MODELING OF BUILDING FROM TERRESTRIAL LASER SCANNING CONSIDERING TOPOLOGY FOR OCCULUSION

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ABSTRACT:

Manual modeling of buildings from point clouds obtained by terrestrial laser scanner (TLS) may take time and produce distorted model because of errors contaminated in the data or lacking of data. Automatic modeling is applicable for buildings with relatively simple structure, such as rectangular solid, but it is not applicable for buildings with intricate structure. The author's goal is to model Japanese traditional houses and buildings in a district using TLS and photogrammetry for the sake of disaster simulation. According to the preliminary study, it was found that automatic processing cannot estimate surfaces of such Japanese buildings properly. The present paper proposes a methodology to produce three-dimensional (3D) wireframe model of buildings from TLS data even if some surfaces of buildings are not measured. Instead of directly determining the vertices of the building, vertices are estimated after planes and edges of planes are estimated in order to improve the accuracy and prevent distortion of models. In the initial step, points on or close to the plane are manually selected to estimate plane equations. After the step, planes are estimated considering whether the planes are parallel or orthogonal to other planes. And then, the edges are estimated from planes, and vertices are estimated from edges. The occluded planes and edges are estimated utilizing building topology. For example, the occluded planes are estimated by referring to existing planes which can be assumed to be parallel or orthogonal to the occluded planes. In the proposed methodology, users are requested to define the procedure to estimate planes, edges and vertices. Once this procedure is fixed, the model is automatically estimated. The validation result to comparing with the lengths of actual edges indicates that the error of the estimated boundary lengths was 0.054 m, which is acceptable for many applications. With the proposed methodology, a building model can be produced even if TLS cannot measure all planes of the building.

1 INTRODUCTION

Urban building models are expected in various fields and laser scanner is capable of providing three-dimensional (3D) data necessary for the modeling. As the data acquired using laser scanner are point clouds, modeling is required to classify point clouds into a certain categories. Biosca and Lerma (2008) proposed an unsupervised robust clustering approach based on fuzzy methods for the segmentation of huge volum of terrestrial laser scanning data.

Airborne laser scanner is capable of estimating the building height and simple building models can be produced using airborne laser scanner. Existing researches focused on modeling of buildings fusing airborne laser scanner and other sources, e.g. satellite imagery (Sohn and Dowman, 2007), aerial imagery (Huber *et al.*, 2003) and terrestrial laser scanner (TLS) (Haala *et al.*, 2007) (Caceres *et al.*, 2007).

There is indeed a demand for the detailed urban model in a relatively small area, for example $100m \times 100m$ area of district and $100m$ distance of street. Instead of airborne laser scanner, TLS provides detailed data of side surfaces of the buildings, and then has potential to meet the demand for the detailed modeling. However, modeling of the buildings from TLS data is quite challenging because TLS measure the signal reflected from many small planes of buildings, and accordingly, the modeling is more complex than the modeling using airborne laser scanner. Therefore, in the present paper, we propose a methodology effectively and accurately to model buildings from TLS data.

2 THREE-DIMENSIONAL MODELING OF BUILDING FROM TLS DATA

In the present research, wireframe model is targeted to produce. It requires coordinate values of vertices of a building. If the vertex coordinate values are extracted manually, it may cause errors and take time to select the best vertex. And, the coordinate value may have measurement error. In addition, it is possible that actual vertex is not measured by not only TLS but also photogrammetry when the vertex is occluded to the position of TLS. Therefore, manual process in determining vertices should be avoided to produce accurate wireframe models.

The occluded planes can be estimated logically by referring to other measured planes as long as the structure of the building is not complex. For example, many Japanese houses have features that the corners of the rooms are orthogonal, and that walls are parallel or orthogonal to each other. If such rules are true, the occluded planes can be estimated by referring to topology of the buildings.

In the present paper, we propose a methodology to estimate accurate vertex coordinate values from TLS data measured at a single position by taking steps to estimate planes and edges. The flow of the procedure is shown in Figure 1. It starts with measured planes, lines and vertices, and then processes the occluded ones. The details on each item in Figure 1 are described in the following subsections.

