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Slope Monitoring System Using Internet of Things for Opencast Mines

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Abstract

Slope failure and debris flow result in several deaths and property losses. Natural disasters, such as landslides and slope failures, result in numerous fatalities and economic losses each year. This significant issue prompted the development of an early warning system to reduce accidents, failures, and financial losses. The majority of studies on real-time early warning systems have focused on forecasting unstable locations; however, studies on predicting slope failure occurrence using real-time slope displacement monitoring systems are still lacking and require more investigation. In this paper a three-dimensional displacement sensor, a rain sensor, and a soil moisture sensor, as well as an Internet of Things (IoT), were coupled to monitor slope failure using cutting experiments on a real-scale model slope. The slope movement was monitored in real time in the lab using an integrated, low-cost, efficient, and simple-to-use IoT system. The data was analyzed and the results were explained based on the collected displacement data. This work can be further extended by implementing it in various fields and different industrial applications where slope failures are a part of the production process.

Keywords: *Displacement, Internet of Things, Sensors, Slope Failure*

1.0 Introduction

Landslides or slope failures occur as a result of topographical circumstances and changes in climatic variables such as severe rainfall and earthquakes. The slopes can travel in either an uphill or downhill orientation[1]. Slope collapses are caused by a variety of factors. The fundamental source of slope instability is a steeper slope. The natural inclination of steep slopes is for items to be moved downward. The presence of too much water on the slopes is dangerous, as it causes the slopes to become unstable[2]. The loss of flora on the slopes is also a contributing factor. The strength of the slope increases as the vegetation grows. Slope collapses are caused by a variety of factors, including human-made objects. The slope failures were caused by the construction of highways, which blasted the humans' leads. As a result, an effective monitoring system is required to detect slope failures in advance, inform people, and limit human life loss[3]. The research project's major goal is to develop a

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slope failure monitoring system that takes readings with the fewest possible components and high efficiency. Slope failures and dump failures have been on the rise in recent years, according to an examination of mishaps in open-pit mines. Slope failure is a word used to describe the downward movement of soil, rock, and organic materials under gravity's effect. External mechanisms such as intense or prolonged rainfall, quick snowmelt, or sharp variations in groundwater levels, shocks or vibrations induced by earthquakes; blasting or construction activities; loading on upper slopes; or a combination of those and other variables are frequently initiated[4]. When a slope failure occurs, material is carried by a variety of mechanisms, such as sliding, flowing, and falling. Slope failures can come in a variety of shapes and sizes, depending on the following factors: Movement speed: This might range from a very slow creep (millimeter per year) to a very fast creep (metres per second). Kinds of material such as bedrock, unconsolidated sediment, and/or organic material, make up the slope. Slope failure is most common in India due to excessive rainfall; hence, this study focuses on rainfall-induced slope failure[5]. Landslides can also be caused by earthquakes; however, in India, this is mostly limited to the Himalayan zone. Sliding and slumping inside existing hazard zones is accelerated by high rainfall intensity. In India, the annual loss due to landslides is equal. Rain infiltration on the slope during heavy rains causes instability, a reduction in the factor of safety, transient pore pressure responses, changes in water level height, a reduction in the shear strength that holds the soil or rock in place, a rise in soil weight, and a reduction in the angle of repose[6]. Runoff happens when rainfall intensity exceeds the slope's saturated hydraulic conductivity. During a slope failure, three separate physical events occur:

- The initial slope failure,
- The subsequent transport, and
- Deposition of the slide materials in their final form.

Under heavy rains, first slope failure might occur due to a rise in pore pressure and soil moisture content, necessitating the integration of geophysical sensors for detecting changes in pore pressure and moisture content with the landslide warning system. For capturing in-situ measurements, the system proposed in this work also comprises geophysical sensors such as pore pressure transducers and dielectric moisture sensors. Following the breakdown of the slope, the material will be transported, resulting in changes in slope gradient, vibration, and other factors that must be detected and monitored in order to offer an effective warnin[7]. As a result, the warning system will comprise a strain gauge and a tilt metre for sensing in-situ slope gradient changes. Geophones are used in conjunction with them to analyse vibrations. Slope failure occurs when the downward movements of material due to gravity and shear stresses exceed the shear strength. Therefore, factors that tend to increase the shear stresses or decrease the shear strength increase the chances of failure of a slope. Figure 2 shows the geometry of an opencast mine and some factors affecting slope instability in opencast mines.

