Research Article

Application of GIS Sensor Technology in Digital Management of Urban Gardens under the Background of Big Data

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Since the reform and opening up, China's urbanization level has been continuously improved, and the national demand for urban greening is also increasing. However, at present, there are many problems in domestic urban gardens, such as low management quality and high management cost, which have a certain negative impact on urban development and residents' life. In this study, a digital management system of urban garden plant growth state based on sensor client/server structure, GIS (geographic information system) sensor technology and big data technology are designed, and its practicability is tested. The test results show that 52.90% and 40.70% of the people have positive comments on the satisfaction of the system client and the sensor comprehensive application value of the system based on WebGIS sensor technology, respectively. The former is 12.2 percentage points higher than the latter, and the server response speed and CPU (central processing unit) resource consumption of the former are also better. In addition, the robustness of the former is not significantly different from that of the latter. The data show that the digital sensor management system for the growth state of urban garden plants designed in this paper has complete and normal functions and good user experience.

1. Introduction

With the development of China's economy and society, the national urbanization rate shows a steady upward trend. More and more residents choose to live in cities, which brings greater demand for urban landscaping. Therefore, in order to better meet the needs of residents, garden big data, smart planting management, and other technologies are constantly applied to urban garden management. On the other hand, the application premise of these technologies is to have a certain amount of relevant garden plant data. However, at present, the garden management in most cities in China is still mainly realized manually, and there is a lack of garden plant growth status data. On the one hand, this phenomenon leads to an increase in the labor cost of relevant government departments in garden management. On the other hand, managers cannot accurately grasp the growth state of the garden they are responsible for. In view of this, the research integrates big data and GIS sensor technology to build a digital management system for the growth state of urban garden plants, in order to reduce the cost of urban garden management and promote the digitization of urban garden management process.

In the research process, GIS sensor technology is used to collect the image data of garden plants to be tested. GIS is a technical system for geographic data acquisition, storage, calculation, analysis, and display of the earth's surface space including the atmosphere with the support of computer hardware and software system [1]. It is a computer-based technical tool. Technicians often integrate GIS sensor technology with database functions to facilitate users to query and upload relevant information. Because the objects of landscape vegetation management in large- and medium-sized cities are often distributed in a wide range of regions, and there are many vegetation objects to collect data, urban landscape plants with these characteristics are more suitable for data collection and management using GIS sensor technology.

The innovation of this research is to use GIS and big data technology to deal with the management of urban garden plant growth state. So that the scattered, diverse, and large-
scale garden plant data in the city can be efficiently and accurately collected and managed. The urban garden plant growth state system developed based on big data and GIS sensor technology can analyze the plant growth state according to the collected plant image data, so as to automatically provide the fertilization. Management suggestions such as pest control and planting are helpful to improve the management efficiency and quality of urban garden plants.

The paper consists of three parts. The first part is used to discuss the research results and research methods of domestic and foreign researchers in GIS sensor technology and urban garden digital management. The second part focuses on the construction of urban garden plant growth state management system based on GIS and big data technology, including the selection of plant image data acquisition mode, the overall architecture and function plate design of the system, the specific structure and workflow design of each plate function, and the development of system trial version. The third part is to test the practicability of the system designed by the Research Institute, including the operation efficiency test of the server and the function test of the client, and summarize the advantages, disadvantages, and application prospects of the system according to the test results.

