EFFICIENT 3D MODELING FOR HISTORICAL STRUCTURE BY IMAGE SEQUENCES ANALYSIS

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ABSTRACT:

In order to perform object modelling by using images processing procedures, line or feature extraction and stereo matching will be performed in general. However, there are some issues of efficient 3D modelling for historical structure. In particular, efficient line matching for reconstruction of objects is needed to be resolved. With this objective, this paper investigates a robust line matching method which include trifocal tensor and epipolar matching. This paper will lead to automatic 3D modelling for historical structure by means of image sequences.

1. INTRODUCTION

Recently, efficient spatial data acquisition and visualization have been receiving more attention from the view point of digital city, VR museum including digital archives. Generally, in order to perform object modelling through digital images, line or feature extraction and stereo matching are performed, and many matching methods such as area based matching, future based matching have been proposed. In particular, line gives important information for object extraction, and satisfied 3D results depend on rigorous line extraction and matching.

With this motive, the authors have developed a city modelling method using high vision air-borne imagery (Kunii, 2002). The city modelling method contains line matching which is performed by line extraction and line tracking. The line extraction was performed by Canny operator (Canny, 1986), and line matching was performed using optical flow which was proposed by Lucas-Kanade and epipolar matching. City modelling was achieved efficiently by the method, and availability of image sequences for object modelling was demonstrated.

In these circumstances, 3D modelling for the “Koma house” through image sequences was investigated in this paper. The Koma house was built in 17th century (about 300 years ago), and designated as national important cultural assets in 1971. The image sequences for the Koma house were taken while amateur video camera was moving in horizontal direction, and line matching was performed using optical flow. In addition, this paper investigates additional line matching method which is performed by using epipolar geometry. Therefore, 3D data for the Koma house can be acquired efficiently. Furthermore, wire frame model for the Koma house can be reconstructed by using the line information, and texture mapping was performed on the wire frame model. Consequently, low-cost 3D modeling system for the cultural structure was achieved.

2. IMAGERY ACQUISITION SYSTEM

The image sequences by the Koma house were obtained by imagery acquisition system which is constituted by amateur video camera, tripod, carriage and rails. The rails were set to parallelized for the Koma house, and the video camera with the tripod were set on the carriage. Therefore, the image sequences for the Koma house were taken while the video camera was moving in horizontal direction using the rails. Figure 1 shows the image acquisition system, and Figure 2 shows the first image of the image sequences.

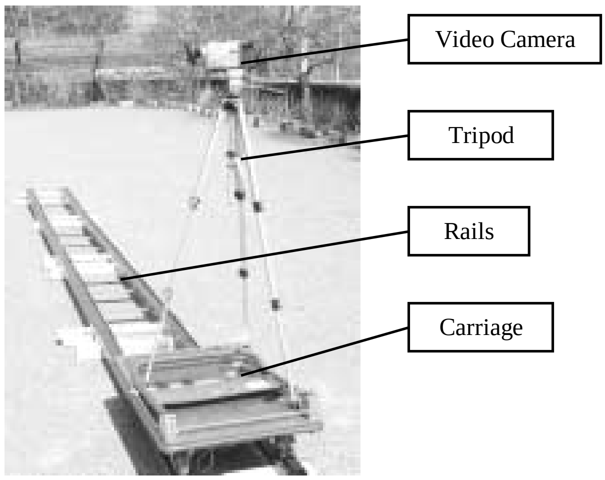


Figure 1. Imagery Acquisition System

Figure 2. Koma House (First Image)

3. LINE MATCHING

Automatic line matching was performed by line extraction and line tracking. Detail procedures of the automatic line matching method are as follows.

3.1 Line Extraction

Line extraction was performed by Canny operator with 2 threshold values which are called height and reliability of edge. The height of edge is a variation of a gray level around an interest point, and represented by integer value from 0 to 255. The reliability is an index for representing influence of noise, and represented by decimal value from 0 to 1. The threshold value for the height of edge was set as 5, and the reliability value was set as 0.1 in this paper. Figure 1 shows the extracted lines by the Canny operator for the first image. Furthermore, as a preprocedure for line matching, both ends of the each line were connected by straight lines. However, there are some useless lines for line tracking in the first image. Then, the useless lines were removed by manual operation in the first image.

Figure 3. Canny Operator

3.2 Optical Flow Estimation

In order to perform line matching, both ends for each extracted line were tracked by optical flow. Although many optical flow estimation methods have been proposed, Lucas-Kanade method (Chiba, 1998), which is capable of correct and fast procedure, was adopted in this paper. The optical flow by Lucas-Kanade method is calculated by following equation, and estimated optical flow is shown in Figure 4.

