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Space-based information service in Internet Plus Era

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Abstract "Internet Plus" represents a new form of society that provides a vast platform for reform, innovation, and development. Given the continued integration of the Internet in many fields, Internet Plus is profoundly transforming and influencing a variety of traditional industries. Internet Plus has created conditions favorable for the transformation of earth observation and satellite navigation into an intelligent and real-time geospatial information service. The authors propose that in order to implement continuous, all-weather, all-terrain services for the specific purposes of each individual, it will be necessary to overcome the flaws in existing space-based information systems, such as limited regional coverage, slow response, and weak interoperability. Furthermore, to meet the Big Data Era's geospatial information service requirements, an "Internet Plus Space-Based Information Service" system, intrinsically linked to ground Internet networks, will have to be constructed. With reference to the developments of aerospace information technology, this paper discusses three levels of the proposed structure of the Internet Plus space-based information service system and ideas for its implementation. Finally, in recognition of the demands facing the Internet Plus space-based information service system, the prospects for geomatics and important supporting technologies are examined.

Keywords Internet Plus, space-based information service, space information network, satellite remote sensing, satellite navigation, satellite communication

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1 The rise of Internet Plus

During two sessions in March 2015, Deputy Huateng Ma of the People's National Congress submitted the motion "Using Internet Plus to Drive the Forces Advancing China's Economic and Social Development and Innovation," which attracted widespread attention. Internet Plus represents a new form of society that provides a vast platform for reform, innovation, and development. By exploiting the capability of the Internet to improve, allocate, and share social resource distribution, Internet Plus considers the Internet as an essential infrastructure and tool necessary for economic development. Specifically, in the Internet Plus Era, the Internet of things, cloud computing, and big data will help integrate the Internet with traditional industries, creating a new environment for eco-social development. The continuous

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integration of the Internet with traditional industries such as online financial services, television streaming, electronic mapping, real-estate listing, remote monitoring of health care, consulting, travel, and tourism, demonstrates that a variety of industries are embracing the Internet and being influenced by it.

The Chinese government is highly committed to the development of Internet Plus. During the third session of the Twelfth People's National Congress held on March 5, 2015, Premier Keqiang Li discussed the plan for the Internet Plus Campaign for the first time. Subsequently, on July 1, 2015, the State Council issued "Guidelines on the Internet Plus Campaign," that specifically mentioned that "enhancing the global serviceability of the BeiDou satellite system, constructing integrated space-ground interconnected networks," and "making full use of multidimensional GIS (geographic information system), intelligent maps, and other technologies to build stereo monitoring systems of resources and environment carrying capacity," would raise the expectations of China's next generation of space-based information service systems.

Internet Plus will help satellite navigation and earth observation industries create popular and widely applicable real-time services. Therefore, we should vigorously promote the various levels of Internet Plus space-based information services, and make the satellite navigation, remote sensing, and communication sectors bigger and stronger in order to meet the demands of national defense, economic reconstruction, and public life.

2 Opportunities and challenges of Big Data Era's geomatics

In the Big Data Era, instrumental acquisition of geoinformation will expand from professional space-air-ground-based sensors (e.g., satellites, aircraft, and unmanned aerial vehicles) to billions of non-dedicated sensors such as smartphones and urban video surveillance cameras connected to the Internet of Things [1, 2]. Currently, the number of orbiting satellites exceeds 1000 with over 500, 120, and 140 deployed by the United States, the Russian Federation, and China, respectively. Furthermore, the number of manned and unmanned aircraft is over 10000 worldwide, and especially in recent years, there has been a rapid increase in the number of UAVs. Land-based mobile measuring systems and smart cars total over three million globally, and smart monitoring sensors are ubiquitous in most cities. According to statistics, the number of video surveillance cameras has reached more than 20 million, and the numbers of active smartphones and smart-type watches are in billions. These devices are all equipped with temporal data communication, global positioning, navigation, photographic, video, and transmission functions. They are able to provide large amounts of Peta Byte, even Exa Byte, level continuous imagery [2], which if used, would greatly improve the capability of geomatics data acquisition.

