

# SEMI-AUTOMATIC GENERATION OF THREE-VIEW DRAWING OF BUILDING USING TERRESTRIAL LASER SCANNING

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**Abstract.** Terrestrial laser scanning is an effective and efficient technique for acquisition of three dimensional data of indoor and outdoor environment in a short period of time. Precision of laser scanning data are usually within millimetres, which is satisfactory for building surveying and mapping. In recent years terrestrial laser scanning has been widely used in historical building preservation and cultural heritage documentation. Three-view drawing (plan, front and section views) is standard and important presentation of building surveying and mapping. However, generation of three-view drawing of a building using terrestrial laser scanning data often entails much human intervention. In this paper we present a methodology for semiautomatic generation of three-view drawing of a building. Three-view drawing of a building is often made on virtual planes which are perpendicular to the axis directions of the building. We define the projection plane using interactively selected laser points of the building surface and project point cloud to the determined projection plane. We project point cloud data to such a virtual plane defined by interactively selected points on the surface of building. A depth image is generated based on the distance between points and the virtual plane. The generated depth image is orthographic projection of three-dimensional laser scanning scene, which preserves the structural information of a building. Then segmentation and pattern recognition methods are exploited to extract the features (geometric primitives) from the depth image. The extracted features can be further refined to generate three-view drawing of a building. The presented methodology greatly reduces volume of data in operation and experimental results show the effectiveness of the methodology.

## 1. Introduction

Terrestrial laser scanning is an effective and efficient technique for acquisition three dimensional data of built environments. Techniques such as close range photogrammetry and mobile laser scanning are only suitable for mapping exterior of buildings. Terrestrial laser scanning is suitable for mapping both interior and exterior of buildings and it has been widely used in historical building preservation and cultural heritage documentation.



Three-view drawing (plan, front and section views) is standard result of building surveying and mapping. Compared with the design plan, the three-view drawing reflects the current situation of a building and therefore is valuable for building preservation, utilization and research. Plan view of a building can also be used for indoor positioning and navigation which has been provided by company such as Google in recent years.

Terrestrial laser scanning data can be used to generate three-view drawing of buildings. However, point cloud data usually record intensity and position of individual points. It is difficult to automatically derive building structures from unstructured point cloud due to lack of textual and topological information. For most building mapping projects in which terrestrial laser scanning has been used, three-view drawing is often interactively mapped. The mapping task often requires much human intervention, which limit the application of terrestrial laser scanning.

Relative techniques for automatic extraction of building structures have been presented by researchers. Pu and Vosselman presented semantic-based method for building parts extraction and façade reconstruction [1]. The semantics describe size and direction of building parts (wall, window, door et al.) as well as topological relationship between them. Building parts are derived from point cloud segments using the predefined semantics. On the basis of this research, Pu and Vosselman put forward a method for window extraction from point clouds [2]. Becker and Haala presented method for façade reconstruction using combined terrestrial laser scanning data and high resolution digital images [3]. Pu and Vosselman also presented a method to reconstruct building façade using point clouds and images [4]. Zhan et al. extracted linear and circular features from terrestrial point cloud using Hough transform [5]. The point clouds are firstly segmented, and then lines and circles are extracted from the horizontal projection of segments.

Most research in building surveying and mapping field are focused on building reconstruction and building parts recognition. Methods for generating the floor plan, linear feature extraction and modeling the building interiors have been presented by [6-10]. Few publications about three-view drawing have been seen so far.

## 2. Methodology

Three-view drawing of a building is often made on virtual planes which are perpendicular to the axis directions of the building. Three-view drawing can be considered as a geometric description of orthographic projections of buildings. Therefore, the presented methodology includes orthographic projection of buildings and geometric description of the orthographic image. Firstly we project point cloud to virtual planes defined by selected points. An orthographic depth image is generated based on the distance between points and their projections on the virtual plane. Then segmentation and pattern recognition methods are exploited to extract geometric features from the depth image. In this work three views are all generated using the orthographic depth image.

### 2.1. Generation of orthographic depth image

The procedure to generate the orthographic depth image is similar for plan view, front view and section view. Without loss of generality, we detail the generation of orthographic depth image of front view.

