SINGLE VIEW RECONSTRUCTION FOR SPECIFIC CURVE STRUCTURES

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ABSTRACT: This paper presents effective algorithms for reconstructing three-dimensional models of specific curve structures from single perspective view images. The proposed method begins with edge detection and filtering from photographs or paintings with fine perspective geometry. Feature lines and corner points are extracted by transferring detected edges to normal distance and normal angle space. Curved segments are also extracted separately. Three mutually orthogonal vanishing points are then calculated automatically using k-means cluster and standard deviation filter on the intersections of extended straight feature lines. Feature points are extracted using a corner point filter with geometry constrains, and their corresponding base points also can be predicted with vanishing points. Three-dimensional coordinates of feature points are computed based on vanishing points using single-view metrology. In addition to straight lines and planar features, two types of curved segments are processed and reconstructed, including cylinder shape and figure-of-rotation structures. Finally, regular and curved models are reconstructed from their shared feature points. Experimental results from computer-simulated images and close-range photographs of buildings indicate that the developed algorithms can successfully extract 3D information and reconstruct 3D building models. The developed algorithms are highly automated, providing an effective and efficient method for reconstructing building models with specific curved structures from single-view images.

1. INTRODUCTION

With the rapid development of 3D-GIS, 3D building model is an essential element., Therefore, building modeling an important issue. Examples and applications of this task include cyber city, augmented and virtual reality, digital documentation of buildings, monuments and sites, architectural surveying and others. For the purpose of 3D model generation, direct measurement or surveying such as using LIDAR, total stations or well-calibrated cameras are practical methods for ground-based construction. However, these types of approach often require expensive equipments and professional operator. In addition, traditional photogrammetry-based reconstruction often requires multiple views of objects and known camera parameters. On the other hand, single view reconstruction (SVR) techniques have a potential to extract 3D geometry from an image without knowing the priori parameters, which should provide a more economic and efficient way for building model reconstruction. Furthermore, non-existing buildings can also be reconstructed from historical images or paintings with perspective projection, which may be difficult to achieve using traditional reconstruction methods.

Researchers in the fields of computer vision and close-range photogrammetry have investigated in single view reconstruction. Hoiem et al. (2005) assumed that the scene consists of horizontal and vertical planes and than classified the image into to several vertical regions and based ground plane to build up a scene. Therefore, this method does not apply to scenes that are not made up only of vertical surfaces standing on a horizontal plane. Saxena et al. (2008) proposed a method by over-segmenting an image into small homogeneous regions and using a Makove Random Field (MRF) to infer the 3-d position and orientation of each polygon of non-vertical structure. They improved previous method to handle scenes with significant non-vertical structure and also increased correctness, but lack of geometry constraint and the classification results heavily related to training datasets. Zhang et al. (2001) and Prasad et al. (2006) addressed the problem of reconstructing free-form curved surfaces by combining a sparse set of user-specified space topology cues, such as surface position, normals, silhouettes and creases. Their method can generate high-quality and visually pleasing 2.5D mesh surface model manually.

Another popular single view reconstruction approach is using single, two or three vanishing points to obtain approximate 3D information of objects. Horry et al. (1997) used the cues of different scales along the line to the single vanishing point. The vanishing point is the most distant point from the observer; other points away from the vanishing point will having lager scale. If two of the vanishing points in the horizontal direction can be found in the image, a vanishing line can be constructed and used for modeling scenes (Kang et al., 2001) or camera calibration

(Grammatikopoulos et al., 2007). Colombo et al. (2005) proposed a method to recover the 3D structure of a generic surface of revolution object and its texture from a single uncalibrated view, based on the projective properties expressed through planar and harmonic homologies. In general, the most popular algorithms for scene reconstruction is to using vanishing points which are corresponding to mutually orthogonal directions in the world space. Hartley and Zisserman (2003) explained the geometric meaning of these three vanishing points that are related to camera parameters, including focal length, principle points, and camera pose. Based on the vanishing points and vanishing lines, polyhedral models can be constructed from measuring lines and other features as well as topological and geometric constrains, such as planarity, parallelism, alignment and angles topology of objects in a single image (Van Den Heuvel, 1998; Criminisi et al., 2000; Wang et al., 2005).