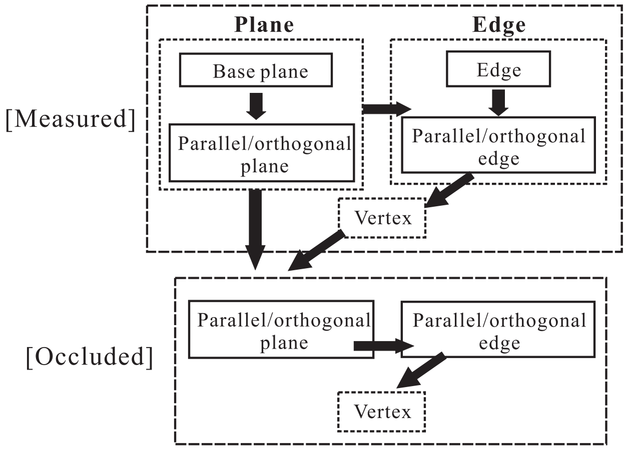

Figure 1: Flow of building modeling using TLS data

2.1 Estimation of planes

The author's goal is to model buildings using terrestrial and airborne laser scanners to compensate for each other. However, in the present paper, the modeling using TLS data is reported.

As shown in Figure 2, not only TLS but also photogrammetry cannot measure all the planes of the target. Registration of the data measured at different positions is popular, but it is quite difficult to avoid occlusion in the case of residential area because the measurement from the street or road has limitation to measure the back or side of the buildings. Under these circumstances, the effective modeling methodology should be developed.

In addition, the structure of the buildings should be properly modeled. In the author's previous experience, if the planes of the house in Figure 2 were estimated independently, the estimated model tended to be distorted because parallel or orthogonal relationship in planes are not always reflected in the produced model. Especially, when the incident angle of laser to the plane is bigger, the larger distortion was found. Therefore, technique to avoid such distortion is desirable.

In the proposed methodology, planes composed of buildings are classified into

1. Base plane,
2. Measured plane parallel or orthogonal to base plane, and
3. Occluded plane parallel or orthogonal to base plane

In the following subsections, the features of the three classified planes are described.

2.1.1 Base plane Base plane is defined as the plane which is referred to when estimating other planes in order to keep parallel or orthogonal topology of the estimated building model. For example, Figure 2, three planes, Planes 1, 2 and 3 can be measure by TLS. It is natural that Planes 1 and 2 are orthogonal to each other as well as Planes 1 and 3 in Japanese houses. In terms of actual measurement on the street or road, the roof, i.e. Plane 3, cannot be always measured. In addition, errors are contaminated in the beam reflected from sloping roof because the roof of traditional Japanese house has many tiles. Therefore, Planes 1 and 2 are selected as "base planes" in this case. The selection of base

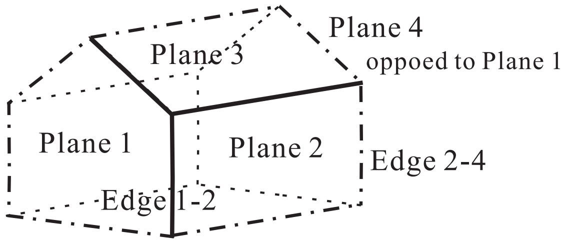

Figure 2: Planes and edges of a building. Planes 1 and 2 denote wall and Plane 3 denotes roof. Solid line is an edge between two measured planes, chain line is an edge between a measure plane and an occluded plane, and dash line is an edge between two occluded planes.

planes depends on the structure of the building and the position of the measurement.

When two base planes are measured, the plane equation is estimated as follows.

1. Initial points are selected manually, which are on or close to Planes 1 or 2. The points should be widely spread on the plane.
2. Initial equations of Planes 1 and 2 are estimated.
3. Edge between Planes 1 and 2 is estimated.
4. Plane 3 is estimated, which is a bisector of the interior angle of Planes 1 and 2.
5. The equations of Planes 1 and 2 are corrected so that both are orthogonal to each other by utilizing Plane 3.

Due to the errors contaminated in the reflected beam, it was found that selecting points from a small area produce unstable results of the plane parameter estimation. The manual selection of initial points is intended to avoid the estimation of the distorted plane.

2.1.2 Planes parallel or orthogonal to base plane After the base plane equation is fixed, other planes are estimated by referring to the topology of the building, which is parallel or orthogonal relationship. For example, the norm of Plane 3 in Figure 2 can be corrected so that it should satisfy the condition to be orthogonal to the norm of Plane 1. The norm of Plane 4, which is an opposite plane to Plane 1, is assumed to be same as the norm of Plane 1. In addition to the norm, the estimation of Plane 4 requires a point on it. The edge between Planes 2 and 4 helps in fixing the Plane 4 equation. In Subsection 2.2, the procedure to estimate the edge estimation is described.

