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Research Article

Promoting Geospatial Service from Information to Knowledge with Spatiotemporal Semantics

Jing Geng ,[1,2] Shuliang Wang ,[1,2] Wenxia Gan ,[3] Hanning Yuan ,[1] Zeqiang Chen,[4] Ziqiang Yuan,[1] and Tianru Dai[1]

[1] *School of Computer Science and Technology, Beijing Institute of Technology, Beijing 100081, China*
[2] *Academy of e-Government, Beijing Institute of Technology, Beijing 100081, China*
[3] *School of Civil Engineering and Architecture, Wuhan Institute of Technology, Wuhan 430074, China*
[4] *State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS), Wuhan University, Wuhan 430079, China*

Correspondence should be addressed to Shuliang Wang; slwang2005@gmail.com, Wenxia Gan; gan.150@osu.edu, and Hanning Yuan; yhn6@bit.edu.cn

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With the development of geoscience, users are eager to obtain preferred service from geospatial information intelligently and automatically. However, the information grows rapidly while the service gets more complicated, which makes it difficult to find out the targeted information for an exact service in geospatial issues. In this paper, a novel method is proposed to promote the geospatial service from information to knowledge with spatiotemporal semantics. Both prompted and professional knowledge are further refined to be published as a service. In terms of an exact task, numerous related services are recombined to a service chain under user requirement. Finally, the proposed method is applied to monitor the environment on the Air Quality Index (AQI) and soil moisture (SM) in the Sensor Web service platform, the results of which indicate geospatial knowledge service (GKS) is more efficient to support spatial decision-making.

1. Introduction

Nowadays, the geoscience issues benefit from the services of geospatial information. Users query the registered services on geospatial information, and the services are composited to form a service chain with the intervention from the users under a given task. But it is hard to meet users' requirements when it comes to accuracy, relevance, and time efficiency of the information. It is difficult to find the most relevant geospatial knowledge from the huge amounts of geospatial information. Lacking semantic attributes, the formalization requirement of geospatial information web service is also strict. In addition, it highly depends on users' manual intervention. Compared to information services, knowledge services pay more attention to the automation and intelligence of services with robust stability and fault tolerance. It is believed that knowledge service can make up for the lack of information services [1, 2]. In geographic information science (GIS), it is inevitable to develop from information services to knowledge services.

Normally, we need to acquire knowledge and get knowledge representation at first and then publish them as a service. At present, knowledge acquisition mainly includes interviews, simulation, oral records, multidimensional measurement from professional experts, engineering data handbooks, and modeling process. Acquisition emphasizes that experts can convert their knowledge or experience to an array of geospatial knowledge [3]. The development of machine learning additionally makes it possible to acquire knowledge with professional tools [4]. Such methods are time-consuming and face difficulty in meeting the requirement of knowledge acquisition, while spatial data mining might precisely solve the problem. The knowledge representation method converts the abstract representation into a linguistic one. Lack of formalizing languages results in that the knowledge exists in specific programs only and the knowledge cannot be reused. Common logic programming languages [5–7] and new expression languages [8] are used for knowledge representation and knowledge reasoning. However, these programming languages have strict requirements on the platform and limit cross-platform knowledge applications. Semantic web can satisfy users' needs for geospatial knowledge and cross-platform application reuse [9–12]. Semantic web is a self-description independent meta markup language that is supported by its special formal description ability. It is conducive to analyzing and regularizing of geospatial knowledge.

Summarizing the state of the art on geospatial services, Gong et al. [13] presented geospatial knowledge service (GKS) that is user-oriented. GKS mainly serves a user with the corresponding solution from the geospatial knowledge. The user no longer needs to determine the required resources by themselves in complex and intricate information. Based on semantic relations, GKS not only automatically realizes service query, service reasoning, and service composition, but also intelligently provides users with the targeted information. To achieve GKS, all information and operations should be described and encapsulated as a service and published on the web. When there is a task, geospatial knowledge service will query, select, combine, and execute to respond to user's requirements [14–17]. Currently, the common description languages for semantic web service are OWL-S (Ontology Web Language-Semantic), WSMO (Web Services Modeling Ontology), SAWSDL (Semantic Annotations for Web Services Description Language), and XML (Extensible Markup Language) schema [13, 18–20].

A task requires not only service query and selection, but also service composition. The service query makes use of the spatiotemporal information to achieve efficient queries and inferences. Then the optional services are found out based on web server [21]. The service composition method is divided into process-driven service composition and semantic movement. The former is based on process modeling in the recombined services that aims at control flow and data flow, while the latter relies on semantics which focuses on semantics description and reasoning [22]. Amounts of common criteria are laid down to regulate the combination of services [23, 24], taking the basic criteria, for example, WSFL (Web Services Flow Language), WS-BPEL (Web Services-Business Process Execution Language), and BPMS (business process management system) [24–26].

However, the development of geospatial knowledge service is generally limited. There are still many fundamental problems in geospatial knowledge, e.g., the reasoning of knowledge-based services [27, 28], intelligent service compositions [29, 30], and the high-efficiency service composition mechanism [31, 32]. The intensive methods for geospatial knowledge service which are modeling, reasoning, and managing are compulsory [14, 33].

Therefore, a novel method is proposed to promote the geospatial service from information to knowledge with spatiotemporal semantics. The rest of this paper is organized as follows: the fundamental principles of the proposed method are described in Section 2. The application in environmental monitoring on the AQI and SM by using the proposed method is explained in Section 3. The conclusion and future plan are included in Section 4.

2. Fundamental Principles

The proposed method firstly promotes the geospatial service from information to knowledge with spatiotemporal semantics. Then, both prompted and professional knowledge are further refined to be published as a service. Given an exact task, several related services are recombined to a service chain under user requirement.

2.1. Geospatial Knowledge Service. Geospatial knowledge service (GKS) can rapidly query and access geospatial information by enhancing the semantic information on spatial distribution and serial trend. Its semantic reasoning with spatiotemporal constraint assists the service selection and composition, and both semantic information and prior knowledge are added for bettering services. To achieve an intelligent GKS, many services are composited to make a service chain for providing more complicated service automatically. GKS contains the concept model, technology, mode, infrastructure, and application on service (Figure 1).

The conceptual model defines the denotation and connotation of GKS. It is an abstract description of geospatial issues without any specific geospatial information processing program. Geospatial knowledge is stored in a specific resource management database which is accessible to applications that utilize metadata services, knowledge content services, and knowledge processing services separately or together, to provide geospatial knowledge to users.