However, most SVR methods rely heavily on manual operations and are not systematically implemented. In addition, vanishing points detection might be stable, but vanishing points are imaginary points, which are difficult to assess the accuracy. To address this issue, this research extends a previous work (Chang and Tsai, 2009) to develop a systematic approach for feature detection and increasing the level of automation for 3D building model reconstruction from a single perspective view image. Moreover, in addition to planar facades, two types of curve structures can also be reconstructed with the proposed algorithms. The developed algorithms are based on vanish point metrology and require only a single image with perspective projection; no camera and other parameters are needed. This is one of the most economical means to extract 3D information, because no expensive equipments and professional operators are required. The data can be acquired with consumer digital cameras or even downloaded from the Internet.

METHODOLOGY

Figure 1 illustrates the general procedure of the developed reconstruction method. First, feature edges are detected from the image for feature line extraction. Extracted straight line segments are separated from curved segments and used to select feature points and to obtain vanishing points. Coordinates of the feature points are calculated from three vanishing points. Height equalization and vanishing points fine-tuning processes are developed to adjustment the systematic and random errors. Curved structures are reconstructed with obtained parameters and combined with planar models generated from extracted feature points.

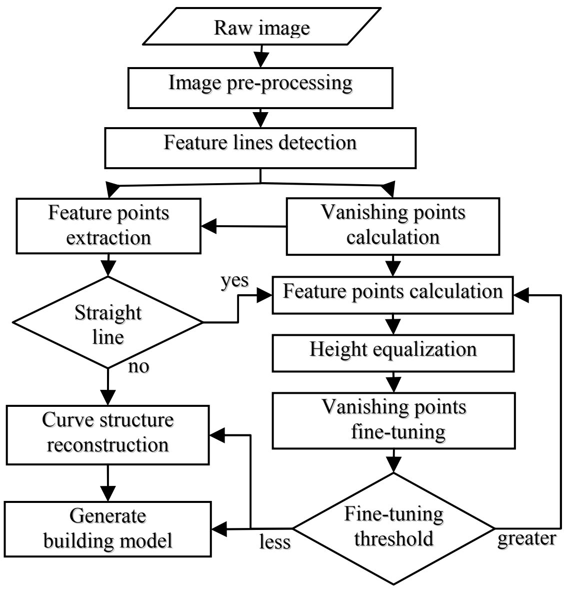


Figure 1. Building model reconstruction procedure

2.1 Feature lines detection

The left part of Figure 2 shows the procedure of feature line detection. The first step is to transfer raw image to greyscale, and then extract feature edges by Canny operators. Canny operator is a discrete differentiation operator. The operator computs an approximation of the gradient of the image intensity function, and traces edges through the image with hysteresis thresholds, which has good detection, good localization, and minimal response. Obtained binary image will be used in subsequent procedures. Image enhancement might be helpful for improving edge detection, and morphology could also be useful for merging discontinuous lines.

By transferring extracted feature edges to normal distance and normal angle (ρ-θ) space, straight feature lines can be detected automatically. For the best results, this study uses the inverted pyramid pattern iterative calculation for ρ-θ parameters, and the iteration stops when vanishing points are stable. A voting scheme can be used to select candidate peaks from the accumulated histogram for collinearity detection in ρ-θ space. Afterward, similarity rectification is applied to identify different line segments. Then using least square methods to trace line groups iteratively by adjusting the threshold of histogram peaks, until the number of line groups is satisfied.

2.2 Vanishing points calculation, feature points extraction and corresponding base points prediction

A vanishing point is the point in the perspective space where a group of parallel lines in the object space converge. However, in practice, these lines do not intersect at a single point. Each two lines will converge into a point, so the convergent points will be dispersed within a certain areas. This study use k-means cluster to separate convergent points for three mutually orthogonal directions, and uses the standard deviation as the threshold to determine the most possible position of a vanishing point as described in Chang and Tsai (2009) and indicated in the right part of Figure 2. There are two conditions for obtaining stable vanishing points. The first is the number of convergent points. If the number is too large, it means most detected lines are pointing to a certain direction. Adjust line group number threshold can fix this problem. The other is the representative vanishing points should be stable under different ρ-θ parameters. Modifying ρ-θ parameters can increase the reliability for vanishing point calculation. In this step, the initial location of the vanishing points can be quickly obtained. Coefficients of radial symmetric lens distortion can also be calculated using vanishing points and feature lines.

