Wireless Sensor Networks and Real-Time Slope Monitoring: A Brief Review

Sathish Kumar Mittapally and Raj Kumar Marichamy(✉)

Department of Mining Engineering, University College of Engineering, Osmania University, Hyderabad, India
rajkumarmarichamy99@gmail.com

Abstract. Slope monitoring is an essential component of Opencast mining operations for workmen's safety and uninterrupted production. Slope failure incidents in the recent past remind the crucial significance of implementing effective slope monitoring protocols. Continuous increase in demand for mineral production impels the mining industry to deploy steeper and deeper opencast mines that ultimately result in making working conditions unsafe, on the other hand mitigating the associated risks entails increased production costs. Popular slope monitoring techniques such as Slope Stability Radar (SSR), Light Detection and Ranging (LiDAR) and Global positioning system (GPS) are quite expensive while Wireless sensor networks (WSN) equipped with Micro Electro Mechanical System (MEMS) sensors accomplish better results by enabling real-time slope data analysis at low cost. Cloud computing platforms, such as ThingSpeak, provide real-time data analysis, an email alert system compatible with early warning alerts and a user-friendly interface with convenient customization free of cost. This paper reviews the sensors, micro-computers, data communication systems and data analysis methods employed in real-time slope monitoring across multiple research studies.

Keywords: Arduino · LoRa · Opencast mines · Slope Monitoring · WSN · Zigbee

1 Introduction

Slope instability turned failure is the most occurring accident in opencast mines. The mining industry places a strong emphasis on safety and risk assessment due to the critical nature of geotechnical risks, which are often unpredictable [3]. To anticipate slope failures, it's crucial to monitor surface movements and study the underlying factors that trigger such movements, using measurements as the primary source of data [12]. Effective slope monitoring is essential for managing instability, predicting failures, and issuing timely warnings in the event of uncontrollable slope movements. Although various techniques such as LiDAR [23], SSR [7, 25], and GPS [4] are utilized to monitor slopes and landslides in civil and mining industries, they often encounter limitations such as imprecise data collection, vulnerability to data loss, suboptimal transmission

B. Raj et al. (Eds.): ICETE 2023, AER 223, pp. 1307–1317, 2023.
https://doi.org/10.2991/978-94-6463-252-1_131

efficiency, and delayed information dissemination [22]. WSN provides offers a solution to these limitations by enabling low-cost MEMS (Micro Electro Mechanical System) sensors to collect data at multiple locations within a short range, resulting in cost-effective and increased frequency of data collection in the monitoring areas. Utilizing sensors to measure slope parameters that affect slope stability and connecting them to a wireless network has been demonstrated to be a cost-effective method with significant advantages [13]. Parameters that are classified as an external source of disturbance, such as load on the slope, blast vibration, rainfall and others, collectively contribute slope failure. Expensive conventional slope monitoring techniques may not be able to detect all of these factors at once, while WSN and integration of various MEMS sensors that detect different parameters increase the efficiency of monitoring systems both technically and economically. WSN also promotes real-time and automated slope monitoring, which are essential for early warning functions, research efforts are focused on improving real-time monitoring technology and reducing system cost [26].

Shaikh and Shitole [17] explain that MEMS is a widely adopted miniaturization technology used by various industries, including the IC sector, to reduce the size of various systems such as electrical, mechanical, optical, fluidic, and magnetic systems, which can enable the creation of a proactive computing world, automatic connectivity of computing nodes, and the acquisition and utilization of real-time data from physical environments. A few MEMS low-cost sensors that are commonly utilized and researched in slope monitoring studies are shown in Fig. 1. Dorthi and Karra [27] incorporated LVDT and Strain gauge into their Zigbee-based wireless data acquisition slope monitoring system, while Jawalker et al. [9] developed a low-cost and robust landslide detection and monitoring system that incorporates gyro and soil moisture sensor. Susanto et al. [20] evaluated the effectiveness of landslide monitoring system that consists Humidity, vibration and slope sensors. Mittapally and Karra [13] proposed and assessed the performance of an advanced slope monitoring system that utilizes soil moisture and vibration sensors.