The technology is that, to utilize GKS, users need to understand the formal representation, automatic identification, and automatic composition of geospatial knowledge. The criteria of ontology referring from semantic web are used to formalize the geospatial knowledge representation. The related technology and GIS are utilized to share and integrate, analyze, and process geospatial knowledge.

The mode refers to the interaction modes between the GKS platform and the application client, and it has three types: (1) centralized mode, (2) distributed mode, and (3) mobile agent mode [34–36]. The centralized mode concentrates on a single server or a small local area network, and the centralized server provides all services. The distributed mode distributes knowledge services on the wide area network, which enables the interactions between the servers and clients, and realizes the function of network management collaboratively. The mobile agent allows the user to provide relevant communication and transactions on the agent platform.

The infrastructure refers to the geospatial service web (GSW) which is a virtual geospatial infrastructure based on the internet that integrates various geospatial-related resources (sensors, data, processing programs, information, knowledge, computing resources, network resources, and storage resources). GKS can manage data, extract information, and obtain knowledge in the geospatial community domain [37]. GSW consists of five parts: geospatial

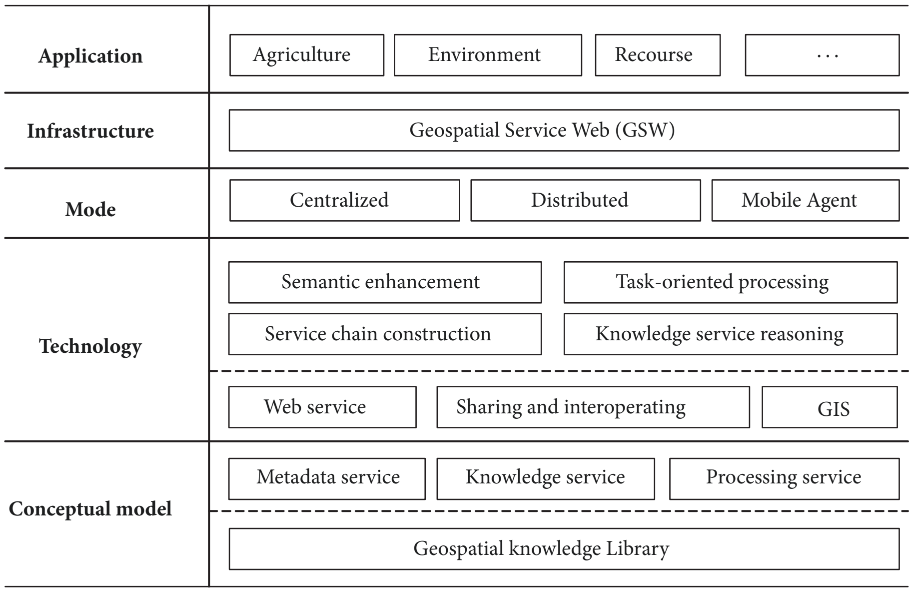

Figure 1: Geospatial knowledge service (GKS).

information resources, geospatial service, geospatial applications, GSW interoperability, and security standards. GSW offers comprehensive services about resources, information, applications, etc., where the functions are implemented by web services and communicated through the standardized protocols of the internet. Under the GSW, all resources are packaged as a service and published on the web. Users can choose corresponding services according to their own needs without understanding the resources, which can easily manage and analyze services.

The application of GKS covers various industry fields which can provide powerful online services, scalable geospatial analysis, and other auxiliary support. And it can be used on mobile phones, computers, personnel, etc. GKS can provide more information than the traditional information system and management decision suggestions. With GKS, users can realize the necessary procedures at the same time, such as information acquisition, management, processing, and analysis.

2.2. Promoting the Geospatial Service from Information to Knowledge with Spatiotemporal Semantics. The semantic enhancement of service is on the basis of GKS, with which the semantic function will be added to the original service. For instance, OWL-S is used to utilize the service configuration file, service model, and services infrastructure to realize the semantic web service. As a result, the generated logical description can be recognized by programs which make it possible to achieve intelligent services.

The logical description of OWL-S includes the service profile, service model, and service binding [38, 39] in Figure 2: (1) the service profile explains the content of the web service, including its usage and function, (2) the service model provides the service execution logic, including the executing sequence, and (3) the service binding rules introduce the rules for invoking the web service, which is mainly the specific binding information, such as message format, communication protocol, and URL.

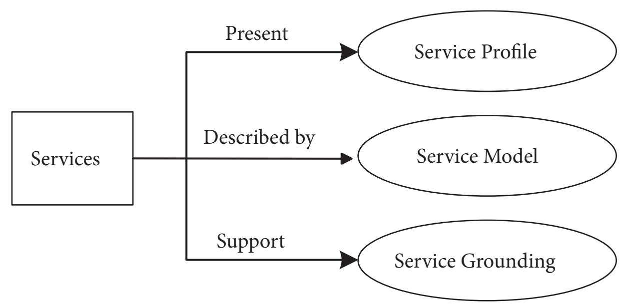

Figure 2: Semantic-enhanced service.

2.3. Publishing Prompted and Prior Knowledge as a Service. We publish promoted and prior knowledge as a service. The black box approach was implemented to facilitate the publishing of knowledge to web services. The black box approach [40] can be used without understanding how its inner algorithm works; the user only needs to know the input and output characteristics.

The "inside" of the black box is critical for generating web services with their names, inputs, outputs, and executable programs. The black box is accessed by a visual user interface, and the outline for mapping the relationship between a model and a web service is shown in Figure 3. The input, output, and execution code of a model are mapped to the input, output, and execution code of a web service, respectively. The input and output parameters are consistent with the executable program inputs and outputs of the black box.

