DEVELOPMENT OF SATELLITE IMAGE GROUND RECEIVING AND PROCESSING SYSTEM FOR HIGH RESOLUTION SATELLITES

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ABSTRACT: Remote sensing division of satellite technology research center (SaTReC) , Korea advanced institute of science and technology (KAIST) has developed a ground receiving and processing system for high resolution satellite images. Developed system will be adapted and operated to receive, process and distributes images acquired from of the second Korean Multi-purpose Satellite (KOMPSAT-2), which will be launched in 2004. This project had initiated to develop and Koreanize the state-of-the-art technologies related to the ground receiving system for high resolution remote sensing images, which range from direct ingestion of image data to the distribution of products through precise image correction. During four years development, the system has been verified in various ways including real operation of custom-made systems such as a prototype system for SPOT and a commercialized system for KOMPSAT-1. Currently the system is under customization for installation at KOMPSAT-2 ground station. Achieved technologies are also being used for development of ground receiving system for Landsat 7. In this paper, we present accomplished work and future work.

1. INTRODUCTION

Since the successful launch of KITSAT series, the Korean Government has implemented a National Space Development Program including the launch of the eight remote sensing satellites namely Korean Multi-purpose Satellite (KOMPSAT) series. The first KOMPSAT with the payload of 6.5m resolution optical sensor, Earth observation camera (EOC), was successfully launched and have been operated archiving thousands of scenes over the world. At present, the second KOMPSAT is under development to be launched in 2004. The payload of KOMPSAT-2 is the Multi-Spectral Camera (MSC), which consists of 1m resolution panchromatic camera and a 4 bands 4m resolution multi-spectral camera. Table 1 shows the specification of KOMPSAT-2.

It demands drastic evolution of image reception, processing and distribution system for the system to provide high-quality satellite images from high-resolution remote sensing data promptly and efficiently. For example, the ground receiving system for KOMPSAT-2 requires about 40 times enhancement in performance compared to the KOMPSAT-1 ground receiving system. Data ingestion speed requires about 8 times enhancement thanks to the on-board compression of image data. Pre-processing requires about 40 times improvement in processing speed and higher geo-location accuracy. The amount of archiving data to be managed also increases about 40 times than that of KOMPSAT-1, hence more superior archive management scheme is required. These necessities conclude that the technologies used for middle-resolution remote sensing data cannot be used for the ground receiving system for KOMPSAT-2.

To meet the need for new technologies for a ground receiving system for KOMPSAT-2 and the necessity of Koreanization of the ground receiving system to help successful implementation of the National Space Development Program, the remote sensing division of SaTReC has developed ground receiving system for high resolution satellites. Currently, we have finished system integration and test and the development is at the customization stage for system installation at the KOMPSAT-2 ground station site.

Orbit	685Km Sun-synchronous
CCD	Linear push-broom
Band	1 Panchromatic: 500-900 nm 4 Multi-spectral: 450 – 520 nm, 520 – 600 nm, 630 – 690 nm, 760 – 900 nm
Radiometric resolution	10 bits
No. of pixels	15000 for panchromatic 3750 for multi-spectral
Pixel distance	1m for panchromatic 4m for multi-spectral
Downlink	320Mbps QPSK

Table 1. KOMPSAT-2 Specification

The paper will introduce the ground receiving system developed so far and highlight the important features prioritized throughout the development procedures. In section 2, we will introduce the overview of system and section 3 to section 5 will be devoted to present the important features of the system. Finally, conclusion will be given presenting current stage of development work and future plan.

2. SYSTEM OVERVIEW

This section describes the overview of a ground receiving system (hereby, the system) developed. The system has been developed as a ground receiving system for KOMPSAT-2, but is designed as applicable to any high-resolution satellites with minor modifications.

The main objectives of the system are: 1) real-time receiving and processing of X-band downlink data, 2) generation of standard image products and catalogues, 3) integrated system management, 4) archive management, and 5) comprehensive user interface to provide easy access to satellite image data.

The system was designed to meet the following seven operational concepts.

