Research and Implementation of Key Technologies for High Resolution Satellite Image Instant Service System

Jin Liu [1], Ye Du [2]

[1] Beijing SatImage Information Technology Co., Ltd, Beijing, China - liujin@satimage.cn
[2] Beijing SatImage Information Technology Co., Ltd, Beijing, China - duye@satimage.cn

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Abstract

With the development of earth observation technology, the application of China's high-resolution satellite remote sensing imagery has achieved high-quality progress. At present, the in-orbit land resource satellites can acquire more than 4,500 scenes of satellite imagery worldwide on a daily basis. As the scale of satellite remote sensing imagery data volume growth explosively, the traditional image processing methods, which are time-consuming and highly reliant on manual intervention, can no longer meet users' demands for high-frequency and large-scale image services. Therefore, it has become an urgent issue to realize the automated production of large-scale satellite remote sensing imagery and provide users with efficient, convenient and real-time image services.
Focusing on the difficulties in the automated and rapid processing of satellite remote sensing imagery and the application of real-time image services, this paper researched on the key technologies including distributed image processing, color stretching, data compression, non-tiling service publishing, as well as tile generation and update. From an engineering perspective, it realized the automatic production of satellite remote sensing imagery, and the generation, management and update of massive tile pyramid data. A satellite remote sensing instant service system was designed and developed, with a daily processing capacity of approximately 800 scenes. The system achieves the daily processing and settlement of China's high-resolution satellite imagery from data acquisition to service publication, providing a guarantee for industrial users to access real-time image services with the latest temporal imagery covering China.

1. Introduction

With the development of Earth observation technology, China's high-resolution satellite remote sensing technique has achieved high-quality development. Currently, in orbit land resource satellites can obtain over 4500 images globally every day. With the explosive growth of data volume, traditional image processing method can not meet users demand for spatial information services with high frequency and large area. Therefore, it has become an urgent issue to realize the automated production of large-scale satellite remote sensing imagery and provide users with efficient, convenient and real-time image services. Solving the technical challenges in instant image services will play an important part in fields such as navigation map data updates, landcover / landuse change monitoring, environmental inspection, deforestation and emergency disaster reduction.

2. Problems in traditional image processing method

With the increasing availability of satellite remote sensing data resources, the production of satellite remote sensing image services involves large-scale image data processing chain. The overall workflow of image service production typically includes steps such as orthorectification, image fusion, color balancing, mosaic, tile generation and service publishing (Huang et al., 2015). Faced with nearly 1 million square kilometers of satellite data obtained and covered in China everday, the challenges of time efficient and cost effective data production are becoming increasingly greater. The traditional process involved a high degree of manual work, as the data volume increases, the time required for data processing also rises, which brought the following issues:

(1) How to perform geometric correction based on distributed image processing message queue.

(2) How to resolve color balance in large-scale satellite imagery without compromising image resolution and color fidelity, while reducing processing steps and accelerating speed.

(3) How to compress data to conserve storage space and increase transmission rates, while maintaining image quality.

(4) How to generate cloud mask to publish an cloudless image service.

(5) How to perform rapid browsing of image data immediately after image processing is completed.

Based on the cloud service, this research focused on key technical challenges such as automated image data processing based on distributed computing, data compression, dynamic tile service based on COG(Cloud optimized GeoTIFF). It aimed to address technical difficulties in massive data processing, fast image service publishing and sharing for applications (Liu et al., 2009).

3. Methodologies

The technologies for rapid processing, real-time visualization and publishing of satellite images constitute a crucial component in realizing the operational mechanism of "real-time production and real-time visualization" for satellite image data.

A cloud-based network system was built relying on cloud services, and the research was conducted on key technical challenges including automated production for satellite image data, lossless slicing technology, multi-level massive tile pyramid image management technology, hybrid static-dynamic tile service technology and data updating under cloud architecture, so as to address the technical difficulties in the production, storage, management, sharing and application of high-resolution satellite image data (Liu et al., 2009).

3.1 Distributed Image Processing Based on Message Queue

RabbitMQ middleware was adopted to realize parameter transmission and allocation of the image processing task queue. The master node was responsible for conducting key steps such as ground control point extraction, block adjustment and orthorectification of panchromatic images, while other processing tasks (including orthorectification of multispectral images, image fusion, and bit reduction) can be distributed to different processing nodes for parallel execution. By leveraging message queues for task distribution, load balancing can be effectively achieved. When the data volume increases, additional nodes can be added for processing, thereby enabling large-scale image data processing.

