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Design and Implementation of a Biomass Temporal-spatial Variation Simulate System

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Abstract: In order to facilitate the monitoring, analyzing and forecasting of cyanobacteria bloom, a Biomass Temporal-spatial Variation Simulation System (BTSVSS) is developed under the IDL and ENVI environment. This system simulates the process of cyanobacteria bloom by visualization method based on multi-temporal remote sensing images and GIS data. Meanwhile, by combining with auxiliary information such as meteorological data, field data and multimedia information quantitative analysis in this system becomes more reliable. It is an efficient tool for analyzing temporal and spatial variation of cyanobacteria biomass with the purpose of seeking the change law. Two patterns, named field data pattern and remote sensing data pattern, have been established in the system respectively, which allow users to acquire algae-data from various sources. Taking the Dianshan Lake in Shanghai as a case study, the application of BTSVSS demonstrates its practicality and advantages in the prevention and the treatment of algae bloom integrating L andsat TM data, vector data and field data of Dianshan Lake. The scalability of BTSVSS could potentially be applied to the monitoring variety of environmental pollution in future research and applications.

Key words: Cyanobacteria bloom, simulation, IDL, temporal-spatial variation, remote sensing

INTRODUCTION

As one of the most important fresh water resources, lake is the basis of people's survival and sustainable economic development in the lake basin (Duan *et al*., 2008). However, the lake eutrophication leads to the abnormal growth of cyanobacteria and brings serious ecological disaster.

With the rapid development of sensor technology and space technology, acquiring remote sensing data becomes more selective and timely. The applications of remote sensing technology focus on not only the recognition and the calculation of blue-green algae areas, but also on the growth pattern of the bloom combing with meteorological conditions such as wind direction, wind speed and temperature. As the biggest freshwater lake in Shanghai, Dianshan Lake has been suffering water eutrophication with a significant impact on sustainable development and living quality in surrounding areas. The abnormal propagation of algae destroys l andscape, breaks the balance of eco-system and results in deterioration of water quality. On the other h and, since the breakout of cyanobacteria bloom is frequent and large-scale, it is necessary to utilize remote sensing technology to provide analysis and prediction information of Dianshan Lake.

However, relating to the judgment on forecast of algae-bloom breakout, it is not convincing that only rely on hydrologic data, like history and field data. High-resolution multi-temporal remote sensing images overlap with GIS data, meteorological data of lakes and surrounding areas (wind speed, flow rate, temperature and so on), field data and multimedia information to display the whole process of its cyanobacteria biomass (He *et al*., 2004).

As the 4th generation visual language, IDL is one of the best development tool of cross-platform due to its characteristic of matrix oriented and familiar syntax to visualize and analyze scientific data. The outst anding features of advanced image processing ability include objected oriented programming approach and quantitative visualization performance. These peculiarities attract more and more attention of researchers from different fields, such as geoscience, medicine, aviation, engineering and software engineering.

Therefore, based on remote sensing technology, BTSVSS is designed to monitor cyanobacteria bloom under insight visualization. This system includes following functions: Spatial data reading and registration, biomass monitoring data reading and management, contour lines generating, multimedia information reading

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and management, coordinate registration, data overlapping display and contrast operation. The framework of the system will be applied to implement functions including data processing, management, operation and visualization.

MATERIALS AND METHODS

Data preprocessing: Remote sensing images and vector map data adopted in the system contain L and sat 7 ETM images covering Dianshan Lake, the latest vector data of study region and surrounding areas. The image b and combination is with B and 5, B and 4 and B and 3 since this combination can benefit algae-bloom information extraction. The same with remote sensing data, vector map data are under UTM projection and saved in Shape file format. In addition, biomass, meteorological data and multimedia information collected in the field survey are saved in database by date.

Extraction of cyanobacteria bloom information: Base on the analysis of spectral curve and features of cyanobacteria bloom and other typical ground object, the normalized difference cyanobacteria bloom index (NDI_CB) is developed to extract the algae information via unsupervised classification method (k-means) (Xie *et al*., 2010). B and 3, B and 4, B and 5 and NDI_CB compose the multi-feature space. NDI_CB is constructed by expressions Eq. 1:

$$\begin{cases} a = B4 - B3 \\ b = B5 - B4 \end{cases} \tag{1}$$

The technical route is shown as following in Fig. 1.

