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INTEGRATION OF IMAGE ANALYSIS AND GIS FOR 3D CITY MODELING

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ABSTRACT

This paper focuses on the integration of range image analysis and GIS for 3D-city modeling. Special attention is given to the generation of buildings and ground surfaces in urban areas. We try to integrate data from multi-sources, optimizing the algorithms in different levels, and to find a suitable way for operationally generating 3D city databases. The algorithm of range image analysis is developed for extraction feature in different levels and reducing the range data uncertainties by adding constrained vector data from GIS. For generation of complicated buildings in detail, four kinds of spatial data (GPS/TS points, CAD data or old drawings, close-range digital images, and close-range range data) have been integrally used in our processing. In order to create 3D virtual reality models, several kinds of digital data are used for texture mapping of generated 3D objects surface by surface. Finally, some experiments with real application data have been given for building 3D city models.

Keywords: Image Analysis, Laser Range Data, Information Fusion, Object Reconstruction, and Virtual Environments.

1. INTRODUCTION

Over the past few years, the need for describing 3D spatial data in urban areas is continually increasing. These data are used for variety of applications such as urban planning, architecture, disaster prevention, emission or pollution of industry, microclimate investigations or transmitter placement in telecommunication. Many kinds of raster and vector based models for describing, modeling, and visualizing 3D spatial data in urban areas have been developed. At the mean time, with the fast development of sensor techniques and computer science, several kinds of airborne or close-range laser scanners are available for acquisition of 3D digital surface data in real or very fast time. A few more kinds of digital photogrammetry workstations are also available for semi-automatic interpretation of the complicated man-made 3D objects in urban areas. However, due to image noises and limited resolutions of currant laser range data, many existing techniques are still need to be extended to fit real applications. Integration of data from multi-sources is also needed for reducing data uncertainties.

This paper focuses on the integration of range image analysis and GIS for 3D-city modeling. Special attention is given to the generation of buildings and ground surfaces in urban areas. We try to integrate data from multi-sources, optimizing the algorithms in different levels, and to find a suitable way for operationally generating 3D city databases. For range image analyzing, a feature extraction algorithm has been developed. The key points of this algorithm are integration of feature extraction in different levels and reducing the range data uncertainties by adding constrained vector data from GIS. For generation of complicated buildings in detail, four kinds of spatial data (GPS/TS points, CAD data or old drawings, close-range digital images, and close-range range data) have been integrally used in our processing. Since the data from multi-sources may cause different scales and accuracy, the algorithm for fusion of multi-source information has also been presented. To interpret man-made or high structured spatial objects from laser range data, a new up-to-down method by using model based matching is also used in our system. In order to create 3D virtual reality models, several kinds of digital images (high-resolution remote sensing images, digital air photos, and close-range images) are used for texture mapping of generated 3D objects surface by surface. For generation of ground surfaces based on DSM and extracted buildings, Constructive Solid Geometry (CSG) operations are used. Due to noises in laser range data, several filtering and editing methods are also developed in our approach.

By using the above presented algorithms and methods, some experiments with real application data have been made for building 3D city models. Related spatial objects, such as buildings and ground surfaces, have been extracted and transformed into our 3D GIS system. From our approaches and experiments, we can find that the laser range finder will play more important role in generation of 3D urban GIS. Integration of ranger image analysis and GIS can supply an efficient way for building 3D city models.

2. METHODS FOR 3D MODELING

2.1 **Basic definitions**

There are several areas in urban system whose design and management can be considerably improved with the help of 2D or 3D visual modeling. Among these needs are traditional mapping, infrastructure design, urban planning and environment. Since there is not a clearly defined terminology for various types of 3D city models, we may simply call a 3D city model as a special computer representation of all fixed 3D spatial objects (buildings, vegetation, traffic- and waterways) within an urban area.

For different purposes and applications, such as GIS related 3D spatial management and analyzing, simulation and visualization of urban planning, and building design and construction, there are several kinds of 3D city models existed now. The 3D spatial objects in urban areas are described as the different detail of their structures. The 3D object is called the prismatic model, in which the building is represented as a cubic box with the fixed parameters or as an object with the plain polygon adding the same height. The 3D spatial object is called the parametric model, in which the building is represented with its roof structures. The complicated representation of 3D objects also added their surface textures.