For interface implementation, a black box can be deployed in many different forms (e.g., executable file (EXE), script, dynamic link library (DLL), or other written program languages). These form-executable programs are essential to

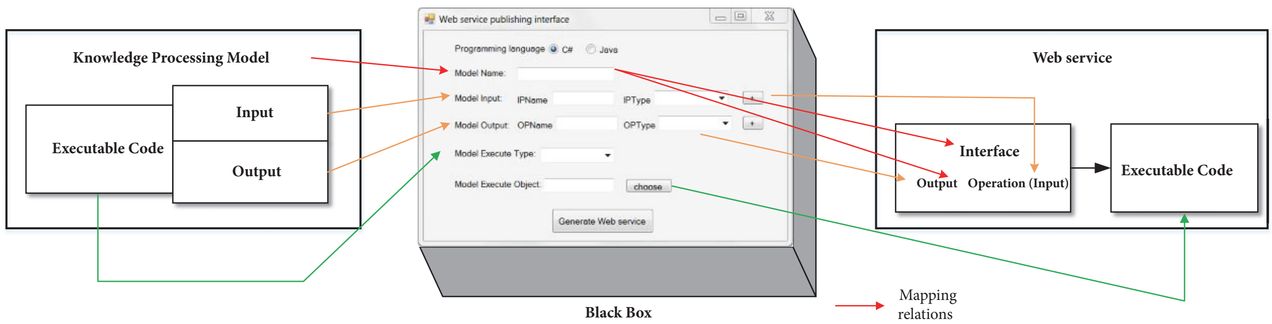

FIGURE 3: Mapping a model to a web service.

TABLE 1: Table of a service chain.

Entry	Type	Notion
ID	long	Unique identification
Service_id	varchar	Related service
relationship_id	varchar	Related relationship
MD_id	varchar	Related metadata
UNIQUE(Service_id, relationship_id, MD_id)		Unique constraint key
PRIMARY KEY (ID)		Primary key

running a local black box. The web service development library could support the development of web services. And the open source project of Java, such as Axis2, can be used to develop and deploy web services.

2.4. Creating a Service Chain under Task Requirement. With the explosive growth of knowledge, a single service cannot meet the needs of users. It is necessary to aggregate multiple services and form a service chain to provide a solution. This section presents the expression, storage, construction, and management of the service chain.

2.4.1. Task-Oriented Service Chain Construction. A service chain is an aggregation of multiple services based on logic and it can be divided into two types: abstract service chain and specific service chain. An abstract service chain completely describes the concept of the service chain and its logical relationship. A specific service chain integrates each service in the abstract service chain with a concrete service and then uses the service chain engine to execute.

The database-based storage and construction of the service chain are developed in light of the database that facilitates internet access. To store both the services and their relationships, the service chain storage tables are designed to construct a service chain in the database. Their structures are shown in Tables 1–3.

As many of their entries are complex and connect with other tables, the definition $*$_id is used to define the table's entry, which is applied in other tables.

The construction method for the abstract service chain and specific service chain is developed, respectively. The builder needs to know the processes involved and the relationships between these processes precisely. Based on these processes and their relationships, the builder constructs the service chain and registers it to the library by utilizing the service chain expression method and service chain storage method.

The following three steps are carried out to construct the abstract service chain: (1) Analyze the content of each process and clarify the links between them. (2) Create the abstract element for each process. Once the service chain builder has selected a series of processes, it is necessary to decompose the series into single processes abstractly. (3) Establish the relationship between the processes. After abstracting the processes, the tuple representation of the service chain is entirely expressed by defining the relationships between the processes.

A visual method is employed to construct an abstract service chain, which utilizes icons and human-computer interaction to complete the construction simply and briefly. In the service chain constructing panel, the visual drag module and the relationship building module are predeveloped, which are shown as red boxes and arrows in Figure 4.

There are three steps to construct the abstract service chain: (1) for any given task and its corresponding processes, drag the red boxes representing the required processes to the panel; (2) submit the required information by operating the red box to clarify the function, name, and temporal data of the processes; and (3) create the relationship among the processes by dragging the relationship icons and providing the related information.

The specific service chain can be built based on the abstract chain, or by combining the specific services directly. So there are two service chain construction methods. The first is to construct a specific service chain with the abstract service chain. Its core is to bind the concrete service to the abstract service chain and integrate the information of the specific service to the process and the relationship. When an abstract service chain is established, the icons for the abstract service processes and relationships appear in the opened operation panel, as shown in Figure 5. The detailed steps of this method are as follows: (1) Initialize the services and set the parameters of the abstract services. This operation is realized in the dialog box that emerges after right-clicking the icon. (2) Clarify the relationship between the input

Table 2: Table of a service.

Entry	Type	Notion
ID	long	Unique identification
types_id	varchar	Related types
inport_id	varchar	Related import
message_id	varchar	Related message
porttype_id	varchar	Related portType
operation_id	varchar	Related operation
binding_id	varchar	Related binding
Service _id	varchar	Related
MD_id	varchar	Related metadata
UNIQUE(types_id, input_id, message_id, porttype_id, operation_id, binding_id, Service _id, MD_id)		Unique constraint key
PRIMARY KEY (ID)		Primary key

Table 3: Table of a service relationship.

Entry	Type	Notion
ID	long	Unique identification
Service _id	varchar	Related service
Service _id	varchar	Related service
MD_id	varchar	Related metadata
r	string	Relationship between services (optional pattern, circulation pattern, sequential pattern)
UNIQUE(Service_id, Service_id)		Unique constraint key
PRIMARY KEY (ID)		Primary key

and output and the concrete services to form a concrete executable logical sequence.

The second is to directly construct the service chain with specific services. If all the services are known, there is no existing abstract service chain to combine them. The service chain can be constructed directly by combining these known services (Figure 6). The detailed steps of this method are as follows: (1) Drag the service icon to initiate the specific service, and then right-click the icon and enter the WSDL of the service. The program will automatically analyze the WSDL and generate the related information about the specific services. (2) Establish a service node to analyze WSDL automatically. Clarify the operation and the input-output relationship of the specific services to bind the relationships between specific services.

After the service chain is established, the dynamic updating of the associated tables makes it simple to add, modify, or maintain the service chain. The visual management method presents the simple service chain diagram to manage the service chain. The dynamic management of the service chain consists of two major steps: (1) extracting the data contained in the service chain and its related relationship and, (2) based on the specific conditions, dynamically updating all the tables and information involved in the service chain.

A GKS can contain a single service or multiple services. Under both conditions, the proper service must be entered orderly to achieve a given objective. Knowledge reasoning methods may help achieve the reuse of geospatial knowledge. Introducing the spatiotemporal characteristics of geospatial knowledge, the semantic spatiotemporal reasoning rules are created by extending Jena's reasoning rule with spatiotemporal constraints and benefit the service selection accuracy improvement. Meanwhile, the service composition reasoning rules are proposed based on the existing reasoning rules.

