AUTOMATIC STEREO MATCHING USING OPTICAL FLOW FOR 3D OBJECT MODELING

Yoichi KUNII*, Hirofumi CHIKATSU**
Tokyo Denki University, Japan
Department of Civil Engineering
*99smg08@g.dendai.ac.jp
**chikatsu@g.dendai.ac.jp

Working Group IC V/III

KEY WORDS: Optical Flow, 3D Object Modeling, Stereo Matching, Coplanarity Condition, Line Tracking, Sequential Images.

ABSTRACT

In order to acquire 3D spatial data for objects using stereo image, stereo matching such as SSDA, area based matching and so on have been proposed. However, there are some issues for efficient 3D object modeling. In particular, efficient line matching for reconstruction of the objects such as buildings is needed to be resolved. With this objective, this paper investigates automatic stereo matching method using optical flow estimation. Furthermore, this paper investigates a 3D spatial data acquisition method using coplanarity condition, and shows 3D modeling of a building which was performed automatically.

1 INTRODUCTION

Recently, efficient spatial data acquisition and visualization have been received more attention from the view point of 3D-GIS, city modeling, and so on. Generally, 3D spatial data is acquired by stereo matching, and there are many stereo matching methods, e.g. SSDA, area based matching. However, automated segmentation of feature areas or extraction of feature lines of objects are still issues which are needed to be resolved for efficient modeling. With this objective, this paper investigates an automatic stereo matching method using optical flow. The optical flow is estimated using sequential images for objects, and the optical flow has ability for line tracking. The line tracking is performed automatically in the sequential images from the first frame to the last frame. Then, this paper shows that the stereo matching can be performed automatically, and the feature lines for objects can be acquired simultaneously.
Furthermore, 3D spatial data acquisition method using coplanarity condition is investigated as follows: Firstly relative ground coordinates are calculated by the relative orientation using coplanarity condition. Secondly, the relative ground coordinates are transformed to absolute ground coordinates. Finally, the absolute ground coordinates were set as approximate values for the bundle adjustment, and 3D coordinates of the each point on the object are calculated. Therefore, 3D spatial data can be acquired efficiently, and shows that 3D modeling of a building is performed automatically in this paper.

2 AUTOMATIC 3D OBJECT MODELING METHOD

2.1 Automatic Stereo Matching

Stereo matching was performed automatically using optical flow in this paper. The detail procedures of the automatic stereo matching method are as follows.

2.1.1 Line Extraction: The line extraction was performed by Canny operator (CANNY, J., 1986.) with 2 threshold values relative to 2 components which called the height and reliability of edge in this paper (YOKOYAMA, H. et al., 1998.). The height of edge is a variation of the gray level periphery at the point, and the reliability is an index for representing influence of noise. Threshold value of height was set at 10, and reliability was set at 0.1 in this paper. In order to perform line tracking, each both ends for the line was connected by straight line. Figure 1 shows original image of the house model and figure 2(a) shows filtering image, and (b) shows straight line image.

Figure 1. Original image

(a) Filtering (b) Straight line

Figure 2. Line Extraction image

However, there are some useless lines for line tracking in the first line extracted image. Then, the useless lines were removed by manual operation in the only first sequential image.

2.1.2 Optical Flow Estimation: Many optical flow estimation methods have been proposed. The optical flow was estimated using the Lucas-Kanade method which has features for correct and fast procedure in this paper (CHIBA, N., KANADE, T., 1998.). Lucas-Kanade method is one of the spatial local optimization, and the optical flow by Lucas-Kanade method is calculated by following equation.

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

where,

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

Furthermore, in order to improve accuracy of the optical flow, the optical flow was corrected by hierarchical estimation (SATO, M., SASAKI, H., 1986.) and reliability function (YOSHIDA, T. et al., 1997.). Figure 3 shows optical flow estimation.

