APPLICATION OF ROBUST REGRESSION FOR EXTERIOR ORIENTATION OF VIDEO IMAGES

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ABSTRACT:

Nowadays, the 3-D measurement system using the video image sequences has been used in many fields, for example the vision sensor for machine control or the measurement technique of city area for GIS or landscape simulation. However, the robust estimation of the exterior orientation parameters for each video frames is still important issues. In recent years, the authors have been concentrating for development of 3D measurement system using video image sequences with robust tracking and robust exterior orientation. However, some problems should be resolved for this systems goal, such as limitation for camera movement, robustness of bundle adjustment. Therefore, the authors are developing the new algorithm of robust exterior orientation for video image sequences using robust regression procedure. In this paper, authors describe the effectiveness of robust exterior orientation method for video image sequences which developed by authors. Moreover, application for 3D measurement of this algorithm is also described.

1. INTORDUCTION

In order to perform the 3D measurement using video image sequences from the platform moving freely, the technique of exterior orientation for each video frame is still important issue.

In the field of general photogrammetry, the exterior orientation is performed using many control points that have accurate 3D coordinate. In addition, the position and rotation sensor such as GPS or gyro sensors are used in the real-time application field of 3D measurement from video image sequences recently. However, the construction of accurate control point generally needs a lot of time and labor. In the case of GPS, the accuracy of positioning is depending on GPS satellite position and condition of the environment, and the positioning at inside of structure is particularly impossible. Similarly, the high accurate gyro sensor's cost is still expensive. In addition, high accurate synchronization in time axis between these sensors and video camera is necessary, and it becomes the rise in size or cost of system.

From these backgrounds, automatic estimation technique of the exterior orientation parameters from video image sequences without using the above-mentioned equipments has become important issue in late years, and many research groups had shown the studies and applications [1, 2, 3].

On the other hand, the authors have developed PC-based 3D Image Measuring Station called PI-3000, and many applications of 3D measurement using consumer digital still cameras have been achieved previously. This system can estimate the interior orientation parameters of consumer digital still camera accurately. Furthermore, this system can perform bundle adjustment with many images simultaneously. Therefore, exterior orientation parameter of camera and 3D coordinate of object can be obtained in high accuracy [4, 5].

From circumstances mentioned above, the authors have been concentrating for development of the 3D measurement system using consumer video camera with robust tracking and robust exterior orientation method. In this method, in order to perform the automatic rejection for error correspondences of natural feature points in each video frames, tracking process and relative orientation process in exterior orientation procedure performed robust regression based on the LMedS (Least Median of Square) method. However, in this exterior orientation procedure, there is a limitation for movement of a camera because of the limit of relative orientation procedure. In addition, the robustness of relative orientation is insufficient when there is the big change of the scene such as the structure corner [6].

Therefore, in order to resolve these problems, the authors are developing the new algorithm of robust exterior orientation for video image sequences.

In this paper, authors describe the effectiveness of algorithms of robust exterior orientation for video image sequences, and application for volume measurement from video image sequences is also described.

2. EXTERIOR ORIENTATION PROCEDURE FROM VIDEO IMGAE SEAQUENCES

2.1 Main Flow of Exterior Orientation Procedure

The exterior orientation procedure in this system consists of the tracking process and bundle adjustment process. The tracking process performs the extraction of natural feature points from video image sequences and tracking the natural feature points. As the result of tracking process, corresponding points in each video frames are obtained. Finally, bundle adjustment for all

video frames are preformed, and exterior orientation parameters for each video frames and 3-D coordinates of natural feature points are obtained.
Figure 1 shows the flow of robust exterior orientation procedure.

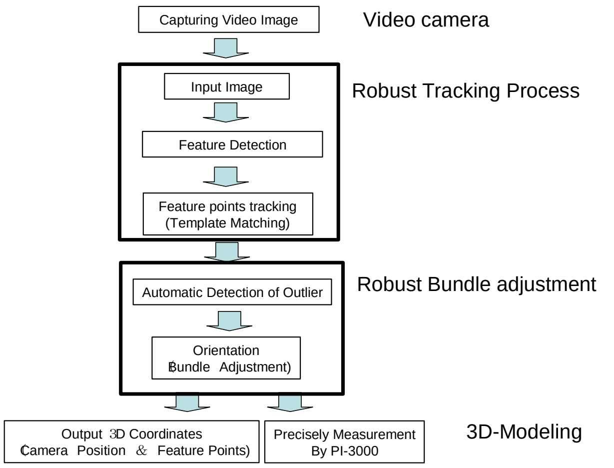


Figure 1. Flow of Robust Exterior Orientation

2.2 Least Median of Square Method

Generally, corresponding points include error correspondence as outlier. Therefore, in order to perform the automatic rejection of outlier in corresponding points, the robust regression based on the LMedS method is performed for the tracking process and bundle adjustment process.

