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Remote sensing application system for water environments developed for Environment Satellite 1

WU ChuanQing[1], WANG Qiao[1*], ZHANG YongJun[1], LI JunSheng[2], WU YuanFeng[2], ZHU Li[1] & YAO YanJuan[1]

[1] *Satellite Environment Center, Ministry of Environmental Protection, Beijing 100029, China;*
[2] *Center for Earth Observation and Digital Earth, Chinese Academy of Sciences, Beijing 100190, China*

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Remote sensing data collected by the Environment Satellite I are characterized by high temporal resolution, high spectral resolution and mid-high spatial resolution. We designed the Remote Sensing Application System for Water Environments (RSASWE) to create an integrated platform for remote sensing data processing, parameter information extraction and thematic mapping using both remote sensing and GIS technologies. This system provides support for regional water environmental monitoring, and prediction and warning of water pollution. Developed to process and apply data collected by Environment Satellite I, this system has automated procedures including clipping, observation geometry computation, radiometric calibration, 6S atmospheric correction and water quality parameter inversion. RSASWE consists of six subsystems: remote sensing image processing, basic parameter inversion, water environment remote sensing thematic outputs, application outputs, automated water environment outputs and a non-point source pollution monitoring subsystem. At present RSASWE plays an important role in operations at the Satellite Environment Center.

water environment, Remote Sensing Application System, Environment Satellite 1

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Water pollution is one of China's most serious environmental problems. It is therefore important to establish a dynamic and rapid water quality monitoring, evaluation and forecasting system for environmental protection and pollution control in China [1, 2]. However, the frequency and speed of existing field monitoring cannot satisfy the need of environmental management and decision-making, especially when significant environmental accidents occur. To monitor large-scale environmental changes, we need an effective monitoring system. The use of remote sensing (RS) technology to monitor water environments has the advantages of large spatial extent, high speed and low cost. It is also convenient for long-term monitoring, and can monitor pollutant migration to degree unattainable by traditional monitoring methods [3–6].

Improved remote sensing technologies and models are being applied increasingly to water environmental monitoring [7–10]. However, RS data applied to water monitoring in the past were not designed specifically for monitoring freshwater systems but primarily for monitoring oceans, other land resources and the atmosphere [11, 12].

With the successful launch in September 2008 of the two optical satellites HJ-1A and HJ-1B, also called Environment Satellite 1 (ES 1), which were designed especially for environmental and disaster monitoring, the water resources in China can be monitored more effectively. HJ-1A carries

*Corresponding author (email: wangqiao@mep.gov.cn)

two wide-coverage multi-spectral visual optical cameras and a hyper-spectral imager. HJ-1B carries two wide-coverage multi-spectral visual optical cameras and an infrared camera. The main parameters of the multiple-spectral CCD data are: sub-satellite point resolution of 30 m, width of 700 km, a return period 48 hours, single-scene maximum data volume of 800 MB, and TIF format. The parameters of the infrared camera are: sub-satellite point resolution of 150 m (near and middle infrared) and 300 m (thermal infrared), width 720 km, return period 96 hours, single-scene maximum data volume of 200 MB, and TIF format. The parameters of the hyper-spectral imager are: average spectral resolution 5 nm, sub-satellite point resolution 100 m, width 50 km, return period 96 hours, maximum data volume 100 MB, and HDF5 format [13]. The satellites provide valuable data for water environmental monitoring, with the advantages of high temporal resolution, high spectral resolution and mid-high spatial resolution.

Environment Satellite 1 produces daily 200 GB of data, from which information on key water bodies needs to be extracted. Different remote sensors require specific pre-processing procedures and water quality model parameters. The use of commercial RS software (e.g. ENVI, ERDAS and PCI available internationally, and RSIES, IRSA, SAR INFORS, and CASM ImageInfo developed domestically in China) makes data processing complicated and cumbersome. Without an efficient water RS data processing system, the data remain in the laboratory and cannot provide support for comprehensive water environmental management [14]. SeaDAS is an example of a mature commercial RS software applied to data from the SeaWiFS oceanic monitoring satellite [15]. A similar platform is required to analyze inland water bodies in China using ES 1 data.