Short segments and small closed polygons from detected segments can be removed because most of them are windows, patterns or additional structures. Use the rest segments to calculate intersected corner points as candidate feature points. Some of the geometry constrains can be used for filtering candidate points. An important issue is to define a reference plane with the reference origin and vanishing points along x and y axis. The reference origin is the intersection point from the bottom edges along x and y axises of the main structure. Candidate feature points below the reference plane or collinear to others can also be removed.

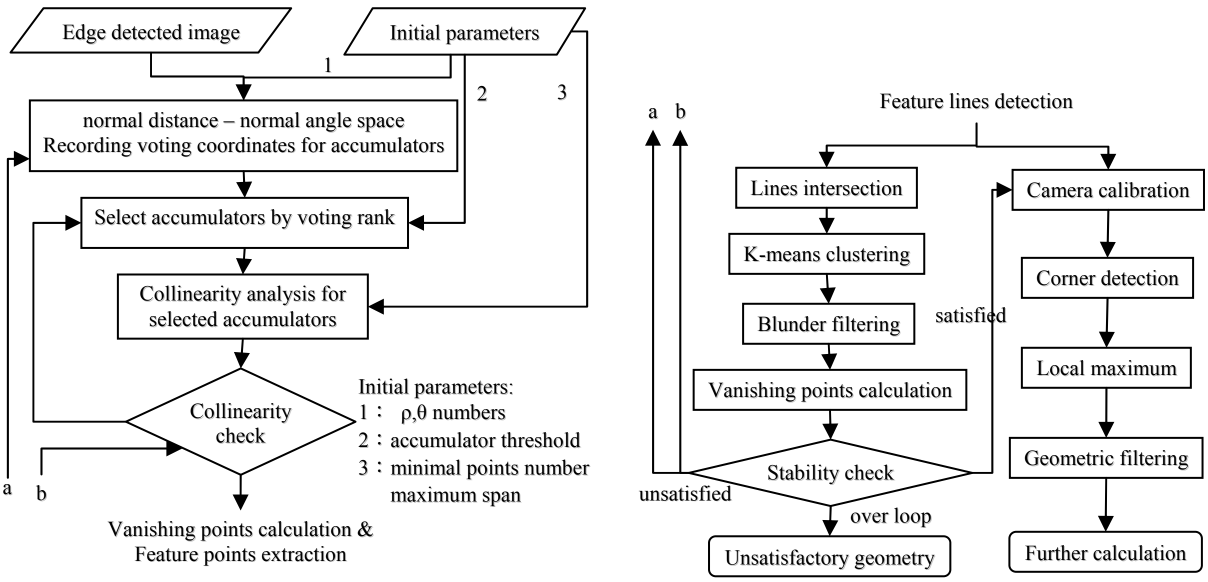


Figure 2. Systematic working flow for feature line detection (left), vanishing point calculation and feature point extraction (right).

Figure 3 is an example of base point prediction. Feature points are marked in blue square dots, and the origin is in red shown in Figure 3(a). According to the vanishing points along Y and Z or X and Z direction, feature points are projected onto the X-Z or Y-Z plane, and record the projection path. The projection for the feature points are marked in red triangles in Figure 3(b). The same procedure using vanishing point along Z direction to project them onto Y or X axis noted in green squares in Figure 3(c), record and link to the vanishing point along y or x direction shown in Figure 3(d). The intersection point to the line linked from feature points to the vanishing point along z direction (green line in Figure 3(e)) are the base points (blue points in Figure 3(e)). In Figure 3(f), green lines represent the target heights between the feature points and their corresponded base points to determine in the next step.

