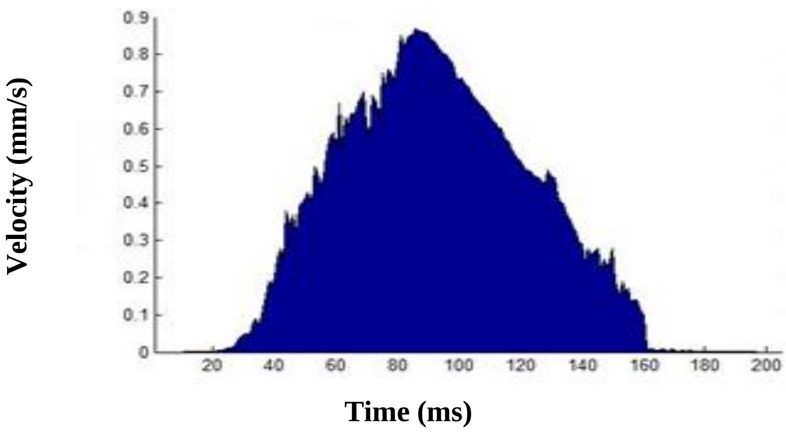

Figure 7. Recorded PPV using accelerometer based test bed at 600 distance

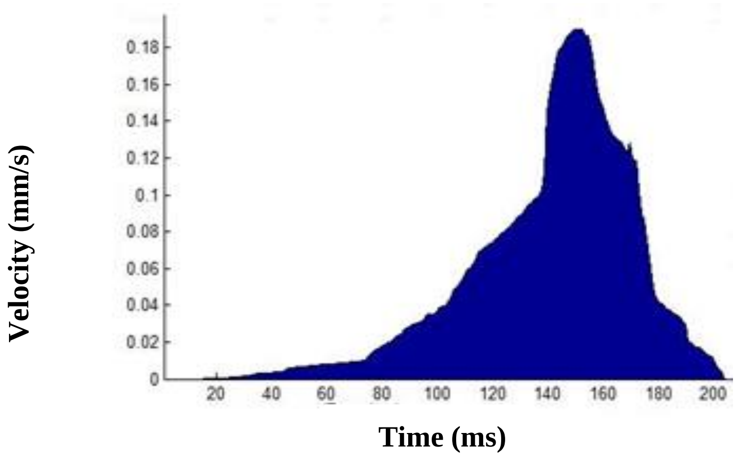

Figure 8. Recorded PPV using accelerometer based test bed at 750 distance

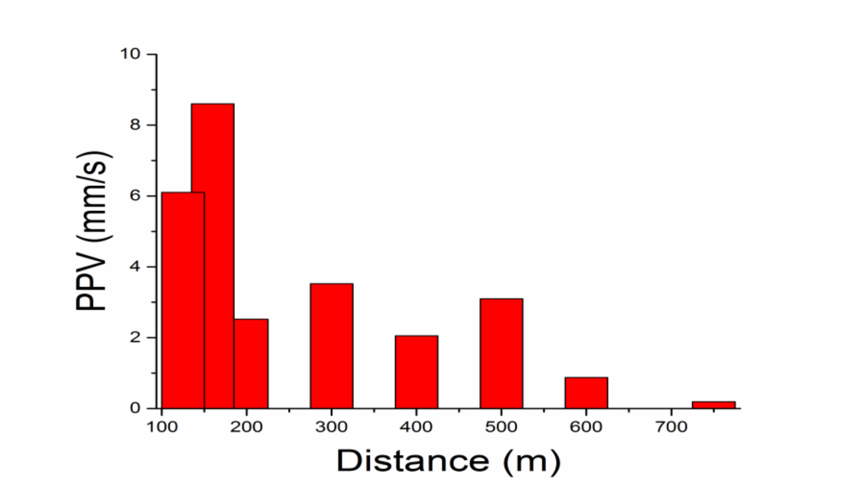

Figure 9. Measured PPVs with respect distances

5 CONCLUSIONS

In this investigation, a system was developed for monitoring the peak particle velocity induced by blasting. Three-axis ADXL 335 accelerometer sensor was employed as a sensing device and GSM 800 RF module for establishing communication between test setup source to the authorized mobile user. The following conclusions were drawn from the field investigation:

1. Developed an inexpensive system by integrating an accelerometer sensor, GSM RF module to Arduino UNO microcontroller board. Software programming has been implemented in Arduino IDE open source software and installed in Mine-A, India.
2. The investigation has been conducted a period of eleven days and recorded eleven PPV values at different locations (distances) from the blast point.
3. The obtained results were revealed that minimum PPV observed as 0.191 mm/sec at a distance of 750m from blast source to the monitoring point. On the contrary, maximum PPV value (8.6 mm/sec) detected at a 150m distance.
4. The rigorous investigation should be required to monitor the BIGV at various locations from the blast source to monitor PPVs with the developed system

6 FUTURE SCOPE

A number of PPVs values obtained by installing more accelerometer sensors (sensor nodes) which monitor a larger area within a low budget. The GSM RF module has an added feature i.e., it can be used as a warning system by giving the alarm. Thus, it was utilized for alerting through the audio signal to the persons working in the mines. LoRa is an RF module which has a coverage range around 2-15km. However, integration of IoT with LoRa RF can be implemented for accessing monitoring data from anywhere in the world which is an emerging area.

REFERENCES

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. 2002. Wireless sensor networks: a survey. Computer Networks, 38(4):393-422.

Chen, S., Xu, H., Liu, D., Hu, B., & Wang, H. 2014. A vision of IoT: Applications, challenges, and opportunities with china perspective. IEEE Internet of Things journal, 1(4):349-359.

Kim, J., Kwon, S., Park, S., & Kim, Y. 2013. A MEMS-based commutation module with vibration sensor for wireless sensor network-based tunnel-blasting monitoring. KSCE Journal of Civil Engineering, 17(7):1644-1653.

Łuczak, S., Grepl, R., & Bodnicki, M. 2017. Selection of mems accelerometers for tilt measurements. Journal of Sensors, 2017:1-13, Doi:10.1155/2017/9796146.

Manjiyani, Z. A. A., Jacob, R. T., Keerthan Kumar, R., & Varghese, B. 2014. Development of MEMS based 3-axis accelerometer for hand movement monitoring. International Journal of Scientific and Research Publications, 4(2):1-4.

Nimaje, D.S., & Prashanth, R. 2019. Application of MEMS-Based Accelerometer Wireless Sensor Systems for Monitoring of Blast-Induced Ground Vibration and Structural Health: A Review. IET Wireless Sensor Systems, DOI: 10.1049/iet-wss.2018.5099.

Ragam, P., & Nimaje, D. S. 2018a. Evaluation and prediction of blast-induced peak particle velocity using artificial neural network: A case study. Noise & Vibration Worldwide, 49(3):111-119.

Ragam, P., & Nimaje, D. S. 2018b. Monitoring of blast-induced ground vibration using WSN and prediction with an ANN approach of ACC dungri limestone mine, India. Journal of Vibroengineering, 20(2):1051-1062.

Ragam, P., & Nimaje, D. S. 2018c. Selection and Evolution of MEMS Accelerometer Sensor for Measurement of Blast-Induced Peak Particle Velocity. IEEE Sensors Letters, 2(4):1-4.