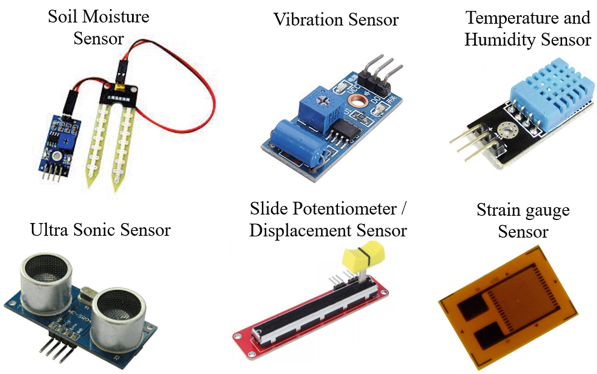


Fig. 1. MEMS Sensors employed in Slope monitoring

2 Microcomputers

The MEMS sensors are operated by a microcontroller/computer, such as an Arduino which converts the sensor's analog and digital signals to data form. Arduino UNO, Arduino Nano, and Arduino Mega have been widely used in both small and large-scale IoT projects. However, NodeMCU and Raspberry Pi are controllers enhanced and equipped with inbuilt Wi-Fi and Bluetooth capabilities. The picture in Fig. 2 displays the Arduino UNO and NodeMCU microcomputers, along with their pinouts. Arduino UNO micro-computer's non-complex functions made it a popular choice among researchers and developers in slope monitoring, as evidenced by the works of Karthik et al. [11], Susanto et al. [20], Yadav et al. [24], Taqwa et al. [21], Azharudin and Daud [2], Sudarmanto et al. [19], and numerous others who have utilized it in their research and development. Arduino UNO has its own microcontroller as the brain of the board, typically using Atmega328. It contains multiple components, including a Power USB to feed codes and to power the board, a barrel Jack for alternative power, a voltage regulator for voltage control and stability, a crystal oscillator for timekeeping with the time issue, and a reset button to run the program from the beginning. In addition to that it has 6 Analog and 14 Digital input/output pins through which it receives sensor signal and passes instructions and TX-RX pins through which wireless data communication is possible. A LED indicator that indicates power source connection. Arduino UNO operates in the 3.3 to 5-V and most of the components used with Arduino board work fine in this range. Arduino IDE is used to feed program codes on Arduino boards. Arduino IDE is renowned for its built-in libraries and examples that serve as useful guides for users in writing and uploading code to Arduino boards, making it one of the popular software options available for this purpose.

Due to its ability to support Wi-Fi, the NodeMCU has gained fame as a type of micro-computer in IoT projects. In particular, researchers working on landslide and slope failure detection have used the NodeMCU in their work, including Jawalkar et al. [9], Shetty et al. [18], Idris et al. [8], and others. The NodeMCU consists of components that are similar to those found in the Arduino UNO, albeit with some minor differences in Analog and Digital pins and the inclusion of a Wi-Fi chip and a 2.4GHz Antenna. It