Figure 1. Slope failure at the open cast mine at Rajmahal opencast mine, India on 29-12-16[8].

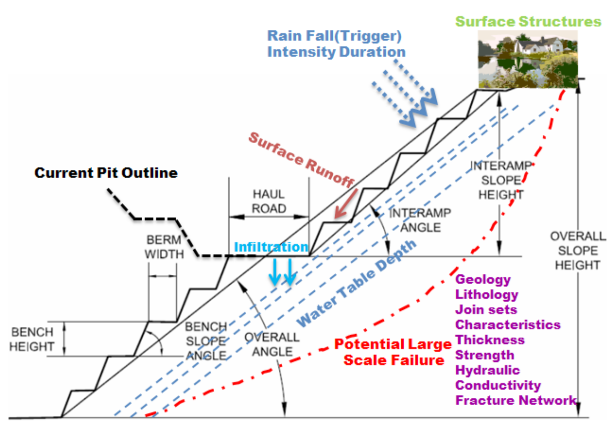

Figure 2. Geometry of opencast mine and some factors affecting slope instability in opencast mines[9].

2.0 Literature Survey

Yan, *et al.,*[10] discussed about the slope of an openpit mine is found to be anomalous, the WSN sends data to the monitors in a timely manner to avoid avoidable losses[11]. Within the multi-objective optimization issue of slope detection using WSN's, the Quantum Genetic Algorithm (QGA) is investigated. It's used to create a slope detection system's networking plan. Chang, *et al.,*[12] employed a Micro-Electro Mechanical Systems (MEMS) tilt metre with a sensitivity of 0.5 degrees in the xy direction to detect changes in slope stability properties[13]. The zigbee IEEE standard is used in the wireless communication network. Scaioni, *et al.,*[14] used fake rainfall to initiate a landslide runoff. The sensor network is built on a wireless architecture that allows data from the experiment site to be transmitted to a remote control room. It was not put at the mining site for evaluation because it is a laboratory experiment. Chang, *et al.,* used WSN to monitor slope stability. It's a WSN early warning and reporting system with intelligence that can be used in slope disaster avoidance engineering. Mustafa, *et al.,*[15] introduced a monitoring network for landslide monitoring to discover the simplest possible antenna position[16]. It's accepted as a multi-criteria decision-making process. Data from a geographic data system was used to reach a consensus on the most convenient site for remote monitoring applications. Steger, *et al.,*[17] discussed how each sensor node was fitted with a Global Positioning System (GPS) receiver and put on the slope being monitored. Real-time positioning algorithms identify the movement of each sensor node once the raw global positioning system data is transmitted to the base station[12]. Singh, *et al.,* reported the simulation and test results of a project for wireless data transmission via the Universal Asynchronous Receiver-Transmitter (UART) port utilizing an Advanced RSIC Machine (ARM) processor and a Radio Frequency (RF) transceiver operating in the license-free band of frequencies 2.4 GHz to 2.4835 GHz[15]. The impact of underground performing on the slope is investigated using seismic event impact contours and seismic clusters, which characterize the seismically active zone for measuring the stability of the high wall up in real-time, according to Vinoth and Ajay (2014)[11]. The high wall stability was not harmed by the intensity of general micro seismic activity along the slope caused by mine construction operations[17]. The low-cost solution for soil moisture measurement was presented by Bhushan, *et al.,* (2015). Rather than using a sophisticated field programmable gate array, a low-cost microcontroller is used to reduce the value[18]. The Time-Domain Reflectometer (TDR) readings are frequently delivered electronically in a short period of time using a Global System for Mobile Communication (GSM) module, which allows a low-cost, wireless connection. To provide the TDR reading at the site, a simple 16*2 Liquid Crystal Display (LCD) is employed. The writers of Nur, *et al.,* (2015) described many functional units in this work, and multiple applications of TDR were consciously discussed. Nur, *et al.,* (2016) the first part of this study covers a wide range of slope movement parameters such as soil water content, ground water, and ground movement[14].

