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Technical Feasibility Analysis of Digital Twin Technology in the Field of Urban Disaster Prevention

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Abstract. In recent years, disasters have occurred frequently around the world, causing great harm to national finances and people's safety. There is still a lack of research on digital disaster prevention technology, but with the development of technologies such as artificial intelligence and computer vision, it has gradually become possible to use digital twin technology in urban disaster prevention. This paper is mainly based on digital twin related technologies, briefly introduces the concept and importance of digital twins, and the applicable fields, and then discusses the mode of data interaction between real entities and twins and the feasibility of digital disaster prevention, so as to prevent and simulate urban disasters and derive strategies for dealing with disasters. This paper reviews the existing research on digital twin technology through the method of literature retrieval and analysis. By analyzing technologies such as the Internet of Things, sensors, three-dimensional laser technology, urban monitoring technology, satellite remote sensing technology, drone remote sensing technology, mobile device technology, lidar technology, and oblique photography, a systematic review of critical analysis is obtained, and a macro method of data interaction and modeling for digital twin technology for disaster prevention is obtained, thereby deriving the feasibility of disaster prevention based on digital twin systems.

Keywords: Digital twin, Urban disaster prevention, Urban modeling, Data interaction.

1. Introduction

Disasters have always been an unavoidable topic for human survival in nature. Compared with accidents, disasters pose a huge threat to human life and property safety. According to statistics, the New South Wales wildfires from 2019 to 2020 not only caused serious economic losses to Australia, but also dealt a fatal blow to its biodiversity. The economic losses of the Turkish earthquake in 2023 reached nearly 100 million US dollars. Humans are extremely weak in the face of natural disasters. How can humans take precautions before disasters and make reasonable plans in time when disasters occur to remedy casualties and economic losses? This is the most important task in the field of disaster prevention. With the rapid development of technologies such as artificial intelligence and computer vision, digital twin technology has gradually been applied to the field of disaster prevention [1].

Digital twins achieve pre-disaster prevention, disaster governance, and post-disaster recovery through the disaster prevention and control cycle. This makes digital disaster prevention possible [2].

This paper uses China National Knowledge Infrastructure and Google Scholar to conduct literature retrieval to analyze and study previous papers. Keywords: digital twin, digital disaster prevention, disaster visualization, etc. First, the concept, importance and application areas of digital twins are described, and then the methods of data interaction between real entities and digital twins in digital twin technology, modeling of twins and how digital twin technology can be used for disaster prevention simulation are specifically discussed. The feasibility of digital twin technology in urban disaster prevention is mainly introduced, providing scholars studying this field with ideas for digital disaster prevention.

2. Concept, importance and application areas of digital twin technology

2.1. Concept and importance of digital twins

Digital twin technology is based on Building Information Modeling (BIM) and is updated with real-time data. The digital twin concept model was first proposed by Professor Grieves in 2003. It was not until 2011 that National Aeronautics and Space Administration(NASA) first introduced the concept of "twin" in the "Apollo Project" and defined digital twins in detail: Establish a virtual twin of the real world in a virtual network to predict and understand its real entity. This concept consists of three parts: physical data, virtual data, and data information that connects the real and virtual. The function of digital twin is to collect data such as physical models, real-time update status, and operation history, and to map entities to virtual models through multi-simulation technology and reflect their entire life cycle. The unpredictability and suddenness of disasters often lead to increased damage from disasters, posing a threat to people's lives and property [2]. Compared with traditional information-based disaster prevention, this technology can timely feedback on changes in the natural and man-made environment, which is conducive to improving risk identification and prediction, enhancing the predictability of disasters, better preventing and predicting disasters, avoiding risks, simulating more efficient and scientific disaster response strategies, and analyzing the entire cycle of disasters from the beginning, development, to extinction [1]. Digital twins conduct real-time visual dynamic monitoring and intelligent management of the real world through digital holographic simulation, making twin cities in both real and virtual spaces interact and operate simultaneously, thus realizing city twins.

2.2. Application fields of digital twin technology

The “simulation first, then execution in the real world” function of digital twin technology has important value in industrial design, aerospace and other fields. Performing performance and quality testing through simulation can reduce the cost of later design and trial and error, and more efficiently iterate and innovate products [3].

In the field of intelligent manufacturing, the traditional manual design and manufacturing is transformed into computer-aided, digital simulation and optimized intelligent design. Secondly, the digital twin is constructed through the data generated at each stage, which can monitor and diagnose the machinery in real-time, visualize industrial manufacturing, achieve predictive maintenance, performance improvement, assembly line optimization, and improve production efficiency.

