Remote Sensing Satellite Data Processing and Applications

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***Abstract*—Remote sensing satellites, ground data receiving system, ground data processing system and various application systems of satellite remote sensing composes of the total satellite and ground system. Ground data processing system is located in the middle of the entire data process, which is not only the destination of the original data, but also the source of applications of satellite remote sensing data. The system architectures of different generations are analyzed and the difference of three generations are summarized from system design, processing abilities, algorithms and workflow. Based on different characters of satellite payloads, the remote sensing satellite system solution can process the satellite image to standard level image products. The system platform can support to produce thematic maps from standard level image products and ground supported data. At last, it provides a total solution from upstream to downstream to different customers.**

***Index Terms*—development process, flow, ground processing system, system architecture**

I. INTRODUCTION

REMOTE sensing satellites Ground data processing system is to complete raw data processing and archive management, data pre-processing, standard product production, etc. [1]

From the view of computer application system, the system is mainly involved in high-performance computing, database technology, network technology, large data management and rapid query technology, system design and integration; from the view of data processing, the system also involves the remote sensing satellite data pre-processing, standard product definition and production, satellite and payload operation status tracking and parameter analysis, satellite remote sensing application and other aspects of the key technologies. After 40 years of development and the actual test running, to the end of 20th century, ground data processing system basically formed the data processing standards process and similar system structure, and system development tasks are gradually transferred to the relevant high technology companies worldwide. However, there are still a considerable number of research institutions, universities research institutes continue to do research on functions and performances, architecture, development methods and other aspects of the relevant ground processing system. In the U.S., aerospace company, the Air Force Space Command, Space and Missile Systems Center (SMC), state investigation office (NRO), Jet Propulsion Laboratory (JPL), System and Software Engineering Center of University of Southern California, software Engineering Institute of Carnegie Mellon University, Institute of Software of University of California, NASA, NOAA and other research institutions jointly organized the annual symposium of the ground system architecture, a wide range of activities related to the space required for various types of ground systems, carried out for 10 consecutive years of technical seminars, participants have more than 300 people, and the size of each year also continued to expand and gradually internationalized.

With the process of satellite platform technology and the growing number of remote sensing satellites in the worldwide, remote sensing data can be obtained in different types and scopes. Now, there are some representative series of the Earth resource satellites, such as the U.S. Landsat series, the French SPOT series, India's IRS series and CBERS series co-developed by China and Brazil. In addition, Israel, Japan, South Korea [2], Germany, China Taiwan and other countries and regions are developing their own earth observation resources satellites. Algeria, Nigeria, Turkey, Thailand and a large number of developing countries are actively exploring the small satellite platform-based earth observation satellite system. Satellite platform changes and different types of satellite sensors carried by the increasing number of different platforms make the structure and workflow of data processing some changes. Furthermore, the increase of remote sensing satellites and the expansion of applications, in turn, require the ground processing system with a stronger satellite data processing capacity and more flexible system reconfiguration, to achieve an efficient system to process multiple satellite data and to provide a solution of value-added image product processing. Because of these changes, the remote sensing satellite data ground processing system design structure and architecture have changed a lot in the 21st century.

Generally speaking, as the remote sensing technology and computer technology developing, along with the continuous

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development and expansion of remote sensing applications in the depth, the remote sensing satellite data processing system development has gone through three significant generations.

II. The Functions and Composition of Ground Processing System

Remote sensing satellite data processing system is an important support of earth observation space system, which is a linking bridge between spatial data acquisition and ground application. From the processing function analysis, remote sensing satellite data processing system includes the following functions [3].

(1) The separation of raw data, data archiving and management;

(2) Data processing, carried out based on satellite attitude and orbit, the sensor characteristics and other system parameters of the radiometric correction, geometric correction and other related process;

(3) Different standard levels of image product generation and distribution.

With the continuous development of remote sensing applications, remote sensing satellite ground processing system functions are expanding, precision processing of remote sensing data goes into the ground context of process system functions, including geometric correction, ortho-correction process, image fusion, etc.

