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Design and Development of a Visualization System for COVID-19 Simulation Based on WebGIS

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***Abstract*—In order to more visually display and analyze the temporal and spatial evolution of coronavirus disease (COVID-19), and provide refined data support and information reference of epidemic prevention decisions for government departments, this paper designs and develops a COVID-19 epidemic simulation and visualization system based on WebGIS through a third-party open-source framework and visualization library. The system can visually portray the microscopic behavior of individuals spreading the epidemic and the macroscopic epidemic situation. The system implements three modules: epidemic visualization, intra-urban travel intensity and individual model transmission simulation. In this paper, the changes of travel intensity within the city and the temporal and spatial evolution of the epidemic were analyzed with Wuhan city as an example. This study is valuable for the development of systems for visualizing outbreaks of highly infectious epidemics.**

Keywords: COVID-19; WebGIS; Travel Intensity; Individual Model

I. INTRODUCTION

At the end of 2019, the first case of coronavirus disease (COVID-19) was found in Wuhan, and the subsequent Spring Festival "Homecoming Tide" further expanded the spread of the epidemic [1]. In the early stage of the epidemic outbreak, it was difficult to obtain accurate and timely information about the epidemic, which made it difficult to provide a reliable basis for the deployment of resources for prevention and control, and thus the epidemic could not be controlled in a timely and effective manner [2,3]. WebGIS is a computer system for storing, processing, analyzing, displaying and applying spatial information in a network environment [4], which can provide an effective platform and reliable technical support for rapid access to epidemic information, spatial graphical representation, spatial decision analysis and evaluation, and real-time dynamic release. Based on the national provincial tuberculosis disease data, Hu et al. applied mapping technology to display the field of epidemic diseases, and identified spatiotemporally and spatially high disease clusters through clustering analysis methods [5]. After analyzing the 2008-2009 national bacterial dysentery surveillance data using spatial-temporal scanning statistics, Xiao et al. visually and comprehensively display the spatial-temporal distribution patterns and change trends of disease incidence through geographic information system (GIS) [6]. Therefore, design and development of the COVID-19 epidemic simulation and visualization system based on WebGIS can assist the government and other relevant departments to scientifically develop targeted epidemic prevention and control programs, thereby maximizing the control of epidemic spread and reducing the negative impact of the epidemic on society and the economy.

In response to the COVID-19, many scholars have conducted a series of studies on the prediction of the epidemic and the evaluation of epidemic prevention measures based on the epidemic data from the Wuhan Municipal Health Commission. For example, Fan et al. established a novel coronavirus kinetic model based on a complex network theory and predicted the inflection point of the epidemic [7-9]. Chen et al. simulated the transmission process of the novel coronavirus in Hubei province based on the WPF method and analyzed the development trend of the epidemic [10]. Although these studies were able to provide sufficient theoretical support and control guidance for this epidemic, they failed to visually portray the microscopic behavior of the epidemic-transmitting individuals

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and the macroscopic epidemic situation for government decision-makers. While some domestic internet platforms (e.g., Clove Garden, Alipay APP and Tencent News APP [11]) have developed epidemic visualization modules, but they are limited to the visual display of existing epidemic data and do not delve into the link between the intensity of travel within cities and the development of the epidemic. Therefore, based on the visualization of COVID-19 epidemic, this paper adds two modules, the travel intensity and individual model propagation simulation, to the visualization of the neo-crown epidemic. The modules are designed to show the changes of travel intensity and spatiotemporal characteristics of the epidemic in the city, and provide more detailed information to support the government's epidemic prevention decisions.

II. KEY TECHNOLOGY

A. WebGIS framework

WebGIS is a large-scale integrated geographic information system created through the internet platform, using network protocols to achieve geographic information collection and spatial platform information sharing [12]. In this paper, the individual model simulation module must be initialized for each individual as a model input condition. Wuhan, as a large city with a population of 10 million, has a large amount of data, which consumes a lot of resources for storage and transmission. Therefore, the advantages of using WebGIS framework are more obvious than traditional GIS systems, especially the data sharing is easier and more convenient, and the client no longer needs to store many business files and data, it is easier to achieve cross-browser and cross-platform work.

