3-D Reconstruction of Buildings using 3-D Line Grouping for Urban Modeling

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Abstract—In order to obtain a 3-D urban model, an abstraction of the surface model is required. This paper describes works on the 3D reconstruction and modeling by the grouping 3D line segments extracted from the stereo matching of edges, which is derived from multiple images. The grouping is achieved by conditions of degrees and distances between lines. Building objects are determined by the junction combinations of the grouped line segments. The proposed algorithm demonstrates effective results of 3D reconstruction of buildings with 2D aerial images.

Index Terms—3-D reconstruction, line matching, line grouping, urban model

I. INTRODUCTION

A 3-D reconstruction with 2-D images has become one of important issues of computer vision. The studies on 3-D reconstructions using high-resolution images from aircrafts haves been the center of interest in an aspect of the environment, military and remote sensing of natural resources. Particularly, the research works could be utilized in the construction of the 3-D map production and virtual space in the virtual reality.

Most of the 3-D reconstruction algorithms has been implemented based on the region-based stereo matching method[1-4]. It can be accomplished a precise 3-D reconstruction in a continuous shaped landscape. 3-D reconstruction from urban images has discontinuities such as boundaries of buildings, however, it may contain a lot of errors around the boundaries. In order to solve a problem in the 3-D reconstruction of urban images including both artifacts and the natural landscape, a hybrid reconstruction method combined a region based stereo matching and a feature based method[5-7] has proposed. It can decrease errors occurred around the region that joins artifacts and the landscape. DEM(Digital Elevation Map) was used for the extraction of a building area[1]. It greatly reduced a computational cost compared to perform the reconstruction over the whole image. In [2], a 3-D reconstruction method using 3-D lines was introduced. It helps to compensate problems that lots of errors can be contained in 2-D line matching without height information.

In this paper, we work on the 3D reconstruction and modeling by the grouping 3D line segments extracted from the stereo matching of edges and propose a new optimized 3-D line extraction method through a classification of 2-D lines that have similar characteristics and a way of a building object definition by using junctions of 3-D lines. We also define 3 types of junctions such as L-shapes, T-shapes and U-shapes to group line segments as a building object.

II. 3D BUILDING RECONSTRUCTION SYSTEM

We categorize the whole processing into 4 stages of which each contributes to producing the final, 3-D reconstruction as shown in Fig.1.

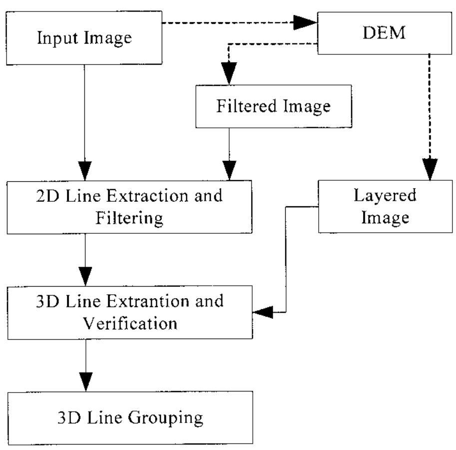

Fig. 1 A Flow Diagram of the proposed 3D building reconstruction system

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First stage is a preprocessing that generates filtered images to be extracted a building area using DEM and layered images to be compared heights of 3-D lines. Next, we extract building areas and derive 2-D line segments from them. And then 3-D line segments are generated and verified through the stereo matching of line segments extracted from multiple images. Finally, 3-D line grouping that determines individual 3-D lines into a building object is performed.

A. Preprocessing

1) Filtered Image Generation

DEM information represents a relative height of each building as disparities between two images by a stereo image matching with them. Note that we can determine whether a building exists or not from a thresholding of a histogram of DEM image as shown in Fig. 2. It performs a filtering role that extracts an area in which an actual building exists by combining filtered image and original image. Fig.3 and Fig.4 show DEM image and filtered image generated from DEM.

2) Layered Image Generation

The results of 3-D line extraction may contain some height errors induced in 2-D line stereo matching process. To lower these errors, we employ a layered image. It is layered by grouping areas that have same heights. A DEM image represents a relative height of each building and 3-D line segments imply relative heights of those segments. Therefore if the heights are identical when we compare those two heights, the line segments become valid. Otherwise, the remained segments are removed. That is all information except line segments that have same heights are considered as errors. Fig.5 shows a layered image extracted

