Research on Satellite and Ground Multi-Sensor Collaborative Sensing Method for Floating Plants

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Abstract

Dynamic monitoring of water environment is the basis of maintaining urban security and promoting urban sustainable development. To effectively solve the problems caused by the large-scale flooding of floating aquatic invasive plants, such as water environment destruction, clogging river, water quality pollution, water ecological balance destruction, etc., a satellite and ground multi-sensor collaborative sensing method for floating plants is proposed in this paper. For the monitoring of floating plants in macro watershed, the vegetation index and chlorophyll concentration were used to extract floating plants, analyzing, and calculating the distribution and coverage area of floating plants based on 4-band high-resolution satellite images. For the monitoring of floating plants in small watershed, combined with visible light video, multispectral images, and LiDAR data, optimized spectral feature variable processing, semantic segmentation network, and symmetric function neural network are utilized to obtain real-time information on the invasion location, distribution pattern, and coverage area of floating plants. In this paper, the upstream basin of the Huangpu River in Shanghai in 2023 was selected as the experimental area. The distribution of floating plants in different watercourse and different periods was successfully obtained by this method, and the coverage area was accurately calculated with an identification rate of more than 90%, which provided technical support for cross-regional management and efficient cleaning of floating plants.

1.Introduction

Floating plants float on the surface of the water, and their roots are not born in mud. They have the characteristics of fast drifting speed and strong reproduction ability. Taking the most common Eichhornia in Huangpu River Basin of Shanghai as an example, most of them are invaded by drift from other provinces and cities, and their breeding speed is affected by climate, season, water temperature and other factors. The most suitable temperature for breeding is 25-35℃, and the annual mass breeding period is from September to November (Dong B et al., 2019). Under sufficient sunshine, the weekly growth rate can reach 10-20%. At night, it is prone to wind and rain, and the drifting speed of Eichhornia increases. When they drift to large-scale or slow-flowing rivers, they will accelerate the growth rate and quickly cover the entire watercourse. This phenomenon will hinder water navigation and farmland irrigation, disrupt the ecological balance of the water body, and bring negative impacts to the river landscape.

The key to efficient management of floating plants is rapid detection and dynamic monitoring, the first time to detect the invasion, and feedback to the salvage operation department, to avoid the additional costs and labor costs generated by disposal after mass reproduction. The common methods for monitoring floating plants currently include drones, vehicle patrols, ship patrols, and manual inspections (Liu J et al., 2019). The monitoring of floating plants is faced with such challenges as wide basin coverage, difficult source tracing, incomplete monitoring, high timeliness requirements, and difficult quantification of monitoring results. The monitoring cost of drones is high, and they are greatly limited by weather conditions, making it impossible to form a 24-hour detection mechanism。Due to factors such as river width and bridge height limitations, ship patrols are unable to fully detect floating plants. Car patrol and manual investigation are mainly judged by human eyes, which is easy to produce the phenomenon of missing inspection and misjudgment, and it is difficult to obtain accurate quantitative information.

In response to the pain points of traditional monitoring methods such as poor timeliness, lack of quantitative description, and being limited by harsh environments, this paper proposes a satellite and ground multi-sensor collaborative sensing method for floating plants. Satellite remote sensing, visible light video technology, multi-spectral technology and LiDAR technology are integrated to carry out dynamic monitoring of floating plants, and the monitoring results of floating plants are analyzed based on interdisciplinary technical means such as spectral calculation and artificial intelligence, so as to realize multi-scale, multi-temporal and multi-dimensional monitoring of floating plants, and provide technical support for the comprehensive management of floating plants.

2.Methodology

2.1The Technical Route of Satellite and Ground Multi-Sensor Collaborative Sensing Method

The satellite and ground multi-sensor collaborative sensing method comprehensively utilizes satellite remote sensing and ground multi-sensors to achieve integrated multi-scale dynamic monitoring of space-ground. By utilizing the advantages of satellite remote sensing technology such as wide coverage, continuous data space, quantifiable analysis, and low cost, the distribution of floating plants in large-scale watersheds can be quickly obtained through spectral feature variable processing. Considering the fast flow and susceptibility to large-scale outbreaks of floating plants, satellite monitoring has a certain periodicity, and it is necessary to supplement real-time monitoring of key monitoring areas on the basis of satellite remote sensing macroscopic monitoring. This study designed a ground multi-sensor，utilizing visible light video obtained in real-time from a ground fixed station to quickly detect floating plants; utilizing multispectral images can improve the accuracy of vegetation automatic recognition; utilizing active laser scanning technology to achieve nighttime dynamic monitoring, enabling rapid detection and all-weather monitoring of floating plants, and utilizing deep learning networks to quickly identify floating plants.

