Research on Multi-Dimensional Disaster Information Perception and Fusion Service Technology in Underground and Shelter Space

Shenghua Xu, Jiping Liu, Yong Wang and Xianghong Che

April 14, 2023

Research on multi-dimensional disaster information perception and fusion service technology in underground and shelter space

Shenghua Xu [a,*], Jiping Liu [a], Yong Wang [a,*], Xianghong Che [a]

[a] *Chinese Academy of Surveying and Mapping, Beijing 100036, China, Shenghua Xu - xushenghua@gmail.com, Jiping Liu - liujp@casm.ac.cn, Yong Wang - wangyong@casm.ac.cn, Xianghong Che - chexh@casm.ac.cn*

* Shenghua Xu, Yong Wang

Abstract: The disaster information of human casualties and infrastructure damage in underground and sheltered spaces usually demands to be acquired timely during natural disasters such as earthquakes. Therefore, to address the last link problem in the field of disaster relief, the paper investigates the service technology of multi-dimensional disaster information perception and fusion in underground and sheltered space. In this paper, the classification and characteristics of disaster information in underground space are summarized. The key technologies for the extraction and identification of geo-environmental information, the detection methods and sensors used for the data of real-time environmental parameters, and the means of multi-source disaster information fusion under a unified spatio-temporal framework are discussed respectively in the underground space. Finally, a method of dynamic visualization of underground space disaster information is proposed to visualize the underground space scene and environmental parameters. It is achieved the visualization of 2-3D linkage and the simulation of environmental parameters.

Keywords: natural disasters, disaster information perception, underground and shelter space, dynamic visualization

1. Introduction

China is one of the countries most seriously affected and threatened by natural disasters in the world. Underground and sheltered space rescue missions caused by earthquakes and other major natural disasters are the last link in the field of international disaster relief (Jinghai, Junxiu, & Gaozhong, 2015). Sheltered space, which refers to the geographic areas that are blocked or inaccessible due to the occurrence of a disaster, making it impossible to effectively allocate and distribute resources such as personnel, materials, and information. Due to the underground "blind, narrow, chaotic, dangerous" environment of information transmission interruptions, positioning and orientation accuracy and disaster information attribute dispersion and other major challenges have not yet been radically addressed, the related positioning and orientation and disaster perception is to remain a technical bottleneck (Cui, Wen, & Zhang, 2019). To meet the needs of earthquake and other natural disasters for real-time acquisition of disaster information such as casualties and damage of infrastructure in underground and shelter space, and to solve the problem of unclear situation in disaster environment, multi-modal configurable disaster information perception terminal is studied and multi-source disaster information situational perception intelligent service platform is established. Furthermore, it will promote the technology guidance and industry development in the field of disaster information perception and emergency communication in underground space.

In China, disaster information perception is realized mainly through image transmission and manual analysis of disaster scene, which is inefficient (Ziyu, 2020). Meanwhile, the underground and sheltered disaster space rescue operational environment is more complex and dangerous than outdoor (Wang, Zhou, Zheng, & He, 2017). In this paper, an intelligent perception fusion and representation mechanism driven by multi-dimensional and multi-modal disaster information is established to cope with the above challenges effectively. The paper mainly discusses the classification and characteristics of underground space disaster information, extraction and recognition of underground space ground object environmental information, detection and monitoring of underground space environmental parameters, multi-source disaster information fusion under the unified framework of spatio-temporal datum, and dynamic visualization service of underground space disaster information. Multi-dimensional disaster information perception and fusion services are established in underground and shelter space to comprehensively support the on-site command and decision of emergency rescue.

2. Classification and characteristics of underground space disaster information

Underground space refers to the closed space developed, constructed and utilized below the surface of a city to meet the needs of human production and living, which can only be accessed to the ground through limited channels and entrances (Bartel & Janssen, 2016; Yu & Guo, 2022). The content of on-site multi-source perception data in underground space should not only meet the requirements of operational environment disaster analysis, situation analysis, risk warning, emergency rescue and other business work, but also meet the functional requirements of perception data, such as perception accuracy. Perception data refers to data collected through various sensors, monitoring devices, cameras and other IoT devices, including temperature, humidity, gases, air pressure and many other forms. Underground space data can be divided into disaster environment perception data and personnel equipment perception data according to the content and purpose of use. The paper primarily discusses disaster environment perception data. Disaster environment perception data is mainly divided into operational environment perception data and 3D scene perception data. The operational environment perception data mainly includes gas perception data (oxygen, carbon dioxide, carbon monoxide, hydrogen sulfide, sulfur dioxide, nitrogen oxides, methane, hydrogen, ammonia, etc.), temperature perception data (temperature is necessary for gas concentration and personnel work, mainly refers to the ambient temperature in the operating environment), humidity perception data (The relative humidity value at the current time is the percentage of the actual water vapor pressure in the air to the saturated water vapor pressure at the current temperature), air pressure perception data (air pressure monitoring data of underground space rescue site in the area where personnel and unmanned equipment are located), and particulate perception data (harmful particulate matter suspended in the air). 3D scene perception data mainly includes LiDAR point cloud data and position data.