2.2 Edge

The planes explained in Subsection 2.1 should have edges for the modeling. But, it is not always easy to estimate the edges because we have different cases, such as

1. Case that both of two planes are measured,
2. Case that only one plane is measured, and the other is occluded, and

3. Case that both of two planes are occluded.

Hereafter, the procedure to estimate edges in the cases of 2 and 3 is described. The lack of data regarding the occluded plane should be compensated logically from the measured plane. For example, Intersection 2-4 in Figure 2 can be estimated as follows.

1. Points are selected along Intersection 2-4.
2. Project the points onto Plane 2, and the points whose distance to the plane is within a certain threshold are selected.
3. Estimate a line which goes through the furthest point from Intersection 1-2 among the projected points and whose vector is the same as the vector of Intersection 1-2.

The line estimated by following the above procedure can be regarded as Intersection 2-4. The estimated Intersection 2-4 preserves the relationship that it is parallel to Intersection 1-2, and accordingly four corner points of Plane 2 are on the same plane.

Next, the procedure to estimate the edge of two occluded planes is focused on. It is expressed as a dash line in Figure 2, and it can be estimated after the measured planes and edges are determined. For example, Intersection 4-5 can be estimated as an edge of Planes 4 and 5, which is oppose to Plane 2. As mentioned earlier, Plane 4 can be estimated by using the norm of Plane 1 and Intersection 2-4. In the same manner, Plane 5 can be estimated from the norm of Plane 2 and Intersection 1-5. In short, edges of two occluded planes can be estimated using the topology of planes and edges of the building.

3 RESULTS

3.1 TLS measurement

In the present research, LMS-Z360i produced by Riegl, was used. As shown in Figure 3, it has a laser scanner and a digital camera on its top. It can measure range r, vertical angle θ, horizontal angle ϕ and signal amplitude using 900-nm laser beam with 90-degree vertical scan angle and 360-degree horizontal scan angle. The measured data is recorded in the sensor coordinate, and the coordinate data, i.e. x, y, z, was used for the analysis.

3.2 Study area

Kyoto is famous as the old Japanese capital city, and it still has plenty of traditional buildings and landscape. The authors' goal is effectively to model Japanese traditional houses and buildings from terrestrial or airborne laser scanner data.

In the present research, the district in front of Hohkanji-temple, Higashiyama-ku, Kyoto was selected because the 3D building models are required in the district to plan for the preservation of old temples against fire caused by earthquake. There are traditional Japanese houses and buildings around the temple. The district where ground-based LiDAR measurement was conducted was an approximately $80m \times 130m$ of area. LiDAR measurement was conducted at 9 positions along the roads around the temple area and 4 positions inside the temple area. Figure 4 shows the images obtained by laser scanner. The data measured at a single position was used for the analysis.

Figure 3: Terrestrial laser scanner used for the measurement (LMS-Z360i, produced by Riegl)

3.3 Initial points used in plane estimation

In the proposed methodology, several points are manually selected prior to the plane estimation. These points are referred as "initial points" hereafter. Figure 5 shows that the boundary of the plane to be estimated is highlighted.

Figure 5: Points selected for the plane estimation

Plane equation can be estimated when three points on the plane are given. In reality, the measured TLS data have errors, and then more points are preferable for more accurate estimation. However, manual sampling of many points should be avoided in terms of efficient processing. Therefore, we examined the optimal number of points. As a result, it was found that sampling with more than thirty points produced stable estimation results.

3.4 Three-dimensional building modeling

The procedure of modeling is explained in case of Building 1 shown in Figure 6. And, the wireframe models of Buildings 1 and 2 in Figures 6 and 8 were obtained as shown in Figures 7 and 9.

- Base plane (Plane 1 and 2)
    1. Extract points on or close to Planes 1 and 2 respectively, and estimate plane equations respectively.
    2. Edge between Planes 1 and 2 is unchanged, and the parameters of two plane equations are corrected so that both planes are orthogonal to each other.

Figure 4: Two-dimensional image of TLS data measured in front of Hohkanji-temple, Higashiyama-ku, Kyoto.

3. Norm of ground surface is estimated so that it is orthogonal to both of Planes 1 and 2.

- Measured planes (Plane 3)
  1. Extract points on or close to Plane 3.
  2. Estimate the equation of the plane whose norm is the norm of Plane 1 and on which the gravity point of the extracted points is.