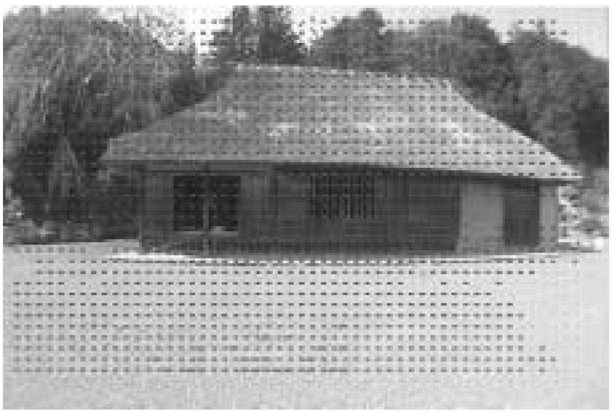


Figure 4. Optical Flow Estimation

$$u = \frac{\sum_w \frac{\partial I}{\partial x} \cdot [J(p) - I(p)]}{\sum_w \left(\frac{\partial I}{\partial x}\right)^2}, v = \frac{\sum_w \frac{\partial I}{\partial y} \cdot [J(p) - I(p)]}{\sum_w \left(\frac{\partial I}{\partial y}\right)^2} \quad (1)$$

where,

$I(p) = I(x, y, t),\ J(p) = I(x, y, t + \delta t)$

3.3 Epipolar Geometry

The line matching was performed rather efficiently by the optical flow. However, the optical flow can not be applied for all the lines resulted from fragment or multiple. Therefore, the unmatched lines were corrected using 2 kinds of epipolar geometry; trifocal tensor and epipolar matching. Details of each geometry are as follows.

3.3.1 Trifocal Tensor

Trifocal tensor is geometric relation of 3 images which contained the same objects from different perspectives (Pollefeys, 1999). The trifocal tensor is expressed by 3 square matrixes (3×3), these 3 matrixes are $\mathbf{T_1}$, $\mathbf{T_2}$ and $\mathbf{T_3}$, components of these matrixes are t_{1ij}, t_{2ij} and t_{3ij}, and image coordinates of matched points for these 3 images are (x_1, y_1, z_1), (x_2, y_2, z_2) and (x_3, y_3, z_3). Thus, following equations are obtained by the geometric relation.

$$\begin{aligned} -z_2z_3g_{22} + z_2y_3g_{23} + y_2z_3g_{32} - y_2y_3g_{33} &= 0 \\ z_2z_3g_{21} - z_2x_3g_{23} - y_2z_3g_{31} + y_2x_3g_{33} &= 0 \\ z_2z_3g_{12} - z_2y_3g_{13} - x_2z_3g_{32} + x_2y_3g_{33} &= 0 \\ -z_2z_3g_{11} + z_2x_3g_{13} + x_2z_3g_{31} - x_2x_3g_{33} &= 0 \end{aligned} \quad (2)$$

where,

$g_{ij} = x_1t_{1ij} + y_1t_{2ij} + z_1t_{3ij}$

These 4 equations are generated by one conjugated point of these 3 images. The trifocal tensor has 27(=3×3×3) unknown parameters which can be calculated by more than the same number of equations. Therefore, more than 7 points needed to be conjugated between these 3 images for acquisition of the trifocal tensor. Consequently, the unmatched points in the third image are calculated by the following equation.

$$\begin{aligned} x_3 &= y_2(x_1t_{131} + y_1t_{231} + z_1t_{331}) - z_2(x_1t_{121} + y_1t_{221} + z_1t_{321}) \\ y_3 &= z_2(x_1t_{112} + y_1t_{212} + z_1t_{312}) - x_2(x_1t_{132} + y_1t_{232} + z_1t_{332}) \\ z_3 &= x_2(x_1t_{123} + y_1t_{223} + z_1t_{323}) - y_2(x_1t_{113} + y_1t_{213} + z_1t_{313}) \end{aligned} \quad (3)$$

The both ends of each unmatched lines for 3 sequential frames were corrected by equations above.

3.3.2 Epipolar Matching

Epipolar matching was performed by using epipolar lines for first image and last image. In order to estimate epipolar lines, relative orientation was performed by coplanarity condition by using the first image and the last image. The both ends for the each matched lines were used as control points in the image, and the orientation parameters (φ_1, κ_1, ω_2, φ_2, κ_2) were determined. After the orientation, resampling of the first and last image was performed using the orientation parameters. Consequently, epipolar lines were estimated. Figure 5 shows the epipolar lines and conjugate points.