2. Related Works

Many research results show that computer technology, including GIS and big data technology, is more and more applied to urban garden management, which helps to improve the efficiency and quality of urban garden management. Yu et al. believe that the focus of plant protection and management is to protect the soil microbial environment, so they designed a garden management system based on GIS sensor technology. The test shows that the system can meet the needs of plant protection in most garden management [2]. Chen et al. applied GIS sensor technology and Oracle database to design an urban intelligent planning management information system. In the system, the query statement formulated by Oracle command is used, and the geometric code of data dictionary is used to represent the combined integrated data. The test results show that the impact of the system on the environment is small and controllable, which meets the expected standard [3]. Tresch et al. selected 81007 soil animal samples from 120 species, analyzed the role of soil animal activities and development on plant litter decomposition, and found that soil animal species richness plays an important role in garden plant growth [4]. Korpilo et al. collected tourist data of a park using the web-based public participation geographic information system and analyzed the impact of tourist trampling behavior on the growth status of different species of plants [5]. Hiscock et al.’s research team used the high-precision GIS images obtained by overpass technology to create a multifunctional classification system of urban land cover. Through case study, it was found that the overall classification accuracy reached 89.3%, which is conducive to improving the working method of urban water management [6]. Deng et al. applied GIS sensor technology to collect and analyze the data of community buildings in Changsha, China. The results show that the overall accuracy is 86%. The data show that GIS system is helpful to efficiently determine the year of building construction [7]. In order to explore the impact of different types of gardeners on garden management, Homework et al. selected several gardeners with different types of work from 18 gardens in Zurich, Switzerland, for garden management test. The test results show that the garden species richness of conservative gardeners who spend the most management energy is the highest. It shows that a certain degree of garden management and detection is helpful to improve the species richness of gardens [8]. Schneider et al. developed an application based on GIS sensor technology and web technology to solve the problem of poor coordination between private gardens and municipal planning and insufficient utilization of the potential as a wildlife corridor and habitat. Users can provide relevant information about their own gardens through this application. The trial results of the application show that this application can have a positive impact on urban sustainable planning and development [9]. Mirshafie et al. developed an underground water network management system based on WebGIS sensor technology to solve the water leakage problem of urban underground pipe network. The trial effect of the system is evaluated by the water distribution network of Tehran District 5. The test results show that the system improves the safety of urban water network and has certain popularization operability [10]. Dereli built an urban land planning and prediction system based on remote sensing data and GIS system to solve the problems of unreasonable residential settlements and traffic planning in rapidly developing cities. The test results show that the system can effectively predict the situation of land construction. It is conducive to assisting urban land planning [11].

According to the above analysis, GIS sensor technology has been widely used in agriculture, urban planning, and other fields, and some application results have been achieved. However, there are few studies on the application of it and big data technology to urban landscape management. Therefore, this study attempts to apply them to urban garden plant management, in order to provide some convenience and constructive suggestions for relevant managers.

3. Design of Urban Garden Digital Management System Integrating Big Data and GIS Sensor Technology

3.1. Data Processing and Evaluation Index Design of Urban Garden Plant Growth State. In this section, according to the garden plant image data collected by the sensor, the indexes such as leaf area and coverage are extracted. At the same time, the image is denoised, segmented, and feature calculated for subsequent input to the urban garden growth state management system built based on big data storage, processing technology, and GIS sensor technology, so as to judge the growth state of garden plants and assist professionals to manage fertilization and construction. The image processing process and methods are described in detail below [12].
NDVI, fully known as normalized difference vegetation index, is the necessary data for calculating the key growth state indicators of vegetation. In this study, portable spectral sensors are used to collect relevant optical signals, and then, the reflectance $R_{810}$ and $R_{650}$ of vegetation in 810 nm and 650 nm bands are calculated through the definition of reflectance, so as to calculate NDVI through

$$\text{NDVI} = \frac{R_{810} - R_{650}}{R_{810} + R_{650}}. \quad (1)$$

In order to further improve the signal acquisition accuracy, empirical formula (2) is used to correct the original NDVI.

$$N_{\text{NDVI}} = 1.3559O_{\text{NDVI}} - 0.0474, \quad (2)$$

where $O_{\text{NDVI}}$ and $N_{\text{NDVI}}$ are NDVI before and after correction, respectively. Then, take $N_{\text{NDVI}}$ as the variable to calculate the leaf area index, coverage, and other indicators of vegetation. These indicators are calculated by querying the corresponding books, which will not be repeated here. Then, design the image processing flow of vegetation. First, denoise the image, and design the image denoising flow as shown in Figure 1.