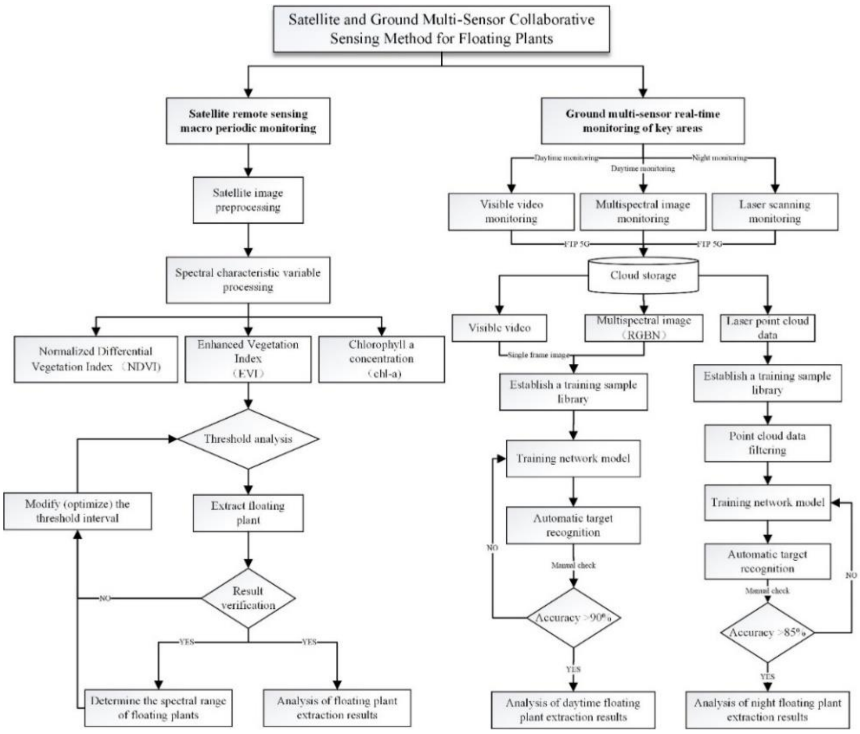


Figure 1 Technical route

2.2Satellite remote sensing macroscopic monitoring technology

Floating plants usually contain a large amount of chlorophyll, which has special spectral characteristics. Vegetation is highly sensitive in the near-infrared band, while water is easily extracted in the visible light band. The sensitivity of the two in the same spectral curve is different (Li N Y.2023). Therefore, based on the RGBN four-band satellite image, the vegetation index algorithm developed by using the special spectral curve of vegetation in the visible and near-infrared bands can be used to distinguish floating plants from water bodies and other floating objects, and realize the automatic identification and extraction of floating plants. Using the spectral characteristic variable processing of vegetation can realize the rapid identification and extraction of floating plants on water surface.

2.2.1**Normalized Differential vegetation index (NDVI):** The normalized differential vegetation index refers to the ratio of the difference in reflectance values between the near-infrared (NIR) and red light (R) bands to the sum of the two bands (Li N Y.2023), As shown in formula 1.

$$\mathrm{NDVI} = \frac{DN_{NIR} - DN_R}{DN_{NIR} + DN_R} \qquad (1)$$

In the formula, NIR represents the near-infrared band, and R represents the red band. The NDVI result interval is [-1,1], the non-vegetation calculation result is 0, and when there is vegetation coverage, the result is greater than 0, and the size of the result value is proportional to the density of vegetation. Through experimental verification, the NDVI value of floating plants is within the range of [0.2, 0.8].

2.2.2**Enhanced vegetation index (EVI):** Enhanced vegetation index can improve the ability to detect sparse vegetation and has a good detection effect on floating scattered plants. At the same time, the index corrected for atmospheric aerosol scattering using the blue band and added a canopy background adjustment factor (Li N Y.2023). The formula is as follows.

$$EVI = 2.5 \times \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + 6 \times \rho_R - 7.5 \times \rho_B + 1} \qquad (4)$$

In the formula, ρ_{NIR}、ρ_R、ρ_B represent the reflectance of the near-infrared, red, and blue light bands, respectively. The EVI result interval is [-1,1], and it has been experimentally verified that the NDVI value of floating plants is within the range of [0.2,0.8].

