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Ground Receiving System for KOMPSAT-2

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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. The 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 for 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 from Dec. 1998 until Aug. 2002, the system had 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. In this paper, we present accomplished work and future work.

Key Words : KOMPSAT-2, Ground Station, Satellite, Pre-processing, High Resolution.

1. Introduction

Since the successful launch of KITSAT series, the Korean Government had 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 was necessary to develop an indigenous ground receiving system to maximize benefits of operation of succeeding KOMPSAT series. Developing a ground receiving system needs close collaboration with developing satellite system. Therefore, depending on foreign system makes communication difficult and may cause security problem. The ground receiving system is a very expensive system. Once having chosen a system, you should depend on that system because of the

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Table 1. KOMPSAT-2 Specification.

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
GSD	1m for panchromatic 4m for multi-spectral
Downlink	320Mbps QPSK

incompatibility among different systems. However, the upgrade of the system for other satellites and even small change of the system for customization requires high costs and a lot of time. On such reasons, to help successful implementation of the National Space Development Program, Koreanization of the ground receiving system was essential.

In technical aspects, the development of a ground receiving system for the KOMPSAT-2 required quantum leap of technologies from what we had. Data ingestion speed requires about 8 times enhancement. 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 (hereby, the system) and the necessity of Koreanization of the ground receiving system had initiated this project, developing ground receiving system for high resolution satellites. The objective of the project was to acquire key technologies needed to develop our own ground receiving system. We considered the target satellite as KOMPSAT-2, and had reflected KOMPSAT-2 specification as available.

Currently, we had finished the system integration test, and the development is at the customization stage for system installation at the KOMPSAT-2 ground station site.

This paper will present the result of the integration test of the ground receiving system for KOMPSAT2 developed and highlight the important features prioritized throughout the development procedures. In Section 2, we will introduce the objectives of the system and Section 3 will explain the development methods used. The Section 4 will be devoted to present the overview and the important features of the system. The verification methods and the results will be presented in Section 5. Finally, conclusions will present the current stage of development work and future plan.

2. System Objectives

The main objectives of the system are: 1) real-time receiving and near real-time processing of X-band downlink data for moving window display, 2) generation of high quality 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 (Kim, 2000c).

The first objective involves real-time archiving of satellite data and image processing for real-time display (Moving Window Display: MWD). This is a challenging task since high-resolution imaging satellite not only has higher data rate but also requires more extensive real-time data processing. For imaging satellites at 1m resolution, the data rate between satellite and ground station is not enough to transfer all information obtained by the sensor, hence compression process is usually adopted. Also for security purpose, encryption process may be added to the processing for effective communication such as forward error correction (FEC) and pseudo-randomization. All such processings with high data rate require higher processing power at the ground to recover image data. Moreover as satellite downlink is a very expensive process, the receiving system should be very reliable and have high availability. Summarizing all, the real-time receiving process requires high performance, reliability and availability.

The second objective requires high performance and high accuracy due to the extensive amount of data to process and the higher accuracy demanded for high-resolution imagery. To achieve this objective, efficient radiometric/geometric correction algorithms and accurate modeling are needed.

Third and forth objectives are more related with operation of system. Complete ground receiving system involves many components and operation requires various information and data to fulfill its objectives. Therefore system requires comprehensive management scheme for effectual operation. Also, enormous amount of data requires successful archive management. The operation of KOMPSAT-2 is expected to require at least 136T bytes storage for three years.

The last objective is to provide easy-to-use interface for inside and outside users to search, order and acquire satellite images of interest. In the viewpoint that a ground receiving system is a service and information provider, user interface as well as quality of processed images is very important.

