A Survey of Abnormal Event Perception Research Based on Mobile Phone Location Big Data

Hu Yang¹,²,³, Zhang Xiaoyong¹,²*, Xiao Di²

¹Beijing Information Science & Technology University, Automated institute, Beijing, China
²Beijing Key Laboratory of High Dynamic Navigation Technology, Beijing, China
³Key Laboratory of Modern Measurement & Control Technology, Beijing, China

*Corresponding author’s e-mail: zhangxy@lreis.ac.cn

Abstract: The perception of human behavior that is different from normal has always been a common concern in many fields. The widespread use of smartphones makes it possible to obtain a large amount of user activities at fine spatial scales. In this context, this article first systematically summarizes the research on human behavior patterns in the era of mobile phone big data. Although the current research has made certain research progress, there are certain limitations in data source selection and activity semantic analysis. Then it focuses on the relevant research on the perception of abnormal events by mobile phone positioning big data, including the research progress in abnormal event early warning and emergency response, and believes that there is more room for development in related research. The analysis of these studies provides reference value for handling similar emergencies in the future, especially for post-disaster emergency response and resource allocation. It provides strong theoretical support.

1. Introduction
Factors such as rapid population growth, accelerated urbanization, and global climate change have caused frequent occurrences of abnormal events, causing serious losses to people's lives and property. The development of globalization technology and the changing role of mankind in society need to rethink how to avoid abnormal events and how to make scientific decisions decisively under unstable factors. In recent years, mobile communication technology has developed rapidly. According to statistics from the Ministry of Industry and Information Technology of China, as of the end of 2017, the total number of mobile phone users in the country reached 1.42 billion, of which the total number of 4G users reached 997 million, and the penetration rate of mobile phone users reached 102.5 units/Hundreds of people. The popularization of smart terminals and the big data era background that derived from it has given a new way of thinking about the perception of abnormal events. The link between mobile phone big data and urban abnormal event management is human activities. The city’s security maintainers using mobile phone big data can perceive the activities of the crowd, thereby helping to predict potential abnormal events and avoid danger in time, and improve the ability to prevent urban hazards. In addition, emergency managers can also use mobile phone data to assess the impact of disasters in real time, stop losses in time, and help decision makers formulate emergency rescue plans [1].

Based on the theoretical basis of mobile phone positioning technology, this paper systematically
summarizes the current research status of using mobile phone big data for individual behavior patterns and group movement patterns. On this basis, it sorts out the application research of mobile phone big data in abnormal event warning and response. Finally, it points out that mobile phone positioning big data has more room for development in the perception of abnormal events.

2. Mobile phone positioning big data

Mobile phone positioning refers to obtaining the location information of mobile phones or terminal users through specific positioning technologies. According to different positioning implementation methods, mobile phone positioning technologies mainly include network-based positioning and mobile terminal-based positioning [2]. Network-based positioning is to estimate the location of the mobile phone by measuring and processing the communication signal data between the mobile phone and the base station. It mainly includes positioning technology based on Cell-ID, time advance (TA) positioning technology, and angle of arrival (AOA) based positioning technology. Based on time of arrival (TOA) positioning technology, based on time difference of arrival (TDOA) positioning technology [4]. See Figure 1.

The positioning technology based on the mobile terminal uses the GPS module in the mobile phone for positioning, mainly including GPS positioning technology, assisted GPS positioning technology, etc. The positioning accuracy is higher than the former, and the maximum can reach within ten meters [5]. The data generated by various mobile phone positioning technologies including the location information, timestamp, call duration, etc. of the positioned user is the mobile phone positioning data, and the mobile phone positioning data of a large number of users generated over time in a certain area constitutes the mobile phone positioning Big data [3].