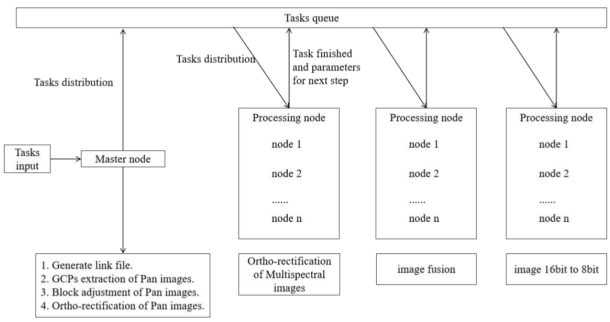

Figure 1. Distributed image processing workflow.

3.2 Stretching Strategies for Chinese Satellite Image Data

In the traditional production process of satellite image data, color balancing and mosaic not only reduce the image definition, but also generate a large volume of intermediate data, which was time-consuming and highly reliant on manual intervention. Based on tests and verifications conducted on a large amount of Chinese high-resolution satellite image data, this paper adopts three steps:

Firstly, performing percentage stretching to the fused 16-bit images and reduced bit depth to 8-bit (see Table 1 for stretching parameters).

Satellites	Min (%)	Max (%)
GF1, GF1B/C/D, GF6	0.001	0.001
GF2, GF7, ZY1E/1F	0.00005	0.00005
ZY3-01/02/03	0.00001	0.00001

Table 1. Streching parameters of difference Chinese satellite image data from 16-bit to 8-bit

Secondly, recalculating the green band of the bit-reduced images to highlight vegetation areas, using the formula:

Green Band = Green Band × 80% + Near-Infrared Band × 20%.

Thirdly, performimg a second round of percentage stretching to enhance the overall color and brightness of the images (see Table 2 for stretching parameters).

Satellites	Min (%)	Max (%)
GF-1, GF-1B/C/D	0.03	0.03
GF-6	0.04	0.04
GF-2, GF-7, ZY1-E/F	0.02	0.02
ZY3-01/02/03	0.009	0.009

Table 2. Streching parameters of difference Chinese satellite image data (second round)

3.3 Compression Algorithms for Satellite Image Data

High-resolution satellite imagery involved massive data volumes, which consumed significant storage and computing resources during browsing and visualization, and thus greatly increased the difficulty of data browsing. To meet the demands of saving storage space and massive data service publishing, real-time service acquisition, transmission and effective visualization, a lossless and high-compression-ratio method was applied for image data compression (Fang et al., 2010).

This paper implemented the comparison between LZW, JPEG and WebP. It has been seen that LZW was a lossless compression format with the lowest compression-ratio; JPEG was a lossy compression format with high compression-ratio; WebP is an image format developed by Google, which supports both lossy and lossless compression and can save a large amount of server bandwidth resources and data storage space.

The study has shown that an uncompressed remote sensing image (in GeoTIFF format) was approximately 4.72 GB, about 3.06 GB after LZW compression, around 946 MB after JPEG compression, and roughly 1.27 GB after lossless WebP compression. Among lossless compression methods, WebP was far superior to the traditional LZW, with a space saving rate more than twice that of LZW, and can significantly reduce storage usage while preserving the pixel information of the original images. JPEG had the problem of abnormal visualization in NoData values, and it cannot preserve the pixel information of the original images, thus failing to meet the basic requirements for visualization.

Compression method	GeoTIFF (uncompressed)	LZW	JPEG	WebP
Data volume	4.72 GB	3.06 GB	946 MB	1.27 GB
Compression ratio	1	1.54	5.11	3.72
space saving rate	0.00%	35.17%	80.43%	73.09%
compression categories	/	Lossless compression	Lossy compression	Lossless compression
Strength	/	natively supported by GeoTIFF	High CR, reduce storage usage	High clarity, normal NoData values
Weakness	/	Low CR, large storage usage	Low clarity, abnormal NoData values	CR < JPEG

Table 3. Comparison between different compression methods

(a) JPEG compression (b) WebP compression

Figure 2. Comparison between JPEG and WebP of visualization in NoData values.

Considering the compression quality and compression ratio comprehensively, satellite images compressed with the WebP method have obvious advantages over those compressed with other methods. When a large number of images need to be stored, the WebP method can save a great deal of storage resources and without loss of image quality.

3.4 Automatic cloud extraction

Using the quick views of multispectral images and their corresponding cloud coverage vectors as sample data, a cloud extraction model was trained based on deep learning technology, and a cloud coverage extraction program integrated with cloud extraction model and based on quick views was developed to achieve the rapid identification and extraction of cloud coverage in satellite images, as shown in Figure 3.