B. Baidu's open-source interactive map framework and ECharts visualization library

Baidu Maps provides rich geographic information data that developers can call interfaces to make use of the underlying geographic information data [13]. At the same time, according to the system requirements, the map can be personalized and customized to achieve the visualization of geographic information data. To provide an intuitive and easy to interact with epidemic data visualization charts in the COVID-19 epidemic visualization module, this paper uses the ECharts visualization library to highly customize the charts. ECharts is an open-source visualization library implemented in JavaScript that runs smoothly on both PC and mobile devices, and it is compatible with most current browsers (e.g., IE8/9/10/11, Chrome, Firefox, Safari, etc.) [14].

C. Modelling intra-urban travel intensity

Travel intensity is an indicator used to measure the travel demand of urban residents [15]. The higher the intensity of travel of residents, the higher the probability of person-to-person contact, and the higher transmission risk of the virus. Wuhan is the first city in China where confirmed cases of COVID-19 were found and the epidemic was the most serious. Wuhan is also an important integrated transportation hub in China, with 13 districts under its jurisdiction, a built-up area of 812.39 km2, and a resident population of 11.2 million. In this paper, based on these data, such as land use type data, building contour vector data, and street census data, a population geographic model is generated by establishing spatial association rules between geographic information and population to match individuals with environmental entities. Subsequently, an internal travel intensity simulation algorithm of Wuhan city was designed by assigning household roles, home addresses, workplaces, schools, and other places to individuals. And the results are presented in the form of a heat map in the system.

The Algorithm is divided into three parts:

(1) Assigning personal residences and their belonging groups. Calculating the construction area of the entire building based on the area and number of floors in the residential area. Combined with the 2010 Wuhan township-level population census data, the population density per unit area of each street was calculated to estimate the population of each residential area building and eliminate outliers. According to the information on the age structure of the registered population in the Wuhan Statistical Yearbook 2019, the urban population was divided into three categories: students, office workers and retirees.

(2) Setting different travel tracks and travel times for different types of personnel based on travel rules (Table 1).

(3) Obtaining individual location and filtering moving individuals. Calculating the location of the inhabitants at each moment according to the travel rule, and round up the time information. The location of each individual at moment n is compared to the location of moment n+1, keeping the individuals that have moved. The flow of the algorithm is shown in Fig.1.

Table 1 travel rules

	Student	Office worker	Retiree
Going out	Around 7:00 am	Around 7:00 am	7:00-19:00any time
Commute	15 to 20 minutes	15 to 20 minutes	\
Dwell	8 to 10 hours	8 to 10 hours	\
Other	\	2 hours	6 hours
Track	Home – School - Home	Home – Work – Other- Home	Home – Other - Home

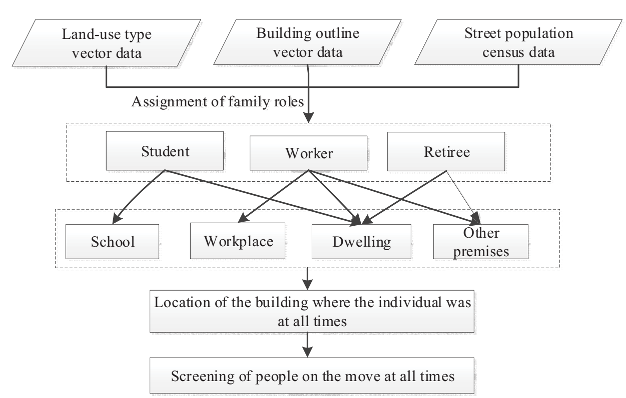


Figure. 1 Intra-city travel intensity

D. Simulating the spread of COVID-19 epidemic network based on individual models

Networks are commonly divided into regular networks and complex networks, and complex networks can be further divided into random networks, small-world networks, and self-similarity networks [15]. Both small-world networks and self-similarity networks are between regular and random networks. People are the sum of all social relations, and individual agents are social and can interact with other agents. A small-world social network of the untreated infected and susceptible individuals in the same building will be created to simulate the process of person-to-person transmission. The detailed simulation process is shown in Fig. 2. Table 2 specifies the set of individual and environmental attributes of the agent at any time period. Individuals are correlated with environmental entities, and the spread of multi-agent viruses in the same building in each period can be simulated in chronological order.