3. Key technologies and implementation

This paper mainly explores the technical system architecture for multi-dimensional disaster information perception and fusion services in underground and sheltered spaces. A general overview is shown in Figure 1. Specifically, it includes the extraction and recognition of ground feature environmental information in underground space, the detection and monitoring of environmental parametric information in underground space, the multi-source disaster information fusion under the unified framework of spatiotemporal benchmarks, and the dynamic visualization service for underground space disaster information. Through these technical means, we can obtain and integrate various environmental information in underground spaces, providing strong support for rescue and decision-making.

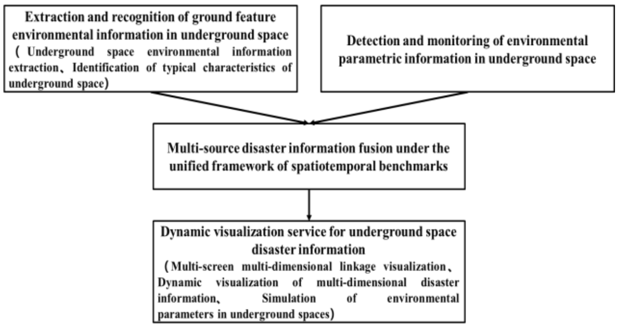


Figure 1. General overview

3.1 Extraction and recognition of ground feature environmental information in underground space

3.1.1 *Underground space environmental information extraction*

Facing the characteristics of complex structure and poor lighting conditions of underground and sheltered space, the extraction of environmental information of underground and sheltered space can start from the acquisition of environmental information based on laser sensors, and dynamically compensate through data to eliminate the influence of high-frequency bumps and angle abrupt changes on laser data. The stable laser feature extraction method for complex scenes is to realize the reconstruction of extreme environment scenes through multi-level feature matching. The point cloud registration algorithm is the basis for 3D scene reconstruction. The efficiency and accuracy of the registration algorithm profoundly affects the effectiveness of 3D reconstruction. The laser odometry and mapping algorithm (Zhao, Fang, Li, & Scherer, 2019) is rewritten based on the traditional ICP registration algorithm (Chen, Zhu, Wu, & Wang, 2017). The laser odometry and mapping algorithm first extracts the feature points, corner points and surface points of two frame point cloud data, and then does proximity search to find the corresponding corner lines or surface blocks of the feature points, thus greatly reducing the computational load. The algorithm is mainly divided into four parts, namely point cloud acquisition, feature point extraction, motion estimation and map construction. The reconstruction extraction results are shown in Figure 2.

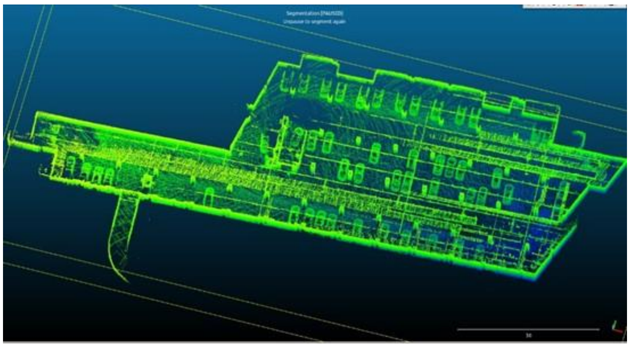
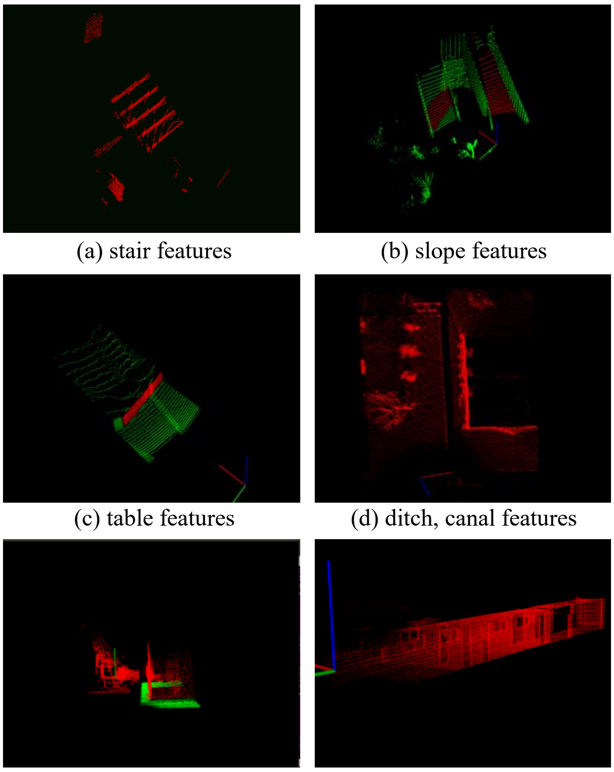


