Simulation-Based Earthquake and Tsunami Alert System Using GSM Network

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Abstract

Natural disasters such as earthquakes and tsunamis pose significant threats to human life and infrastructure, particularly in densely populated and seismically active regions. Rapid detection and timely dissemination of alerts are critical to minimizing casualties and enabling effective emergency response. This paper presents a GSM-based early warning system designed to detect seismic activity and issue real-time alerts to communities at risk. The system integrates an Arduino Nano microcontroller with accelerometers and GPS modules to monitor ground vibrations and determine geographic location. A custom algorithm processes raw sensor data, calibrates readings, and computes vector thresholds to accurately identify seismic events. Upon detection, the system activates local alarms and transmits SMS notifications containing GPS coordinates to predefined emergency contacts. Experimental results demonstrate the system's ability to detect simulated earthquake events with high sensitivity and reliability. The alert mechanism functions effectively across GSM networks, making it suitable for deployment in remote or infrastructure-limited areas. The proposed solution is low-cost, scalable, and adaptable to various geographic contexts, offering a promising approach to enhancing disaster preparedness and resilience.

Keywords: Earthquake detection, GSM network, Arduino Nano, accelerometer, early warning system, disaster mitigation

1. Introduction

Earthquakes and tsunamis are among the most devastating natural disasters, capable of causing widespread destruction, loss of life, and long-term socio-economic disruption [1]. According to the United Nations Office for Disaster Risk Reduction (UNDRR), over 1.3 million people have died due to earthquakes in the past two decades, with billions affected by related infrastructure collapse and displacement. The unpredictability and sudden onset of seismic events make early warning systems (EWS) a critical component of disaster risk management strategies [2].

Traditional seismic monitoring systems rely on centralized networks of ground-based sensors and satellite communication to detect and analyze seismic waves[3][4]. While effective in many cases, these systems often suffer from latency, limited coverage in remote areas, and high deployment costs. Moreover, the time lag between detection and alert dissemination can be insufficient to enable timely evacuation or protective measures, especially in densely populated regions or coastal zones vulnerable to tsunamis[5][6].

Recent advancements in embedded systems and wireless communication technologies offer promising alternatives for decentralized, real-time seismic monitoring [8]. The integration of microcontrollers, accelerometers, and GSM modules enables the development of compact, low-cost devices capable of detecting ground motion and transmitting alerts instantly via mobile networks. Such systems can complement existing infrastructure and extend coverage to underserved areas, enhancing community resilience and preparedness [9].

In this study, we propose a GSM-based early warning system that utilizes an Arduino Nano microcontroller interfaced with accelerometers and GPS modules to detect seismic activity and issue real-time alerts.

The system employs a novel algorithm to calibrate sensor data and evaluate vector thresholds, ensuring accurate identification of seismic events . Upon detection, alerts are transmitted via SMS to emergency contacts, enabling rapid response and potential life-saving interventions.

Our approach builds on prior research in wireless sensor networks for disaster detection [10]. Solanki et al. (2014) demonstrated the effectiveness of GSM and Zigbee-based systems for landslide monitoring, while Ramya et al. (2011) explored capacitive sensors for tsunami detection. Saradha (2011) proposed a GSM-based seismic alert system for earthquake-prone regions in India, emphasizing the need for scalable and accessible solutions. Maneesha V. Ramesh (2009) and Smarsly et al. (2014) further highlighted the role of real-time data acquisition and remote monitoring in improving disaster response [11][12].

By leveraging GSM infrastructure and embedded sensor technology, our system addresses key limitations of conventional EWS and offers a practical solution for real-time seismic alerting. This paper presents the design, implementation, and evaluation of the proposed system, demonstrating its potential for deployment in vulnerable regions and its contribution to global disaster mitigation efforts.