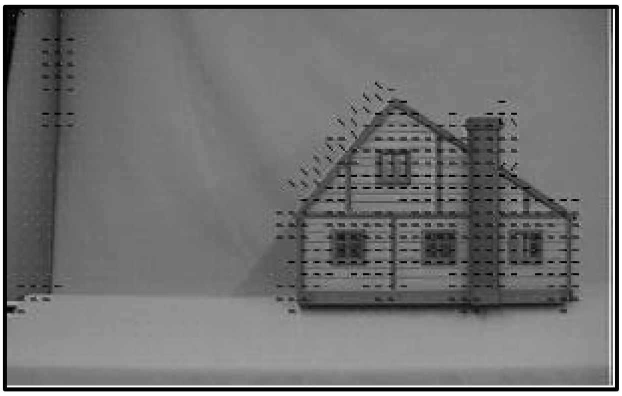


Figure 3. Optical flow estimation

2.1.3 Similarity Function: Line tracking was performed using similarity function in this paper. The similarity is an index for representing how similar are the 2 lines, and the lines which have the highest similarity were discriminated as corresponding lines. Figure 4 shows 2 lines (L_i and L_j) and a middle separating line (L_m). The average distances of end points between L_m and 2 lines are D_i and D_j, and the lengths of overlapping part of the 2 lines to the L_m are P_c and P_w. Consequently, the similarity of 2 lines is calculated by following equation.

$$s = \frac{1}{k_d D + k_p P} \tag{2}$$

where,

$$D = D_i + D_j\ ,\ \ P = \frac{P_w}{P_c}$$

k_d, k_p: coefficient parameters set by a user

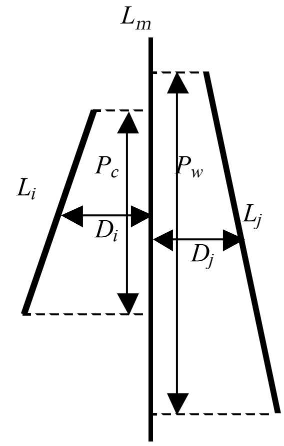
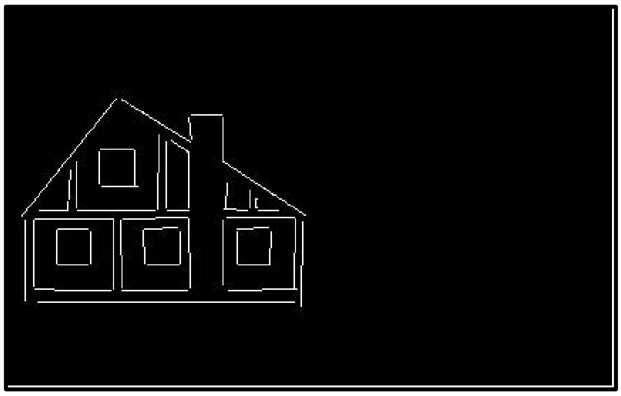


Figure 4. Similarity function

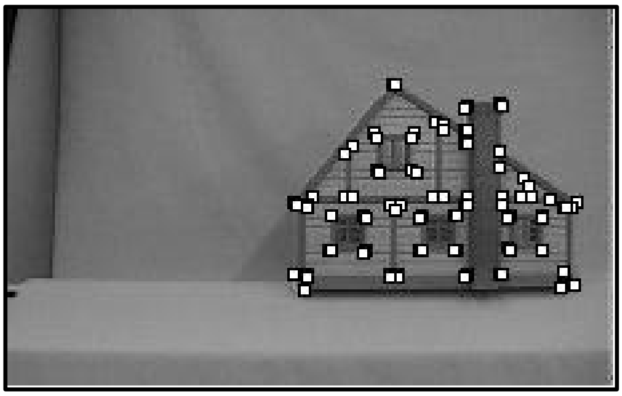
2.1.4 Line Tracking for Stereo Matching: Sequential images for the house model was taken while a video camera was moving in horizontal direction, and the line tracking was performed using the sequential images and threshold value of similarity (0.7). On the other hand, affine coefficients are calculated using the corresponded points between the 2 frames in the sequential images, and let make correspond for the points which were less than 0.7 similarity using the affine coefficient.