It can be predicted that in the Big Data Era, the application of geomatics will become increasingly omnipresent, expanding from expert use to global public use. Geomatics will face challenges associated with data volume, velocity, variety, and veracity. However, it is often difficult to extract useful information from large datasets, resulting in a situation of "massive data, missing information, and unavailable knowledge" [3]. Existing space information services cannot reach the level of performance of delivering the correct data, information, or knowledge to the right person at the right place in a timely manner [4]. Despite the advent of the Big Data Era, the procedures and content of spatial information services need innovation.

China's existing space-based information services operate in isolation and cannot satisfy military and civil demands. On one hand, China's demand for space-based information coverage has expanded from domestic to global use, and the speed of the spatial information service chain, from acquisition through transmission to processing, has shown an increasing trend. On the other hand, China's existing communications, navigation, and remote sensing satellite systems are independent. China's existing satellite navigation systems can only provide position "points" and road "path" information, and they omit other elements such as geographical changes and relationships, and real-time observation images (video) that represent the "surface". Satellite navigation data communication services rely primarily on dedicated terminal devices (e.g., the BeiDou terminal) or on terrestrial mobile communication networks. Such systems have limited communication capacity and speed, and they cannot transmit vast amounts of information in a timely manner. Operational and service isolation means that systems have difficulty meeting the majority of the Smart Earth Era's military and civilian needs, and it is difficult to achieve market orientation and raise international competence.

3 Proposing Internet Plus space-based information services

To provide global, continuous, all-weather services, it will be necessary to overcome the defects of existing space service systems, such as the limitations of coverage area, slow response, and weaknesses of systematic interoperability. As well as meeting the Big Data Era's geospatial information service requirements, the authors believe a network that couples the ground-based Internet network with a space-based real-time information system should be planned systematically, according to China's national needs and technological capabilities.

First, the development of China's space technology has made significant achievements that can offer great technological support for the construction of an integrated Space-Based Information System. Since the founding of the People's Republic of China, and especially in the last 30 years, China's space industry has produced considerable achievements, such as the development of a complete satellite system including remote sensing, communication, and military monitoring satellites. In particular, through the high-resolution earth observation system, second-generation satellite navigation and positioning system, manned space flight and lunar exploration project, and other ambitious national projects, it is believed that China's space technology will become increasingly competitive internationally in the next few years.

The Internet Plus space-based information service system is intended to implement an integrated service that incorporates satellite remote sensing, navigation, and communication and Internet access, to provide continual geospatial information acquisition, high-precision positioning and navigation, and multimedia communication services to global users. It will also form a new global space-borne augmentation system for China's BeiDou system, which could greatly improve real-time navigation precision without reliance on ground Continuously Operating Reference Stations (CORS). In line with the principles of "one satellite with multiple functions, multi-satellite networking, and multiple network cooperation," the space-based network with remote sensing, navigation, and communication functions could be integrated seamlessly with existing ground-based Internet and mobile networks. With the support of spatiotemporal Big Data, cloud computing, and intelligent terminals for space-based information services, all sectors of the national economy, industry, and the vast majority of public users would be provided with rapid, accurate, and intelligent positioning, navigation, timing, remote sensing, and communication services in real time [2].

4 Three levels of the Internet Plus spaced-based information service system

Given the level of domestic and international technical development, the authors believe there are three different levels in the Internet Plus Space-based Information Service system.

4.1 Primary stage—Web GIS

The main feature of Web GIS is that it processes different types of geographic information and distributes them via the Internet, providing fundamental geographic references to various kinds of applications. Web GIS is an Internet-compatible computer system that can store, process, analyze, apply, and display geographic information. It is a cooperative product incorporating Internet, web, and traditional GIS technologies [5]. Its basic starting point is to use the Internet to publish geographic information, allowing users to retrieve geographic data and functions through their Internet browser. Examples of these programs include Google Maps$^{\mathrm{TM}}$ and Google Earth$^{\mathrm{TM}}$, China's World Map, and electronic maps provided by major portal websites. Since the late 1990s, modern society has stepped into the Digital Earth [6, 7] and Digital City [8] era with the support of Web GIS technologies. China has already built its own Digital China and Digital City infrastructure framework. The National Administration of Surveying,