2.4.2. Spatiotemporal Semantic Reasoning Rules for Service Selection. In this study, the semantic spatiotemporal reasoning rule based on OWL-S is used to realize the discovery and binding of GKS. Like the query model shown in Figure 7, Profile, Service Name, Service Parameter, Layer, Feature, Coverage, Observation, BBox, and Time are all classes which have both data and objects attributes. The query relies on keywords such as the type of service, time and space conditions, categories, and titles, which correspond to the Service Name, BBox, Time, CategoryName, and Title in the model. Those keywords can be used separately or together.

Supported by Jena's reasoning machine, we defined the following query rules based on OWL-S.

Rule 1. Relationship between "CategoryName" and "Profile."

Rule 2. Relationship between "Thing" and "Profile."

Rule 3. Relationship from "Layer," "Feature," "Coverage," and "Observation" to "BBox."

Rule 4. Relationship from "Layer," "Feature," "Coverage," and "Observation" to "Time."

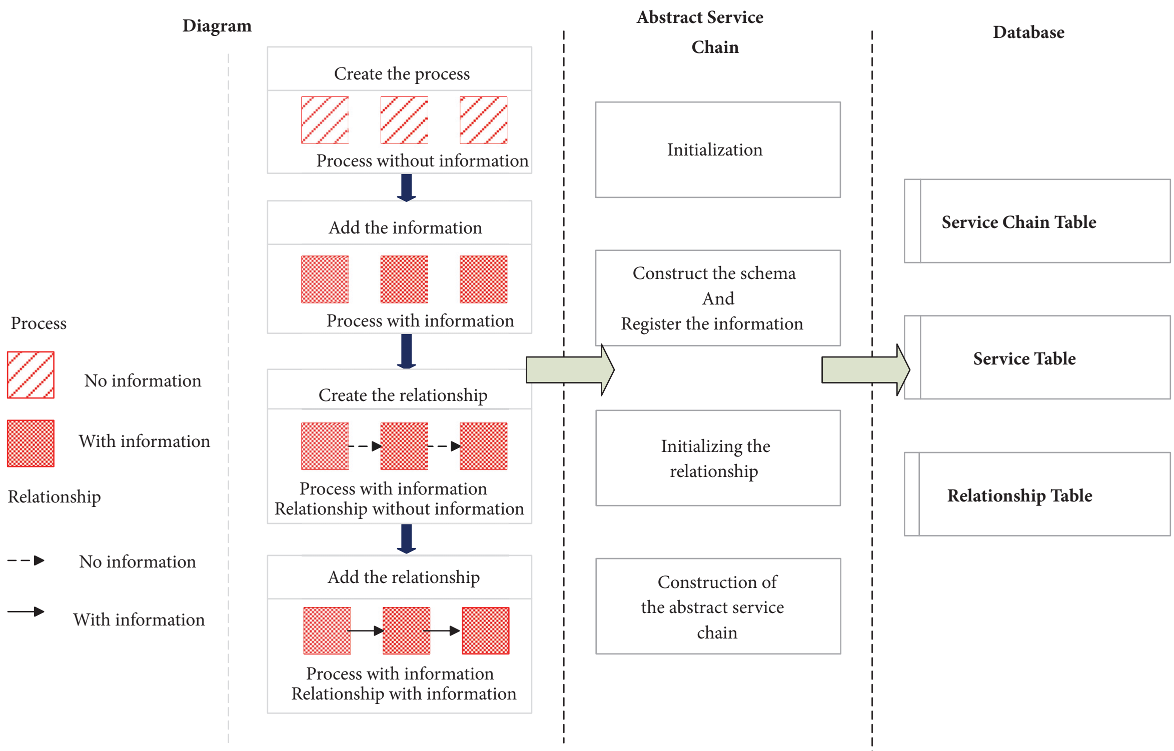

Figure 4: Construction of the abstract service chain.

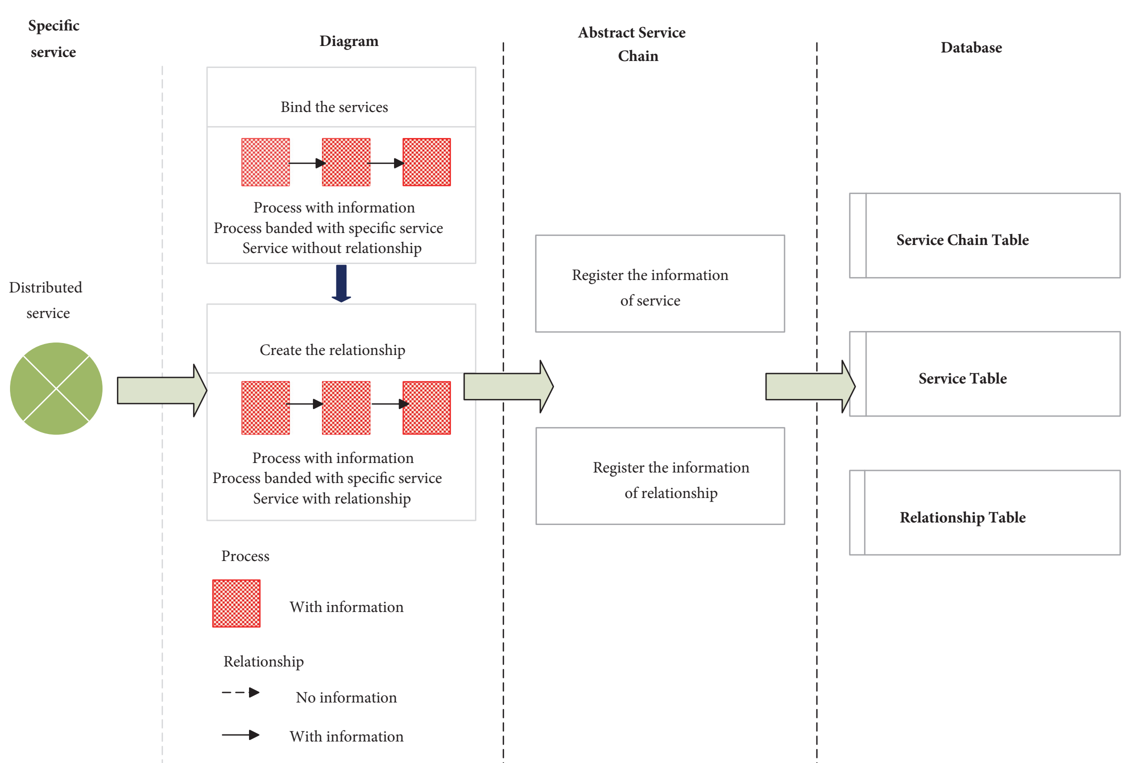

Figure 5: Construction of a specific service chain based on the abstract service chain.