- Measured planes (Plane 4)
  1. Extract points on or close to Plane 4.
  2. Correct the norm of the plane so that it should be parallel to Plane 2.
  3. Recalculate the equation of Plane 4 using the corrected norm and the gravity point of the extracted points.

- Measured planes (Plane 5)
  1. The norm of Plane 5 is obtained by rotating the norm of Plane 4 by 90-degrees on the norm of ground surface.
  2. Estimated the edge of Planes 1 and 2, Intersection 1-2, and the edge of Planes 1 and 4, Intersection 1-4. Then, the vertex 1-2-4 is estimated from the two edges.
  3. Estimate the equation of Plane 5 using the norm and the condition that the vertex 1-2-4 is on the Plane 5.

- Occluded planes (Plane 6: occluded roof)
  1. Extract points on or close to Plane 7, which should be along the slope of Plane 6.
  2. Estimate the equation of Plane 7 using the gravity point of the extracted points and the norm of Plane 1.
  3. Project the extracted point to Plane 7, and apply principal component analysis to the projected points. The vector of the first principal component is used as the slope of Plane 6.
  4. Estimate the norm of Plane 6 using the norm of Plane 1 and the slope of Plane 6.
  5. Estimate the equation of Plane 6 using the gravity point of Plane 7 and the norm of Plane 6.

Table 1: Comparison between the edge lengths estimated by the proposed methodology and the measured lengths at Houses 1 (H1) and 2 (H2)

	Line	Measured (m) x_i	Estimated (m) $\hat{x}_i$	Error (m) $\|x_i - \hat{x}_i\|$
H1	1	9.970	9.920	0.050
	2	6.078	5.988	0.089
	3	1.867	1.834	0.033
	4	0.920	0.932	0.012
	5	1.732	1.660	0.072
H2	6	6.828	6.738	0.090
	7	1.843	1.861	0.018
	8	2.111	2.040	0.071
	9	1.914	1.939	0.025
	10	4.660	4.603	0.057
	11	0.995	0.963	0.032
	12	1.740	1.714	0.026
	13	1.168	1.129	0.039
$RMSE = \sqrt{\sum_{i=1}^{13}(x_i - \hat{x_i})^2/13} =$				0.054

3.5 Validation

The produced building model was validated by comparing the estimated lines of the model with the measured ones. Figures 7 and 9 show the lines to be used for the validation, and the comparison result is shown in Table 1.

4 DISCUSSIONS

We proposed a methodology to produce a wireframe model of Japanese buildings from TLS data. Instead of directly determining the vertices of the building, vertices are estimated after planes and edges are fixed in order to improve the accuracy. Occluded features are estimated assuming topology such as parallel or perpendicular relationship. The proposed methodology still takes time to select initial points to estimate planes and edges.

The automatic detection of initial points for the plane and edge estimation requires segmentation of TLS data. If the segmentation is successful, the process of the modeling is accordingly reduced. However, the automatic understanding of the plane and edge topology is much more challenging than the automatic segmentation. This understanding still requires manual interpretation.

The validation result indicates that the error of the edge lengths estimated by the proposed methodology was 0.054 m, which is acceptable for such applications as landscape and fire simulations. However, inaccurate edges were found in non-flat planes.