From the test, 58 lines were extracted for the first frame, and 51 lines out of those lines were tracked correctly from the first frame to the last frame. 7 lines were not tracked and could be erased automatically. Consequently, 102 points by the both ends for first flame lines could be corresponded to the last frame. Thus, it can be said that the proposed stereo marching method is effective for automatic stereo matching. Figure 5 shows result of stereo matching.

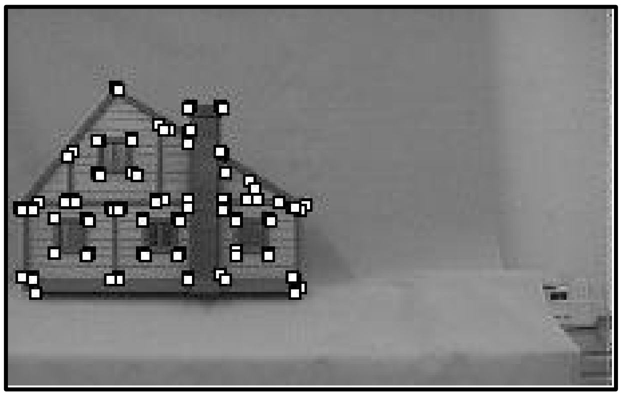
(a) Lines in the first frame



(b) Lines in the last frame



(c) Points in the first frame



(d) Points in the last frame

Figure 5. Result of Stereo Matching

2.2 3D Spatial Data Acquisition

3D coordinates of an object were calculated using coplanarity condition in this paper. The detail procedures of the 3D spatial data acquisition method are as follows:
+ Extraction of feature points.
+ Select one line, and one feature point perpendicular to the line on the image.
+ Horizontal length for the line is measured.
+ Relative ground coordinates for each feature point on the object are calculated by relative orientation using the coplanarity condition.
+ The relative ground coordinates are transformed to absolute ground coordinates using the horizontal length and the vertical direction.
+ The absolute ground coordinates were set as approximate values for the bundle adjustment, and 3D coordinates of the each point on the object are calculated.

Therefore, 3D spatial data is acquired effectively using coplanarity condition and the bundle adjustment.

2.2.1 Evaluation of Accuracy: In order to evaluate accuracy for the above method, experiment was performed using a test model shown in figure 6. The horizontal length from point No.1 to No.2 was given (26cm) and point No.3 was selected as the perpendicular point. The squared points are control points for orientation, and another 34 black circle points are check points for checking accuracy. Figure 7 shows the stereo image for the test model, and base-depth ratios for the stereo image is 0.38.

