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Internet of Things for Earthquake Disaster Mitigation

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Abstract: Earthquakes are among the most damaging natural disasters, since they are responsible for a significant amount of property damage and fatalities. Studies have demonstrated the ineffectiveness of traditional disaster management techniques in properly anticipating earthquake damage or reducing its extent. By using the Internet of Things (IoT), which is a system of connected devices that share data instantly, we can greatly enhance how we manage earthquakes, monitor building safety, and use GPS and mobile devices, leading to early warnings, real-time alerts, and better decisions during emergencies. This paper investigates the potential use of the IoT in earthquake mitigation, preparedness, response, and recovery. Within the context of post-disaster response, early warning systems, and seismic monitoring, it discusses the operational and technological aspects of the IoT. Additionally, we discuss the limits and potential future applications of IoT integration in disaster management, emphasizing the importance of scalability, data security, and seamless integration capabilities.

Keywords: Internet of things, earthquake disaster mitigation, early warning systems, real-time monitoring, disaster recovery.

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1. Introduction

Unpredictable in nature, earthquakes frequently cause serious harm to the environment, infrastructure, and human lives (Mezősi, 2022). Instead of emphasizing prevention and mitigation, current disaster management strategies mostly concentrate on recovery and response. The Internet of Things (IoT) has the potential to revolutionize this situation in terms of earthquake preparedness, detection, and response. The IoT is a network of interconnected devices that gather and share data. IoT-based systems can send early alerts, monitor seismic activity continuously, and assist in coordinating disaster response activities (Sharma et al., 2021).

In addition to discussing the possibilities for future advances, this study looks at how IoT technologies are now being used in earthquake disaster management. However, it has been demonstrated that IoT is fundamentally capable of offering more substantial, scalable, portable, and energy-efficient solutions to a number of issues in earthquake disaster management. These problems make it crucial to have a general awareness of how IoT is currently used to detect and manage earthquakes. This study reveals that a number of seismic disaster management solutions are entirely dependent on the Wireless Sensor Network (WSN), a crucial component of the IoT in which geographically dispersed nodes perceive and respond appropriately.

Additionally, these WSN systems typically have smart sensors and processing units along with a variety of topological structures. Because of this, these WSN-based solutions are now a necessary component of connecting to IoT-supported systems. This paper provides a thorough analysis of the many facets of IoT enabled seismic catastrophe management in order to accomplish this goal.

Here are the key points from this article:

- A comprehensive review of the topic highlights the critical protocols for seismic catastrophe management based on IoT.
- We present a curated analysis of commercially available IoT solutions for earthquake disaster mitigation systems, including both open-source and proprietary options.

- The article concludes by outlining the major obstacles faced by earthquake disaster mitigation systems that rely on the IoT and offering suggestions for moving forward.

1.1. Objectives

Objectives of this research are summarized below:

- To examine the role of IoT technology in the phases of earthquake disaster mitigation
- To analyze the operational and technological components of IoT-based systems used in seismic monitoring and early warning systems.
- To identify the limitations and challenges in implementing IoT for earthquake disaster mitigation
- To propose potential strategies for the effective integration and deployment of IoT technologies in earthquake-prone regions.

1.2. Research Questions

This paper endeavors to answer the following questions:

- How can IoT technologies enhance the effectiveness of earthquake disaster mitigation?
- What are the key technological and operational requirements for deploying IoT-based seismic monitoring and early warning systems?
- What challenges and limitations are associated with the integration of IoT into current disaster management frameworks, particularly in developing regions?
- What strategies and frameworks can ensure secure, scalable, and interoperable IoT deployment for earthquake disaster mitigation and response?

Section 2 presents various reviews of concepts, including the IoT Earthquake Disaster Management, and IoT-based Earthquake Disaster Mitigation Systems. Section 3 presents the Effect of IoT on Earthquake Disaster Mitigation. Materials and Methods and IoT Architecture in Earthquake Disaster Mitigation in Section 4. Section 5 deals with the Application of IoT in Earthquake Disaster Mitigation. Section 6 presents the Proposed Reference Model. Section 7 provides the challenges in implementing IoT for Earthquake Disaster Mitigation, and Section 8 provides the Future Prospects for research-related issues. Finally, Section 9 concludes this survey.

2. A Review of Concepts

An accurate picture of earthquake disaster mitigation systems and their operations is necessary for comprehending the revolutionary role of the IoT in this area. In this section we will first discuss the IoT, its needs, and the uses IoT in earthquake disaster mitigation systems. Our next section will discuss the benefits of IoT collaboration for earthquake disaster mitigation and some of its requirements.