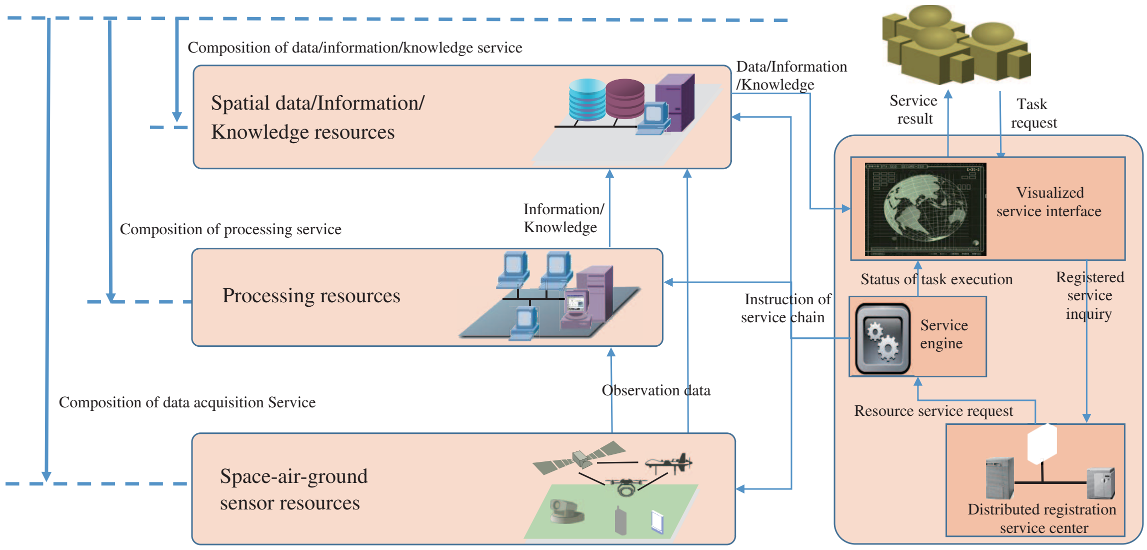

Figure 1 Task-oriented geospatial service.

Mapping, and Geoinformation of China issued a "World Map" in 2010 [9], which became an important carrier of Digital China and Digital Cities information. The electronic map and location-based service (LBS), supported by Web GIS, work cooperatively with e-commerce, vehicle navigation, logistics, and other industries and play an increasingly indispensable role in people's daily work and lives.

In this initial stage, the spatial information service flow can be described as follows. First, various types of earth observation data can be received and preprocessed by ground stations. Second, useful information can be extracted through specific application software. Finally, the spatial information products and services can be distributed to users via the Internet. At this stage, there is an urgent demand for an automatic space-earth observation data processing system and a considerable amount of research has been focused in this direction [10]. However, the service mode of Web GIS has obvious drawbacks, e.g., the currency of the information distributed by Web GIS cannot be ensured because the information processing procedure is offline and not in real time. Therefore, at this stage, Web GIS cannot guarantee the complete accuracy and currency of the geospatial information service.

4.2 Intermediate stage—sensor network-based GIS

The intermediate stage is the main form of the current space-borne information service system. The main feature of sensor network-based GIS is that it implements online accessing of satellite and other sensor data through a sensor network [11, 12], allowing spatial information services based on cloud computing. Various types of data acquisition, data processing, network, data storage, and geo-knowledge resources are combined in an integrated service model under an integrated GIS framework (see Figure 10 in [13]). After a registration procedure [14] is implemented via distributed registration centers, the sensor network-based GIS can organize these resources to implement multiple sensor scheduling, data processing, information extraction, and knowledge discovery based on this distributed network, providing task-oriented geospatial services (TOGS) to users with different needs.

By extending the connotation of the service, data resources, processing resources, sensor resources, and network transmission resources, all referenced resources are organized by the TOGS mode. The essence of TOGS is to gather distributed service resources with small granularity according to users' needs to provide larger and more complex value-added services to meet the individual requirements of different tasks. The TOGS mechanism consists of two processes: on-demand composition of resources and collaboration of services. On-demand composition is the process of discovering, aggregating, and organizing resources, while collaboration of services is the process of interaction and cooperation of multiple atomic services to accomplish a common task.