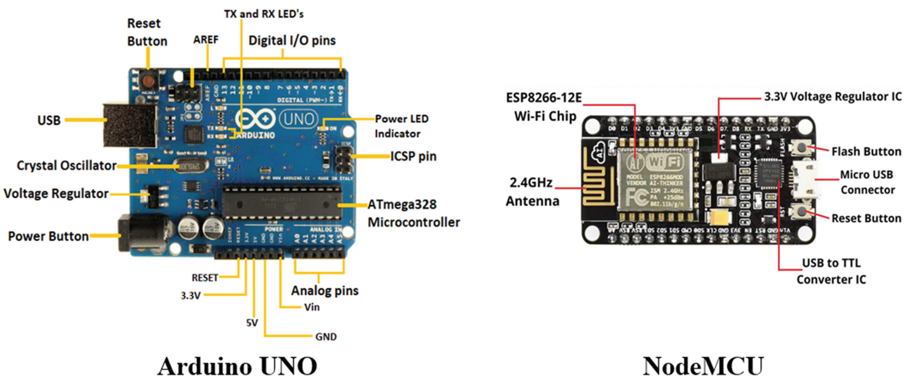


Fig. 2. Arduino UNO and NodeMCU microcontroller with pinouts

can transmit sensor data directly to the user through the internet provided that there is an active Wi-Fi connection in the area. In mining areas where connectivity is limited, the use of Wi-Fi chip in NodeMCU may not be feasible without a communication medium. Therefore, radio frequency modules such as Zigbee and LoRa devices are often employed as alternative communication solutions. Program code is written and uploaded using Arduino IDE just by changing the board settings to NodeMCU in the software.

3 Integrated Development Environment and Code Editors

The Arduino and NodeMCU boards come with 33KB and 4MB of built-in memory, respectively, where the program is stored. To write and upload program codes onto micro-computers, the commonly used software is the Arduino IDE (Integrated Development Environment). The window of the Arduino IDE display is shown in Fig. 3. It employs a variant of C++ programming language with an addition of special functions and methods to code. Program code is written on the text editor, which comprises two segments. The "void setup" segment contains code that runs once and will not execute again until the reset button is pressed. The "void loop" segment contains code that runs repeatedly. The software contains numerous example programs for various sensors and projects, and additional examples can be found in open-source online GitHub repositories. The software provides a serial monitor where sensor readings can be printed, or transmit them through communication channels such as ZigBee or LoRa RF. The readings can also be uploaded to a cloud analytics platform, local websites, or mobile apps like the Blynk app or others by writing program code accordingly.

The Arduino IDE is suitable for beginner-level coding, which involves writing a few lines of code without much complexity. However, for more complex coding tasks such as updating the sensor readings in a user-friendly Graphical User Interface (GUI) website or

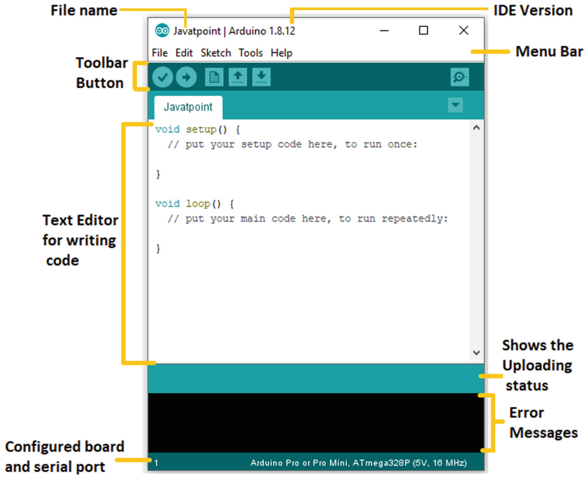


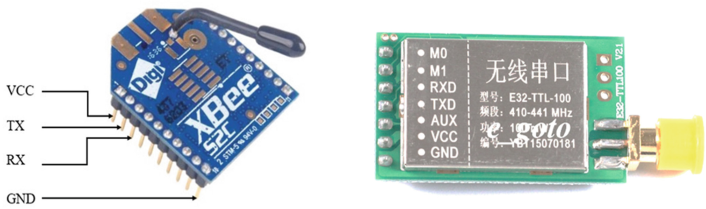
Fig. 3. Arduino IDE software

integrating the sensor readings into an existing cloud data analysis platform like ThingSpeak, or when working on code within a team with many individuals contributions, the Arduino IDE may not be the most ideal software. Among the various code editors used by coders based on their comfort level and line of work, one of the most widely used and popular editors is Visual Studio Code (VS Code). Researchers, such as Dolinay et al. [5], worked on improving the version of the source-level debugger for Arduino that can be used to debug Arduino programs in VS Code and other code editors. The VS Code editor supports hundreds of programming languages for thousands of applications, including Arduino, which can be added simply by installing an extension. It provides a comfortable coding environment with its in-build libraries, auto code completion, bracket-matching, auto-indentation, auto-suggestion, snippets, box-selection and more functions. Source code management using Git and GitHub is found to be extremely easy in VS Code.