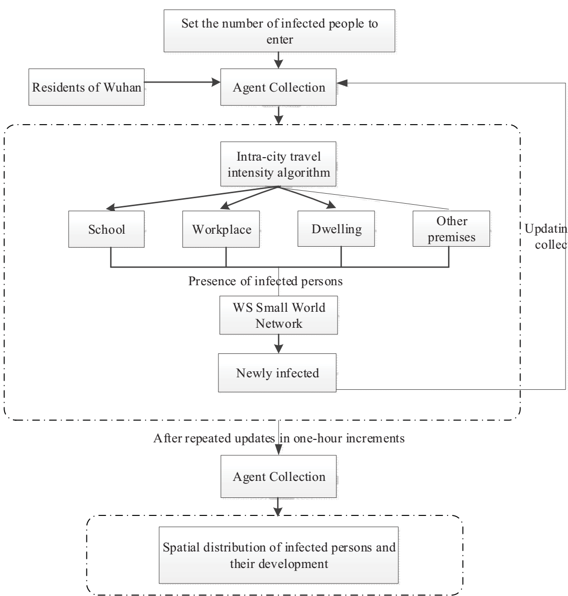


Figure. 2 Framework of network propagation simulation based on individual model

Table 2 agent individual attribute set and environment attribute set

Individual attribute	Environmental attribute
Personal Identification ID	Building ID
Building ID	Number of floors
Home Id	Type of building
Type of person	Longitude
State of health	Latitude

III. System Design

Since this system is mainly used for epidemic information visualization, agent simulation and decision analysis, it requires high reliability and real-time data. Therefore, the system adopts a four-layer B/S structural model, which can better meet the requirements of system objectives. The overall framework of the system is shown in Fig. 3, which is mainly divided into the infrastructure layer, data resource layer, application system layer and user layer. the infrastructure layer includes some software, such as geographic information system, data management system for processing and managing data, as well as network communications equipment for data transmission and network connectivity. The data resource layer includes spatial data (Wuhan city land-use type data, building contour vector data, and national epidemic data) and attribute data (street census data, agent data, and other data). The data is managed uniformly in the Oracle database. The application system layer corresponds to all application modules, including epidemic visualization, intra-city travel intensity and individual model transmission simulation; The user layer presents a comprehensive visualization of each application module.

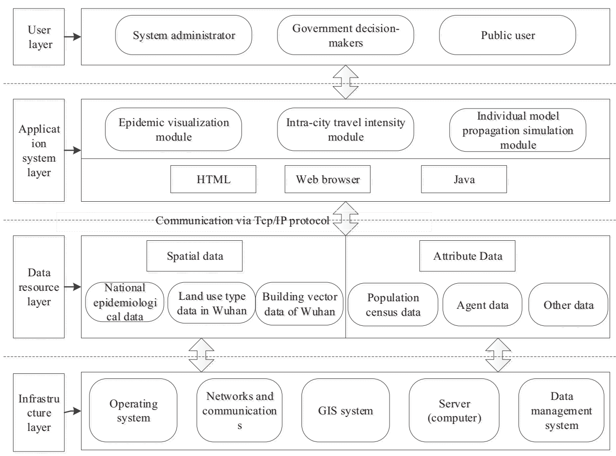


Figure. 3 System architecture

IV. System Implementation

A. Epidemic visualization module

The epidemic visualization module mainly displays the epidemic situation in China, Hubei, and Wuhan (Fig. 4). It includes the temporal dynamic display of the number of infections in different regions in the map; Trend line graphs of new confirmed cases in China (excluding Hubei), Hubei (excluding Wuhan) and Wuhan; Trend line graphs of new death cases in China (excluding Hubei), Hubei (excluding Wuhan) and Wuhan; The number of imported cases from abroad and the number of new local cases and population migration in key cities.