Table 4: Different rules for different query parameters.

Query parameter	Rule
Service type	Rule 1
Spatial range	Rule 3, Rule 2
Temporal range	Rule 4, Rule 2
Title	Rule 5, Rule 2
Service type, spatial range	Rule 3, Rule 6, Rule 1
Service type, temporal range	Rule 4, Rule 6, Rule 1
Service type, title	Rule 6, Rule 2
Spatial range, temporal range	Rule 3, Rule 4, Rule 2
Spatial range, title	Rule 3, Rule 2
Temporal range, title	Rule 4, Rule 2
Service type, spatial range, temporal range	Rule 3, Rule 4, Rule 6, Rule 1
Service type, spatial range, title	Rule 3, Rule 6, Rule 1
Service type, temporal range, title	Rule 4, Rule 6, Rule 1
Spatial range, temporal range, title	Rule 3, Rule 4, Rule 2
Service type, spatial range, temporal range, title	Rule 3, Rule 4, Rule 6, Rule 1

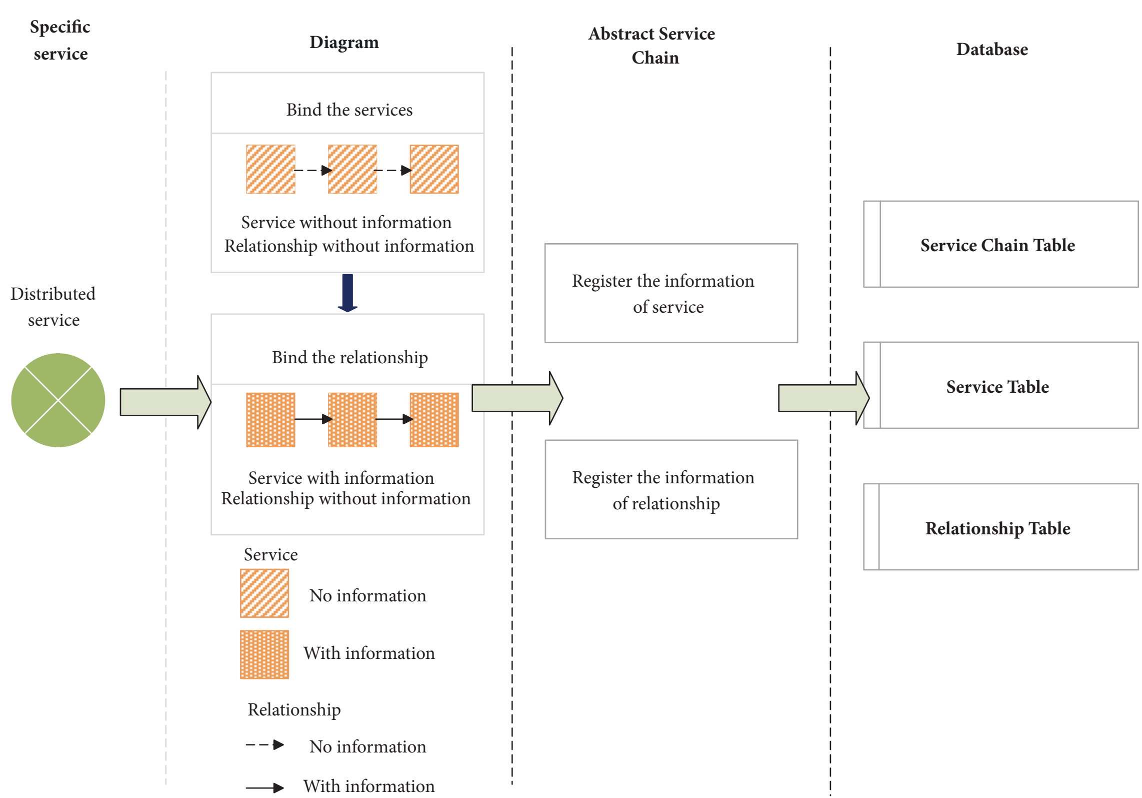

Figure 6: Construction of a service chain based on specific services.

Rule 5. Relationship from "Layer," "Feature," "Coverage," and "Observation" to "Title."

Rule 6. Relationship between "CategoryName" and "Thing."

The query parameters (the service type, spatial range, temporal range, and title or their compounds) and its corresponding rules are illustrated in Table 4. For example, when query parameters are spatial range, temporal range, and title, the instances of "CategoryName" and "Thing" are found with Rule 6 and then the Time instances as specified by the data property of the instance of "Thing." Then, the Time instance of "Title" with the instances of "Thing" and Rule 4 are found. At last, the BBox instance of "Title" with the instances of "Thing" and Rule 3 are found, as well as the instance of "Profile" with Rule 1, and thus the URL of the web service was found.

2.4.3. Semantic Spatiotemporal Reasoning Rules for Service Composition. The service composition method selects the

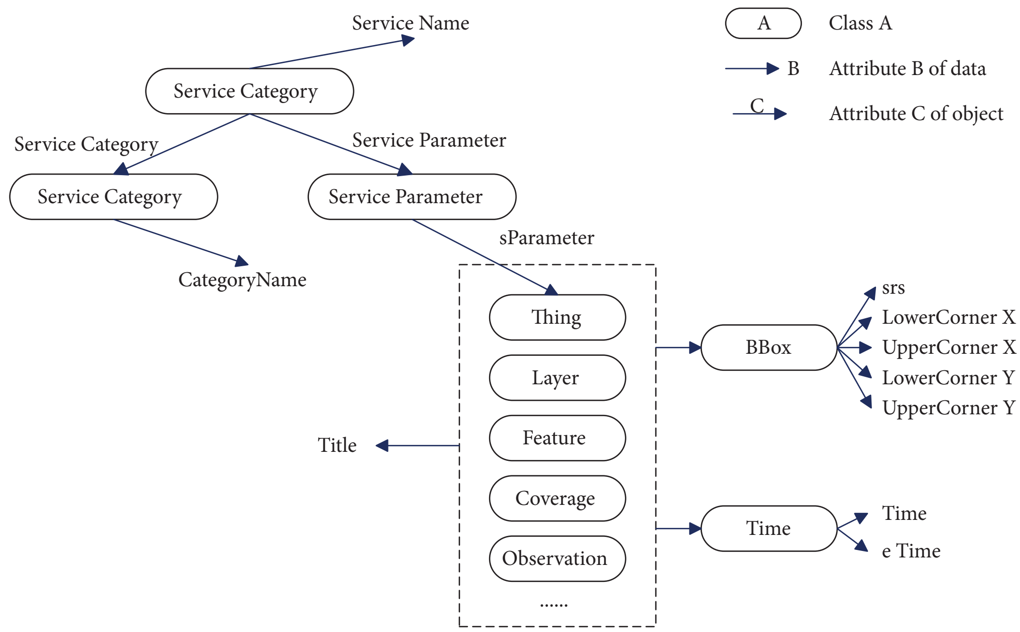

Figure 7: The query model based on OWL-S reasoning.