The TOGS procedure can be summarized as follows (Figure 1). Once a service demand is committed

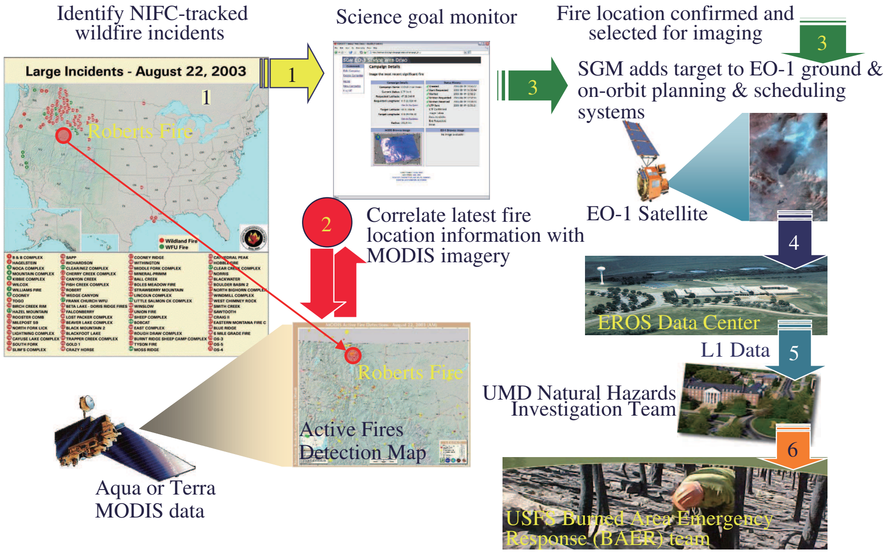

Figure 2 Sensor network application in fire disaster.

via a visualized service interface, the registered service resources will be queried in the registration center. Then, the service engine will generate an instruction of service chain by matching the capacity of registered resources and service demands. Next, the resources will execute the service according to the instructions, including data acquisition, data processing, and transmission. Finally, the customized result of information service will be returned to the users through the visualized interface.

In 2003, the area of Roberts in the northwest of the United States experienced a fire disaster. Sensor network technology was used for disaster monitoring and assessment (Figure 2). First, the sensor network accessed MODIS data because the MODIS satellite had high temporal resolution and vast aerial coverage. After rapidly identifying the location of the fire by analyzing the MODIS data, the network scheduled other high-resolution satellites such as EO-1. Then, greater information about the fire was acquired by processing the high-resolution images from these satellites. Finally, ground-based site surveying was conducted to investigate the losses attributable to the disaster. The application of the sensor network changed the mode of space-borne information for disaster response from static surveillance based on archived imagery to dynamic task-oriented monitoring via the space-air-ground sensor network [15].

The sensor network-based GIS service model is shown in Figure 3. In this model, air-ground sensor data nodes (including in situ sensors, unmanned aerial vehicles, and satellite sensor nodes) and various types of data processing nodes are organized as different network services under a framework that comprises sensor information models and interface specifications. There are four information models (Sensor Model Language Sensor Marker Language, Observation and Measurements, Common Data model, and Event Pattern markup Language) and five service interfaces (Sensor Planning Service, Sensor Observation Service, Sensor Alert Service, Sensor Event Service, and Web Notification Service). In this framework, data processing nodes are responsible for various data processes and information extraction, including network coordinate transformation, network processing, and network coverage services. All the different types of services are registered in the Web Service directory. According to the specific task, clients can combine a variety of services to form a service chain, and the results obtained will be rendered through the network map service. This model implements task planning of various sensors and task-oriented processing of multiple streams of earth observation data.

A research team from Wuhan University, China, used sensor network technology to develop an ecological management system for the Yangtze River. Since the 1980s, conflicts have arisen between the hydropower development and the flood control and navigational requirements on the Yangtze River. The Three Gorges Reservoir and other reservoirs are expected to discharge water when necessary to prevent flooding. From the perspective of power generation, the reservoirs are expected to operate through impoundment. Therefore, reconciling the contradiction between flood control and power generation on