2.2. Data acquisition methods

Acquisition of 3D data need to distinguish objects visible from space, objects only visible from the ground and objects below ground. Most efficient techniques are those which can rely on images, intensity images of range images, and at the same time can cover large areas. For acquiring building, vegetation and streets a number of techniques are available:

- *Photogrammetry* in this context is based on aerial photographs. It allows deriving 3D information with high accuracy and efficiency.
- *Laser Range Scanner* immediately leads to a high-resolution DSM, which can be used for reconstruction of buildings, traffic networks, vegetation, and power lines. Cost is getting comparative to photogrammetric techniques.
- *Remote Sensing* relied on the digital satellite images with high resolution. This kind of space image has expected to be used for acquiring 2D or 3D spatial information over large areas.
- *Mobil Mapping* in this context is based on the real time data acquiring system, which integrated by GPS, INS, digital cameras or laser scanners. These kinds of systems are very efficient for acquiring 3D traffic network data, and large-scale spatial objects around the roads.

Even though there are several kinds of techniques available for acquiring 3D spatial data in urban areas as mentioned above, due to their resolutions, qualities and costs many practical problems are still existing for efficient use of these techniques.

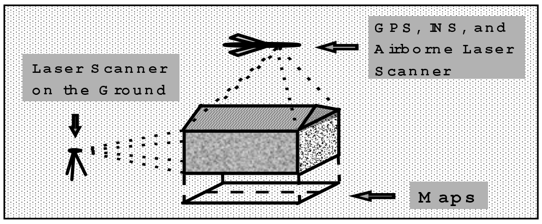

Figure 1. Integration of laser range images and existing maps

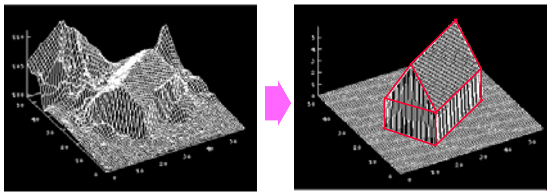

Figure 2. 3D object reconstruction based on laser range images

2.3. Strategy for generating 3D models

Our goal towards to reconstruct large-scale 3D spatial objects in urban areas by using the laser range images (airborne or on the ground) and existing maps or 2D geographic databases as shown in Figure 1 and Figure 2 [Weidner and Foerstner, 1995]. Laser range images can be thought as a kind of high-resolution digital surface models (DSMs). The reconstruction of 3D objects from laser range images can be simply thought as the 3D raster-vector conversions from a noisy DTM to parametric CAD formatted 3D vector data. Due to the limited resolutions and noisy, the existed low-lever processing methods for reconstruction of 3D objects from laser range images generally can not fit to real application needs. Large scale urban planning maps (generally in the scales from 1:500 to 1:2,500) serve as set of well organized high lever data source interpreted and generalized by human operators would be a kind of useful knowledge for 3D object reconstruction and recognition. According to this basic idea, we designed our strategy for generating a 3D city model as follows:

- Laser range image filtering and segmentation;
- Generation of 2D spatial objects on the ground surface by 2D map raster-vector conversion;
- Integrated processing for reconstruction of parametric 3D objects;
- In-door modeling complicated buildings based on ground surveying and closed range data;
- Texture mapping and visualization.

3. KEY ALGORITHMS

3.1. Range image filtering and segmentation

For the purposes of range image filtering and related object segmentation, here we used Mathematical Morphology (MM) based approaches (Chen, 1991). Generally, MM operators (such as dilation, erosion, opening, closing, hit or miss, thinning...) can be described as a kind of combination of shift and logic operations. Shifting operations are controlled by the given structuring elements (SEs) whose size, shape and orientation can be changed by the different applications. Logic operations are organized by different MM operators according to the different purposes.