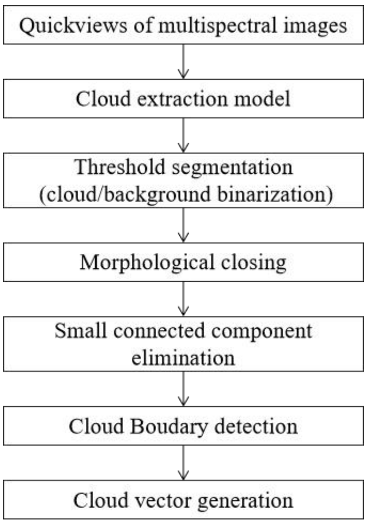

Figure 3. Non-Tiling Service Publishing workflow.

This flow chart showed the complete workflow of automatic cloud vector extraction from multispectral remote sensing images. Starting from multispectral image quickviews, the cloud extraction model performs threshold segmentation, morphological closing, small connected component elimination, cloud boundary detection and finally generated standardized cloud vector coverage data through a sequential automatic processing pipeline, as shown in Figure 4.

This method can reduce manual intervention and improve the efficiency of image production. The extracted cloud coverage was used to provide data masking for visualization of COG service and generation of image tile.

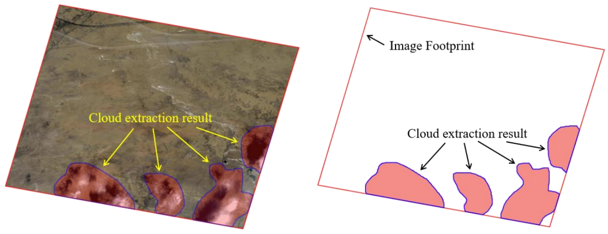

Figure 4. Automatic cloud extraction result.

3.5 Non-Tiling Service Publishing

The image data was compressed and converted into Cloud Optimized GeoTIFF (COG), which allowed partial data retrieval via HTTP requests and rapid generation of dynamic tile data (Niu and Liu, 2015). The core of this method was image format conversion and metadata spatial indexes generation. Based on the metadata spatial network model, a dynamic service mode was constructed using cloud service to improve the real-time service efficiency of images. It enabled random access to the imagery, allowing for fast loading and seamless browsing of any region within image datasets, resulting in a smooth user experience. This method was applicable to online users with low concurrency.

The non-tiling service publishing workflow was established and illustrated in Figure 5. Starting from DOM products and corresponding metadata, then conducting format conversion to generate Cloud Optimized GeoTIFF (COG), constructed image overviews and data indexes, and uploads all data to cloud storage. Finally, it realized metadata retrieval by area of interest (AOI) and rapid image loading through overview retrieval, completing the publish of standardized, high-efficiency and cloud-based services.

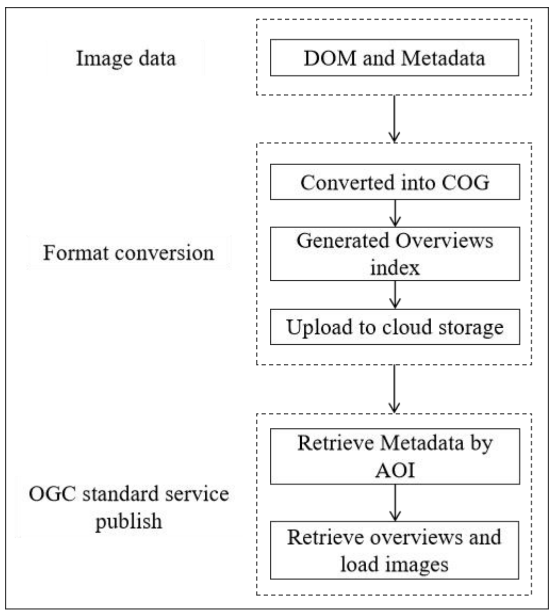

Figure 5. Non-Tiling Service Publishing workflow.

3.6 Tile Generation and Management

The tile pyramid model was applied for the real-time visualization of massive imagery data. The process involved tile generation based on single image and the construction of a monthly-version tile database according to the data acquisition

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date. Tile data was stored in cloud object storage, while metadata was stored in a MongoDB database. This achieved separate management of metadata and tile data by taking advantages of cloud object storage (Qiu, 2016).

Several key steps were involved in this procedure, which including data preparation, tile generation, tile merging, tile updating, and service publishing, as shown in Figure 6. For DOM datasets produced and organized in batches, after the extraction of cloud vectors and footprints, tiles can be generated based on Web Mercator specification to tile databases. Subsequent to this, tiles were merged with the master database to create a real-time tile database, which was used to publish the instant image service. Based on the monthly tile-covered areas, the required tiles were retrieved from the real-time tile database each month to build a monthly version tile database, enabling the publishing of the monthly temporal image service.