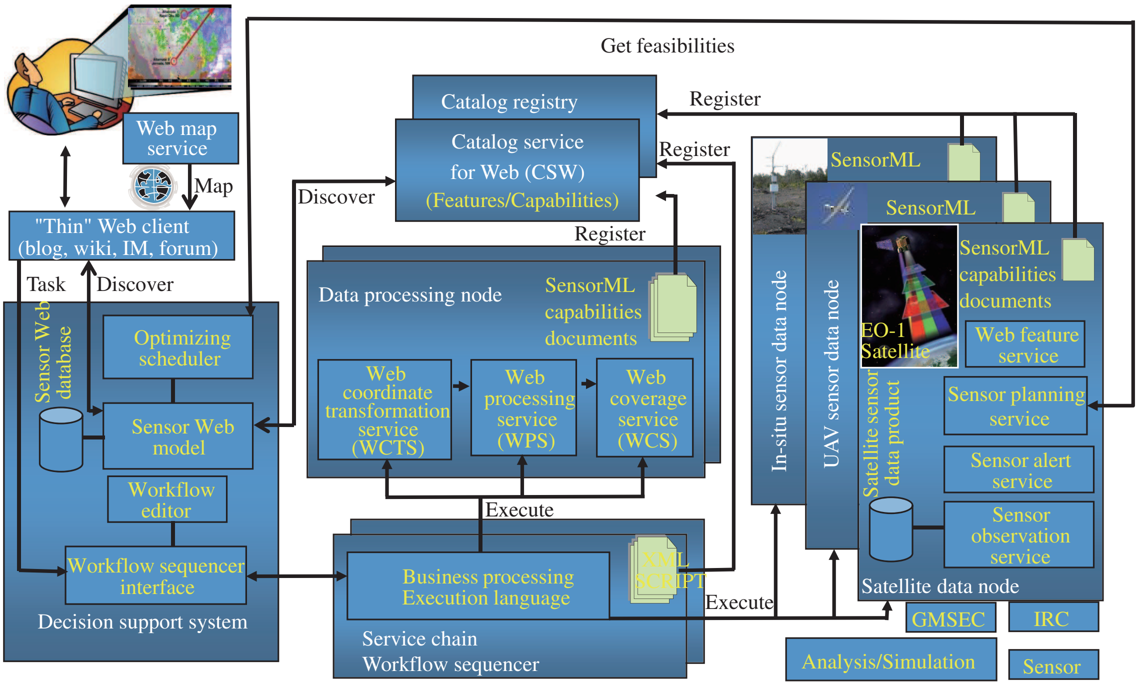

Figure 3 Sensor network-based GIS service model.

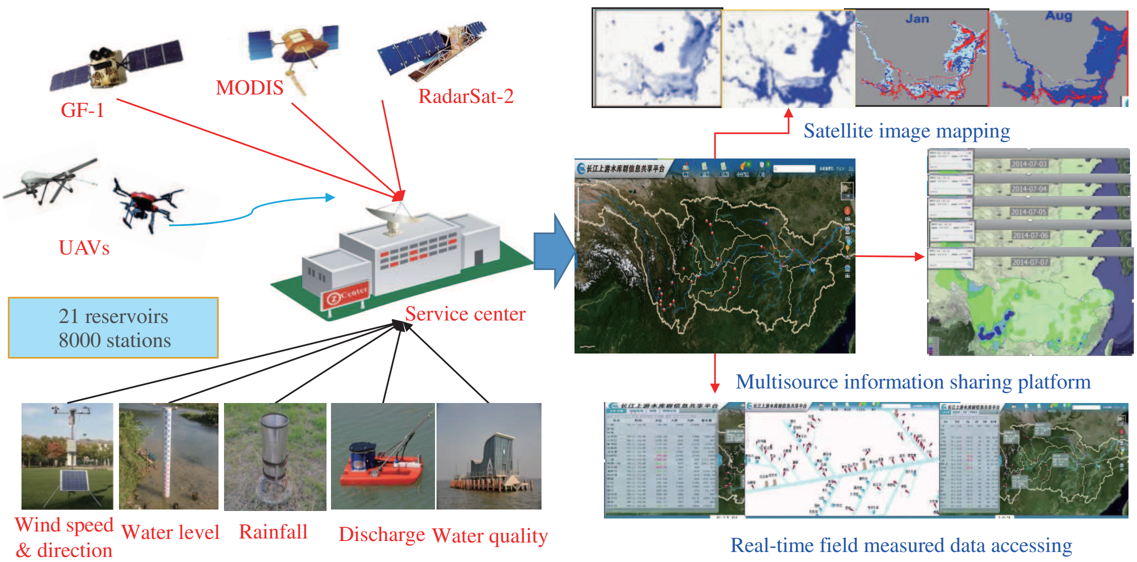

Figure 4 Intelligent ecological environment sensory management system of the Yangtze River basin.

