Analysis of crowd flow characteristics based on multi-space scale and multi-source data fusion

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Abstract. In the big data background, multi-source data fusion provides a very effective means for researchers to extract hidden and valuable information and knowledge from many heterogeneous data sources. Large-scale crowd movement is a complex process with big size of data coming from several sources such as safety risks of crowding and trampling in public places in the possible form of subways, railway stations, airports, tourist attractions, or large-scale exhibitions. The analysis of crowd flow characteristics among these high risk areas has also become a major research hotspot. Based on the multi-space scale concept and the available data source information, this paper proposes a technical framework of crowd flow characteristics analysis. Finally, a case study of crowd flow characteristics analysis is implemented to validate this technical framework. This study can provide a effective theoretical support and security warning for the public management department.

1. Introduction

In today's big data era, both variety and scale of data is increasing, so the demand for extracting knowledge with high utilization value from complex data has become more urgent \cite{1}. Multi-space scale refers to observing targets at multiple scales, filtering redundant data and obtaining more detailed feature information \cite{2}. Multi-source data fusion refers to the use of multiple data sources collected, the fusion of different metric features according to actual requirements, finally transforming data into valuable knowledge interpretations, and thus providing a series of effective decision support.

Crowd mobility has spatial uncertainty and time variability. However, in a specific spatial area, there is a certain correlation between people in crowded public places such as transportation hubs, exhibitions, and tourist attractions \cite{3}. This paper digs deeply from the spatial and temporal dimensions to understand the association, analyses the characteristics of crowd movements in high-risk areas with crowd density, and forms quantitative data results to prevent and guide sudden events such as crowded stamping \cite{4}. Finally, it’s obvious to achieve crowd flow monitoring and crowd evacuation warning from a macro perspective with important social application value.

2. Data fusion model

2.1. Fusion level

Data fusion is a comprehensive analysis and processing technology for multi-source information, which is divided into three levels: pixel level fusion, feature level fusion and decision level fusion \cite{5}.
Pixel level fusion is the lowest level of fusion, directly processing the original data. The advantage is that original information is retained, and the loss of information is very small. While the disadvantage is the large amount of processed data, long processing time, poor system real-time and anti-interference ability. Feature level fusion is the middle level, with original data being extracted, processed and then merged. The advantage is that the calculation amount is reduced and the real-time performance is enhanced. While the disadvantage is that the fault tolerance is relatively weak. Decision level fusion is the highest level of intelligent integration, providing a reasonable and effective basis to command and control decision-making. The advantage is that it can fuse different types of data, with small calculation, strong fault tolerance and anti-interference ability. At the same time, the disadvantage is the decreased accuracy due to the large loss of data information [6]. See Table 1 for details.

**Table 1. Comparison of data fusion at different levels**

| Fusion level       | Pixel level | Feature level | Decision level |
|--------------------|-------------|---------------|----------------|
| Information        | Maximum     | Smaller       | Minimum        |
| processing         |             |               |                |
| Information loss   | Minimum     | Smaller       | Maximum        |
| Anti-interference  | Minimum     | Smaller       | Maximum        |
| Fault tolerance    | Worst       | Poor          | Better         |
| Pre-fusion         | Minimum     | Medium        | Maximum        |
| processing         |             |               |                |
| Fusion performance | Best        | Medium        | Poor           |
| Fusion algorithm   | Weighted average method, election decision method, Kalman filter method, mathematical statistics method, etc. | Kalman filtering method, fuzzy inference method, neural network method, production rule method, etc. | Bayesian Probabilistic Reasoning, Dempster-Shafer (D-S) Evidence Reasoning, etc. |

### 2.2. Functional model

The functional model is designed to be able to demonstrate the interactions between different functional modules involved in the data fusion process. Through dynamic monitoring of the fusion processing, resource optimization and sensor management, real-time feedback of the fusion result information, the fusion process is becoming adaptive, so as to achieve the best fusion effect. At present, the latest data fusion function model is based on the improvement of the JDL data fusion function model in the United States [7], as shown in figure 1.

**Fig. 1. The latest data fusion function model**

The functional model divides the data fusion into five layers [8]. The zeroth layer as sub-target data evaluation: based on the data association and feature description at the pixel or signal level, the estimation and prediction of targets with observable state. The first layer as target estimation: entity state estimation and prediction based on the relationship established from observation to tracking, including continuous state estimation (such as motion state) and discrete state estimation (such as...
target type and identity). The second layer as situation assessment: Estimation and prediction of interrelationships between entities, including communication interactions and direct interactions between people. The third layer as impact assessment: Estimation of the plan made by participants and prediction of the action results, including the interaction between multiple participant action plans (such as threats and confrontation). The fourth layer as process improvement: a resource management component that supports adaptive data acquisition and processing of tasks.