The method to detect whether there is noise in Figure 1 is to create an $n \times n$ window and use candy edge detection algorithm to detect the window edge. If pixels with gray value greater than 128 are found, the window is considered invalid. The noise power $P_w$ calculation method of the effective window is shown in

$$P_w = \frac{\sum_{p \in w} (p(x,y) - \bar{p})^2}{n \times n}, \quad (3)$$

where $p(x,y)$ is the gray level of the pixel $p$ in the window and $\bar{p}$ is the average gray level of all pixels in the window. Then, the noise type is determined by calculating the image kurtosis coefficient $K$, and the calculation formula is as follows:

$$K = \frac{C_4}{P_w^2}. \quad (4)$$

In equation (4), $C_4$ represents the fourth-order central moment of the gray value of the pixel. When $K$ is not less than 5, the noise is considered as salt and pepper type, when $K$ is not more than 3, the noise is considered as Gaussian type, and when $K$ is in the range of (3,5), both kinds of noise are considered to exist. Finally, the number of noisy windows is set as the threshold to judge whether there is noise in the image [13].

Due to the influence of shooting ambient light, image denoising also needs to be enhanced; otherwise, it will seriously affect the computer’s recognition of image features [14]. In this paper, a Gaussian wave algorithm is used to better achieve Gaussian denoising. The idea of the algorithm is to use Gaussian template to calculate the weighted sum of the gray values of all pixels in the neighborhood of the pixel to be processed. The weighted result replaces the gray value of the pixel to be processed to achieve the denoising effect. This linear smoothing method can better preserve the edge and detail information of the image. The algorithm is simple and easy to implement and has better visual effect and higher accuracy. Considering that the portable hardware device with weak performance is used to process data in this study, the histogram equalization algorithm with the least amount of calculation is selected to enhance the image [15].

After the image collection and preprocessing, the image needs to be segmented in order to calculate the plant growth index. In this study, the algorithm based on visible light color index is used to convert the image color, and then, Otsu (i.e., maximum interclass variance) threshold algorithm is used to classify the converted image. The calculation process is as follows. Suppose there are $n_i$ pixels with the original gray level of $M$ and the gray level of $i$; first, normalize the gray histogram according to

$$P_i = \frac{n_i}{M}. \quad (5)$$

In equation (5), $P_i$ is the normalized gray value. The occurrence probability of pixels of types $C_0$ and $C_1$ is shown in

$$\begin{align*}
W_0 &= \sum_{i=0}^{t} P_i, \\
W_1 &= \sum_{i=t+1}^{M-1} P_i = 1 - W_0.
\end{align*} \quad (6)$$

In equation (6), $t$ is the set gray value threshold for classifying images. Then, the average gray value of various
types can be calculated according to formula (7).

\[
\begin{align*}
\mu_0 &= \frac{\sum_{i=0}^{t} iP_i}{W_0}, \\
\mu_1 &= \frac{\sum_{i=0}^{t-1} iP_i - \sum_{i=0}^{t} iP_i}{1 - W_0}.
\end{align*}
\]  

(7)

\(\mu(t)\) and \(\mu_\tau\) in equation (7), respectively, represent the cumulative gray value of the gray level range \(0 \sim M\) when the gray level is \(t\). See equations (8) and (9) for the calculation method.

\[
\begin{align*}
\mu(t) &= \sum_{i=0}^{t} iP_i, \\
\mu_\tau &= \sum_{i=0}^{M-1} iP_i.
\end{align*}
\]

(8)

(9)

Since there is a relationship between \(W_0\mu_0 + W_1\mu_1 = \mu_\tau\) and \(W_0 + W_1 = 1\) among the above variables, the variance within each pair of pixels can be described by

\[
\begin{align*}
\sigma^2_0 &= \frac{\sum_{i=0}^{t} (i - \mu_0)^2 P_i}{W_0}, \\
\sigma^2_1 &= \frac{\sum_{i=0}^{M-1} (i - \mu_1)^2 P_i}{W_1}.
\end{align*}
\]

(10)