the Yangtze River under the premise of ecological environment security has become a major challenge. Through sensor network based GIS technology, the Wuhan University team integrated 32 different types of sensors, including hydrological, meteorological, soil, and navigational aids totaling tens of thousands of devices (Figure 4), to construct a network for monitoring the ecological environment of the Yangtze River mainstream [16]. This network has been applied to the regulation of power generation, flood control, and channel management of the Yangtze River.

With the help of the ecological environment monitoring network, the operators of the Jinsha River (alias for the upper Yangtze River) cascade hydropower station are able to acquire real-time hydrological and sedimentation data. Furthermore, the operation mode of scouring and silting in the Luoxidu and Xiangjiaba reservoirs has changed from a scheduled to real-time (dynamic/responsive) basis. During the flooding seasons of 2013–2015, they impounded 0.8, 1.6, and 1.8 billion cubic meters of water in advance,

Table 1 Effects on shipping of the application of intelligent ecological environment management system of Yangtze River

Application scenario	Before application	After application
Navigation aids maintenance mode	Inspection system	Monitoring duty system
Frequency of shallow waterway dimension information publishing	Every 10 days	Every 7 days
Beacon abnormal finding time	Up to 1 day	Up to 10 min
Beacon abnormal recovery time	8 h	2 h
Water level forecast	Once daily or 3 manual readings	Hourly remote sensing report

respectively, resulting in huge economic benefits. A joint flood control and drought relief information system for the reservoirs on the upper reaches of the Yangtze River has been developed based on the above monitoring network. This achieves near real-time sharing and exchange of information for these reservoirs, including water level information, water and rainfall forecast information, and dispatching commands. The information feedback efficiency has improved considerably, and the time delay from data acquisition to data arrival at flood control headquarters has shortened from several hours to 20–30 min. The team has developed a Yangtze River waterway management information systems based on the sensor network, which has significantly improved efficiency, as shown in Table 1.

Another research team from Wuhan University developed a smart web-based remote sensing image retrieval system in a public remote sensing image database released by World Map (Tianditu.com). The system is a joint innovation for deep learning, cloud computing, semantic understanding, and big data. It provides fast, accurate, convenient, and pure online image searching services. The framework of the system is shown in Figure 5.

The system supports three types of content to search: objects, land cover, and scenes. Users can use keywords, human-like language, scratch images, and example images as inputs to execute the image retrieval. When a user submits an image search request, the system can find similar images based on a hybrid similarity measure: the content feature and the semantic relationship feature. To improve the response speed for a large dataset, which is a key factor that affects the user experience, a deep learning-based hash function was developed. With the support of the hash function and hybrid similarity measure, a response time of 0.1 s with high recall and accuracy was achieved for a 10-million-image tile database. The open source code for this hash function, library-LSHBOX, has been released on Github.com for research purposes.

Another typical application of sensor network-based GIS is in taxi reservation software that is used throughout the world. Using a mobile phone equipped with a location sensor, such as a GPS signal receiver, both travelers and taxi drivers can transmit their location data to a dispatching center via the mobile network. This allows the dispatching center to send the traveler's request to the most appropriate taxi driver based on rapid analysis of their mutual locations and the real-time road conditions. With the support of mobile communication technologies, sensor network-based GIS can implement real-time acquisition, sharing, and exchange of taxi and traveler locations.

This service model is a considerable improvement over the primary stage of the space-based information service because it enables real-time integration of web GIS and the space-air-ground sensor network [17]. However, the retrieval and processing of space information such as satellite remote sensing imagery requires specific ground stations. Because of the constraint on the number of available satellites and their transmission capacity, sensor network-based GIS does not currently fulfill the requirement of global real-time resource processing, thus limiting the degree of automation and real-time availability of spaced-based information services.