4 Wireless Data Communication

Wireless data communication or data transfer refers to the transmission of data as electromagnetic waves from a transmitting point to a receiving point. Electromagnetic waves are defined in the electromagnetic spectrum according to their frequency and wavelength, with long radio waves and FM radio waves having lower frequencies, followed by microwaves, infrared, ultraviolet, X-rays, and gamma rays with increasing frequencies. Cellular networks, such as 4G and 5G, as well as Wi-Fi and Bluetooth, all operate within the lower microwave spectrum. While they offer incredibly fast communication speeds, the lower microwave spectrum is not very reliable for long-range communication and consumes more power. Radio Frequency modules and others operate in long radio waves spectrum, supporting long-range communication with relatively lower speed and lesser power consumption.

The wireless communication technologies, ZigBee and LoRa which operate in long radio wave spectrum, are popularly used in industrial and domestic projects because of their ease of use in configuration and operation. The provided image in Fig. 4 shows the XBee S2C ZigBee module alongside the E32 LoRa module. Researchers including Kim and Han [12], Jayanthu and Karthik [10], Nishikawa et al. [14], and Dorthi and Chandar [6] have utilized ZigBee transmission modules in their slope/landslide research. ZigBee is ideal for short-range data transmission, similar to Wi-Fi. According to Karthik et al. [11], ZigBee can efficiently transmit data within a range of 400 m without any loss of data. One significant benefit of ZigBee is the XCTU ZigBee module configuration software that enables the assignment of unique roles and responsibilities such as Co-Ordinator, Router and End device to each module. The window of the XCTU software displayed is shown in Fig. 5. The Co-Ordinator radio's primary responsibility is to create a network that the other two radio types can join. There can only be one Co-Ordinator in a network, and it is also responsible for managing network security and assigning addresses. The Router radios are equipped to send, receive, and route information between two radios when they cannot communicate due to range constraints. A network can have multiple Router radios. The End device radios, on the other hand, can only send and receive information but cannot route it. LoRa technology is particularly useful in situations where long-range communication is required, as it offers a data transmission range of 15 km, as



XBee S2C Zigbee module **E32 – LoRa module**

Fig. 4. XBee S2C and E32 LoRa RF Module pinout

noted by Romdhane et al. [16]. LoRa operates within the ISM (Industrial, Scientific, and Medical) band, with a frequency range of 433 MHz, 868 MHz, or 915 MHz, depending on the region in which it is used, as stated by Augustin et al. [1]. The address and channel number settings of a LoRa module are crucial in facilitating communication between a transmitter and a receiver. The configuration process involves setting specific parameters to ensure the module functions correctly within a network, for this several software options are available, one of which is the EBYTE software. The window of the EBYTE software displayed is shown in Fig. 6.

XCTU application offers a graphical network view for easy wireless network configuration and architecture, as well as an API frame builder as a simple development tool for quickly building XBee API frames. There are many parameter settings available in the XCTU, but only a few are necessary for networking, such as the "PAN ID" parameter, which enables the modules to join the respective network created by the coordinator with the same ID. The "Coordinator enable" option is used to designate a module as the coordinator. The "Node identifier" parameter assigns a name to the module that will be displayed in the devices list. The "Serial Number High" and "Serial Number Low" parameters provide the module's MAC address, and by assigning this address to the destination address of another module, data will be transferred to that module. XCTU also performs range testing between ZigBee modules using RSSI (Range Signal Strength indicator). The other way of configuring ZigBee modules is by AT commands, in that AT abbreviates for "ATtention". Tools such as the Trang multi-function program, Access port, and other software are commonly used to test data communication circuits. During data transmission, the module enters command mode when it receives ' +++' and responds by sending 'OK'. It then pauses data transmission for 10 s from the last command. After this time, it exits command mode and resumes data transmission. Commands to conFig. The module begin with 'AT', followed by the category of the command, such as 'G' for general commands, 'N' for networking commands, 'S' for serial interface, 'I' for input/output control, and 'P' for power control. For example, to reset the module configuration that falls in the general command category, the command would be 'ATGRD' and to write it to the module 'ATGWR' command is used.