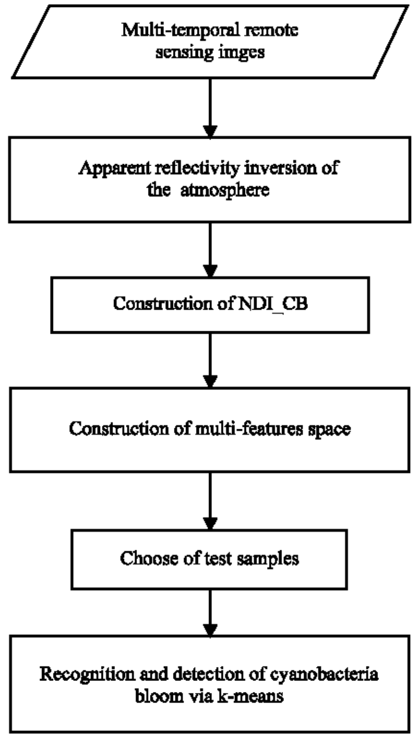

Fig. 1: Extraction of cyanobacteria bloom technology route

The Fig. 1 demonstrate the main tactic of information extraction. The feature space based on the improved index which can distinguish the bloom area from lake efficiently. The K-means is unsupervised classification. According to experiment results, it shows that the menthod can extract the useful information from mid-resolution remote sensing images.

SYSTEM FRAMEWORK AND INFORMATION ORGANIZATION

Data reading and registration: BTSVSS consists of Field data Pattern and Remote sensing data Pattern for two different ind of data sources. The choice of pattern depends on varied situation. For instance, when the remote sensing images are available, it is more reliable to use Remote sensing-data Pattern.

After radiation correction of images, all raster data are adjusted to the same size matrix and geographic coordinates and projection information are exported and saved separately. The coordinates and attribute information of rivers, roads and lakes will be saved into the structure after reading the vector data. The storage of multimedia information is classified by time. It also demonstrates that the reading speed and efficiency of display can be improved for the same storage rule. The method of registration is to transform the data from the WGS-84 coordinate system to the normalized coordinate system.

Biomass survey data reading and contour lines generation: In field data pattern, the h andling of the biomass survey data is based on numerical analysis. In this system, contour lines are generated by calculating the discrete observation spots under interpolation method. In remote sensing data Pattern, it is easier to acquire coverage area via edge detection of classification result and then coordinate system of new biomass data are

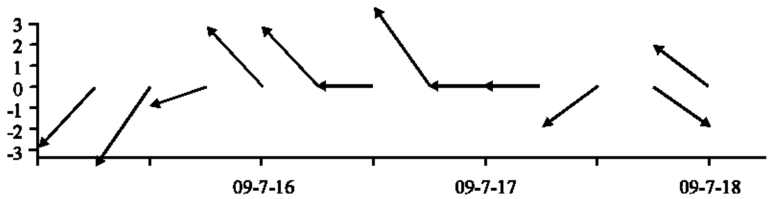

Fig. 2: Wind data visualization display

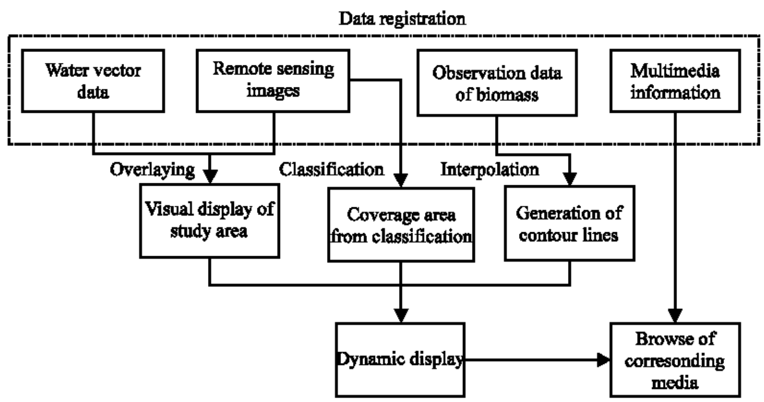

Fig. 3: Structured information layer organization

changed to the normal coordinate system by the same rule to make all data layers match. The details are showed as follow in IV-C.

Overlapping visualization and contrast operation: The remote sensing data layer is the bottom map overlaid with vector data layers and contour lines layer, which benefits from object-oriented image display technology in IDL. Moreover, the wind-display form describes power and direction of wind by vivid graphics at different time. The direction of arrow st ands for direction, length for power (Fig. 2). The system leads to multimedia information by coordinate points. Other environmental information likewise shows on the main form for auxiliary analysis.

