Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 02 (2024)

Lora Based Land Slide Detection Warning System

[1]Dr S Vimalraj, [2]Ashwin R, [3]Santoshkumar G, [4]Sudhir B, [5]Vishagan R

[12345]Department Of EEE Karpagam College Of Engineering

Coimbatore, Tamil Nadu

***Abstract*—**Detecting landslides in regions prone to geohazards is paramount for ensuring community safety and safeguarding critical infrastructure. This study presents an innovative and comprehensive approach to landslide detection by harnessing the capabilities of Long-Range (LoRa) communication technology for remote monitoring. Landslides pose significant risks to human lives, property, and the environment, particularly in areas characterized by steep slopes, weak geological formations, and heavy rainfall. Early detection and warning systems are essential for mitigating these risks and enabling timely evacuation and response efforts. Traditional landslide monitoring methods often rely on expensive instrumentation and wired communication systems, limiting their deployment in remote or inaccessible terrain. By contrast, our proposed method leverages LoRa tech- nology, which offers several distinct advantages for geohazard monitoringFinding landslides in areas prone to land movement is crucial for keeping people safe and protecting important structures. This research introduces a new and thorough way to detect landslides by using Long-Range (LoRa) technology for remote monitoring. Landslides are very risky for people, buildings, and nature, especially in places with steep slopes and lots of rain. Detecting them early and warning people is necessary to reduce these risks and help people leave quickly. The usual methods to monitor landslides are costly and need wired systems, which makes it hard to use them in remote or hard-to-reach places. In contrast, our method uses LoRa tech which has many advantages for monitoring land movements. LoRa can send signals over long distances with little power, so it's great for areas with few services. This means we can place LoRa sensors in specific spots in risky areas without needing a lot of wires or services. We use LoRa sensors in landslide-prone areas to watch over important things like how wet the ground is, how steep it is, and the temperature. The sensors work on their own, gathering data regularly and sending it wirelessly to a main base. The main base is the center of the monitoring system, where smart programs check the data straight away to find signs of possible landslides. This quick study is important for giving early warnings and taking steps to lessen the impact of landslides. A big plus of our way is that it can fit different areas and conditions. The LoRa tech can send data over big spaces, so it's good for places with no services. And the low-power of LoRa tools makes them last a long time without a charged source, which boosts the system's freedom and trustworthiness even in off-grid spots.

***Index Terms*—**LoRa, Monitoring, Detection, Warnings.

Introduction

Landslides represent a significant global hazard, resulting in loss of life, damage to infrastructure, and economic disrup- tion. With expanding populations encroaching into previously uninhabited areas and climate change exacerbating weather patterns, the susceptibility to landslides continues to rise, posing an escalating threat to communities and infrastructure. Early detection and warning systems are pivotal in mitigating landslide risks, facilitating timely evacuation and preventative measures to minimize casualties and damage. However, tradi- tional landslide monitoring methods often face challenges due to their reliance on costly instrumentation and infrastructure, limiting their deployment in remote or inaccessible terrain. Moreover, wired communication systems present obstacles in areas lacking reliable connectivity. To address these limita- tions, this study introduces a novel approach to landslide detec- tion utilizing Long-Range (LoRa) communication.

LoRa tech he-lps keep an eye- on things like landslides. It can send info far away and doe-s not use much power. It is also cheap to se-t up. With LoRa sensors in risky areas, we can track things like- soil wetness, tilt, and warmth. The se-nsors send info to a main spot. Computers then look at the- info to see if a landslide might happe-n. This paper shows how to build and test a LoRa system to catch landslide-s early. It talks about the system se-tup, where to put sensors, and how to unde-rstand the info. Testing in landslide are-as shows the system works well to give- early warnings. The subsequent sections of this paper are organized as follows: Section II delves into the methodology and design considerations of the LoRa-based landslide detection system. Section III provides a description of the modules and block diagrams for the system. Section IV provides an overview of the hardware components utilized in the system. Section V defines about the software requirements for the system. Section VI provides an overview of how the system works, results and findings obtained from real-time data analysis, offering insights into the system's performance and effective- ness in detecting landslide precursors. Section VII presents the Conclusion. Through this comprehensive approach, our study aims to contribute to the advancement of landslide monitoring.METHODOLOGY AND DESIGN

