3D CITY MODEL RECONSTRUCTION FOR VISUALIZATION FROM STEREO URBAN SCENES

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ABSTRACT

In this paper, a 3D urban visualization data generation system is introduced. The system mainly includes following four subsystems :

1) 3D geo-object extraction from stereo aerial images. This step focused mainly on 3D building extraction. The outputs of this step are 3D roofs(irregular in shape).
2) 3D building regularization. This step regularize the roofs extracted from step 1).
3) 3D building skeleton formulization with regularized roofs. In this step, the walls are firstly produced from roof edge lines. The cross arc between each wall plane and ground surface constructed from DEM or DSM is then calculated.
4) Rendering for visualization.

1. INTRODUCTION

There is a rapidly growing demand for 3D geographical products, especially 3D urban visualization data, in a wide range of applications(Danahy, 1997, Gruber, 1997). This paper aims to develop a practical system for automated 3D city model reconstruction from stereo urban scenes. The system includes four main parts :

1) 3D object acquisition model. In this paper, 3D building extraction method proposed by the authors(1997) is applied, in which both the area-based and feature based stereo matching are used for 3d object reconstruction.
2) 3D object regularization. In general, the boundaries of extracted objects from step 1) are irregular because of the impact of shadows, noises, and so on. Accordingly, the regularization is essential.
3) 3D object skeleton generation. A 3D skeleton of a man-made object can be generated from each edges of a roof.
4) Texture mapping and/or Rendering. Several existing software and tools, such as OpenGL, VRML, AutoCAD, etc., may be selected for fulfilling such a task.

As "building" is the major object in urban areas, the discussion will be focused on 3D building extraction and its visualization data generation in this paper.

2. FRAMEWORK OF THE SYSTEM

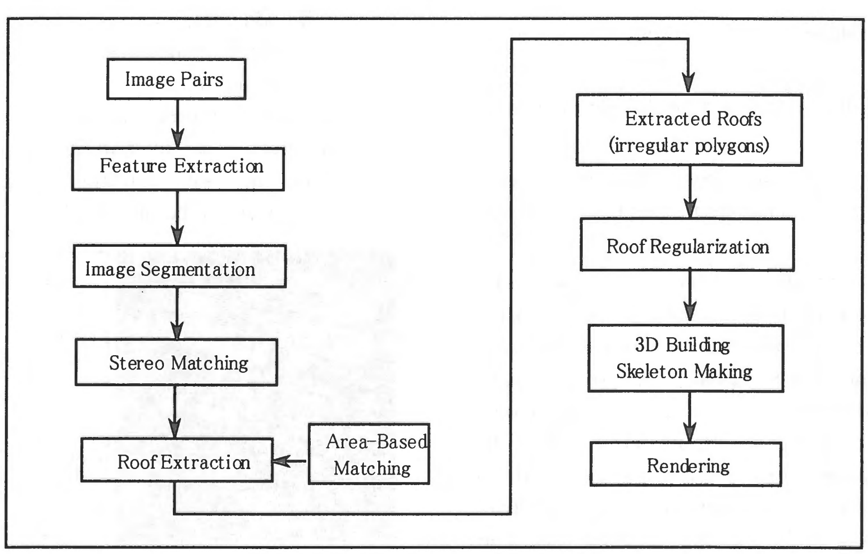

Fig. 1 General framework of a visualization data construction system.

Fig.1 shows the general framework of a practical 3D building extraction and visualization data construction system. As mentioned before, the system is composed of three main models : roof extraction model, roof regularization model, and rendering model, in which roof extraction model is the core of the system. We would like to introduce each model below.

3. AUTOMATIC 3D BUILDING EXTRACTION

A practical automatic 3D building extraction method was proposed by the authors in 1997(Shi and Shibasaki, 1997). In this paper, we would like to give a brief introduction about this method.

3.1 Basic Consideration

It is reasonable to assume that the operation of building extraction is equivalent to the detection of roofs from images. Such an assumption will not lose the generality because in many applications, such as in GIS database revision study, the existence of a building is more important than the geometric description of a building. Therefore, automatic building extraction problem can be simplified as a roof extraction problem. The discussion below will then be focused on how to extract the roofs from stereo photographs with two high objectives : high possibility and high reliability.