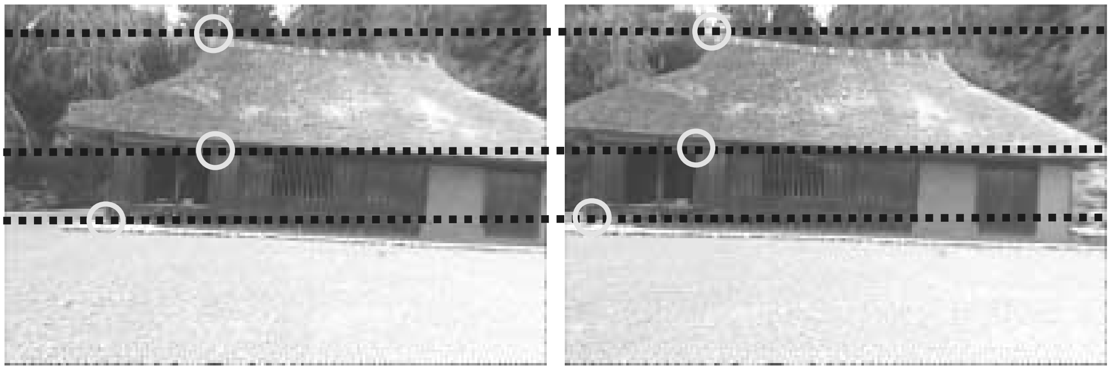


Figure 5. Epipolar Line and Conjugate Points

Furthermore, in order to perform stereo matching by using these epipolar lines efficiently, probabilistic relaxation method was adopted in this paper. The probabilistic relaxation method was developed as an algorithm for numerical calculation, and the method has been widely applied to image matching techniques. The image matching is performed by the following procedures: firstly, candidate ranges for matching points are estimated in stereo images. Secondly, matching probabilities of each point are calculated respectively. Finally, these candidate points are iteratively improved, and the image matching is achieved. Generally, the matching probability is called labelling probability. The search range is *a*, the label of each point is *λ*, and the similarity of each point is *S*. Consequently, labelling probability P_i is calculated by the following equation.

$$P_i(\lambda_k) = \frac{S(\lambda_k, a_i)}{\sum_{k'=1}^{m-1} S(\lambda_{k'}, a_i)} \{1 - P_i(\lambda_{NIL})\} \tag{4}$$

where,

$i = 1,2,\cdots,n$

$k = 1,2,\cdots,m-1$

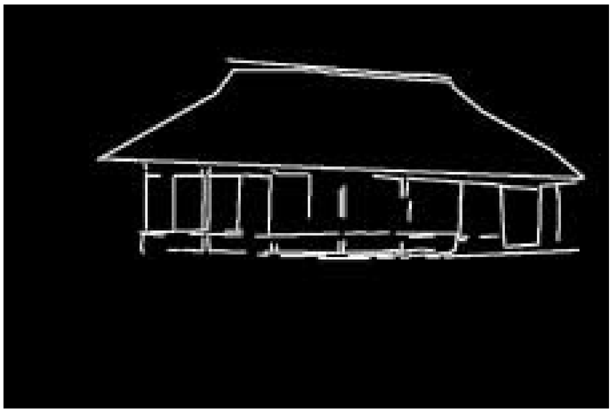
$P_i(\lambda_{NIL})$: asumptive lavelling probability (usually 0.05 ~ 0.3)

3.4 Results of Line Matching

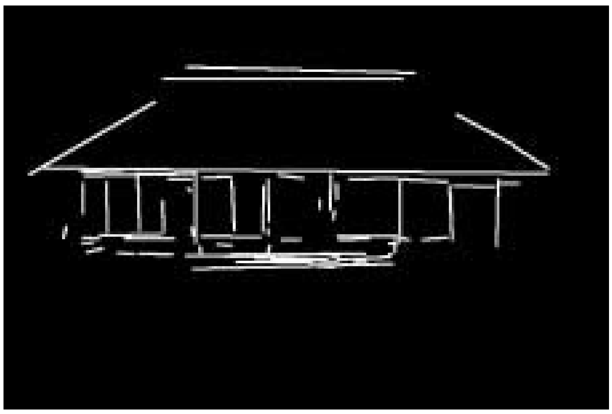
Detail procedures for the line matching are as follows:

(1) Lines in the first image of the image sequences are extracted. Similarly, lines in the next image are extracted.
(2) Optical flow is estimated by using both the first image and the next image, and each line position in the first image is moved according to values of the optical flow.
(3) Moved lines and the lines in the next image are matched, and just conjugated lines are remained.
(4) Unmatched lines are corrected by trifocal tensor matching using 3 images.
(5) The procedure explained above is successively repeated to the last image, and epipolar matching is performed by first image and last image.

As a result, 87 lines for the first image were extracted by Canny operation and manual correction was performed for removing useless lines. Then, line matching for 72 lines out of those lines could be performed correctly. Figure 6 shows the result of the line matching.