With the insightful visualization of complex image data and survey data, it provides multi-temporal biomass or coverage area dynamically to help users' contrastive analysis. Therefore, it plays a vital step in revealing potential laws and predicting breakout for prevention.

Structured information layer organization: The area covered with cyanobacteria bloom can be traced by calculating exact value via using the means of remote sensing and water vector data. Combing biomass data and spectral feature of corresponding remote sensing images is a promising way to explore quantitative model of biomass calculation using spectral features. The multimedia information offers users intuitive feelings and performance characters.

The structured information layer organization is designed as follows (Fig. 3). Remote sensing images, water vector data, algae biomass and media information are basic data to show the coverage and biomass distribution visually. All of the data are normalized to the same coordinate system and are guaranteed to have correct link of all study information. At last, the display on the ground of timeline achieves dynamic analysis on multi-layer data.

Transform between space coordinate and normal coordinate: During the stage of preparing and pre-processing data, all the information base on geo-spatial coordinate system. For high-accuracy of overlying display and analysis after a series of operations, space coordinates of all information layers must be normalized to Normal Coordinates. After transformation, the value of x, y, z is limited to [0, 1].

The steps of transformation in the system are explained as follows:

- **Space coordinate range:** X_{min}, X_{max}, Y_{min}, Y_{max} are minimum value and maximum value at x-axis and y-axis, respectively
- Calculation of scale factor is according to Eq. 2:

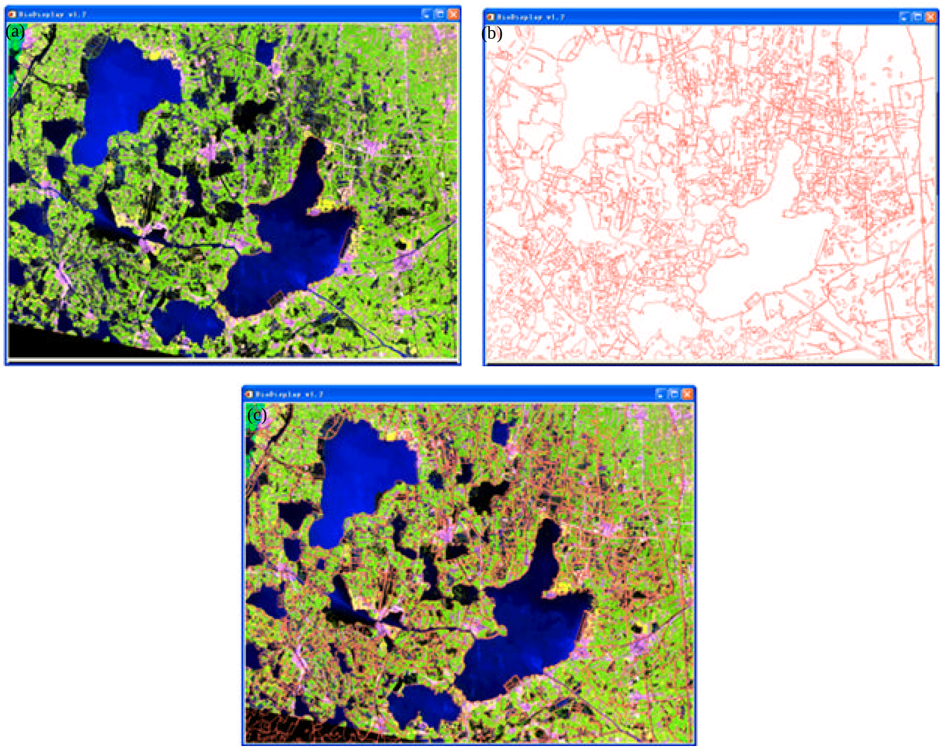

Fig. 4(a-c): Visualization of remote sensing image, water vector data, overlying display (a) Remote sensing image overlying display (b) Water vector data display and (c) Overlying display of remote sensing image, water vector data and bloom distribution

$$\text{Xscale} = \left[-\frac{X_{min}}{X_{max} - X_{min}}, \; \frac{1}{X_{max} - X_{min}} \right] \tag{2}$$

- Transformation based on scale factor is expressed as:

$$X_{conv} = \text{Xscale}_0 + \text{Xscale}_1 * x \tag{3}$$

where, X is space coordinates, X scale is scale factor, Xscale0 and Xscale1 are 1st and 2nd elements of X scale, respectively.

