REFINING COARSE 3D BUILDING MODELS BY USING HIGH RESOLUTION AIR-BORNE LINEAR CCD (TLS) IMAGERY

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[ABSTRACT]

3D spatial data are used in various fields of applications, especially, for urban areas. Recently, it becomes easy to generate 3D building models automatically by using airborne laser data. However, the resolution is too rough to apply to some GIS and CG applications such as texture mapping. Therefore, it is necessary to prepare finer resolution building models.

This paper describes an approach to refine existing DSMs or coarse 3D building models with TLS (Three Line Scanner) imagery and to generate 3D building model. At first, a building model is defined. Next, a method for model optimization and generation is described. Then, the preliminary experiments are conducted in case of flat roofs. Finally, the results are compared with existing DSMs. And it is confirmed to evaluate the approach.

1: Introduction

1.1: Background

Recently, it becomes easy to generate 3D building models automatically by using airborne laser data. Moreover, it is also demanded to generate textured models automatically. But the resolution of the laser data is too rough to apply to GIS and CG applications such as texture mapping. Therefore, it is necessary to prepare finer resolution building models. Actually, huge manual editing works are demanded for operators to generate fine-resolution 3D model.

1.2: Objectives

The objective in this paper is to develop an approach to generate 3D building model by refining existing DSMs with fine aerial imagery. The approach has three steps, approximately. 1) Prepare initial building parts or initial values for model fitting. 2) Generate Building parts. 3) Generate building models by clustering the building parts. These are done through the model-based approach. Then, the preliminary experiments are conducted in case of flat roofs. In this experiment, laser data (point-cloud data with ground resolution of 50cm) are used as existing DSMs, and TLS images (ground resolution: 3cm) are used as fine aerial photos. Finally, the result is compare with existing DSMs. And it is confirmed which this approach is successful or not.

1.3: TLS (Three Line Scanner)

TLS (Three Line Scanner) is an optical sensor for aerial survey. TLS is composed of three linear CCD arranged in parallel, and it can acquire three images of each direction (forward, nadir and backward) at the same time. Orienting it on an aircraft perpendicularly to flight direction, and scanning a ground plane, a treble stereo image of a ground object can be acquired (See Figure 1). As a result, occlusion area can be extremely reduced. Using two images of the three, it is also possible to get 3D coordinates by stereo matching. As one of advantages of a linear CCD sensor, more pixels can be arranged in a single scene compared with an area CCD sensor. This means that a linear CCD sensor can achieve a resolution comparable with that of an air photo. Though a linear CCD sensor can acquire data only by one line at a time (The ground resolution of TLS data in this research is 3 cm approximately). However, time of acquiring each line image is different. Since position and direction of each line when acquiring image is also different, orientation cannot be done by an existing method of photogrammetry. Moreover, the image is greatly influenced by fluctuation of an airplane position and attitude because TLS is air-borne. But a 'stabilizer' can reduce the influence of fluctuations in position and attitude.