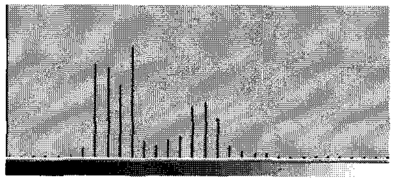


Fig. 2 Building area histogram

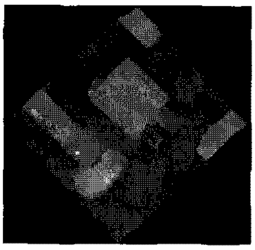


Fig. 3 DEM Image of building area

Fig. 4 Filtering image of building area

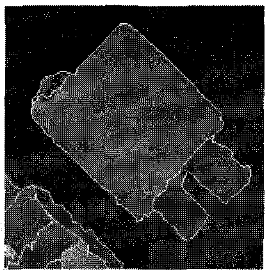


Fig. 5 Layered Image

B. Extraction of 2-D line segments and Filtering

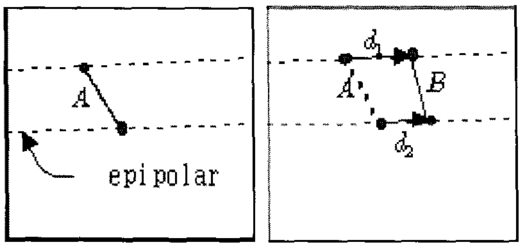
To get the structural information about the site, feature extraction routines are applied to produce geometric representations of potentially important image features. Basically, the proposed algorithm relies on straight-line segments extracted from the edge image. We produce an edge image first by the Canny edge detector, extract 2-D lines from that and then finally reconstruct 3-D buildings with 3D line segments extracted from 2-D lines. However, it is a computation-consuming procedure. To reduce the computational complexity, a target area to be filtered from the whole image is required to compute the 3-D line extraction on the area in which a building exists. The edge information of the target area only can be extracted by multiplying (logical AND) the whole edge image and the filtered image. We derive a straight line firstly from edge points in an image and determine line segments by searching the start and end point of a straight line.

C. 3-D Line Generation

In this stage, we generate 3-D line segments through the stereo matching between 2-D line segments extracted from multiple images. The procedure of 3-D line generation has 3 steps as follows:

1) Disparity reference

The DEM image is used for effective matching in the 3-D line generation. Since DEM information represents a disparity value between two images, a point of one image can be predicted in that of another image by a DEM value.



(a) reference (b) target

Fig. 6 Disparity reference in 2-D line matching.

A line segment in the real world appears at a different position in both stereo images. If disparities in the line segment in one image are used, the matched line segment in the other image can be a simple search.

Fig. 6 shows the principle of the disparity reference. If a 2-D line segment A of the reference image is translated by disparities d_1 and d_2 along epipolar lines, it is approaching a 2-D line segment B of the target image. As disparities d_1 and d_2 are close to actual values, the matching of line segments A and B are obviously carried out.

2) 2-D line matching

2-D lines detected in epipolar resampled images are matched by the disparity reference. As the reliable disparity has a very small error, it is possible to limit the possible matched lines in the target image through the use of only starting and ending points. With this scheme, 2-D line matching can be quickly carried out.

3) Generation of 3-D line segment

After performing the line extension and linking to the 2-D line matching result, the improved 2-D line matching result is obtained. The application of a triangulation calculation to the starting points and ending points of the matched lines results in a 3-D line segment.

D. 3-D Line Grouping

We group the 3-D line segments that exist independently, and produce grouped 3-D lines that compose a building and finally reconstruct a building with them. This stage consists of approximated line extraction, junction extraction, and line segment grouping.

1) Approximated Line Extraction

The generated 3-D line segments are grouped using 3-D line fitting so that the redundant appearance of a single line segment can be eliminated. The prerequisite thing before we group the elements of buildings is a linking process of fragmented lines.

As shown in Fig.7, the fragmented lines are linked based on the similarities of the relative angle and distance between lines. If both the distance and angle between lines are lower than threshold, we link the similar shaped lines as a single line as shown in Fig. 8.

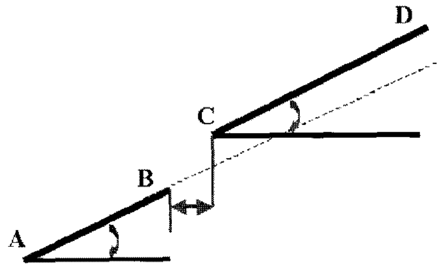


Fig. 7 Example of a similar shaped line

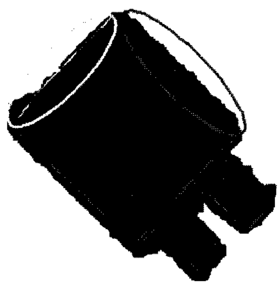


Fig. 8 Classification of a similar shaped line

A representative line approximated is defined by a line that minimizes the sum of errors of distances from all start and end points as shown in Fig.9. Fig.10 shows an extraction result of an approximated line on the building area.

