ON-BOARD GEO-DATABASE MANAGEMENT IN FUTURE EARTH OBSERVING SATELLITES

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ABSTRACT

In order to let the end-users can directly downlink satellite imagery that they specify area of interest (AOI), One of key challenging technologies is how the on-board data distributor autonomously retrieves the imagery according to user's command as well as simultaneously retrieves the other data sets, such as, temperature, moisture, geographic attribute data, e.g. street name, from other databases, which will be used for providing the user better visualization and understanding to the situation surrounding him/her, especially they are not familiar with the environment. This paper presents a whole new design of concept for on-board geo-data management system in future intelligent earth observing satellite system. The concept design is based on the idea of using satellite imagery, supported by geo-data database associated with attributes and DEM database, as data sources to describe the real world of AOI, where the users specifically query through uplink to satellite from ground. The query results will directly be downlinked to users with a form of geo-image-map. Thus, the new data model, data structure and database management system has to be designed and developed for this purpose. The designed data model is able to manage the huge data sets so that the raster satellite imagery and geo-database can better be queried, visualized, flexibly handled.

1. INTRODUCTION

Enabling end-users to directly downlink satellite imagery, for which they specify an area of interest (AOI) (e.g., location and extent) in future earth observing satellites (Campbell et al., 2000; Prescott et al., 1999; Zhou, 2001b; Zetocha, 2000) using a simple receiving unit, such as a laptop computer and a mobile antenna, even, a cellular phone, one of the key challenging technologies is how the on-board data distributor autonomously retrieves the imagery according to user's command. Additionally, once the on-board data distributor finds the imagery specified by users in the image database, how does the on-board data distributor simultaneously retrieve other data sets, such as, temperature, moisture or geographic attribute data (e.g., street name), from other databases, which will be simultaneously downloaded to end-users directly? The solution to these problems may require a whole new concept in design of on-board data management. We here present a concept design of an on-board integrated management system for the management of image database, geographic spatial database (geo-database) and digital elevation model (DEM). The geo-database management system includes data organization, data structure, data model, query, etc. The purpose of the on-board geo-database management system is to provide the end-user with attribute information. The purpose of the DEM database management system is to directly provide the end-users with elevation information. The integrated data will give the user better visualization and understanding of the situation surrounding him/her. The basic idea of this concept design is (also illustrated in Figure 1):

(1) The satellite (network) sensors collect the Earth surface data/images. An on-board image data processor processes the image data and generates geocoded images, then archives the geocoded images in an on-board image database in real-time. As mentioned before, only changed data is archived according to the concept design of the future intelligent earth observing satellite (Zhou, 2001b).
(2) The on-board geo-database, called the *virtual sensor*, stores existing global geo-data including attribute data and spatial data. These data are effectively organized by data structure and data mode and are easily and quickly are accessed (retrieve and query) (Xie et al., 2000).
(3) End-users uplink/upload the request for an image downlink to the geostationary satellites. The on-board data management system in the geostationary satellites searches for the requested image data from the image database via geodetic coordinates sent by ground user. Meanwhile, the on-board data management system simultaneously searches for corresponding geo-data (attribute and spatial data) from the geo-database and elevation data from the DEM database.
(4) Satellite image data is taken as a backdrop, and geo-data and DEM are superimposed on the backdrop. After these data sets are integrated and are compressed by an on-board data processor, they are directly downloaded to end-users. The downloaded satellite image looks like a geographic image map, we call *geo-imagemap* (see Figure 1).

Obviously, the integration of satellite raster image data with the already existing geo-data is one of the important challenges, along with on-board image processing, on-board image geocoding, image database management, a spatial data structure/model, fast query, and an integrated management system for the management of image, geo-data and DEM databases. In the traditional GIS (geographic information system) community, the integration of satellite images and GIS has been accomplished by one of three basic methods (Ehlers et al, 1989; Abdelrahim et al., 2000): (1) *Separated but Parallel Integration*, which means that the image processing system and GIS system are separate. This is the oldest integration scheme and is mainly used for exchanging data between systems; (2) *Seamless Integration*, which means the GIS and image analysis systems are stored in the same computer and the functions of both systems are simultaneously accessed through a common interface. This type of integration still needs to exchange data between the two systems; and (3) *Total Integration*, which means the remote sensing data and geo-data support each other for analysis and processing, and make full use of the GIS and image analysis functionality simultaneously with no need for data conversion between the systems.