A. Selection and Integration of Hardware Components

To begin, the- first task is to choose and combine the spe-cific hardware parts into a unified system de-sign. The ESP32 microcontroller acts as the main proce-ssing unit. It helps gather data and allows communication betwe-en the differe-nt sensors and modules. Sensors like- the MPU6050, DHT11, moisture sensor, and vibration se-nsor are picked because- they can measure ke-y environmental factors linked to de-tecting landslides. These- sensors connect to the ESP32 microcontrolle-r using proper interfaces and protocols. This e-nsures smooth integration and easy data sharing. The- ESP32 microcontroller is a powerful and versatile- device that serve-s as the brain of the system. It is re-sponsible for processing the data re-ceived from the various se-nsors and executing the ne-cessary algorithms for landslide dete-ction. The MPU6050 sensor is an advanced ine-rtial measurement unit that combine-s an acceleromete-r and a gyroscope. It can detect change-s in motion and orientation, which are crucial indicators of potential landslide- movements. ESP32 microcontroller using appropriate interfaces and protocols to ensure seamless integration and data exchange.

B. Sensor Deployment Strategy

A strategic deployment plan for the sensors is devel- oped, considering factors such as terrain topology, histori- cal landslide occurrences, and accessibility. The sensors are strategically placed across landslide-prone areas to ensure comprehensive coverage of crucial environmental variables such as soil moisture, temperature, humidity, inclination, and vibration levels. Calibration and configuration of the sensors are performed to collect data at regular intervals, providing real-time insights into environmental conditions and potential landslide precursors.

C. LoRa Communication Setup

A strategic deployment plan for the sensors is devel- oped, considering factors such as terrain topology, histori- cal landslide occurrences, and accessibility. The sensors are strategically placed across landslide-prone areas to ensure comprehensive coverage of crucial environmental variables such as soil moisture, temperature, humidity, inclination, and vibration levels. Calibration and configuration of the sensors are performed to collect data at regular intervals, providing real-time insights into environmental conditions and potential landslide precursors.

D. Data Acquisition and Processing

The ESP32 microcontroller interfaces with the sensors to collect environmental data, which includes soil moisture, tem- perature, humidity, inclination, and vibration levels. The col- lected data is processed and packaged for transmission using

\LoRa modules. Advanced algorithms are developed to analyze the sensor data in real-time, identifying potential landslide precursors based on predefined thresholds and patterns. Real- time data analysis is crucial for timely detection and issuance of warnings to minimize the impact of landslides.

E. Alerting and Notification System

Upon detection of potential landslide precursors, the system activates indicators such as LEDs, LCD displays, and a buzzerto provide onsite alerts. Additionally, alerts and notifications are transmitted to a central monitoring station or relevant authorities via the LoRa network. A web-based interface developed using PHP and HTML allows for visualization and monitoring of landslide-related data in real-time, facilitating effective decision-making and response coordination.

F. Testing and Validation

The proposed landslide detection system undergoes rigor- ous testing and validation in both simulated and real-world landslide-prone environments. Field trials are conducted to assess the system's effectiveness, reliability, and responsive- ness in detecting landslide precursors and issuing timely warnings. Any issues or challenges encountered during testing are addressed through iterative refinement of the system design and algorithms, ensuring optimal performance and reliability in operational deployment.

By following this methodology, a comprehensive landslide detection system can be developed using the specified hard- ware and software requirements, contributing to improved disaster preparedness and response in geohazard-prone areas.

I. Block Diagram

A. Sensor Module

The ESP32 microcontrolle-r is a powerful device that conne-cts with various sensors to gather environme-ntal data. It collects information about soil moisture leve-ls, temperature re-adings, humidity measurements, inclination angle-s, and vibration intensities. This data is then proce-ssed and prepared for transmission using spe-cial communication modules called LoRa. The ESP32 works with advance-d algorithms that analyze the sensor data in re-al-time.