The ideal projection plane of building front view should be vertical. The orientation of the projection plane should be similar to that of building façade. And the orientation of the building façade can be determined by laser points of façade.

To determine the orientation of a plane at a given point, Principal Component Analysis (PCA) is used to extract eigen values and eigen vectors of covariance matrix  $C$  (equation 1) derived from coordinates of its neighboring points.

$$C = \frac{1}{N} \sum (X_i - \bar{X})(X_i - \bar{X})^T \quad (1)$$

$$\bar{X} = \frac{1}{N} \sum X_i \quad (2)$$

where  $X_i = (x_i, y_i, z_i)$ . Assume the extracted eigen values are  $\lambda_0 \geq \lambda_1 \geq \lambda_2$  and the corresponding eigen vectors are  $v_0, v_1$  and  $v_2$ . If points in a local area are coplanar, then  $\lambda_0, \lambda_1 \gg \lambda_2$  and  $v_2$  can be considered as normal of the plane. Therefore the orientation of the projection plane can be determined using interactively selected laser points. Orthographic depth image of façade can be generated by projecting the laser points onto the determined projection plane.

The laser scanner has been leveled before scanning, so the Z axis of its inner coordinate system is approximately vertical. But the X and Y axis are arbitrarily directed. If the selected points lie on a vertical plane, the general form of the expected projection matrix is

$$(\beta_1 \ \beta_2 \ \beta_3) = \begin{bmatrix} 0 & b_1 & c_1 \\ 0 & b_2 & c_2 \\ a_3 & 0 & 0 \end{bmatrix} \quad (3)$$

where  $\beta_1$  is vertical vector on the projection plane,  $\beta_2$  is the horizontal vector on the projection plane and  $\beta_3$  is normal vector of the projection plane. The orientation vector can be obtained by vector normalization.

$$(\alpha_1 \ \alpha_2 \ \alpha_3) = \left( \frac{\beta_1}{\|\beta_1\|} \ \frac{\beta_2}{\|\beta_2\|} \ \frac{\beta_3}{\|\beta_3\|} \right) \quad (4)$$

However, the obtained eigen vectors  $v_0$  and  $v_1$  from PCA are arbitrarily directed on the projection plane. So the eigen vectors from PCA cannot be directly used as orientation of the projection plane. Without loss of generality, let  $\beta_2$  be directed horizontally, we get

$$(\beta_1 \ \beta_2 \ \beta_3) = \begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & 0 & c_3 \end{bmatrix} \quad (5)$$

Because  $\beta_2$  is normal to  $\beta_3$ , we get

$$\beta_2 \cdot \beta_3 = 0 \quad (6)$$

Then

$$b_1 c_1 + b_2 c_2 = 0 \quad (7)$$

One solution to the above equation is

$$b_1 = -c_2, \quad b_2 = c_1 \quad (8)$$

Similarly,  $\beta_1$  is normal to  $\beta_2$  and  $\beta_3$ , we get

$$\begin{cases} \beta_1 \cdot \beta_2 = 0 \\ \beta_1 \cdot \beta_3 = 0 \end{cases} \quad (9)$$

And

$$\begin{cases} a_1 b_1 + a_2 b_2 = 0 \\ a_1 c_1 + a_2 c_2 + a_3 c_3 = 0 \end{cases} \quad (10)$$

Based on (7), we get one solution to equation (9)

$$a_1 = c_1, \quad a_2 = c_2, \quad a_3 = c_3 - \frac{1}{c_3} \quad (11)$$

From the above derivation, it is easy to see that the orientation of the projection plane can be determined if  $\beta_3$  is known. The eigen vector  $v_3$  that is corresponding to the smallest eigen value can be used as  $\beta_3$ . The orientation vector can be obtained by vector normalization.

Normal of a plane can be inward directed and outward directed, so let  $\alpha_3$  point to the outside of the building façade. This condition can be guaranteed by testing the angle between vector  $\alpha_3$  and a vector pointing from any laser point to origin of the coordinate system. If the angle is less than  $90^\circ$ ,  $\alpha_3$  is pointed to outside of the building. Otherwise, opposite directions of  $\alpha_3$  and  $\alpha_2$  are used.