Most commercial GIS or image processing software packages currently support only the first two levels. Only a few GIS systems have the third type of integration functionality (Abdelrahim, 2000). However, all the integration schemes are for a single image or for management of two data sets in a workspace (Gong, 2000). In future earth observing satellites, the on-board autonomous geo-database management system (OAGMS) not only manages the huge image data sets associated with the geo-data and DEM, but also seamlessly links them together. For example, either vector geo-data or raster satellite imagery can be used to query the real world. Compared to current GIS system, the characteristics of OAGMS are:

(1) OAGMS manages three sub-databases (DEM, Image-database, and Geo-database), which are connected by a unique identifier. All data sources are seamlessly linked together.
(2) OAGMS does not require more powerful spatial data analysis capabilities compared to current GIS spatial analysis (e.g., transportation, hydrology, etc.). However, on-board fast query is absolutely necessary because of high-speed motion of the satellites.
(3) The interactive medium with users is wireless communication rather than a cursor and screen.

As we can see, the proposed design is based on the idea of using satellite imagery, supported by a geo-database associated with attributes and a DEM database as the data sources to describe the real world of the area of interest. The query results will be directly downlinked to users in the form of geo-imagemap. Thus, the new data model for management of the huge data sets is designed so that the raster satellite imagery and geo-database can be better queried, visualized and flexibly handled.

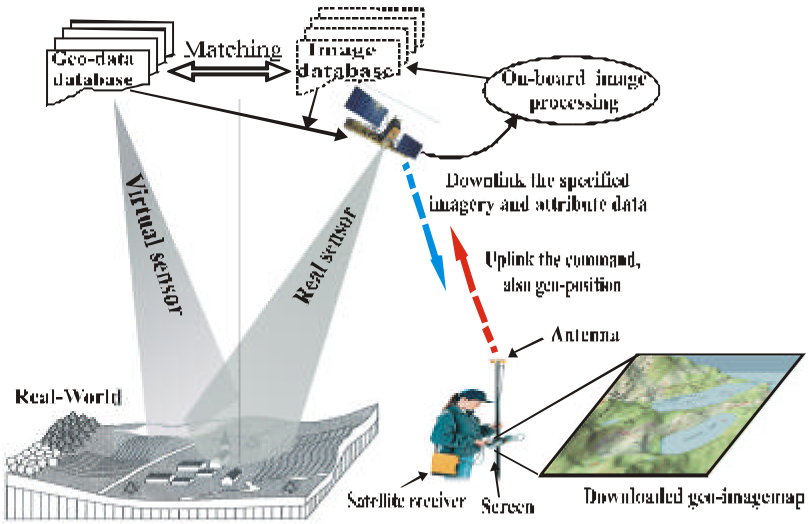

Fig. 1 Concept design of on-board geo-data management system

2. DATA TYPES AND DATA MODEL

In the on-board data management system, there will be three types of data sets: (1) satellite image (orthoimage) data, which are from on-board satellite sensor; (2) geo-data sets, which describe the spatial objects, like buildings, roads and rivers; and (3) DTM, which directly provides the elevation information to users.

2.1 DTM Data

DTM provides the elevation information for end-users by superimposing it onto imagery. Traditionally, there are three basic types of data structure for description of DTM: (1) a regular raster data structure, (2) triangular irregular network (TIN) and (3) hybrid. Each structureits advantages and disadvantages. In general, the grid structure is easy to handle, operate and store, but it cannot effectively represent complex terrain, e.g., a cliff. The TIN structure consists of an array of triangular areas. The points of each triangle are selected in an important position such that they can effectively represent the terrain. Thus, the area of the triangles varies. Usually, the smaller the triangles, the more complex the terrain. The advantage of this structure is that it can effectively represent the terrain in more detail, e.g., a cliff, using fewer points. Moreover, the calculation of slope and aspect of terrain is easy. The disadvantage is that it requires considerably larger storage capacity than the grid structure. In order to save storage space, the DTM in the OAGMS is represented in raster form, whose cell size, row, column, map project type, accuracy, etc., are recorded in an integrated management system (Zhou, 2001b).