2.2.3**Chlorophyll A (chl-a):** The proportion of chlorophyll in green plants is stable, easy to measure, and can be used as an important parameter to distinguish floating vegetation coverage (Li N Y.2023). A large number of research results have shown that chlorophyll-a has obvious absorption valleys near the blue and red bands, and obvious reflection peaks near the infrared band, while water has obvious absorption valleys near the near-infrared band. Therefore, the content of chlorophyll a in water can cause significant changes in the reflection spectrum characteristics of water, which can extract floating plants. The formula for calculating the concentration of chlorophyll a is as follows:

$$Chl - \alpha = (-135 \pm 43) + (451 \pm 42)(\frac{R_{NIR}}{R_R}) \pm 72 \qquad (5)$$

In the formula, R835 and R660 mainly correspond to the near-infrared and red bands.

Using the vegetation index and chlorophyll concentration calculation model, the inter-band operation of the collected images can quickly obtain the parameters such as the distribution position and area of the floating plants, and quantitatively describe the floating plants.

2.3Real time ground multi-sensor monitoring technology

2.3.1Fixed station multi-sensor unmanned monitoring system: This study designs a fixed station multi-sensor unmanned monitoring system, as shown in Figure 2. Using a passive and active collection mode of multiple sensors such as visible light video, multispectral imaging, and laser scanning, three different monitoring data of the same field of view are obtained, and based on the monitoring data, automatic identification of floating plants is carried out. When the daytime lighting conditions are sufficient, use visible light videos and multispectral images to identify floating plants; When the lighting conditions are weak due to nighttime or rainy weather, use LiDAR data to identify floating plants. At the same time, the weather around the river is changeable, and the power environment and network environment are poor. Therefore, the system combines wireless network transmission technology and new energy power supply technology to realize uninterrupted monitoring during the day and night, ensure the quality of monitoring data, and realize all-weather unattended automatic monitoring of floating plants.

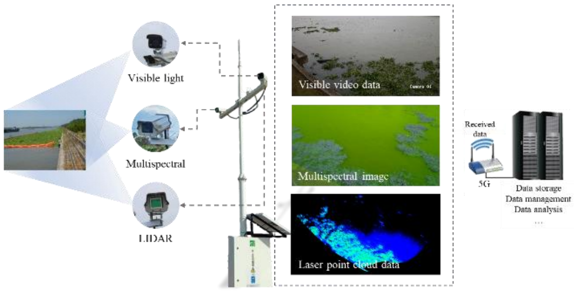


Figure 2 system architecture

2.3.2Recognition of Floating Plants Based on Semantic Segmentation Network: This study is based on a semantic segmentation deep learning network using U-Net, optimized based on the characteristics of floating plants, to achieve the recognition of floating plants in single frame video images and multispectral images, and to obtain the position information of floating plants in different environmental states. This network consists of four encoder layers and four decoder layers (Perrin J E et al.,2022), Used to understand different texture spectral information in the image and distinguish the position of floating plants in the image. Improving the clarity of image texture information through up and down sampling. Combining convolution and deconvolution operations, extract texture information of different scales from the image and restore it to the original image size. By collecting supplementary classification target information through max pooling layer and skip layer, accurate identification of floating plants is achieved.

2.3.3Recognition of Floating Plants Based on Symmetric Function Neural Network: In response to the characteristics of disorder, sparsity, and rotation invariance of laser point clouds, this study designed a special symmetric function neural network to identify and segment laser point clouds belonging to floating plants in the monitoring area. This network is based on the invariance of point cloud permutation, and designs symmetric functions such as summation and maximization to extract semantic information from point clouds. To ensure the spatial consistency of point cloud data, a T-Net transformation was designed for the rotation invariance of point clouds, allowing point clouds obtained from different angles to be first transformed into a unified coordinate system, ensuring the robustness of the model to point cloud rotation. To prevent information loss caused by max pooling operations, the network has designed a multi-layer perceptron (MLP) that maps each point to a redundant high-dimensional space, greatly reducing the excessive information loss caused by max pooling. Concatenate the global features with the local features of previously learned point clouds, and then obtain the semantic segmentation results of each data point through MLP to achieve floating plant recognition.