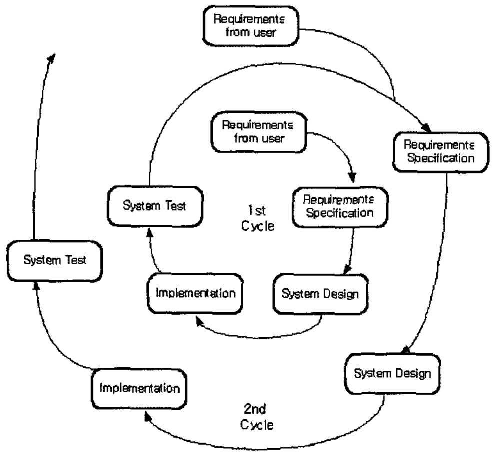

Fig. 1. Spiral Model.

Table 2. Prototypes developed.

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

3. Development Procedure

Spiral model had been used for process model as given in Fig. 1. The reason is to illustrate the progress in functionality and performance of system. When project began, there was big technical gap between what the ground receiving system for KOMPSAT-2 required and what we had. Therefore, prototyping was a good process model to give confidence.

This model is also very useful when final users cannot figure out all the requirements at the beginning of the project. User could provide additional requirements after operation of the prototypes meantime. Furthermore, as the KOMPSAT-2 project began later then this project, it was a good process model to make progress until the specifications of KOMPSAT-2.

As a result, three prototypes had been developed before the final system as shown in Table 2. First prototype was developed for SPOT. In this period, we

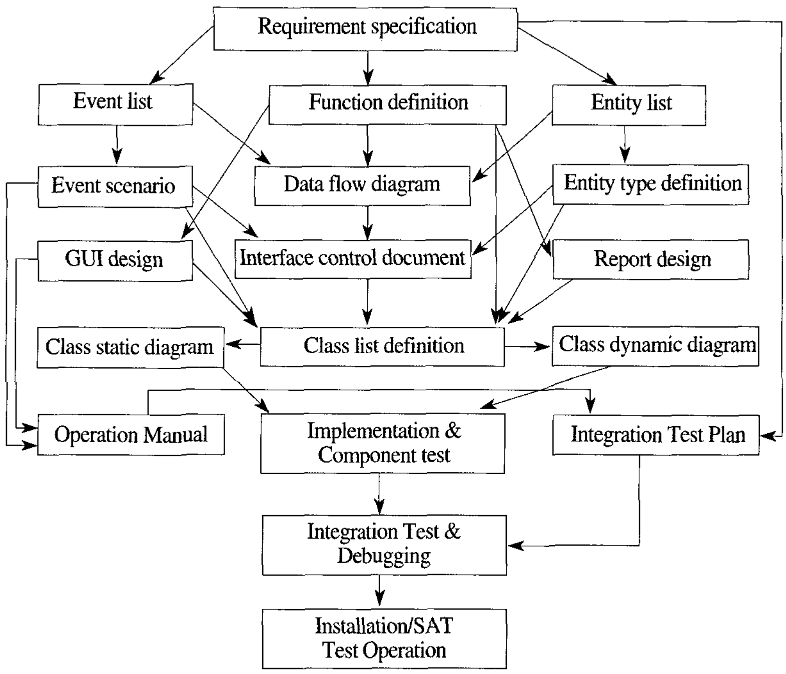

Fig. 2. Development procedure.

laid out the structure of the system, and demonstrated core modules for the ground receiving system such as direct receiving subsystem and pre-processing component. Second prototype was the more operable system for SPOT. The third one was developed for the KOMPSAT-1. In this period, we also demonstrate the portability of the technology achieved.

The final system was developed after three (3) prototypes with increased performance and functionality as project progressed.

In the spiral process model, we performed requirements specification, design, implementation and test procedures for each cycle. Fig. 2 shows the development procedure and the documentations available in detail.

1) Design Concept

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 a 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 catalog data and only authorized operators to system modules. For public data, user shall be able to access easily.

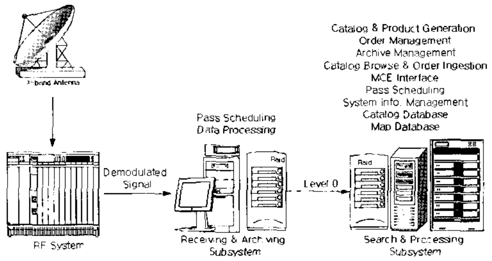

Fig. 3. Top level system block diagram.