Based on the ES 1 characteristics described above, we designed the Remote Sensing Application System for Water Environment (RSASWE). The system to processes remotely sensed data of water environments, extracts water environment parameters and produce maps and reports on an integrated platform. The RSASWE supports operations and decision-making on water environmental monitoring and water pollution prediction, and is an early warning system.

1 System design and implementation

The system is designed in accordance with industrial standards and is based upon the practical requirements of operational departments, and integrates advanced remote sensing inversion models. It has been installed and tested in the Water Department of the Satellite Environment Center, Ministry of Environmental Protection (MEP). The design has taken into account the principles of extensibility, applicability, consistency and compatibility. With regards to the system classification codes, function modules and data structure are all designed to be extensible. As for applicability, the system is user-friendly and easy to manipulate. For consistency, it complies with both international and national industrial standards and specifications so that it can be connected with other systems. Developed with C++ language, it is compatible with all Windows platforms utilized by the Satellite Environment Center. It can also be inserted readily into other operating systems such as UNIX and Linux. The standard data format of the system is compatible with the IMG format of ENVI. It produces reports on water environment monitoring in Microsoft Word. The generated thematic maps are also saved in the widely-used image formats JPG, BMP and GeoTiff.

The RSASWE consists of six subsystems: an image processing, basic RS parameter retrieval, thematic outputs, applications outputs, automated water environment outputs production, and a non-point source pollution monitoring subsystem. The RSASWE interface is presented in Figure 1.

1.1 Operation modes

Based on different user requirements, two operation modes were designed for both experts and general users. An expert performs tasks step by step and adjusts parameters within individual procedures (Figure 2), and the process can be rearranged to meet particular demands. In general user mode, monitoring reports are generated directly by defining the study area and data source. Analysis can be conducted automatically without intervention. This means that users consider about the detailed steps within the dashed box in Figure 2.

1.2 System architecture

In accordance with engineering standards, RSASWE was designed in tiers and composed of different modules. As illustrated in Figure 3, the system is composed of four tiers: user interface, business logic, supporting tier and database. In the Graphical User Interface (GUI), users conduct thematic mapping of water environment monitoring and generate statistical analysis monitoring reports. The middle tier serves as the business logic and consists of subsystems including automated water environment outputs, water environment application outputs, and thematic products. Both the image processing engine and spatial data engine are provided in the supporting layer. The database operations are encapsulated in this layer. The engines are deployed in a distributed manner, enabling distributed calculation. The database is designed to use study area and sensor type as an index in analysis operations. In the database, diverse data are consolidated including metadata, parameters of radiometric calibration and atmospheric correction, models of water quality inversion, data on inherent optical properties, spatial data, and some statistical disk files.

The system is designed using Client/Server architecture.