The EBYTE software is a user-friendly tool that allows the configuration of LoRa modules. By connecting a LoRa module to a computer via USB, the EBYTE software can detect the module and provide an interface for configuring its settings. The software

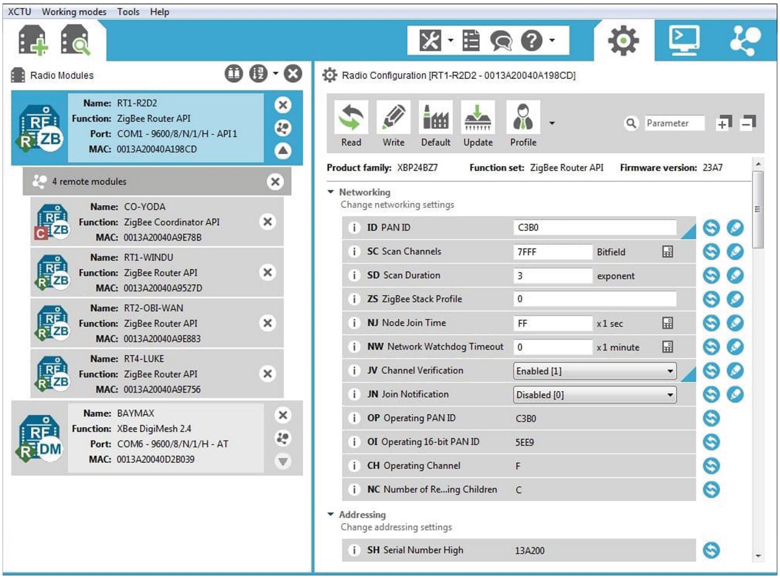


Fig. 5. XCTU ZigBee configuration software

enables the selection of the desired LoRa frequency band, channel, and transmission power, as well as configuring the address and other relevant parameters. LoRa modules are transceivers that can both transmit and receive data simultaneously. Two types of transmissions are commonly used for LoRa networking: fixed transmission and broadcasting transmission. Fixed transmission is used when data must be sent to a specific receiver, with the receiver module's address and channel number set as the target address and channel number in the transmitter. Broadcasting transmission is used when data must be broadcasted to all receiver modules under the same channel, with the target address fixed as "FFFF" in the transmitter and the channel number of receivers for which the data needs to be broadcasted set as the target channel number in the transmitter. Data transmission in this network works in both ways.

5 Cloud Computing and Real-Time Slope Monitoring

To determine the stability status of slopes, it is necessary to analyze the data obtained from sensors. Traditional techniques involve the use of a data logger to collect and store sensor data, which is then transported to the mining office for analysis. Similarly, total station slope displacement surveys using prisms entail taking the instrument to the observation site, recording the data in the total station, and later analyzing it in the office. AutoCAD software is commonly employed to transform the slope data into 2D and 3D visualizations. To establish a real-time slope monitoring and early warning alert system, it is crucial to collect data continuously and analyze it automatically round-the-clock. However, utilizing local computers for slope data analysis may result in inconsistent data analysis during system maintenance or repair. It is reliable to adopt