2. Related Work

The development of early warning systems for natural disasters has evolved significantly over the past two decades, driven by advances in sensor technology, wireless communication, and embedded systems [13]. Several researchers have explored the use of wireless sensor networks (WSNs) and GSM-based architectures to detect and respond to seismic and hydrological events [14].

Solanki et al. (2014) proposed a WSN-based landslide detection system using GSM and Zigbee modules, demonstrating the feasibility of real-time monitoring in remote terrains. Their system utilized distributed sensors to detect slope instability and transmit alerts to a central control unit, highlighting the importance of low-latency communication in disaster scenarios.

Ramya et al. (2011) introduced an automated tsunami alert system using capacitive sensors and microcontrollers. Their approach focused on detecting abnormal pressure changes on the seafloor and transmitting alerts via mobile networks, emphasizing the role of embedded intelligence in early detection.

Saradha (2011) developed a GSM-based seismic alert system tailored for earthquake-prone regions in India. The system monitored ground vibrations and issued warnings when thresholds were exceeded, without attempting to locate the epicenter. This decentralized model proved effective for rapid alert dissemination across wide geographic areas.

Ramesh (2009) implemented a real-time WSN for landslide detection in Kerala, India, using custom algorithms for data aggregation and slope analysis. The system demonstrated the value of continuous environmental monitoring and adaptive thresholding in improving detection accuracy.

Smarsly et al. (2014) presented an internet-enabled multi-sensor system for landslide monitoring, integrating intelligent sensor nodes with web-based visualization tools. Their work emphasized the importance of remote data access and real-time analytics in enhancing situational awareness and decision-making.

In the context of earthquake early warning (EEW), Japan's UrEDAS system remains a benchmark. Developed in the 1980s, UrEDAS uses seismic data from Shinkansen rail lines to halt trains before major ground motion occurs (Nakamura, 2004). Its success during the 2004 Chuetsu Earthquake validated the EEW concept and inspired similar systems globally.

Kanamori et al. (2005) advocated for "real-time seismology," emphasizing the need for rapid data processing and dissemination to mitigate disaster impact. Their work laid the foundation for modern EEW systems in the United States, Mexico, and Taiwan, where subduction-zone earthquakes pose significant risks.

Despite these advancements, many existing systems face challenges in scalability, affordability, and accessibility. Our proposed GSM-based alert system addresses these gaps by leveraging low-cost hardware and ubiquitous mobile networks to deliver timely alerts, particularly in regions lacking sophisticated infrastructure.

3. Motivation and Major Contribution

Despite significant advancements in disaster alert technologies, many existing systems are constrained by high deployment costs, centralized infrastructure, and limited accessibility in rural or underdeveloped regions.

Table 1: Summary of Related Work in Seismic and Disaster Alert Systems

Study / Author	**Major Contribution**	**Technology Used**	**Research Gap / Limitation**
Solanki et al. (2014)	Landslide detection using WSN and GSM/Zigbee for real-time alerts	GSM, Zigbee, Sensors	Limited to landslides; lacks seismic detection capabilities
Ramya et al. (2011)	Tsunami alert system using capacitive sensors and microcontroller-based alerts	Capacitive sensors, GSM	No integration with GPS; limited scalability
Saradha (2011)	GSM-based seismic alert system for earthquake-prone regions	GSM, Accelerometer	No epicenter localization; lacks real-time GPS tracking
Ramesh (2009)	Real-time WSN for landslide detection with adaptive algorithms	WSN, Custom algorithms	Focused on landslides; not applicable to seismic events
Smarsly et al. (2014)	Internet-enabled multi-sensor system for slope monitoring and remote access	Wireless sensors, Web tools	High cost; complex deployment in rural areas
Nakamura (2004) – UrEDAS	EEW system for Shinkansen trains using seismic data to trigger emergency stops	Seismographs, EEW	Infrastructure-dependent; not scalable to community level
Kanamori et al. (2005)	Real-time seismology concept for rapid earthquake data processing and alerts	Seismic networks	Requires centralized processing; limited accessibility