In the view of system functions and composition analysis, remote sensing satellite ground processing system consists of raw data processing and management subsystem, data pre-processing subsystem, value-added image product processing subsystem, product generation and distribution subsystem, mission control and operation subsystem and other related support subsystems.

Raw data processing and management subsystem is responsible for the separation of the raw data, data archiving and management, and to extract data and metadata from the stripe data; data pre-processing subsystem is used to provide related remote sensing data processing algorithms; product generation and distribution subsystem is used to generate and distribute standard level image data formats, and to produce physical media storage products. System support subsystem contains a variety of auxiliary functions such as cloud cover assessment, image quality assessment, data query and retrieval, etc.

III. The Development Process of Ground Processing System

From a broader point of view, the development of remote sensing satellite ground processing system is closely related to the development of computer processing system. Because of the massive remote sensing data and special algorithms, the system has its own specific development. Through analyzing and summarizing ground processing system development and architecture in different periods of history, it can be roughly divided into three generations, which named the formation of the first, second and third generation ground processing system.

A. The 1st generation ground processing system

The first generation of ground processing system is represented by the satellite ground system of U.S. Landsat series. In 1972 the United States launched the first Landsat series of earth resource satellite, remote sensing satellite ground processing system was used to solve how the satellite data received could be processed to image to generate corresponded image product. In order to build ground processing system to a computer processing system, some main questions were shown as follows. Under the conditions of computer technology at that time, select what kinds of operating platform to conform to the characteristics of remote sensing image processing and access to the fast processing of large data [4]; how to reasonably determine the ground processing system workflow and process and the corresponding data processing algorithms [5] to ensure the remote sensing satellite data quality products.

Remote sensing image processing is characterized by large volumes of data, high computational complexity. Because of the computer's computing power is limited at that time, people have tried to use the mainframe, special parallel processing system to achieve the processing ability. However, from the view of cost-effective system development and operation and maintenance, it is more towards how to use the massive data processing machine known as dedicated processor [6], for computing resources through a structured approach to software development to achieve the required algorithms and processes. Ground processing system is formed to use vector machines, pipeline processor as the core data processing platform, micro-computer unit as system control and management platform. In such systems, the implementation skill of algorithm determines the overall system performance. At that time, because of the small number of remote sensing satellite and simple data processing algorithm, researchers pay more attention to how to design data processing workflow in order to adapt to the hardware system requirements, and standardize raw data processing and procedures to form standard data products. After several times of updates and development, the first generation of remote sensing satellite ground processing system determined the processing of raw data archiving, radiometric correction, geometric correction, and standard level data products, and the formation of the corresponding standard processes [7].

Overall, the first generation of ground processing system focuses on data processing techniques of the design and implementation with a special processing system hardware structure. Therefore, ground processing system is based on specific satellite data processing design and implementation structure. From the system architecture, the system can be divided into raw data acquisition subsystem, data pre-processing subsystem and product generation subsystem and other subsystems. But in the realization of the function of each subsystem, a different satellite processing system design and implementation could get different result. The first-generation satellite data processing system is designed for specific, dedicated application. Portability and scalability is poor.

B. The 2nd generation ground processing system

With the application of space technology and remote sensing technology continues to develop and the number of earth resource satellites increases, the ground processing system designed for each satellite became uneconomical to operate and increased management difficulties. On the other hand, the development of computer hardware and software technology made ground processing system based on general-purpose computer systems as possible. As the increasing speed of computing and the lower cost of computer hardware, the computing capability is no longer a constraint on the ground processing system development. The development of network technology, storage technology and database technology provides massive remote sensing data management and processing solutions for ground processing system. Object-oriented design and object-oriented programming languages have enabled the development of various algorithms to reduce the degree of difficulty, while improving the reusability of the software system, shortening the ground processing system development cycle. Based on general-purpose micro-computer and high-performance workstations, different kinds of ground processing system were developed. Vector machines and pipeline processor withdraw from the system architecture at the same time. It is necessary and possible to develop multi-satellite ground processing system combined with technology development and research.