Figure 2. Results of 3D scene reconstruction of underground parking garage

3.1.2 *Identification of typical characteristics of underground space*

For the recognition of ground object environmental information in underground and sheltered space, when acquiring the point cloud of the scene, the original point cloud data obtained by using LIDAR is often too dense and complex, in addition to the target point cloud, the data also includes obstacles, noise, occlusion, etc., which is extremely unfavourable for subsequent processing. To improve the operation speed and processing efficiency of the subsequent link, the original point cloud must be sparse to reduce the number of point clouds to be processed. Meanwhile, noise and obstacles in the environment are removed to reduce interference, so as to reduce the time complexity of the traversal algorithm in all subsequent links and further improve the efficiency. The pre-treated point cloud samples are processed, including the detection of potential areas of ground objects, wall removal, PCA principal component analysis of the facade, and calculation of the facade centroid. To obtain the best wall fitting effect in complex point cloud samples, RanSAC algorithm can be used for fitting, which is robust and can adapt to the environment with more noise (Derpanis, 2010). The typical features of underground space can be identified by using the features or adjacency and geometric features around a structure. After feature identification, the typical features of the underground space environment can be divided into: stair features, slope features, table features, ditch, canal features, wall and top features, as shown in Figure 3.



(a) stair features (b) slope features

(c) table features (d) ditch, canal features

(e) ditch, canal features (f) wall and top features

Figure 3. Typical characteristics of underground space

3.2 Detection and monitoring of environmental parametric information in underground space

For the perception of environmental parameters in underground and shelter space of natural disasters such as earthquake, the high-density multi-chip 3D micro-assembly process is implemented by toxic gas/temperature humidity/pressure sensing technology. Develop domestic temperature and humidity, pressure, toxic gas parameter measurement sensor. For the detection of temperature environmental parameters, a thermoelectric reactor infrared detector based on a double-end beam structure and a theoretical model based on the performance analysis of temperature sensitive elements are used to obtain. For the perception of pressure parameters in the underground and sheltered space of natural disasters such as earthquakes, SOI-based semiconductor piezoresistive high-temperature pressure sensors can be obtained. It has the characteristics of small size, low cost, simple and adjustable output signal, and has high reliability and anti-harsh environment working ability. For the perception of toxic gas parameters in the underground and sheltered space of natural disasters such as earthquakes, the alternating photoion PID toxic gas sensor can be used to dynamically select multi-gas parameter monitoring methods based on gas sensors. In view of the perception of humidity parameters in the underground and sheltered space of natural disasters such as earthquakes, a micro electro mechanical system humidity sensor based on candle ash nanoparticle layer is used, which uses the candle ash nanoparticle layer treated by oxygen plasma as a moisture-sensitive material, and the electrode adopts conductive copper tape. It is shown in Figure 4. Table 1 shows the sensors and instruments for the detection and monitoring of environmental parameters in underground spaces.

Table 1. Sensors and instruments

	Sensors and instruments	Function
1	domestic temperature and humidity, pressure, toxic gas parameter measurement sensor	
2	thermoelectric reactor infrared detector based on a double-end beam structure	detection of temperature environmental parameters
3	SOI-based semiconductor piezoresistive high-temperature pressure sensors	perception of pressure parameters
4	the alternating photoion PID toxic gas sensor	perception of toxic gas parameters
5	a micro electro mechanical system humidity sensor based on candle ash nanoparticle layer	perception of humidity parameters

Figure 4. QCM-type humidity sensor based on candle ash nanoparticle layer

3.3 Multi-source disaster information fusion under the unified framework of spatiotemporal benchmarks

Based on indoor engineering files such as building structure and piping layout CAD, multi-feature tracking processing of scene space targets is carried out. Priority should be given to the extraction of the graphic topological structure, text annotation, digital information and distance relation data of the building in the engineering documents, and the modeling transformation of the engineering data files should be completed. The extracted coordinates of the indoor and outdoor 3D information master plan are used for 3D model coordinate registration. The spatial information is integrated with the location information, and the absolute location reference information is provided for the interior elements. Location information registration is used to integrate spatial information while providing absolute location reference information for indoor elements.