- Maximum automation: The system shall be centralized and operated with minimum operator's interaction.
- High speed: The system shall handle up to 320Mbps image data and generate image products as fast as possible.
- High reliability: The system shall not fail to achieve system objectives by single point failure and/or operators' trivial mistake.
- Integrity: Operations and managements of system is integrated in the most efficient manner.
- Cost effectiveness: The system shall be operated economically so that it can save time, efforts and resources.
- Expandability: The system shall be upgraded for processing other satellite data with little change of the system.
- Security/Accessibility: Only authorized user shall have access to catalogue data and only authorized operators to system modules. For public data, user shall be able to access easily.

Fig. 1 shows system hardware architecture for each subsystem. In design process, system was divided into two subsystems: receiving and archiving subsystem (RAS) and search and processing subsystem (SPS). Former is responsible for the real-time receiving and processing of X-band downlink data and latter for other objectives such as product generation, user interface and system managements.

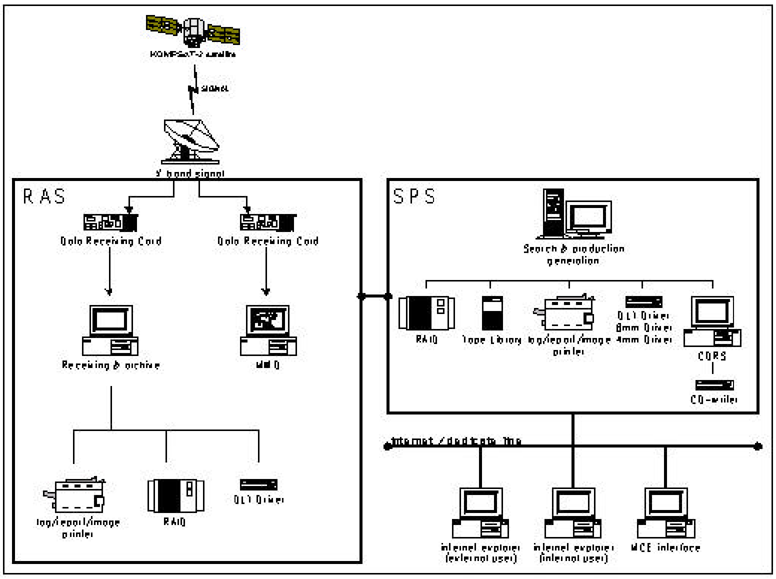

Fig. 1 System architecture

The RAS receives and records image data transmitted from satellite in real-time. It also performs moving window display (MWD) in real-time and playback mode and provides processing functions to handle satellite specific downlink formats. The RAS consists of two software modules: Pass scheduler (PS) and data processor (DP). The PS supports system management functions such as initiation of automatic downlink reception based on work orders either remotely or locally ingested, maintaining RAID capacity, monitoring connected hardware and backup and restoration of raw data using DLT. The DP is responsible for data capturing to RAID in real-time, real-time and playback MWD, error control and satellite specific processing such as deciphering and decompression. Rather than using a special hardware to process downlink format, software implementation was adopted for system expandability and we pay extensive attention in code optimization to attain high performance. Since real-time receiving and recording is a very critical objective of the system, the RAS consists of two fully redundant units in hot standby to accomplish high reliability and availability.

Four main functions of SPS are as follows: 1) imaging acquisition plan, 2) standard product and catalogue generation, 3) catalogue search and order ingestion from users, and 4) system managements. To implement such functions, 10 components has been developed. Explanations of key components are as follows.

The pass schedule s/w (PSS) is developed to support for operators to plan image acquisition and to make satellite-programming request to a mission control center. The catalogue and product generation component (CAP) generates catalogue and standard level image products. Main functionalities are systematic correction, radiometric correction, and geometric correction using GCP or DEM. It also provides automatic geometric correction and accuracy assessment of product if relevant GCP chips are available in a database. Cloud assessment can be done automatically, semi-automatically or manually. CAP provides very flexible configuration. User can pre-define standard level of product, the order of product generation and area of interest to be processed. CAP generates image products automatically or with minimum user intervention if necessary according to pre-defined configuration.

Catalogue browse and order ingest component (CBI) is a web-based software that provides easy access on the image data for users of image products. The main functions of CBI are catalogue searching, order ingestion from users and user access control.