2.1. Internet of Things

In the future, there will be an internet of misconfigured gadgets, according to the IoT, a relatively new paradigm in communication using radio frequency identification (RFID) technology. Ashton Kevin first used the phrase "Internet of Things" in 1999 to describe a network of interconnected, individually identifiable things. The International Telecommunication Union (ITU) clearly defined the term in their 2005 "ITU internet report and recommended the concept of the IoT" (Atzori et al., 2010). At the World Summit on the Information Society (WSIS) conference in Tunis, Tunisia, on November 17, 2005. The United Nations' Specialized Agency for Information and Communication Technology (ICU) later in 2009 defined the IoT as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technology (Din et al., 2018).

Unsurprisingly, the IoT will enable the full utilization of things to provide a service to various applications while guaranteeing the fulfilment of security and privacy needs by leveraging device identification, data gathering, processing, and communication capabilities. When considering the IoT in a broader context, it can be viewed as a vision that has significant social and technological implications (Sunyaev et al., 2020). With the help of standard and interoperable communication protocols, the IoT is a "dynamic global network infrastructure with self-configuring capabilities where physical and virtual things have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network," according to the European Research Cluster Internet of Things (IERC) in 2013 (Singh et al., 2014).

2.2. Earthquake Disaster Mitigation Systems

Natural disasters akin to earthquakes occur nearly every day in various regions of the world. As a result, millions of people lose their lives or become homeless (Convertito et al., 2024). The term "earthquake disaster mitigation" refers to a methodical strategy that brings together public and private organizations at the federal, state, and local levels to coordinate efforts in the event of an earthquake, including mitigation, preparation, response, and recovery. We can view the concept of earthquake disaster mitigation as a collection of several interconnected processes to better understand, evaluate, monitor, and anticipate the occurrence of seismic disasters. The rapid advancements in Information and Communication Technology (ICT) over the past 20 years have made it possible to initiate modern disaster response within realistic time and budget constraints. One type of information system that can aid in earthquake disaster mitigation is the Earthquake Disaster

Mitigation System (EDMS). Decision-makers and responders can use this system to acquire, manage, and use data on earthquake disasters in a timely and effective manner. Data mining, multi-criteria decision-making, and data integration are the three primary parts of an EDMS (Peng et al., 2011).

EDMS are sophisticated, highly interconnected systems that need design and maintenance tailored to each application. The design and implementation of an EDMS has become a multi-faceted and complicated task currently because of massive amounts of data that are required in real-time analytics and the participation of several interconnected data nodes. We can classify different seismic disaster mitigation apps into two stages: pre- and post-disaster, due to their distinct features and varying needs for reaction speed, accuracy, and efficacy. Therefore, measured and comprehensive data analysis is the main emphasis of pre-seismic disaster applications, including earthquake prediction, early warning systems, simulation exercises, and more. Emergency operations following an earthquake, including evacuation, rescue, and monitoring, need prompt and precise outcomes. Nevertheless, EDMSs in their many forms should facilitate the interactive extraction of valuable knowledge from disparate and dispersed data sources by decision-makers. Reliability, availability, maintainability, correctness, and usability are some of the ideal technical criteria that EDMSs should have (Bayrak et al., 2009).