The LMedS method is one of the robust regression methods suggested by Rousseuw 1986 [7]. Classically least square regression consists of minimizing the sum of the squared residuals. Generally, a result of least square regression takes influence of outlier included in data greatly. In order to perform robust regression from data containing outlier, sum of the squared residuals in least square regression is replaced by the median of the squared residuals in LMedS method as following equation.

$$LMeds = \text{med}(\min(\varepsilon_i^2)) \tag{1}$$

Where i = index of data (i = 1~n)
ε= residual of data
med( ) = median
min( ) = minimum

2.3 Robust Tracking Process

The tracking Process of this system aims real-time processing in the near future. Therefore, the tracking process consisted of simple addition and subtraction processing, such as MORAVEC operator [8] for detection of natural feature points or SSDA template matching for tracking between each video frame. Furthermore, in order to perform robust tracking, authors implemented the estimation process for corresponding points using LMedS method.

Figure 2 shows the flow of tracking process and details are as follows.

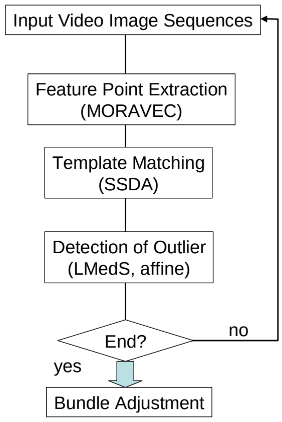


Figure 2. Flow of Robust Exterior Orientation

2.3.1 Feature Point Extraction: At the first frame of video image sequences, many natural feature points are extracted by using MOVRAVEC operator and template image of each natural feature points for SSDA template matching is acquired simultaneously.

2.3.2 Template Matching: SSDA template matching is performed between first and second frame and temporary correspondences of natural feature points are obtained.

2.3.3 Detection of Outlier: The temporary correspondences of natural feature points generally include many error corresponding points as outlier in main transformation between each video frames. In this system, the transformation between each video frame is approximated with affine transformation as following equation.

$$\begin{aligned} u_{i+1} &= a_1 u_i + a_2 v_i + a_3 \\ v_{i+1} &= a_4 u_i + a_5 v_i + a_6 \end{aligned} \tag{2}$$

Where a1~a6 = affine parameter
(u, v) = image coordinates at frame i

The unknown affine parameters are calculated using LMedS method with random sampling algorithm Figure 3 shows the flow of LMedS Method in this process and details are as follows:

a) At the first, random sampling of corresponding points is performed.
b) Affine parameters are calculated from selected corresponding points.
c) Moreover, estimation of affine transformation model is performed with LMedS.
d) These procedures are performed repeatedly, and affine parameter to minimize LMedS is selected.
e) Finally, detection of outlier in corresponding points is performed by thresholding for residual of corresponding points.

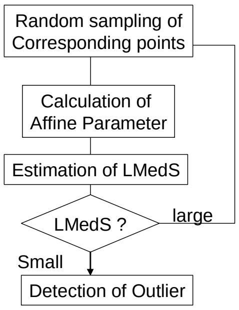


Figure 3. Flow of Outlier Detection in Tracking Process

These processes are performed to all video frames repeatedly. Finally, corresponding points on each video frames are obtained.

2.4 Robust Bundle Adjustment Process

From the results of tracking process, exterior orientation parameters for each video frames and 3-D coordinates of natural feature points are calculated simultaneously by using bundle adjustment. However, bundle adjustment is usually impossible because the result of tracking includes some error corresponding points. In previous study, in order to resolve this problem, the authors have been developing relative orientation by using LMedS method. In addition, for the more robustness of bundle adjustment and for solution of the limitation for camera motion because of the limit of relative orientation, authors use LMedS in the backward intersection procedure in this study. Figure 4 shows the flow of bundle adjustment of this study and details are as follows.