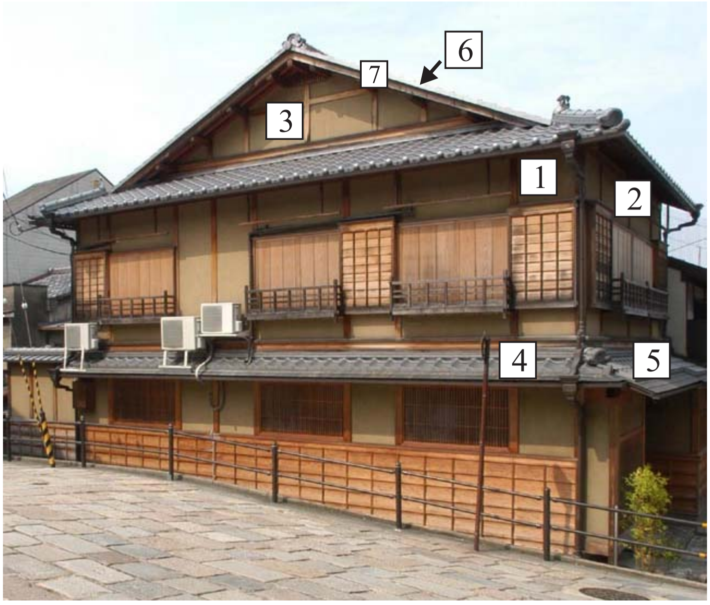

Figure 6: House 1 used in explaining the modeling procedure

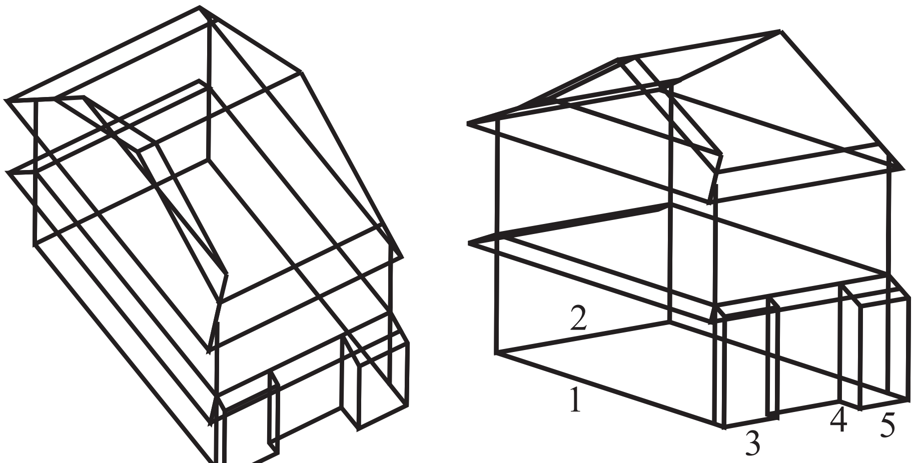

Figure 7: Three-dimensional wireframe model of House 1 produced by using the proposed methodology. The number of the figure denotes the number of the line used for the validation in Table 1.

Figure 8: House 2

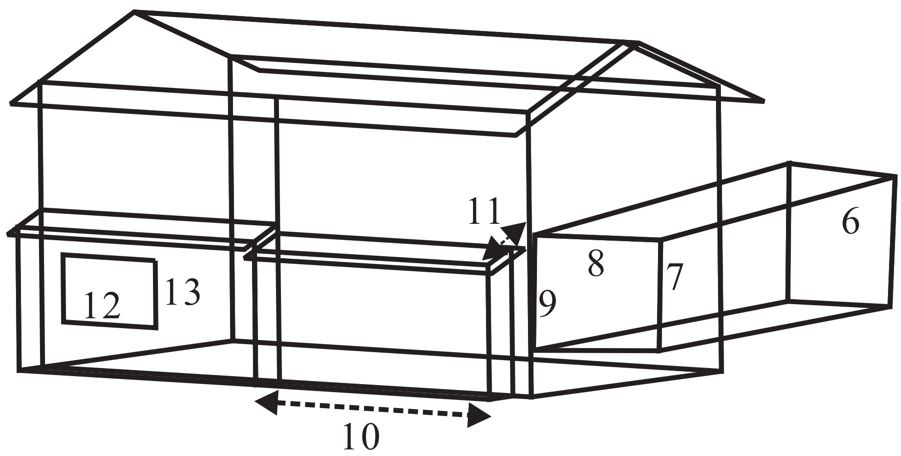

Figure 9: Three-dimensional wireframe model of House 2 produced by using the proposed methodology. The number of the figure denotes the number of the line used for the validation in Table 1.

It should be investigated to achieve more accurate and robust estimation methodology in case that the data with big errors are given.

5 CONCLUSIONS

The present paper proposed a methodology to produce a wireframe model of a building even when some parts of the building were occluded. In the proposed methodology, users are requested to define the procedure to estimate planes, edges and vertices. Once this procedure is determined, the model is automatically produced. In the experiments, two models were produced by using TLS data measured at a single position. The validation result to comparing with the lengths of actual edges indicates that the error of the edge lengths estimated by the proposed methodology was 0.054 m, which is acceptable for many applications. With the proposed methodology, a building model can be produced even if TLS cannot measure all surfaces of the building. The validation result to comparing with the measured line lengths indicates that the error of the edge lengths estimated by the proposed methodology was 0.054 m, which is acceptable for many applications.

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