In the field of smart cities, digital twin technology can inject energy into urban planning, construction, operation, etc., improve the scientific nature of urban planning throughout the entire process, and understand and optimize the city status in real-time through precise modeling. For example, it can improve the transportation system by predicting and regulating traffic flow, and monitoring the environment, air quality and energy consumption, thereby improving the safety, efficiency and convenience of the city. Artificial intelligence algorithms can also be used to optimize building structure design or analyze aging and failure during operation and maintenance.

In addition, digital twin technology also has important applications in industries such as energy, medical care, and automobiles.

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3. Technical feasibility analysis of digital twins in urban disaster prevention

3.1. Functions of digital twins for disaster prevention

The operation of digital twin disaster prevention technology is divided into three parts: physical entity, virtual twin, and disaster simulation system. By collecting and analyzing data on the conditions and cycle patterns of real disasters, the scope of impact, the degree of damage, etc., visual disaster prediction, simulation and analysis are carried out in the digital twin to guide pre-disaster prevention and building structure consolidation of real entities. During a disaster, by obtaining information collected by all parties, real-time simulation is carried out to quickly assess the scale of the disaster, the scope of damage, and the affected area, and to visualize and analyze the location, real-time situation, and disposal of sudden disasters. To achieve coordinated dispatch of multiple resources, provide solutions for the allocation and dispatch of rescue resources, strengthen the emergency response capabilities of disasters, and improve the efficiency of handling sudden disaster events. After the disaster, rapid and accurate assessments can be made on the repair and reconstruction of building structures, damage to infrastructure, and economic losses, as well as simulations and predictions of casualties.

3.2. Data and information interaction of digital twins

The difficulty of digital twin disaster prevention lies in the data interaction of real entities, the establishment of twins and disaster simulation, so these three parts are discussed in detail. When acquiring building damage data, different types of buildings such as bridges and houses require different physical data, but they are basically: structural sliding, structural deformation, structural vibration characteristics, and images of the destruction process. Traditionally, manual collection is the main method for collecting disaster data. However, manual data collection is inaccurate and takes a long time. At the same time, there are major safety risks when collecting data in high-risk buildings. With the development of theory and technology, sensors, 3D laser scanning, monitoring systems, satellites, and drones have gradually been applied to disaster assessment and prevention, thereby improving data detection accuracy, simplifying the process of disaster data collection, and avoiding personnel entering dangerous environments to collect data[4].

3.2.1. Application of Internet of Things (IoT) and Sensors. As an important means of pre-disaster monitoring for digital twins, IoT systems are composed of sensors, drivers, controllers, and data analysis systems. After obtaining the disaster information, the corresponding data information is obtained through large data processing. Sensors are the most critical part of the system, and they mainly monitor earthquakes, floods, tsunamis, forest fires, and other geological and meteorological events in real time. Disaster prevention sensors include pressure sensors, angle sensors, thermometers, and ultrasonic sensors, and have the advantages of high precision and real-time performance [4]. IoT is mainly used for disaster monitoring and pre-disaster warning of digital twins. For example, Morello, R et al. used sensor networks to provide timely landslide disaster maps [5]. Ariyachandra et al. introduced the use of sensors to predict different geological disasters before disasters. Sensors can also be installed inside building structures to monitor the real-time status of the structure and obtain post-disaster damage data inside the structure [6].

3.2.2. Application of 3D laser technology. 3D laser scanning technology has great potential in characterizing solid three-dimensional models. It is used to obtain physical information data of structures and can quickly collect a large number of irregular three-dimensional model point clouds, coordinates and other attributes for comparison of physical information of buildings before and after disasters, and for evaluating disaster levels and the extent of building damage [4]. In addition, Pan Y et al. proposed using the fusion of laser scanning and measurement to upload small but critical parts of the building to the twin model [7]. There are many types of 3D laser scanners: field-mounted, handheld, vehicle-mounted, airborne, etc., which can cope with data collection in various complex environments. Although this technology has obvious advantages in physical data collection, the environment has a great impact on laser scanning. Laser scanning technology still needs to make breakthroughs in the recognition and integration of complex environments. Since 3D laser scanners are precision instruments that require frequent maintenance, they are relatively expensive to use.

3.2.3. Application of urban monitoring technology. The urban monitoring system refers to the existing monitoring facilities in the city. It obtains data such as videos and pictures of the city. After using Computer Vision Technology (convolutional neural network), the obtained videos and images are processed to obtain information such as the degree of disaster damage and the scope of impact. The advantages of this technology are low cost, wide monitoring range, and strong real-time performance [8]. It can be used to analyze data such as structural displacement and vibration frequency during disasters and to analyze the degree of structural damage after disasters. However, the disadvantage is that some equipment is aging and the accuracy of the data obtained is not high.