2.3. IoT-Based Earthquake Disaster Mitigation System

Although scientists have not yet developed a foolproof method of earthquake prediction or prevention, IoT offers a promising alternative: early warning systems that use foreshocks to mitigate damage. That said, scientists are busily working on new kinds of IoT-based technologies that can alert potential victims who are far away before the incident even happens. "Nerve Net," a recent deployment in Onagawa, Japan, represents a recent development in the integration of the IoT with earthquake monitoring. The foundational idea is a bypass network, which is durable in the face of disasters. Technologies like Wi-Fi, satellite, optical Ethernet, and Unmanned Aerial Vehicles (UAVs) that enable local and distant communications over a range of several kilometers (Adhikari et al., 2023). (Babu et al., 2018) developed a system that detects earthquakes by measuring the earth's minor shocks. The system generates and transmits alarm signals upon identifying an earthquake. This system utilizes the M2M (Machine to Machine) connection protocol, the Lua programming language, and the NodeMCU platform. The system also utilizes the GY-61 DXL335 sensor module for dynamic acceleration detection. Cayenne software also plays a crucial role in creating and delivering the warnings. (Roy et al., 2024) constructed an instrumentation system using IoT technology to detect the foreshocks. The system's components and gadgets include a piezoelectric accelerometer, an ADC 809 converter, a P89V51RD2 microcontroller, a vibration sensor, GSM, an LCD, and a form of 64kB flash memory with 1024 bytes of RAM. C and the 8051 microprocessor are the backbone of the platform. (Gupta et al., 2018) created a system that detects earthquakes, sensing circumstances in real-time and updating the data accordingly. The Node MCU microcontroller serves as the system's central processing unit. Microelectromechanical systems (MEMS) are the sensors utilized in this setup. The IoT's serve as the foundation for this system's open-source platform, Thinkspeak. (Karaci et al., 2018) created an earthquake warning system that not only alerts inhabitants but also identifies non-destructive foreshocks and tweets the start and finish times of the earthquake. A Grove-Piezo vibration sensor card, an IMU sensor, and an Arduino Mega microcontroller all work together to detect vibrations in the system. This system also utilizes a buzzer and an ESP8266 WiFi module. In addition, the system's platform is developed through a combination of processing and wiring language. (Zambrano et al., 2017) developed an early warning system that uses smartphone data to forecast the epicenter's maximum shaking intensity for up to 12 seconds in advance, and has integrated a three-tiered design. Microcontrollers are replaced by smartphone nodes. Wi-Fi, 2G, 3G, and 4G networks, as well as the sensor web, are the components of the system. System protocols include a Secure Socket Layer (SSL), Network Time Protocol (NTP), and Message Queue Telemetry Transport Protocol (MQTT).

We must upgrade modern earthquake disaster mitigation systems to more advanced ones that can handle data from a variety of sources and utilize cutting-edge technology to improve connectivity, storage, real-time analytics, and efficiency without incurring significant costs. These systems can effectively implement IoT technology for earthquake-related emergency operations.

3. Effect of IoT on Earthquake Disaster Mitigation

In particular, the IoT can identify and anticipate crucial events and crises, prepare for the necessary circumstances, and utilize potential pre-disaster and post-disaster resources and situations. This section has covered the impact of IoT technology on all phases of earthquake disaster mitigation.

3.1. Mitigation

This phase, which must occur before an earthquake, involves placing sensors in various high-risk areas to regulate environmental and seismic conditions. In the event of a threat, these sensors can prevent numerous financial and human casualties through early warnings and enabling better preparations, thereby reducing the impact of disasters through the use of zoning and building codes, risk assessments, and public awareness campaigns. For example, with constant monitoring, gyroscopes and ultrasonic sensors can identify atypical earthquakes. Unquestionably, space technology contributes to precisely visualizing Earth's movements in every region. Geographic Information Systems (GIS) aid in the definition and development of disaster management infrastructures, while satellite imagery offers a useful perspective on earthquake-prone areas (Kaku et al., 2019).

Fig. 1. Effect of IoT on earthquake disaster mitigation

3.2. Preparation

At this stage, various models for potential disasters can be created with the use of the pre-stored data and its assessments. Even before the consequences of a disaster become widespread, it may be possible to assess and forecast the affected areas and the extent of destruction, provided that models faster than real-time simulations are available (Ujjwal et al., 2019). By simulating the location and space of a disaster and utilizing technologies like virtual reality, it is possible to improve disaster mitigation techniques and increase the readiness of key emergency response system members (Longo et al., 2019), as well as to train people on how to handle mental health and environmental issues in the event of an earthquake and prevent physical harm to the public (Sakurai et al., 2019).

3.3. Response

At the current stage of development, gathering situational information is a decisive and essential step in addressing the primary needs that arise after an earthquake. Social networks like Facebook and Twitter are valuable sources of information for two-way exchanges between individuals and management organizations (Pourebrahim et al., 2019) The aforementioned examples include TERA, a text messaging system that connects individuals and relief organizations (Ghasemi et al., 2020), SERVAL, a technology that allows mobile phones to communicate directly even when the network is unreliable, and Cisco's Tactical Operations, a satellite-based telecommunication strategy with cloud teleology. All of these technologies are intended to help people communicate during disasters. Following the discussion of collecting data, the topic of first aid is brought up, and poor management can result in the loss of both money and human resources. For this reason, (Wex et al., 2014) provided a model for scheduling and assigning tasks to rescue units in emergency situations. A real-time model for implementing a suitable approach in disaster management operations and rescue plans has also been proposed by (Kumar et al., 2017).