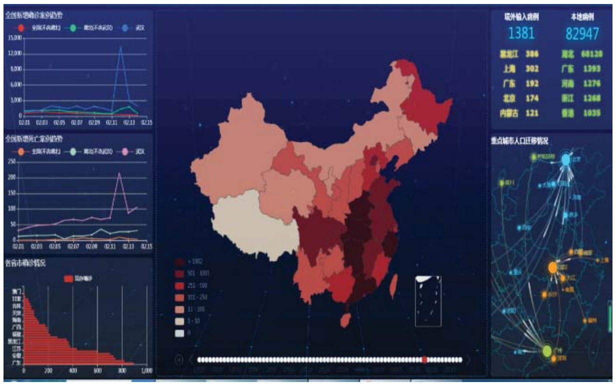
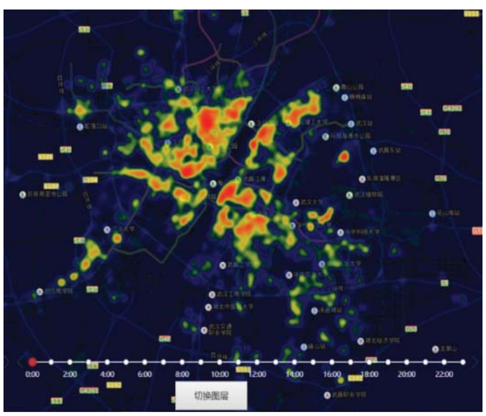


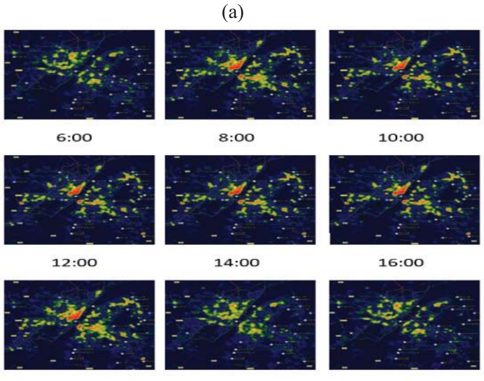
Figure. 4 Epidemic visualization module interface

B. *Intra- City travel intensity module*

The Intra-City travel intensity module uses a dynamic heat map to show the 24-hour change in population travel intensity in Wuhan and provides a query function for different moments (Fig. 5(a)). The user can know the population movement in different time periods by the color of the heat map. The darker the color means the greater the population movement. By adjusting the zoom level of the map, people can get an overview of the city's travel intensity as a whole, or view the population intensity of a particular street locally. Fig. 5(b) shows the intensity of the population movement in Wuhan from 6:00 to 22:00.



(a)



(b)

Figure. 5 Intra-Wuhan travel intensity map

C. *Individual model propagation simulation module*

According to the output of the small-world network propagation simulation model based on the individual model, the time and location information of the infected person was screened out. The interface is presented in the form of a scatter plot with a timeline added to highlight the spatial and temporal evolution of the epidemic (Fig. 6(a)). Fig. 6(b), on the other hand, shows the temporal and spatial evolution of the epidemic for the period time from January 27 to March 5 simulated by the module.

(a)

(b)

Figure. 6 Distribution of infected population

V. CONCLUSION

In this paper, a COVID-19 epidemic simulation and visualization system is developed for the current needs of epidemic prevention and control in China. This system can realize cross-platform deployment, has the characteristics of high reliability and good stability, can better demonstrate the temporal and spatial evolution characteristics of the epidemic development, and provide corresponding data support and information reference for government functional departments. In addition, the intra-city travel intensity module of the system also better reflects the relationship between the spread of the epidemic and the travel intensity of the population. Therefore, based on the simulation results of the system, it is recommended that prevention efforts should focus on areas with high residents' travel intensity.

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