4.3 Advanced stage—smart sensor network-based GIS

The advanced stage is characterized by its capacity for full coverage of global real-time positioning, navigation, timing, remote sensing, communication (PNTRC), based on the integration of various types of sensor networking, satellite-ground cooperative real-time data processing, fast inter-satellite and satellite-

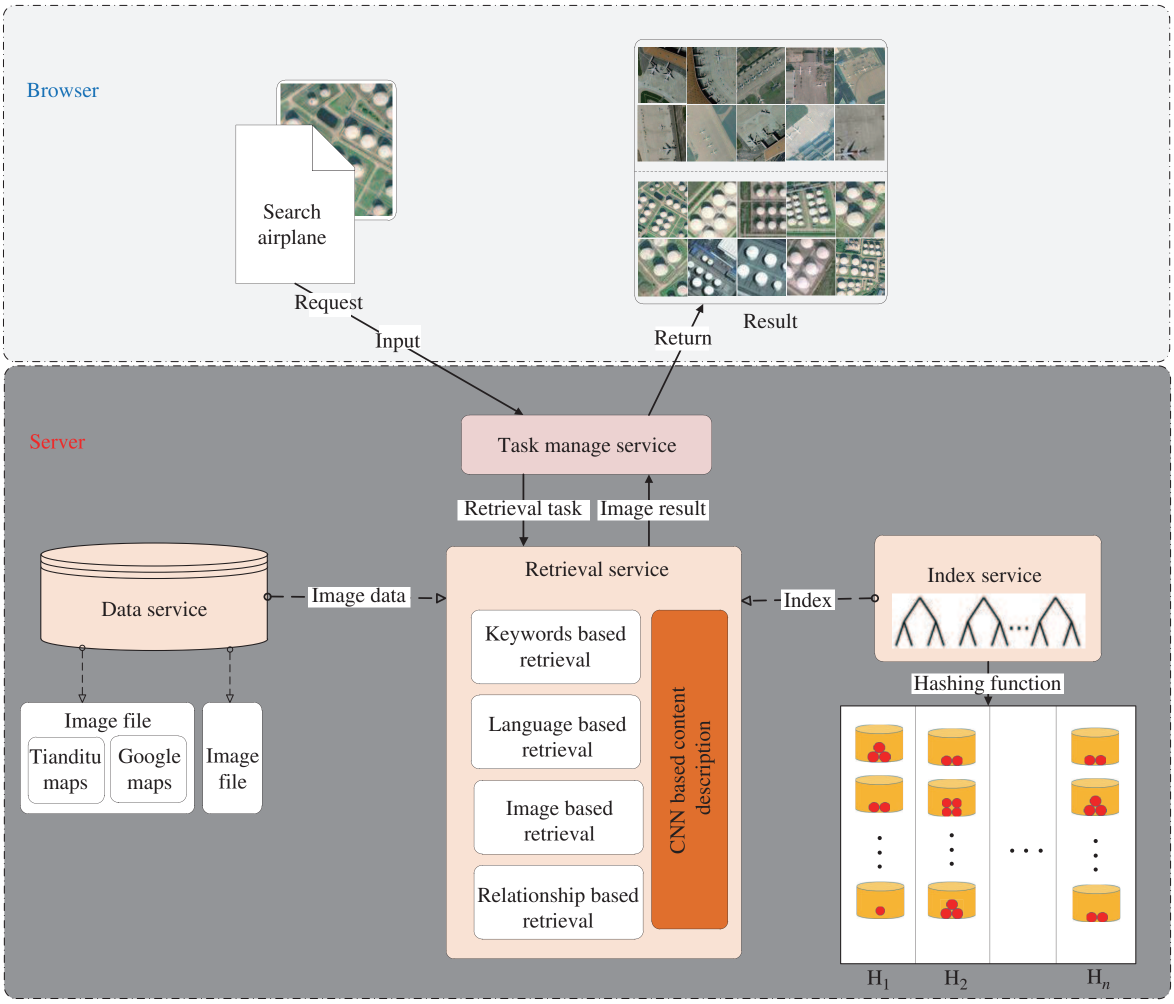

Figure 5 Online image retrieval system in large scale tile-based image database.

ground communication, and task-oriented information service technologies. It can be subdivided into two steps, each of which are discussed next.