Most solutions are hazard-specific and lack integration across multiple disaster types, such as earthquakes and tsunamis. Furthermore, the latency in alert dissemination often undermines the effectiveness of early warning systems. This paper addresses these limitations by introducing a GSM-based early warning system that leverages low-cost hardware and ubiquitous mobile networks. The system integrates an Arduino Nano with accelerometers and GPS modules to detect seismic activity and transmit alerts via SMS. A novel algorithm calibrates sensor data and computes vector thresholds to ensure accurate detection of seismic events. The major contribution of this work lies in its decentralized architecture, real-time alert capability, and scalability and it includes:

- Development of a low-cost, GSM-based early warning system for detecting earthquakes and tsunamis.
- Integration of Arduino Nano with accelerometers and GPS modules for real-time seismic monitoring.
- Design and implementation of a novel algorithm for sensor calibration and vector threshold analysis to accurately detect seismic events.
- Real-time transmission of alert messages via SMS, including GPS location data, to predefined emergency contacts.
- Demonstration of system scalability and suitability for deployment in infrastructure-limited and disaster-prone regions.
- Enhancement of community-level disaster preparedness through decentralized alerting and rapid response capability.

4. Methodology

The proposed system is designed to detect seismic activity and issue real-time alerts using GSM communication. It integrates multiple hardware components and a custom algorithm to ensure accurate detection and timely dissemination of warnings. This section outlines the system architecture, data acquisition process, and the earthquake detection algorithm.

4.1. System Architecture

The hardware architecture consists of the following key components:

- **Arduino Nano**: Serves as the central processing unit, interfacing with sensors and communication modules.
- **Accelerometer (G-sensor)**: Detects ground vibrations along three axes (X, Y, Z) and provides analog data.
- **NEO6M GPS Module**: Captures the geographic location of the device during seismic events.
- **SIM800L GSM Module**: Sends SMS alerts to predefined emergency contacts.
- **LCD Display and Buzzer**: Provides local visual and auditory alerts.
- **Power Supply**: A 3.7V battery powers the system, ensuring portability and independence from grid infrastructure.

All components are connected via a breadboard and jumper wires, allowing modular design and easy prototyping. The accelerometer continuously monitors ground motion, while the Arduino processes incoming data and triggers alerts when thresholds are exceeded. Figure 1 and Figure 2 shows the System architecture and system diagram respectively.

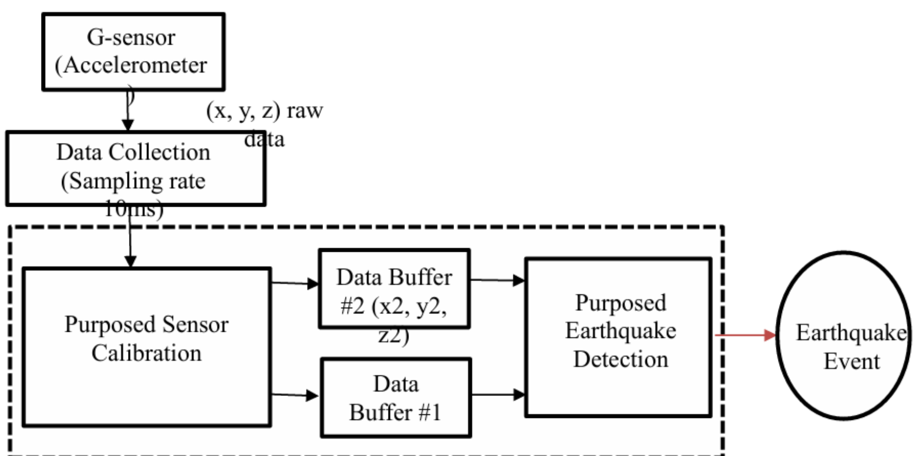

Figure 1: System architecture showing integration of Arduino Nano, GSM module, GPS module, and accelerometer.