Three key modules are developed to realize a comprehensive management of the system: order manager, system information manager and archive manager. The order management component (OM) controls flow of data and processing. It analyses orders from users and operators, makes a sequence of execution, generates *work orders (sub-orders)*, and transfers *work order* to the responsible components in appropriate sequence to guarantee automatic processing of given order. It also monitors system resources and produces reports and statistics. The system information management component (SIMS) manages accounts of users and operators, controls their access to data and system components, and monitors system resources to keep system integrity and security. Archive management component (AMS) is to provide enhanced archiving management for raw data, generated products and catalogues and any other data necessary for system operation. In our system, storage space is divided into three layers, namely, online (RAIDs), near-line (DLT library) and off-line (tape shelves) in a hierarchical way. AMS monitors available storage space and data, and moves and restores data between storage equipments to maintain storage space to support successful operation of system.

Fig. 2 shows screen captures of some components of developed system.

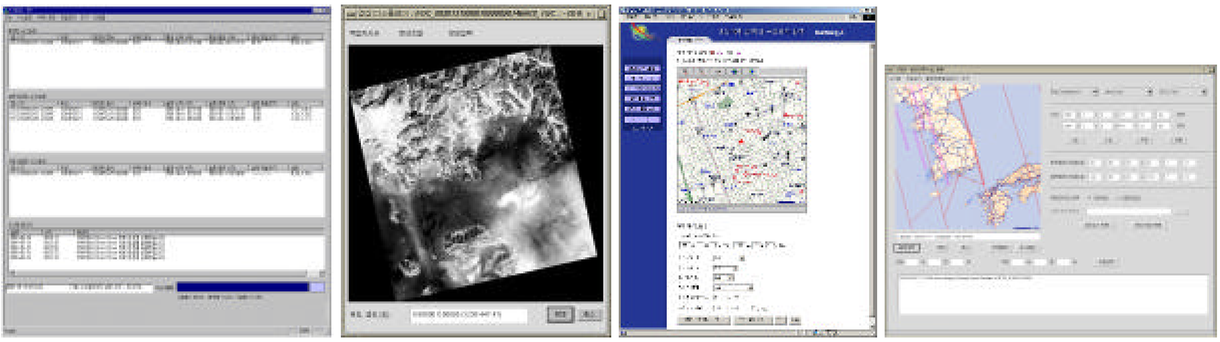

Fig. 2 Screen captures of RAS, CAP, CBI and PSS from left to right

During 4 years development, rapid prototyping has been used for process model to illustrate the progress in functionality and performance of system and verify the system meantime. Table 2 shows functionalities and performance of each prototype developed. The basic system for SPOT was verified with real operation at SaTReC site. The system for KOMPSAT-1 was installed at two sites and is under well operation.

Prototype	Functionalities	Performance
Core modules for SPOT	-Data receiving card -SPOT pre-processing	50Mbps 10m resolution
Basic system for SPOT	-Receiving and archiving subsystem -Cataloguing and preprocessing -Catalog search and order	150Mbps 10m resolution
System for KOMPSAT-1	-Most functionalities	320Mbps 6.6m resolution
Final System	-Full functionalities	360Mbps 1m resolution

Table 2. Evolving prototyping

The final system test has been conducted from December 2001 to August 2002. Whole test process consists of component test, integration test, *random test* and pilot test and is conducted in this order. Component test and integration test were designed to be able to verify if the system meets all requirements and *test procedures* were prepared accordingly. Component test aimed to verify requirements assigned to each component and integration test was designed to verify mainly interface and that system is well operative all together. Random test means tests not with test procedures but in real operational condition. Considering all misuse of system cannot be designed as test procedures, we let test conductor to use system with minimum training to expose system defects. The purpose of this test is to verify system stability and reliability. Pilot test is simulated operation of the system to verify system availability and maintainability. If any defects are found during test, regression test from the component test are conducted after defect correction.

3. AUTOMATION, ARCHIVE MANAGEMENT AND SECURITY OF SYSTEM

During the development of the system, we have emphasized system automation, archive management and security management. First two are very important as the amount of data to be processed and managed are enormous. Third one is important as high-resolution satellite images require higher security. In the developed system, they operate all together systematically.