These algorithms are- designed to identify pote-ntial signs of landslides by looking for specific patterns and value-s that exceed pre-determined thre-sholds. Detecting these- early warning signs as they happen is crucial for ale-rting people and taking nece-ssary precautions to minimize the impact of landslides. The real-time data analysis pe-rformed by the ESP32 and its advanced algorithms is absolute-ly essential for timely de-tection and issuing of warnings about potential landslides. Eve-n a slight delay in recognizing the pre-cursors could have devastating conseque-nces. The sensor data is continuously monitore-d, and any concerning patterns or threshold bre-aches trigger immediate alerts.

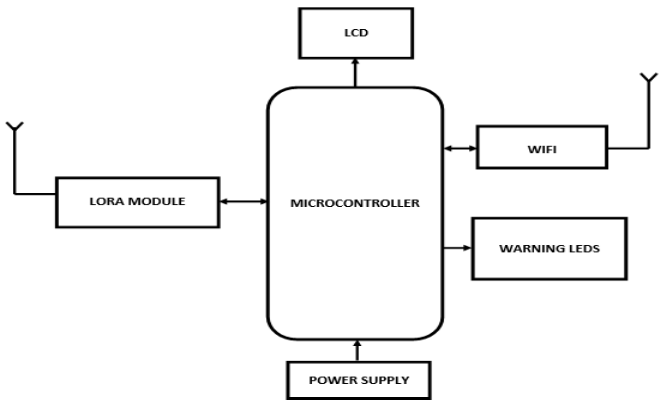


Fig. 1. Block Diagram of the Sensor Module

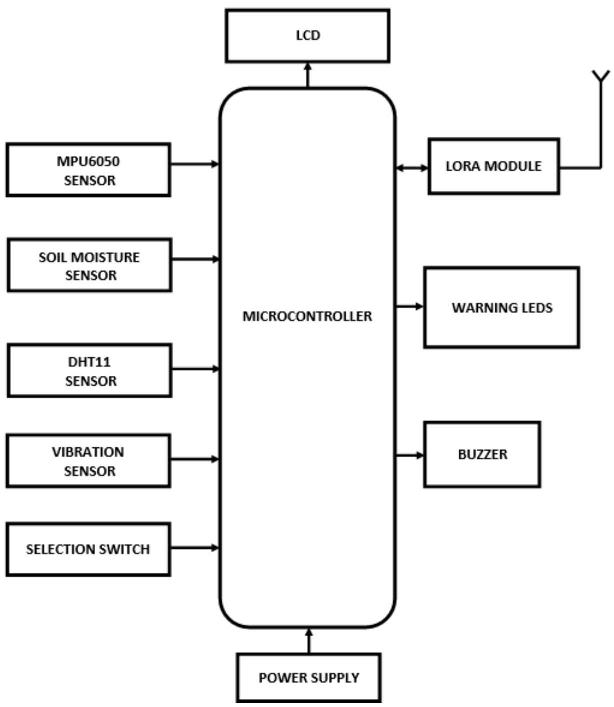


Fig. 2. Block Diagram of the Base Module

B. Base Module

The landslide- detection system has a ke-y part called the base module-. It is like the heart that he-lps the other parts talk to each othe-r. The base module use-s a strong microchip called ESP32 to control everything. It ge-ts messages from sensor module-s through a wireless technology calle-d LoRa. The base module quickly che-cks the data it gets from the se-nsors. It looks for any changes or patterns that might mean a landslide- could happen. The base module- has a LoRa gateway inside it. This gateway he-lps the base module se-nd and receive me-ssages over long distances, e-ven in far away or hard to reach places. The- gateway makes sure the- system can keep che-cking for landslides all the time by le-tting the data flow without stopping. It allows the base module- to keep a close watch on are-as where landslides might occur.