3. Determination of multi-space scale and multi-source data

3.1. Space scale

Space scale is a concept that simulates the human eye to observe things. For example, when a human eye observes different objects at different scales, it has different feelings. The main contour area is observed when the distance is far away, and more detailed information is observed at a close distance. For the same reason, in the case of large-scale parameters, the high-frequency information is seriously lost, mainly showing the outline message. While the high-frequency band of small-scale contains significantly rich information, which is easy to find and identify, and can be mostly applied in the image field for feature extraction and target recognition [9]. In this paper, the space scale refers to the size of the geographical area.

3.2. Data source

In the crowd feature data mining, multi-source data can be chosen such as literature documents, video surveillance, specific photos, thermal maps, crowd flow maps and online parallel computing and simulation systems, as well as video file retrieval, crowd evacuation backtracking and disaster data analysis method [10]. Based on the theory of physiology and sociology, the paper analyzes the individual's movement characteristics and crowd flow characteristics. According to availability and achievability, this paper selects thermal map [11], real-time video, literature documents and other data sources to construct the technical framework for the analysis of flow characteristics of the crowd.

Thermal map relies on the obtained mobile phone base station to locate the number of users in the area around a given base station, and displays the density and crowding degree of a certain area at a certain moment in a special highlight form. The darker the color, the more people, and the lighter colors represent fewer people. The thermal map has different space scales and can be scaled as needed. Through data analysis, it is possible to obtain a general rule of crowd flow for a specific time period, thereby predicting future congestion and planning the journey in advance.

Video can reflect and describe the visible state of the scene in real time, accurately, comprehensively and clearly. It is a continuous process, which can fully show the evolution process and result of the event or object state, such as the dynamic flow direction and quantity of small-scale regional population. In addition, the video can be converted into a video frame, then a sequence of images of one frame after another is generated, and the movement characteristics and situation trend of the crowd are obtained through some static data like density and speed.

Literature documents are an important source of historical data that can help clarify the significance of research and the latest developments in research. For example, according to the reference [12], population density values can be quantified into five risk levels, very low, low, medium, high, and very high. Therefore, the study of crowd movement characteristics and flow characteristics in high-risk areas is very valuable, can prevent emergencies and provide technical support for safety decisions.

4. Case study of crowd flow characteristics analysis

4.1. Location of the geographic area in case study

The research is carried out by two important places with intensive crowd, Shanghai Hongqiao High-speed Railway Station and Shanghai National Convention and Exhibition Center. First of all, Shanghai Hongqiao High-speed Railway Station is a one of largest transportation hub with a daily traffic about 200,000 or 300,000 [13]. Shanghai National Convention and Exhibition Center is a large commercial area holding various exhibitions frequently, with 200 meters walking distance from the
subway station. Then, the straight-line distance between them is only 1.5 kilometers, and the subway is only one stop away, as shown below in figure 2. What’s more, the opposite direction of this subway line runs to Shanghai urban district, so quite a few people from Hongqiao Railway Station to the terminal station Xujing East go to visit the National Convention and Exhibition Center. According to human traffic data between the two subway stations, considering the small number of people taking the bus, the characteristics of the crowd flow can be obtained finally.

Fig. 2. Location of Hongqiao Railway Station and National Exhibition Center

Fig. 3. BaiduThermal map

4.2. Application of multi-source data in multi-space scale

First, the large-scale area of 3km*3km is divided. It’s observed by the thermal map that the color of Shanghai Hongqiao High-speed Railway Station and National Convention and Exhibition Center is deeper than that of the surrounding buildings, which shows the crowd density value of them is relatively higher. From the comparison of data sources of the literature documents, it is known that there will be crowded and high-risk situations over a period of time, which in turn determines the value of this study.

Second, the space scale is reduced to 1km*1km area then. Data information of Hongqiao Railway Station and National Convention and Exhibition Center is collected respectively, and the passenger
flow between 6:00-22:00 in one day is displayed in the form of a graph. From November 5th to November 10th, the 2nd China International Import Expo was held at Shanghai National Convention and Exhibition Center. As a research background, data of the thermal map was continuously extracted for three consecutive days, and some relationships between these two places were finally discovered. There are relevance and time lag in the number of people, that is, certain characteristics of crowd flow. Relevance refers that based on the statistical results of crowd proportion, it is found that about 42% of the people from Hongqiao Railway Station to Xujing East Subway Station will go to the National Convention and Exhibition Center. Time lag is that the curve shows that when the No. 2 subway line of Hongqiao Railway Station heading for Xujing East enters the morning peak at around 8:10, the maximum number of people in the National Convention and Exhibition Center correspondingly appears at 8:40.