Traditional cell phone positioning data can be divided into cell phone bill positioning data and cell phone signaling positioning data [6], both of which are purchased from mobile operators. The positioning technology used is base station positioning, which does not require the phone to have GPS. Positioning capability, but the accuracy largely depends on the density of the base station, sometimes the error can even exceed one kilometer in mountainous areas. As smart phone positioning technology becomes more powerful and its popularity gradually increases, social software such as WeChat and
Weibo, and location query service software such as Baidu Maps will actively or passively record the user's location, resulting in a new Internet mobile phone positioning. Most of the data sources depend on the GPS positioning function of the mobile phone, and its positioning accuracy is high [7]-8. In addition, there are data obtained by using Wifi to locate mobile phones in a small area.

Both traditional mobile phone signaling data and Internet mobile phone positioning data can directly or indirectly reflect the behavior patterns of a single user and the activity patterns of user groups within a certain period of time.

3. Analysis of human behavior patterns based on mobile phone positioning big data

3.1. Research on personal behavior patterns

In urban planning that emphasizes "people-oriented", the study of individual behavior patterns is the foundation and the key link. The study of personal behavior patterns mainly reflects the individual's intentions, preferences and spatial activity trends to a certain extent through the individual's time series movement trajectory [9], and then understands user habits and provides personalized services.

Traditional thinking believes that individual behavior is random and disorderly, but BARABASI et al. [10] based on the results of human historical behavior proved that human behavior has obvious bursts and heavy tails in many aspects, that is, long-term inactivity and short-term behavior. The time burst behavior is interlaced, and the time interval obeys the heavy tail distribution. Licoppe et al. [11] proved that the uneven spatial distribution of human activities is mainly due to human circadian rhythms and periodic patterns. Ahas et al.[12] used 8 days of mobile phone location data of 277 users in a new residential area outside the city of Estonia to analyze the circadian rhythm and spatial differences of urban life, including the regular work, school and leisure activities of the respondents. This deepens the understanding of the residents' cycle activities and also contributes to the development of the location-based service market. In addition, identifying the points of interest (office, leisure and entertainment, dining, etc.) of different types of individuals in their daily travel can also help understand individual characteristics. Huang et al. [13] proposed a spatio-temporal mining technology based on mobile phone positioning data to extract the main anchor points of large cities, including the identification of work places, residences, and leisure places. Phithakkitnukoon et al. [14] combined the spatial distribution of various buildings (restaurants, shopping malls, movie theaters) and used mobile phone location data of 1 million users in Massachusetts to obtain the characteristics of individual daily activity patterns. Sibren Isaacman [15] uses a clustering algorithm to identify home and work locations. Lin Nan [16] combined the temporal and spatial continuity characteristics of individual behavior patterns, and proposed a method of using the growth clustering algorithm to more accurately identify the location of stay, and used the mobile phone positioning data of Shenzhen as an example to prove the algorithm’s effectiveness. reliability. In addition, many scholars analyze the predictability of individual travel. Miao Lin et al. [17] pointed out that personal trips always give priority to certain specific locations, even if they occasionally explore new locations, human activities basically follow a simple recurring model, and proposed a new Markov model Make predictions about individual behavior. Calabrese F et al. [18] proposed a probabilistic model-based personal behavior prediction model.

Individual-based behavior patterns indicate that user travel has a certain degree of regularity and predictability, and this discovery is of great significance for understanding user travel dynamics at a micro level and making personalized recommendations [19].