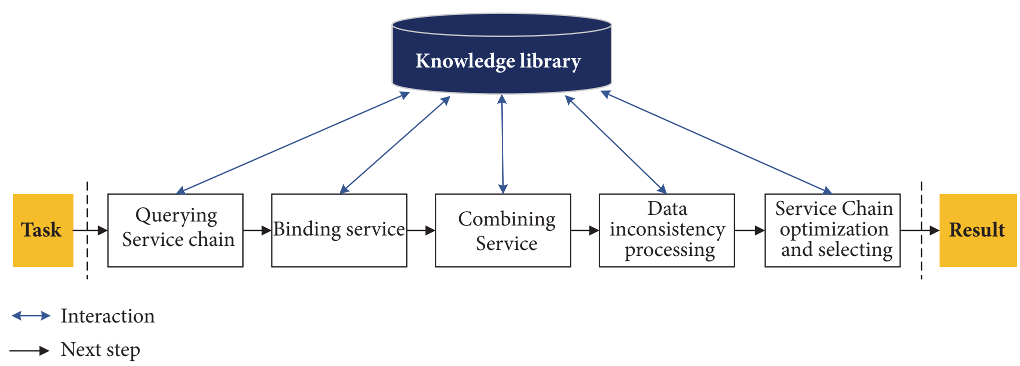

Figure 8: Workflow of semantic reasoning of GKS composition.

suitable services from a number of service sets and combines these services automatically in accordance with their inherent rules. The artificial intelligence and the workflow generation approach are employed to realize intelligent service compositions. To obtain the results of a specific task, there are 6 steps in Figure 8: (1) Query the service chain or single service from the knowledge library, according to the demands of the task. (2) Bind the abstract service with a specific service if necessary. (3) Combine the services and convert instances of the services to form a combined executable service. (4) Process data inconsistency. Adjust the compositing processing of web services to deal with the data inconsistencies among different services. (5) Optimize and select service chain. Find the optimal composition of services from the multiple possible permutations for services composition. (6) Output the results.

The reasoning method used in this workflow includes the service chain selecting inference, service binding inference, service compositing inference, inconsistency eliminating inference, and service optimal select inference.

(1) The main goal of the service chain selecting reasoning method is to match the task, queries, and the usage of the service or service chain, including semantic matching and matching based on grammatical keywords

(2) The binding service reasoning method combines the service chain with the service instances and the abstract service chain with specific services automatically, instead of relying on human interaction. The reasoning method is similar to the service chain selecting method, mainly through the grammatical keyword matching between the name of the service and the instance. When the process is successful, the chosen services are banded directly; but if it fails, it is necessary to check for another matching service in the semantic knowledge library

(3) Service composition reasoning transfers the semantic chains to an executable workflow chain. Since the service is operated through an interface, three basic composition relationships between two interfaces are proposed. The first one: if the output of a specific operation in an interface is part or all of the input of another interface, indicating

Table 5: Data inconsistency table.

data1	data2	Data inconsistency
Vector data	Raster data	Data type
Raster data	Vector data	Data type
Vector data	Vector data	Coordinate system
Raster data	Raster data	Coordinate system
		Resolution
		Data format

these two interfaces are associated. The composition of these two interfaces have to obey the specific order. The second one: if the input of an interface is the outputs of both interfaces, the two interfaces have to work together to form a collaborative relationship. The third one: based on these composite relationships, multiple web services are integrated for each task

(4) Data inconsistency processing forms the data flow of the service chain. Two commonly used data types in GIS and remote sensing (RS) are vector and raster data. Data inconsistencies of GIS and RS are shown in Table 5.

A transformation service is employed to overcome data inconsistency, which includes data type transformation, coordinate system transformation, data format transformation, and resolution transformation. In order to solve this problem automatically and achieve the data transformation, a metadata model is proposed, which consists of data type (DT), satellite/sensor type (ST), coordinate system (CS), resolution (RE), and data format (DF)

(5) The service optimal select reasoning method intends to improve efficiency by choosing and optimizing the integration processes of the web services needed. For example, if a task has many web service composition schemes, the objective is to determine the scheme with the minimal cost. Zeng et al. came up with five generic quality criteria for elementary services including execution price, execution duration, reputation, reliability, and availability [41]. They also selected a global optimal execution scheme. According to the features of GKS, the global optimal execution time is the primary consideration. The final service chain schemes are the outputs of the workflow. The process of reasoning rule is as follows: (1) Query the relevant abstract service chains through the semantic query. (2) Bind the corresponding services to the service chains. This process might link to other services. Thus, a variety of possible specific service chains might be formed. (3) Calculate the cost of different schemes, and then choose a specific service chain to perform the task

3. Application in Environmental Monitoring on AQI and SM

As serious environmental problems emerge frequently, this has become harmful to human health and caused amounts of economic loss. Government officials and citizens have been paying more attention to air quality than ever before. The availability of environmental monitoring data could offer useful information and rapidly respond to environmental events. And the comprehensive knowledge is vital for officers to propose a proper and efficient management plan and schema. This section focuses on the application of GKS in environmental monitoring.

Air pollution is a well-known environmental problem in the whole world, where the Air Quality Index (AQI) and Air Pollution Index (API) are two common indexes to reflect the air quality. Soil moisture (SM) is an important environmental indicator for studying climate change, indicating the degree of agricultural drought, and guiding agricultural irrigation. Monitoring the SM conditions in the whole experiments will assist the decision-making of the drought degree in the area. Air quality and soil moisture monitoring are explored in Wuhan, China.