3.4. Recovery

Returning the community to normal at this stage can be achieved through temporary housing, grants, medical care, and IoT, which would also assist in assessing the effects and damages of the earthquake, while implementing the recovery plans that have been decided upon, as well as continuously monitoring the remaining human and financial resources in relation to unresolved damages (Elliott et al., 2020). In order to optimize energy-related decisions during emergencies, (Nourjou et al., 2017) presented a system that uses real-time monitoring software of power outages and their macroeconomic losses.

As discussed previously, the IoT holds significant promise for advancing seismic disaster mitigation, which might become a core component of relief organizations' agendas. By changing disaster mitigation from reactive to proactive, IoT reduces risks and enhances response through the use of sensors, robotics, and autonomous vehicles, among other technologies. Additionally, the information produced by these gadgets helps everyone make better judgments by reducing the possibility of being caught off guard. Improved communications technologies also help with rescue operations.

4. Materials and Methods

IoT devices may collect data in real-time, allowing for better earthquake disaster mitigation. Predictive analytics examines data from both historical and real-time sensors to forecast catastrophes, while risk assessment is crucial for identifying potential dangers and weaknesses. The agile approach is all about breaking down the development process into tiny sprints, which helps with both producing value rapidly and reacting to changing needs. For earthquake disaster mitigation that relies on the IoT to keep tabs on environmental conditions and notify users of possible disasters, real-time monitoring is crucial. Based on data analysis and customer input, continuous improvement is necessary.

4.1. IoT Architecture in Earthquake Disaster Mitigation

Sensors, devices, networks, and platforms make up IoT systems, which work together to record and transfer data. Architecture generally consists of the following:

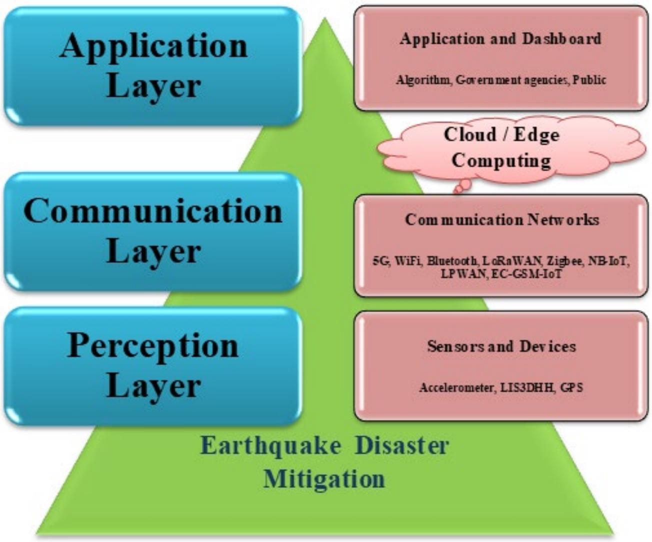


Fig. 2. IoT Architecture in earthquake disaster mitigation

- Sensors and Devices: Seismic sensors, GPS devices, and accelerometers that monitor ground motion, building vibrations, and structural integrity.
- Communication Networks: Wireless communication technologies such as 5G, LoRaWAN, and Zigbee that enable real-time data transmission.
- Cloud/Edge Computing: Data collected from devices are processed and analyzed in the cloud or at the edge of the network for rapid decision-making.
- Applications and Dashboards: User interfaces that display real-time earthquake data and alerts to first responders, government agencies, and the public.

5. Applications of IoT in Earthquake Disaster Mitigation

In this section, we present the significant application of earthquake disaster mitigation using the IoT.

5.1. Seismic Monitoring and Data Collection

IoT sensors are essential for tracking earthquake activity. To find tremors and vibrations, these sensors might be placed on buildings, in cities, or in high-risk locations. Data is sent to centralized systems upon detection of an earthquake, where computers assess its magnitude and its consequences. This information aids in improved comprehension and readiness by offering insightful information on the features of the earthquake (Rosca et al., 2024).

5.2. Earthquake Early Warning Systems

The creation of Earthquake Early Warning Systems (EEWS) is one of the most important uses of IoT in seismic disaster mitigation. These systems identify the first seismic waves (P-waves) produced during an earthquake using Iot sensors. An EEWS can issue warnings before the more destructive secondary waves (S-waves) hit populated areas by utilizing real-time data transmission. IoT-based systems can anticipate the magnitude and intensity of an earthquake by analyzing ground motion and incorporating real-time data from seismic sensors. Smart speakers, mobile devices, and other linked platforms are used to send alerts to emergency services, businesses, and citizens. People may have critical seconds to seek shelter, stop equipment, or leave buildings in response to this notice (Abdalzaher et al., 2021). IoT-driven early warning systems, for example, have been deployed in nations including Taiwan, Japan, and Mexico. These systems send out alerts through public broadcasting systems, radios, and cellphones. By halting trains, cutting off gas supplies, and initiating safety procedures, these alerts enable authorities to prevent fatalities and minimize damage to infrastructure (Pierleoni et al., 2023).