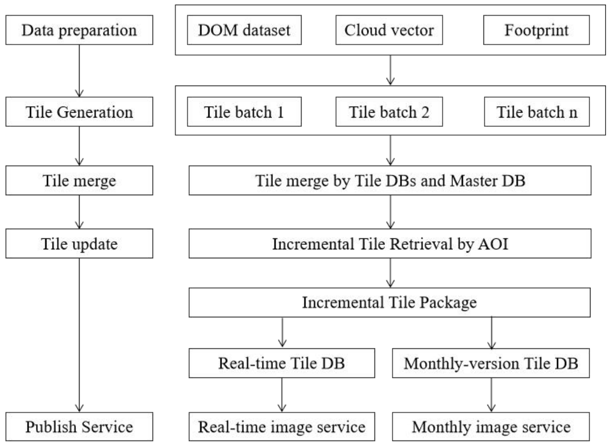

Figure 6. Tile generation and Management workflow.

4. Applications

Through the research on the key technologies for satellite image service processing mentioned in this paper, the programs and algorithms for each link of image production were modularly integrated, and a satellite image instance service system has been developed. This system adopted modular design and supported parallel scheduling, which included automatic image processing subsystem and tile management subsystem. The objective was to enable full automated processing of satellite imagery, covering the entire workflow from raw data ingestion to the delivery of visualization services.

The system was designed and developed based on the automatic processing workflow for satellite imagery, from raw data compressed packages to applications, which including: decompressing the raw satellite image data; performing orthorectification, image fusion, stretching, compression, cloud extraction, and boundary extraction under parallel scheduling; generation of COG images, tile generation and updating, publish OGC-standard map services, and support applications. The system workflow was shown in Figure 7.

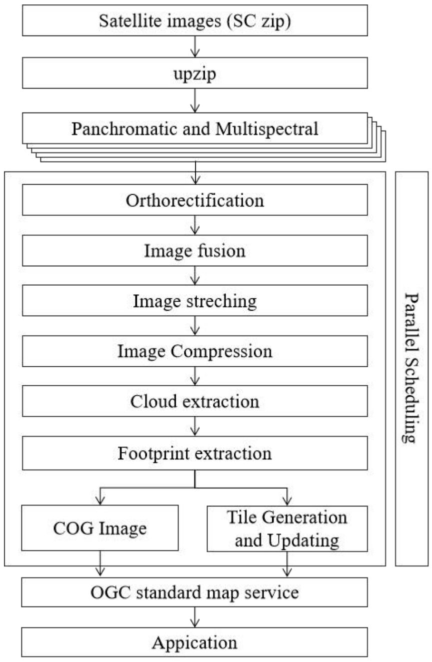

Figure 7. Satellite Image Instance Service System workflow.

4.1 Automatic Image Processing Subsystem

Automatic image processing subsystem consists of an image processing module, a cloud extraction module and a non-tiling service publish module. The image processing module incorporated functions such as data decompression, orthorectification, image fusion, image stretching and image compression, which achieves the satellite image processing from raw data to DOM (natural color) automatically. The cloud extraction module incorporated functions such as cloud extraction, image footprint extraction and real boundary extraction, which providing cloud mask to sevice publish module to enable browsing of images. The non-tiling service publish module includes COG conversion and Index construction functions, which is used for publishing non-tiling services and enabling users to browse images rapidly.

Automatic image processing subsystem provides a drag-and-drop visual workflow construction interface and offers tool components involved in image processing, allowing professional users to build workflows directly via drag-and-drop operations. It also enables users to view the processing status of each scene of data through a monitoring interface.

4.2 Tile Management Subsystem

Tile managment subsystem consists of tile generation module and tile update module. It is mainly used for generating tiles from massive image data and performing batch tile updates, building a multi-version tile database to realize time-series tile data services. The tile generation module includes tile generation, tile management and metadata management functions. It is mainly responsible for generating tile data from massive satellite images in accordance with the Web Mercator specification, management and maintenance of tile data, as well as the metadata of the generated tiles. The tile update module includes incremental tile extraction, metadata update and multi-version tile database update functions. It is used for extraction and merging of tiles based on the spatial range of metadata to generate an incremental tile update package, updating of tile metadata, as well as updating of the multi-version tile database.