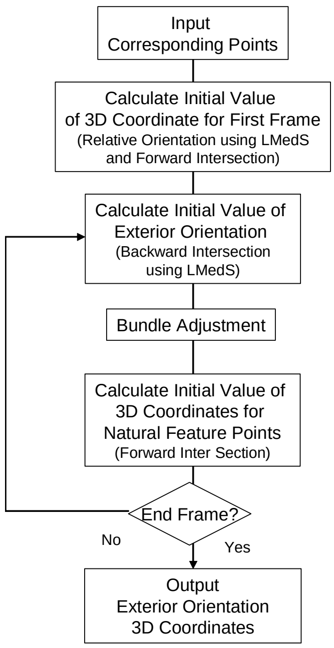


Figure 4. Flow of Bundle Adjustment

2.4.1 Initial Value of 3D Coordinate for First Frame : The initial value of 3D coordinate for natural feature points in first frame is calculated from relative orientation procedure using LMedS method with random sampling algorithm. At the first, stereo pair frame is selected by checking the arrangement of corresponding points on video frames automatically. As the next, random sampling for corresponding points in stereo pair frame is performed and estimation of LMedS for residual of y-parallax is calculated. These procedures are performed repeatedly, and relative orientation parameter to minimize LMedS of residual y-parallax is selected. Finally, initial value of 3D coordinates of natural feature points are calculated with forward intersection using stereo pair frames.

2.4.2 Initial Value of Exterior Orientation Parameter: The initial value of exterior orientation parameters for each video frames are calculated from backward inter section using LMedS method. Figure 5 shows the flow of backward intersection in this study and details are as follows;

a) At the first, random sampling of corresponding points which have initial value of 3D coordinate is performed.
b) The exterior orientation parameters are calculated with backward intersection from selected corresponding points.
c) Moreover, estimation of LMedS for residual of image coordinate is performed.
d) These procedures are performed repeatedly, and exterior orientation parameter to minimize LMedS is selected.
e) Finally, detection of outlier in corresponding points is performed by thresholding for residual of image coordinate for corresponding points.

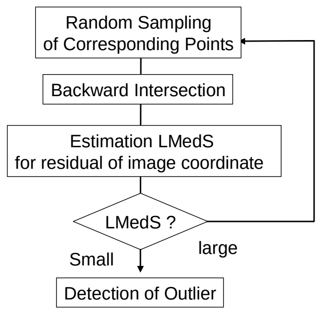


Figure 5. Backward Intersection using LMedS

2.4.3 Bundle Adjustment: The bundle adjustment for each video frames is performed using initial value of exterior orientation parameter and 3D coordinate of natural feature points which obtained previously. As the result of bundle adjustment, exterior orientation parameter and 3D coordinate of natural feature points is adjusted.

2.4.4 3D Coordinate for Natural Feature points: The initial value of 3D coordinates for new added natural feature points are calculated from forward intersection using all video frames which include corresponding point for same natural feature point. Forward intersection is calculated with weighted least-squares method and the weight of each video frame is calculated from the RMSE of residual of image coordinate for each video frames.

These processes are performed to all video frames repeatedly. Finally, exterior orientation parameters for all video frames and 3D coordinate of each natural feature points are obtained.

3. EFECTIVENESS OF ROBUST EXTERIOR ORIENTATION PROCEDURE

In this section, authors describe the effectiveness of robust exterior orientation procedure which developed by authors in this study. Moreover, evaluation of accuracy for volume measurement application in the field of mining is also described. Table 1 shows the Detail of Digital Video Camera.

Name	Sony DCR-PC110
Image Resolution	720×480
Video Format	Standard DV Format
Focal Length	4.2mm (at wide side)
Sensor Size	1/4 in.

Table 1. Detail of Digital Video Camera

3.1 Robustness of Exterior Orientation in this study

In our previous sturdy, the limitation of camera motion and robustness of exterior orientation in the big change of the scene such as the structure corner are the still remained problem. Figure 6 shows the example for big change of the scene. These video images include the near object and far object. Also, the yawing of camera is very quickly.