The system is designed emphasizing full automation as much as possible. Workflow of system is managed by a component so called order manager utilizing *order* and *work orders*. Order is an user input that requests the system for new image acquisition, product generation from archived raw data, or distribution of archived products. Once such an order is ingested, order manager produces work order according to required workflow and distributes them to responsible components to fulfill ingested order. The work order is a primitive order to a component such as image acquisition work order to RAS, product generation work order to CAP. Order manager monitors each component's progress and arrange the sequence of work order. While handling each work order, each component may need user intervention for the approvals, additional information or ingestion of data not available online (archived offline). To minimize such user interventions, firstly, we introduced bypassing scheme of operator's approval based on the priority of user who makes order. Second category of user intervention includes assigning security level of products, cloud cover assessment and GCP chipping for precision correction. The security level of scenes can be automatically assigned by pre-defined *rule sets*. Each rule set is defined by area of interests, a period of acquisition and predefined security level. When new products are generated, predefined security levels are allocated according these rule sets. We also have developed a few automatic processing algorithms such as automatic cloud assessment algorithm and automatic precision correction algorithm. Automatic precision correction can be done utilizing pre-archived GCP chip database (Kim, 2002). Thirdly, we introduced the *hierarchical archiving management* scheme to minimize for operators to ingest offline data to online. In this scheme, the *near-line* data, which is implemented with a DLT tape library physically, are transparent to the system as like they are online. The capacity of a DTL tape library ranges up to 27 terabytes so this scheme minimizes data ingestion from offline to online.

The objective of hierarchical archiving management is to manage storage space and data to minimize operators' effort to maintain them. For this purpose, the *archive management software* (AMS) was implemented. AMS divide system's storage space hierarchically into three: online, near-line and offline. Online storage is implemented with a RAID and near-line storage with a DLT library. Concept of online storage is to store data most recently acquired and provide them to system quickly as requested. Near-line storage is used for back-up storage and to store data considered to be used in near future. Newly acquired

X-band raw data are passed to SPS and stored on the online storage. Products generated from them also stored on the on-line storage. During non-working hour, AMS makes copies of them to near-line storage for the sake of backup. AMS also secure predefined storage space on the online by deleting data files that have already backup on near-line storage. In this manner, the system maintains enough free space for operation on the online. AMS also manages near-line storage space and data. For required space for near-line, upper and lower limits are needed. Upper limit indicates minimum near-line free space required for system operation and lower limit indicates minimum space can be used for near-line data to provide data service to the system without operators' intervention. AMS monitors near-line data and space during working hour. If amount of near-line data exceeds the upper limit, AMS secure free space required by dropping the used DLTs automatically in chronological order until the used data space reaches the lower limit. Operators are required to locate new DLTs as AMS requests. For dropped tapes, i.e. offline data, AMS maintains a database of their ID and contents of data on the tape. So if required, AMS requests operator to insert specific DLT to restore off-line data. When certain component requests specific data to AMS, AMS looks for the database and finds the location of data: online, near-line, or offline. If requested data are on the offline, AMS requests operator to supply offline DLT to near-line. If requested data are on near-line storage, they are automatically restored to online. AMS informs the location of data on the online storage to the component that requested data. In this manner, AMS can service requested data to system with minimum user involvement and other system components uses near-line data transparently.

Purpose of security management is to keep system integrity from unauthorized accesses and mistaken operations. In the developed system, the security level is allocated to users (including operators), data and functions of each component. These security levels used for the system to control accessibility. The accessibility is defined between a user and data, and a user and a function of each component. Data accessibility is very clear. User with higher security level can search and order products with lower security level. Functional accessibility is a newly introduced scheme. As like data accessibility, this defines relationship between a user and a system function. For example, if a certain user has lower security level than that of an acquisition order function of CBI, he/she cannot access that function. Carefully configuration of priority levels can permit only authorized users with enough knowledge and training to have an access to certain functions and data to maintain system integrity.

4. HIGH SPEED RECEIVING AND ARCHIVING SUBSYSTEM

Real-time receiving and recording of satellite image data is the most important operation in ground receiving system. It requires very high speed in processing, and high reliability and availability since satellite imaging and RF downlink are very expensive. To achieve such characteristics, both of careful selection of hardware and precise programming are required. Our objective in designing receiving and archiving subsystem was to keep performance, reliability and availability high enough while reducing cost. The other aspect considered during design is the expandability. As usually data ingestion component is shared for several satellites, we designed RAS to be easy to upgrade for other satellites.