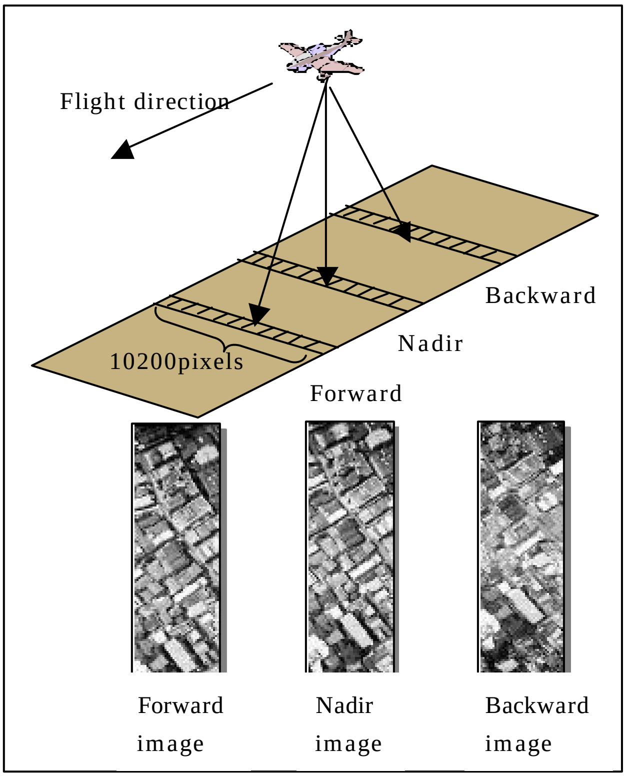

Figure 1. Method of TLS data acquisition

2: Methodology

In this research, approximate processing flow is as follows. 1) Prepare initial building parts for model fitting 2) Optimize building parts 3) Generate the building model by clustering the building parts.

2.1: Definition of the Building model

In this research, the Building model is defined as follows (Figure.2).

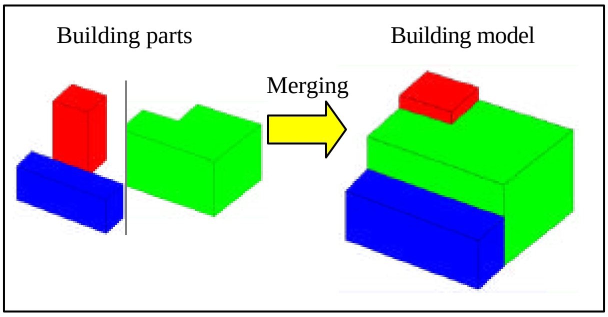

Figure 2. The definition of building model

One building model consists of some primitives. They are called building parts in this paper. Each building part has height information and various shape. Basically, they are processed as 3D objects.

2.2: Generation of initial building part

When model fitting is applied, it is necessary to prepare an initial building model. It is possible to use laser data or existing 3D digital maps for the preparation of initial building model. In this research, laser data (50cm resolution DSMs) are used as an initial building model.

Processing flow in this stage is as follows.

?? Detect buildings
?? Extract height information
?? Vectorize building data

At first, building detection is applied. Concretely, labeling operation is applied to input data. When DSMs is used, it is applied region glowing method with height information. Of course, in DSMs, there are not only building but also trees and ground. But buildings can be extracted by using various filtering. For instance, trees are deleted with applying region glowing and area filtering. Moreover, ground surfaces are deleted by filtering with height information. As a result, individual buildings are extracted from DSMs (See, Figure3).

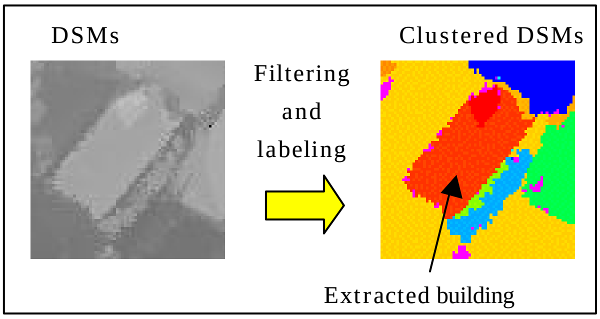

Figure 3. Individual buildings extraction

Secondary, height information extraction is applied. Each clustered building has pixels with height information. When the height values are uniform, the building has a flat roof. When the height values are not uniform, the building has an inclined roof. In this step, 'horizontal roof' or 'inclined roof' is labeled to the building, and it is given the average value as the building's height.

Finally, building data vectorization is applied. When building data is vector data, of course, it is no need to apply it. But, when the building data are raster data, vectorization is applied to do to make the following processing easy. In this step, SUSAN filter is applied to building regions. And vertex points are extracted topologically. As a result, initial 3D building vector data are generated (See, Figure4).