5.3. Real-Time Structural Health Monitoring

Infrastructure and buildings are susceptible to seismic activity. Real-time structural health monitoring can be provided via IoT-enabled sensors placed in buildings and infrastructure, including highways, bridges, and dams. During seismic occurrences, these sensors measure tilt, vibrations, and other important factors that may point to structural stress or damage. Authorities can evaluate the state of vital infrastructure and respond quickly when necessary by continuously gathering and sending data to central systems. Building-integrated smart sensors, for instance, can detect cracks or changes in load-bearing structures, triggering automated safety procedures or alerting engineers of possible dangers. This enhances long-term safety planning and lessens the chance of collapse during an earthquake (Roghaei et al., 2014).

5.4. Disaster Response and Recovery

IoT technologies play a crucial role in disaster response and recovery following an earthquake, as they provide real-time data on the condition of affected areas. Drones and robots with sensors are examples of IoT equipment that can evaluate damage and look for survivors in difficult-to-reach places. Data from these devices is evaluated to effectively distribute resources and prioritise rescue operations.. Furthermore, IoT-enabled communication solutions help maintain coordination between command centres and responders by preserving connectivity when traditional networks fail. Additionally, keeping an eye on supply levels and making sure that necessities like food, water, and medical supplies get to the areas where they are needed most IoT-based tracking systems can also assist in controlling the distribution of aid and resources. As a result, these systems help support and coordinate more effective recovery efforts (Kamruzzaman et al., 2017).

5.5. Smart Cities and Earthquake Resilience

IoT plays a vital role in enhancing earthquake resistance in urban areas as cities evolve into smart cities. Connected systems– such as utility grids, traffic control systems, and emergency communication networks– are key components of smart city infrastructure and can be adjusted to react more effectively to seismic activity. By integrating IoT across multiple systems, cities can implement automatic safety measures such as turning off electrical grids, rerouting traffic, or dispatching emergency crews to affected areas in real-time. By incorporating the IoT into smart city infrastructure, earthquake-related disruptions can be reduced, and recovery operations can be better organized and executed (Shah et al., 2019).

5.6. Smart Government

The future of e-governance lies in smart government, an adaptable evolution of e-government that aims to enhance citizen engagement, accountability, and interoperability in response to the rapid changes in digital technology. These governments employ IoT to ensure sustainability and meet citizens' needs. After recognizing numerous advantages, governments worldwide have begun allocating billions of dollars to transition from e-government to smart government. To thrive in diverse and unpredictable environments, they are turning to smart technology as a driver of innovation, sustainability, competitiveness, and livability. As a result, the concept of "smart government" has gained global momentum. Consequently, there is a strong correlation between the expansion of smart governance and the use of the IoT (Poudyal et al., 2025).