3.Experimental scheme

To verify the feasibility and universality of the technology, this study selected the upper reaches of the Huangpu River in Shanghai as the experimental area to verify the monitoring method of satellite and ground multi-sensor collaborative perception of floating plants.

3.1Satellite remote sensing macroscopic monitoring experiment

3.1.1Experimental area and data: The 80% of floating plants in Shanghai drift along the upper reaches of the Huangpu River (Li N Y.2023). According to historical data statistics and analysis, four river basins in the Huangpu River and its upper reaches have been identified as key areas of floating plant invasion, namely the Pingshen route, Hangshen route, Changhu Shen route, and Sushen Outer Port route, as well as tributaries of each river basin. We selected the image data of Jilin-1 satellite on October 17, 2023 as the data source, and after image preprocessing, the spatial resolution was 0.5 meters. The experimental scope and data are shown in Figure 3.

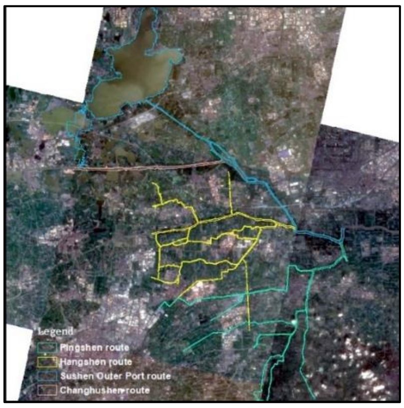


Figure 3 experimental area

3.1.2Floating plant monitoring results: Through experiments, the identification and distribution of floating plants in the study area are shown in Figure 4. A total of 433 floating plants were found, covering an area of 161927.42 square meters, mainly concentrated on the Sushen Outer Port route and the Hang Shen route.

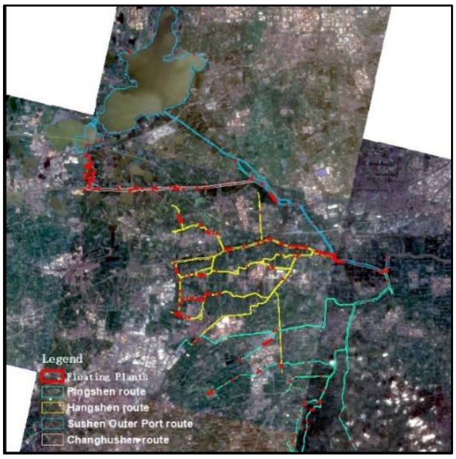


Figure 4 Floating plant monitoring results

According to the monitoring results, there are four main forms of floating plant pollution, as shown in Figure 5, namely sporadic distribution (a), block distribution (b), strip distribution (c), and whole river distribution (d). Based on the pixel count of the image and the resolution of the satellite image, combined with the spatial position of the patch, the coverage area of floating plants can be calculated and the invasion channel can be obtained.

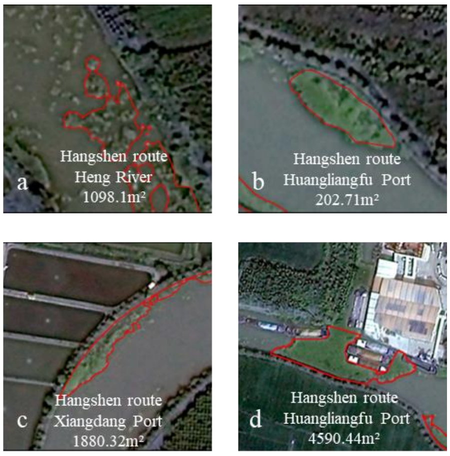


Figure 5 Example of Floating Plant Identification

3.1.3Result analysis: Based on the identified floating plant pattern information, calculate the floating plant coverage area in each key watershed, as shown in Figure 6. According to the statistical results and distribution, there are two main invasion channels of floating plants in Shanghai. In the north, floating plants invade from Sushen outer Port route, mainly from Dianshan Lake and Yuandang River, and in the southwest, they invade from Hangshen route.