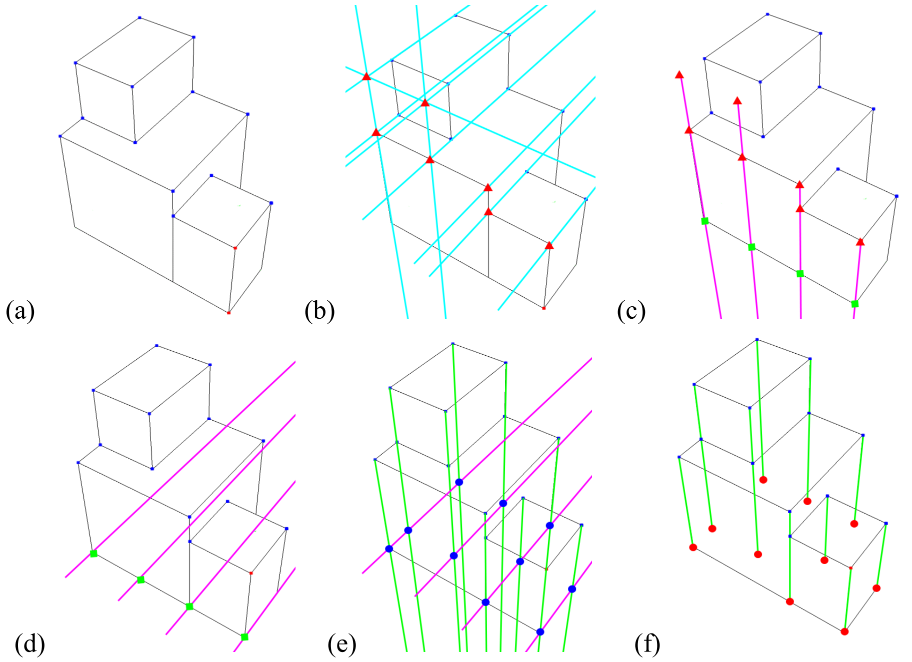


Figure 3. An example for a series procedure of base point's prediction.

2.3 Feature points calculation

After calculating three main vanishing points, connect X and Y directions' vanishing points, V_x and V_y, to form a vanishing line, L_v. As illustrated in Figure 4, feature point F_r is at a known (or reference) distance H_r to B_r from the reference plane. Another feature point F is with an unknown distance H from the reference plane. Points B and B_r are the base points for vertical distances lie on the reference plane. The four points I, F, B, V_z are collinear. Point I can be obtained from eq. (1), which projects point F_r on to the line linked by F and V_z. Once a reference height, H_r, is defined, every feature points' height, H, can be calculated from eq. (2). If there is no reference information available, this algorithm can still provide a relative model. Horizontal information can be obtained by project feature points onto X-Z and Y-Z plan and measured by their scales.

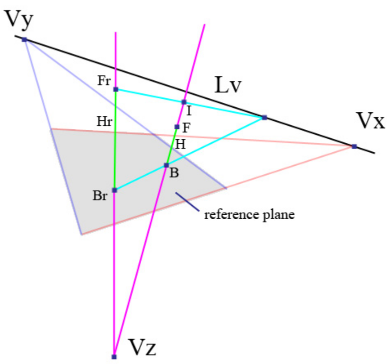


Figure 4. Feature points calculation.

$$I = \overline{V_z F} \times \overline{F_r \times L_v \times (\overline{B_r B})} \quad (1)$$

$$H = \frac{\left\| \overline{FB} \right\|}{\left\| \overline{IB} \right\|} * H_r \quad (2)$$

2.4 Curve structure reconstruction

Curved segments are separated from the extracted straight lines in the previous procedures. To fill the gaps due to occlusions, spline curve fitting are used to fit the discontinuous curves on the image. Two types of curves were separated for different reconstruction methods, including cylinder shape and surface of revolution (SOR). For cylinder shape reconstruction as shown in Figure 5, find two intersection points of straight lines and the curve line as the starting (s) and ending point (e) of the major axis, as indicated in the general procedure of curve structure reconstruction (Figure. 6). The line passing thought the center of the major axis (c) and corresponding vanishing point (v) will intersect curve line to indicate the position of the arc apex (c'). The minor axis is the line linked from apex to the center of the major axis. Next, project the image on to the vertical and horizontal planes according to the vanishing points respectively to calculate the length of the major and minor axises. The cylinder shape structure can then be generated from the coordinates of the starting and ending points with the length of major and minor axis. As for the SOR structure, the image is rectified and projected on to the vertical plane using vanishing points. The contour line is generated from projected contour points, while the symmetry axis is the line that passes through the center of rotation and the vanishing point in vertical direction. According to the contour line and symmetry axis, SOR structure can then be reconstructed. Finally, combine the curved structure with the main body to form a complete building model with curved structures.