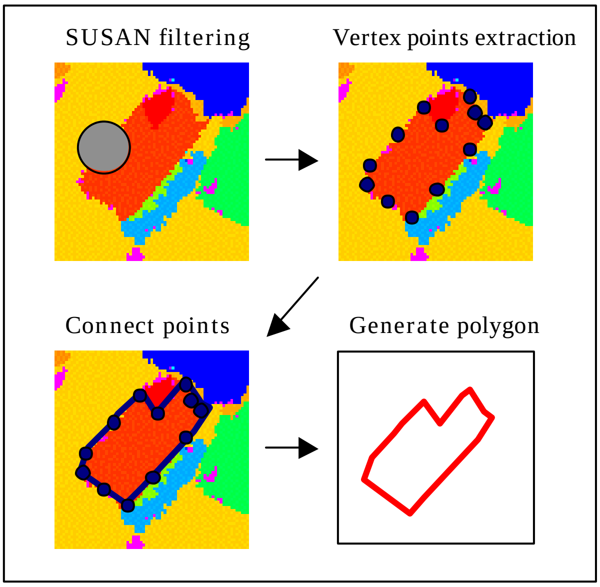

Figure 4. Generation of initial 3D building vector data

2.3: 3D building part optimization

The initial building part is generated in the previous stage. In the next stage of processing, an optimization is applied to this initial model, and the vector data is modified to the real building shape. An approach in the case of flat roof is described. Processing flow in this stage is as follows.

?? Modify initial building shape approximately
?? Generate emphasized edge image
?? Apply SNAKE fitting

At first, the initial building shape is modified approximately.

In this step, the point reduction and the geometrical modification are applied. In case of reconstruction building, building knowledge is able to used. For example, they consist of straight lines and they have right angles or approximate right angles, and so on. So, when a vertex point is not approximate right angles, it is possible to be deleted. As a result, the initial model has better value (See, Figure5). And also, the processing time is shortened because points are reduced.

Secondary, emphasized edge image is generated. Emphasized edge image has emphasized features on the height. This is generated as follows. At first, original TLS images (forward, nadir and backward image) are projected on the height of the initial building model. Next, edge images are extracted from each projected image. Then, they are overlaid, and only edges overlapping with the others are extracted from them. In this case, the result is better when morphological operation is applied to all edges. As a result, edge segments on the same height are extracted. That is, building edges are extracted (See, Figure6).

