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Methods of 3D map storage based on geo-referenced image database

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Abstract: In order to store and manage a large amount of ground and indoor image data with high resolution, an integrated data management system needs to be developed. Possible strategies for this purpose were discussed together with initial test on the newly defined 3D maps. The features of such 3D maps, data organization, key techniques used for the map storage, such as image compression based on wavelet transformation, quadtree index, update and retrieval, were analyzed, with the goals of bringing some profits to the storage and management of the digital data in the visual construction of digital mine, digital city and digital community.
Key words: 3D map; geo-referenced image; image database; storage technology

1 Introduction

With the development of remote sensing and photogrammetry technology, people are able to obtain high-resolution images with ease. Still there are many unmet needs. Traditional 2D map and low resolution image data obviously cannot provide enough information to meet the growing spatial information needs for various applications. Therefore, the high resolution 3D landscape model and 3D map data become the indispensable basic data in today's information society [1−3]. In fact, three-dimensional geo-information has become an important subject within the geo-spatial information community for many years. Research mostly has been concentrated on aspects such as 3D data collection and modeling, data management (e.g. topological, geometrical models), 3D data analysis and visualization (e.g. virtual reality etc.).

In this work, the methodologies were discussed to store a 3D map which was developed primarily for navigation purposes. The concept of the map was introduced along with the database technique used. The database management techniques for the 3D map were discussed in detail.

2 Concept of 3D maps and database techniques

2.1 Introduction of 3D map

One of the most important applications of a 3D map is navigation because a 3D display of the environment simulates spatial reality, thus enabling the viewer to recognize and understand the navigational environment with ease.

In the literature of 3D navigation, a good number of contributions have been made using various technologies and methodologies. The method discussed here is especially designed for the map proposed earlier [4−5].

The 3D map is defined as a sum of geo-referenced points with three dimensional (3D) local or global coordinates that are overlapped on images of the environment [4]. This means two types of information should be stored: images themselves and 3D coordinates, and it is important to realize the relevance between these two types of data. The development process as well as the function of the map is shown in Fig. 1.

The main function of the map would be for positioning and navigation purposes. Whenever a new image is taken, it can be matched with the images stored in the 3D map database and therefore enables the user to locate its position. The main difference between our approach and the available image-based navigation methods lies in the fact that the images are geo-referenced, which means that they themselves can give absolute position information (local or global) in 3D, functioning like a sensor, and at the same time can be used as a map for any indoor localization services [4]. At the same time, it can be used for visualization as well as an advanced surveying tool.

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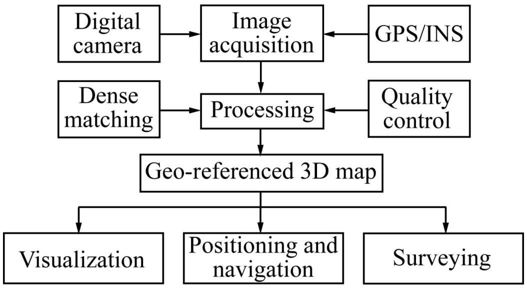

Fig. 1 Generation and function of 3D map

2.2 Database technique

As has been mentioned, it is basically a database of images along with the interest feature points from each image. Even when the interest features have been extracted and stored with the images to improve efficiency, most image database still requires matching through the entire database.

The database techniques adopted here use a mixed management strategy. The original images are stored and remain stationary when the metadata information and snapshot view are extracted and stored separately. When inquiring any (image) data, metadata is searched via attributive and spatial fields, then the image in need is identified. When processing the data, the original data were obtained according to the storage path information in query results and the related processing is performed. Because the original image does not move, the possible data lose and the damage is avoided. The database only stores metadata and snapshot view, thus it only needs a small amount of storage space, avoiding the expansion of the database. As long as setting up search conditions at the start, due to the existence of the index, the querying process can be very efficient. Only by inquiring the indexed database, we get to know the image information, the location where they are stored, their properties, and relevant snapshots. Through those information, we can distinguish different types of data, thus obtaining the needed image data, instead of checking every image.

3 Storage and management of 3D map

3.1 Storage structure design of 3D map

3.1.1 Organization structure of 3D map database

Most existing GIS softwares are not suitable for organization, schedule, store and managment of such mass data, for they do not considered the question of unified management and integration of the multi-data-source, multi-scale and multi-temporal image data. If we want to efficiently store and manage the image data in the spatial database, we must resolve the following questions:

1) The management of the mass image data;

2) The data organization structure, data compression, quick retrieval mechanism and related algorithm of 3D map;

3) Studying the management of the multi-source data [6].