The physical and mechanical characteristics of soil, and thus the saturation condition, are complex, and understanding how water decreases soil shear strength necessitated simplification. After researching the benefits and drawbacks of traditional geotechnical instruments, it is required to design a wireless continuous monitoring system for a stability monitoring systems in opencast mines using IoT. Yagimli, *et al.,*[19] has discussed the Global Positioning System (GPS)-based mobile prototype vehicle carrying a system that can jam electromagnetic waves to blow up the mines with a remote control. This vehicle runs on solar energy, and it can be steered with simulation glasses. These threating mines are classified as wooden, plastic and metal types. In this study, a detector, that is able to detect all the mines placed on the ground, has been developed[19]. Molaei F, *et al.,* (2020) discussed about the integration of computer-based technologies interacting with industrial machines or home appliances through an interconnected network, for teleportation, workflow control, switching to autonomous mode, or collecting data automatically using a variety of sensors, is known as the Internet of Things (IoT). IoT can assist real-time platforms in remotely monitoring and operating a complex production system with minimal human intervention. Hence, it can be beneficial for hazardous industries, such as mining, by increasing the safety of personnel and equipment while reducing operation costs[20]. Anandhi S., *et al.,*[21] discussed about the recent innovations eliminate the difficulties in traditional approach such as manual counting, locating the object, and data management.

Radio Frequency Identification (RFID) implementation in Supply Chain Management (SCM) improves the visibility of real-time object movement and provides solutions for anti-counterfeiting. RFID is a major prerequisite for the IoT, which connects physical objects to the internet. Various research works have been carried out to perform object tracking using GPS, video cameras, and Wi-Fi technology[21]. Bhattacharjee, *et al.,*[22] discussed about the Proposed system for detecting fire hazard in a Bord-and-Pillar coal mine panel. It uses Wireless Sensor Networks (WSNs), and can be used to detect the exact fire location and spreading direction, as well as provide a fire prevention system to stop the spread of fire and save natural resources and mining personnel from fire. The proposed system is capable of early detection of fire and generating alarm in case of emergencies[22]. The available literature shows the utilization of displacement sensors only for slope and land slide monitoring. But the major reasons for slope failure include the rain fall, slope movement and the presence of water in the ground. So the proposed integrated system has three different sensors for monitoring the above parameters.

3.0 Block Diagram

Figure 3 shows the block diagram of the integrated system, which uses a displacement sensor to measure elevation measurements, rain sensor to detect rainfall and a soil moisture sensor to detect the presence of water in the ground. The data was presented on the ThingsSpeak cloud platform. The recorded values were sent to the cloud through the ESP8266 Wireless Fidelity (Wi-Fi) module. The hardware requirements are a power supply, microcontroller (ARM based LPC2148), displacement sensor, rain sensor, soil moisture sensor, IoT module and LCD (Liquid Crystal Display). The software requirements are ThingSpeak and Keil.

3.1 Power Supply

A power supply is a component that provides power to at least one electrical load. It usually transfers one type of electric power to another, but it can also convert a different type of energy into electricity, such as solar, mechanical, or chemical energy.

3.2 ARM-based LPC2148

This microcontroller has 32kB of static Random Access Memory (RAM), which is ideal for storing data or code. It's compatible with 8-bit, 16-bit, and 32-bit computers. P0 and P1 refer to the two input/output ports

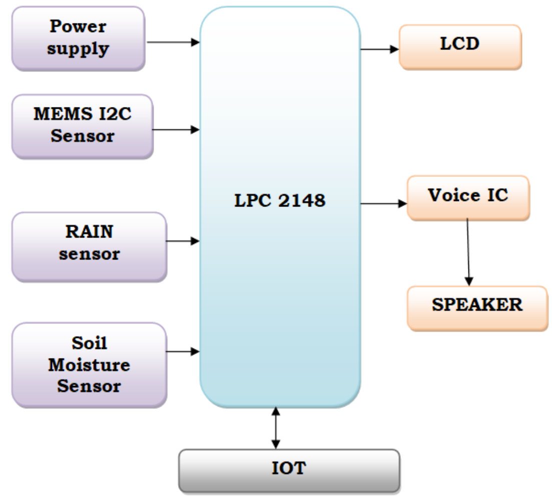

Figure 3. Block diagram of slope monitoring system.

of the LPC2148 microcontroller. The LPC 2148/66/65/64 is capable of running at Central Processing Unit (CPU) rates of up to a 100 MHz.

3.3 Displacement Sensor (MEMS)

A displacement sensor is a device that detects the quantity of displacement through a spread of elements and converts it into a distance between the sensor and an object. Displacement sensors assess how much a machine's spinning part moves away from its stationary housing. A probe tapped within the machine's frame, just above the surface of a rotating shift, is used in displacement sensors.