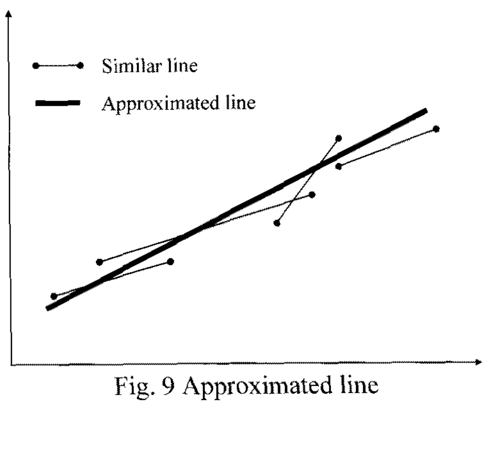


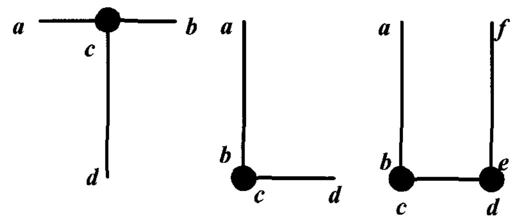
Fig. 9 Approximated line

Fig. 10 Approximated line extraction on a real image

2) Junction points Extraction

To define a rooftop with 3-D lines derived from former steps, a processing of the definition from 3-D lines into a building object is also required. In order to describe the building object from the extracted 3-D lines, we define 3 shapes of junctions such as L shape, T, shape, and U shape that represent the relationships between lines as shown in Fig. 11.

L-junction represents that two lines join one point perpendicularly. T-junction shows that two lines join on one point in the line *ab* and an intersection point must be in a line as shown in Fig. 11. T-junction indicates that one building adjoins a part of another building structure. And U-junction is that two L junctions are appeared on both ends of a line and the lines are not formed a closed loop.



(a) T junction (b) L junction (c) U junction

Fig. 11 T, L and U shape junctions

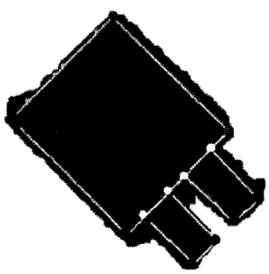


Fig. 12 T, L and U junction classification

As shown in Fig.12, we extract junction points through the extracted 3-D line segments and classify them based on the junction conditions. All junction points consist of more than two line segments and their own lines between junctions jointly if they belong to a building object. Thus, the lines are grouped along the joint lines between junctions.

3) Approximated Line Extraction

A rooftop construction is made by grouping of 3-D line segments. In grouping, we use the junction features of 3-D lines such as L shape, T shape and U shape.

First, the grouping is preceded by searching along the common 3-D line segments on the junction from an initial starting point of L shape junction. As shown in Fig.13, L1 junction which is the starting point and L2 junction own jointly the line segment l1. L2 and L3 junction also own the line segment l2.

While the lines are grouped, the existence of a T-junction is checked. Because T-junction indicates that one building adjoins a part of another building structure. If a T-junction exists in grouping, a process that searches every joint line on a T junction is performed recursively.

Then when we reach the starting point L1 again in the searching process, all lines are grouped into one object completely.

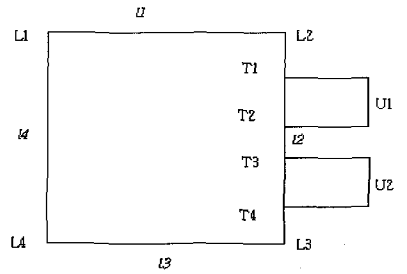


Fig. 13 3D building object grouping

III. SIMULATION RESULTS

Fig.14 shows input aerial images. We extracted DEM images from them through the stereo matching and derived 3-D reconstructions of buildings based on the3-D line segments. Fig.15 shows a result of the edge extraction by Canny algorithm, and Fig.16 represents a result of the filtering of building area from the whole edge image.

Fig.17 shows results of the generation of 3-D lines by using a stereo matching of 2-D lines extracted from each image. Those are verified by comparison of heights with a layered image. Fig.18 shows the results verified lines through comparing 3-D lines with the heights of DEM image, classified, and linked into similar lines by the terms of distance and angle between 3-D lines.