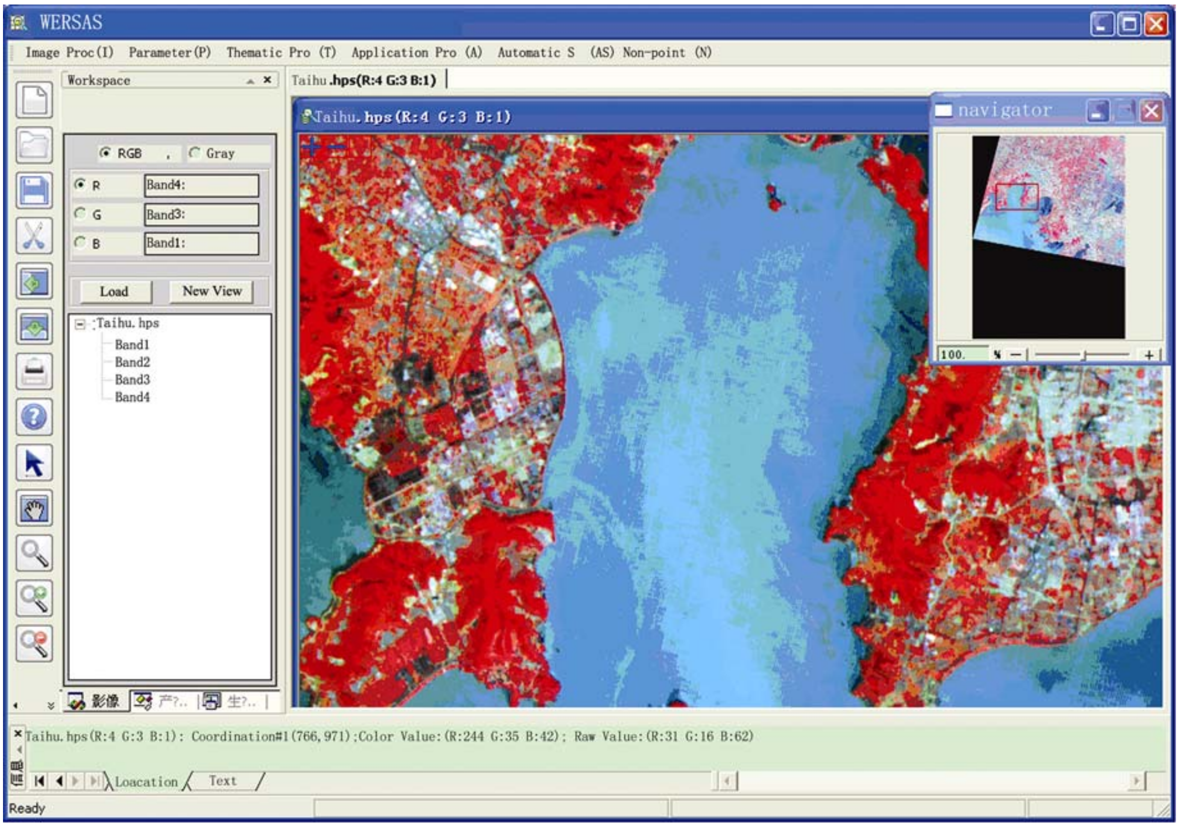

Figure 1 The RSASWE software interface.

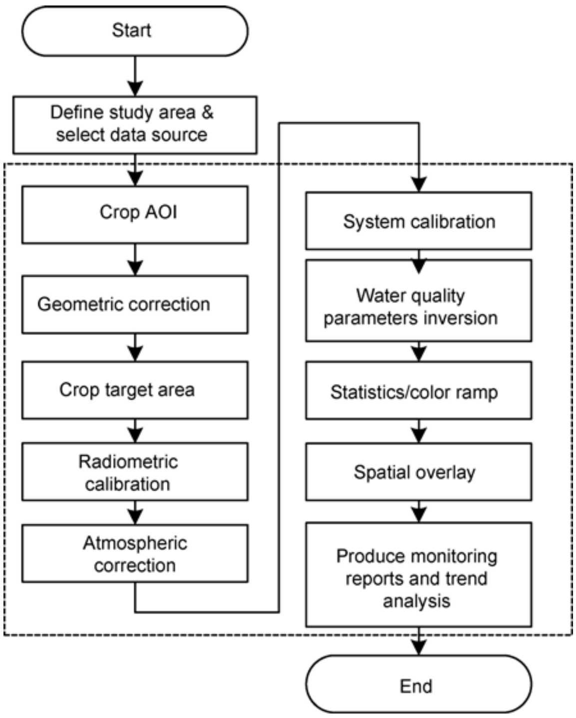

Figure 2 Operation mode.

Databases and image files are stored in the server side. Subsystems employ modules to keep loose coupling between business logic and other tiers. The modules are encapsulated into various services according to grain size. The mechanism of Input/Output (IO) is designated to adopt server files and metadata tables, database files and metadata tables, and local files. Metadata tables are stored in the metadatabase are also described using XML schema.

Message middleware is adopted to communicate among different subsystems. Messages are coded in XML to deliver among heterogeneous platforms, enabling interactions among different applications.