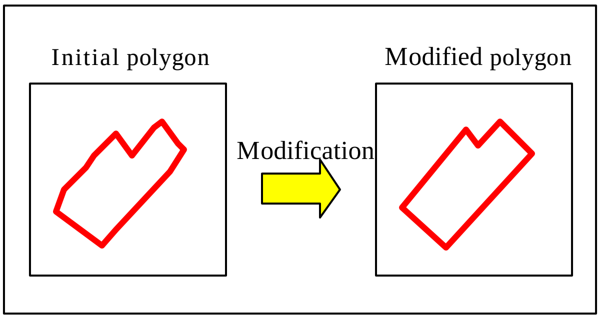

Figure 5. Modification of initial polygon

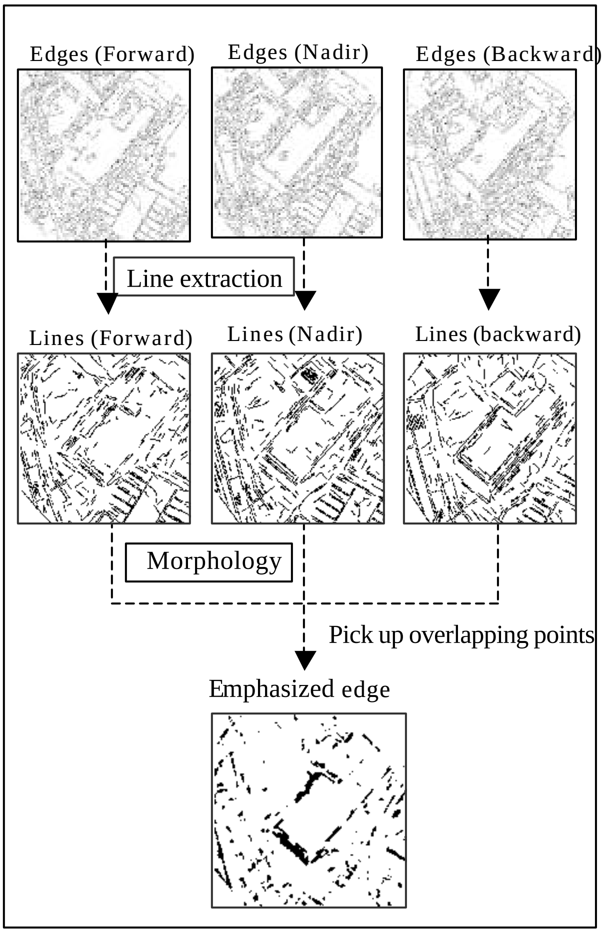

Figure 6. Generation of emphasized edge image

Finally, the model fitting is done to fix the horizontal plane of the 3D building model.

In this step, SNAKE model is applied to the emphasized edge image. And the polygon is fitted to the building boundary. Parameters for SNAKE fitting are edge's angles, shift length. And optimized positions are detected with the hill-climbing method, line by line. When the object is easy shape (e.g. a hexahedron), it is possible to apply a restriction of the shape (e.g. every vertex is right angle). As a result, the 3D building part is generated, and this is labeled 'the building number' (See, Figure7). When other 3D building parts exist around it, '3D building part optimization' is applied to them.

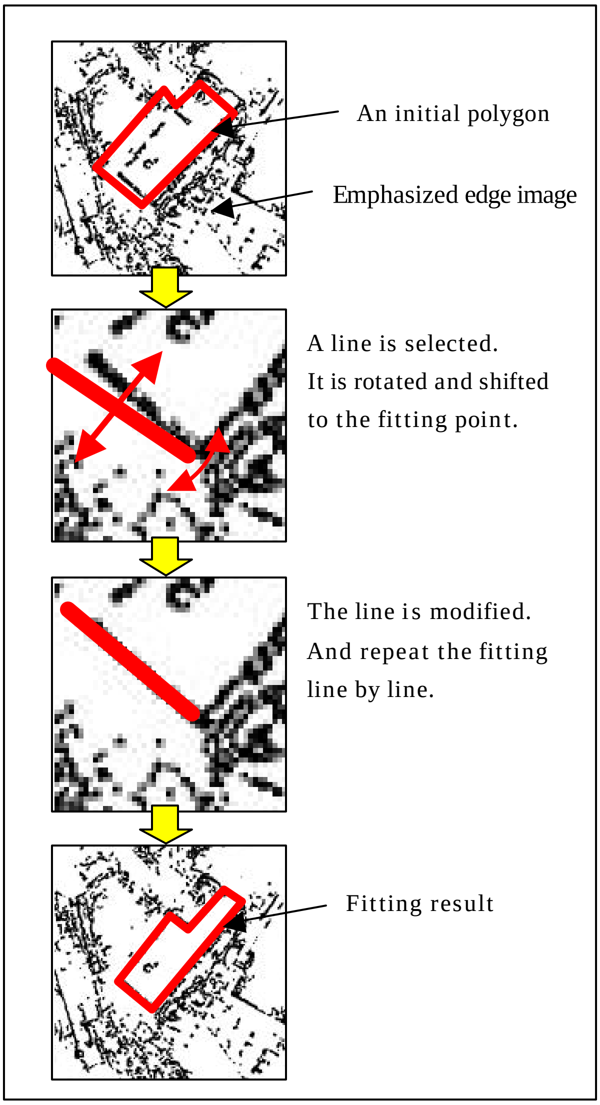

Figure 7. SNAKE fitting

2.4: 3D building model generation

The 3D building parts are generated in the previous stage.

As the next processing, 3D building parts are clustered to one model.

Processing flow in this stage is as follows.

- ?? Sort the 3D building parts
- ?? Re-optimize the building parts
- ?? Merge the building parts

At first, the 3D building parts are sorted in order of height. It is necessary for the following step. The order of modifying parts is decided by this result.