The governmental agency named Wuhan Environmental Monitoring Centre established some environmental monitoring stations and deployed many sensors in Wuhan to monitor SO_2, NO_2, PM10, CO, O_3, and PM2.5 pollutants. As to SM, an automatic observation station with more than 20 soil moisture sensors was deployed in horizontal planes in a 20 m × 40 m experimental area (center location at 114°31′ 35. 61″E 30°28′ 12. 98″N) in Baoxie town, Wuhan.

3.1. Publishing Prior Knowledge as a Service.

The computing of the AQI and SM is published as a service in the platform, which is implementation with Sensor Web technologies by the Sensor Web Group of Wuhan University, China [42, 43].

(1) Air Quality Index (AQI). The United States Environmental Protection Agency has released a guideline for standardizing the AQI, individual AQI calculation methods, and category descriptors. The calculation method was illustrated as follows:

$$\mathrm{AQI} = \mathrm{MAX}\left(I_1, I_2, \cdots, I_n\right) \tag{1}$$

$$I_P = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{LO}}\left(C_P - BP_{LO}\right) + I_{LO}, \tag{2}$$

where I_P is the exponent of the value of pollutants, C_P is the floor of the value of pollutants, BP_{HI} and BP_{LO} are the upper breakthrough value and the lower breakthrough value of C_P, respectively, and I_{HI} and I_{LO} are the corresponding AQIs of BP_{HI} and BP_{LO}.

(2) Soil Moisture (SM). The deployed soil moisture sensors only monitor discrete points in the area, and their number is limited. Inverse distance weighted (IDW) interpolation was adopted to interpolate values at unobserved points in the experiments. The IDW interpolation is under the assumption that the attribute value of a point is weighted related to the values of its neighborhood, and the weights are inversely related to the distances between the predicted location and the sampled locations.

Assume the sampled point is represented as $P_n = \{x_n, y_n, v_n\}$, where x_n, y_n are its location information and v_n is its attribute value. For the required interpolation point $P = \{x, y, v\}$, if x and y are known, v can be calculated using the equations below.

$$v = \sum_{i=1}^{n} w_i v_j, \quad (3)$$

where v is the SM value, v_j is the SM value of the neighbor point j, n is the number of the neighbor points, and w_i is the weight calculated by using the following equation:

$$w_i = \frac{1/d_i}{\sum_{i=1}^{n}(1/d_i)}, \quad (4)$$

where the distance d_i is calculated by

$$\mathrm{d}_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}. \quad (5)$$

According to the method introduced in Section 2.2, the calculation of AQI and the interpolation of SM were published as a web service. The sensors were registered into Sensor Observation Service (SOS) [44], and then the data from the sensors were inserted into SOS. The input of the AQI calculation service is the observed concentration of various individual pollutants, and its data format is observations and measurements (O&M). The input of the SM interpolation service is the value of the observed point and the regional grid image, in which the observation data format is O&M, and the output result is raster data with soil moisture data in each grid.

3.2. Semantic-Enhanced Knowledge Service. As introduced in Section 2.2, the service configuration file, service model, and services infrastructure are used to realize the semantic enhancement of web services. Supported by OWL-S, semantic annotations (e.g., title, parameters, temporal range, and spatial range) are added to all of the Sensor Observation Service, the AQI calculation service, the soil moisture interpolation service, etc.

3.3. Task-Oriented Services Recombination in a Service Chain. GKSs and service chain are supposed to register on the content library and knowledge library, respectively.

The AQI service chain includes standardized AQI and IAQI calculation service. According to the service chain regularization method introduced in Section 2.4, the AQI calculation can be described as SC={ID, S, R, MD}, where SC is the AQI monitoring service chain, ID is a globally unique identification assigned by the program automatically, and S is the set of services, including the observation service of SO_2, NO_2, PM10, CO, O_3, and PM2.5. The relationship set R={C, S} consists of the collaborative relationship among the observation services and the sequential relationship between the observation service and the AQI calculation service.

The SM monitoring service chain contains interpolation and cartography service; it can be expressed as SC= {ID, S, R, MD}, where SC is the SM monitoring service chain, R={C} is the sequential relationship between the interpolation and the cartography service, and MD is the corresponding metadata.

3.4. Results and Analysis. The air quality monitoring experiment started from 2014-09-08 14:00 to 2014-09-10 15:00; and for soil moisture, it was from 2014-07-05 to 2014-07-07. The data used in this experiment was provided by the Wuhan Environmental Monitoring Centre.

Firstly, the AQI and SM monitoring service chain were queried from the knowledge library. The queried service chains are the combination of abstract and specific services. Queried by the keywords "the air quality of Wuhan city from 2014-09-08 14:00 to 2014-09-10 15:00" and "the soil moisture of Baoxie in Wuhan city from 2014-07-05 to 2014-07-07," following the reasoning method introduced in Section 2.4, the air quality monitoring service of Wuhan and the soil moisture service of Baoxie were achieved, as shown in Figures 9-10 (created from MapWorld: http://www.tianditu.cn/).

As can be seen in Figures 9-10, the refresh rate is 10 seconds. Real time environmental data are measured by three air quality indicators including AQI 1, PM2.5, and PM10. Information of sensors contains name, expected application, work status, keywords, loading sensors, organization, schema, detailed information, and so on. According to the 24 h AQI line graph, the value of AQI peaked at approximately 190 between 15 pm to 17 pm since this period of time is the normal commuting rush hour in China. And the value of the AQI reached the lowest point around 22 pm in Wuhan, China. Compared with the 48 h AQI line graph, the value of the AQI shows the same trend. And different indicators are used to measure SM. The user can choose different time periods to visualize the temporal observation of SM.

The specific observation service and processing service were banded together to achieve the optimal service chain. And the air monitoring and SM monitoring results were shown in Figure 11. The user has to choose the temporal range and quarrying time at first, and then the corresponding status of the map can be seen on the monitor. The information sensor includes Num, Sensor, Platform, Value, and Time. And each piece of sensor data can be visualized as a scatter graph.

4. Conclusion

In this paper, a novel method is proposed to promote the geospatial service from information to knowledge with spatiotemporal semantics. Both prompted and professional knowledge are further refined to be published as a service. In terms of an exact task, several related services are recombined to a service chain by using spatiotemporal enhanced reasoning under user requirement. An air environmental and soil moisture monitoring application was equipped in Wuhan, China, and proved the flexibility of GKS and successfully reached satisfaction. However, due to the complexity and comprehensive nature of GKS, the related theory should be improved, for example, the method for constructing GKS domain ontology. The reasoning method proposed in this paper still needs the prior knowledge and is not fully automated and intelligent. Thus, importing artificial intelligence technology to GKS is our next step.