3.2. Research on Group Movement Mode

The movement behavior of user groups between different geographic regions is actually a spatial interaction process, which not only reflects the intensity of social and economic connections between regions, but also reflects the relevance of human gathering and urban spatial structure elements [20], and The participation of mobile phone location data allows scholars to analyze the mobile characteristics of large-scale urban groups from different perspectives. First, the migration
characteristics can be analyzed from the perspective of short-term large-scale spatial uneven flow. Zhou Xiaojin [21] conducted statistics on the population flow during the Spring Festival travel period in China, and divided the population flow during the Spring Festival into three components: "incoming population returning home", "business travel flow" and "reverse flow of left-behind population". "Returning home flow" is the main component. This kind of short-term and long-distance population flow change research can provide help for traffic hub detection. Second, the travel rhythm of urban people can be analyzed from the perspective of long time series. Francesco Calabrese [22] used mobile phone data from eight counties in eastern Massachusetts to capture the difference in travel patterns between weekdays and weekends, and distinguished travel into work schedules and non-work schedules. Yang Xiping [23] took Shenzhen as an example, used autocorrelation analysis to identify the temporal and spatial differentiation of urban crowd gathering and dispersion, and obtained 9 temporal and spatial patterns of crowd gathering and dispersion, and possible corresponding land use types. Li Mingxiao et al. [24] took Shanghai as an example, analyzed the city's fine-scale temporal and spatial population distribution based on the continuous trajectory data of mobile phone signaling, and found that the temporal population distribution among urban areas in Shanghai is relatively stable and the difference is small. Urban planning and emergency management provide scientific basis. Jonathan Reades [25] used a set of three-month-long mobile phone data to obtain the connection between the mobile phone data of Roman citizens and business activities through the research of "characteristic location", which proved that the urban spatial distribution and the movement of people are inherently related. Third, we can study residents' mobility behavior from the perspective of commuting. Bao Ting [26] established three population mobility models for entering and leaving cities, between districts and counties, and residence/work to further understand the characteristics of the temporal and spatial distribution of user groups, which helps to rationally allocate social resources and cope with traffic pressure.

At present, research based on group movement patterns mainly study population flow changes from the urban time series level, use data mining technology, combined with spatial geographic information for visual analysis, explore the characteristics of urban population movement and its evolutionary law, and increase the dynamic understanding of urban space. The analysis of urban hotspot area detection [27], the analysis of urban land function characteristics [28], the analysis of job-residential distribution structure and traffic conditions [29] are particularly important.

3.3. Research summary of human behavior patterns

The research of human behavior patterns presents diversified characteristics in data foundation, analysis methods and application fields, but it also has many limitations. For the research methods, most of the single data analysis for users, and most of them do not fully understand the characteristics of residents' travel by combining spatial characteristics. Research on individuals only records their spatial location in the city, but lacks the understanding of the semantic information of users participating in various activities during their journey. The choice of research area is basically concentrated in the megacities everywhere. As far as my country is concerned, it is mainly concentrated in the urban areas with high population density such as Beijing, Shanghai, Guangzhou and Shenzhen, and it is easy to overlook the characteristics of the large-scale secondary cities. In the future, we should try to obtain data beyond the limits of the city in data collection. We should combine multi-source data such as bus and subway station swipe data, floating car data to obtain richer information to explore the relationship between the individual and the whole of the human movement model. Relevance, an in-depth understanding of daily travel patterns and the law of action, also lay the foundation for subsequent emergencies research.

4. Analysis of abnormal event perception based on mobile phone positioning big data

4.1. Early warning of abnormal events

Group abnormal events (such as crowding, trampling, etc.) usually occur in crowded public places
with large traffic[30]. Social activities such as concerts, elections, sports events, etc. will generate large-scale crowds, which are mutations of the crowd. Because of the continuity of people's movement behavior, any sudden crowd change is a process of gradual gathering of a large number of individuals in time and space. From a long-term perspective, the sudden change in the value of the crowd is actually a continuous gradual process [31].