In general, most of the roofs are relatively regular in gray-level intensity. Hence, the most facile but a little bit ideal method regarding to building extraction should be : to segment the images into ***meaningful*** regions and try to pick ***all*** of the roofs up from these segmented regions. We say it is an ideal method because there is still no such a robust segmentation method which can segment an image into so-called ***meaningful*** regions. Indeed, at least following three cases have to be taken into account even a ***robust*** region segmentation method is performed(Fig. 1) :

case 1 : a roof is able to be segmented into regions in both left and right images;

case 2 : a roof is able to be segmented into a region in one image;

case 3 : a roof is unable to be segmented into regions in both images;

Therefore, the building extraction problem can be simplified as a problem how to extract buildings from three kinds of feature pairs.

Since the ground surface in a finite region(e.g. 1 km square) of an urban area is generally flat, it is reasonable to assume that all of the roofs in a finite area lie ***above*** a ***common*** plane which is able to be reconstructed(Shi & Shibasaki, 1995). We call such a common plane ***ground surface***. If the disparity of the ground surface is known, the problems left are 1) to derive the correspondences of features in image pairs and 2) to estimate the disparities of 3D features, such as region-region pairs(case 1), region-lines pairs(case 2) and the grouped lines-lines pairs(case 3). Here, case 1 and case 2 may not be with difficulty to understand. But for case 3, one should firstly group these lines which are the edges of a ***would-be*** region and then match the grouped polygons in different images.

3.2 Building Extraction Algorithm

According to above basic consideration, buildings may be extracted with following procedures :

1) Feature extraction. Wavelet transforme is untilized to obtain multiresolution images. Features(edges, corners) are then extracted from images in different resolutions.

2) Image segmentation. Meaningful regions are segmented with proposed modulus-based image segmentation (MOBIS) in different resolutions. Line segments are extracted in local Hough space.

3) Stereo matching. Hierarchical feature-based stereo matching and area-based stereo matching are performed.

4) Ground surface estimation. The height of ground surface is estimated with a proposed disparity-based voting algorithm(DBVA) based upon 3D lines. The basic idea of DBVA comes from following observation : if we remove all the 3D lines relevant to segmented region boundaries, most of the 3D lines should be located on the ground. Thus, ground surface is able to be captured from where the most votes for height(disparity) are made with (DBVA). Region-based stereo matching is employed, in our approach, for the purpose of building recognition. which are the region pairs higher than ground surface.

5) Building hypothesis extraction models(from 3D regions, 3D lines etc.).

4. ROOF REGULARIZATION

Generally, most of the buildings have following geo-properities :

1) Even edges of a roof are parallel with one another and similar for odd ones.

2) Even edges are perpendicular to the odd ones.

3) Edges are stright lines.

But, because of the noises, shadows, etc., edges extracted from images are irregular as shown in Fig.2. It is therefore necessary to regularize the roof boundaries in order to let the geo-properties of each roof be satisfied(Fig.3).

Fig.2 Results of image segmentation

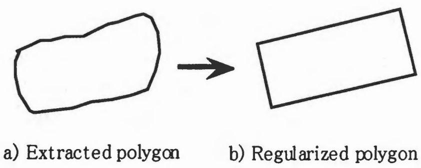

Fig.3 Polygon regularization.

There are many methods to regularize irregular polygons into regular polygons which have the geo-properties 1)-3) giving above. In this paper, we would like to describe a very simple but effective method with an example.

Fig. 4 a) shows a typical shape of a roof extracted from an image. The polygon can be regularized with following steps :

Firstly, to extarct straght lines from edge points of the polygon with Hough transform. Suppose four lines L1,L2,L3,L4 were extracted in this example(see Fig. 4 b)).

Secondly, to find out the longest line. Here, L1 is the longest line.

Thirdly, to calculate the distance from each edge point to the longest line L1 and obtain the maximum value of the distance.

Fourthly, to form a rectangular with the longest line and the maximum value of distance(see A-B-C-D in Fig.4 c)).

One can use the similar method to regularize the polygons with any styles.

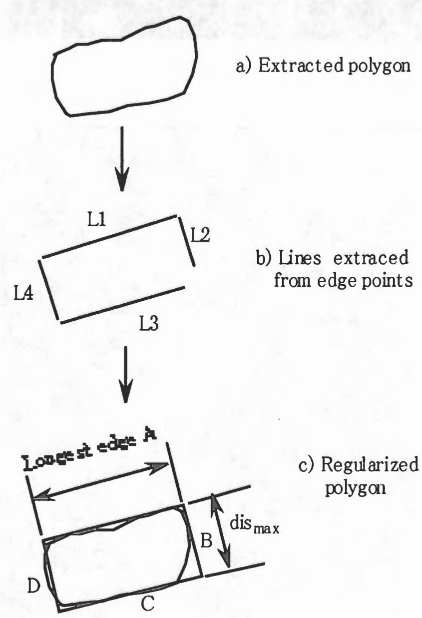

Fig.4 A method of polygon regularization.