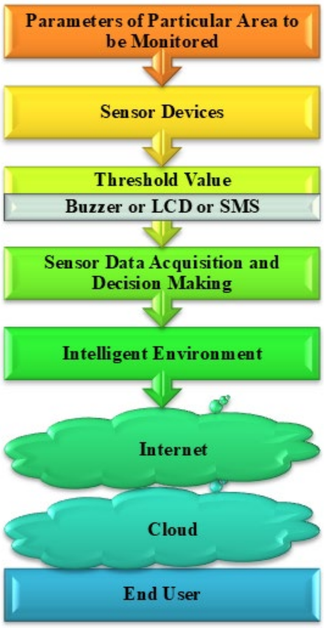
6. Proposed Reference Model

The proposed concept uses wireless communication to monitor Earth's coordinates in a specific area, in order to create an intelligent environment that interacts with nearby objects. Figure 3 illustrates the suggested model, which is more distributive and flexible in nature and may be used to track the parameters of coastal areas. The suggested model was created to monitor earthquakes. The first model identifies key parameters under the area that needs to be watched in order to control earthquakes. The second part focuses on sensor devices with appropriate features and characteristics. Each sensor device is regulated and operated according to its sensitivity and sensing range. Depending on the circumstances, essential sensing and controlling activities will be conducted between the second and third parts. These include setting the threshold value, determining the frequency of sensing, and sending out signals (such as an LCD, siren, or buzzer). The parameter threshold values, under regular working conditions and critical situations, are established based on the data analysis and prior experiences. The third section discusses how sensor data is acquired and incorporates decision-making, indicating which parameter the data reflects. The intelligent environment is covered in number four. This means it will detect changes in the sensor data and set the threshold value based on the determined coordinate level. It will process the sensed data, store it in the cloud, and display a trend of the sensed parameters in relation to the designated values. When a certain range is exceeded, end users can also receive alerts via SMS.The Atmel SAM3X8E ARM Cortex-M3 CPU is the basis of the microcontroller board known as the Arduino Due. It uses a 32-bit ARM core microprocessor, making it the first Arduino board to do so. The Arduino Due is a basic microcontroller. It has 54 I/O digital pins (12 of which are PWM outputs), 12 analogue inputs, 4 hardware serial ports (UTG), an 84 MHz clock, 2 Digital-to-Analogue Converters (DACs), 2 Two-Wire Interfaces (TWIs), and a power jack SPI header. All you need is a micro-USB cable, an AC-to-DC converter, or a battery to get this board going; it comes with everything you need to support the microcontroller. We can use the Due with any Arduino shield that has a 3.3V output and a 1.0 pinout. The Arduino Due board operates at 3.3V, which is different from previous Arduino boards. The input/output pins have a maximum voltage tolerance of 3.3V. Compared to standard 8-bit microcontroller boards, the Due's 32-bit ARM core offers superior performance. The most notable distinction is the 32-bit core, which allows operations on data up to 4 bytes in size within a single CPU tick. Runs at 84 MHz. The system utilizes 96 kilobytes of static random access memory (SRAM). 512 KB of flash memory has the capacity to store code. The DMA controller can free up the CPU from activities that require a lot of memory.

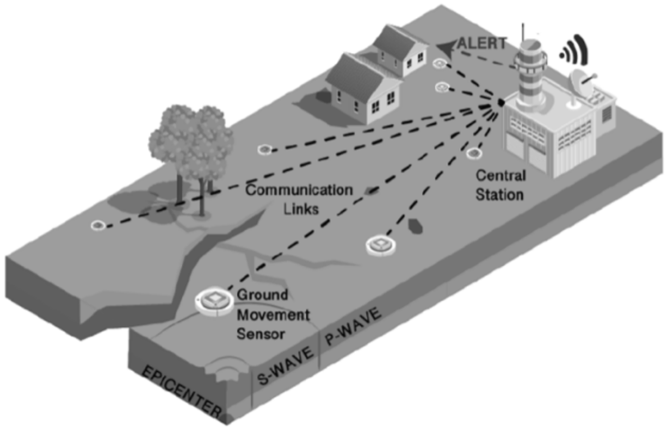
Alphonsa et al. (2021), suggested an extremely basic IoT system that operates on this principle. It gathers data on ground vibrations using accelerometers linked to microcontrollers, processes it using Zigbee, and then transmits the results to a receiver linked to a personal computer, which in turn notifies users. Additionally, by transmitting warning signals to a base transceiver station, GSM modules can notify mobile phone users.

7. Challenges in Implementing IoT for Earthquake Disaster Mitigation

This section summarizes some of the main problems that IoT -based earthquake disaster mitigation systems are currently facing.



(a)



(b)

Fig. 3. (a) Procedure of earthquake disaster mode and (b) implementation of earthquake disaster model based on IoT and P-Wave

7.1. Earthquake Disaster Data Quality

To mitigate the effects of an earthquake, it is essential to have high-quality data; in the event of a disaster, issues and lost time might result from data that is noisy, incomplete, or prone to errors. Before conducting any study on the IoT seismic catastrophe mitigation system, we must resolve this issue. Data quality parameters play a crucial role in evaluating the reliability of an analysis on a specific dataset. The five data quality parameters are well-known and appropriate for use in the disaster data formulation and filtering processes. In order to proceed with processing, each dataset must meet the requirements described against the provided parameter. There are a lot of data format converters and filtering algorithms that are presented all the time, but improving data quality—which should be the top goal in catastrophe prevention efforts like earthquakes—remains an unsolved research problem (Jayawardene et al., 2021).

7.2. Cost and Scalability

Large-scale IoT system implementation can be costly, especially for poor nations that are most susceptible to earthquakes. In IoT deployments, researchers worldwide are primarily concerned with minimizing hardware and software expenses while optimizing system performance. The expense of setting up, maintaining, and modernizing IoT infrastructure may prevent its broad use. Disaster management is thought to be a life-saving endeavor. Therefore, in order to further reduce costs, multinational farms should think about developing cutting-edge technologies in this area. Furthermore, covering large earthquake-prone areas necessitates a substantial investment in infrastructure, maintenance, and training in order to ensure that IoT solutions are scalable to handle large-scale disaster situations (Chen et al., 2013).