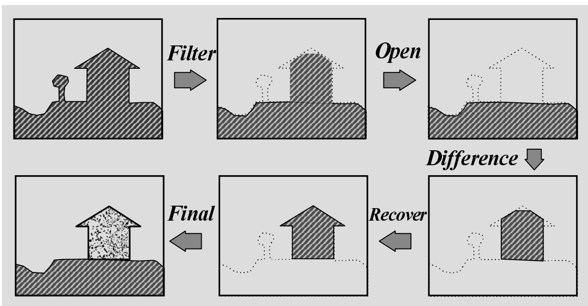

Figure 3. MM filtering and 3D object segmentation

MM filtering is one of the most successful tools for MM applications. For range image processing, we used the opening filter to remove dirty voxels and small connected volumes. We also used the closing filter to fill the small holes within surfaces and to link short gaps among objects. Here, the key problem is how to select suitable SEs, since the spatial features in range images are very dense in most cases, the direction-oriented SEs are suitable for many applications. How to select the parameters and algorithms for segmentation processing is highly dependent on different applications. Generally, before the real processing of whole large images we can process several selected typical small testing areas to find the suitable parameters and optimal processing procedures. We also can generate simple knowledge bases based on these selected parameters and procedures using for other range image processing.

Segmentation 3D object is also based on open processing. In this case, the size of SEs should be a little larger than the segmented objects, the shape of SEs can be a simple convex object, such as a cubic box in 3D space or a rectangular area in the 2D horizontal plain. The basic idea of MM based object segmentation is firstly filtering all the parts smaller than the given SEs, then segmenting the objects by the logic difference operations between the original 3D data set and the filtered 3D data set. Since MM based filtering with a small SE in the first step processing also will damage the detail object features, a feature recovering is better to be added in the object segment procedure. The algorithm of feature recovering is based on the conditional dilation operations, in which the segmented object parts sever as the dilation seeds and the original 3D data set serves as the masking field for limiting dilated ranges. Weidner and Foerstner (1995) have also used the similar MM based methods for filtering and segmentation of 3D spatial objects from small scale DSMs. In large-scale laser range image processing, we think it is better to add the feature recovering procedures during segmentation of spatial objects for protecting the detail object structures. When we integrally using the 2D map data for range image processing, a feature protected filtering based on the conditional masking volumes generated by the 2D boundary lines of building or roads also can be realized. Figure 3 shows a simple procedure of MM filtering and object segmentation

3.2. Acquisition of 2D ground-surfaces from exiting maps

As an efficient method of acquiring 2D spatial objects (such as buildings, roads, power lines, and contours), map digitizing based on automated or semi-automated raster-vector conversion plays an very important role in the GIS related applications. Several comical used systems are available in the markets, which can acquire 2D vector data and generating their topological relations in very efficient ways. During these years, we also developed a production system called Auto-2D for related raster-vector converting works based on MM approaches [Chen and et.al., 1994, 1997]. Here we will briefly introduce the basic procedure and several key algorithms in our system. Figure 4 show a basic procedure of raster-vector conversion of scanned maps and generation of topologic relations. The basic procedure in our approaches for raster-vector conversion of 2D scanned maps contains following steps:

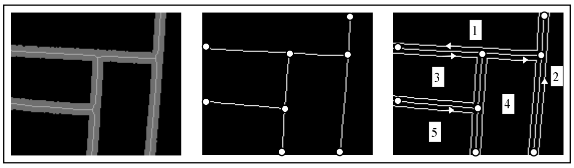

Figure 4. Raster-vector conversion of scanned maps and generation of topologic relations

- MM based binary image filtering, segmentation, and feature extraction;
- 2D raster-vector conversion, data compression, and line feature refinement;
- Generation of topological relation and linked to recognized attribute features (such as contour elevations and the numbers of land parcels).

Within above processes, one of the most important algorithms is the feature based image segmentation. Here we used MM based operators (such as hit or miss, opening, closing, labeling, and thinning...) with selected suitable SEs. We can easily extract different kinds of image features, such as broken points, crossed points, line width, pattern length, pattern density or distribution, Eular numbers, inside/outside of polygons, shape features, and et.al. When the different kinds of features have been successfully extracted, we can realize the full-automated batch processing for image segmentation.