According to design and implementation of multi-satellite ground processing system based on general-purpose computer, engineers pay more attention towards different satellite data processing algorithms, the business processes and management of different satellites, the integration and transformation of different data format, massive data organization, management and visualization and data processing automation and intelligence. The points that how to manage large volumes of data and how to schedule the multi-satellite business process management became the main problem of the second-generation ground processing system.

During the process of developing the second generation of ground processing system in different countries, there are some differences in system architecture because of the historical reason and the different technologies. One type is that multi-satellite ground processing systems updated from single satellite ground processing prototype system. After improved, the system can accommodate the process of several special satellites, such as South Korea's KOMPSAT-2 satellite ground processing systems. These kinds of systems follow the original type of ground processing system workflow processes and focus more on how to manage the scheduling of processes of different satellites on the structure of the system. The other type is several single-satellite ground processing systems grouped into a unified management platform. Through the management platform, it can schedule different satellite ground systems to complete the corresponding tasks, such as MEOS (Multi-mission Earth Observation System). MEOS integrated management system includes many different sets of satellite ground processing system. Through reasonable and effective integration of different platforms, the ground processing systems run on a unified management platform.

Compared to the first-generation system, the second generation of ground processing system is relatively with simple system architecture and reduced development effort. The system with a certain degree of openness, can processing remote sensing satellite data from multiple satellites. The user or the third party can add new processing modules under limited conditions. However, in the 1990s, the number of civilian remote sensing satellites available is still limited. The system could basically satisfy with the process for several satellites, but the upgrade ability is poor.

C. The 3rd generation ground processing system

In the twenty-first century, on the one hand, the number of available remote sensing satellites and corresponding sensor types increased; on the other hand, the depth and breadth of remote sensing satellite data applications have made new demands and requirements. Remote sensing satellite ground processing system faces new challenges and needs in the reconstruction of flexible features and capabilities in a variety of image products. It is hoped that the ground processing system can satisfy users' requirements as much as possible and realize the idea of "on-demand design, on-demand service"[8]. The ground processing system tends to be an integrated application system platform. A new generation of remote sensing satellite ground processing system has a large improvement in system structure and functions. The development of ground processing system turns the satellite-specific processing mode to reconfigurable system architecture development based on remote sensing sensors [9]. The development of the new generation system is based on data and information products service rather than data processing.

On the other hand, parallel processing and massive data storage technology make large-scale reconfigurable computing system possible and more convenient. And as the development of networked computer application system architecture, object-oriented applications and service-oriented process applications, the research and development of ground processing system has new vitality.

Therefore, the main task of the development and research of the new generation ground processing system is to improve process capacity, increase processing functions and to form a reconfigurable software and hardware system architecture. In the view of system structure, the new generation ground processing system should have a completely open architecture. The users can add and remove the corresponding processing function modules from the system platform which is cost-effective, stable and scalable platform. Also, the system must provide a highly automated, intelligent business process management workflow. The users can easily get different satellite data processing workflows on-demand and can easily get the satellite data or image product they want. In the view of the processing functions [10], in order to meet different users' requirements in the breadth and depth of applications, the ground processing system should be able to integrate different processing function modules. Some functions have the same processing capabilities compared with the commercial remote

sensing image processing software. The users can get all information they want from one software and hardware platform. The only way to meet the different requirements for different users is to provide satellite data products and information services totally and to get the value and role of satellite remote sensing data.

Based on the requirements and technologies, we have done some research on the third-generation remote sensing satellite ground processing system. The prototype system with high performance has been finished. The system's architecture is shown in Figure 1.

