The Social Impact of IoT in Disasters

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***Abstract*—Disasters, both natural and man-made, pose significant global threats, causing loss of life, economic damage, and social disruption. The rising frequency and severity of such events highlight the urgent need for effective disaster management. The Internet of Things (IoT) offers transformative potential to meet these challenges, particularly by improving early warning systems, enhancing emergency responses, and facilitating post-disaster recovery. This paper explores the role of the IoT in disaster management, highlighting its architecture and applications. It covers benefits such as improved response times, enhanced resource allocation, and reduced casualties, while also discussing challenges namely communication reliability in harsh environments, data security, and standardization issues. Additionally, the paper emphasizes the need for region-specific solutions, particularly in areas like Chongqing and Sichuan in China, which confront unique geological and meteorological risks, suggesting approaches for future research.**

***Index Terms*—Disaster Management (DM), Internet of Things (IoT), Early Warning System (EWS), IoT-based Applications.**

I. Introduction

The occurrence of disasters represents a significant global concern, as they present a considerable risk to human life and socio-economic stability. The United Nations Office for Disaster Risk Reduction [1] defines a disaster as 'a serious disruption of the functioning of a community or society on any scale resulting from the interaction of hazardous events with exposure conditions, vulnerabilities and coping capacities, causing loss and impact on one or more aspects of human, material, economic and environmental well-being. In general, disasters can be classified into two main categories: natural disasters and man-made disasters [2]. Natural disasters, such as earthquakes, typhoons and floods, are caused by natural causes and are inherently difficult to control. In contrast, man-made disasters have their origins in human activities, including military conflicts, terrorism, political unrest and industrial accidents. Although this categorization is somewhat superficial, it provides a basic framework for understanding the different natures of disasters.

Over the past 10 years, the International Federation of Red Cross and Red Crescent Society's (IFRC) 2018 World Disasters Report [3] identified 3,751 natural disasters, as in floods, earthquakes, landslides, tsunamis, etc. The economic losses associated with these disasters are estimated to be around $165.8 million, and human casualties are estimated to be around 2 billion. By 2023, the situation is expected to have worsened. According to the Global Natural Disaster Assessment Report 2023 [4], the frequency of natural disasters globally in 2023 will be 326, a decrease of 3 % compared to the average of the last 30 years, but the number of deaths will be 86,437, an increase of 73 % compared to the average. Despite a 53 % decrease in the number of people affected, direct economic losses have increased by 32% to around $202 billion. Turkey suffered particularly severe economic and population losses because of the earthquake, while the United States, China and India were the top three regions at risk of disasters. Disasters not only bring about economic losses, but also have an immediate impact on public health, humanitarian and the environment, as well as long-term negative effects. Particularly in densely populated urban and coastal areas, developing countries are more vulnerable to disasters owing to a lack of adequate data and resources. In recent news, the British Broadcasting Corporation (BBC) reported [5] that on November 5, 2024, Spain experienced a year's worth of rainfall within just eight hours, leading to catastrophic flooding. Due to the absence of a timely and effective early warning system, the disaster caused significant economic losses and casualties, with over 200 confirmed deaths.

In light of this, reducing disaster risks effectively presents a serious challenge for researchers, scientists, and authorities, while finding a suitable solution to efficiently handle and process the flow of information is crucial. Recent advancements in technologies, particularly the Internet of Things (IoT), have shown great potential in disaster management, which has become one of the key buzzwords. This paper projects on how IoT can play a transformative role in disaster management by mitigating risks and reducing the social impact of disasters. Additionally, it also explores the main challenges associated with IoT implementation in this field, including ensuring reliable communication, maintaining data security, and managing energy efficiency in resource-constrained environments [6]–[9].

II. Internet of Things (IoT) and Disaster management (DM)

A. Architecture

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it [10]. IoT is the extension of Internet connectivity into physical devices and everyday objects. The functions and characteristics of IoT systems can be described starting from their architectural configuration. A three-layers architecture can be used to describe a generic IoT-based electronic system [6], as shown in Fig.1, a common IoT architecture basically consists of a perception layer, a communication layer and an application layer [6], [10]–[13].

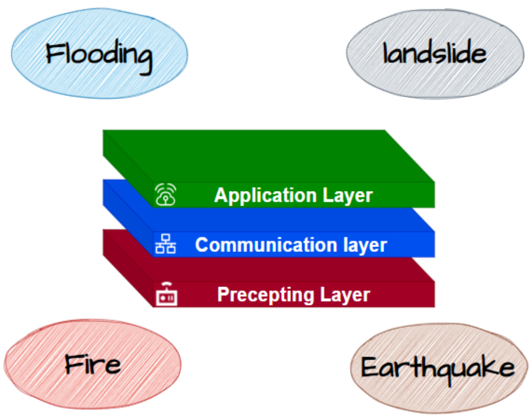

Fig. 1. Architecture of IoT

The perception layer is responsible for sensing and collecting environmental data through a network of heterogeneous sensors that form an effective Wireless Sensor Network (WSN). These networks, widely used in disaster monitoring, consist of nodes equipped with sensing and communication units that collect data and forward it to gateway nodes for further processing. The communication layer transmits the data from the perception layer to servers, cloud services, or applications, handling routing, communication between heterogeneous networks, and ensuring reliable data transfer using various communication technologies like WiFi, Zigbee, LoRa, etc. At the top of the IoT architecture, the application layer utilizes this data to provide services, combining it with historical records, satellite information, or weather forecasts. It analyzes data and implements algorithms to generate and disseminate timely warnings for impending disasters, facilitating effective prediction and response.