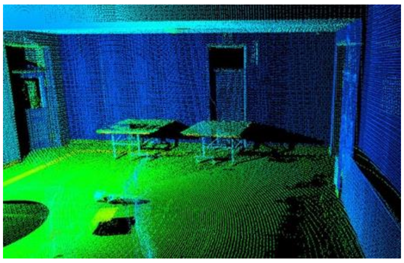


Figure 5. Lobby point cloud data

The target building scene point cloud data and the office building internal structure point cloud are generated by the ground lidar scanning system (Figure 5). The original point cloud is spliced and integrated based on the target of the measurement system. Based on engineering documents such as building structure and CAD, and on the basis of multi-feature tracking processing of scene spatial targets, combined with close-range photography data and liDAR point cloud data of target buildings, 3D model transformation construction is formed on 2D basic images, and the establishment of indoor and outdoor 3D scene model is completed. The overall external scenario is shown in Figure 6.

Figure 6. 3D model data

3.4 Dynamic visualization service for underground space disaster information

3.4.1 *Multi-screen multi-dimensional linkage visualization*

2D spatio-temporal data has a strong global nature, while 3D dynamic data has a better sense of intuitive experience (Cheng, 2018). To achieve a balance of the advantages of 2-3D spatio-temporal data, we can not only use mature 2D space technology to manage complex disaster information and related spatial analysis, but also use 3D virtual reality technology and the processing ability of multi-source and multi-scale data. Through coordinate mapping, the geographic coordinates of 2D spatio-temporal data correspond to the spatial location of 3D scenes and are synchronized through an interactive event triggering mechanism. With the support of viewpoint view synchronization and LOD synchronization, the multi-dimensional information linkage will also have interactive browsing function to realize real-time dynamic tracking of disaster scene perception data under 3D scene conditions. Figure 7 shows the 2D-3D linkage visualization.

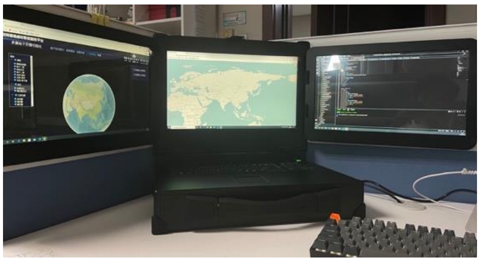


Figure 7. 2-3D linkage visualization

3.4.2 *Dynamic visualization of multi-dimensional disaster information*

Based on cesium.js and using particle system, it is possible to simulate fire and smoke in subway scenes. Particle system is a graphics technology that can simulate complex physical effects (Nguyen, Fedkiw, & Jensen). Particle systems are collections of small images. They form a more complex "blur" of objects, such as fire, smoke, weather or fireworks when viewed together. These complex effects can be controlled by specifying the behaviour of individual particles using properties such as initial position, velocity, and lifetime. By simulating the flames in a fire with a large number of moving particles, the flow field can be expressed with a realistic feel and effectively reflect the changes in the fire scene by varying the position, transparency, and other properties of the particles. Figure 8 shows dynamic visualization of underground disaster conditions

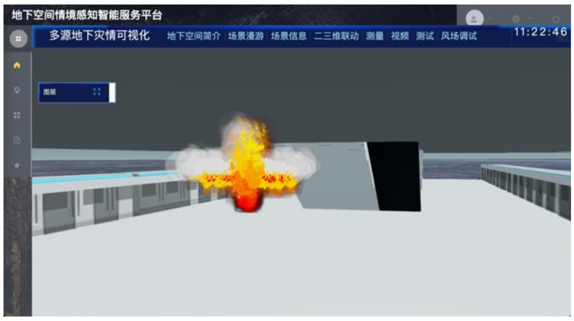


Figure 8. Dynamic visualization of underground disaster conditions

3.4.3 *Simulation of environmental parameters in underground spaces*

The spatial boundary of real-time environmental parameter data is obtained by establishing a 3D grid. For the expression perspective, the corresponding octree index is established, the expression model is constructed and the visualization is realized. The time dimension attribute information is supplemented for the gas concentration data. Based on the gas monitoring data obtained by gas sensors, unmanned vehicles and unmanned aerial vehicles, a spatial-temporal voxel model is constructed to describe the properties of diffused gases. Then, the multi-temporal gas data are predicted by the improved spatiotemporal Kriging interpolation method, converted into voxel values and stored in the spatiotemporal database. Finally, the volume rendering of the spatial-temporal voxel data is carried out directly based on the ray projection method to dynamically display the internal concentration of the gas and its change over time, and realize the real-time volume visualization of the gas diffusion simulation. Figure 9 shows Gas diffusion simulation.