3.2.4. Application of satellite remote sensing technology. Satellite remote sensing technology transmits data to the city twin through electromagnetic waves and aperture radar. Satellite remote sensing is mainly used to monitor geological characteristics before disasters. It can continuously observe the surface for a long time, grasp the landform, meteorology and other environmental characteristics, and realize real-time updates of information [9]. However, the data collected by this technology is relatively limited. It can only detect surface features. In addition, the optical sensors that satellite remote sensing technology relies on are greatly affected by weather factors. There is still a need to break through the resolution of various types of remote sensing data [4].

3.2.5. Application of UAV remote sensing technology. UAV remote sensing technology can achieve rapid acquisition of physical information and the extent of disaster damage. It has the advantages of low cost, high mobility, real-time, and high-resolution data collection. In times of disaster, drones can quickly locate victims and warn of secondary disasters, and optimize escape routes after interacting with the twin system [4]. However, the flight and remote control of drone technology are greatly affected by objective factors. On the one hand, complex aerial conditions, such as complex mountains, small buildings, forests, and fire conditions, make drone flights more difficult, which reduces the flight capability and safety of drones to a certain extent. Similarly, high-rise building structures and signal towers in cities also limit the role of drones in disasters.

3.2.6. Application of mobile devices. Mobile devices include mobile phones, smart watches, etc. They contain functions such as positioning (GPS) and vibration recognition. The use of mobile data functions can greatly help obtain disaster information [8]. The activities of people in a disaster can be collected through their mobile devices and transmitted to the twin system. When a disaster occurs, the vibration recognition function of the mobile device is used to determine the earthquake, and the GPS is used to locate the affected people. At the same time, the dynamic evolution of people in the disaster and their handling methods in the face of the disaster can also be obtained. In addition, smartphones can be used to collect useful environmental data, such as images and videos, and the location of the disaster, after being processed by computer vision technology, video and images can be used to evaluate disaster events [6].

3.3. Modeling and disaster simulation using digital twin technology

The modeling of digital twins can directly establish the corresponding virtual model through the aid of detailed design information and on-site measurement to obtain data. At present, the methods for constructing three-dimensional model data of building structures mainly include laser radar (LiDAR) and oblique photography technology. When constructing a structural point cloud model based on LiDAR, the sensor receives the reflected signal laser after sending a laser pulse to the physical entity, obtains and stores the point cloud information, and thus constructs a three-dimensional information model of the physical entity [8]. Oblique photography technology uses optical cameras to obtain overlapping

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images of the target, and then reconstructs the three-dimensional structure based on the motion recovery structure algorithm of multi-view vision [8,10]. To improve the accuracy of twin models, Ioannis B. et al. used deep learning technology to detect and identify building entities to improve the accuracy of digital twin models [11].

Disaster simulation mainly relies on virtual digital twins to use artificial intelligence to analyze mechanical data and other data to simulate possible disaster scenarios of structures and urban areas, analyze the destructive mechanisms and development trends of disasters, and serve disaster drills and early warnings. After the above data collection, the twin can quickly deduce and handle disasters. For example, Niwa, T et al. conducted a projection mapping disaster simulation for the South Sea Trough earthquake in Japan [12]. YuLin Ding et al. used geographic information technology and computing resources to simulate flood disasters and conduct visual analysis of floods [13]. Han Hongxing et al. conducted simulation analysis on hydrological monitoring, forecasting and early warning, flood dynamic simulation, beach relocation, flood dispatch, emergency response and command decision-making based on the establishment of a digital twin system [14]. Disaster simulation is based on simulation results to scientifically evaluate the flood inundation range, water depth, water conditions, disaster severity and economic losses, and to carry out flood control engineering construction in key river sections in reality to reduce the losses caused by floods. Through real-time information interaction, digital mapping is achieved between digital basins and physical basins, forming real-time images and virtual-real interactions of basin dispatch, so as to effectively utilize and deeply excavate water conservancy information resources and ensure water conservancy safety.

4. Conclusion

This paper mainly discusses the concept, importance, application field, operation mode, information interaction mode, modeling method and disaster simulation of digital twin technology, and concludes the feasibility and Macro-implementation method of digital twin technology in urban disaster prevention, providing direction and ideas for researchers in this field. This paper only briefly introduces the data interaction between physical entities and digital twins, modeling methods and disaster simulation.

In terms of scientific cognition, the technology and theory of digital twin cities are still in the exploratory stage, and the industry and society do not have a deep understanding of them. The information acquisition equipment standards of various departments of urban disaster prevention are different, which is difficult to integrate and unify, resulting in low-quality data information. Different departments in the city are relatively independent when applying digital twins to ensure the safety of the city. The data of each department is isolated data, making it difficult to achieve data interoperability. At the same time, the digital twin system obtains information from a wide range of sources, and the acquired data is stored relatively concentratedly, most of which involves private data such as videos and pictures. It is inevitable that criminals will take the opportunity to steal citizens' personal information, and system protection needs to be strengthened.

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