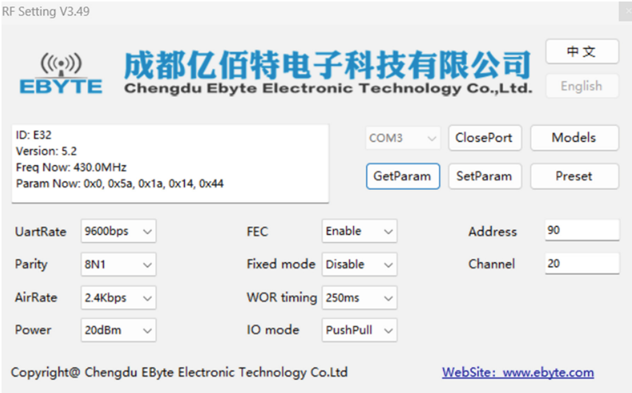


Fig. 6. EBYTE LoRa configuration software

cloud-based servers for data analysis to avoid such issues. There are numerous cloud data analytics services accessible online, but among them, ThingSpeak has gained the most popularity. ThingSpeak is an IoT analytics platform that operates on the cloud, allowing users to collect, display, and analyze real-time data streams. The platform supports the instant visualization of data sent by various devices, including sensors and sensor nodes. Researchers, including Pitambar et al. [15] and Taqwa et al. [21], have used ThingSpeak to design landslide detection systems, by incorporating MEMS sensors and NodeMCU/RasberryPi microcomputers, they were able to develop reliable and effective monitoring systems that provided real-time data analysis and visualization. These studies highlight the potential of ThingSpeak as a cloud-based platform to enhance the real-time slope monitoring system.

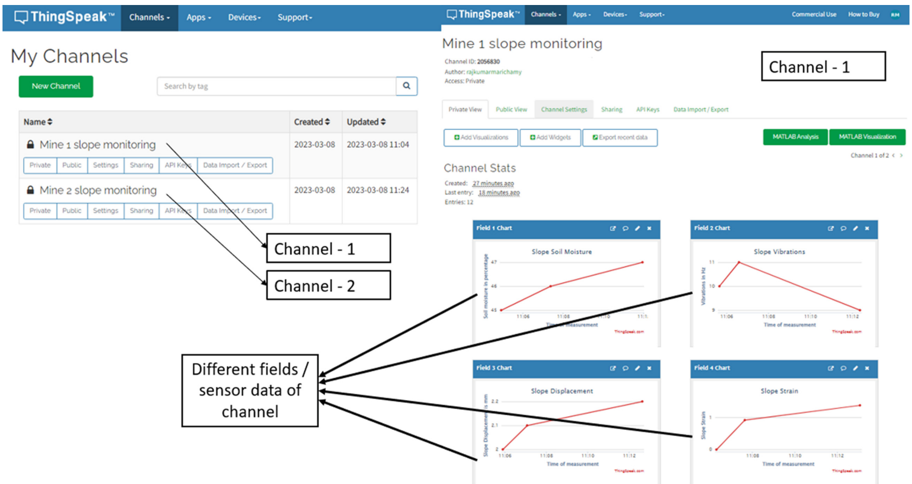


Fig. 7. Thingspeak online data analytics platform

In its free version, ThingSpeak allows users to create up to four channels, each with a maximum of eight fields. Each channel has a unique channel ID and Read and Write API keys that enable data updates. The eight fields correspond to eight distinct data inputs from different sensors that are updated every 15 s. The display window of ThingSpeak is depicted in Fig. 7. It features a list of channels associated with the account on the left-hand side, while the right-hand side displays graphical representations of the collected sensor data for channel 1. The x-axis displays the time of data feed, while the y-axis shows the units of sensor data. The chart's title and other parameters can be modified using the chart options button provided on top of it, which includes the option to change the type of visualization. ThingSpeak provides an alert system through its React app, which requires MATLAB coding and allows alerts to be sent via Gmail and SMS. In addition, ThingSpeak supports external cloud computing via its Read API key, which allows data stored in ThingSpeak to be read by other cloud platforms for generating alerts via email and SMS when sensor readings reach a threshold. PythonAnywhere is an example of such a platform that can be used to achieve this goal by utilizing simple Python code, along with IFTTT webhooks to activate notifications and alert users via email and SMS. In addition to ThingSpeak, other cloud-based data analysis platforms such as AWS (Amazon Web Services), Microsoft Azure, and Google Firebase can be utilized by incorporating HTML-CSS codes in Arduino programs. Alternatively, mobile apps such as BLYNK, which offer built-in graphical interfaces and human-machine interfaces tailored for IoT projects, can also be used. The Blynk app has been utilized in landslide detection monitoring systems by Jawalker et al. [9] and Sudarmanto et al. [19], and their studies reported successful results in their respective models.