Due to differences in urban spatial functions, crowd movement is often purposeful. Discovering the relationship between population mobility and social events and predicting the trend of group-level activities are essential requirements for early warning of abnormal events. Ahas[32] is an early scholar who tried to use mobile phone location data to conduct urban space public safety research. He proposed a mobile-based social positioning method (Social Positioning Method) to monitor the temporal and spatial distribution of the flow of people, predict and prevent various problems caused by the agglomeration of the flow of people. Haoyi Xiong [33] introduced the collective behavior model (CBP) and proposed a new location prediction method based on the strong correlation between the locations of similar user groups. Zhao et al. [34] combined individual trajectories with group activity trajectories, and used dynamic Bayesian networks to predict group trajectories. Sun Ying et al. [31] deduced the change process of crowd gathering and dispersion, proposed a crowd prediction model at the base station scale, and proved the applicability of the model to sudden crowds, providing theoretical guidance for fine-grained crowd prediction. Short-term population flow is uneven in time and space, and there are often potential abnormal events. Therefore, timely and accurate identification of major events and prediction of crowd flow patterns make it possible to achieve active prediction and control, from the source Avoid losses. Laura Ferrari [35] used ten months of telecom operator data in two Italian cities to identify major events in the city, and identified social events (football matches) by giving definitions of 'overcrowded events' and 'sparsely staffed events', Shopping mall activities), the results show that the success of the detection of social events largely depends on the location of the investigated venue. Although the results did not reach the expected goal, on this basis, we can try to establish large-scale simulation experiments to realize the process of complex social events and predict the risk coefficient of the event. Calabrese et al. [36] used mobile phone trajectory data of 1 million users to analyze the relationship between people participating in activities and types of social events. Calabrese also introduced a large-scale city real-time monitoring platform called "Real-time Rome" [37], which can combine cell phone location data and bus data to conduct real-time assessment of pedestrian flows and traffic conditions throughout the city, in order to respond to emergencies and Alleviate congestion and provide decision-making assistance information flow. Fang Jia [38] studied the dynamic changes of large passenger flows based on the difference between the passenger flow during the Cherry Blossom Festival in Shanghai Gucun Park and the usual holidays, and quantified the correlation between the number of people entering the park and the passenger flow of surrounding subway stations through mobile phone signaling data Analysis and development of three-level early warning programs, which provide a basis for the analysis and management of large festivals. The Big Data Laboratory of Baidu Research Institute [39] based on the mining of Baidu's positioning data and related data, and found that Shanghai’s “12-31” Bund stampede accident has the possibility of realizing an early warning of the peak flow of people.

Current research on group abnormal events shows that real-time tracking and recognition of crowd behaviors through mobile phone positioning data has realized the transformation of population distribution from static historical time-space data analysis to dynamic crowd perception. Improving the management system by predicting group behavior is an important means to prevent and reduce abnormal events. Only by taking into account the real-time and accuracy of crowd behavior analysis, can it provide important decision-making basis for urban traffic management and public safety incident risk assessment.

4.2. Emergency response

Emergencies refer to natural disasters, accidents, public health incidents, and social security incidents that occur suddenly that cause or may cause serious social harm and require emergency response
measures to be taken[40]. Various emergencies such as earthquakes, floods, freezing rain and snow, explosions of dangerous goods, outbreaks of epidemics, terrorist attacks, etc. will eventually be manifested through abnormal human behaviors, which are reflected in the rapid changes in local population density in a short period of time, movement direction and sudden changes in speed and other aspects. Using mobile phone data to capture human behavior patterns in sudden changes in abnormal conditions will help to re-understand human behavior in panic and guide emergency rescue work.

Emergencies refer to natural disasters, accidents, public health incidents, and social security incidents that occur suddenly that cause or may cause serious social harm and require emergency response measures to be taken. Various emergencies such as earthquakes, floods, freezing rain and snow, explosions of dangerous goods, outbreaks of epidemics, terrorist attacks, etc. will eventually be manifested through abnormal human behaviors, which are reflected in the rapid changes in local population density in a short period of time, movement direction and sudden changes in speed and other aspects. Using mobile phone data to capture human behavior patterns in sudden changes in abnormal conditions will help to re-understand human behavior in panic and guide emergency rescue work.