4.3.1 *Step 1: space information networks based on an Earth Observation Brain*

Using existing navigation satellites, communication satellites, and other space-based network platforms to build an Earth Observation Brain, collaborative observation and in-orbit processing can be achieved to provide services customized to the users' demands. Using space platforms (including geostationary satellites, low-orbit satellites, stratospheric balloons, and unmanned aircraft) as carriers, the Space Information Network is a new type of network system that implements real-time data acquisition, fast network transmission, and information processing. Through real-time data access/transmission, network interconnection, and cooperative data processing, the Space Information Network can realize the integrated application and collaborative service of satellite remote sensing, navigation, and communication. Currently, China has many major projects based on the theory of the Space Information Network and related research areas.

The Earth Observation Brain is an integration of various types of satellite- and ground-based sensors and data processing systems. It provides functions that include fast data acquisition and processing, as well as information extraction. Moreover, it drives corresponding applications that simulate processes of the human brain such as perception, cognition, and reaction. Research related to the Earth Observation Brain is interdisciplinary, and involves the fields of cognitive and geospatial information sciences, which is an extremely challenging proposition. By developing different levels of the Earth Observation Brain, geospatial information sciences will be able to achieve the automation of three processes: massive geospatial data acquisition (perception of the earth), intelligent spatial data mining (cognition of changes in the rules of the earth), and geospatial data-driven applications (reaction to upcoming changes).

4.3.2 *Step 2: Space-based Real-time Information Service system*

In line with the principles of "one satellite for multiple purposes, multisatellite networking, and multiple network cooperation," a proposal for an integrated space-based real-time information service system was presented. The space-based network is formed by a number (60–100) of low earth orbit satellites with remote sensing, navigation, and communication functions that can be integrated seamlessly with existing ground Internet and mobile networks. Using such a system, the following services can be realized.

1) Location-based services based on real-time data. Through cooperative observation, processing, and fast air-ground information exchange, remote sensing and video data can be received all day, in all weathers, and in near real time. This information can be delivered to a user's mobile phone or to various portable terminals with temporal resolution better than 0.5 h and spatial resolution better than 0.5 m.

2) Space-air-ground integrated communication network with broadband. This can overcome the lack of coverage of ground-based communication networks and provide safe, reliable, and fast communication and data transmutation services to users around the world.

3) Enhanced satellite navigation services. Currently, the BeiDou system has a direct positioning accuracy of approximately 10 m. However, through the use of low earth orbit satellites such as the mobile CORS stations and their integration with fixed CORS ground stations, all types of BeiDou users (including terrestrial mobile users) will be provided with meter/decimeter-level accuracy, real-time navigation, and positioning services.

With the support of spatiotemporal Big Data, cloud computing, and intelligent terminals for space-based information services, all sectors of the national economy, industry, and vast majority of public users could be provided with rapid, accurate, and intelligent PNTRC services in real time. However, many technical challenges must be overcome before this level of real-time Internet Plus space-based information service can be reached. These are: 1) establishment and maintenance of terrestrial spatial data that takes into consideration non-linear variation, 2) space-based Global Navigation Satellite System (GNSS) augmentation, 3) space-air-ground integrated transmission of Geomatics data, 4) in-orbit processing of multi-source satellite imaging data, 5) intelligent information service technique suitable for smart mobile terminal, 6) multi-platform sensor observation mission scheduling and space network security technologies, and 7) design and development of payload-based multifunctional satellite platforms.

5 Conclusion

A space-based information service system integrated with ground Internet will inject vitality and create new opportunities for the development and application of satellite technologies. In addition to enhancing remote sensing, communication, and navigation functions, it will promote the development of real-time location services on behalf of the space-based value-added information services industry, including the creation of mobile terminals and software for the new space-based information service (such as mobile phone APPs), satellite multimedia communication services, and real-time precise navigation and positioning services.

Based on current national demands and the trends of international technological and industrial development, the authors believe that China's Internet Plus space-based information service system could achieve the goals established in the "Initiative to Advance Internet Plus and Suggestions" as well as provide an important step in the implementation of the national strategy for deeper civil and military integration. Because practical service systems have not yet been established in Western nations, China should seize this opportunity and forge the required original technological innovation.

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Conflict of interest The authors declare that they have no conflict of interest.

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