6 Conclusion

Ensuring slope stability is crucial for mine safety, and mine management must monitor areas prone to slope failures continuously. However, conventional slope monitoring methods are limited in terms of quick data analysis and automation. To improve the efficiency of slope monitoring, real-time data analysis and early warning alerts are necessary for the event of unexpected slope movements. The review of WSN and real-time slope monitoring systems shows that a low-cost MEMS sensor that detects and transmits slope behaviour through wireless transmission systems and is analyzed in cloud analytics platforms can provide an effective and affordable solution for slope monitoring.

In real-time slope monitoring using WSN the slope behaviour is often detected using MEMS sensors and microcomputers, such as Arduino UNO and NodeMCU. Wireless communication technologies, such as the ZigBee module and LoRa communication system, are frequently used in both industrial and domestic projects due to their easy setup and operation. Cloud-based data analysis platforms like Thingspeak enable early alerts to be sent via email and SMS. Mobile apps like BLYNK can also provide an alert system, making real-time slope monitoring a timely and effective method for improving safety and preventing accidents in open-cast mines.

References

1. Augustin, A., Yi, J., Clausen, T. and Townsley, W. M.: A study of LoRa: Long Range and Low Power Networks for the Internet of Things. Sensors, 16(9): 1466 (2016).
2. Azharudin M. A. A., Daud, N. N. N.: Vibration effects on soil slope detected by using Arduino System. The 9th AUN/SEED -Net regional conference on Natural Disaster, IOP Conference series: Earth and environmental science 1091 (2022) 012002. doi:https://doi.org/10.1088/1755-1315/1091/1/012002
3. Chandarana, U. P., Momayez, M., Taylor, K. W.: Monitoring and predicating slope instability: A review of current practices from a mining perspective. International journal of research in engineering and technology, 5(11), 139–151 (2016).
4. Chen, G., Chen, X., Chen, W., Li, X., Chen, L.: GPS-based slope monitoring systems and their applications in transition mining from open-pit to underground. International journal of mining and mineral engineering, 5(2), 152–163 (2014).
5. Dolinay, J., Dostalek, P., Vasek, V.: Advanced debugged for Arduino. International ournal of advanced computer science and applications, 12(2): 30–36 (2021).
6. Dorthi, K., Chandar, K. R.: Slope stability monitoring in opencast coal mine based on wireless data acquisition system - a case study. International journal of engineering and technology, 7(2.21):24–28 (2018).
7. Harries, N. J., Roberts, H.: The use of Slope Stability Radar (SSR) in managing slope instability hazards. 1st Canada – U.S. rock mechanics symposium, Vancouver, Canada. (2007).
8. Idris, A., Hafez, M. A., Sidek, N., Zailani, W. W. A. Baharuddin, N. A. Z. M.: Smart monitoring and warning landslide system using internet of things. Mathematical statistician and engineering applications, 71(4):7226–7238 (2022).
9. Jawalkar, M., Malviya, N., Hage, P., Chakule, S., Pattewar, P.: IoT based landslide detection and monitoring system. International journal for research in applied science and engineering technology, 10(5): 3396–3399 (2022).
10. Jayanthu. S., Kathik, G.: Development of effective technology for online slope monitoring in opencast mines – R&D iniitative. Workshop on emerging mining technologies and low-carbon footprints with waste management, Vigyan Bhawan, New Delhi, India, 13–14 Febraury (2017).
11. Karthik, G., Jayanthu, S., Patil, B. N., Prashanth, R.: Laboratory and field investigations on XBEE module and its effectiveness for transmission of slope monitoring data in mines. International Journal of Electrical and Electronics Engineers, 8(2): 349–355 (2016).
12. Kim, K. T., Han J. G.: Design and implementation of a real-time slope monitoring system based on ubiquitous sensor network. The 25th International symposium on Automation and robotics in construction, Lithuania. 330–336 (2008).
13. Mittapally, S. K., Karra, R. C.: Functions and performance of sensors for slope monitoring in opencast coal mines- laboratory experimentation. Petroleum science and technology (2023). doi: https://doi.org/10.1080/10916466.2023.2175858.
14. Nishikawa, Y. et al.: Design of stable wireless sensor networks for slope monitoring. IEEE Topical conference on wireless sensors and sensor networks, Anaheim, CA, USA. 8–11 (2018). doi: https://doi.org/10.1109/WISNET.2018.8311550.
15. Pitambar, P., Akshay, P., Hardik, R., Ravi, H. and Shubhangi, K.: IoT based landslide detection and monitoring. International journal of research and analytical reviews, 6(2): 52–59 (2019).
16. Romdhane, R. F., Lami, Y., G-Catalot, D., Fourty, N., Lagreze, A., Jongmans, D., Baillet, L.: Wireless sensor network for landslides prevention. IEEE International conference on computational intelligence and virtual environment systems and applications. 222–227 (2017).