The main working principle of an accelerometer is that it converts mechanical energy into electrical energy. When a mass is kept on the sensor, which is actually just like a spring, it starts moving down. Since it is moving down, it starts experiencing acceleration. That acceleration hen gets converted into an amount of electric signal which is used for the measurements of variation in the position of the device.

3.4 Rain Sensor

A rain sensor is a type of switching device that analyses rainfall to detect it. It functions as a switch, and the functioning rule of this sensor is that anytime it rains, the switch will be normally closed. This sensor is regarded as a water-saving technology, and it is frequently connected to an irrigation system to shut it down in the event of rain.

The purpose of the rain sensor is to detect the presence of water drops on its surface, of sensor and we defined as wet and dry condition. A sensing pad with a series of exposed copper traces acts together as a variable resistor (just like a potentiometer) whose resistance varies according to the amount of water on its surface.

3.5 Soil Moisture Sensor

A soil moisture sensor is a type of sensor that is used to determine the volumetric content of water in the soil. The working of this sensor is frequently accomplished by inserting it into the world, and the status of the water content within the soil is frequently provided in the form of a percentage. This sensor is ideal for experiments in science classes such as ecology, agricultural science, biology, soil science, botany, and horticulture, among others.

3.6 IoT Module

The ESP8266 Wi-Fi Module is a self-contained system on chip (SOC) with an integrated Transmission Control Protocol/Internet Protocol (TCP/IP) protocol stack that provides access to your Wi-Fi network to any microcontroller. The ESP8266 may either host an application or offload all Wi-Fi networking functionality to a separate application processor. Each ESP8266 module is pre-programmed with AT command set firmware, which means you can just connect it to your microcontroller device and get nearly the same level of Wi-Fi-ability as a Wi-Fi shield (right out of the box). The ESP8266 module is a very low-cost board with a large, and rapidly increasing, community.

3.7 LCD (Liquid Crystal Display)

We use an LCD module to display interactive messaging. We take a look at a smart LCD display of lines with sixteen characters per line, which is frequently connected to controllers. The display protocol (handshaking) has been established. The data strains are D0 to D7th bit, the control pins are RS, RW, and EN, and the last pins are +5V, -5V, and GND to provide power. The Register Select pin is RS, the Read Write pin is RW, and the Enable pin is EN.

3.8 Speaker

Speakers are devices that transform electricity into energy (motion). The energy compresses the air and transforms the motion into sound energy, or the degree of instantaneous Sound Pressure Level (SPL). A magnetic flux is created when an electrical current is sent through a coil of wire. A current is sent through the voice coil in speakers, creating an electrical field that interacts with the magnetic flux of the speaker's static magnet.

3.9 ThingSpeak

It's an open-source Internet of Things (IoT) application called "ThingSpeak". Using the Hypertext Transfer Protocol (HTTP) and Message Queuing Telemetry Transport (MQTT) protocols through the web or via a local area network, you can store and retrieve data from items. ThingSpeak is a cloud-based IoT analytics tool that allows you to gather, visualize, and analyse live data streams. ThingSpeak visualizes knowledge posted by your gadgets in real time.

3.10 Keil

The Keil 8051 development tools are meant to help embedded software developers address challenging challenges. This program is an Integrated Development Environment (IDE) that includes a text editor, a compiler, and the ability to convert ASCII text files to hex files.

4.0 Methodology

Figure 4 depicts the methodology of the integrated system as a flowchart. The systematic steps to achieve our objectives are presented in the form of a process flow, as given below. In general, there is a tendency for slope failures in mountainous terrain and opencast mines in India. To provide some relief from the current difficulty, we devised a technique in which the accelerometer sensor is used to measure elevation data. The data was presented within the ThingSpeak program since the captured values were transferred to the cloud via the ESP01 Wi-Fi module. The literature survey related to the chosen areas was completed. The objectives are identified and a methodology is proposed. Selected the required software and hardware modules for system integration. Interfaced the rain sensor, soil moisture sensor, accelerometer and IoT module with the controller to detect the displacement of sensors. Cloud based Graphical User Interface (GUI) was created to know the status of sensors. Cloud based GUI can be utilized to know the real-time status of sensors and store the data on the cloud. The integrated system was tested in a laboratory, and output data was observed.