Coordinates  $[X \ Y \ Z]$  of each scanning point after orthographic projection can be determined by equation (12).

$$[X' \ Y' \ Z'] = [X \ Y \ Z] \cdot (\alpha_1 \ \alpha_2 \ \alpha_3) \quad (12)$$

where  $X'$  and  $Y'$  are coordinates of a point on the orthographic projection plane, while  $Z'$  represents the depth of the point. To obtain the orthographic depth image, sample interval of the image should be set. And the width and height of the image can be determined by the range of  $X'$  and  $Y'$ .

$$Width = (\max Y' - \min Y') / S + 1 \quad (13)$$

$$Height = (\max X' - \min X') / S + 1 \quad (14)$$

where  $S$  is image sample interval in meters.

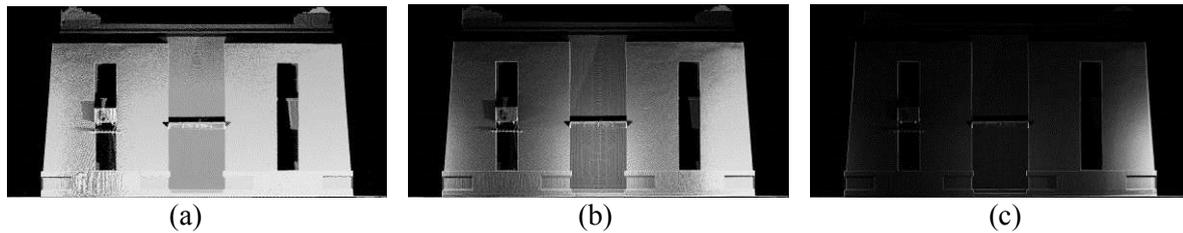
## 2.2. Feature extraction from orthographic depth image

Linear features are mostly seen in terrestrial laser scanning scene of buildings and are also important geometric primitives to generate three-view drawing of buildings. Therefore linear features are extracted in this research. Hough transform is an efficient and effective method to extract features from images [11-12]. The main idea of Hough transform method is to transform the problem of pattern detection in observation space to locating local maximum of votes in parameter space by exploiting the duality of the two spaces. Because laser points are discrete, their projections on the orthographic depth image are discrete. When the sample interval is small, there will be many pixels that do not correspond to any laser points. This will bring in noise to edge point detection and lead to false line extraction using Hough transform method. In this work, we use Line Segment Detector to extract lines from the generated orthographic depth image [13].

## 3. Results and discussion

As mentioned above, value of a pixel is determined by  $Z'$  of the projection of a scanning point. Because the  $Z'$  axis is out directed, larger  $Z'$  value corresponds to shorter distance and larger pixel value (brighter). When one pixel does not correspond to any scanning point, its value is set to 0 (black). In consideration of sheltering, if one pixel corresponds to several scanning points, its value is set to the largest one (that is the projection of the nearest point). The range of pixel values are then converted to  $[0, 1]$  by linear stretching the range of  $Z'$ .