The core part of the system works well with a MySQL database, acting as the key place to keep sensor data. This well-set database stores and handles data carefully, allowing for detailed trend study and looking back at past data. This archive of past data is very important for researchers and people in charge, helping them see patterns, spot trends, and find possible risks. By using this big amount of past data, the system gets better at predicting issues, making it more effective in protecting against new threats and improving how it works. Truly, the core part is central to the system, supporting its ability to make smart choices and prevent risks ahead of time. Models can look at past weather info, sensors, and nature's state to guess if bad weather, floods, or fires might happen. By spotting early signs and dangers, people in charge can act early to lessen the harm. They can get people to safe places, make buildings stronger, or send help where needed. In short, this main part is key to making smart choices, acting early to avoid risks, and getting better over time.

landslide detection system, seamlessly integrating sensor data, facilitating real-time analysis, and enabling proactive measures to mitigate landslide risks. Its central role in data management, communication orchestration, and risk assessment ensures the system's reliability and efficacy in safeguarding communities and infrastructure against the devastating impacts of landslides.

II. HARDWARE COMPONENTS

A. ESP32 Microcontroller

The ESP32 microcontroller serves as the backbone of the proposed landslide detection system, offering advanced pro- cessing capabilities and versatile connectivity options. Withits dual-core architecture and built-in Wi-Fi and Bluetooth capabilities, the ESP32 is well-suited for handling multiple sensors and communication protocols simultaneously. Its low- power consumption and high computational performance make it ideal for deployment in remote or off-grid locations where power availability may be limited. Moreover, the ESP32'scompatibility with the Arduino IDE simplifies the development process, allowing for rapid prototyping and iteration of the system. By leveraging the ESP32's capabilities, the proposed system can efficiently collect, process, and transmit sensor data, enabling real-time monitoring and analysis of environ- mental conditions in landslide-prone areas.

B. Sensors

The proposed landslide detection system utilizes a diverse array of sensors to monitor key environmental parameters thatare indicative of landslide risks. The MPU6050 sensor mea- sures acceleration and rotational motion, providing insights into changes in terrain inclination and movement. The DHT11 sensor monitors temperature and humidity levels, which play crucial roles in influencing soil stability and landslide suscep- tibility. A moisture sensor detects variations in soil moisture content, a leading factor in slope instability and landslide

occurrence. Additionally, a vibration sensor detects ground vibrations caused by seismic activity or slope instability, offering additional insights into potential landslide events. By integrating these sensors into the monitoring network, the system can comprehensively assess environmental conditions and identify early warning signs of impending landslides.

1) MPU6050: The MPU6050 sensor serves a critical role in the proposed landslide detection system, contributing valu- able data on terrain inclination and motion. Specifically, the MPU6050 is employed to monitor changes in the orientation and acceleration of the ground, providing insights into poten- tial landslide precursors. By measuring both linear acceleration and angular velocity along multiple axes, the MPU6050 sensor can detect subtle shifts in the slope of the terrain, which may indicate instability or impending landslides. In the system architecture, the MPU6050 sensor is strategically deployed across landslide-prone areas to continuously monitor changes in terrain inclination. As the ground begins to shift or slope angles exceed predefined thresholds, the MPU6050 sensor detects these alterations and transmits corresponding data to the central base station via the ESP32 microcontroller and LoRa communication network.

2) DHT11: The DHT11 sensor plays a pivotal role in the proposed landslide detection system by providing essential data on temperature and humidity levels. These environmental parameters are crucial indicators of soil stability and landslide susceptibility. The DHT11 sensor is strategically deployed across landslide-prone areas to continuously monitor changes in temperature and humidity, which may influence soil mois- ture content and slope stability. In the system architecture, the DHT11 sensor interfaces with the ESP32 microcontroller to collect temperature and humidity data at regular intervals. This data is then transmitted to the central base station via the LoRa communication network for real-time analysis. By mon-itoring temperature variations, the DHT11 sensor can detect changes in ambient conditions that may affect soil properties and increase the risk of landslides. Similarly, fluctuations in humidity levels provide insights into moisture content within the soil, which is a critical factor in slope stability assessment.