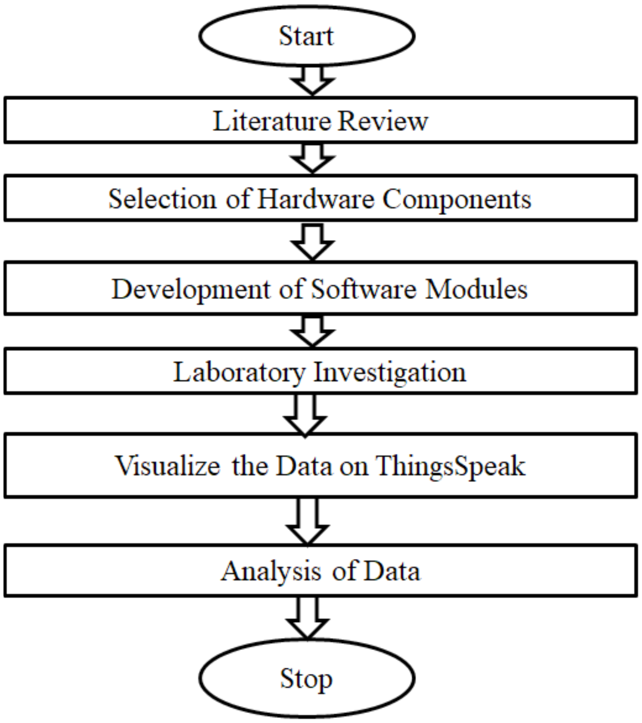

Figure 4. Process flow.

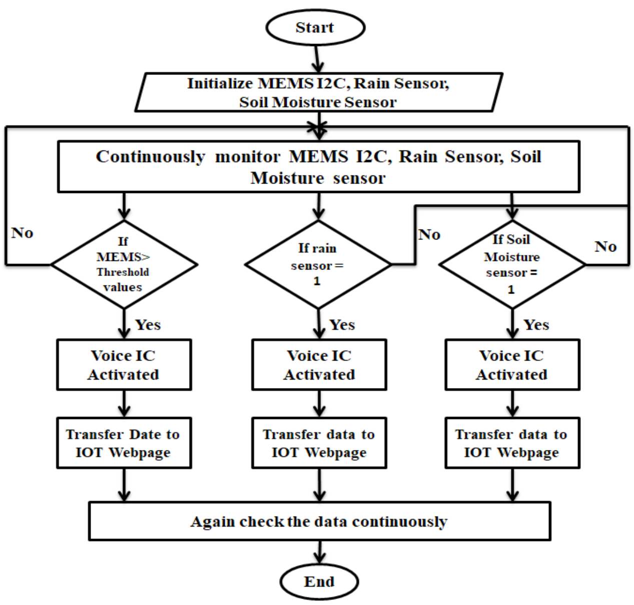

Figure 5. Algorithm.

4.1 Algorithm

Figure 5 shows the Principle of the integrated system in the form of algorithm. The first step is to initialize the MEMS I2C, Rain sensor, and Soil moisture sensor then it continuously checks the MEMS I2C, Rain sensor, and Soil moisture sensor for the MEMS > Threshold value.

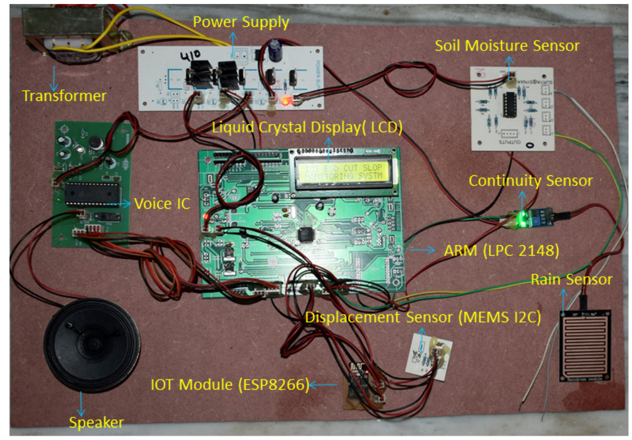

Figure 6. Hardware physical connections.

Table 1. Data measured by the Integrated System during laboratory investigations in the July and August 2021 event

DATE	SLOPE ANGLE	RAIN SENSOR	SOIL MOISTURE
20/7/2021	24.5	Dry	236
22/7/2021	20.4	Wet	258
26/7/2021	19.3	Wet	269
28/7/2021	15.8	Dry	240
30/7/2021	28.5	Wet	282
1/8/2021	33.9	Wet	296
6/8/2021	31.2	Dry	239

If the value is yes, the speech IC is triggered, the data is communicated to the IoT webpage and the data will be reviewed on a regular basis. If the answer is no, the process will be repeated. In the case of 'Yes', the rain sensor and soil moisture sensor are equal to one. The voice IC will be turned on, and data will be sent to the cloud platform. It also checks the data on a regular basis. If the answer is no, the process will be repeated.