B. IoT applications in Disaster management

Disaster management is a structured process that involves planning, managing, and applying strategies at any stage of a disaster, that are mitigation, rescue, response, and recovery [14]. The field has undergone significant transformation with the integration of IoT techniques, which can be leveraged at every stage of disaster management.

1) Early warning system (EWS): One of the most significant applications of IoT technology in disaster management is the development of early warning systems [14]. By deploying sensors in critical locations—such as humidity sensors, water-flow sensors, and water level monitors—IoT enables the real-time collection of environmental data. This data can be processed using traditional hydrological models or AI techniques to predict imminent disasters, allowing for timely alerts to relevant authorities and the public. For example, the European Flood Awareness System [15] uses rainfall detection and forecasts to predict floods, while *Zahir et al.* [16] highlight a web-based system that provides the public with access to real-time flood information. Additionally, Pascador [17] demonstrates the use of industrial IoT to develop a sensor system for monitoring volcanic activity, employing over 80 IoT sensors within a volcano's crater to predict eruptions. These studies illustrate how IoT can significantly enhance early detection systems for various natural disasters.

2) Emergency Response and Rescue: In the aftermath of disasters, IoT devices have become essential in enhancing emergency response and rescue operations, with drones or UAVS recognized as integral components of the evolving IoT ecosystem. Research highlights that drones leveraging FANET (Flying Ad Hoc Network) technology function as mobile interconnected sensors, enabling infrastructure-free, self-organizing networks that facilitate real-time transmission of rescue information, thereby enhancing the success rates of disaster relief missions [18]. Similarly, studies propose a cloud-based IoT system designed to improve emergency response efficiency through the integration of an android application, an IoT toolkit, and a cloud middleware platform, which collectively ensure seamless data exchange and effective load balancing between publishers and subscribers [19]. Furthermore, IoT-based automated ambulance rescue systems have demonstrated significant advantages in accident response scenarios. These systems utilize accelerometers to detect traffic accidents and instantly relay location information to rescue teams and relevant personnel via a WiFi module [20]. This enables the design of effective and emergency routing roads during disasters.

3) Post-disaster recovery and reconstruction: The application of the IoT in post-disaster scenarios holds significant academic and practical value. By enhancing information exchange and system connectivity, IoT technologies can greatly improve the efficiency of recovery efforts, thereby mitigating the adverse impacts of natural disasters. While such events are unavoidable, IoT solutions play a critical role in ensuring communication continuity and saving lives, particularly when conventional communication networks are disrupted or unavailable. For instance, a proposed approach involves incorporating a "disaster mode" into mobile phones [21]. When traditional cellular networks fail, devices would automatically switch to a Device-to-Device (D2D) communication mode, forming an ad hoc WSN. In such networks, specific devices act as relays or gateway proxies to maintain connectivity during outages. Another example is the deployment of unmanned aerial vehicles (UAVs) equipped with sensors to restore communication links in disaster-hit areas [22]. These drones can provide wireless coverage for ground users, bridging communication gaps in various environments. Additionally, satellite communication systems serve as a robust alternative; for example, Elon Musk's Starlink initiative restored internet connectivity to the Kingdom of Tonga following a tsunami-induced network failure [23].

C. Challenges and social impacts of technology

1) Technology Challenges: IoT holds tremendous potential in disaster management, but its practical implementation endures numerous technical challenges, one of the most significant being fault tolerance [6], [8]–[10], [24]. The requirement for disaster monitoring systems is long-term operation in harsh environments, including remote mountainous areas with complex terrains, where maintenance costs are prohibitively high. In adverse conditions, strong magnetic fields or heavy rain, the communication quality of sensor nodes can degrade significantly. This results in compromised data quality and increased energy consumption, making it difficult for the system to function reliably at times. Encountering these issues, the design of network topology and the implementation of mesh networks and wireless communication protocols must consider these factors. Adaptive solutions and appropriate communication protocols, as in LoRa—which operates in unlicensed frequency bands—are critical for optimizing both energy consumption and coverage. Furthermore, non-terrestrial networks, such as satellite communications, provide more reliable and extensive connectivity when ground networks fail or offer limited coverage.