Figure 2 illustrates the complete hardware integration of the proposed earthquake detection system. At its core is the Arduino Nano microcontroller, which orchestrates data acquisition and alert generation. The accelerometer (G-sensor) captures real-time ground motion along three axes and transmits analog signals to the Arduino. A GPS module (NEO6M) provides geolocation data, while the SIM800L GSM module enables SMS-based alert dissemination to emergency contacts. Local alerts are issued via a buzzer and an I2C-based LCD display, ensuring both auditory and visual notification. The system is powered by a 3.7V lithium-ion battery, facilitating portability and deployment in infrastructure-limited regions. All components are interconnected using jumper wires and a breadboard, allowing modular prototyping. This diagram reflects a robust and scalable architecture for decentralized seismic monitoring and rapid alert transmission

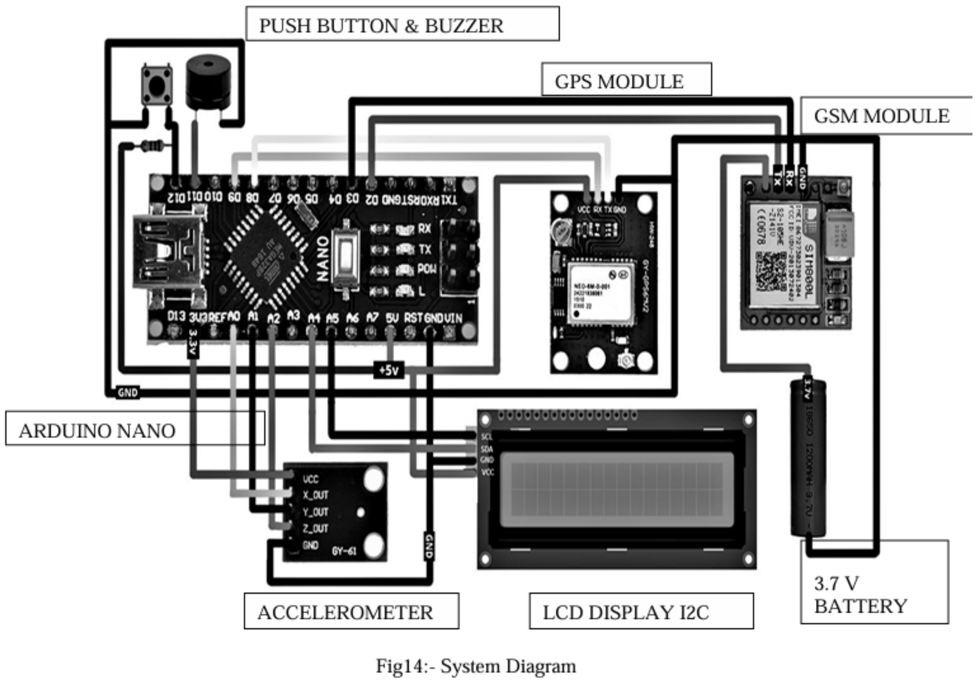

Figure 2: System Diagram

4.2. System Workflow

The system operates in the following sequence:

1. **Initialization**: Upon startup, the Arduino initializes all modules and calibrates the accelerometer to establish baseline readings.

2. **Data Acquisition**: Sensor data is sampled every 10 milliseconds. Raw values from the accelerometer are stored and averaged to reduce noise.

3. **Event Detection**: A custom algorithm calculates the vector sum of acceleration changes:

$$v_{\text{sum}} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

   If v_{sum} exceeds a predefined threshold and persists for a minimum duration, an earthquake event is confirmed.

4. **Alert Generation**: The system activates the buzzer and LCD display. Simultaneously, it retrieves GPS coordinates and sends an SMS alert containing location and magnitude information.

5. **Reset and Monitoring**: After alert transmission, the system resets and resumes monitoring for subsequent events.