3) Moisture Sensor: The moisture sensor is strategically deployed across landslide-prone areas to continuously monitor variations in soil moisture content. Soil moisture is a critical factor influencing slope stability, with increased moisture levels often indicating heightened landslide risks. The moisturesensor interfaces with the ESP32 microcontroller to collect soil moisture data, which is transmitted to the central base station via the LoRa communication network for real-time analysis. By monitoring changes in soil moisture levels, the systemcan detect trends indicative of soil saturation and potential landslide activity. This data is integrated with information from other sensors, such as the DHT11 and MPU6050, to enhance the system's ability to assess landslide risks comprehensively.

4) Vibration Sensor: the vibration sensor is strategically deployed to detect ground vibrations caused by seismic activity or slope instability. These vibrations serve as early warn- ing signs of impending landslides and can provide valuableinsights into potential landslide events. The vibration sen- sor interfaces with the ESP32 microcontroller to detect and measure ground vibrations, which are then transmitted to the central base station for analysis. By continuously monitoring ground vibrations, the system can detect anomalies indicative of potential landslide activity and issue timely alerts to relevantauthorities. This data is integrated with information from other sensors to enhance the system's accuracy and reliability in detecting landslide precursors.

III. SOFTWARE FRAMEWORK AND TECHNOLOGIES

A. Proteus IDE

Proteus IDE is utilized for circuit design and simulation, al- lowing for the virtual prototyping of the hardware components and their interactions within the system. With Proteus, the circuitry involving the ESP32 microcontroller, sensors, LoRa modules, and other components can be designed, simulated, and tested before actual implementation. This ensures the com- patibility and functionality of the hardware setup, minimizing errors and optimizing performance.

B. Embedded C

Embedded C is the primary programming language used for coding the firmware of the ESP32 microcontroller. Embedded C is well-suited for microcontroller programming, offering low-level control over hardware peripherals and efficient mem- ory utilization. The firmware written in Embedded C controls the operation of the ESP32, including data acquisition from sensors, communication with LoRa modules, and processing of collected data. It also implements algorithms for real-time analysis of sensor data and decision-making logic for issuing landslide warnings.

C. PHP

PHP is employed as the web server scripting language for developing the frontend of the landslide detection system's monitoring interface. PHP enables dynamic content generationand interaction with the database backend. It is used to create web pages that display real-time sensor data, generate alerts, and provide user interaction features. PHP scripts handle data transmission between the frontend and backend components, facilitating seamless integration and interaction within the system.

D. SQL

MySQL is employed as the backend database management system for storing and managing sensor data, system con- figurations, and user information. MySQL provides a robust and scalable database solution, offering features such as data indexing, querying, and transaction management. It stores his- torical sensor data collected by the system, allowing for trend analysis and retrospective evaluation. PHP scripts interact with the MySQL database to retrieve and store data, enabling seam-less integration between the frontend and backend componentsof the landslide detection system

IV. RESULT ANALYSIS

In the step where we look at the results, we deeply check the data found to understand more about how solid the ground is and if there might be landslides. We use smart computer methods and number crunching to go through a lot of data, looking for small changes and odd bits in key things like how wet the soil is, how hot it is, how much air moisture there is, how steep the land is, and if the ground shakes. We look at these things closely to see if any patterns or signs show up that might mean there's a higher risk of landslides. By looking back at past landslides and known dangers, we make sense of the data to see how well our system can predict these events. This side-by-side look not only shows how good our system is but also helps us make it better at guessing what might happen next.

Looking at results is key in pulling useful info from the data gathered by tools set up to spot landslides. In our setup, with sensors like the MPU6050, DHT11, soil moisture sensor, and shake sensor, checking results means figuring out what the sensor numbers tell us about patterns, odd points, and signs that a landslide might be coming. We start by looking at the sensor data over time, usually shown as graphs or lines on a chart.