3.3. Integrated processing for extraction of 3D objects

Based on the extracted ground truth data from 2D existing maps, we can generate the parametric or prismatic building and road models with the unknown heights firstly. In this way, we can also generate a little detail object features, such as the roof structures of buildings by using the vectored feature lines. Then we can estimate the height parameters of generated spatial objects based on the processed laser range images, which can be thought as a kind of model based matching between the pre-interpreted models (generated from 2D vector maps) and objected data sets (processed range images). The matching operation will cause four kinds of results as described following:

- A pre-interpreted model matched a object with almost same height;
- A pre-interpreted model matched a object with almost different heights;
- A pre-interpreted model can not match the object on the given range image;
- A object on the given range image can not match the pre-interpreted object on the map.

In the first case, the matching result means that the object is a prismatic object and we can simply estimate the object height by using the average or the maximum height value within the matching region. In the second case, the match result means the object may be with the complicated structures. If we know some detail object features from vector maps, we can estimate these parameters by using the height values within the matching region. The last two cases of matching results mean that the object changes have been detected, in which the first case means that the old object has been deleted and the last case means that a new object has been created. For solving the change detected problems in our system now is based on semi-automated editing, i.e. the computer automated searching the changed places and operators modify these change places with manual editing. Figure 5 shows a basic matching procedure between map models and range image objects.

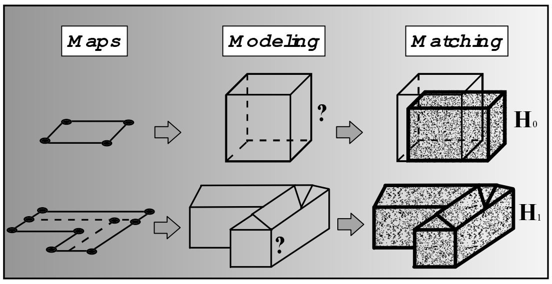

Figure 5. Matching objects between maps and range images

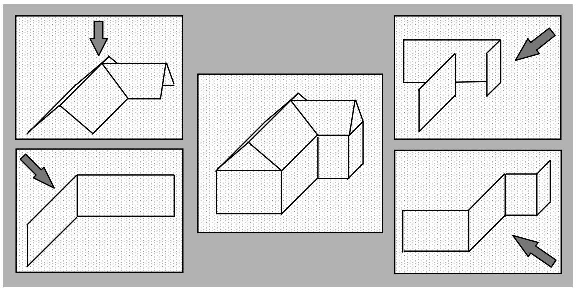

Figure 6. Object reconstruction by using the laser range images from deferent view points

3.4. Modeling Complicated Objects

If not only airborne laser range images but also ground laser range image in the different view points are available, above presented methods can be extended for reconstruction of high accurate 3D spatial objects with their detail features. The basic idea is to extract different DSMs from the different viewpoints (as Figure 6). After that we can integrate these DSMs to generating whole 3D spatial objects by using the data fusion methods. The processing steps are as follows:

1) Object model selection: The matching result generally

contains a huge number of points each of that has XYZ coordinates. Therefore, a more suitable geometric representation of data is required in order to display and interact with this data. The most suitable representation is a voxel-based triangular mesh [Chen and et.al., 1994].

2) Coordinate system translation: The points on the 2.5D digital surfaces got from image matching are generally in their local coordinate system. A coordinate system translation is needed to integrate all spatial points in the global coordinate system.
3) Sub-object merging: Since there will be many overlaps or gaps between the successive 2.5D digital surfaces, a algorithm for sub-object merging is needed to remove the redundant data and to interpolate the data between the gaps.
4) Object editing: Due to miss matching and merging, there will be some error points in the object models. Editing is needed to check and correct these errors.
5) Boolean operation: Due to the resolution of the object, some kinds of detail features (such as holes and breadlines) will be not eliminated in the object. We can use Boolean operations (union, intersection, and difference) to recreate these features based on the selected simple parameter models.