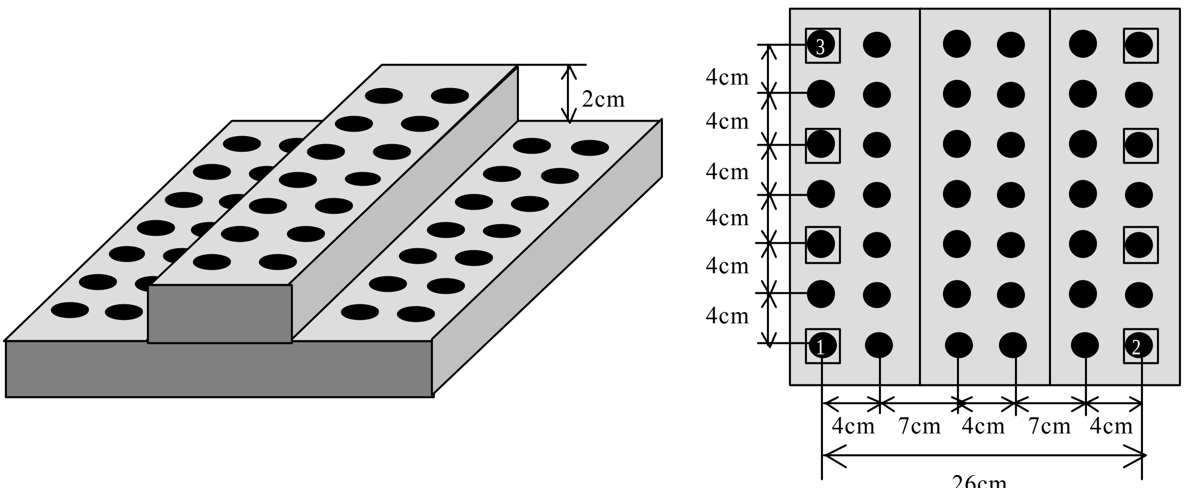
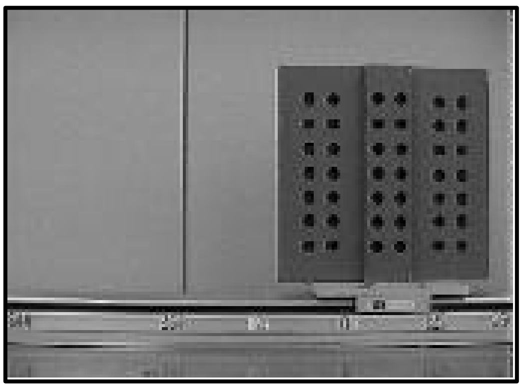
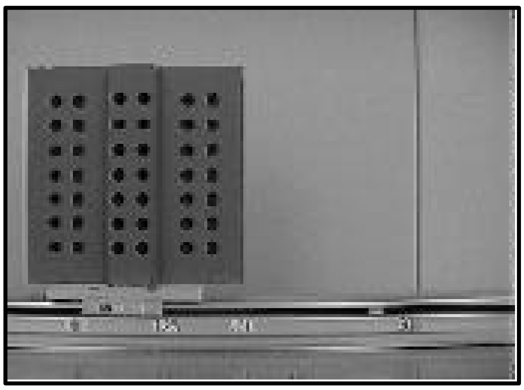


Figure 6. Test model



(a) Left image



(b) Right image

Figure 7. Stereo image for the test model

2.2.2 Experimental Results: R.M.S.E. were investigated by the coplanarity condition and combined adjustment with the coplanarity condition and the bundle adjustment.

Table 1 shows the R.M.S.E. for check points by each method. It may be seen from the results of this experiment that the 2D accuracy for the each methods are high value, and the accuracy of Z-coordinate for the combined adjustment is almost equal to the 2D accuracy. It means that the combined adjustment is sufficient for 3D object modeling. Therefore, the combined adjustment is useful method for 3D spatial data acquisition.

Table 1. RMSE of the each methods

Method	σ_{xy}(mm)	σ_z(mm)
Coplanarity Condition	±1.030	±10.752
Combined Adjustment	±1.206	±1.196

2.3 3D Object Modeling

3D spatial data of the house model could be acquired using the combined adjustment in this paper. Then, wire frame model of the house model could be reconstructed automatically. Figure 8 shows the wire frame model of the house model. Furthermore, texture mapping was performed by following procedures: firstly one square surface was selected on the wire frame model on manually. Secondly, color information which was corresponded to the square surface was obtained from an image. Finally, the color information was put on the square surface, and repeating this procedures. Figure 9 shows the texture mapping model.

