Accurate Geometric Transformation of Laser Scanner Data for Landslide Monitoring

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ABSTRACT: Landslide is a phenomenon of mass slowly movement in wide area. It is difficult to measure whole landslide area by using existing monitoring systems. Nowadays, ground based portable the laser scanner is expected to monitor landslide, because the laser scanner can acquire three-dimensional data of wide area in a short time. The acquired data by the laser scanner has own coordinates. The coordinate is called laser coordinate in this study. The laser coordinate must be transformed into the ground coordinates using Ground Control Point(GCP). The prism or reflector sheet is usually used as GCP. GCPs of ground coordinate can be precisely measured by total station. The laser coordinates of GCPs can be acquired automatically by image processing software of laser scanner. The image processing is based on reflection strength of the laser around the prism or reflector sheet. The reflection strength of the prism is higher than reflector sheet. Then prism can be set up widely. However, cost of the prism is so expensive that many prisms cannot be set up. On the other hand, cost of reflector sheet is so cheap that many reflector sheets can be set up. Therefore, the prism and the reflector sheet should be compared in order to establish accurate transformation method. In this study, 6 prisms and 16 reflector sheets were used for geometric transformation. The accuracy of geometric transformation was discussed. The required accuracy is 10mm of Root Mean Square Error(RMSE) for land slide monitoring. In the case of prisms, result showed 95.9mm RMSE. In the case of reflector sheets, result showed 25.0mm RMSE. Many reflector sheets were effective for accurate transformation. Repeat measurement will make accurate transformation by average calculation. The average calculation of 10 times measurement showed 5.4mm error. Therefore, this measurement method will be effective to monitor land slide.

1. BACKGROUND

A landslide is a phenomenon of mass movement on the ground, which moves 0.01mm to 10mm a day in the wide area. Current monitoring systems are used expansion gauge, inclinometer or GPS. Those monitoring systems for landslide displacement can measure at some points or along lines. It is difficult to measure whole landslide. Laser scanner is expected as a useful measurement equipment for monitoring landslide. Laser scanner can acquire three dimensional data in a short time, in wide area. For the extraction of landslide displacement by using laser scanner, 10mm accuracy is required at least.

However, used laser scanner has 25mm error in standard deviation. And laser scanner data must be transformed geometrically to extract displacement of landform using multi temporal data. Therefore, accurate geometric transformation is needed.

2. OBJECTIVES

Objective of this study is establishment at of accurate geometric transformation of laser scanner data. Accuracy of geometric transformation is depending on the type of ground control point (GCP). In this study, prism and reflector sheet were used as GCP. Two types of GCP were compared in this study. And spatial distribution of the GCP and the accuracy was evaluated. The required accuracy of in this study is 10mm root mean square error for landslide monitoring.

3. USED LASER SCANNER

In this study, LMS-Z210 produced by Riegl was used as laser scanner. Maximum measurement range by this the laser scanner is 350m. Measurement accuracy is about 25mm in standard deviation. Laser scanner can acquire color information, reflection strength and 3 dimensional coordinate of the object. Figure 1 shows picture of laser scanner. Table 1 shows Performances of measurement distance. Table 2 shows specification of laser scanner.

Figure 3.1 Used laser scanner

Table 3.1 Performances of measurement

Range	≦350m (reflectance≧80% of objects)
Range	≦150m (reflectance≧10% of objects)
Shortest Distance	2m
Measurement Accuracy	±2.5cm (Standard Deviation)
Laser Wavelength	0.9µm (Infrared)

Table 3.2 Specification of laser scanner

	Frame scan	Line scan
Pixel(max)	1106 pixels	4621 pixels
Angle Range	±40°	0°～333°
Pixel(max)	1106 pixels	4621 pixels
Angle resolution	0.036° (actual 0.072°)	0.018° (actual 0.072°)

4. CONTROL POINT

The acquired data by the laser scanner has own coordinates. The coordinate is called laser coordinate in this study. Laser scanner data must be transformed into the ground coordinates using GCP. The prism or reflector sheet is usually used for GCP. GCPs of ground coordinate can be precisely measured by using total station. The laser coordinates of GCPs can be acquired automatically by image processing software of laser scanner. The image processing is based on reflection strength of the laser around the prism or reflector sheet.

4.1 Prism

The prism is often used as a GCP. Figure 4.1.1 shows a picture of the prism. The prism can be reflected laser strongly. Then the prism can be set up in maximum range of 300m. Cost of the prism is expensive with 1,500 US dollars. The cost of the prism is so expensive that many prisms cannot be set up. In this study 6 prisms were used. Firstly accuracy of laser coordinate of prism was validated. By 8 times measurement in condition, laser coordinate of the prism were extracted by image processing.

Figure 4.1.1 Prism

Standard deviation of the laser coordinate showed 150mm when the prism set up at 60m range from laser scanner. The coordinates of the control points in laser scanner data cannot be accurately extracted.