1.3 Workflow design

The major steps of operation workflow are as follows: 1) pre-processing of remote sensing images, including image cutting, stripping removal, bad line elimination, geometric correction and image filtering to obtain high quality Digital Number (DN) values; 2) calculation of primary parameters of remotely-sensed water color, including radiometric calibration, atmospheric correction and system calibration to acquire relatively accurate water reflectance data; 3) production of thematic outputs in the form of water parameters such as chlorophyll-a, suspended solids (SS), transparency, thematic maps showing change of river courses and coast lines, enclosure aquaculture and sediment deposits; 4) publishing of reports on algal blooms and red tides, oil spills, eutrophication and water quality assessment; 5) routine

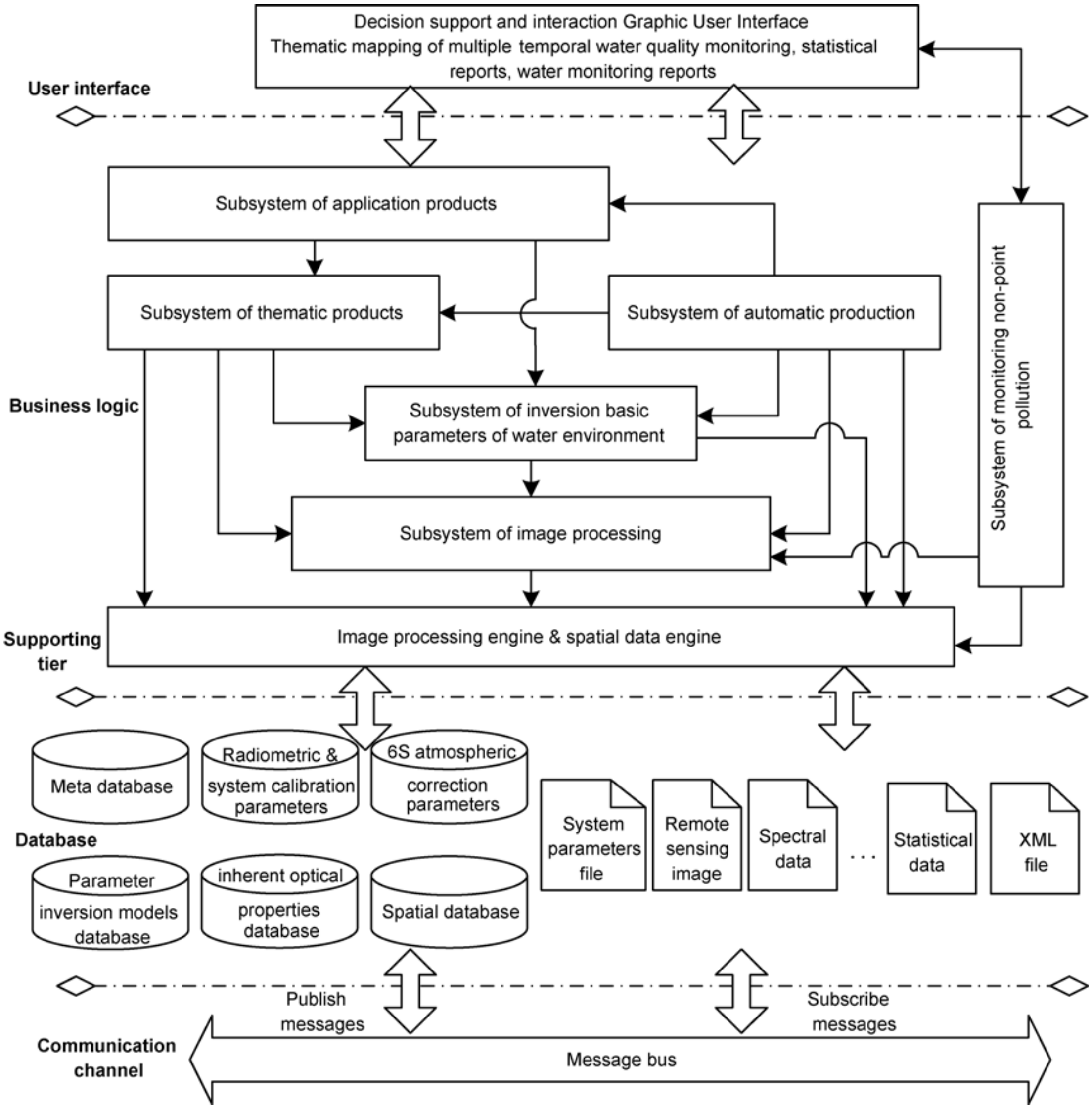

Figure 3 System architecture of RSASWE.

monitoring and evaluation of non-point source pollution of major lakes, reservoirs and river segments on a monthly, quarterly and annual basis, and investigations of particular areas having experienced storm events.