In order to quantify the interclass variance of pixels at gray level, the following definitions are made:

\[
\begin{align*}
\sigma^2_W &= W_0\sigma^2_0 + W_1\sigma^2_1, \\
\sigma^2_B &= W_0 W_1 (\mu_1 - \mu_0)^2, \\
\lambda &= \frac{\sigma^2_1}{\sigma^2_W}, \\
\eta &= \frac{\sigma^2_B}{\sigma^2_W}.
\end{align*}
\]

(11)

It can be seen from equation (11) that there is also a relationship of \(\sigma^2_W + \sigma^2_B = \sigma^2_\tau^2\). So far, the image classification problem is transformed into finding an optimal \(t_m\) so that when \(t = t_m\), \(\lambda\) and \(\eta\) values are the largest. Therefore, \(\eta\) is selected as the objective function to obtain

\[
\sigma^2_B = \frac{\left(\sum_{i=0}^{t} P_i \sum_{i=0}^{M-1} iP_i - \sum_{i=0}^{t} iP_i\right)^2}{\sum_{i=0}^{t} P_i(1 - \sum_{i=0}^{t} P_i)}.
\]

(12)

When the Otsu segmentation algorithm runs, it will traverse the gray level within the range of \([0, M-1]\), calculate the gray level that makes equation (12) obtain the maximum value, and take it as the optimal segmentation threshold of the algorithm. After the image is classified by the segmentation algorithm, the leaf area index of the plant is estimated based on the data to deduce other growth parameters. In this study, the commonly used method in the industry is used to calculate the leaf area index \(LA\), as shown in

\[
LA = -2 \ln P_0(\theta).
\]

(13)

In formula (13), \(P_0(\theta)\) is the canopy porosity of garden plants, and its calculation method is shown in

\[
P_0(\theta) = \frac{N_{\text{bg}}}{N_{\text{count}}}. \tag{14}
\]

(14)

In equation (14), \(N_{\text{bg}}\) is the number of pixels in the background in the plant canopy image, and \(N_{\text{count}}\) is the total number of pixels in the image.

### 3.2. Construction of Urban Garden Growth State Management System Based on Big Data and GIS Sensor Technology

At present, the commonly used method for trace component analysis is to use a spectrophotometer. Its principle is to measure the absorbance by using the light absorption characteristics of the substance, estimate the composition of the substance by the position of the absorption peak, and estimate the content of the component by using the height of the peak. The traditional spectrophotometer is mainly used in the analysis and detection of substances, and its function is relatively single. With the development of chip integration technology and the progress of grating technology, the spectrophotometer has undergone revolutionary changes in function, volume, and detection speed. For example, the use of spectrophotometer to form a field soil monitoring network can detect the material content of soil in real time, so that agricultural producers can effectively improve the soil in a certain area to improve the productivity. In order to obtain garden vegetation image data, a specially assigned person needs to carry a smartphone equipped with mobile GIS application to sample the area to be detected, which requires optimization and calculation of the trajectory of mobile sampling [16]. The research improves the traditional fixed frequency point taking recording method. Its principle is to appropriately increase the frequency of position recording and judge whether the recorder is moving or stationary according to the distance between two adjacent positions, so as to determine whether to record the position of the point. The calculation method of the distance \(D_{ab}\) between two points \((X_a, Y_a)\) and \((X_b, Y_b)\) (coordinate values are expressed by longitude and latitude, \(X_a\) and \(X_b\) are longitude, \(Y_a\) and \(Y_b\) are latitude) is

\[
\begin{align*}
C &= \sin (X_a) \sin (X_b) \cos (X_a - X_b) + \cos (Y_a) \cos (Y_b), \\
D_{ab} &= \frac{R \times \arccos (C) \pi}{180}.
\end{align*}
\]

(15)
In equation (15), $C$ is the intermediate substitution variable and $D_{ab}$ is the radius of the earth, taking 6371 km. Set a threshold $K$. If the distance between the current acquisition point and adjacent track points is less than $K$, it will be classified into one nearest neighbor point set. Otherwise, another nearest neighbor point set will be created to include it. After all acquisition points are divided, the $k$-means algorithm is used to find the center point of each nearest neighbor point set, delete other points in the set, and take the sequential connection of each center point as the sampling track [17].