In order to explore people's reactions to emergencies, scholars have done a lot of research. James et al. [41] compared the real-time changes in the communication and flow patterns of surrounding people under 8 emergencies (such as bomb attacks, earthquakes, etc.) with the situation under 8 non-emergency events (such as concerts, sports activities) and found with the advent of emergencies, people’s call intensity has a rapid increase and then a sharp drop in a short period of time, which is clearly different from the gradual increase in call intensity under non-emergency events. This research guides people to use mobile phones as on-site sensors to understand humans. Research on the way to deal with the environment under the influence of unstable factors. Lu X[42] analyzed the different characteristics of human behavior patterns before and after the earthquake based on the mobile phone location data of 1.9 million mobile phone users in more than 400 days before and after the 2010 Haiti earthquake, and found that the movement behavior of the population after the disaster is as predictable as 85%. Pastor-Escuredo D[43] used mobile phone call records data before and after the flood disaster in Tabasco, Mexico, and found that the behavior patterns of people in the disaster-stricken area were abnormal during and after the flood. Yuan Ning[40] studied the impact of emergencies on human behavior patterns from a group perspective based on the outstanding performance of human alarm behavior. Li Dongping[44] took the Jiuzhaigou earthquake-stricken area in Sichuan in 2017 as an example. The simulation experiment of population distribution based on nuclear density analysis proved that the use of mobile phone signaling data can provide reliable information for government disaster relief during the black box period within a few hours immediately after the earthquake. And pointed out that the accurate calculation of the base station withdrawal rate is particularly important. In the future, we can make full use of mobile phone positioning data to make more detailed analysis of the population movement in the epicenter and the detention of traffic lines. Zhang Xiaoyong [45] used the Apriori algorithm to determine the call status of mobile phone users after the earthquake to evaluate the damage caused by the 2008 Wenchuan earthquake. Wang Hexun [46] analyzed the practicability of mobile phone positioning technology in maritime search and rescue operations.

Many scholars have pointed out the importance of quickly and accurately grasping real-time information about human activities in emergencies in actual rescue. The real-time and dynamic recording characteristics of mobile phone location data complement the previous use of census data and low-information post-disaster data (witness reports, questionnaires, etc.) [1], which provides a dynamic interpretation of human behavior in emergencies Provides a new perspective, which makes it possible to more quickly and accurately determine the temporal and spatial distribution of the population after the disaster, and provide strong support for emergency rescue.

4.3. Summary of abnormal event perception
In recent years, scholars at home and abroad have used mobile phone location data and other survey
methods as well as geospatial data to summarize and analyze disaster events that have occurred. They have also done a lot of research on how to perceive the dynamic changes of the crowd to sharply identify potential abnormal events. Hard work. First, we divide the relevant research into two aspects according to the controllability of abnormal events. For abnormal events induced by human factors, scholars often consider avoiding similar events from the perspective of crowd movement. Combined with many research results, it is found that in order to achieve passive monitoring of population movement to active prevention of abnormal events, a quantitative analysis is needed. Standards, so as to evacuate people in time. For uncontrollable emergencies, scholars mainly use comparative analysis methods to describe the characteristics of abnormal behavior patterns of human beings facing uncontrollable emergencies, so as to provide an effective way to quickly grasp the dynamic distribution of the population after the disaster. Understand the disaster situation in various places and arrange rescue work to provide services. These studies provide reference value for handling similar emergencies in the future, especially for post-disaster emergency rescue and resource allocation. In general, unlike the research on the interaction between fixed patterns of human activities and urban space, there are more unstable factors in the research of using mobile phone positioning big data to detect abnormal events in large-scale group gatherings and dispersions. Makes research more challenging. At present, the research on the regular urban day and night, periodic pattern social activities is more comprehensive, specific, and in-depth, while the capture of human activities in abnormal events is still in the development stage and needs in-depth research.