4.2 Reflector sheet

Reflector sheet can be also used as GCP. Figure 4.2.1 shows a picture of the reflector sheet. Reflector sheet can not reflect laser strongly comparing with the prism. Reflector sheet can be set up in maximum range of 60m. Cost of the reflector sheet is cheap with 5 US dollars. The cost of reflector sheet is so cheap that many reflector sheets can be set up. In this study 16 reflector sheets were used.

Figure 4.2.1 Reflector sheet

Standard deviation of the laser coordinate showed 20mm by 8 times measurement when the reflector sheet set up at 60m range from laser scanner. Standard deviation of reflector sheet is smaller than the prism very much.

5. TEST AREA

The test area was selected CHOJA landslide in the NIYODO, KCOHI, JAPAN. This landslide is moving 10mm to 30mm a year. Figure 5-1 shows the location of GCPs. 6 prisms were widely set up around the landslide site. 16 Reflector sheets were set up in about 80m range from laser scanner. One validation point of the geometric transformation was set on the edge of landslide.

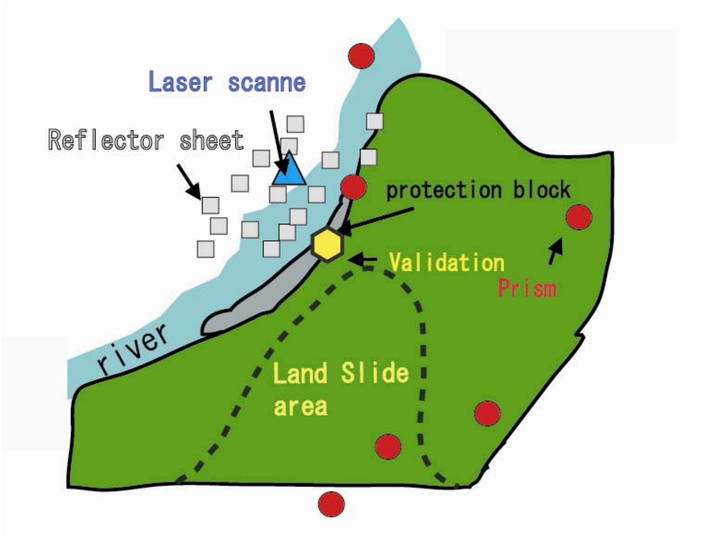

Figure 5.1 Location of GCPs

6. EVALATION METHOD

The geometric transformation was applied 3D Affine transformation. The conversion equation shows as follows.

$$\begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} = \begin{pmatrix} P_0 & P_1 & P_2 \\ P_3 & P_4 & P_5 \\ P_6 & P_7 & P_8 \end{pmatrix} \begin{pmatrix} u_i \\ v_i \\ w_i \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix} \qquad (6.1)$$

x_i,y_i,z_i: Ground coordinates
u_i,v_i,w_i: Laser coordinates
X_0,Y_0,Z_0:Coordinate of laser scanner
$p_0 \ldots p_8$:Coefficients of transformation

Coefficients of transformation are calculated by least square method using GCPs. GCPs have ground coordinates(x_i,y_i,z_i) and laser coordinates(u_i,v_i,w_i). At least 4 GCPs are needed for solution. Established transformation using GCPs is evaluated using validation point. Ground coordinate of validation point can be measured accurately by total station. The coordinate can be assumed true. When laser coordinate of the validation point input to the established transformation, ground coordinate of the validation point can be calculated. The error can be calculated comparing with true ground coordinate. By repeat measurement, distribution of the error can be plotted. In this study, root mean square error (RMSE) is calculated by following equation.

$$Error = \sqrt{\frac{\sum_{i=1}^{n}(X_v - x_i)^2 + (Y_v - y_i)^2 + (Z_v - z_i)^2}{n}} \qquad (6.2)$$

X_v,Y_v,Z_v: True coordinates
x_i,y_i,z_i: Transformed coordinates
n: Scanning number

RMSE is used for evaluating accuracy of geometric transformation.

7. RESULT

Laser scanner measurements were repeated 10 times in same condition. Coordinates of validation point were converted by each GCP. Figure 7.1 shows Error on validation point after transformation.