4.2 Hardware Connection

Figure 6 represents the physical integration of sensors, communication modules, a controller and a power supply. The soil moisture sensor to which it was connected measures the water level, whether it is high or low. It will also connect directly to the rain sensor, displacement sensor module, voice IC, and speaker on the microcontroller.

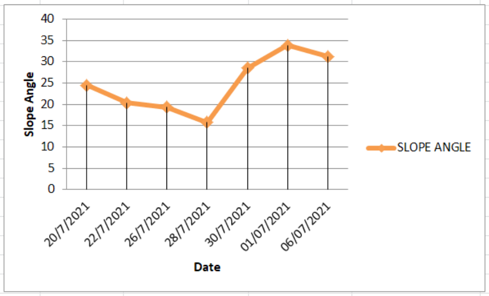

Figure 7. Graphical representation of slope angle.

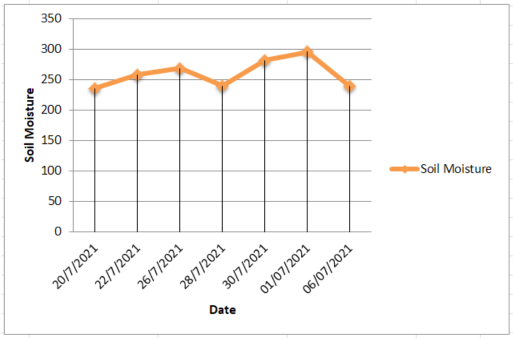

Figure 8. Graphical representation of soil moisture.

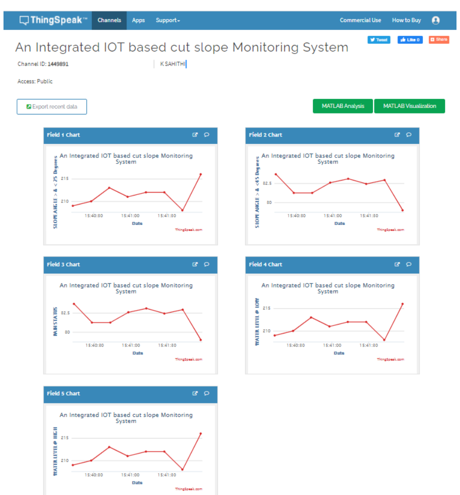

Figure 9. ThingSpeak output.

5.0 Results

The stable bench slope angle should be 45 degrees, according to the Indian Director General of Mine Safety Guidelines**.** The angle of slope is measured by the displacement sensor in four different ways: less than 45 degrees, more than 45 degrees, less than 25 degrees and greater than 25 degrees, which are shown on the LCD screen and offer the voice of the angle slope. The rain sensor detects the presence of rain and displays "It's raining" on the LCD screen when it's raining. It also makes the voice seem like it's raining. The required amount of water indicates the water level; if it is high, the LCD panel will display high; otherwise, it will display low as shown in the Table 1. Figure 7 shows that the output of the x and y axis values of the slope angle, whether it is high or low, is defined in a graphic manner. Figure 8 shows that the output of the x and y axis values of soil moisture, whether it is dry or wet, is defined in a graphic manner.

Figure 9 represents the status of integrated sensors on the cloud platform. The data and values of the slope angle are stored for the displacement sensor by tilting the displacement sensor and two for soil moisture, which indicates if the water level is high or low. One is for the rain sensor, which records data about when it rains and displays the values of these sensors in a graphical manner.

6.0 Conclusions

Slope monitoring is one of the challenging research areas. In this paper, we designed the hardware prototype in order to detect the movement by using the accelerometer sensor. The factors affecting the slope failure include rain fall, slope movement and the presence of water in the ground. The integrated system consists of three different sensors for monitoring the above parameters. The data that was generated by the sensor was successfully transmitted and synchronized with the cloud for visualization and accessibility. The designed system proved useful in both normal hilly areas and mining areas. This system will also be helpful for the people living in mountain areas in order to reduce mortality. The future studies can be carried out by applying soft computing techniques and data processing algorithms using signal processing tools like MATrix LABoratory (MATLAB), to forecasting the future failures. This work can be further extended by implementing it in various fields and different industrial applications where slope failures are a part of the production process.

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