5. Conclusions
This article first starts from the perspective of human dynamics, systematically summarizes and analyzes the current scholars using mobile phone positioning big data to study human behavior patterns from the micro to macro, from static to dynamic perspectives. Relevant research reveals the general laws of individual and group activities, and deepens the understanding of the relationship between human activities and geographic space elements. Then the focus is shifted from human normal behavior to the research of human abnormal behavior, and the research of abnormal event perception based on mobile phone big data is summarized into two parts: abnormal event early warning and emergency response. At present, on the one hand, researchers analyze the law of user group activities to perceive potential safety hazards caused by a large number of crowds, and on the other hand, analyze the abnormal behavior patterns of the crowd by collecting mobile phone data before and after historical disaster events, and then grasp emergencies. The essential characteristics of human behavior behind it help managers formulate scientific emergency response plans and make scientific decisions.

The study of human abnormal behavior in emergencies is in the ascendant as an important branch of human dynamics research, but the research still has certain limitations: First, the researcher hopes to obtain higher temporal and spatial recognition of mobile phone data for fine-scale analysis. Worried about taking the risk of privacy leakage, it is necessary to formulate relevant constraints to prevent unauthorized sharing and other issues so that more in-depth research can be conducted while protecting user privacy to the greatest extent. Secondly, the user travel mode constructed by mobile phone location data only summarizes and records the user's actual travel time and space location information, which is still difficult to express for complex individual interaction activities. It is necessary to explore how to integrate multi-source data to conduct a more comprehensive and in-depth study of human activity patterns. Thirdly, it is very necessary for managers to establish a comprehensive emergency management system based on mobile phone positioning big data. Usually, emergencies have cascading effects [1] (such as tsunami, subsequent earthquake), and a real-time analysis platform can be developed to prioritize emergency problems, prevent subsequent hazards, coordinate aid organizations, and arrange first rescuers. Finally, it is worth mentioning that the Beidou navigation system covering my country's territory, with its fast positioning, precise timing, and short communication, has brought new possibilities for the acquisition of more fine-scale mobile phone positioning data, which will definitely be abnormal in the near future. The study of event perception
adds new ideas.

Acknowledgments
Supported by The National Natural Science Foundation of China (Grant No.41871348) and Beijing Natural Science Foundation (Grant No.9182004).

References
[1] Akter S, Wamba S F. Big data and disaster management: a systematic review and agenda for future research[J]. Annals of Operations Research, 2017(9):1-21.
[2] Deng Ping. Research on mobile station positioning technology in cellular network [D]. Southwest Jiaotong University, 2002.
[3] Ratti C , Pulseli R M , Williams S , et al. Mobile Landscapes: using location data from cell phones for urban analysis[J]. Environment & Planning B Planning & Design, 2006, 33(5):727-748.
[4] Yang Fei. Traffic OD data acquisition technology based on mobile phone positioning[J]. Systems Engineering, 2007, 25(1): 42-48.
[5] Zandbergen P A, Barbeau S J. Positional Accuracy of Assisted GPS Data from High-Sensitivity GPS-enabled Mobile Phones[J]. Journal of Navigation, 2011, 64(3):381-399.
[6] Ran Bin, Qiu Zhijun, Qiu Weiyi, et al. Practice of mobile phone positioning data in urban planning under big data environment [A]. China Urban Planning Society. Urban Era, Collaborative Planning-2013 China Urban Planning Annual Conference Proceedings (13-Planning Information and New Technology) [C]. China Urban Planning Society, 2013:13.
[7] Guo Can, Zhen Feng, Zhu Shoujia. The progress and prospects of the application of smart positioning data to urban research[J]. Human Geography, 2014(6):18-23.
[8] Wolf J, Guensler R, Bachman W. Elimination of the Travel Diary: Experiment to Derive Trip Purpose from Global Positioning System Travel Data[J]. Transportation Research Record Journal of the Transportation Research Board, 2007, 1768(1):125-134.
[9] Gonzalez M C, Hidalgo C A, Barabasi A L. Understanding individual human mobility patterns[J]. Nature, 2008, 453(7196):779-782.
[10] BARABÁSI A L. The origin of bursts and heavy tails in human dynamics[J]. Nature, 435(2005): 207-211.
[11] Licoppe C, Diminescu D, Smoreda Z, et al. Using mobile phone geolocalisation for 'socio-geographical' analysis of co-ordination, urban mobilities, and social integration patterns[J]. Tijdschrift voor Economische en Sociale Geografie, 2008,99(5):584-601.
[12] Ahas R, Aasa A, Silm S, et al. Daily rhythms of suburban commuters’ movements in the Tallinn metropolitan area: Case study with mobile positioning data[J]. Transportation Research Part C, 2010, 18(1):45-54.
[13] Huang W , Dong Z , Zhao N , et al. Anchor Points Seeking of Large Urban Crowd Based on the Mobile Billing Data[C]// Advanced Data Mining & Applications-international Conference. DBLP, 2010.
[14] Phithakkitnukoon S, Horanont T, Lorenzo G D, et al. Activity-aware map: identifying human daily activity pattern using mobile phone data[C]// Human Behavior Understanding, First International Workshop, Hbu, Istanbul, Turkey, August, 2010.
[15] Isaacman S, Becker R, Cáceres R, et al. Identifying important places in people’s lives from Cellular Network data [A]. Pervasive Computing[M]. Springer Berlin Heidelberg, 2011:133-151.
[16] Lin Nan, Yin Ling, Zhao Zhuyuan. Recognition algorithm for individual staying area of mobile phone positioning data based on sliding window[J]. Journal of Geo-Information Science, 2018, 20(06): 762-771
[17] Calabrese F , Di Lorenzo G , Ratti C . Human mobility prediction based on individual and collective geographical preferences[C]// International IEEE Conference on Intelligent
Transportation Systems. IEEE, 2010.