3.5 Texture Mapping

Based on reconstructed 3D objects and generated their orthoimages in different views, we can make the texture mapping for these 3D object. Following are our procedures for texture mapping based on SOFTIMAGE| 3D system:

- To separate 3D object to different 2.5D surfaces;
- To generate the orthoimage for each 2.5D surface;
- To convert the orthoimage to picture (.pic) file;
- Sequentially selecting the different 2.5D surfaces and to determine the surface sides;
- To read the different to picture files (orthoimage) and wrapping to each 2.5D surface.

4. EXPERIMENTS

Based on the above presented algorithms and methods, some experiments have been tested by using the real range images ground surveying data and the scanned maps. The testing region is the section of city phoenix, USA. Figure 7 (a) shows the generated range image. Figure 7 (b) shows the 3D shading result of the range image of Figure 7 (a). Figure 7 (c) shows the extracted 3D city models. Figure 8 (a) shows the integrated ground range data. Figure 8 (b) shows the modeling result of Figure 8 (a). Figure 8 (c) shows the texture mapping results of an indoor-model of the complicated building.

5. CONCLUSIONS

From above approaches and experiments we can find that the laser range profiling, as a new technique for direct acquisition of high resolution DTM, will play more important role in GIS related data acquisition and 3D object reconstruction. Integrated processing of laser ranger images and existing vector maps can supply a more efficient way for generation of 3D city models and fit to real applications. MM based algorithms for 2D and 3D raster filtering, segmentation, and object reconstruction are useful tools for fast and parallel processing range image data. For our further researches, the algorithms for extraction of complicated 3D spatial objects in their detail structures and photo image based 3D texture mapping should be investigated. For the application of 3D city models, reconstruction of 3D power line networks with related vegetation models are most interested.

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REFERENCES

F. Ackermann, “Airborne Laser Scanning for Elevation Models”, GIM. 1996

X. Chen, “Image Analysis and Mathematical Morphology -- the development of application models for computer mapping”. Surveying & Mapping Press, Beijing, 1991.

X. Chen and et.al., “AUTO-2D --- A Super Map Digitizing System Assisted by Mathematical Morphology”, Asia GIS/ LIS AM/FM and Spatial Analysis Conference, Hong Kong, 1994.

M. Flood and B. Gutelius, “Commercial Implications of Topographic Terrain Mapping Using Scanning Airborne Laser Radar”, PE&RS, Vol. LXIII(4):327-366, 1997

O. Henricsson and et.al., “Automated 3-D Reconstruction of Buildings and Visualization of City Models”, The Workshop of 3-D City Models, Bonn University. 1996.

U. Weidner and W. Foerstner, “Towards automatic building extraction from high-resolution digital elevation models”. ISPRS Journal of Photogrammetry and Remote Sensing, 50(4):38-49, 1995

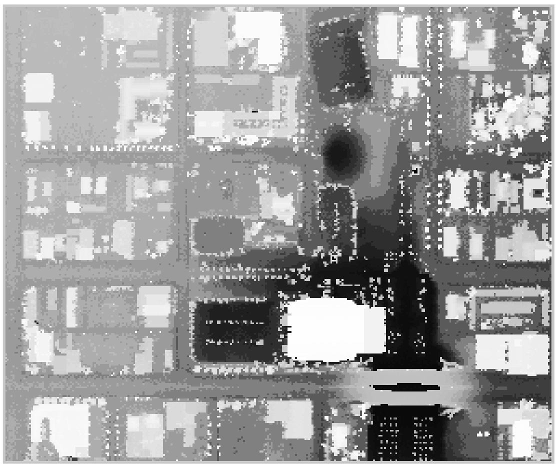

Figure 7 (a). The generated range image

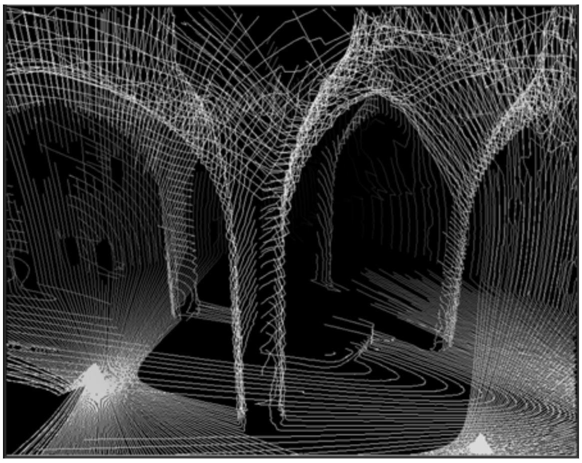

Figure 8 (a). The integrated ground range data.