In IoT-based disaster management, ensuring data security and privacy is one of the key challenges [24]–[26]. During disasters, IoT systems collect and transmit large volumes of environmental and personal data, which makes them vulnerable to data breaches and cyberattacks. The resource-constrained nature of IoT devices and the complexity of their operating environments, security challenges in IoT are more severe compared to other domains. Moreover, the surge in disaster-related data often overwhelms traditional data storage and processing systems, which struggle with efficiency, scalability, and accessibility in handling large datasets. While some progress has been made, comprehensive research on cybersecurity in disaster scenarios remains limited, particularly in securely collecting and safeguarding data from networks. Future efforts must focus on developing robust security frameworks tailored to disaster contexts, incorporating lightweight cryptographic methods, real-time threat detection, and resilient data protection strategies to ensure the integrity and confidentiality of critical information.

Differences in IoT technology standards and disaster management policies across countries and regions can hinder international cooperation and slow the adoption of these technologies. Therefore, establishing a globally unified IoT standard and disaster management framework is essential [24], [25], [27]. Currently, IoT-based disaster monitoring and early warning systems lack unified technical standards in key areas namely sensor selection and production for field environments, data acquisition instruments and their interfaces, communication networks, and gateway manufacturing. Although some research has explored post-disaster applications, there are no specific standards in this domain. In addition, disaster management requires a range of sensors for both pre- and post-disaster phases, each designed according to different manufacturer and application-specific requirements. This heterogeneity impedes data integration and sharing. Additionally, initial disasters can trigger secondary events, and analyzing data from related sensors can help predict these cascading hazards. Future research should focus on sensor integration, data visualization, and the dissemination of multi-hazard alerts.

2) Impact: The integration of Internet of Things technology into disaster management has significantly reduced casualties, enhanced response capabilities, and promoted social equity. A prominent example is the advancement of earthquake early warning systems, a concept dating back to 1868, which represents an early form of IoT application [28]. Modern systems, such as ShakeAlert in the United States, have further refined this technology and tested its effectiveness among pilot users in California, Oregon, and Washington [29]. Similarly, Mexico's SASMEX system has expanded its reach, covering multiple states and cities. Alerts in Mexico are disseminated through dedicated radio receivers in schools and government offices, as well as 12,000 city-wide sirens in Mexico City, ensuring comprehensive public notification [29].

In addition to earthquake warnings, IoT-powered flood early warning systems have shown the potential to reduce annual economic losses due to flooding by up to 35% [30]. These systems must provide tailored warnings to effectively reach vulnerable populations, particularly in multilingual or remote areas. For instance, in Pakistan, uneducated Punjabi-speaking women struggled to comprehend formal Urdu alerts that included technical terms such as rainfall millimeters and flood probabilities, underscoring the importance of delivering alerts in native languages and simple terminology [31]. Similarly, in Florida, the integration of Geographic Information Systems (GIS) data into flood management systems facilitated efficient traffic control, ensuring safer and more organized evacuations during emergencies [32].

Regarding this, IoT plays a significant role in promoting social equity by improving resource allocation. Its widespread adoption ensures that remote areas have access to the same monitoring and early warning services as urban regions, bridging the gap in disaster management capabilities. This ensures that all social groups, including vulnerable populations, receive timely warnings and equitable access to emergency resources, reducing risks and losses during disasters and fostering overall social fairness.

III. Conclusion

Frequent global disasters pose severe threats to life and property. While the Internet of Things cannot prevent disasters, it can help identify hazards early, alert authorities, and assist in rescue operations, thereby saving lives, resources, and funds. IoT technology enhances emergency management, improves disaster response efficiency, and reduces casualties and economic losses. Early warning systems, emergency response tools, and post-disaster recovery frameworks have already demonstrated their significant potential in disaster management. Despite its advantages, IoT encounters challenges in disaster management, including ensuring reliable communication in harsh environments, maintaining data security. Additionally, IoT can extend its reach to remote and vulnerable communities, promoting equitable resource distribution and fostering social equity. As the frequency and severity of global disasters increase, leveraging IoT to build disaster-resilient communities and mitigate disaster impacts is crucial.

IV. Future Work

The rapid advancement of information technology has significantly transformed daily life, with the Internet of Things emerging as a key enabler in addressing critical global challenges, including disaster management. While extensive research on related technologies has been conducted globally, there remains a notable gap in studies tailored to the unique disaster contexts of Chongqing and Sichuan in China. These regions face heightened risks due to their complex topography and climatic conditions, underscoring the urgent need for a robust, region-specific disaster warning and management system. The primary objective is to develop innovative technologies capable of timely prediction and mitigation of complex geological and meteorological hazards, ultimately enhancing disaster preparedness and response in these vulnerable areas. Additionally, these areas present considerable opportunities for enhancement: integrating IoT with satellite communications presents a promising solution for remote areas. Low Power Wide Area Network (LPWAN) technologies, such as ZigBee and LoRa, enhance system robustness, while Narrowband IoT (NB-IoT) enables low-power, highly stable wireless monitoring. Future work seeks to develop cutting-edge solutions coined from the region's needs, aiming to build a comprehensive, reliable disaster management system.

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