The system design emphasizes full automation from image receiving to the generation of value-added products with minimum user intervention. High-speed data handling is achieved by using state-of-art technology in processing and storage equipment and appropriate redundancy is considered to provide high reliability and availability. System integrity and security are realized by comprehensive management system with a high performance commercial database. A PC-based receiving system contributes for low cost system and web-based user interfaces increase data accessibility. The whole system is based on the open architecture for easy upgrade of software and hardware.

In design process, system was divided into two subsystems as shown in Fig. 3: receiving and archiving subsystem (RAS) and search and processing subsystem (SPS). Former is responsible for the first system objective, namely, real-time receiving and processing of X-band downlink data and latter for others. Each subsystem was partitioned into several components considering functionalities.

We also included value-added product generation subsystem (VPG) into the system based on the idea that complete system should provide information not only data. There are many value-added products that can be defined. We selected a few of them to develop and they are DEM generation from stereo pair, road network extraction, and building extraction from high-resolution satellite images.

To achieve high reliability and availability, redundancy was considered. As a result, RAS, which was a mission critical subsystem, was designed to have hot redundancy and SPS to have warm redundancy.

4. System Specification

This section describes the overview of a ground receiving system for KOMPSAT-2 developed. The requirements and the system architecture were described well in Hong (1999) and Park (2001).

To satisfy the system objectives mentioned in Section 2, one hardware component and 13 software components had been developed. The hardware component was the data receiving card for the interface between demodulator of RF system and RAS host. The software developed and the data flow are shown in Fig. 4. We also devoted developing a few operational algorithms for value-added product generation that might be used at ground station to provide higher quality information. These are DEM generation (Im, 2002; Kim, 2002b; Kim, 2002c; Lee, 1999; Lee, 2003) and human-made objects identification (Kim, 2002a)

In this paper, key aspects of the system will be explained as follows.

1) 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. Security has been emphasized as high-resolution satellite images require higher security. In the developed system, they operate all together systematically.

Workflow of the system is managed by a component, so called order manager, utilizing *order* and *work orders*. Order is a user input that requests the system for new

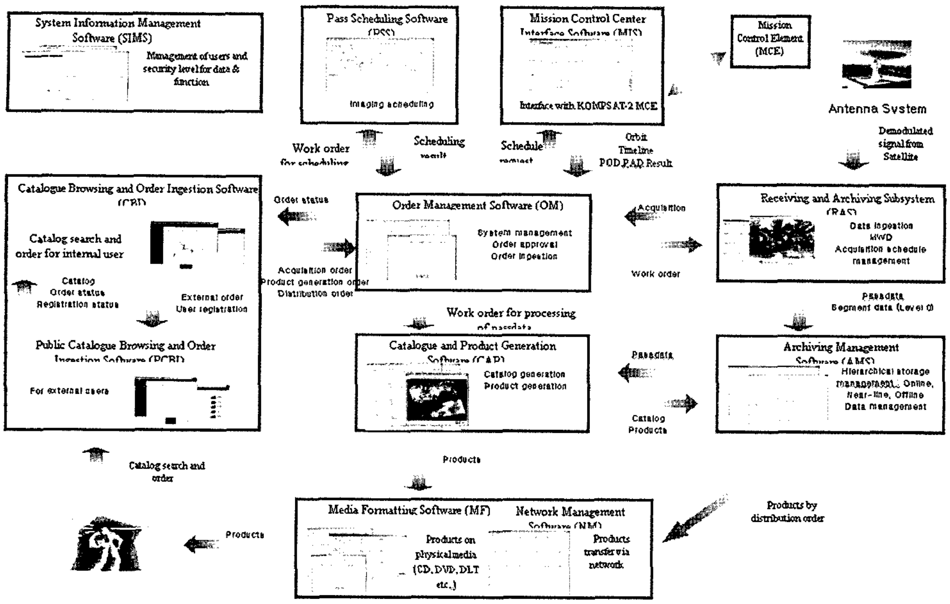

Fig. 4. System block diagram.

