Comparative study of data selection in data integration for 3D building reconstruction

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Abstract: In this research, we presented a data integration, which integrates ultra high resolution images and complementary data for 3D building reconstruction. In our method, as the ultra high resolution image, Three Line Sensor (TLS) images are used in combination with 2D digital maps, DSMs and both of them. Reconstructed 3D buildings, correctness rate and the accuracy of results were presented. As a result, optimized combination scheme of data sets, sensors and methods was proposed.
Keywords: TLS, 3D data reconstruction, Data integration.

1. Introduction

Photogrammetry based on aerial photos is effective for manually reconstructing 3D building in dense urban areas. Especially, ultra high resolution images provide enough information for 3D reconstruction. But, the correctness rate of automated 3D data construction is low.

This study proposes to improve the correctness rate by integrating ultra high resolution images and complementary data. We propose a data integration approach, which integrates ultra high resolution images and complementary data for 3D building data reconstruction. In our method, as the ultra resolution images, TLS images are used in combination with 2D digital maps, DSMs and both of them.

TLS 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. The sensor is oriented on an aircraft perpendicularly to flight direction and scans the ground plane. Therefore, a triple stereo image of a ground object can be acquired.

This paper describes a correctness rate of the automation and accuracies of building data reconstruction in the data integration approaches. As a result, optimized combination scheme of data sets, sensors and methods is proposed.

2. Methodology of the data integration

The method of data integration approach, which integrates ultra high resolution images and complementary data for 3D building data reconstruction, is described in this section. This data integration approach uses TLS images for ultra high resolution image in combination with 2D digital maps or DSMs or both 2D digital maps and DSMs. Each data shall be acquired at almost the same period. The following is the processing flow of this methodology.

1: Generation of approximate 3D data
2: Modification of horizontal building shapes
3: Modification of building in a height direction

2.1 Generation of approximate 3D data

Approximate 3D data are generated in the first step. This 3D data shall be horizontal polygons. We recommend three combinations as following.

2.1.1 Use of three kinds of data

DSMs and the existing 2D maps are integrated to generate approximate 3D data. The Height of buildings is taken from DSMs. The horizontal shape of 3D data is taken from 2D maps.

2 1.2 Use of TLS images and DSMs

Building areas are extracted from normal vectors of DSMs surfaces. Additionally, buildings are identified by segmentation of ortho TLS images. Then, a line fitting algorithm is applied to refine horizontal shapes of the 3D data. Height information of generated shapes is calculated from DSMs. Thus, approximate 3D data are generated.

2.1.3 Use of TLS images and 2D maps

Only 2D maps are used as complementary-data. TLS images and 2D maps generate approximate 3D data. Height information is given to 2D maps through the stereo matching. The horizontal shape of 3D data is taken from 2D maps.

2.2 Modification of horizontal building shapes

Generated 3D data, which are back-projected to image spaces, have rough representation. Therefore shapes of polygons do not correspond with images. The polygons should be modified to correspond with building edges on the nadir image in this stage.

Firstly, a roof of 3D building polygon is back-projected with assuming as a horizontal plane. The SNAKE model given in "Eq.(1)" is used to modify polygon to match the nadir image, which has less occlusion than other images.

$$E_{snake} = \omega_1 E_{internal} + \omega_2 E_{external} \rightarrow \text{Optimize} \qquad (1)$$

where $E_{internal}$; Paragraph that Internal energy is evaluated
$E_{external}$; Paragraph that External energy is evaluated
ω_1 ; Weight of internal energy
ω_2 ; Weight of external energy

The result in this stage depends on SNAKE model. Therefore, the good initial value and the good edge image should be given for the SNAKE model. The initial value is a dilated polygon projected on the nadir image. The edge image is extracted from the nadir image. Moreover, overlapping edge images, which are extracted from some original images changed the dynamic range, are attempted to reduce influences of shadows.

Secondary, the modified polygon is projected from the image-space to the object-space, and a boundary of the polygon is updated in the object-space. As a result, the horizontal position and the horizontal shape of the 3D polygon are modified.

2.3 Modification of building in a height direction

A height of the 3D polygon on the object space is adjusted by line-edge matching based on the geometry model. This process uses not only the nadir edge image but also the forward edge image and the backward edge image. Shapes of polygons in all images are fixed, and positions of polygons in the forward / backward images are shifted in this processing.

Finally, the modified polygon is projected from the image-space to the model-space, and the 3D polygon is updated. As a result, the boundary of the 3D polygon is modified in the vertical direction in detail.

3. Experiments

The study area is Tokyo. Detached houses, complex buildings and large buildings are overcrowded in this area. The following data are used in this research.

1) TLS images: The original spatial resolution is 3cm approximately. The images are reduced to half resolution for a performance of a processing in this research.
2) DSMs: The spatial resolution is 50cm. The data are generated from LIDAR Data.
3) 2D polygon data: The Map level is 1:1000. 116 building polygons are used in this experiment.

Additionally, the following experiments are done.
1) Building extraction by using DSMs and TLS images: An extraction rate is evaluated by using 2D maps.
2) Evaluate performance of line-edge matching: Accuracy is evaluated by comparing processed data and a champion data.
3) Evaluate performance of SNAKE model: SNAKE model makes some random generated polygons match to an edge images. 1000 random polygons are prepared in some patterns.

4. Results

3D building models are refined easily by using this approach. One of results is shown in Figure 1.