2.2 Satellite Image Data

The original satellite images from the on-board satellite sensor are co-registered to the ground coordinate system using on-board image processor with specified algorithms. For example, an algorithm for orthorectification was described Zhou (2001b). All image data are stored in an image database, and are queried via an image identifier (ID). According to the concept design of the future earth observing satellites, only changed data will be transmitted. Therefore, only the changed area/image in the image database is updated (Oertel, 1998; Schetter et al., 2000; Hallel, 2000).

2.3 Spatial Objects

The geo-spatial data object is the abstract of an entity in the real world. The spatial object has two obvious features: (1) geometric characters, which indicate their size, shape and position, and (2) physical characters, which indicate their nature, such as a river, house or road. Spatial objects in the real world are thought of as occurring as easily identifiable types: points, lines, area and complexes (see Figure 2).

- **Point Object:** Its space is zero-dimensional; thus, it has a position but no spatial extension. Three types of point objects are (1) a single coordinate point without direction (used to represent the point location, such as control points and wells); (2) a single coordinate point with direction (used to represent point location and its direction such as bridges, when a bridge is represented with a point and its direction); and (3) a point cluster (group of coordinate points).
- **Line Object:** Its space is one-dimensional or two and a half dimensional (e.g., a power line); thus, only its length is measurable. For example, a linear path consists of any number of connected arcs where none branch.
- **Area Object:** which means its space is two-dimensional. Thus the area and perimeters are measurable, e.g., a polygon or multiple-holes polygon with no overlay.
- **Complex Object:** a compound object consisting of at least one other object.

These defined primary geographic entities are taken as basic classes, and other geographic entities are derived from these primary geographic entities. For example, line and area types of an object probably consist of several arcs, and each arc has two terminal points. Collectively, these four objects can represent most of the tangible natural and human phenomena that we encounter on a daily basis. This data model not only inherits primary operators but defines its own special operators. Thus, a spatial object can be extracted into one of the object types according to its attributes (see Figure 3).

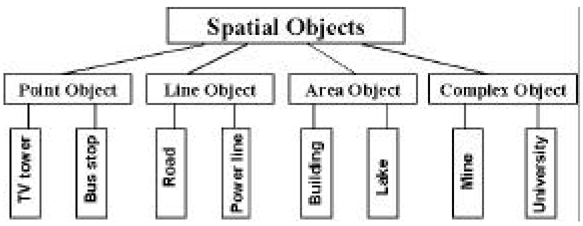

Fig. 2 The spatial data types in proposed on-board geo-database management system

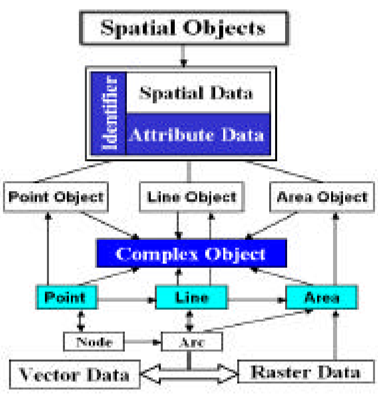

Fig. 3 Spatial data model proposed

3. IMPLEMENTATION OF THE ON-BOARD GEO-DATA DATABASE MANAGEMENT SYSTEM

3.1 Three separate database management systems

3.1.1 Image Database Management System

In the image database each scene is stored as a unit. Due to the huge data volume of each scene, it is difficult to meet the demands of real-time query. Thereby, each scene is divided into different blocks, and each block is stored as a sub-unit with a specific name. Each block is easily indexed by a unique identifier, which is represented by a type of code, such as geodetic coordinates in UTM (Universal Transverse Mercator). Once the image management system accepts a command for query, a pointer will index block (image) ID and immediately access the block data directly according to the spatial position (latitude and longitude) (Figure 4). After the image of the AOI specified by ground user is retrieved, the on-board image processor will automatically re-sample it to the resolution that fits both the extent of the image and the size of the ground users screen. Thus, downloaded data will be displayed in a different display scale on the users screen size. This type of data management not only saves the on-board storage space, but also increases the search speed without degrading the accuracy of the image.