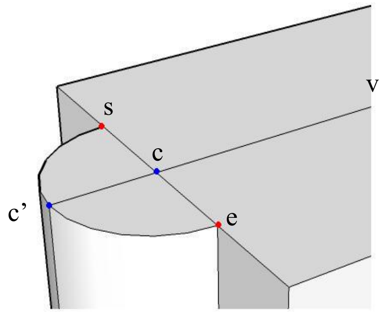


Figure 5. The cylinder shape parameters, $\overline{se}$ is the major axis and $\overline{cc'}$ is the minor axis.

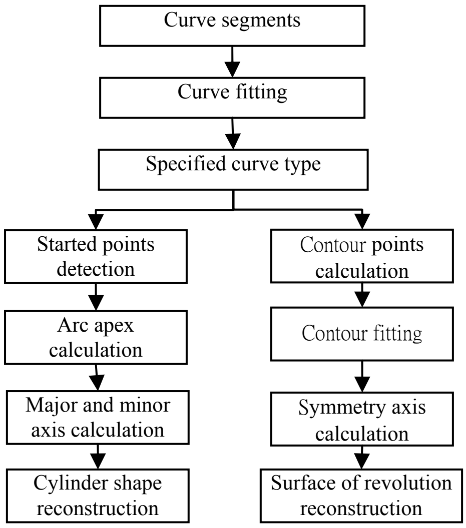


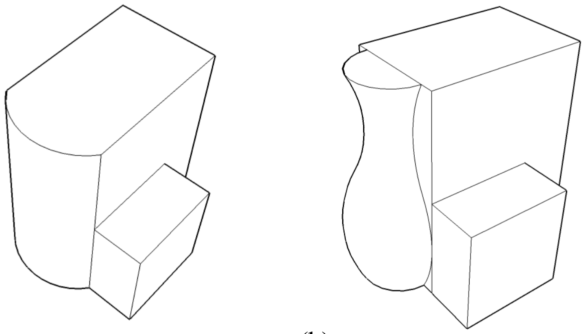
Figure 6. General procedure for curve structure reconstruction

3. EXPERIMANTAL RESULTS

This study used two types of single-view images to test the performance of the developed algorithms, computer-simulated model and close-range photograph of buildings with fine perspective projection. Quantitative evaluations by ground survey and reference data were also performed to validate the reconstructed building models.

3.1 Computer simulated geometric structure image

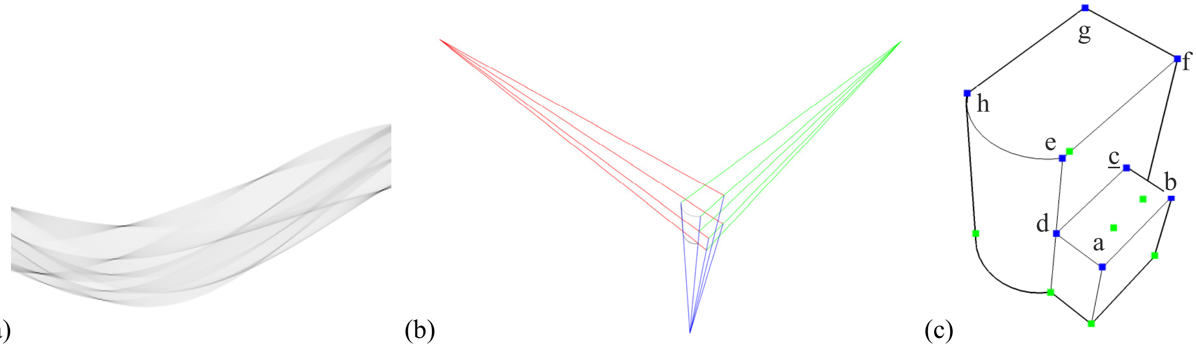
Figure 7 shows two computer-simulated building images, including a cylinder shape structre and a SOR structure. These two test cases were generated with known size and perspectively projected onto an image plane. By using these two case studies, error from lens distortion, occlusions and projection can be ignored. Complete reference data can also be used for quantitative evaluation.