17. Shaikh, A. A., Shitole, D. S.: Micro-Electromechanical System (MEMS) sensor, International journal of scientific and engineering research, 3(11): 1–8 (2012).
18. Shetty, R., Navi, S. S., Sindhu, Channappagoudar, S. R. and Moger, M.: Landslide detection and early warning system using wireless sensor network. International journal of innovative research in technology, 8(12):120–124 (2022).
19. Sudarmanto, A., Khalif, M. A. and Huda, A. K.: Detection of building slope and land subsidence using ultrasonic HC-SRO4 sensors-based Arduino UNO R3 and Blynk. AIP Conference proceedings 2540, 100004 (2023). https://doi.org/10.1063/5.0125207
20. Susanto, E., Budiman, F., Mukthar, D. P. H. and Latief, M. H.: Slope, Humidity and Vibration Sensors Performance for Landslide Monitoring System. IEEE Asia pacific conference on wireless and mobile (2019). DOI: https://doi.org/10.1109/APWiMob48441.2019.8964155
21. Taqwa, A., Fadhli, M., Soim, S., Handayani, A. S., Suroso. Prototype design of landslide early detection system using LoRa and IoT. Proceedings of the 4th forum in research, science and technology, 7(1): 495–499 (2021).
22. Wang, W.: Research on slope monitoring and early warning system. Highlights in science, engineering and technology,7(2022):63–70.
23. Weidner, L., Walton, G., Kromer, R.: Classification methods for point clouds in rock slope monitoring: A novel machine learning approach and comparative analysis. Engineering geology, 263(2019): 105326.
24. Yadav, D. K., Karthik, G., Jayanthu, S. and Das, S. K.: Design of Real-Time slope monitoring system using time-Domain Reflectometry with wireless sensor network. IEEE Sensors letters, 3(2): 1–4 (2019). doi: https://doi.org/10.1109/LSENS.2019.2892435.
25. Kumar, A., Rathee, R.: Monitoring and evaluating of slope stability for setting out of critical limit at slope stability radar. International journal of Geo-Engineering, (2017)8:18. DOI https://doi.org/10.1186/s40703-017-0054-y
26. Chang, D. T. T., Tsai, Y. S., Yang, K. C.: Study of real-time slope stability monitoring system using wireless sensor network. Telkomnika, 11(3):1478–1488 (2013).
27. Dorthi, K., Karra, R. C.: Zigbee Based Wireless Data Acquisition System for Monitoring of Partition Stability above old Underground Coal workings. Arabian Journal of Geosciences 13,307 (2020). https://doi.org/10.1007/s12517-020-5255-6