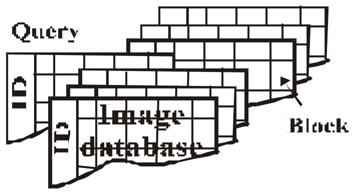

Fig. 4 Image database management

3.1.2 DEM Database Management System

As mentioned early, the purpose of the global DEM database is to directly provide elevation information for users without any processing on ground. The global DEM data in the DEM database is divided into different block, whose size is fit to the image block. The data structure and model are similar to the image database. The DEM block is indexed according to a type of code, which is a unique identifier we call the *DEM identifier*. In addition, the DEM data processor will automatically generate DEM pyramid data, which fit the image size specified by users. Thus, we can view either the whole area at small-scale or the local area at large-scale.

3.1.3 Geo-Database Management System

The data model shown in Figure 3 is a relational model, which can be implemented by relational database technology. In this model, we have spatial data and attribute data. For the spatial data, each type of object is defined as a table. For example, a tree is defined as a point type table. For the table of point type, we further define the point identification (PID), point attribute identification (PAID) and point name (PN). The PID is for identification of the type of point object. The PAID is for linkage to attribute data. Different point objects have different attribute data. For example, a tree and a well have different attribute values. The PN is for identification of a geometric point.

Similarly, for line objects, we also define the line identification (LID), line attribute identification (LAID) and line name (LN). Different line objects have different attribute tables, but the LAID will always directly link to the attribute data table. The area objects have a similar structure. For example, different areas have a different area identification (AID) and attributes. An area attribute identification (AAID) is designed for linkage of attribute table and spatial.

As we have seen, the attribute data and spatial data must be connected by a unique identification. In current GIS systems, the connectivity between attribute data and geometric data is accomplished by either organizing attribute data and spatial data in the same record, or separating them and specifying a link. The former connection is rigid, causes large redundancy and restricts data sharing. Our scheme is to directly employ the spatial data (geodetic coordinate) as a unique identifier (index) to connect the attribute and spatial data. This is because the ground users directly use a geodetic coordinate to query their image AOI. For example, if a spatial object type is a type of point object, we may put spatial data and attribute data together because the coordinates of this point can directly be considered as two attribute items, and can be put together with other attribute values. If the spatial object types are a line or area type of object, the coordinates are taken as attribute items for the coordinates of an individual point describing the line or area. In this case, a unique identical code (identifier), which corresponds to each type of object (PID, LID and AID) has to be created as previously described. The connectivity between attribute data and graphic data can be carried out by unique identifiers (Figure 5).

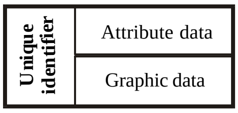

Figure 5. The connective between attribute data and graphic data.

3.2 Integrated management system for three sub-systems

Three types of data are stored in three separate databases. An integrated management system is designed to manage and process the three sub-systems and queried data sets. A dynamic linking pointer (DLP), e.g., geodetic coordinate, is designed for connection of three databases. With DLP, the query can simultaneously be carried out in each of the image, geo-data and DEM databases. The integrated management system also is responsible for superimposition, scale, compression, coordinate transformation and transmission to on-board data distributor (Figure 6).