5. 3D BUILDING SKELETON GENERALIZATION

After all the extracted roofs have been regularized, 3D building skeletons should be generated before establishing 3D city models.

Two typical types of 3D building skeletons are shown in fig.5. It should be mentioned that the ground surface(e.g. DEM) have to be taken into account when the walls of each building is produced.

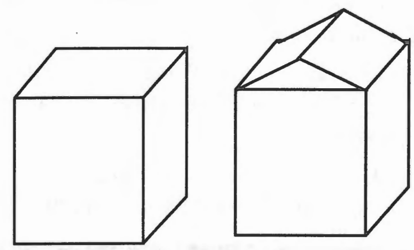

Fig. 5 Examples of 3D skeletons.

6. 3D CITY MODELS

We may not meet any problems in mapping textures from real images to any planes or faces since a lot of software and tools now support such an operation. But, to manage and show the large amount of data(mainly the texture images) requires not only the huge amount of memory and hard desk, but also the facile DBMS(Gruber *et al* 1997).

7. EXPERIMENTAL RESULTS AND DISCUSSION

We demonstrate one set of the testing results. The aerial photographs(scale 1:5000) were used in this experiment. The experimental results are illustrated in Fig.6.

Fig.6 a) shows an image pair(size 1000X1000 pixels) with an range of intensity level from 0 to 255.

Fig.6 b) shows the results from region segmentation. About 96 percent of buildings were able to be segmented into closed polygons. One of the important advantages of our 3D building extraction algorithm is that no strict constraints are required in matching schemes unlike most of the previous algorithms.

Fig.6 c) presents the extracted 3D buildings(with irregular roofs). The problem here is that some of the roofs of buildings are separated into several small polygons. Currently, it is still very difficult to combine these separated polygons belonging to one roof into one object. It is one of our further approaches in future.

Fig.6. d) depicts the 3D buildings with regularized roofs in which the ridges were added semi-automatically. It is still not easy to add ridges onto flat roofs automatically, which is our another research topic in future.