The system makes full use of advanced high-performance computing[11] technologies, advanced software design concept, combined with parallel storage technologies, parallel computing technologies, task scheduling technology, process management technology, design pattern, etc. Through the system design, the performance and function of the system has reached a new height, which meets the requirement of "on-demand design, on-demand service" as the specification of the new generation ground processing system. The system is divided into five layers, which are named hardware layer, the system support layer, data processing extension layer, task management layer and processing functions layer. Hardware layer provides hardware support for ground processing system, including commercial cluster systems, Storage Area Network (SAN) / Network-Attached Storage (NAS) storage systems and high-performance Gigabit Ethernet or infiniband network system. System support layer provides software support environment, focusing on system performance expansion. Remote sensing data processing is a complex application of computation-intensive, data intensive and network-intensive process. And the processing of computing, storage and network performance requirements are not the same. The system is designed by orthogonal design concept to realize parallel computing, parallel storage, parallel network load modules, making the system processing performance, network performance, storage performance can be scaled independently. And according to data processing characteristics, the performance can be optimized. The data processing, data archiving and production and distribution performance provides a powerful technical support system, making the system highly scalable performance and efficient operation. Taking good use of advanced software design pattern, data processing extension layer can design abstract function interfaces and combination functions for different satellites and different sensors. Using inheritance method to realize complementation, it ensures specific processing algorithms expand as needed for various types of satellites and sensors. Task management layer achieves the task scheduling and process management functions. By integrating high-performance systems and workflow management system, it achieves a variety of processing workflow balancing and process capabilities. Processing functions layer provides users with easy use interface. The users can define a variety of process workflows, including data processing, archiving, production and distribution and other function workflows. By the extension of data processing extension layer and processing functions layer, the system architecture can achieve the functions expansion on demand. Not only it can add new multi-satellite remote sensing data processing algorithms and functions, but also it combines the basic processing functions, allowing users to freely customize the remote sensing data processing workflows for specific requirements.

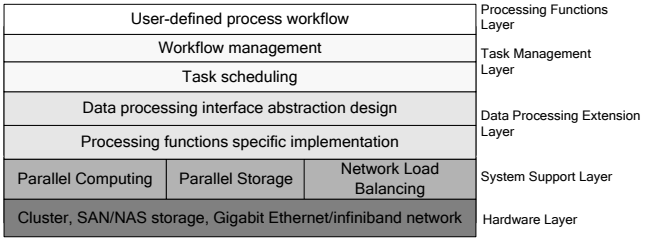

Fig. 1. The system architecture of general high performance ground processing system.

The system has a completely open platform. Due to the use of a variety of high-performance computing and advanced software design concept, the system can satisfy users' requirements conveniently. The users do not need to modify the process programs with the expansion which can be easily balanced system processing, storage and network communication capabilities to improve the speed of the program. The users can add their business function modules on the platform conveniently. When a new remote sensing satellite data added into the system which will be processed, archived, produced and distributed, the system architecture or even equipment remains unchanged. The users only set the appropriate data processing modules according to certain rules.

IV. Architecture of Remote Sensing Satellite Data Application System

The architecture of remote sensing satellite data application system, from the bottom to top, is divided into sensing layer, transmission layer, cloud service platform layer, supporting platform layer for application (application supporting platform) and business application layer. It includes two sets guarantee systems, namely, information safety guarantee system and policies and regulations guarantee system, as shown in Figure 2.

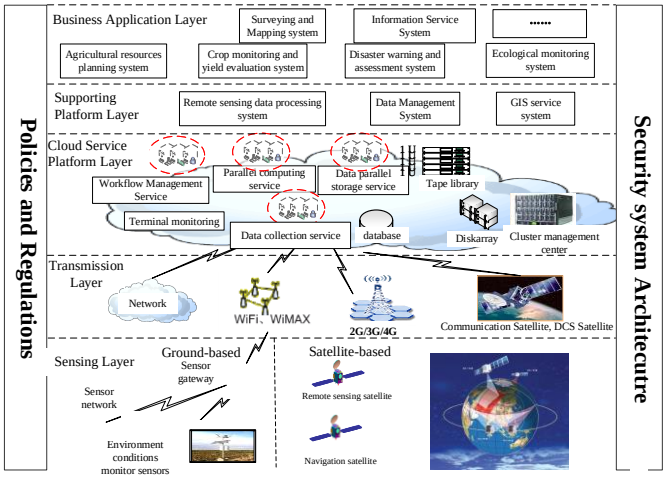

Fig. 2. The architecture of remote sensing satellite data application system.