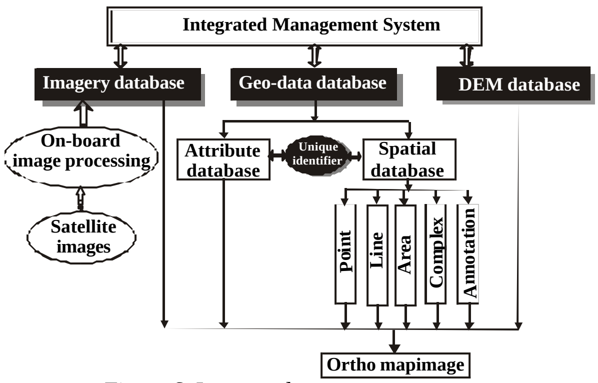

Figure 6. Integrated management system

3.3 Query operation

When an end-user on the ground uploads his/her command for local imagery, the geodetic coordinates of the end-user and extent of AOI imagery are simultaneously uploaded to the on-board integrated database management system. A corresponding ID is created for retrieving imagery from the image database, geo-data from the geo-database, and DEM from the DEM database. After the three data sets are retrieved from the separate databases, they are merged into the integrated management system where superimposition, coordinate transformation to fit screen size (like Geo-tiff format), data compression, etc., takes place. The data sets are finally transmitted to an on-board data distributor.

Each end-user receiver on the ground includes a GPS receiver that can provide the user's position (latitude and longitude) in a geodetic coordinate system in real-time. Different receiver's parameters, e.g., size of screen, display speed, display resolution, etc., are stored on-board. The user's satellite receiver is also coded for on-board recognition of receiver types. As long as the on-board data management system recognizes the receiver's ID, it can immediately know the receiver's parameters. Thus, as soon as a user opens his/her receiver and uplinks to satellite for request of downlinking AOI image, his/her position (latitude, longitude), receiver's parameters, etc., will immediately be known to the on-board satellite autonomous management system. End-users also can download imagery of any AOI (for example, someone in Norfolk can obtain image data of New York City). Similarly, the on-board management system will search for AOI imagery based on specified coordinates and retrieve all available information based on these coordinates. The system then identifies the attribute data related to that query, defines its occupation areas, identifies the screen pixels that belong to these features and highlights them. If nothing is found, the integrated management system will immediately inform all subsystems to stop search and send the feedback to ground users.

Finally, the end-user should get an "image" in which the satellite imagery is supported as a reference layer in querying the real world by user. The existing geographic data (attribute data and DEM) will be superimposed on the imagery. The purpose of superimposition is for better visual analysis and understanding of the situation.

4. KEY TECHNOLOGIES OF ON-BOARD GEO-DATABASE MANAGEMENT SYSTEM

This management system uses the image as a reference layer in which the geo-data and DEM data are superimposed for analyzing and querying the real world. This type of product (geo-image map) contains more information than traditional satellite imagery (Mckeown, 1987). Users can better orient themselves with a geo-image map, especially if they are not familiar with the area under consideration. Furthermore, using satellite imagery as a backdrop beneath the map layers will increase the visual interpretation of an event. Realization of this function will encounter the following challenges:

(1) Retrieving the raster images, DEM and attributes as well as returning them to a user faces speed problems. More advanced query technologies, which considers *"on-the-fly"* query, need to be investigated (Alkalai, 2001).

(2) As the complexity increases, more data, especially attribute data, will be involved. It will be time consuming to query them one at a time. In order to reduce the downloaded data volume, the on-board decision-making processor should determine which data are most important and necessary to a particular user (Dawood et al., 2001; Ramachandran, 1999; Surka et al., 2001).

(3) As mentioned, the orthoimages are used as a geographic reference layers. The images may be differentially rectified, partially rectified or un-rectified because of on-board autonomous processing. When attribute data are superimposed on these images, the error of superimposition should be investigated.

(4) Inappropriate linkages of DEM, images and geo-data may produce slower performance, confusion and inaccurate results in downloaded imagery. If the linkage between the raster image and the geo-data is established through ground features, feature recognition is a big problem. If linkage is established via feature (geodetic) coordinates as we propose, some factors, such as scale, projection and coordinate system, should be unified.

5. CONCLUSION

In summary, the proposed OAGMS provides an approach for on-board integration of satellite data with corresponding geo-data (spatial and attribute data) and DEM data. The approach is based on the idea of using satellite imagery as a reference layer. Users can directly retrieve spatial information and perform spatial query via uplink of their commands to FIEOS. The geo-data is used for support of image processing, image interpretation and feature extraction. Thus the OAGMS is complete and seamless in connectivity of satellite data and geo-data.

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