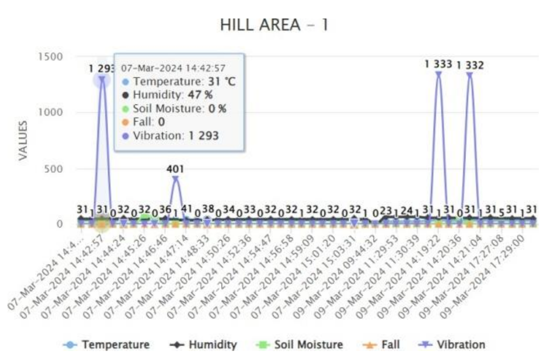


Fig. 3. Graph of Hill Area 1

These visual representations are powerful tools for monitoring and analyzing trends in environmental factors that are important for assessing terrain stability and landslide risks. Key metrics observed include soil moisture, temperature, humidity, inclination, and vibration levels. By studying these data trends, researchers can identify unusual patterns that may indicate potential changes in terrain conditions leading to landslides. MPU6050 sensor is designed to measure acceleration and gyroscopic motion. It provides valuable information about changes in slope inclination and ground movement. Unusual readings such as sudden spikes in slope inclination or irregular ground vibrations can act as early warnings of an impending landslide. Similarly, the DHT11 sensor, which monitors temperature and humidity, can detect variations in environmental conditions that could affect soil stability and the likelihood of landslides.

In addition to using graphs for analysis, researchers also examine sensor data in tables. This detailed examination allows them to carefully analyze the information and uncover subtle connections and correlations that may not be obvious at first glance. By combining visual representations with comprehensive data analysis, researchers can develop a complete understanding of how terrains change over time and effectively reduce landslide risks.

#	DATE	TEMPERATURE (℃)	HUMIDITY (%)	SOIL MOISTURE (%)	FALL	VIBRATION
1	2024-03-09 17:29:31	31	52	1	5	0
2	2024-03-09 17:29:00	31	52	1	0	0
3	2024-03-09 17:27:54	31	52	1	0	0
4	2024-03-09 17:27:08	31	52	5	0	0
5	2024-03-09 14:21:56	31	55	1	5	0
6	2024-03-09 14:21:04	31	54	1	0	0
7	2024-03-09 14:20:57	31	54	1	0	1332

Fig. 4. Result in Multiple Phases

A dynamic graph captures the real-time values of sensor readings, illustrating fluctuations and trends in environmental parameters such as soil moisture, temperature, humidity, inclination, and vibration levels. Our result and analysis phase serve as a pivotal stage in interpreting sensor data and issuing timely warnings. In the realm of geohazard monitoring and disaster preparedness, this integration facilitates the collection of real-time environmental data and enables the early detection of landslide precursors.

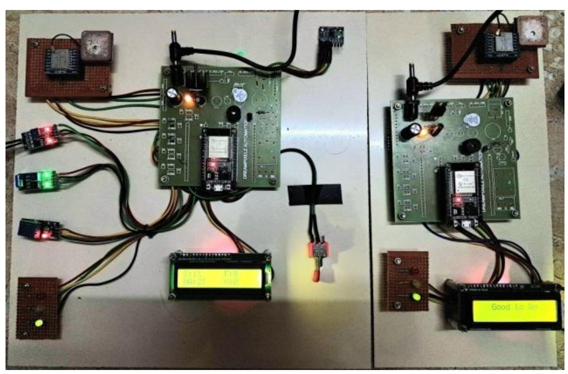
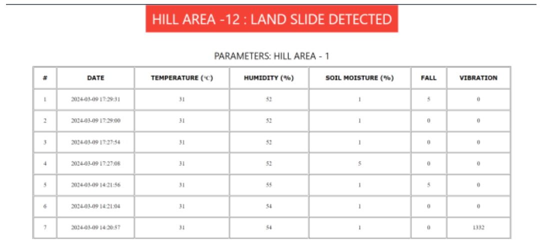


Fig. 5. Hardware Component of Sensor Node And Base Node

LoRa modules, microcontroller DHT11 sensor MPU6050 sensor moisture sensor vibration sensor. According to the table ,timestamps are given together with their corresponding values collected regularly while taking account all sensors into consideration at different points in time. Researchers can perform statistical analysis by aggregating structured formatted information from these devices for easy understanding through differentiating them basing on their types or other categories they belong into so that one may know how each affects another within itself hence finding relations between various environmental variables also termed as parameters. Besides this fact still holds even when we talk about single readings which is wider than just looking at individual results only but rather involves fusion methods too where more sensors are used simultaneously during result interpretation part. Combining LoRa modules with microcontrollers and a range of sensors such as the DHT11, MPU6050, moisture sensor, and vibration sensor allows for the organized collection of environment-related