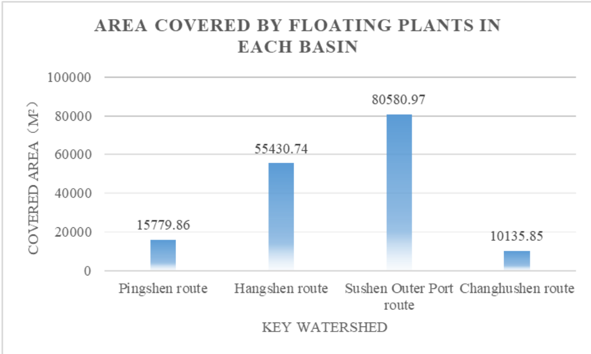


Figure 6 Floating Plant Coverage Area on Various Basin

According to the distribution of floating plants, they can be subdivided by river channel and the proportion of floating plants in the tributaries of each route can be calculated. Taking the Hangshen route as an example, the distribution of floating plants on this route is shown in Figure 7. According to the distribution situation, the floating plants on the Hangshen route are mainly distributed in six tributaries: Huangliangfu River, Yuanxie River, Heng River, Dazheng River, Xiangdang River, and Housha River.

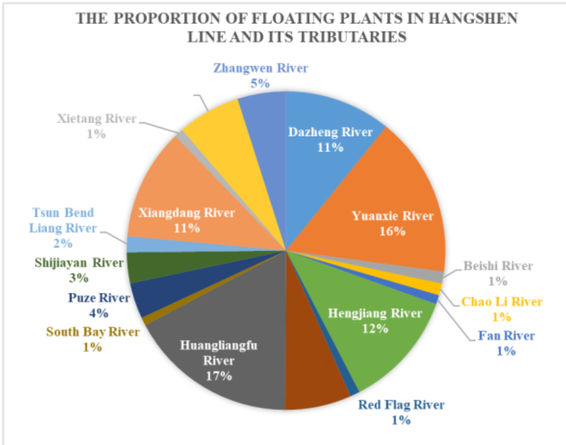


Figure 7 Statistics on the coverage area of floating plants in various tributaries of the Hangshen route

3.2Real time monitoring experiment of ground multi-sensor in the key areas

3.2.1Experimental area: After reviewing historical data and combining with the experimental results in section 3.1, it was found that most of the floating plants in Shanghai were invaded by other provinces and cities. Therefore, this experiment selected three points (number 1-3) on the Pingshen route, Hangshen route and Changhushen route, as well as at the provincial border, and deployed a fixed station multi-sensor unmanned monitoring system, as shown in Figure 8.

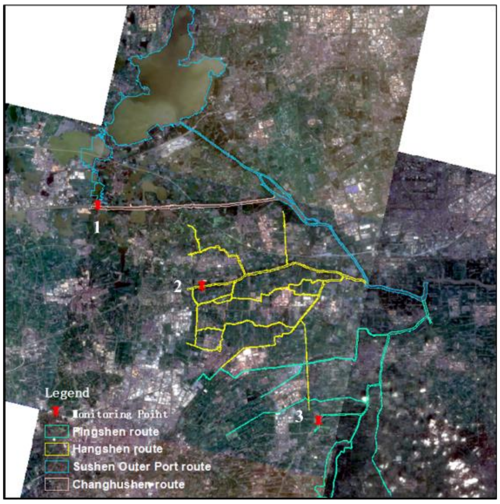


Figure 8 Ground multi-sensor monitoring points

Utilizing the site near the embankment, monitoring poles are erected using foundation bolts, powered by solar panels, and equipped with three sensing devices, including video surveillance, multispectral cameras and LiDAR. The monitoring perspective range is shown in Figure 9, and the data collection interval is once an hour.

Figure 9 Monitoring perspective range

3.2.2Real time monitoring data: Through the experiment, the data collected by different sensors at three points can be obtained. The video data is 10 seconds in MP4 format, the multispectral image data format is JPG, and the laser scanning data format is LAS, as shown in Figure.10.

Figure 10 Monitoring data example

3.2.3Floating plant identification results: Based on the three types of data obtained, the techniques in sections 3.2 and 3.3 are used to automatically extract floating plants on water. For video surveillance data, a single frame image is captured for recognition. As shown in Table 1, various types of floating plants with different distribution forms can be recognized, and the coverage area can be calculated based on the relative spatial position information.