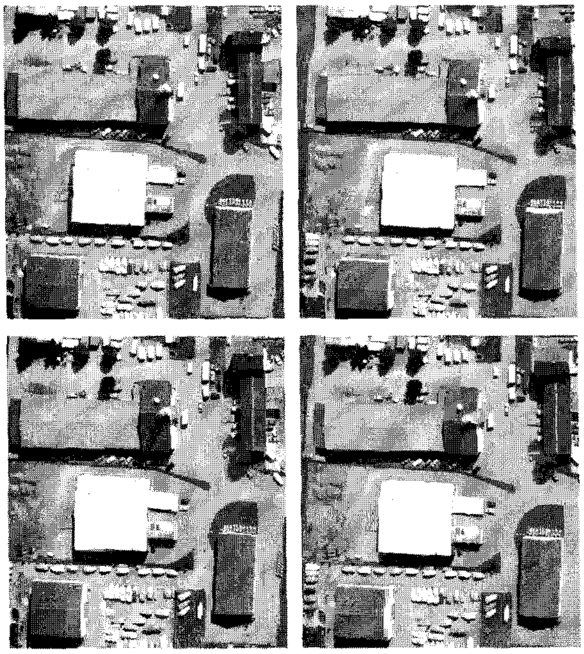


Fig. 14 Input images

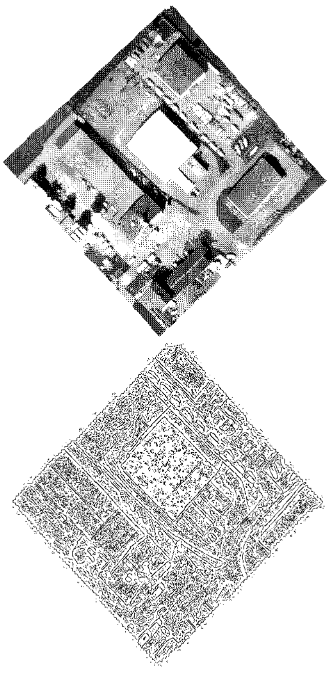


Fig. 15 Input image and edge image

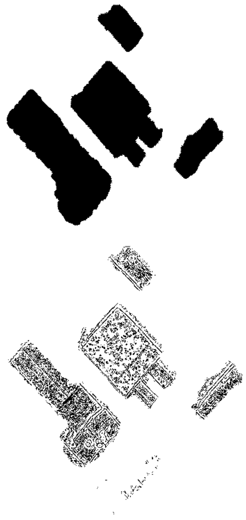


Fig. 16 Filtering image and Filtered edge image

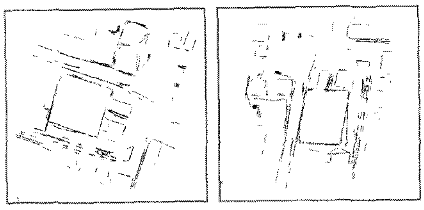


Fig. 17 Result of the 3D line extraction

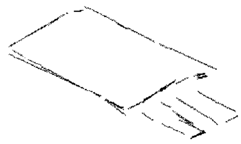


Fig. 18 Result of the similar line classification and linking

Fig. 19 represents the result of the line approximation and junction extraction. Fig. 20 shows a modeling result of building with the linked 3-D lines, respectively.

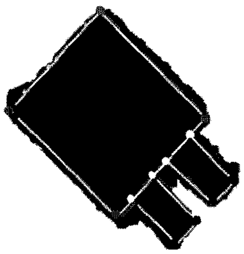


Fig. 19 Optimized line generation and junction extraction

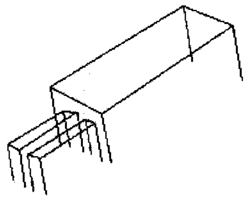


Fig. 20 Modeling of 3-D building

IV. CONCLUSIONS

This paper suggests a 3-D reconstruction system of buildings using multiple aerial images and an effective grouping method of the 3-D lines for 3-D building reconstruction. We first extracted 2-D lines, grouped 3-D lines extracted from them to generate a 3-D model to describe a building in an image. We defined 3 types of junctions such as T, L and U shape to examine the connectivity of lines that form a building and finally generated a 3-D model that forms a 3-D shape of a building. Experimental results show that the suggested approach is promising. We are going to improve our algorithm so that we will be able to reconstruct more various and complex shaped buildings. Eventually, we plan to perform a modeling of virtual city.

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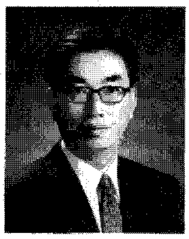

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