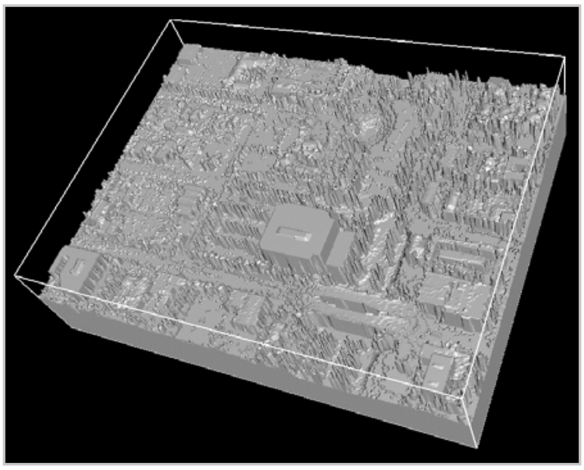

Figure 7 (b). The 3D shading result of Figure 7 (a).

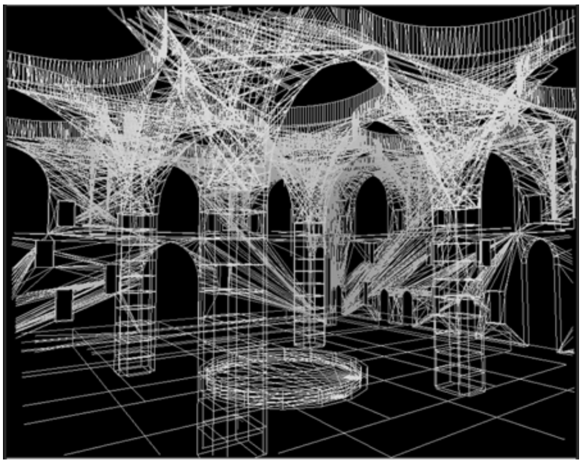

Figure 8 (b). The modeling result of Figure 8(a).

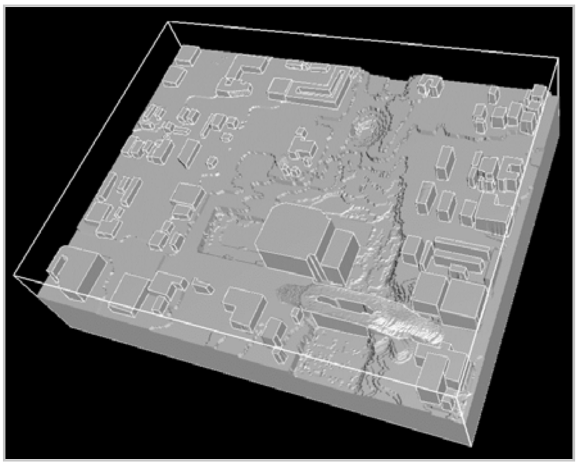

Figure 7 (c). The extracted 3D city models.

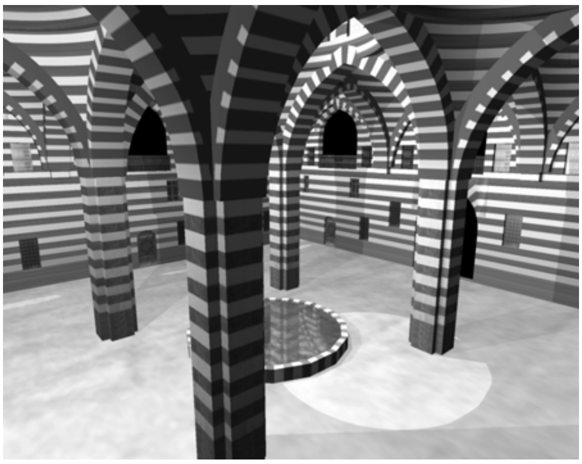

Figure 8 (c). The generated in-door models.