Secondary, the building parts are re-optimized. When the building parts are merged, there are some polygon errors. So, those errors should be modified. In this stage, lower building part is modified to higher building part. Concretely, a vertex point of the lower part is modified to a vertex point of the higher part (For example, see, Figure8). As a result, it is finished the optimization for the building parts.

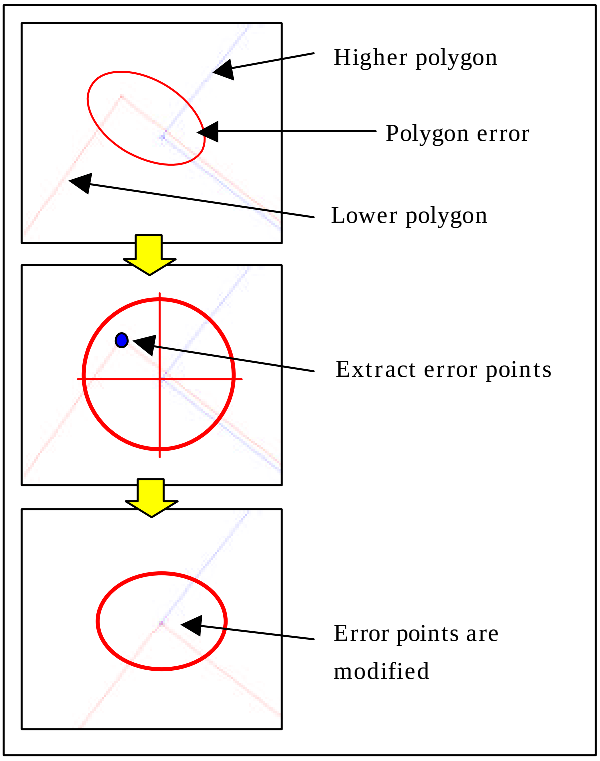

Figure 8. Modification of polygon error

Finally, these building parts are merged. The result is 3D Polygon data. Moreover, it is possible to generate fine DSMs. In this research, a fine DSM is also generated to compare with input DSM.

3: The preliminary experiment

3.1: Data

In this experiment, laser data (point-cloud data with ground resolution of 50cm. See, Figure9) is used as existing DSMs, and TLS images (ground resolution: 3cm. See, Figure10) are used as fine aerial photos.

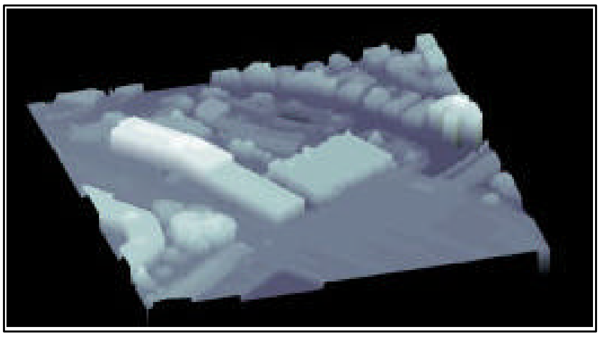

Figure 9. Laser data (ground resolution: 50cm)