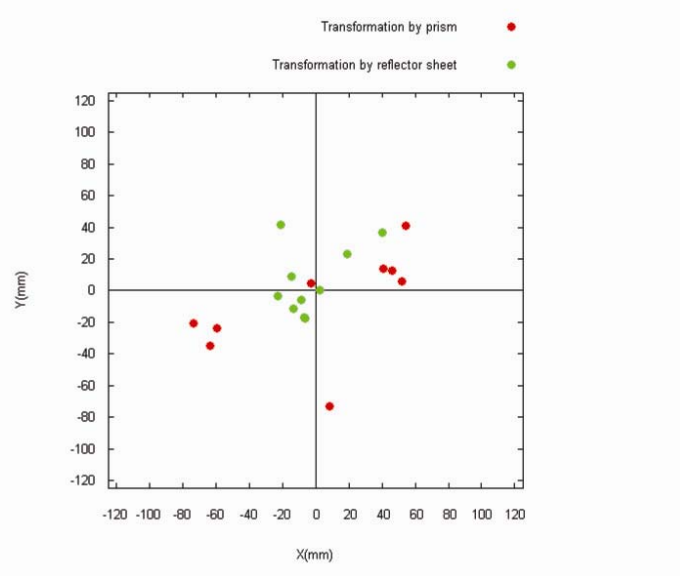

Figure 7.1 Validation point coordinates after geometric transformation by each type of GCP.

Origin is a coordinate of validation point which measured by total station. The prism and reflector sheet are distributed around validation point. RMSE and Standard deviation of the validation point of each GCP are shown in table 7.1.

Table 7.1 RMSE and standard deviation of the validation point

	prism	reflector sheet
RMSE(mm)	95.9	25.0
standard deviation(mm)	38.1	7.9

In the case of prisms, RMSE of the validation point after the geometric transformation showed 95.9mm. In the case of reflector sheets, RMSE of the validation point after the geometric transformation showed 25.0mm. The error using the reflector sheet has smaller than the prism. Standard deviation using the reflector sheet showed also smaller than the prism. Therefore, many reflector sheets can expect accurate transformation. However, this accuracy cannot be used to monitor landslide. If the error in the validation point showed a random error, the error margin can be decreased by average calculation of repeat measurement. The average coordinates of the control point that had been obtained by 10 times measurement. The following table showed the result of the average calculation.

Table 7.2 Average coordinates of 10 times measurements

	prism	reflector sheet
error(mm)	28.1	5.4

In the case of prisms, error of the validation point after the geometric transformation showed 28.1mm. In the case of reflector sheets, error of the validation point after the geometric transformation showed 5.4.mm. The average calculation made satisfy required accuracy for land slide monitoring. Equation 7.1 is showed predicted error by average calculation the repeat measurement based on low of error propagation.

$$E = \frac{\sigma}{\sqrt{n}} \qquad (7.1)$$

E : Predicted error
σ : Each measurement error
n: Number of repeat measurement

Number of repeat measurement to satisfy 10mm accuracy can be calculated using the equation. Relation between number of measurement and the error is shown in the following Figure 8.2.

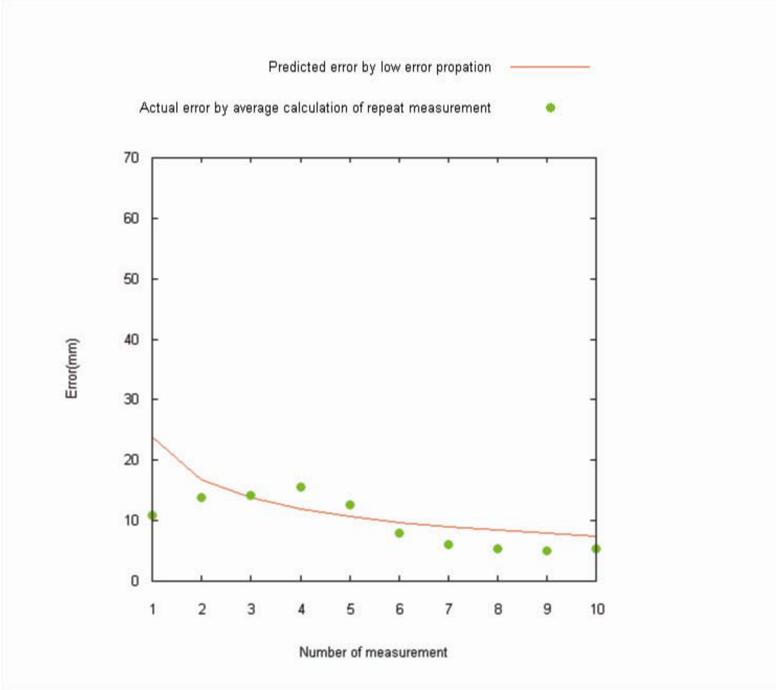

Figure 8.2 Relation between number of measurement and error

A line was drawn predicted error by the low of error propagation, and a point was plotted an error margin in an actual measurement. The result showed at least 6 times measurement is necessary to satisfy required accuracy which is 10mm.

9. CONCLUIONS

Required accuracy for measuring the landslide was able to be achieved by repeat measurement that uses reflector sheet for control point. By using reflector sheets, average calculation of 10 times measurement showed 5.4mm error. measurements that used the reflector sheet. As further study, it is necessary to decide the optimum number of the GCP and the spatial distribution. More over, 3D Affine transformation is not accurate model. More Accuracy geometric transformation can be expected by using rotation matrix

10. REFERENCE

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