3.1.2 Stored data structure of 3D map

Two types of information need to be stored: images themselves and 3D coordinates. It is important to realize the relevance between these two types of data. 3D maps also have characteristics of time, space attribute, etc. We can choose the following data structure [7] to store the image data in the spatial database, as shown in Fig. 2.

Image ID
Image type
Image version
Compress symbol
Image size
Image data
2D coordinate
3D coordinate
Describe information

Fig. 2 Stored data structure of 3D map

At present, the management, query, and display of image information became a practical problem to solve. Graph roaming is a common technique in use. The core of image data management is blocking images. Due to the large volume of image datasets, the requirements of real-time scheduling are hard to fulfill. So, the framing images need to be stored partly. Through the pointer of the index record block, when images are roaming, directly pointing and transferring of the data block are realized according to the spatial position which is indexed to the pointer.

3.1.3 Image compression technology

Setting partitioning in hierarchical trees (SPHIT) was published by SAID and PEARLMAN [8]. The algorithm uses spatial orientation tree to generate and split sets, the so-called quadtree structure, as shown in Fig. 3. After the image is decomposed by wavelet, the nodes of the lowest frequency sub-band are quite special, among them, the node of left is not children, other 3 nodes

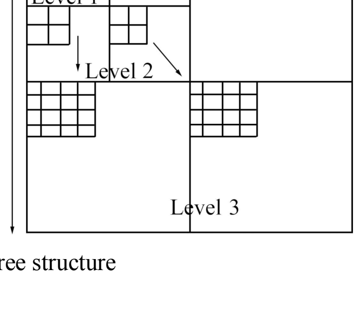

Fig. 3 Quadtree structure

respectively are father nodes of the next frequency domain. Every parent node has four children, constituting the quadtree structure.

First define several sets to facilitate the description: $X(i, j)$ expresses the wavelet coefficients of this node; $O(i, j)$ expresses the coordinate set of direct children of wavelet coefficients which are located at (i, j); $D(i, j)$ expresses the coordinate set of all descendants of wavelet coefficients which are located at (i, j); $L(i, j)$ expresses the part which is the rest after the coordinate set of all descendants of wavelet coefficients of this node removes the direct children nodes; H expresses the set of root nodes. SPHIT algorithm creates three tables, LIP, LIS and LSP, which separately expresses the invalid pixel table, invalid set table, effective pixel table; $S_n(T)$ expresses the effective flag bit of T.

$$S_n(T)=\begin{cases}1, \max\{|x_{i,j}|\}\geq 2^n\\ 0, \text{others}\end{cases}$$

This algorithm process description is as follows. First initialize, obtain $n=|\log_2(\max_{(i,j)}(|x_{i,j}|)|$, and n takes the maximum integer. Let the LSP table empty, the coordinate (i, j) join LIP, the descendants of (i, j) join LIS, taking $D(i, j)$ as class set. The next is classified scanning process, scanning the elements of LIP and LIS in turn, through the maximum or minimum value judge whether the father node under current threshold is effective. If the node is valid, put it into LSP, and output the sign bit of the node coefficient. Because the highest order of this coefficient is “1”, the bit does not output. Then scanning the children nodes whether there are effective nodes. The judgment process is similar to father nodes: $O(i,j)$ has four nodes which need respective judge and classification. The other children nodes may also have children, so $L(i, j)$, which should be scanned and classified. By scanning continuously, the wavelet coefficients of quadtree are judged and classified, the nodes, which have appeared in the LSP, output the most significant bit n of $X(i, j)$. Then make $n=n-1$, sequentially scan points and sets of LIP and LIS, until n becomes a certain value, such as −1.

3.1.4 Retrieval and update of images

A distinctive feature of our tasks from normal image database development is that the system should primarily support images as queries. The best candidate image (most corresponding to real time query image) should be efficiently identified from large quantities of images stored in the database. One of the most beneficial methods for increasing the performance of queries is the creation of efficient indexes, which can help to avoid the necessity of scanning the entire database for results.