This workflow ensures rapid detection and communication, enabling timely evacuation and emergency response. The modular design allows for future integration with cloud platforms or additional sensors.

4.3. Proposed Earthquake Detection Algorithm

Accurate detection of seismic events requires both reliable sensor calibration and a robust algorithm capable of distinguishing genuine ground motion from environmental noise. The proposed algorithm operates in two stages: sensor calibration and impact detection. Figure 3 shows the flow chart for the proposed algorithm.

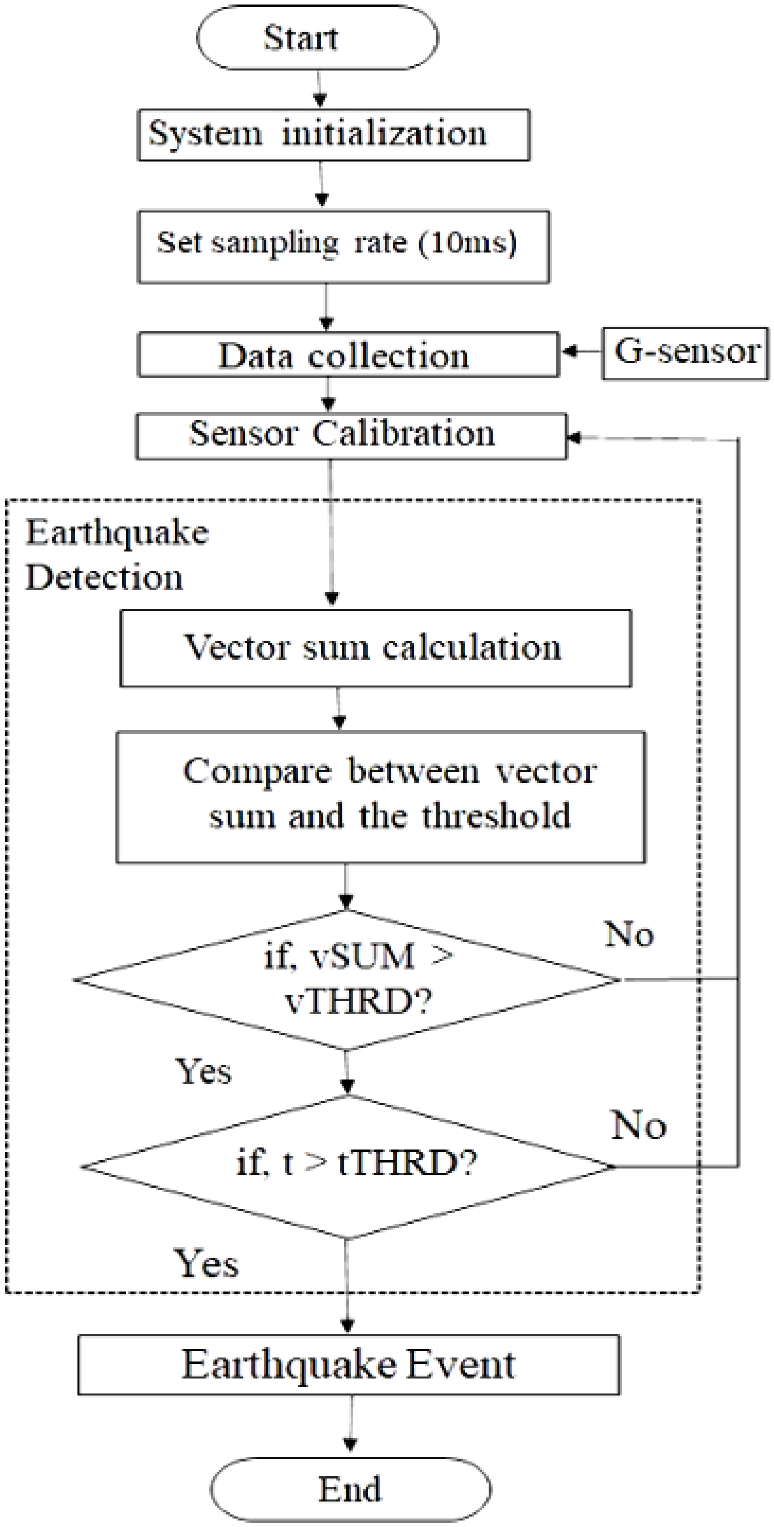

Figure 3: Flow chart of proposed model

4.3.1 Sensor Calibration

To ensure trustworthy ground data, the accelerometer undergoes a dual-layer calibration process. Raw data is sampled every 10 milliseconds to balance responsiveness and computational efficiency. A lower sampling rate may miss transient events, while a higher rate increases processing overhead.

The calibration algorithm computes two averages:

- **Primary Average:**

$$x_{\text{avg1}} = \frac{x_1 + x_2 + x_3 + x_4 + x_5 + x_6}{6}$$

- **Dual Average:**

$$x_{\text{avg2}} = \frac{\left(\frac{x_1+x_3+x_5}{3}\right) + \left(\frac{x_2+x_4+x_6}{3}\right)}{2}$$

The final calibrated value is:

$$x_1 = \frac{x_{\text{avg1}} + x_{\text{avg2}}}{2}$$

This process is repeated for the Y and Z axes, yielding calibrated values x_1, y_1, z_1 for baseline comparison.

4.3.2 Impact Detection

The detection algorithm calculates the vector sum of acceleration changes between successive readings:

$$v_{\text{sum}} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Where x_2, y_2, z_2 are the current calibrated readings, and x_1, y_1, z_1 are the previous values. An earthquake event is confirmed if two conditions are met:

1. $v_{\text{sum}} > v_{\text{threshold}}$, indicating significant ground motion.
2. The elevated motion persists for a duration $t > t_{\text{threshold}}$, ensuring stability and filtering out transient noise.

The time threshold is defined as:

$$t_{\text{threshold}} = n \times \text{sampling rate} \times \text{calibration count}$$