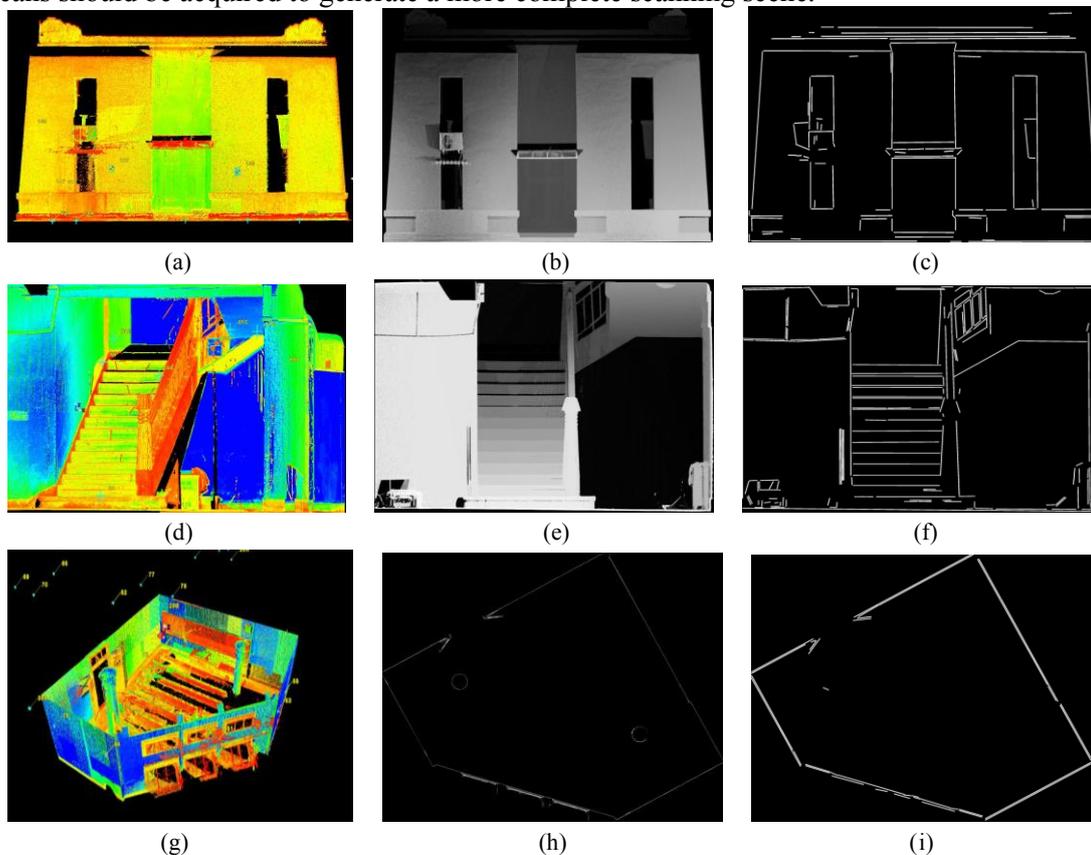
Figure 1. shows the orthographic depth images of a building façade generated with different sample intervals. The point cloud is down-sampled with 1/9 sample rate. With decreasing sample interval, the generated depth images are becoming darker. This is because smaller sample interval leads to more background pixels that do not correspond to any laser points.



**Figure 1.** Orthographic depth image with sample interval of (a) 0.01m (b) 0.005m and (c) 0.002m

Figure 2 shows linear features extracted from orthographic depth images. Figure 2(a) shows the point cloud without downsampling and the generated depth image is shown in Figure 2(b). The extracted feature lines are shown in Figure 2(c). It can be seen from the figure that major linear features are all well extracted from the depth image. Figure 2(e) shows the depth image generated by a point cloud acquired inside a building. The linear features that correspond to stairs and wall are well extracted (Figure 2(f)). This result can be further refined to generate the standard section view of the scene. To generate the plan view drawing, a horizontal slice of a point cloud (Figure 2(g)) acquired in a classroom is used. Orthographic depth image of the slice is shown in Figure 2(h). The extracted lines are shown in Figure 2(i).

It is worth mentioning that there are inappropriate lines which should not appear in standard three-view drawings. The lines generated by the ‘shadow’ near the air conditioning machine at the center of left window in Figure 2(c) is inappropriate. This ‘shadow’ is resulted from inhomogeneous distribution of laser scanning points due to sheltering by the air conditioning machine. While lines extracted at the center of the right window in Figure 2(c) is also due to sheltering. And similar problems appear in Figure 2(f). Double lines are extracted at the upper stairs. To solve this problem, more scans should be acquired to generate a more complete scanning scene.



**Figure 2.** Results of feature extraction from orthographic depth images

#### 4. Conclusion

Three-view drawing (plan, front and section views) is standard and important result of building surveying and mapping. However, generation of three-view drawing of a building using terrestrial laser scanning data often entails much human intervention. In this paper we present a methodology for semiautomatic generation of three-view drawing of a building. Using interactively selected points on the surface of building we define orthographic projection plane. Orthographic depth image is generated based on the distance between laser points and their projections on the projection plane. Then linear features are extracted from the depth image. The extracted features can be further refined to generate three-view drawing of a building. The presented methodology greatly reduces volume of data in operation and experimental results show the effectiveness of the methodology.

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