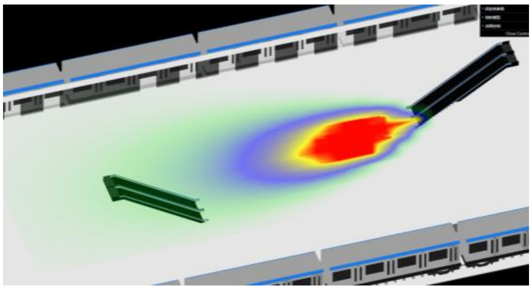


Figure 9. Gas diffusion simulation

4. Conclusion

The paper primarily discusses the technical system architecture of multi-dimensional disaster information sensing and fusion service in underground and sheltered space, which provides a comprehensive approach to solve such problems. Taking the demand on establishing multi-dimensional disaster information sensing and fusion services in underground and sheltered spaces into account, the variety and characteristics of underground space data are analyzed. The method of environmental reconstruction in underground space is illustrated according to existing projects, and it is explained the extraction of typical environmental features in underground space. For the acquisitions of environmental parameters such as temperature, air pressure, humidity, and so on, the prevailing methods and the employing sensor technologies are introduced. To unify these data in the same spatio-temporal basis, a multi-source disaster information fusion method under the unified framework of spatio-temporal datum is proposed. Finally, a 2-3D linkage system for dynamic visualization of underground space disaster situation is constructed to realize the organic integration of the reconstructed underground environment and the environmental parameters obtained. Dynamic visualization display and gas diffusion simulation are carried out on the platform to provide rescue support and decision-making for underground disasters.

5. Acknowledgements

This work was supported by the National Key Research and Development Program of China under Grant No. 2020YFC1511704 and the Basic Research of CASM under Grant No. AR2310.

6. References

Jinghai, X., Junxiu, Z., & Gaozhong, N. (2015). Earthquake disaster extraction based on location microblog [J]. J Nat Disaster, 5, 12-18.

Cui, B., Wen, X., & Zhang, D. (2019). The Application of Intelligent Emergency Response System for Urban Underground Space Disasters Based on 3D GIS, BIM and Internet of Things. Paper presented at the Proceedings of the 2019 International Conference on Artificial Intelligence and Computer Science.

Ziyu, Z. (2020). Research on data processing and analysis System based on seismic social resource information perception. Unpublished Master's Thesis, Beijing University of Posts and Telecommunications.

Wang, X., Zhou, F., Zheng, L., & He, J. (2017). Application and development of infrared imaging technology in disaster prevention monitoring and emergency search and rescue in urban underground space. Strategic Study of CAE, 19(06), 92-99.

Bartel, S., & Janssen, G. (2016). Underground spatial planning–Perspectives and current research in Germany. Tunnelling Underground Space Technology, 55, 112-117.

Yu, H., & Guo, Z. (2022). Design of Underground Space Intelligent Disaster Prevention System Based on Multisource Data Deep Learning. Wireless Communications Mobile Computing, 2022.

Zhao, S., Fang, Z., Li, H., & Scherer, S. (2019). A robust laser-inertial odometry and mapping method for large-scale highway environments. Paper presented at the 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).

Chen, X., Zhu, Y., Wu, T., & Wang, Z. (2017). Point cloud registration technology based on SA&IA and improved ICP algorithm. Journal of Xi'an Polytechnic University, 31(03), 395-401.

Derpanis, K. G. (2010). Overview of the RANSAC Algorithm. Image Rochester NY, 4(1), 2-3

Cheng W. Dynamic visualization of multi-dimensional urban environmental data: a case study of spatio-temporal air pollution dispersion in Hong Kong[J]. HKU Theses Online (HKUTO), 2018.

Nguyen D Q., Fedkiw R., & Jensen H W. Physically based modeling and animation of fire[C]//Proceedings of the 29th annual conference on Computer graphics and interactive techniques. 2002: 721-728.