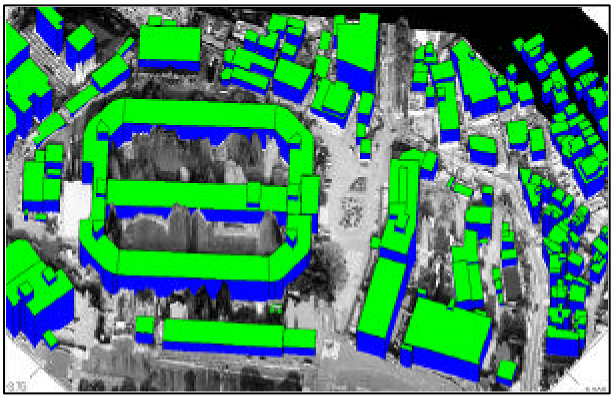

Fig. 1. Result of 3D modeling.

4.1 A success rate of building extraction

Figure 2 shows the result of building area detection, and Figure 3 shows the result of buildings extraction.

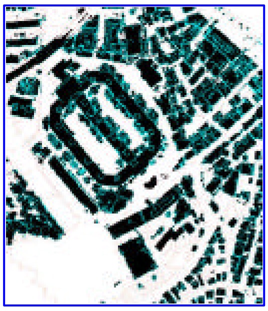

Fig. 2. Building detection.

Fig. 3. Buildings extraction.

Filled polygons show extracted area successfully. The success rate of the buildings extraction by using DSMs and TLS images is 84 % [125/149].

4.2 An accuracy of height values

Figure 4 shows the accuracy of line-edge matching.

Error values of height are plotted against a pixel size in the TLS forward image by a log-log plot. Cross is a result of matching without initial height values. Triangle is a result of matching with initial height values. The standard deviations of height errors in the line-edge matching are as follows.
1) Without initial height values: 7.96[m]
2) With initial height values (DSMS): 0.95[m]

When threshold is set in 2 meters, the success rates of matching are as follows.
1) Without initial height values: 0.55[%] (82/149)
2) With initial height values (DSMS): 0.93[%] (139/149)

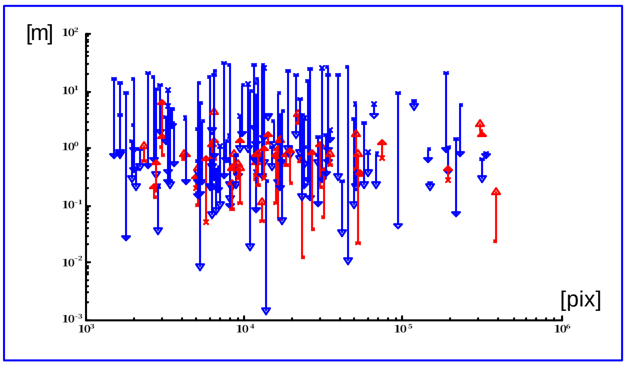

Fig. 4. Accuracy of height values

4.3 Performance of modification

An error value of the SNAKE model is plotted against a range of search. Figure 5 shows an accuracy of the SNAKE model. This figure shows that polygons, which have error 20 pixels, can be modified to accurate polygon, which is within 1 pixel to true values, by this optimization method.

A processing time of the SNAKE model is plotted against a range of search in Figure 6. This figure shows that processing time depends on the range of search strongly.

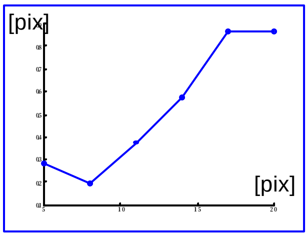

Fig. 5. Pixel errors

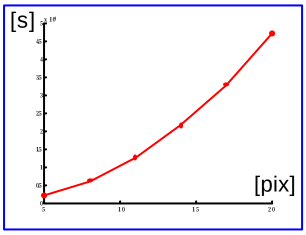

Fig. 6. Processing time

5. Discussions

The data integration approach in this research depends on an accuracy of approximate 3D data. We can directly compare each pattern of the approach by comparing the accuracy of approximate 3D data. However, each pattern uses different techniques partly. Discussions should be classified to the following points when we discuss the comparison of these approaches.

5.1 A success rate of building extraction

The buildings extraction is done perfectly when 2D maps are implemented. In this case, buildings are identified among urban features without complex processing. When DSMs segmentation is applied with ortho images, the buildings extraction is done effectively, especially in urban dense areas. However, the performance depends on the resolution of DSMs. Additionally, a problem of building identification is remained.

5.2 An accuracy of height values

Large features on TLS images can keep accuracy without initial height information, because the features have plenty of information for stereo matching, as figure 4 shows. However, initial height information is needed for stereo matching of small features.

5.3 Performance of modification

When an accuracy of DSMs is 50cm in 1 pixel, polygons on TLS images in this experiment have 8 pixels errors approximately. The SNAKE model can modify these polygons to 0.19pixels errors as figure 5 shows. However, it is important to narrow down the range of the search, considering the processing time.

6. Conclusions

All data, which are available in urban area, can provide best results. However, to use all data is not necessarily the best. Considering a cost, optimized approaches can be described as the following.

- A case of dense area

When 3D building data in dense area are generated, a combination of TLS images and 2D maps is better approach, because 2D maps shall be good initial polygon of buildings. This approach is no need to identify buildings by complex methods, because of perfect building extraction. However, mismatching sometimes occurs when occulusion exists.

- A case of open space

When buildings exist in open spaces, buildings extraction by using height information is easy. Therefore, a combination of TLS images and DSMs is best approach for 3D data generation. However, performance of the buildings extraction depends on a resolution of DSMs.

References

[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 IV/7, 2002.

[2] MICHAEL KASS, ANDREW WITKIN, and DEMETRI TERZOPOULOS, 1988. Snakes (Active Contour Models). International Journal of Computer Vision, pp321-331