(a) (b)

Figure 7. Two computer simulated geometric structures (a) cylinder shape (b) surface of revolution.

Figure 8 shows a few steps of reconstructing the cylinder shape structure model. Figure 8 (a) shows the result of transferring pre-processed image to ρ-θ space with iterative threshold detected peaks. Vanishing points examination is illustrated in Figure 8 (b) after filtering. Figure 8 (c) displays detected feature points (blue points) and their corresponding base points (green points). Table 1 lists the elevation of the reconstructed model using height of feature point a as the reference. The result indicates that the over all RMSE is about 1.32%. Table 2 lists the evaluation of the reconstructed cylinder shape structure. The errors in the major and minor axises are 2.5% and 4%, respectively. The reconstruction result of this example indicates that the developed algorithms can reconstruct building models with cylinder-shape structures accurately.



(a) (b) (c)

Figure 8. Reconstructing computer simulated geometric structure model. (a) Feature lines extraction in ρ-θ space (b) vanishing points examination (c) feature points (blue) and their correspondent base points (green).

Table 1: Validations in elevation of cylinder shape computer simulated geometric structure case.

Feature	Real Height	Calculated Height	Error (%)
a	1	---	---
b	1	1.006	0.62%
c	1	1.006	0.62%
d	1	1.006	0.62%
e	2	2.037	1.86%
f	2	2.037	1.86%
g	2	2.037	1.86%
h	2	2.037	1.86%

Table 2: Validations of cylinder shape parameters.

Parameters	Reference	Proposed method	Error (%)
Major axis	1	0.975	2.5%
Minor axis	0.25	0.24	4%

Figure 9 (a) shows the result of rectifying and projecting the SOR example image on to the vertical plane, while Figure 9 (b) is the contour line fitted from the contour points in Figure 9 (a). Figure 9 (c) marked 4 parameters of contour line for quantitative evaluation, and the comparison is listed in Table 3. The result also indicates that the proposed method can effectively reconstruct SOR-type structures from a single view image.

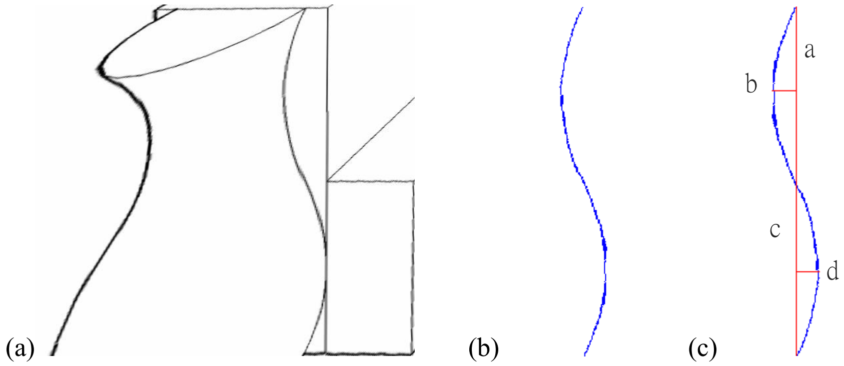


Figure 9. SOR structure reconstruction (a) projected image on the vertical plane (b) fitted contour line.

Table 3: Validations of SOR structure parameters.

Parameters	Reference	Proposed method	Error (%)
a	1	1.013	1.30%
b	0.125	0.135	8.00%
c	1	0.989	-1.10%
d	0.125	0.129	3.20%

3.2 Close-range photograph of buildings

Figure 10 (a) is the photograph of a building taken from an overlooking position. Figure 10 (b) shows the vanishing points calculated automatically from the image and Figure 10 (c) is the projection of the cylinder-shape structure on the vertical plan. The reconstructed 3D model of the building is displayed in Figure 11. A high-precision CAD file generated from stereo air-photo and ground-base LIDAR surveys were used as reference data to evaluate the reconstructed result with the developed algorithms. The evaluation of the result in the X-Y plane is displayed in Figure 12. In Figure 12, numbers in blue and italics are measured from reference data and numbers in black are from the experimental results. The reference height is 38 m from the top of the roof to the building foot point. Validations of cylinder shape parameters are listed and compared with ground truth data in Table 4. As displayed in the figure and the table, the most of the errors are only a few centimeters, except the major axis of the culinder. The average error is approximately 1.36%, further proving that the developed single-view reconstruction algorithms can achieve high accuracy for reconstructing building models with curved structures.