The existing image information retrieval queries are based on text attributes of target images (such as the spatial location and image types). The text database information retrieval is based on the text information. Both have the same semantic information, and cannot fully and uniquely describe complex image information. And the extraction of the semantic information of images must be based on the basis of image processing and computer vision technology. The support which is based on the knowledge technology and database technology is needed. The ability of discovering knowledge from the spatial database, and the semantic information which has been extracted must be managed, analyzed and applied in the spatial database.

The image information update is also the important function of spatial database management, which puts forward the requirement of creating and maintaining the tense library. There is a big difference between the image updates which take the pixel as the basic information unit and the update of text data. With the enhancement of the acquisition time and resolution of images, the frequency of image update is greatly increased. However, the method of image update which mainly relies on the time factor has obvious shortcomings, so it is important to study the updating technologies based on the images information content, especially based on the image texture information and structure information change, also the technology of quickly searching the image update subsegment

3.2 Data processing of 3D map

3.2.1 Data pretreatment

Non-damascene technology is the premise of realizing the seamless mosaic, which involves the geometric correction and grey scale mosaic of images.

The goal of geometric correction is to make images which have been corrected to locate a map projection way over again. The correction is suitable for the recombination of various orientation, measurement, recombination with multi-source images, and the register display and processing with other data. The most extensive used geometric correction method is the polynomial correction. On the basis of image geometric correction, it can realize the geometric mosaic of images. The commonly used method is the geometric mosaic technique, which adopts the polygon broken line to choose juncture points.

3.2.2 Using HDF data structure to realize comprehensive handling of multi-source data

Hierarchical data format (HDF) file format is a hypertext file format [9]. HDF data structure comprehensively manages 2D, 3D, vector, attribute, text information, which can help people to avoid the trouble when transforming the different data format, and analyzing the data using more time and energy. As shown in Fig. 4, HDF can store different kinds of scientific data,

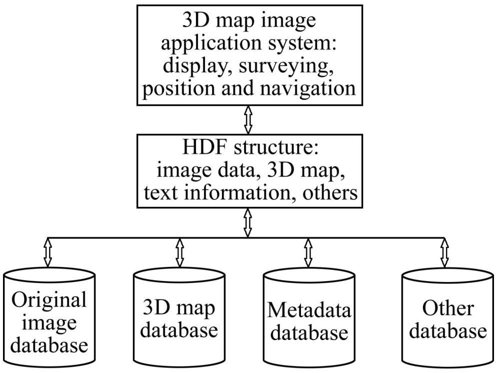

Fig. 4 Principle and structure of HDF applied to 3D map database

including the image multi-dimensional array, pointer and text data [10−11].

The advantages of HDF file format are: the high portability (platform independent); a kind of hypertext documents; storing and processing large amount of data; managing multiple types of data structure by a file set; the extendibility.

3.3 Spatial index and image scheduling

3.3.1 Spatial index

The data structure is arranged according to a certain order either based on the location and shape of spatial object or the spatial relationship among the spatial objects, which includes the summary informations of spatial object, such as the object identity, the outside rectangle, and the pointer to the spatial object entity. Through the screening effect, those massive spatial objects which are irrelevant to the specific spatial operation are removed, to improve the speed and efficiency of the spatial operation [12]. The quadtree index structure is simple, the inquiry efficiency is quick, and the data redundancy is less. But the image data volume is large, and the rapid inquiry is needed.

Split the known range of space into four equal subspaces, among which some can be continuously divided if they are needed, the space subdivision formed by this way is based on the quadtree, as shown in Fig. 5 [13].

After establishing the spatial index of the quadtree, we can retrieve data through the spatial index. Based on the spatial index of the quadtree, when retrieving data, firstly start from the root node to traverse the tree node, and compare the scope of four child nodes of the root node whether overlap with the inquiry scope. If no overlap, then the subtree under the child node is not considered; if there is overlap, then continuously inquire recursively the each child nodes, until the leaf node. Through this process, we can quickly determine where the inquiry range lands on, removing most of factors of files. Then choose each factor of nodes to judge the precise spatial relation in turn, and determine the ultimate selected element.

3.3.2 Image scheduling

Let a user wish to search for an image similar to a query image. Processing of query (image or graphics) involves extraction of visual features and/or segmentation and search in the visual feature space for similar images. An appropriate feature representation and a similarity measure of matched image pairs to rank candidate images from the database, given a query, are essential here.