Third, the space scale is further reduced to 0.5km*0.5km area, only focusing on the National Exhibition Center. Using the data source of real-time video to find more specific crowded places, such as the entrance security checkpoint, the national exhibition hall, and the equipment exhibition area. Then continue to reduce the space scale to 0.1km*0.1km, locate one of them, extract video image frames and collect a large number of photos as another reliable data source, as shown in figure 4. Through the image processing technology of computer vision, more accurate crowd density data is obtained. According to the reference [14], deeply analyzing the movement of small-scale crowd, the evacuation scenario features and the evolutionary characteristics of crowd stability state can be sorted out. Under some artificial intelligence methods like rough set or neural network [15], a useful knowledge base is constructed to effectively predict the danger of stamping and support reasonable scientific crisis decision-making.

4.3. Technical framework of crowd flow characteristics analysis

Based on the contents of 4.1 and 4.2, the entire technical framework is proposed as shown below in figure 5.

5. Conclusion

In the big data background, due to large number of data sources, low value density and real-time update, multi-space scale and multi-source data fusion provide a very effective means for knowledge
acquisition and practical decision-making. Crowd evacuation including crowd flow and crowd movement is a challenging research hotspot. This paper uses data sources with extensive coverage to mine the underlying laws of crowd, analyzes the characteristics of crowd flow from a macro perspective, and timely discovers possible security risks. Gradually reduce spatial scales and locate the high-risk range in small-scale geographic areas, based latest artificial intelligence and image processing technology, crowd movement characteristics are extracted, and emergency evacuation plans can be prepared in advance. The whole paper provides an innovative approach to crowd research with strong achievability and theoretical value.

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References
[1] X.D. Wu, X.Q. Zhu, G.Q. Wu. Data mining with big data. IEEE Transactions on Knowledge and Data Engineering,2014,26(1):97-107.
[2] H.X. Chen, D.Y. Liu, M.S. Xu, et al. Research on the Flowline and Status of Spatial Data Fusion. Geomatics World,2013,20(5):26-31.
[3] J.H. Wang, J.H. Sun. Principal Aspects Regarding to the Emergency Evacuation of Large-scale Crowds: A Brief Review of Literatures Until 2010. Procedia Engineering,2014,71(32):1-6.
[4] X.K. Xu, H.Z. Wu, J.C. Zhang, J. Wang. Research on the Requirements of Emergency Decision-making Based on Multi-source Data Fusion. Information Studies: Theory &Application,2017,40(11),40-44.
[5] H.C. Yan, X.H. Huang, M. Wang. Research progress of multi-sensor data fusion technology. Transducer and Microsystem Technologies,2009,29(3):5-8+12.
[6] B.P.L. Lau, S.H. Marakkalage, Y.R. Zhou, U.l. Hassan N, C. Yuen, M. Zhang, U.X. Tan. A survey of data fusion in smart city applications. INFORMATION FUSION,2019,52:357-374.
[7] D.L. Hall, J. Linias. An Introduction to Multisensor Data Fusion. Int J Proceedings of the IEEE,1997,85(1):6-23.
[8] Y.J. Qi, Q. Wang. Review of multi-source date fusion algorithm. Aerospace Electronic Warfare, 2017,33(06),37-41.
[9] D.J. Fu, B.Z. Chen, J. Wang. An Improved Image Fusion Approach Based on Enhanced Spatial and Temporal the Adaptive Reflectance Fusion Model. Remote sensing,2013,5(12):6346-6360.
[10] R.Y. Zhao, D.H. Dong, C.L. Li, Q. Liu, Q.S. Hu, Y.L. Ma, Q. Zhang. Video based crowd stability analysis used in emergency evacuation. In proceedings of 2019 IEEE 3rd Information Technology, Networking, Electronic and Automation Control Conference. ChengDu:IEEE Press,2019.354-358.
[11] M.A. Erskine; M. Khojah; Alex.E. McDaniel. Location selection using heat maps: Relative advantage, task-technology fit, and decision-making performance. Computers in Human Behavior, 2019,151-162.
[12] H.Q. Song, X.J. Liu, G.N. Lu, et al. Video Scene Invariant Crowd Density Estimation Using Geographic Information Systems. Wireless Communication over ZigBee for Automotive Inclination Measurement. China Communications, 2014, 11(11):80-89.
[13] H.J. Tong, X.S. Liu, L.J. Zhu, L.L. Lou, Y. Xiong. Research and implementation of WiFi sniffing passenger flow monitoring system for Hongqiao Transport. Modern Electronics Technique,2019, 42(07):24-28.
[14] R.Y. Zhao, Q. Liu, C.L. Li. Knowledge Representation Model for Evolution of Crowd Evacuation Stability. Proceedings of 2019 IEEE 3rd Information Technology, Networking, Electronic and Automation Control Conference,2019,404-408.
[15] R.Y. Zhao, C.L. Li, W.Q. Ling, Y.L. Ma, Y. Sun. Crowd evacuation knowledge management based on rough set theory. WIT Transactions on Engineering Sciences,2015,91: 953-958.