From Fig. 4a-c, it's easier to get important information about cyanobacteria bloom development. This can afford visual aids on bloom's monitoring. As to Fig. 4a, remote sensing image overlying display help system users find out the potential areas which might be harmed by cyanobacteria. Added water vector data Fig. 4b to display, it's helpful to observe the water distribution of study area. In Fig. 4c, display overlying remote sensing image, water data and bloom not only help to figure out harm of cyanobacteria bloom to water, but also give an h and to analyse potential dangers to vegetation, communities and animals.

Interpolation of biomass observation data: By interpolation of biomass observation data here means to calculate distributed observation data in study area and acquire evenly distributed points by appropriate function. In this study, biomass data samples measured along the lake are given data. The interpolation of biomass observation data adopts Kriging. Actually, Kriging is a geostatistical estimator that infers the value of a random field at an unobserved location from the samples (He *et al*., 2005). However, the sampled data is interpreted as a result of a random process. The models contained uncertainty in its conceptualization doesn't indicate the phenomena-the forest, the aquifer, the mineral deposit have resulted from a random process. But it solely allows to build a methodological basis for the spatial inference of quantities in unobserved locations and to the quantification of the uncertainty associated with the estimator (Jeffrey *et al*., 2001). Although, kriging was developed originally for applications in geostatistics, it is now a general statistical interpolation method that can be applied within many disciplines to the sampled data from random fields that satisfy the appropriate mathematical assumptions.

QKriging is based on the idea that the value at an unknown point should be the average of the known values at its neighbors; weighted by the neighbors' distance to the unknown point (Kong and Xiang, 2012). Specifically, The unknown value $Z(x_0)$ is interpreted as a random variable located in x_0, as well as the values of neighbor's samples $Z(x_1)$. The estimator $Z(x_1)$ is also interpreted as a random variable located in x_0, a result of the linear combination of variables. In order to deduce the kriging system for the assumptions of the model, the error $\varepsilon(x_0)$ committed while estimating $Z(x)$ in x_0 is declared. The two quality criteria referred previously can now be expressed in terms of the mean and variance of the new random variable $\varepsilon(x_0)$. In order to ensure that the model is unbiased, the sum of weights needs to be one.

Kriging helps to compensate for the effects of data clustering, assign individual points within a cluster less weight than isolated data points. By given estimate of estimation error along with estimate of the variable, Z, itself, kriging has the availability of estimation error providing basis for stochastic simulation of possible realizations of Z(u). In IDL, the KRIG2D function interpolates a regularly-or irregularly-gridded set of points z = f (x, y) using kriging. The parameters of the data model-the range, nugget and sill-are highly dependent upon the degree and type of spatial variation of achieved data and should be determined statistically. Experimentation, or preferably rigorous analysis, is required. For n data points, a system of n+1 simultaneous equations are solved for the coefficients of the surface. Accordingly, the trend of data distribution can be simulated by kriging based on value and distribution of given data which is important to simulation and visualization.

Generation and visualization of contour lines: After the interpolation in 3.2, the biomass data covers the whole study area. Searching for the grid point' value most closed in to generate isoclines. On the basis of isoclines, cyanobacteria bloom extending from weak to strong is divided into 5 levels combining with the relation between biomass and bloom. The range of grayscale levels is divided into intervals by gray density slicing, with each interval assigned to one of value scale st anding for fixed serious degree. The color index is created for fast searching.

According to JPEG (Joint Photographic Experts Group) format protocol, RGB (Red green blue) true color image file generated with JPG format is based on color index and biomass data. Meantime, the ALPHA layer must be generated to keep the area out of the study region transparent.

RESULTS

After all steps of data processing, the study come out several results in biomass temporal-spatial variation simulate. The following figures show these results.

Multi-temporal biomass contour (BC) lines layers on remote sensing data overlying: From Fig. 5, the visualization of contour lines in the picture can show users the whole development of bloom. The series of pictures (Fig. 5a-d) can help users discover the bursting points on the lake, which can contribute to dredge bloom. With these display of the bloom, study find out the area of cyanobacteria do not always spread. The change can be found from Fig. 5(b) Erupt) to 5c (Development). The biomass of cyanobacteria on south west of lake falls during development period. Associating with auxiliary information show around (Fig. 6), traditional methods on analysis of bloom can be utilized to the visual ones. With the corresponding auxiliary information of study area, the users can take advantage of it to forecast development of bloom and adopt the measures. According to Fig. 6a, overlying of GIS data and bloom help officials to analyze