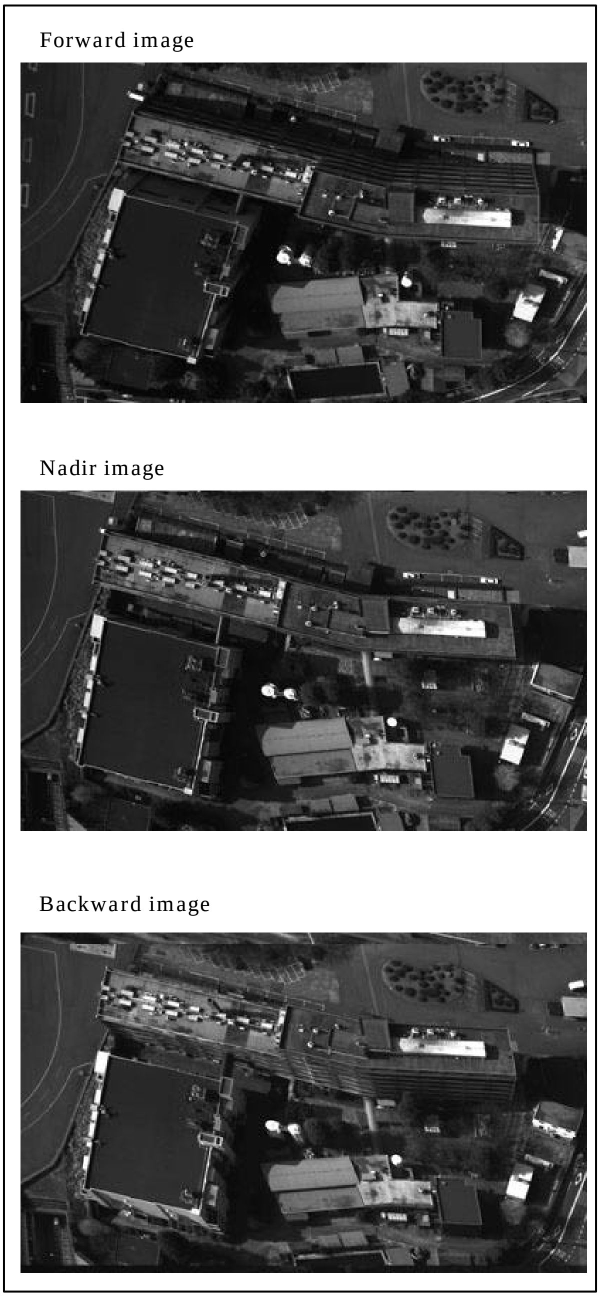

Figure 10. TLS images (ground resolution: 3cm)

3.2: Results of fitting

Here, results of fitting are shown (Figure11, 12, 13, 14, 15, 16).

Figure 11. Test-1 (Initial value)

Figure 12. Test-1 (Successful result)

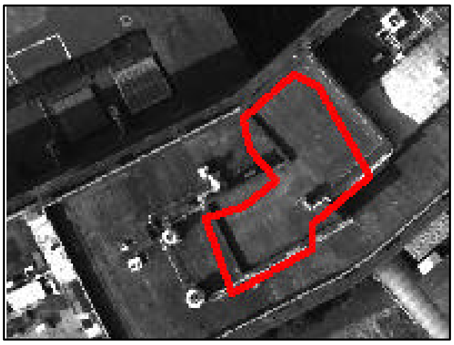

Figure 13. Test-2 (Initial value)

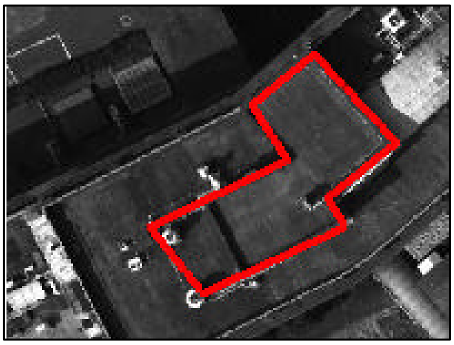

Figure 14. Test-2 (Successful result)

These four figures are successful examples. A red polyline in figure11 or figure 13 is an initial value for the model fitting. Also the polyline is a building's boundary in the existing DSMs. In many cases, the initial value has a distorted shape, because the resolution of the existing DSMs is lower than TLS images in this examination.

Figure 12 is a result in case of simple building shape. If a building' shape is simple (e.g. Rectangle), a restriction of 'Rectangle' can modify the initial polygon's shape. When the initial value is good condition, SNAKE works powerfully. Therefore, modifying the initial polygon leads successful results.

Figure 14 shows a result in case of more complex building shape. In this case, an initial polygon's shape is complex,

However, when the initial polygon positions near a correct value, SNAKE also works powerfully. As a result, the fitting is done successfully.

Moreover, t is possible to conclude that this model fitting can refine existing DSMs.

Next, failure examples are shown as follows (Figure 15, 16).