Figure 6. Big change of the scene

Figure 7 shows the result of exterior orientation with our old procedure. The trajectory of video camera is confused at the structure corner. The 3D coordinates of natural feature points are also confused.

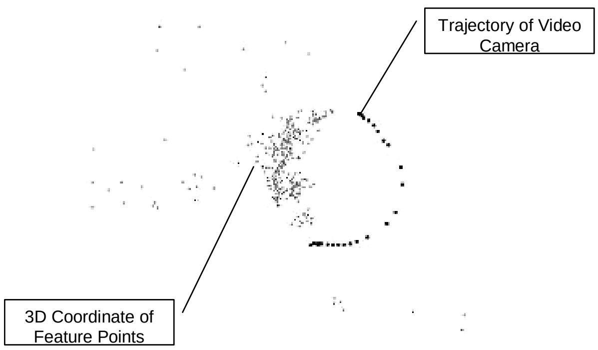


Figure 8. Result of Exterior Orientation with Old Procedure

Figure 8 shows the result of our new exterior orientation procedure. In this figure, it can be understood that the exterior orientation parameter for all video frames can be obtained. In addition, the 3D coordinates for all natural feature points can be obtained correctly. From these result, the robustness of exterior orientation in this study is increased from our old procedure.

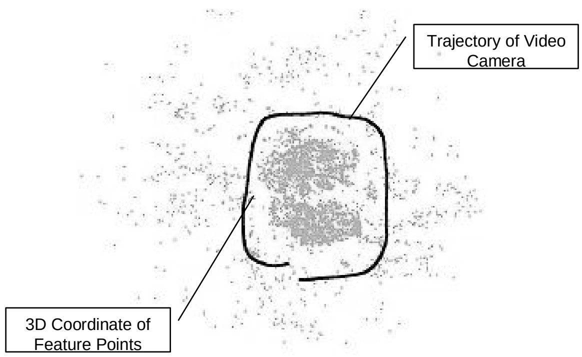


Figure 8. Result of Exterior Orientation in this Study

3.2 Application for Volume Measurement

As the application of this study, volume measurement from video image sequences was performed. In this study, authors assume the application for volume measurement in the mining field. From the experience of authors, the allowable margin of error for volume measurement using total station in the mining field is about 10%.

The exterior orientation for video camera and 3D coordinate of natural feature points were obtained from exterior orientation procedure of this study. The volume measurement from 3D coordinate of natural feature points was performed by using the modelling function of PI-3000.
At the first, accuracy assessment for small model of gravel mound is described. As the next, application for real gravel mound is also described.

3.2.1 Accuracy Assessment with Model Gravel Mound: In order to evaluate the accuracy of volume measurement, experiment of volume measurement for model gravel mound was performed.

Figure 9 shows the situation of this experiment. The model gravel mound is putted on the turntable. Therefore, video camera goes around the gravel mound in stable motion.

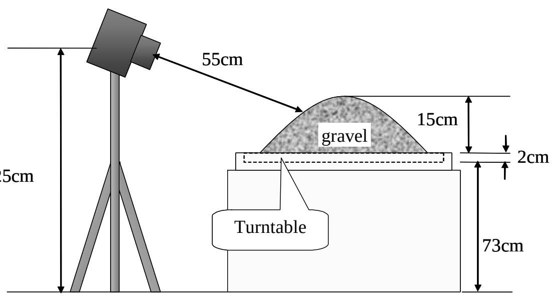


Figure 9. Situation of Model Gravel Mound Experiment

Figure 10 shows the result of exterior orientation procedure and Figure 11 shows the result of TIN modelling from the 3D coordinate of natural feature point using PI-3000.