The image data quantity is enormous, and growing continuously. So scheduling the whole image not only has a low efficiency, but also produces redundant data, and wastes memory resources. Generally, users do not need the whole image data, but only need the data of particular area. And the roam and browse of mass image always demand the process to fast smooth and steady. So, a reasonable image data structure is needed, and the excellent image scheduling algorithm is also needed. Only by combining use of the two, one can achieve the goal of fast browsing of mass image. The cross source image cohesion and scheduling, image slice on-demand scheduling, caching buffering mechanism are the better solutions.

4 Experiments

In the initial test for the storage of 3D maps, we use ESRI ArcSDE geo-database to support the management

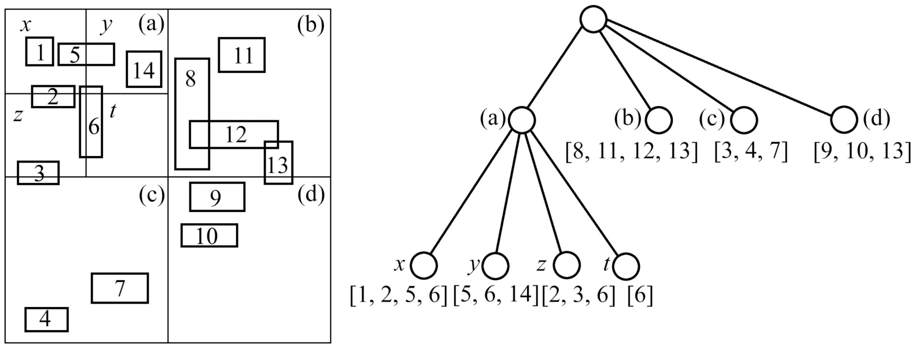

Fig. 5 Quadtree index structure

of initial datasets (geo-referenced images). It enables us to not only store images along with its spatial information, but also view the datasets through an interface.

It mainly consists of two steps. In the first step, images with overlapped areas are stitched together via a mosaic program. The mosaic is based on image matching via SIFT algorithm [14]. It extracts interest feature points from each image and finds corresponding points in images with the common area. In order to remove mismatches and improve the accuracy of the map, the transforming matrix $\boldsymbol{H}$ is computed with RANSAC algorithm [15]. And finally image mosaic is completed with smoothing algorithm. Figure 6 shows one of the initial results from the mosaic program.

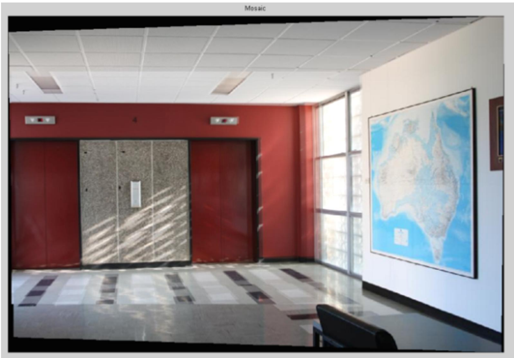

Fig. 6 One example from mosaic program

In the second step, the whole datasets are imported into a database supported by ArcSDE. Main three layers are created: image layer, mosaic layer and spatial information. The image layer consists of multiple images with overlapping areas sharing common space.

The mosaic layer is created for mapping and visualization purposes. The spatial information layer is used to store the 3D coordinates of feature points and can be overlapped with other layers to show their distribution on the map. Figure 7 shows one instance of the database management structure in the same space shown in Fig. 6.

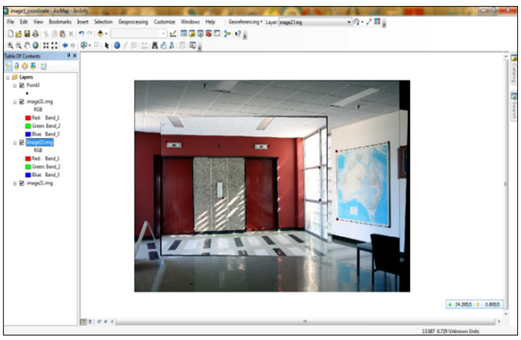

Fig. 7 Database storage and management

5 Conclusions

The database technology was used to solve the newly proposed 3D map storage problem. 3D map was introduced and compared with 2D map. Storage strategy has some main technologies, data structure, compression, update and retrieval problem. 3D map processing and spatial index for the study are also explained, and proved through some experiments. Future study will apply these theories to the construction of digital mine, digital city and digital community.

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