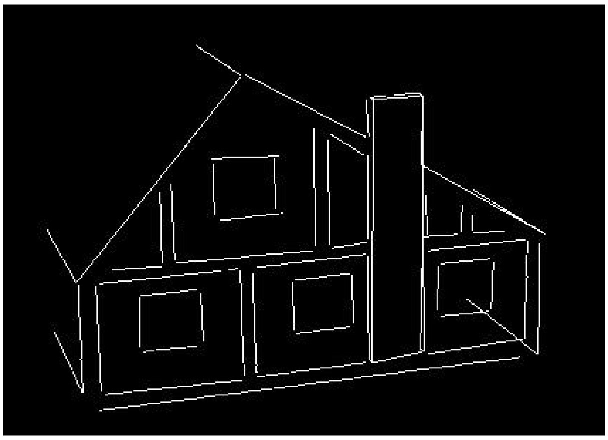


Figure 8. Wire frame model

Figure 9. Texture mapping model

The detail procedures of the automatic 3D object modeling method are as follows:

1. Line extraction is performed for the first image in the sequential images.
2. The image coordinates of the both ends for each extracted lines are calculated, and line tracking start.
3. Optical flow is estimated using the first image and the next image.
4. Similarly, line extraction for the next image is performed, and image coordinates of the both ends for each extracted line are calculated.
5. Each line positions in the first image are moved to amount of the optical flow.
6. Moved lines and the lines in the next image are corresponded by similarity function, and just corresponded lines are remained.
7. Above procedure is successively repeated to the last image, and the matching points between the first image and the last image are automatically acquired.
8. 3D spatial data is acquired using the combined adjustment.
9. 3D modeling of an object is performed.

These procedures are shown in Figure 10.

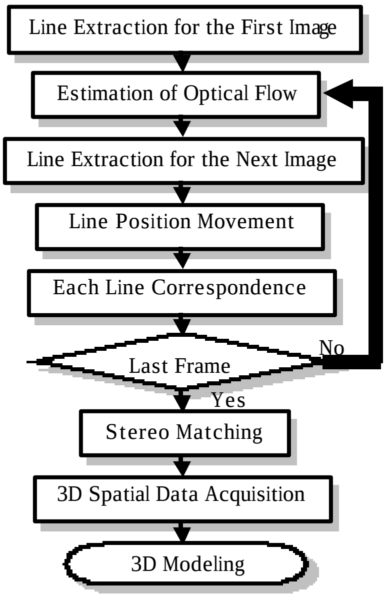


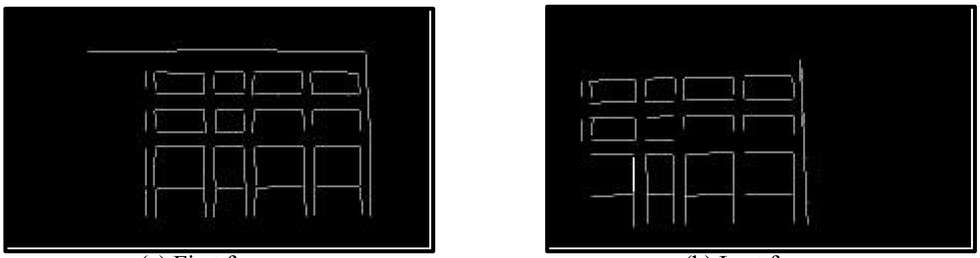
Figure 10. Automatic 3D modeling method

3 APPLICATION FOR A BUILDING

3D modeling for a building was performed by above procedures in this paper. Sequential images for a building were taken while a video camera was moving in horizontal direction, and the line tracking was performed using the sequential images. Figure 11 shows the first frame and the last frame for the sequential images, and base-depth ratios for the stereo image is 0.25. From the result of line tracking, 50 lines were extracted for the first frame, and 45 lines out of those lines were tracked correctly from the first frame to the last frame. Figure 12 shows the result of line tracking. Consequently, 3D spatial data of the tracked lines were calculated by the combined adjustment, and 3D modeling for the building was performed. Figure 13 shows the 3D model of the Building.