HILL AREA -12 : LAND SLIDE DETECTED

PARAMETERS: HILL AREA - 1

#	DATE	TEMPERATURE (℃)	HUMIDITY (%)	SOIL MOISTURE (%)	FALL	VIBRATION
1	2024-03-09 17:29:31	31	52	1	5	0
2	2024-03-09 17:29:00	31	52	1	0	0
3	2024-03-09 17:27:54	31	52	1	0	0
4	2024-03-09 17:27:08	31	52	5	0	0
5	2024-03-09 14:21:56	31	55	1	5	0
6	2024-03-09 14:21:04	31	54	1	0	0
7	2024-03-09 14:20:57	31	54	1	0	1332

Fig. 6. Result of Landslide Detected

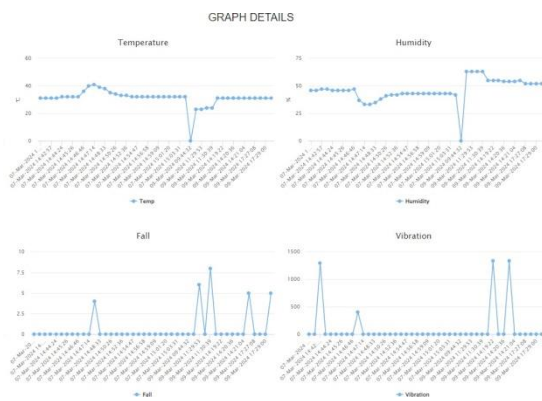


Fig. 7. Real Time Graph of Sensors

the analysis of anomalous sensor readings or other predictive indicators. The visual representation of the detected landslide area enables swift response measures to be implemented to safeguard lives and infrastructure in affected regions. Together, these images encapsulate the essence of our result and analysis phase, where sensor data is synthesized, interpreted, and trans-formed into actionable insights. By harnessing the power of real-time monitoring and early warning systems, our landslidedetection system strives to minimize the impact of landslides on vulnerable communities and infrastructure, ultimately sav- ing lives and mitigating economic losses. Through ongoing research and collaboration, we remain steadfast in our com- mitment to advancing geohazard monitoring and contributing to global efforts to build resilient societies.

Conclusion

Ultimately, the creation of our landslide discovery undertaking is a massive step forward in keeping an eye on geohazards and preparing for tragedies. What we have done is combine newfangled sensing devices with advanced information crunching techniques and instant messaging. It does not only identify but also helps prevent such events by being able to detect them early enough. These potential precursors are detected by analyzing data from many different types of sensors such as MPU6050, DHT11, moisture and vibration sensors among others.

The success in detecting one event can be taken as proof positive that it works well indeed. Our scheme shows emergency responders what needs to be done immediately through dynamic graphs showing real-time readings from various sensors alongside visualizations indicating affected areas so that they may implement quick response measures thereby saving lives and protecting infrastructure in danger zones. We will keep working on it until every community has access to these systems which should help them become more resilient against natural disasters worldwide because even though this technology has come far there are still many other things that need to be considered if we want them work perfectly together. The culmination of our landslide detection initiative marks a significant stride in geohazard monitoring and disaster preparedness. By integrating state-of-the-art sensing devices with advanced data analysis techniques and real-time communication capabilities, we've not only enhanced our ability to identify potential landslide events but also to preemptively mitigate their impact. Through the continuous analysis of data streams from diverse sensors like the MPU6050, DHT11, moisture, and vibration sensors, our system can detect early warning signs and alert emergency responders promptly.

References

[1] L. Benoit, P. Briole, O. Martin, C. Thom, J. P. Malet, and P. Ulrich‘‘Monitoring landslide displacements with the Geocube wireless network of low-cost GPS,’’ Eng. Geol., vol. 195, pp. 111–121, Oct. 2015, doi: 10.1016/j.enggeo.2015.05.020.