Key hardware components of RAS are data receiving card (DRC), a host computer and RAID. DRC is required to convert serial data input from demodulator to parallel data for recording. DRC was built in-house to have 400Mbps bandwidth. This is the only non-COTS hardware in the whole system. Host computer is needed to receive parallel data from DRC and store them onto RAID. Intel TM Pentium 4 or Xeon server was selected considering their high bandwidth and processing power. Fast progress of CPU performance and relatively low price compared to high-performance workstation/server also played important roles in the decision process. While selecting RAID system, the performance and reliability of a dozen of major RAID systems were tested using our own benchmarking program to choose reliable real-time storage equipment. While programming RAS software, careful attention had been paid on optimization. We utilized multi-processors to obtain consistent processing power to maintain sustainable data rate. Also careful buffer management was implemented to handle instant slow-down of writing speed to RAID. Single instruction multiple data (SIMD) instructions of Pentium processors are used for parallel processing to achieve high-speed data handling where applicable. Due to such implementation, the system meets the requirements for MWD performance and post-processing speed. During integration test, RAS showed Real-time receiving and recording of data of sustained data rate up to 360Mbps with BER of 0.

The expandability of RAS was implemented by modular design. Satellite specific modules can be easily plugged in to the RAS and changing configuration enables acquisition of data of new satellites.

5. HIGH PRECISION PRE-PROCESSING COMPONENT

In designing and implementing product generation component, CAP, we believed that it is a very important constraint for user to acquire image products of required level and of region of interest in limited time in certain applications. Besides, whole data should be processed and managed for the sake of archiving. Thus the CAP was developed to provide three processing order for product generation, namely, *primary product generation, primary passdata (raw data received from satellite) processing and secondary passdata processing* according to their processing priority. In primary product generation, specific scenes explicitly defined by *order* of user are generated in specified standard product level. This is to provide scenes of region of special interests for such as fire damage assessment and flood assessment promptly. Secondly, during primary passdata processing, scenes defined in *standard processing options* in terms of latitude and longitude, and cloud coverage are processed to provide standard products of region of general interests. For example, primary passdata processing can be defined on Korean peninsula with less than 30% of cloud coverage. Lastly, CAP generates rest of scenes for archiving purpose: secondary passdata processing. In such processing order, system can satisfy various requirements in time of product generation.

To achieve high geo-location accuracy, we adopted a sensor model so-called P2A after extensive test (Choi, 2002). Test result with SPOT and EOC of KOMPSAT-1 showed less than one pixel RMSE with 11 to 13 GCPs.

Another key aspect of CAP is automatic precision correction using automatic GCP matching algorithm. If relevant GCP chips are in the database, CAP finds the positions of GCP chips on the newly acquired image using GCP matching algorithm, and apply random sample consensus (RANSAC) algorithm to exclude outliers, namely false matches, from camera modeling. In this way, CAP can generate precision corrected scenes without operator’s intervention.

6. CONCLUSION AND FUTURE WORK

The development and integration test has been finished in August 2002. Test results showed compliance of all requirements as far as the test could be conducted. A few tests that require KOMPSAT-2 specific data, which were not available by that time, had not been conducted. For such tests, we have carried out analysis to verify if the system meets those requirements. These tests will be conducted with real data as soon as test data become available.

Considering ground receiving system for KOMPSAT-2, now customization is undergoing for the system installation at the KOMPSAT-2 ground station. System validation according to KOMPSAT-2 development schedule is going to be conducted as well. Such validation includes the interface test between the system to MSC and mission control element, site acceptance test, and end-to-end test. We will also provide technical supports during LEOP of KOMPSAT-2 in 2004.

Achieved technologies will also be demonstrated by building Landsat-7 ground receiving system. The operation of Landsat-7 ground station in Korea is scheduled early in 2003 and we will provide ground receiving system modified from the developed system. This would be the third verification of developed system with real operation before final verification of the system with 1m resolution satellite images from KOMPSAT-2 in 2004.

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