[18] Lin M, Hsu W J, Lee Z Q. Modeling High Predictability and Scaling Laws of Human Mobility[C]. IEEE International Conference on Mobile Data Management. IEEE, 2013.

[19] Wu Qingxia, Zhou Ya, Wen Diyao, et al. Personalized travel route recommendation based on user interest and popularity of points of interest [J]. Computer Applications, 2016, 36(06): 1762-1766.

[20] Yang Xiping, Fang Zhixiang, Yin Ling. Exploration of the relationship between urban spatial structure elements and the stability of crowd gathering and dispersion[J]. Journal of Geo-Information Science, 2018, v.20; No.130(06):83-90.

[21] Zhou Xiaojin, Yao Yang. New changes in the flow and direction of population flow in Beijing and Shanghai based on big data[J]. Big Data, 2016, 2(03): 49-59.

[22] Calabrese F, Lorenzo G D, Liu L, et al. Estimating Origin-Destination Flows Using Mobile Phone Location Data[J]. IEEE Pervasive Computing, 2011, 10(4):36-44.

[23] Yang Xiping, Fang Zhixiang, Zhao Zhiyuan, et al. Exploration and analysis of the temporal and spatial patterns of urban crowd gathering and dissipating: Taking Shenzhen as an example [J]. Journal of Geo-Information Science, 2016, 18(04):486-492.

[24] Li Mingxiao, Chen Jie, Zhang Hengcai, et al. Estimation and Characteristic Analysis of Population Distribution at Fine Spatial and Temporal Scale in Shanghai[J]. Journal of Geo-Information Science, 2017, 19(06): 800-807.

[25] Schlaich J, Otterstätter T, Friedrich M. Generating Trajectories from Mobile Phone Data[J]. Transportation Research Board Annual Meeting, 2010.

[26] Bao Ting, Zhang Zhigang, Jin Cheqing. Urban population flow analysis system based on mobile phone big data[J]. Journal of East China Normal University (Natural Science Edition), 2015(05):162-171.

[27] Hu Y, Gao S, Janowicz K, et al. 2015. Extracting and understanding urban areas of interest using geotagged photos[J]. Computers, Environment and Urban Systems, 54: 240-254.