7.3. Interoperability and Standardization

One of the most prevalent problems with IoT devices is interoperability. IoT-enabled sensor nodes ought to be built so that information can be communicated to nearby or distant users in case of an emergency. The majority of the sensors are situated in areas that do not experience human location, however these areas also require upkeep. Such products would thus be extremely difficult to maintain. It is commonly known that different types of disasters require different approaches and may have distinct standards. The three main issues that need to be addressed with the dissemination of IoT technologies are security requirements, connectivity standards, and identification standards. Earthquake disaster mitigation was challenging (Sharma et al., 2021).

7.4. Context Awareness and Knowledge Discovery

Since billions of devices are connected to one another through the Internet, context awareness becomes very evident for the user community to manage all the collected data at once in the event of a crisis. An enhanced version of the context awareness techniques must be applied in order to assist in processing the data that is critically needed during the disaster phase. The predicate of data validation in the field of continuous interruption seems to be confusing the processor in the context of the disaster. The existence of billions of devices has made knowledge discovery a task. The large number of sensors in various locations accumulates data in a challenging manner until the aggregation is combined into big data to study the information of big data. Effective data mining techniques are required in a disaster. With data similarities and knowledge of data semantics and contexts, discovery is a fairly complex process in a hierarchical solution. Run-time analysis disasters are often required; they are not influenced by humans because of their tremendous complexity. Real-time insights require algorithms (Ray et al., 2017). Tolerance schemes have recently been indicated that related algorithms are often used in the standard real-time decision-making phase.

7.5. Data Security and Privacy Concerns

There are serious security and privacy issues due to the enormous volume of data that IoT devices collect during catastrophic situations. No malevolent attackers may interfere with the data gathered from damaged locations or occurrences. Critical data, including the whereabouts of survivors or the condition of essential infrastructure, could end up in the wrong hands if IoT networks are hijacked. To preserve the confidentiality and integrity of the data gathered, strong cybersecurity measures must be in place (Shah et al., 2019).

7.6. Infrastructure and Connectivity Limitations

Ensuring reliable infrastructure and communication is a major obstacle when implementing IoT devices, particularly in areas that experience regular earthquakes. IoT devices may become inoperable when communication networks are disrupted by seismic occurrences. The success of IoT-based earthquake disaster mitigation depends on creating a redundant and robust communication infrastructure that can tolerate seismic activity (Khan et al., 2023).

7.7. Fault Tolerance

Prior systems were inadequate and lacked fault tolerance, a critical component. We should maintain a very high fault tolerance level to ensure that system failures (such as a low battery signal, memory crunch from dynamic paging, recurrent pooling and sensor interruptions, rapid rise in current, etc.) do not disrupt operation. A dead battery is only one of several potential causes of hardware module malfunction. The wrong reading from a sensor, improper calibration, or a communication failure are all potential causes of a flawed situation. While using multiple communication protocols may result in higher power consumption, they consistently offer seamless connectivity. In this scenario, activating a single protocol at any time can reduce power consumption. Accurate calibration is required before final installation. In addition to power consumption, another factor to consider is the design of the sensors, which may be somewhat rigid. Pre-disaster mode necessitates sensor manufacturing or casing to minimize earthquake impacts and enable quick information retrieval (Zeng et al., 2023).

7.8. Data Analytics and Run-Time Analytics

This is where current disaster-focused IoT solutions are limited. The proposed systems should analyze spatial-temporal datasets gathered from distinct disaster sites at different points in time, taking into account the features of disastrous conditions. When contexts, sizes, formats, and meanings are irregular, this becomes considerably more challenging. As a result, the existing situation should effectively be linked to a smooth data analytics platform in terms of cloud service (Gaire et al., 2020). Because disasters are so dynamic, they are typically beyond human control. Thus, it is true that a hard real-time analytics solution exists. Two techniques were proposed by (Yin et al., 2013) for real-time fault-tolerant systems. The real-time decision-making process may also use similar algorithms.

7.9. Social Media with Synchronized Emergency Communications

Social media presents another difficulty. Facebook, for example, introduced an automatic "safety check" feature during the Nepal earthquake. The stranded survivors should inform their loved ones and neighbours of their precise position and security status. The testing phase for these solutions is currently underway. Facebook and Twitter, two microblogging platforms, help synchronize assistance for disaster locations with more efficient or useful notations. These are the various difficulties encountered during calamities, and we must reduce them (Abdalzaher et al., 2024).