8. REFERENCES

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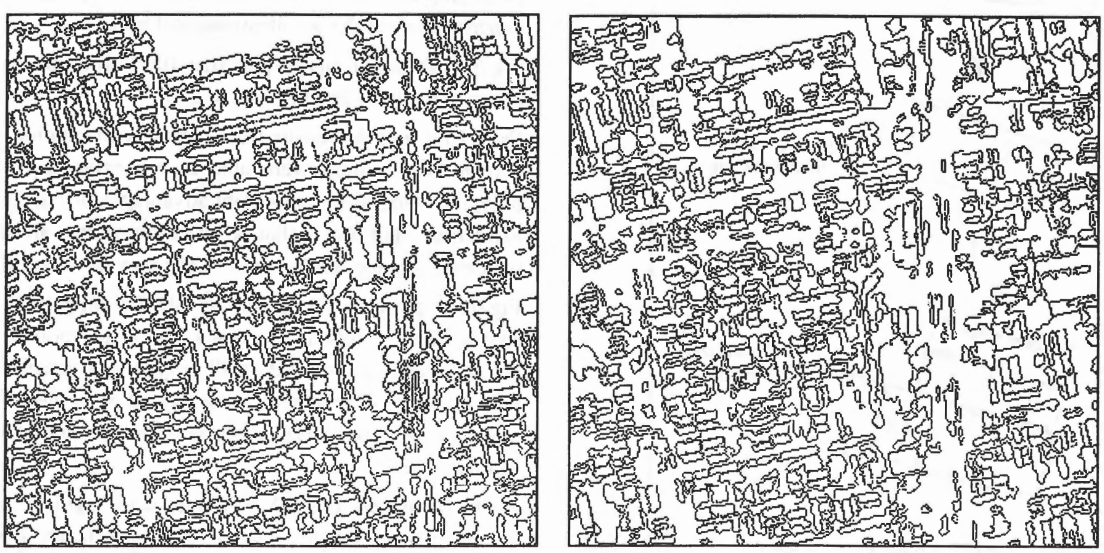
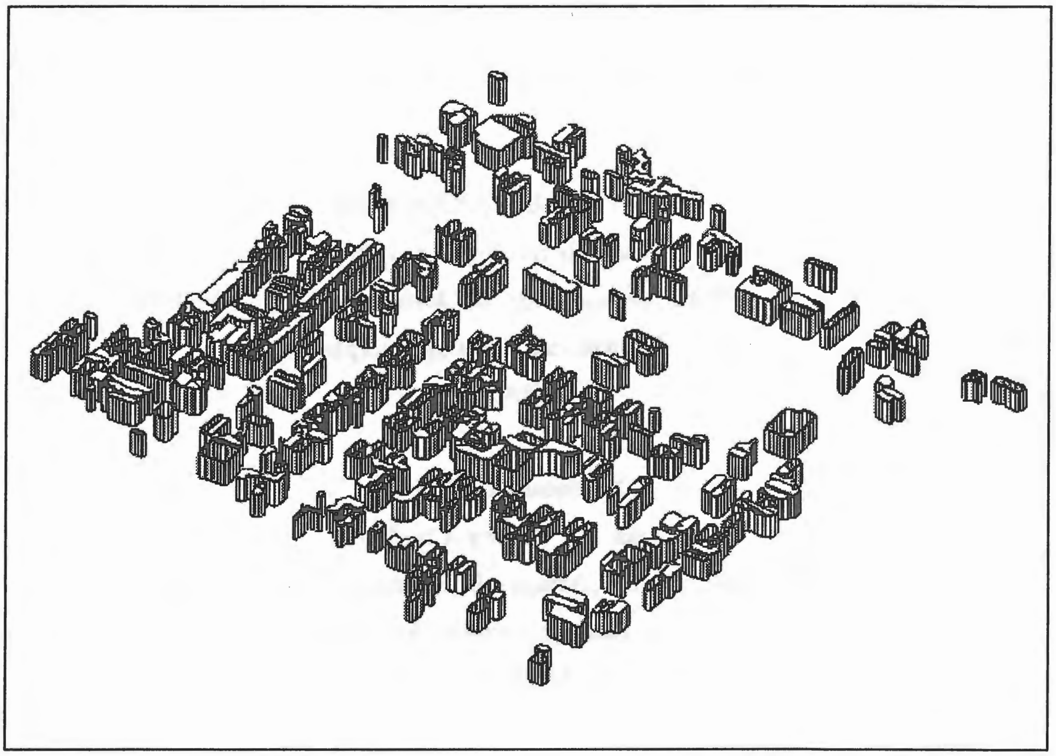
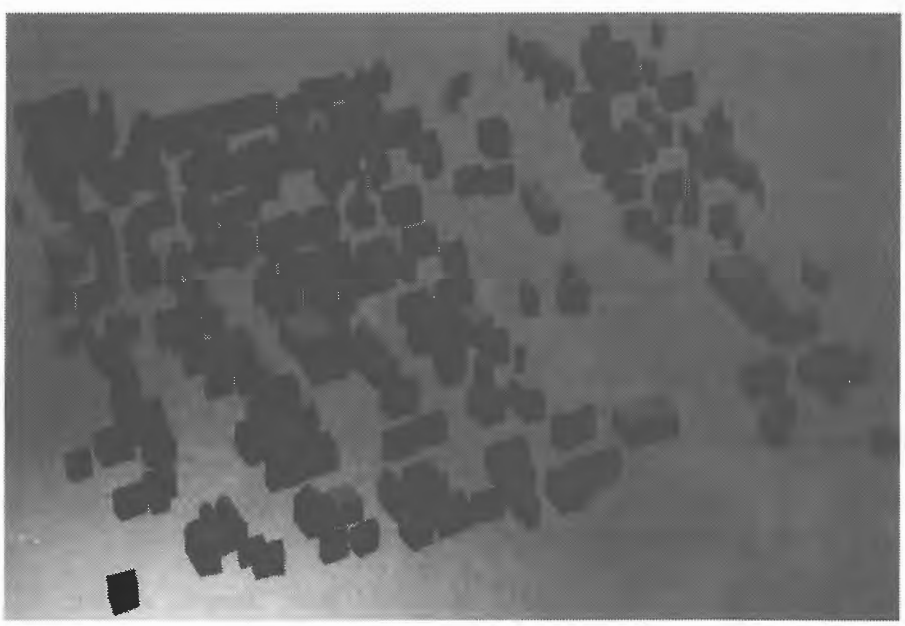
a) Original image pair(scale 1:5000)



b) Segmented polygons



c) 3D Buildings with irregular roofs.



d) Regularized 3D buildings.

Fig.6 Experimental results of urban visualization data generation.