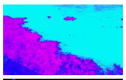
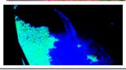
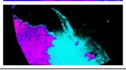
Point number	Route name	Data type	Monitoring image	Identification results	Area (m²)
1	Changhu Shen route	Visible video data			80.61
2	Hangshen route	Multispectral image			189.53
3	Pingshen route,	Laser point cloud data			168.87

Table1. Monitoring result

3.2.4Result analysis: Through experiments, ground multi-sensor real-time monitoring equipment can achieve monitoring and extraction of various forms of floating plants. The recognition accuracy of floating plants is strongly correlated with the distribution morphology of vegetation. By comparing human eye recognition with algorithm recognition, it was found that there were missed detections for scattered floating plants, with a recognition rate of over 90%. For floating plants with large areas of aggregation, such as strip distribution, block distribution, and whole river distribution, the recognition effect is good, with a recognition rate of over 95%,and the edge fitting of the pattern is high, with high accuracy in calculating the coverage area. There are also misjudgments and omissions in the recognition results, with misjudgments mainly concentrated on objects with similar spectral characteristics to floating plants, as shown in the red box on the left of Figure 11, where the ship was mistakenly extracted. omissions mainly focus on the edge of the image and away from the multispectral lens, as shown in the scattered floating plants in the red box on the right of Figure 11.

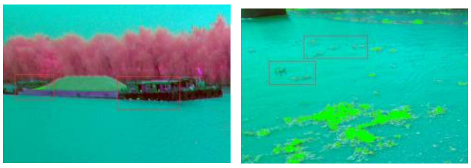


Figure 11 Misjudgments and omissions discovered during the verification process

In terms of timeliness, this experiment can recognize 5-6 images per minute without manual intervention, that is, the fixed station multi-sensor unmanned monitoring system can accurately obtain floating plant information within 1 minute after monitoring effective data.

4.Conclusions

In order to solve the problems of poor timeliness, inability to quantitatively describe, environmental constraints, and high cost in traditional monitoring of floating plants, this study proposes a method for collaborative sensing of floating plants on water using satellite and ground multi-sensor collaborative sensing, taking into account the characteristics of multiple invasion channels, fast floating speed, and susceptibility to explosions of floating plants. By comprehensively utilizing satellite remote sensing technology, multi-source sensor technology, wireless network transmission technology, and cloud server data processing technology, large-scale, all-weather, and uninterrupted automatic monitoring of floating plants can be achieved.

By utilizing satellite remote sensing technology and processing spectral characteristic variables, the coverage area and area of floating plants on the water surface can be macroscopically discovered, which is beneficial for analyzing the distribution characteristics of floating plants. Utilizing a ground multi-sensor real-time monitoring system, floating plant monitoring is achieved under sufficient daytime lighting conditions through visible light sensors and multispectral sensors, and floating plant monitoring is achieved under nighttime and insufficient lighting conditions through LiDAR. Based on the characteristics of monitoring data, semantic segmentation networks and symmetric function neural networks are used to identify floating plants, and quickly obtain information on their distribution and coverage area.

Experiments have shown that the method of satellite and ground multi-sensor collaborative sensing of floating plants on water can achieve multi-scale, multi temporal, and multi-dimensional monitoring of floating plants, forming a periodic intelligent monitoring mechanism for floating plants from both macro and local perspectives. In terms of macroscopic monitoring, satellite remote sensing technology can be used to discover various forms of floating plants, such as scattered distribution, strip distribution, block distribution, and whole river distribution, and analyze the main channels of floating plant invasion. In terms of local monitoring, a ground multi-sensor real-time monitoring system is utilized to quickly detect intrusion behavior, and deep learning network models are used to quickly extract area information of floating plants, with a recognition accuracy of over 90%.

In summary, the prominent advantage of the satellite and ground multi-sensor collaborative sensing method for floating plants is global and timeliness, which can trace the source of floating plant invasion, break through the administrative limitations of floating plant prevention and control, and provide data support and decision-making basis for the comprehensive prevention and control of floating plants across provinces and cities. At the same time, this method can effectively respond to the rapid outbreak of floating plants, achieve early positioning and timely detection, help management departments scientifically organize relevant forces to implement salvage, reduce quantity from the source, save salvage and disposal costs, and provide data support for floating plant outbreak prediction and drift prediction.

Acknowledgments

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