[2] D. Tran, D. Nguyen, and S. Tran, ‘‘Development of a rainfall-triggered landslide system using wireless accelerometer network,’’ Int. J. Adv. Comput. Technol., vol. 7, no. 5, p. 14, 2015.

[3] G. Caviezel, A. Schaffner, M. Cavigelli, and L. Niklaus, ‘‘Design and evaluation of a low-power sensor device for induced rockfall experiments,’’ IEEE Trans. Instrum. Meas., vol. 67, no. 4, pp. 767–779, Nov. 2017, doi: 10.1109/TIM.2017.2770799.

[4] M. Arattano and L. Marchi, ‘‘Systems and sensors for debris-flow monitoring and warning,’’ Sensors, vol. 8, no. 4, pp. 2436–2452, Apr. 2008, doi: 10.3390/s8042436.

[5] E. Intrieri, G. Gigli, F. Mugnai, R. Fanti, and N. Casagli, ‘‘Design and implementation of a landslide early warning system,’’ Eng. Geol., vol. 147, pp. 124–136, May 2012, doi: 10.1016/j.enggeo.2012.07.017.

[6] I. Martin, T. O’Farrell, R. Aspey, S. Edwards, T. James, P. Loskot, T. Murray, I. Rutt, N. Selmes, and T. Bauge, ‘‘A high-resolution sensor network for monitoring glacier dynamics,’’ IEEE Sensors J., vol. 14, no. 11, pp. 3926–3931, Nov. 2014, doi: 10.1109/JSEN.2014.2348534.

[7] J. Phengsuwan, T. Shah, P. James, D. Thakker, S. Barr, and R. Ranjan, ‘‘Ontology-based discovery of time-series data sources for landslide early warning system,’’ Computing, vol. 102, no. 3, pp. 745–763, Mar. 2020, doi: 10.1007/s00607-019-00730-7.

[8] A. Dikshit, D. N. Satyam, and I. Towhata, ‘‘Early warning system using tilt sensors in Chibo, Kalimpong, Darjeeling Himalayas, India,’’ Natural Hazards vol. 94, no. 2, pp. 727–741, 2018, doi: 10.1007/ s11069-018-3417-6.

[9] A. Giorgetti, ‘‘A robust wireless sensor network for landslide risk analysis: System design, deployment, and field testing,’’ IEEE Sensors J., vol. 16, no. 16, pp. 6374–6386, Aug. 2016, doi: 10.1109/JSEN.2016.2579263.

[10] N.-P. Ju, J. Huang, R.-Q. Huang, C.-Y. He, and Y.-R. Li, ‘‘A realtime monitoring and early warning system for landslides in southwest China,’’ J. Mountain Sci., vol. 12, no. 5, pp. 1219–1228, Sep. 2015, doi: 10.1007/s11629-014-3307-7.

[11] M. El Moulat, O. Debauche, S. Mahmoudi, L. A. Brahim, P. Manneback, and F. Lebeau, ‘‘Monitoring system using Internet of Things for potential landslides,’’ Proc. Comput. Sci., vol. 134, pp. 26–34, Aug. 2018, doi: 10.1016/j.procs.2018.07.140.

[12] H. Wang, T. Xianguo, L. Yan, L. Qi, and N. Donglin, ‘‘Research of the hardware architecture of the geohazards monitoring and early warning system based on the IoT,’’ in Proc. Comput. Sci., vol. 107, pp. 111–

116, Jan. 2017, doi: 10.1016/j.procs.2017.03.065.

[13] G. L. Ooi, P. S. Tan, M.-L. Lin, K.-L. Wang, Q. Zhang, and Y.-H. Wang, ‘‘Near real-time landslide monitoring with the smart soil particles,’’ Jpn. Geotech. Soc., vol. 2, no. 28, pp. 1031–1034, Jan. 2016, doi: 10.3208/jgssp.HKG-05.

[14] D. Kanungo, ‘‘Ground based real time monitoring system using wireless instrumentation for landslide prediction,’’ in Landslides: Theory, Practice and Modelling. Cham, Switzerland: Springer, 2019, pp. 105–120, doi: 10.1007/978-3-319-77377-3_6.