The urban garden growth state management system of this research is developed based on Android platform and ArcGIS Server. The system uses client/server structure, the client development tool is Android studio, and the server uses eclipse as the development tool. According to the function, the whole system is divided into three layers: data storage, network service, and client application [18]. The data storage layer mainly stores spatial data and attribute data. The storage and management of the former is carried out through the ArcGIS spatial data engine and the spatial data model of SQL server. The latter includes plant canopy parameters and sampling point parameter data, which are stored on SQL server. ArcGIS Server in the network service layer provides map services and some GP (i.e., geoprocessing tool). The client is an application developed based on Android platform. Its main functions are garden plant information management, image acquisition, sampling point positioning, etc. Combined with the above design ideas, the functional planning of the system is obtained, as shown in Figure 2.

Next, the system functions in Figure 2 are designed in turn. The user management module is used to manage the basic information of the user, including creating and modifying the user’s account and name. It can also bind accounts to common image sensors [19]. The setting module is used for users to modify image annotation, application language, software update, and set image acquisition sensing mode (manual or automatic acquisition). The function of the data acquisition module is to collect the spectral signal data collected by the sensor and calculate the NDVI, leaf area, and other parameters of vegetation. The sampling point planning module is used to plan the sampling point scheme according to the user’s setting preference and plant growth law. The data management module is used to manage the collected data, such as uploading the data to the server in the form of JSON, sharing the data to the designated user, and deleting and modifying the data [20]. The function of GIS service module is realized through ArcGIS Server, which mainly provides GIS function support and base map data for the system. The sensor model management part is used to store the parameter calculation program of the power plant and send the latest calculation program to the mobile terminal. In order to meet the processing and storage requirements of the system for urban garden big data, the database adopts the SQLite type of Android. The sensor database shall contain six data tables: user information table, activity track table, track information node information table, sampling scheme table, sampling schedule, and sampling point location table. The database allows a single user to create multiple sampling schemes. Each sampling scheme can correspond to multiple sampling activities, and each sampling corresponds to a unique acquisition track. Each acquisition track is composed of multiple two-dimensional coordinate point information.

4. Practicability Test of Urban Garden Growth State Management System

4.1. Running Efficiency Test of Urban Garden Growth State Management System. The hardware equipment used in this paper includes portable plant phenotype imaging spectrometer, mobile GIS application MAPGIS explorer, Xiaomi 8 smart phone, and HP war 99 workstation (as a server). The system is designed according to the research scheme, which verifies the practicability of the system designed in this study. At the same time, in order to compare with the system, the corresponding urban garden growth state management system is built by using traditional sensor and web technology and WebGIS sensor technology commonly used in the industry. Firstly, the response efficiency of each system is analyzed, and the Apache JMeter test tool is used to simulate the process that the client initiates a service request to the server. The number of simulation request applications starts at 1 and then increases to 50, 100,... 500 every 2 seconds. In order to reduce the test error, it is
necessary to repeat the test for 5 times under each condition and take the average value of the data to be tested. The statistical results are shown in Figure 3.

“Big data GIS” in Figure 3 is the system designed in this study. According to Figure 3, the corresponding time of the system designed in this study based on big data and GIS sensor technology and WebGIS sensor technology is significantly lower than that based on sensor and web technology calculation. When the number of simulation applications is 500, the average response time of the three is 302, 323, and 642 ms, respectively. Then, count the server CPU share of each system in the test, as shown in Figure 4.

It can be seen from Figure 4 that after the number of simulated applications is greater than 200, the average CPU share of the system server using SQLite database in this study is significantly lower than the other two. When the number of simulation applications reaches 500, the average CPU share of the system server built based on big data and

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**Figure 3:** Relationship between request processing time of each system and the number of analog applications.

**Figure 4:** Relationship between CPU occupancy of each system server and number of analog applications.
GIS sensor technology, WebGIS sensor technology, and sensor and web technology is 42.2%, 75.3%, and 90.4%, respectively.