1.4 Water RS application model

There are two kinds of water quality parameter RS inversion models: experience models and analysis models. Because water optical characteristics change between different locations and between different seasons, these two methods have regional applicability. It is difficult to establish a universal RS model. As a result, RSASWE uses a model-base composed of experience models and analysis models.

With the stored indices of area, time, sensor and water quality parameters, experience models are integrated in the model-base. Model-base structure is defined as shown in Table 1.

The integration of mechanism models is based on the unit Specific Inherent Optical Properties (SIOP) database for target water area. The database provides the corresponding unit SIOP of a few typical remote sensors for mechanism models. Its structure is defined as shown in Table 2.

The use of the experience model-base and database improves the model's regional and seasonal applicability. In the expert mode, users can choose their model based on need and experience. In the general user mode, each water quality parameter model has a priority level evaluated in advance, and the system selects automatically the model with the highest priority.

2 System demonstration

To test the software system, we used field data and ES 1 CCD data of Taihu Lake on March 14th 2009. The three

Table 1 Experience model-base structure

Name	Sign	Type	Example
Region	Region	Character	Taihu lake
Date	Date	Date	2009-01-01
Water quality parameters	Water quality	Character	Suspending matter
Data source	Data source	Character	HJ-CCD RS reflectance
Formula	Formula	Character	1.2×b4/b3
Model reference	Reference	Character	Remote Sensing Application Institute, CAS
Annotation of band	Annotation	Character	The b3 is the third band RS reflectance of HJ-CCD and the b4 is the fourth band RS reflectance of HJ-CCD.

Table 2 Specific Inherent Optical Properties (SIOP) database structure

Name	Remark	Sign	Type	Example
Region	Name of target region	Region	Character	Taihu
Date	Date of data obtained	Date	Data	2009-01-01
Sensor	Sensors type	Sensor	Character	HJ-CCD
Band	Band number	Band	Integer	4
a'_{ph}	Unit absorption coefficient of phytoplankton	Saph	Float	0.2
a'_{d}	Unit absorption coefficient of de-pigment suspended solids	Sad	Float	0.2
a'_{cdom}	Unit absorption coefficient of colored dissolved organic matter (CDOM)	Sacdom	Float	0.2
b'_{p}	Unit back scattering coefficient of suspended matter	Sbp	Float	0.2
$\tilde{b}_{bp}$	Back scattering probability of suspended matter	Cbbp	Float	0.05
a_w	Absorption coefficient of water	Aw	Float	0.01
b_{bw}	Back scattering coefficient of water	Bbw	Float	0.01