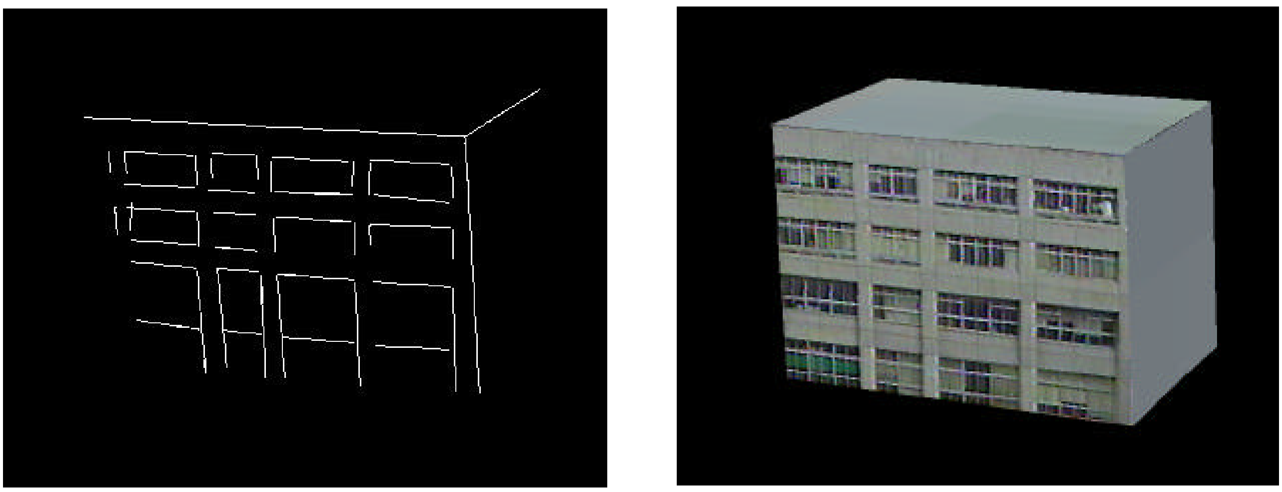
(a) First frame (b) Last frame

Figure 11. Sequential image for the building



(a) First frame (b) Last frame

Figure 12. Result of line tracking



(a) Wire frame model (b) Texture mapping model

Figure 13. 3D Model of the building

4 CONCLUSION

The automatic 3D object modeling method was investigated in this paper. The stereo matching was performed by optical flow estimation using sequential images, and correspondences of the lines for stereo image were acquired. Consequently, 3D spatial data for the lines which were necessary for 3D object modeling could be acquired efficiently. On the other hand, 3D spatial data of the building could be calculated by the combined adjustment. The simple experiment result shows that accuracy of 3D spatial data by the combined adjustment is sufficient for 3D object modeling. Therefore, it is concluded that the optical flow estimation and the combined adjustment is useful method for automatic 3D object modeling.
There are still, however, following issues that need to be resolved before this method becomes operational.

1. Efficient automatic line extraction in the first sequential image.
2. Perfectly line tracking.
3. Acquisition of accurate 3D spatial data.
4. Automation of texture mapping.

REFERENCES

CANNY, J., 1986. A Computational Approach to Edge Detection. IEEE Transaction on Pattern Analysis and Machine Intelligence. Vol.PAMI-8, No.6, pp.679-697.

CHIBA, N., KANADE, T., 1998. A Tracker for Broken and Closely-Spaced Lines. Internationals Archives of Photogrammetry and Remote Sensing, Vol.XXXII, Part5, pp.676-681.

SATO, M., SASAKI, H., 1986. Hierarchical Estimation of Displacement Vectors in Image Sequences. The Transactions of the Institute of Electronics and Information Engineers, Vol.J69-D, No.5, pp.771-777.

YOKOYAMA, H., CHIKATSU, H., ANAI, T., 1998. Drawing for Archeological Artifact Using Multiple Edge Detection Techniques. Internationals Archives of Photogrammetry and Remote Sensing, Vol.XXXII, Part5, pp.665-670.

YOSHIDA, T., MIYAMOTO, A., SAKAI, Y., 1997. A Reliability Metric for Motion Vectors in Moving Pictures and Its Application. The Transactions of the Institute of Electronics, Information and Communication Engineers, Vol.J80-D-II, No.5, pp.1192-1201.