7.10. Privacy and Security

IoT domains extensively use open personal information, posing a major privacy issue. Misuse of this information may lead to dangers including profiling, tracking, theft, and discrimination. The transfer of big data over several networks necessitates stringent security measures since the data typically includes sensitive personal or government information. The data sets collected by social media platforms often include users' personal information and geographic locations, which might raise privacy concerns. A catastrophe such as a civil war or a resistance movement might make these data sets extremely delicate. Also, there isn't enough of a security mechanism in place for open-source big data analytics tools and the majority of Hadoop ecosystem products (Zambrano et al., 2017). An appropriate security system is necessary to manage the access control of large catastrophe datasets, thereby preventing unauthorized use of this data.

8. Future Prospects

New developments in technology bode well for the IoT potential in the field of seismic disaster mitigation. Here are a few potential avenues for further study:

- Low Cost and Low Energy: For the expansion and application of IoT-based solutions in earthquake disaster mitigation systems, low-cost solutions are preferred. For IoT-based sensor modules to be widely deployed, these nodes' manufacturing and sales costs must be kept to a minimum (Sharma et al., 2021). The catastrophe has insufficient energy sources. IoT-enabled nodes should therefore be built with reduced power consumption in mind. Furthermore, harvesting energy from renewable sources emerges as another viable strategy to address a network's energy limitation problems (Biabani et al., 2020).

- AI and Machine Learning Integration: By combining IoT with AI and machine learning, earthquake prediction models can be improved, allowing for more precise, predictive, and behavioural analysis capabilities through the use of real-time evaluations and sophisticated decision support systems (Bhatia et al., 2023).

- 5G and Next-Generation Networks: More devices may be connected and data can be sent more quickly thanks to the introduction of 5G technology, which will increase the speed and dependability of IoT networks (Ahmed et al., 2019).
- Decentralized IoT Systems: Decentralized IoT networks could be built with blockchain technology, enhancing data security and guaranteeing open disaster management procedures (Wang et al., 2022).
- Time-Series and Textile Antenna: Natural disasters happen unexpectedly and without warning. IoT devices could be linked to time-series databases (such as Axibase, Riak TS, InflowData, PipelineDB, and KDB+) in these circumstances to accurately include regular incidences, which could then be examined using NoSQL queries (Pathinettampadian et al., 2024). After a disaster, sufferers can communicate ad hoc using textile antennas powered by Ultra Wide Band (UWB). For this reason, a conductive sheet such as Linqstat or Velostat works well. For emergency scenarios, (Ananda et al., 2019) suggested a conductive textile-based antenna. Furthermore, UWB antennas are compatible with other widely used short- and long-range communications since they operate in the 3:1–10:6 GHz frequency band.
- Public-Private Partnerships: With shared accountability for research, funding, and execution, cooperation between governments, commercial enterprises, and academic institutions will be essential to the advancement of IoT solutions for earthquake disaster mitigation (Ishiwatari et al., 2024).

9. Conclusion

The IoT's ability to provide real-time data, improve early warning systems, and aid recovery efforts after a disaster may completely transform seismic disaster mitigation. Truly, it possesses the ability to bring people together and bridge global gaps. Depending on the circumstances, this technology might end up saving lives. For instance, it enables us to manage seismic disasters, potentially saving many lives when they cause significant harm to both the environment and people. The IoT interoperability enables the seismic disaster mitigation system to utilize computational tools and data analytics for early warning systems. In this study, we discuss some of the open research challenges related to the use of IoT for earthquake catastrophe mitigation. In the field of seismic disaster management, IoT devices are making a huge impact by mitigating the destructive power of these natural disasters. This paper study compares and provides several existing IoT-based seismic disaster mitigation methods. Despite challenges such as infrastructure limitations, data security, and cost, the future of disaster management seems bright with the integration of the IoT with artificial intelligence (AI), 5G, and blockchain. The Iot offers enormous promise for reducing the devastating impact of earthquakes on both infrastructure and human lives via concerted effort and ongoing innovation.

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Author Contributions

Youba Raj Poudyal contributed to conceptualization, methodology, analysis, data collection, draft preparation, and manuscript editing. Gajendra Sharma and Lok Bijaya Adhikari contributed to methodology, data correction, manuscript reviewing, editing, visualization, supervision and project administration. All authors have read and agreed with the manuscript before its submission and publication.

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