(a) Lines in the First Image



(b) Lines in the Last Image

Figure 6. Results of Line Matching

4. SURFACE RECOGNITION BY MATHEMATICAL MORPHOLOGY

The line information for 3D modelling can be acquired efficiently by the method in the previous chapter. However, each surface on the Koma house is needed to be recognized for 3D modelling. Therefore, surface recognition was performed by morphological opening procedure, and the extracted surfaces were conjugated with the matched lines in this paper.
The opening procedure has prominent ability to extract a feature area by using structuring elements. This paper investigates automatic constitution of the structuring element for each surface. Figure 7 shows an extracted line in the first image, detail procedures of the automatic constitution of the structuring element are as follows:

(1) Let assume that two rectangular areas (A and B) are extracted around at the line, and HSI value of each pixel in the 2 areas are obtained respectively.
(2) Variances of HSI value for each area are calculated, and the area which has lower variance rather than threshold value is discriminated as a segment of a surface.
(3) The structuring element is constituted by average of the HSI value of the surface area, and the opening procedure is performed.
(4) The procedures described above are repeated for all matched lines, and surface extraction is achieved.

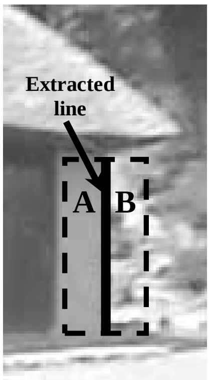


Figure 7. Concept of Structuring Element Constitution

Threshold values were set as $H=\pi/2$, $S=0.2$, $I=0.2$, and radius of the structuring element was fixed by 3 pixels in this paper, and the result of the opening procedure is shown in Figure 8.
After the opening procedure, corner detection was performed by image processing procedure, and the detected corners were conjugated with the nearest end points of the matched lines. Consequently, the lines which constitute each surface were acquired, and surface recognition was achieved.

Figure 8. Result of Opening Procedure

5. 3D MODELLING

In order to generate 3D modelling for the Koma house, camera calibration for the first image and the last image were performed by combined adjustment (Chikatsu, 2002). Therefore, 3D data for the Koma house could be calculated efficiently. Furthermore, TIN for each surface was generated by using end points of the matched lines, and wire frame was reconstructed. In addition, texture mapping could be performed for each surface. Figure 9 shows wire frame model, and Figure 10 shows texture model for the Koma house.

6. CONCLUSION

This paper investigates mainly 2 issues regarding 3D modelling for historical structure by using image sequences: (1) efficient and robust line matching method using optical flow and epipolar geometry, (2) surfaces extraction using morphological opening and followings main results were obtained:
+ Line matching was improved by epipolar geometry.
+ Surface recognition by morphological opening could be performed efficiently.

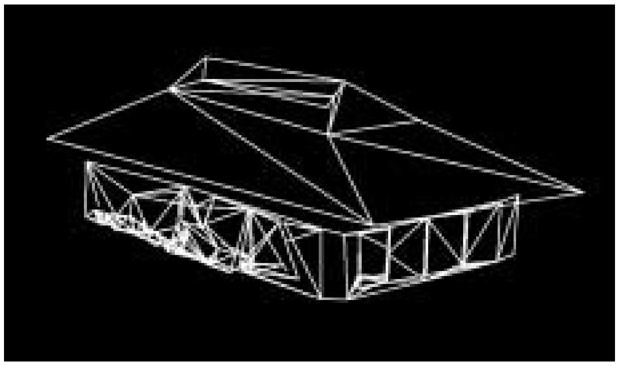


Figure 9. Wire Frame Model

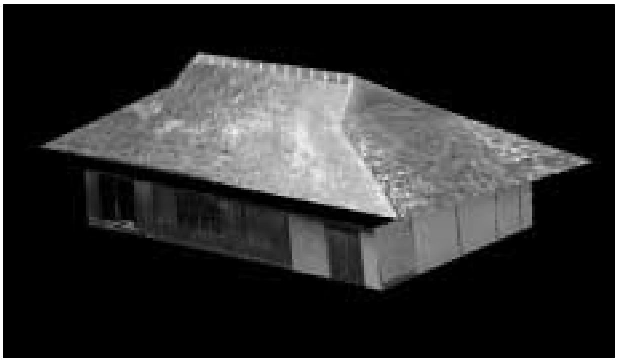


Figure 10. Texture Model

+ 3D data for the historical structure could be acquired by combined adjustment.

Thus, it is concluded that the line matching method comprised trifocal tensor, epipolar matching and morphological opening is useful method for 3D modelling of historical structure. However, there are still the following issues to be resolved before this method becomes operational.
+ Efficient texture mapping.
+ 3D modelling for more complicated object.

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