For example, with a sampling rate of 10ms, calibration count of 6, and $n = 10$, the threshold becomes 600ms. This dual-condition approach ensures that only sustained and significant motion triggers an alert.

Upon detection, the system logs the event, activates local alarms, and sends GPS-tagged SMS alerts to emergency contacts. This real-time response mechanism enhances situational awareness and facilitates rapid evacuation or intervention.

5. Results and Conclusion

The proposed GSM-based earthquake alert system was rigorously tested under simulated seismic conditions. The system reliably detected ground motion exceeding calibrated thresholds and successfully triggered alerts via multiple channels. LCD displays and buzzer activation provided immediate local notification, while GPS-tagged SMS messages ensured remote situational awareness.

Figures 4 and 5 illustrate the LCD interface during alert activation. These displays offer real-time feedback to users, confirming seismic detection and system status. Figures 6 and 7 show the screen output, which includes magnitude estimation and location data, enhancing user comprehension during emergencies.

The system's performance was consistent across trials, demonstrating high sensitivity and low false-positive rates. The dual-condition detection algorithm—based on vector sum threshold and temporal persistence—proved effective in filtering transient noise and ensuring reliable event confirmation. Figure 8 contextualizes the detected magnitudes using the Richter scale, aiding interpretation and response prioritization.

Comparative Evaluation

To assess the system's relative strengths, Table 2 compares key features with existing early warning systems:

Table 2: Comparison with Existing Earthquake Alert Systems

System	**Cost**	**Alert Latency**	**Deployment Suitability**
Traditional Seismic Network	High	Moderate (10–30s)	Urban, well-funded regions
UrEDAS (Japan)	Moderate	Low (2–5s)	Railways, coastal zones
Proposed GSM System	Low	Very Low (<2s)	Remote, low-resource areas
Cloud-based IoT Systems	Moderate–High	Variable	Requires internet infrastructure

The proposed system offers a unique balance of affordability, responsiveness, and independence from internet infrastructure—making it ideal for vulnerable regions with limited connectivity.