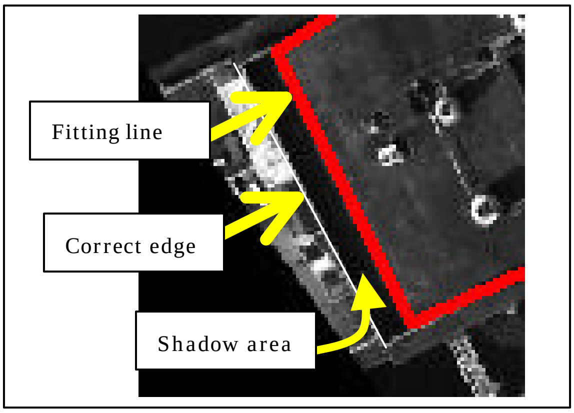

Figure 15. Test-3 (Failure example)

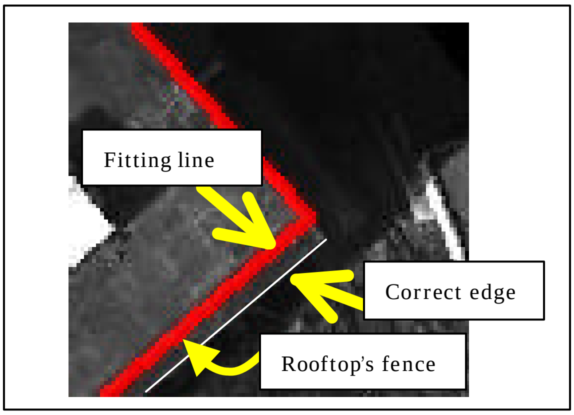

Figure 16. Test-4 (Failure example)

Figure 15 shows that a polyline is fitted to not a building wall's edge but a shadow's edge. When similar features exist, misfitting provides failure results such like this. But, in this case, it is possible to make the result correct by enhancing shadow's area on an image.

However, if the cause of misfitting is not a shadow, it is difficult to recover failure results to success results. Figure 16 is one of examples.

Finally, the result of 3D modeling is shown (See, Figure18). It is enough to express the building shape. And the fidelity is not so bad compared to existing DSMs (Figure17).

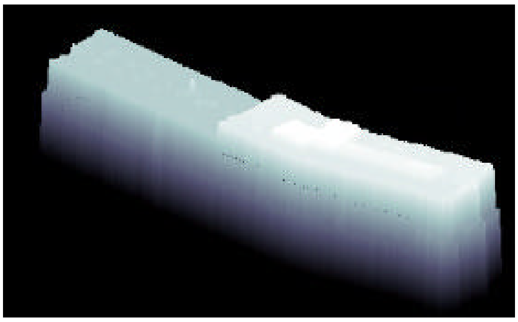

Figure 17. Original building DSMs

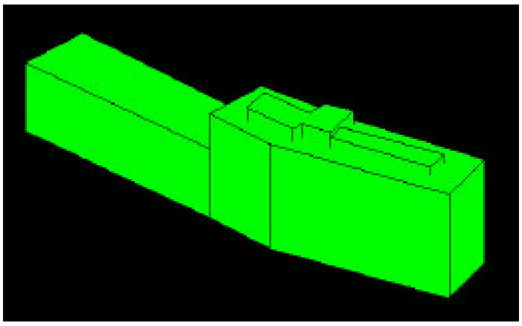

Figure 18. 3D modeling result

4: Conclusion

In this paper, it is described the approach to refine existing DSMs. According to the result in the preliminary experiment, this approach is confirmed as successful method. However, this approach has failure examples in some cases. It is necessary to prepare some recovering methods. Additionally, it is necessary to apply to inclined roofs or crowded buildings.

Authors also think that this method is possible to apply for auto-updating existing 3D digital maps.

- Reference

[1] M.NAKAGAWA, R.SHIBASAKI, Y.KAGAWA, Fusing stereo linear CCD image and laser range data for building 3D urban model, ISPRS Commission IV, WG IV7, 2002.

[2] M.NAKAGAWA, H. ZHAO, R.SHIBASAKI, Comparative study on model fitting methods for object extraction, ACRS, 2000