Data Availability

The AQI monitoring and SM data used to support this study were supplied by Wuhan Environmental Monitoring Centre

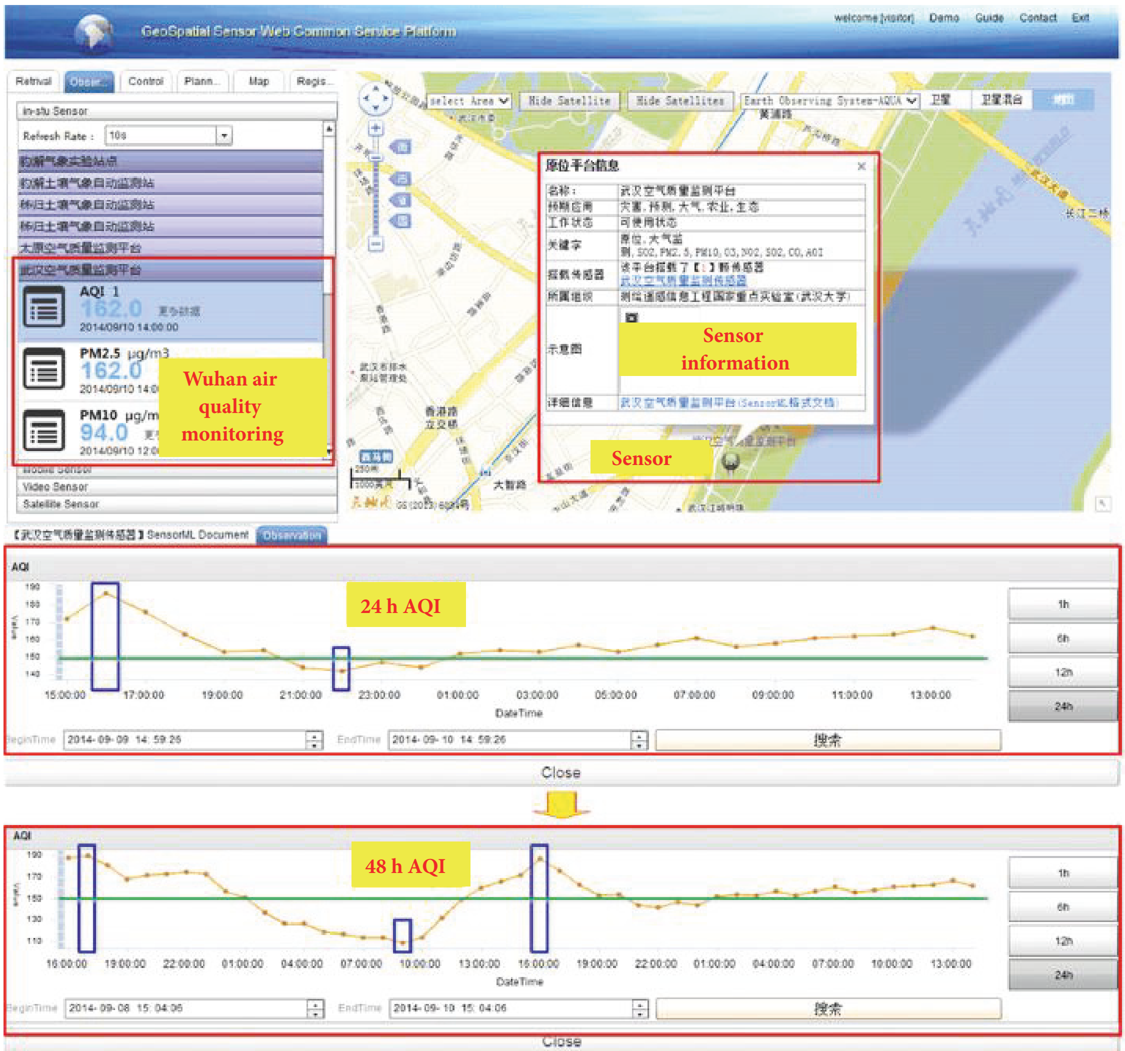

FIGURE 9: Air quality monitoring.

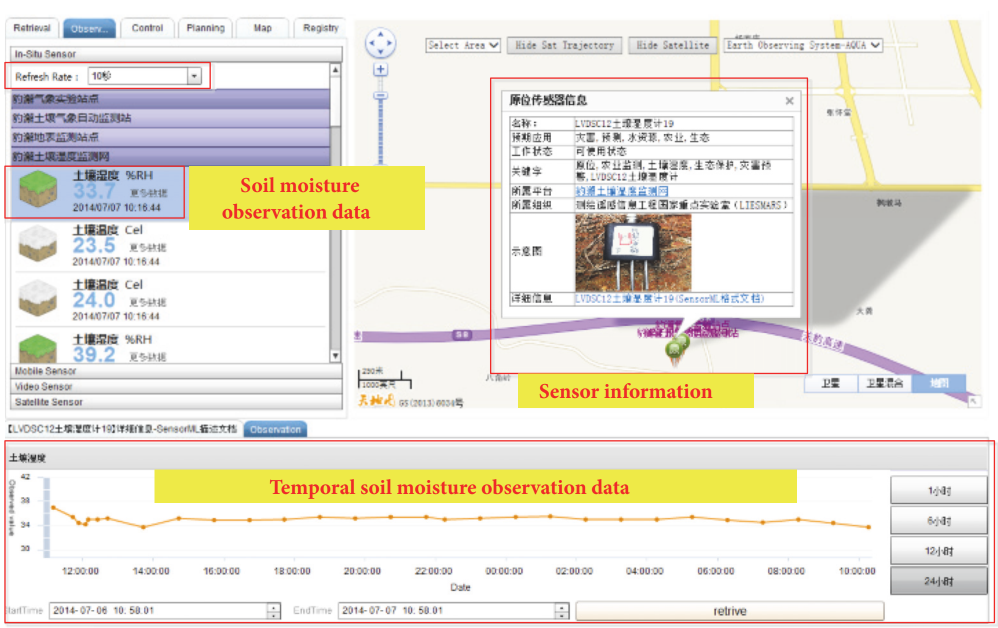

FIGURE 10: Observation of soil moisture.

Figure 11: Air monitoring and soil moisture monitoring results.

under license and they are not available. Requests for access to these data should be done through contacting Wuhan Environmental Monitoring Centre, Tel. + 86 27 85805108.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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