4.2. Functional Evaluation of Urban Garden Growth Management System. 36 garden management experts were selected from China, invited to try out the client functions of the three systems, and scored the satisfaction of various client functions of the system according to the trial process. The statistical scoring results are shown in Figure 5.

It can be seen from Figure 5 that there is no significant difference in the average satisfaction scores of the two systems based on big data, GIS sensor technology, and WebGIS sensor technology in the data acquisition section, but in the user setting, user management, data management, and sampling point planning sections, the average satisfaction scores of the former are 87.6, 89.4, 92.5, and 88.5, which are 9.09%, 8.23%, 9.98%, and 11.60% higher than the latter, respectively. Then, 248 relevant practitioners willing to participate in the study were randomly selected from China to use the clients of the three systems, and the satisfaction of the main module functions of the clients was evaluated. The statistical results are shown in Figure 6.
It can be seen from Figure 6 that the system built based on sensor and web technology has a negative evaluation on other client function modules except response speed. Specifically, the positive satisfaction of the research and design system and the system based on WebGIS sensor technology in response speed, ease of operation, ease of use, automation level, rationality of management suggestions, and comprehensive application value modules (i.e., evaluated as “very satisfied” and “satisfied”) is 79.30%, 52.70%, 76.70%, 37.90%, 40.00%, 52.90%, and 47.00%, respectively, 31.90%, 12.90%, 23.50%, 40.60%, and 40.70%. The former is +32.30, +20.80, +63.80, +14.40, -0.60, and +12.20 percentage points higher than the latter, respectively. Finally, the robustness of the system is tested. Each system client is tested in different climate and geographical environment, and the image recognition accuracy is counted, as shown in Figure 7.

As shown in Figure 7, the image recognition accuracy of the system based on sensor and web technology is significantly lower than the other two in various environments because it has not undergone image denoising and enhancement processing. The difference absolute values of the image recognition accuracy of the system built based on big data, web technology, and WebGIS sensor technology in heavy rain, heavy snow, heavy fog, and sunny climate and hilly, plain, plateau, desert, and grassland environment are 0.70%, 1.10%, 0.30%, 0.40%, 0.90%, 0.50%, 0.00%, 1.40%, and 1.30%, respectively. The basic idea of particle system is to use many small particles with simple shape as basic elements to represent irregular fuzzy objects. These particles have their own life cycles, and they all go through three stages in the system: generation, movement, growth, and extinction. Particle system is a system with “life.” Therefore, unlike traditional methods, it can only generate instantaneous and static object pictures. Instead, it can generate a series of moving and evolving pictures, which makes it possible to simulate dynamic natural scenery. It can be seen that the system designed in this study has good robustness.

5. Conclusion

Aiming at the problems of high cost and untimely management of urban garden monitoring and management, this study combines big data and GIS sensor technology to build a digital management system for the growth state of urban garden plants and tests the practicability of the system. The test results show that the server response speed and CPU share of the system using big data and GIS sensor technology are significantly better than other comparison systems. In terms of client functions, the average satisfaction scores of the system built based on big data and GIS sensor technology in user setting, user management, data management, and sampling point planning are 9.09%, 8.23%, 9.98%, and 11.60% higher than those of the system built based on WebGIS sensor technology, respectively. At the same time, the former in response speed, operation difficulty, convenience, automation level, rationality of management suggestions. The change values of the proportion of positive satisfaction evaluation in the comprehensive application value module compared with the latter are 32.30%, 20.80%, 63.80%, 14.40%, -0.60%, and 12.20%, respectively. In addition, the image recognition accuracy of the system designed in this study in heavy rain, heavy snow, heavy fog, and sunny climate and hilly, plain, plateau, desert, and grassland environment is not significantly different from that of the system based on WebGIS sensor technology. The above data prove that the client function of the system is also better. There are some limitations in this paper, and
the research has not discussed the sensor simulation results in different environments. This may make the generalization ability of research results low. This needs further discussion in future research.

Data Availability
The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

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