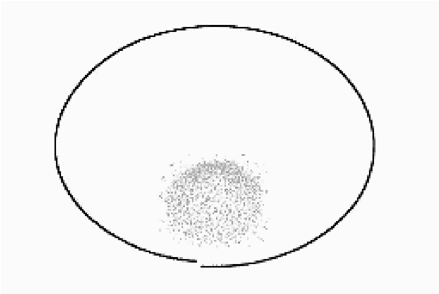


Figure 10. Result of Exterior Orientation Procedure for Model Gravel Mound

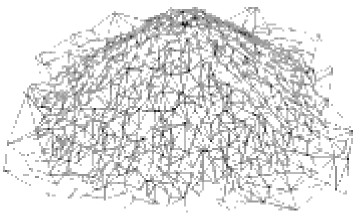


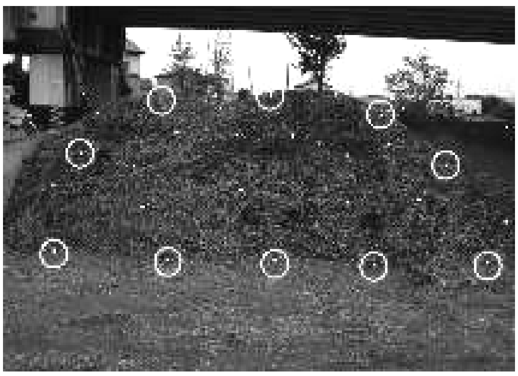
Figure 11. Result of TIN Modelling from the 3D Coordinate of Natural Feature

Table 2 shows the result of volume measurement. The volume error of this experiment was 1.97% for standard volume of gravel mound. This accuracy is enough if considering that error of volume is permitted to 10% in mining field.

Standard Volume of Gravel	7630[cm3]
Calculated Volume of Gravel	7480[cm3]
Error	1.97[%]

Table 2. Result of Volume Measurement for Model Gravel Mound

3.2.2 Application for Real Gravel Mound: The application experiment for real gravel mound was performed as the accuracy assessment for real field measurement. Figure 12 shows the test site of this experiment. The ground control point of this field was measured by Total Station TOPCON GPT-9000A.

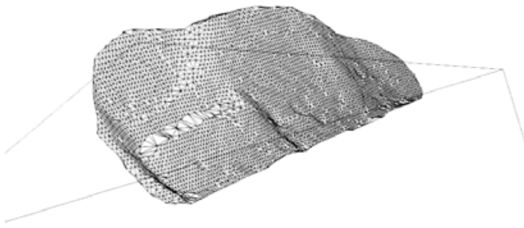


Width :6 [m]
Height :1.6 [mm]

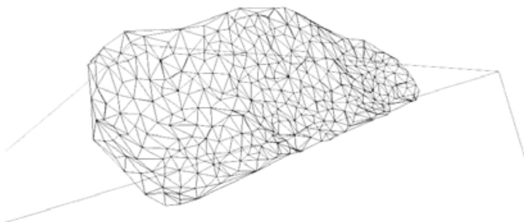
Figure 12. Test site of Real Gravel Mound

In order to obtain the standard volume of gravel mound, the volume measurement using Digital Still Camera (NIKON D80 f = 28mm, 10MPixel) with PI-3000 was performed. Also comparison of measuring time was also performed.

Figure 13 shows the result of volume measurement in this experiment. Table 3 is a comparison result of volume measurement from Digital Video Camera and Digital Still Camera with PI-3000.



a: Result of Digital Still Camera (standard volume)



b: Result of Digital Video Camera

Figure 13. Result of Volume Measurement for Real Gravel Mound

Standard Volume of Gravel	8.69[m3]
Calculated Volume of Gravel	8.82[m3]
Error	1.50 %

Table 3. Result of Volume Measurement for Real Gravel Mound

The volume error of Digital Video Camera result was 1.5% from standard volume which obtained from Digital Still Camera with PI-3000. In addition, the measuring time of Digital Video Camera was about 1/10 of Digital Camera measurement. If considering these results, volume measurement using Digital Video Camera is useful for the mining field.

4. CONCLUSITON

The authors describe the application of robust regression for exterior orientation for video image sequences in this paper. The robust tracking and robust bundle adjustment process developed in this study use the LMedS method for detection of outlier in corresponding points. In addition, in order to increase the robustness of bundle adjustment process and for solution of the limitation for camera motion, authors used LMedS in the backward intersection procedure, and effectiveness of this improvement was also confirmed.

Moreover, volume measurement from video image sequences with exterior orientation procedure which developed by authors was performed as the application of this study. The accuracy of volume measurement from video image sequences was enough for the mining field.

However, in order to obtain the 3D coordinate in global axis, the accurate control points are still needed for our system. Therefore, as the progress of this study, the authors are concentrating for development of the exterior orientation technique which includes the positioning sensor information such as GPS sensor. From this progress, it will be possible that the application of 3D measurement of this study spreads in many fields.

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