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 the *catalogue and product generation software* (CAP). The order manager monitors each component's progress and arranges 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, 2003). 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 digital linear tape* (DLT) library physically, are transparent to the system as like they are online. The capacity of a DLT 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 redundant array of independent* *disks* (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. The upper limit indicates minimum near-line free space required for system operation and the 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 hours. If the 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 the 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 a specific DLT to restore off-line data. When a certain component requests specific data to AMS, AMS looks for the database and finds the location of data: online, near-line, or offline. If the requested data are on the offline, AMS requests operator to supply a offline DLT to near-line. If the 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 the requested data to the system with minimum user involvement, and all the system components use the near-line data transparently.

The 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 the *catalogue browsing and order ingestion software* (CBI), she/he 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.

2) 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 the data ingestion component is shared for several satellites usually, we designed RAS to be easy to upgrade for other satellites.

The 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. The 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 developing the 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 the integration test, RAS showed the real-time receiving and recording of data of sustained data rate up to 360Mbps with BER of zero (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 the data of new satellites.

3) High Precision Pre-processing Component

In designing and implementing the 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 the primary product generation, specific scenes explicitly defined by *order* of user are generated in a 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, the 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, the primary passdata processing can be defined on Korean peninsula with less than 30% of cloud coverage. In the secondary passdata processing, CAP generates the rest of scenes for archiving purpose: secondary passdata processing. In such processing order, the system can satisfy various requirements in time of product generation.

To achieve high geo-location accuracy, we had developed and tested various pre-processing algorithms (Kim, 2000a; Kim, 2000b; Kwak, 1999). Finally, we adopted a sensor model so-called P2A after extensive test (Choi, 2002). The 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.

5. System Verification

Through three prototypes, the system has been verified through the component test, integration test, *random test*, pilot test and real operation. The basic system for SPOT was finally verified with pilot operation at SaTReC site. The system for KOMPSAT-1 was installed at two sites and they are under well operation.

The final system test has been conducted from December 2001 to August 2002. The component test, integration test, *random test* and pilot test had been conducted. The *test procedures* for the component test and integration test were designed to be able to verify whether the system meets all the requirements. The component test aimed to verify requirements assigned to each component and the integration test was designed to verify mainly interface and that system is well operative all together. Since considering all misuse of the system in the test procedures is not possible, so-called, random test was conducted. In this test, the test conductor used the developed system with minimum training to expose the system defects. The purpose of random test was to verify system stability and reliability. The pilot test is a simulated operation of the system to verify system availability and maintainability. If any defect is found during the test, the regression test is conducted after defect correction.

The 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 the test data become available.

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.

The final system will be installed at KOMPSAT-2 ground station sites, and will be verified during the LEOP through the real operation of KOMPSAT-2 in 2004.

6. Conclusions

The ground receiving system for high resolution imaging satellite has been developed aiming KOMPSAT-2. The developed system can support up to 320Mbps in data rate and up to 1m resolution in resolution. It also reflected well-defined design concepts that came from actual operation experience of ground station achieving high quality aspects such as superb archiving management, automation and security management scheme. The system was verified through prototypes for the available non-commercial and commercial satellites, KOMPSAT-1 and SPOT. KOMPSAT-2 specific requirements were also verified using simulated images and analysis.

At present customization is undergoing for the system installation at the KOMPSAT-2 ground station. Afterwards, verification at KOMPSAT-2 program level will be conducted including End-to-End test. We will also provide technical supports during LEOP of KOMPSAT-2 in 2004.

In research area, we will keep developing operable algorithms at ground stations for high resolution satellite images such as automatic precision correction. For the system, we are planning to introduce new technologies such as clustering and component technology in near future. Applying the developed system for other satellites will be continued and currently achieved technology are being used for developing Landsat7 ground receiving system.

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