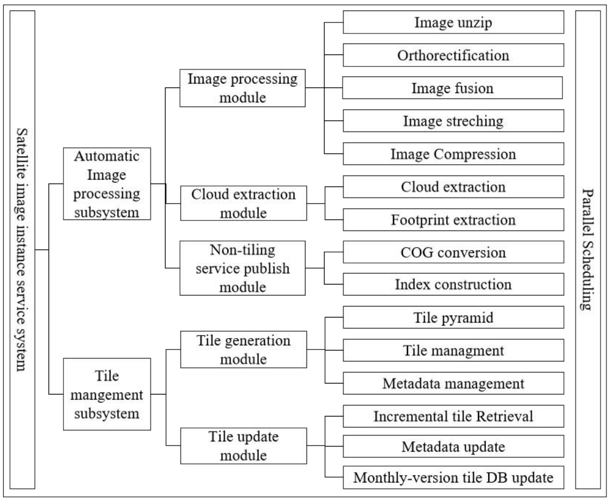

Figure 8. System Module and Function Composition Diagram.

4.3 Verification

The system was tested by using 10 cloud servers (each configured with 32 cores CPU, 64GB RAM, and 200GB ultra-high IO cloud disk), demonstrating the processing capability up to 800 satellite image scenes per day covering China’s territory.

Satellites	Spatial resolution	Swath	Time Consumed	Resource Utilization
GF-1	2 m	60 km	28 mins	Data Volume: 40 GB Peak CPU Utilization: 73% Peak Memory Utilization: 41% Peak Disk Utilization: 31%
GF-2	0.8 m	22.5 km	68 mins	Data Volume: 100 GB Peak CPU Utilization: 99% Peak Memory Utilization: 47.65% Peak Disk Utilization: 51.62%
GF-6	2 m	90 km	210 mins	Data Volume: 230 GB Peak CPU Utilization: 99.98% Peak Memory Utilization: 85% Peak Disk Utilization: 90%

Table 4. Processing Time and Resource Utilization for Every 100 Scenes of Satellite Imagery

4.4 Applications of Users

The applications of the Satellite Image Instant Service System revolved around the full-chain capabilities of image acquisition, automatic processing, rapid image service publish and industrial implementation. With regular operation, standardization, real-time performance and high reliability as its core features, it has been widely applied in such fields as dynamic monitoring of landcover / landuse change, dynamic monitoring of sea area use, environmental supervision, navigation map updating.

In terms of dynamic landcover / landuse change monitoring, monthly image services were utilized to detect changes in landcover / landuse types such as cultivated land, construction land and forest land through multi-temporal image comparison, and to identify issues including illegal land use and the conversion of cultivated land for non-agricultural purposes. In terms of dynamic monitoring of sea area use, it instantly identified marine use activities such as reclamation, aquaculture zone development and port construction, and rapidly detected illegal sea area use problems. In the field of environmental supervision and ecological red line management, real-time image services were leveraged to monitor human activities within ecological red lines areas and detect illegal development and ecological damage. Monthly historical image services can be used to trace the origin of various detected ecological damage incidents, which serve as objective evidence to support the conduct of environmental supervision work. In terms of supporting navigation map updating, map data companies can leverage real-time image services to identify and extract the morphological features of newly constructed road networks and under-construction roads, enabling real-time updates to navigation databases.

By comprehensively collecting practical usage feedback from users in various industries and fields including land use management, marine area supervision, environmental inspection, navigation map updating, it has been found that the service mode of the Satellite Image Instant Service System can accurately align with the actual business demands of remote sensing image applications in these industries. It effectively meets users' core requirements for low-cost investment, high-timeliness response and low-technical-threshold operation in the process of acquiring and utilizing remote sensing images. Meanwhile, it enables non-professional users to access and use remote sensing image services conveniently and efficiently, which embodies the practicality and universality of this service mode.

5. Conclusions

To address the urgent demands of professional industry users for high-resolution satellite imagery services and the major issues in traditional imagery production, this paper researched the key technologies in the processing of China's high-resolution satellite imagery, developed the real-time service system for China's high-resolution satellite imagery, and constructed an integrated solution covering data acquisition, imagery production, rapid browsing via non-tiling services, tile generation, tile update package and service publication. This solution reduces the difficulty and cost of data processing for users, meets their needs for rapid browsing and high timeliness of large-scale and massive satellite imagery data services, and has been widely applied in dynamic monitoring, environmental inspection, navigation map updating, and other work across various sectors in the natural resources field.

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With the ongoing launch of Chinese satellites in the future, user demands for high efficiency image service will continue to increase. Automated massive data processing and service based on cloud computing will face more challenges. The satellite image instance service system will adopt rapid processing and highly efficient visualization techniques to provide industry users with effective and convenient image services.

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