A. Sensing Layer

The space-based earth observing system applied in different areas mainly includes the satellite payloads of visible, infrared, multi-spectral, hyper-spectral, Synthetic Aperture Radar (SAR), etc., and it is armed with the features of wide-range image information, rich spectral information, etc. From the perspective of the development of satellite technology, the space resolution, spectral resolution and time resolution of remote sensing satellites are rapidly improved, and the types of remote sensors are also dramatically increased. As the gradual improvement of space-based earth observation system, its captured information would become the main data sources for future. The ground-based equipment is composed of different sensors.

B. Transmission Layer

The transmission layer is mainly applied to the collection of captured data, the interaction and distribution of information data, etc. The networks of the current transmission layer mainly include: ground wired network/mobile network, satellite communication network and Data Collection System (DCS) satellite collection system. Among them, the satellite communication network combines with other communication means on a basis of communication satellites, providing nationwide covered communication network, which is mainly applied to the remote rural areas; DCS satellite collection mainly applies to data collections, such as crop parameters, environment parameters, etc. It is expected to provide DCS satellite collection channels for data by means of launching DCS satellite constellation and carrying DCS transponders on remote sensing satellites.

C. Basic Cloud Service Platform

The basic cloud service platform system is aimed to provide network information collection service, mass data distributed storage service, distributed parallel computation service, distributed flow scheduling, management service and other basic services. The mass heterogeneous and discrete agricultural remote sensing data, ground collecting data and information service data transmitted to the platform from the transmission layer are collected, integrated and classified via the complex of ubiquitous network information collection; The data are stored in storage cluster via the distributed storage service provided by the platform and kinds of data are further integrated; Meanwhile, the distributed parallel computation service, distributed flow scheduling, management service provided by the platform bear a function on the parallel processing and analysis of the remote sensing data, and the support for the remoter data processing system of upper layer to the production and business flow scheduling of remote sensing data products. It can also provide the integration standard and regulations of industry application system via the distributed application integration service and the management service of plug-in unit of configurable software.

D. Supporting Platform for Application

Based on the collection, storage and computation service provided by the cloud platform of Smart Agriculture system, the business supporting platform is applied to meet the application demands of the planning of resources, crops monitoring and output estimation, disaster warning and

TABLE I
SATELLITE RESOURCES AND PAYLOADS REQUIREMENTS OF AGRICULTURAL REMOTE SENSING APPLICATION

Business Requirements	Data Requirements: Payload Type	Data Requirements: Resolution Requirements	Current Available Satellite Resources	Future Satellite Resource Requirements
Crop growth monitoring	Multispectral/high spectral	High time resolution, low-medium spatial resolution	FY,NOAA, MODIS	High spectral resolution, high time resolution satellite
Crop yield evaluation	Multispectral/high spectral	High spatial resolution, high time resolution	FY, NOAA, MODIS	High spectral resolution, high spatial resolution, high time resolution satellite
Crop area monitoring	Multispectral/high spectral	High spatial resolution, high time resolution	ZY-3, CBERS, QuickBird, SPOT, WorldView, COSMO, ALOS	High spatial resolution, high time resolution satellite
Farmland resource monitoring	Multispectral/high spectral	High spatial resolution	ZY-3, CBERS, QuickBird, SPOT, WorldView, COSMO, ALOS	High spatial resolution satellite
Land ecological monitoring	Multispectral/high spectral	Low-medium spatial resolution	HJ, CBERS, FY, NOAA, MODIS, Landsat ETM+, ALOS	High spectral resolution satellite
Farmland planning	Visible light /Multispectral	High spatial resolution	ZY-3, CBERS, QuickBird, SPOT, WorldView, COSMO, ALOS	High spatial resolution satellite
Disaster monitoring	Visible light /SAR/Multispectral/high spectral	High time resolution, high spatial resolution	FY, ZY-3, CBERS, NOAA, QuickBird, SPOT, WorldView, COSMO, ALOS, RadarSat, TerraSAR, COSMO, EnviSat	High time resolution satellite, high spatial resolution satellite