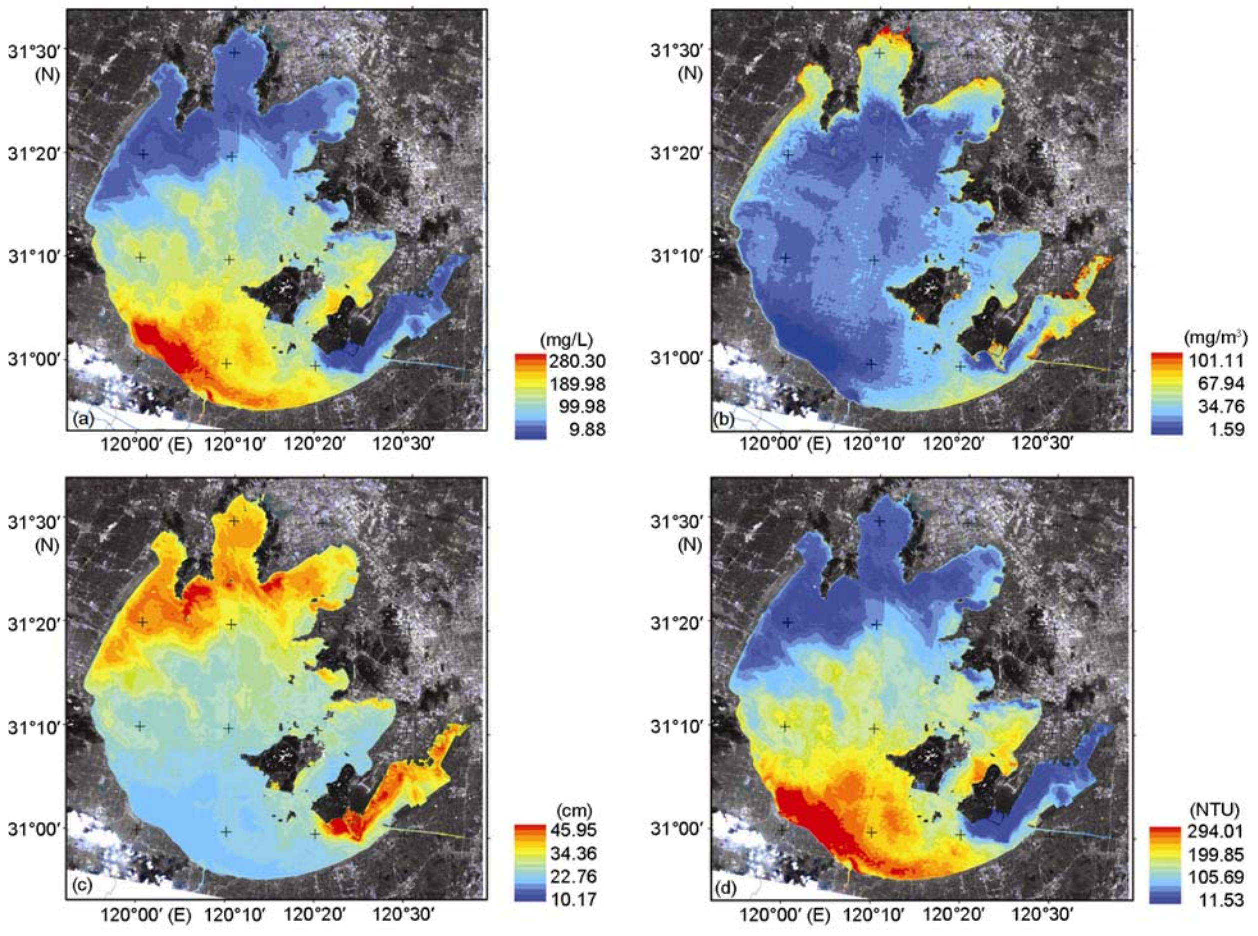

Figure 4 Water quality parameters distribution maps of the Taihu Lake, 3/14/2009. (a) Suspended matter; (b) chorophyll-a; (c) transparency; (d) turbidity.

sample points were sampled at the same time as the ES 1 passed, and so were used to validate the RS result. Four water quality parameters of suspended matter, chlorophyll a, transparency and turbidity, are reversed in this experiment. The results are shown in Figure 4.

The relative error of suspended matter was 27.2%, of transparency was 24.1%, of turbidity was 39.3% and of chlorophyll-a was 31.5%.

3 Summary

Tailored to the characteristics of HJ-1 satellite (ES 1) data, WERSAS integrates parameter management, RS parameter inversion and GIS analysis tools to monitor and predict surface water environments at regional scales. Spatial data are acquired from multiple-spectral, hyperspectral, infrared and SAR data. The resulting parameters are calibrated based on ground survey data. Oriented to level 2 data collected by ES 1, RSASWE's analysis operations include image clipping, observation geometry computation, radiometric calibration, 6S atmospheric correction, and automated inversion of water quality parameters. Based on Service Oriented Architecture, the integrated functions of WERSAS include remote sensing data processing, parameter inversion of water environments, regional non-point source pollution monitoring, pollutant dispersion models, and production and publishing of thematic outputs. Additionally, the system is designed and implemented using COM+ components to support distributed calculations. At present, the system plays an important role in operations at the Satellite Environment Center, MEP.

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