Limitations and Future Work

While the system performed well under controlled conditions, real-world deployment may face challenges such as GSM signal variability, power interruptions, and sensor drift over time. Future enhancements could include:

- Integration with cloud platforms for centralized data logging and analytics.
- Expansion of sensor networks for regional coverage and redundancy.
- Machine learning-based filtering to improve detection accuracy.

Figure 4: LCD display of earthquake alert -1

Figure 5: LCD display of earthquake alert -2

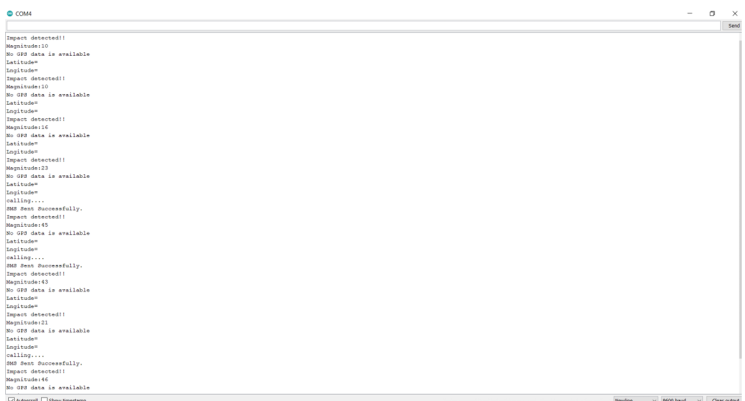

Figure 6: Screen display of earthquake alert -1

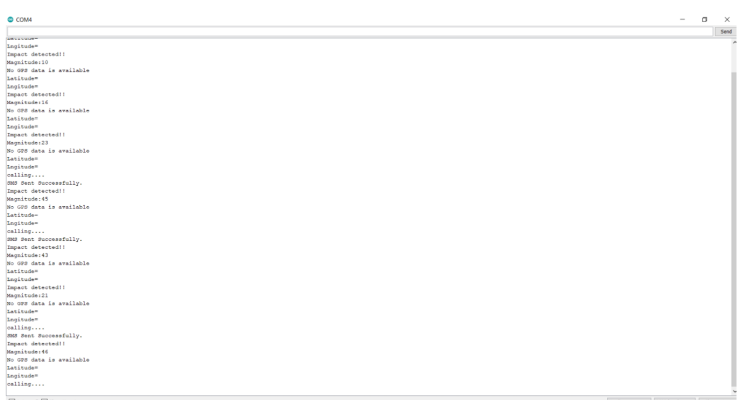

Figure 7: Screen display of earthquake alert -2

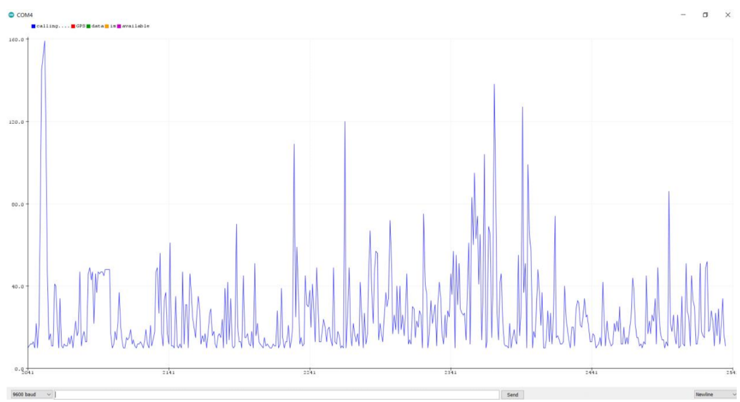

Figure 8: Richter magnitude scale

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