assessment, eco-agriculture monitoring, field precise farming, information service, etc. It is dedicated to the establishment of remote sensing data processing system, data management system and Geographic Information System (GIS) service system and the supply of common processing service of various remote sensing data (the processing and generation of advanced agricultural remote sensing image products), data management service and GIS service.

E. Business Application Layer

Based on cloud and business support platforms, the business application layer forms a business application system, which is clearly functional, divided with explicit business process through the interface of request/service and function encapsulation for service based on cloud platform.

In general, the whole development trend of the satellite remote sensing technology is as follows: regarding satellite system, developing from unitary series to constellation network; regarding satellite sensor, extending from high-medium resolution to high resolution, leaping from single angle observation to multi-angle and three-dimension observation, widening from space dimension to spectrum dimension; regarding the level of satellite remote sensing application, developing from stability to accuracy stability. In actual business application, satellite resource is necessary besides introducing foreign high-resolution satellite image.

The high-resolution multi-spectral and high-spectral satellites applicable should be highlighted and covering power of high revisiting period in national areas and global main grain regions is essential to enhance the accuracy and efficiency of agricultural application.

V. Summary and Conclusion

Four decades, remote sensing satellite ground processing and application system has gone from single satellite and single task processing system to multi-satellite and multi-tasking system. It forms three generations of ground processing system. In each generation system, the processing capacity, system definition, architecture, task scheduling, processing functions and other items are different. The comparison of each generation ground processing system is shown in Table II.

As satellite and sensor technology development and rapid growth of remote sensing applications, remote sensing satellite ground processing systems are not just a system to generate certain level image products. It also includes a variety of value-added data processing. In a sense, the third generation remote sensing satellite ground processing system is going to be an integrated application system. It is believed that with the efforts of researchers in the area of remote sensing and computer science, the new generation of remote sensing satellite ground processing system will serve various industries faster and better in the near future.

For policy suggestions, the government must formulate the policies and regulations for remote satellite application as framework document to promote and guide agricultural satellite application nationwide.

Establish the supporting agency to coordinate national satellite applications. The main duties of the agency are implementing the policies related to remote sensing satellite data, responsible for the systematic planning and construction to realize "satellite-ground integration", undertaking satellite information service provision to government leading body and relevant governmental departments, as well as organizing new technological research, scientific result transformation and promotion of satellite application.

TABLE II
The Comparison Of Each Generation Ground Processing System

	The 1st generation ground processing and application system	The 2nd generation ground processing and application system	The 3rd generation ground processing system and application
Process capability	single satellite	specific multi-satellites	multiple satellites (reconfigurable)
System definition	focus on business processes and how to properly process the raw data	focus on how to manage data and a variety of business processes	focus on how to achieve adding a variety of processes with an open architecture operating platform
System architecture	according to processing workflow, the system consists of different subsystems; structured design	with a certain level of system architecture, to complete a specific multi-satellite management of different processes and scheduling	have a clear hierarchical architecture; with automated business process management and composition
Task scheduling	system process fixed	have a certain level of data management and business process management and scheduling capabilities	with complete data management solutions and business processes designed on demand
Algorithm complementation	single satellite processing algorithms is relatively fixed, algorithm dependent on the specific sensor	different satellites in different algorithms, different functional modules of different satellite data processing	using the factory design pattern in software engineering, the same module can process data from different satellites

Enhance economic support to satellite application technology. Enhance the investment in up-to-date technology research and financially support satellite application production promotion and infrastructure construction.

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