[28] Tao Pei, Stanislav Sobolevsky, Carlo Ratti, 等. A new insight into land use classification based on aggregated mobile phone data[J]. International Journal of Geographical Information Science, 2014, 28(9):1988-2007.

[29] Xu Ning, Yin Ling, Hu Jinxing. Recognizing residents' occupation and residence from large-scale short-term regular sampling of mobile phone location data[J]. Journal of Wuhan University Information Science Edition, 2014, 39(6): 750-756.

[30] Pan Lei, Zhou Huan, Wang Minghui. A real-time detection method for abnormal events in dense crowds[J]. Computer Applications, 2016, 36(06): 1719-1723.

[31] Sun Ying, Chen Xiaoming, Wang Haiyang, et al. Spatio-temporal prediction model of base station population at urban scale[J]. Computer Application Research, 2016, 33(12): 3521-3526+3534.

[32] Ahas R, Aasa A, Silm S, et al. Mobile Positioning in Space–Time Behaviour Studies: Social Positioning Method Experiments in Estonia[J]. American Cartographer, 2007, 34(4):259-273.

[33] Xiong H, Zhang D, Zhang D, et al. Predicting Mobile Phone User Locations by Exploiting Collective Behavioral Patterns[C]. International Conference on Ubiquitous Intelligence and Computing and, International Conference on Autonomic and Trusted Computing. IEEE Computer Society, 2012:164-171.

[34] Zhao Z D, Cai S M, Huang J, et al. Scaling behavior of online human activity[J]. Europhys Lett, 2014, 102(3):36001.

[35] Ferrari L, Mamei M, Colonna M. Discovering events in the city via mobile network analysis[J]. Journal of Ambient Intelligence & Humanized Computing, 2014, 5(3):265-277.

[36] Calabrese F, Pereira F C, Lorenzo G D, et al. The Geography of Taste: Analyzing Cell-Phone Mobility and Social Events[J]. Lecture Notes in Computer Science, 2010, 6030:22-37.

[37] Calabrese F, Colonna M, Lovisolo P, et al. Real-Time Urban Monitoring Using Cell Phones: A Case Study in Rome[J]. IEEE Transactions on Intelligent Transportation Systems, 2011,
12(1):141-151. 2012, 100(4): 48004.

[38] Fang Jia, Wang De, Xie Dongcan, et al. Study on the characteristics and early warning of the large passenger flow of the Cherry Blossom Festival in Shanghai Gucun Park——Exploration based on mobile phone signaling data[J]. Urban Planning, 2016, 40(6).

[39] Big Data Intelligent Analysis-Behind the Bund Stampede [EB/OL].2015-1-20.

[40] Yuan Ning. Research on the impact of emergencies on human communication behavior patterns [D]. Tianjin University, 2016.

[41] Bagrow J P, Wang D, Barabási, Albert-László, et al. Collective Response of Human Populations to Large-Scale Emergencies[J]. PLoS ONE, 2011, 6(3):e17680.

[42] Lu X, Bengtsson L, Holme P. Predictability of population displacement after the 2010 Haiti earthquake [J]. Proceedings of the National Academy of Sciences, 2012, 109 (29): 11576–11581.

[43] David Pastor-Escuredo, Alfredo Morales-Guzmán, Yolanda Torres-Fernández, et al. Flooding through the lens of mobile phone activity[J]. 2014:279-286.

[44] Li Dongping, Huang Le, Chen Haipeng, et al. Analysis of human flow in Jiuzhaigou M7.0 earthquake based on mobile phone location data[J]. Earthquake Research in China, 2017, 33(04): 602-612.

[45] Zhang X, Xie X, Ning B, et al. Estimation of the seismic disaster-stricken area based on wireless communication data[C]// SPIE Defense, Security, and Sensing. 2013.

[46] Wang Hexun, Yu Jianghua. Analysis on the application of mobile phone positioning technology in maritime search and rescue operations [J]. Navigation Technology, 2008(S2): 37-38.