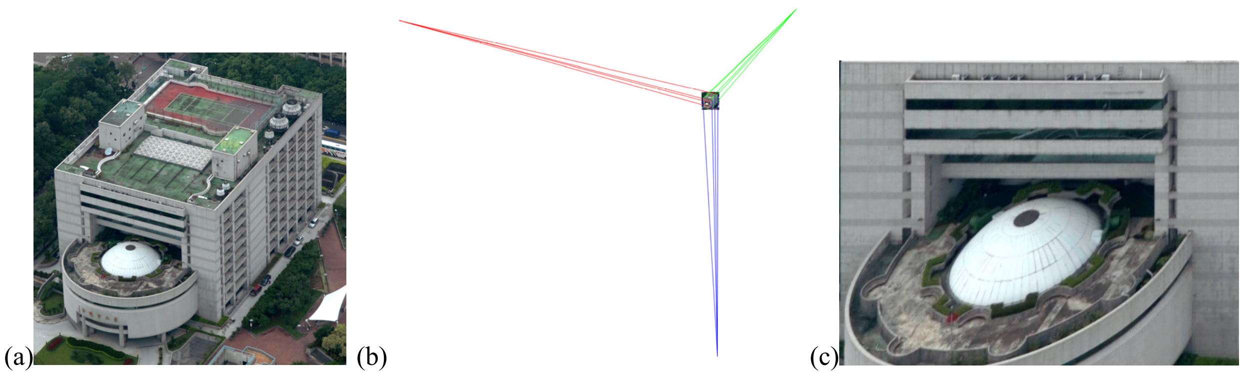


Figure 10. Close-range photograph for buildings
(a) raw image (b) vanishing points examination (c) projected image on the vertical plane.

(a) (b)

Figure 11. Two different view of reconstructed model from close-range photograph

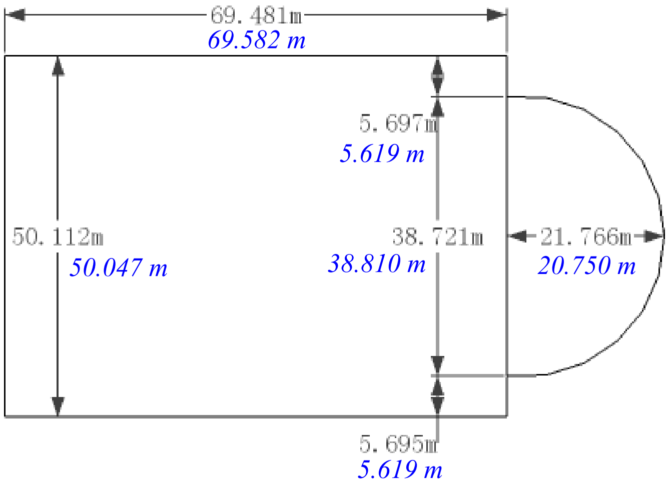


Figure 12. Validations of close-range photograph case in X-Y plane

Table 4: Validations of cylinder shape parameters in the case of close-range photograph.

Parameters	Reference (m)	Proposed method (m)	Error (%)
Major axis	38.810	38.721	0.23%
Minor axis	20.75	21.766	4.89%

4. CONCLUTIONS AND FUTURE WORKS

This study developed algorithms requiring only a single image with perspective view and good geometry to reconstruct 3D building models with curve structures without internal or external camera parameters. With the developed algorithms, vanishing points, feature points and corresponding base points can be extracted automatically with defined thresholds. In addition to planar building structures, cylinder shape and surface of revolution structures can also be reconstructed effectively and with reasonable accuracy. The developed approach is one of the most economical means to extract 3D information, and it can be applied to close-range photos, images obtained from Internet, and even real paintings with perspective views. Experimental results demonstrated that reliable accuracy in the reconstruction of 3D building models can be achieved with the proposed methods. Future improvement of the developed system will focus on the capability of reconstructing free form curved segments, and the ability for curve segment classification.

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