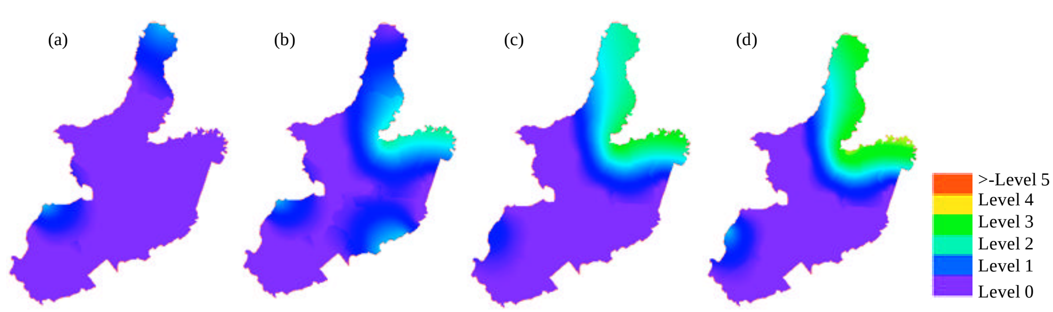

Fig. 5(a-d): Visualization of biomass contour lines

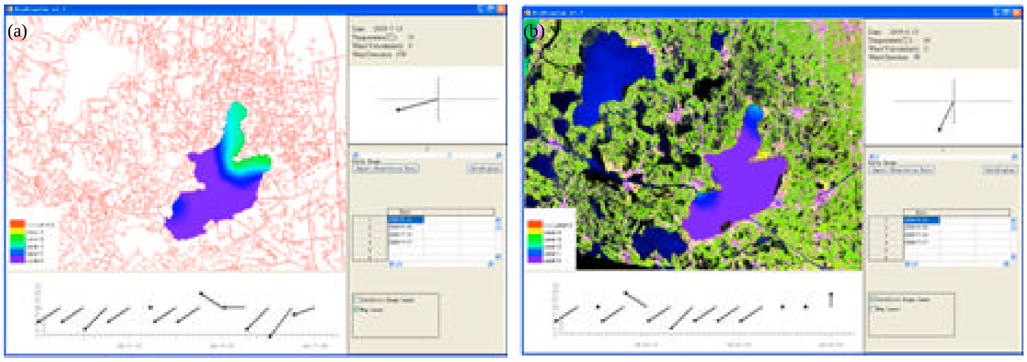

Fig. 6(a-b): Multi-temporal biomass contour (BC) lines layers on remote sensing data overlying

the damage to water in study area. Meantime, layers on remote sensing data Fig. 6b help them to forecast the bloom and its danger to communities. The cyanobacteria bloom is tied to human and animal's health.

DISCUSSION AND CONCLUSION

According to references, there are some disadvantages existing in previous researches related to monitoring of cyanobacteria bloom:

- Single vegetation index isn't most efficient in detecting cyanobacteria bloom in large lakes because of turbid waters and vegetation along shoresides
- There is a lack of utilizing information of watershed and water network, both of which affect the process of cyanobacteria bloom's diffusion

In traditional study, researchers always use value of biomass marked on map to analysis and must reference to the auxiliary information on other files which is not intuitional and convenient. BTSVSS provides more well-pleasing cyanobacteria bloom analysis than previous studies. Just like decrease of biomass (Fig. 5), the users can quickly find out the change in the display but cannot observe it only to marked numbers. The system developed in this study provides solutions to these disadvantages in previous researches. The resultful prevention and timely treatment provided by the system is beneficial for sustainable development and improvement of regional water environment.

However, there are still many aspects needed to be improved. The future work is to develop the accuracy of remote sensing image classification and deeply integrate classification methods to the system. The research on exploring the calculating relation between remote sensing data and biomass value is the key. If system has the ability to calculate the biomass from the remote sensing data, it must be more convenient and simple for environment monitoring with immeasurable economic benefits and the cross-platform program is also the pursuit of future.

Biomass Temporal-spatial Variation Simulation System (BTSVSS) proposes a new management of environment protection and monitoring. Visualization of temporal-spatial variation of cyanobacteria bloom based on remote sensing images simulates the growth and breakout law. As the high-efficiency system, it can especially help researchers analyze and predict timely the rapid development of remote sensing technology. The design of the system is not only aimed at field data or classification result, but also pay attentions to the meteorological data and other relevant data which can enhance the accuracy and reliability of analysis conclusion and forecast.

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