Monitoring Method of Landslide Using Laser Scanner
-Accurate Geometric Transformation by Multi Surfaces Measurement-

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ABSTRACT: A landslide gives the big loss to various structures. However, a detailed mechanism of a landslide is not understood completely. Ground based laser scanner is expected as useful measurement equipment for monitoring landslide. However, there are some problems in accurate measurement using the ground based laser scanner. Laser scanner data must be transformed into the ground coordinates using Ground Control Points (GCP). The prism is usually used for GCP. The ground coordinate of the prism is precisely measured by using GPS and Total station. However the acquisition of accurate coordinate of the prism in laser scanner data is very difficult. The error of the transformation showed maximum 10cm.

This study focused on solving the problem in the geometric transformation. The accurate measurement of control points can be improved by measuring some flat surfaces. When three flat surfaces are measured, coordinates of the intersection in three planes can be calculated. This intersection can be used as a control point of the laser scanner data. This method should make accurate geometric transformation. Geometric transformation by using multi surface measurement was higher accuracy than geometric transformation using a prism. And, accuracy of geometric transformation showed less than 1cm.

1. BACKGROUND

1.1 The current landslide observation

A landslide is a phenomenon of mass movement on the ground, which moves 0.01mm 10mm/day in the wide area. There are various inducements of a landslide such as geology, topography, soil and hydrology. Current monitoring systems of a landslide are using borehole inclinometer, extensometer or GPS. Borehole inclinometer can measure the angle of the guide pipe by using strain meter. Extensometer can measure the amount of expansion and contraction between two points. GPS is used for point measurement. Those monitoring systems for detection landslide displacement can measure at some points or along lines. It is difficult to measure whole landslide area by current systems.

1.2 Laser Scanner Measurement

Laser scanner is expected as 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, less than 1cm accuracy is required.

1.3 Problem in Accurate measurement using A Laser Scanner

1.3.1 Accurate Measurement

Figure1-1 showed Digital Surface Model(DSM) of smooth flat board which was measured by laser scanner in 20m measurement distances. The DSM was represented contour line with Triangulated Irregular Network, which was given shading for easy understanding. In the DSM, measured points seemed rough surface including random error. Therefore, the noise reduction system should be developed for accurate measurement.

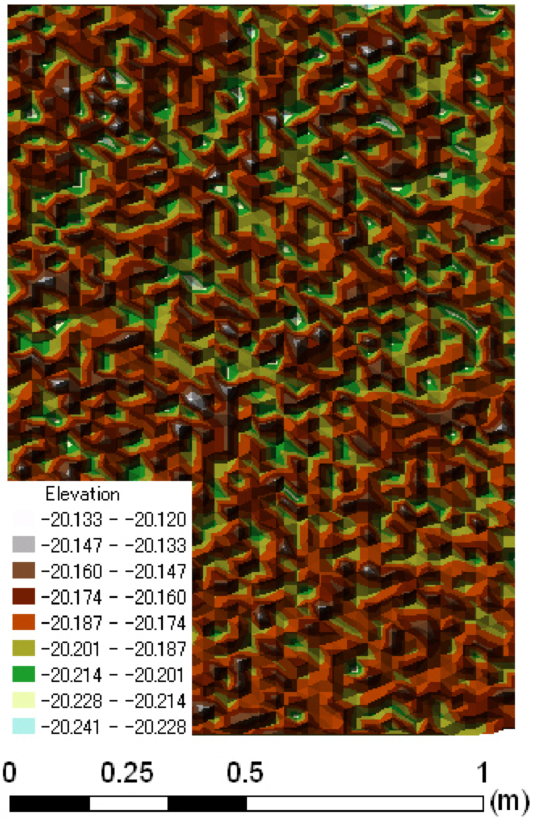

Figure1-1 Sample of Laser Scanner data in case 20m distance

1.3.2 Accurate setting

When displacement of a landslide is measured by using portable laser scanner, time series data are needed. Then the laser scanner must be set repeatedly at same point. It is difficult to set accurately at same point in each observation. The position of laser scanner in horizontal plane can be adjusted by centering equipment. However, it is difficult to set in vertical axis by using tripod. In addition, starting point for scanning is not always same point. Because, telescope for collimation is not mounted on the laser scanner.

1.3.3 Accurate control points in laser scanner data

Laser scanner data must be converted into the ground coordinate using Ground Control Points. A prism is usually used as GCP. The ground coordinate of prism can be precisely measured by using GPS or Total station. The location of the prism in laser scanner data are extracted automatically by reflection strength of the prism by with bundle software of laser scanner. However, coordinates of the control points in laser scanner data cannot be accurately extracted. When control points have some errors, precision of geometric transformation becomes low accuracy. Therefore, acquisition of the control point coordinates becomes important.

1.4 Experiment in landslide field

In Shikoku, Japan, there are four big active faults. Many landslides are occurred along the active faults. Now, landslide prevention areas exist over 1,500 places in Shikoku, Japan. In this study, test area was selected Chouja landslide in kochi pref. In Chouja, width of landslide is about 200m, length is about 900m and average slope is about 15 degrees. It is one of the biggest landslides in Japan. Figure1-2 showed Arial photograph of Choja landslide.

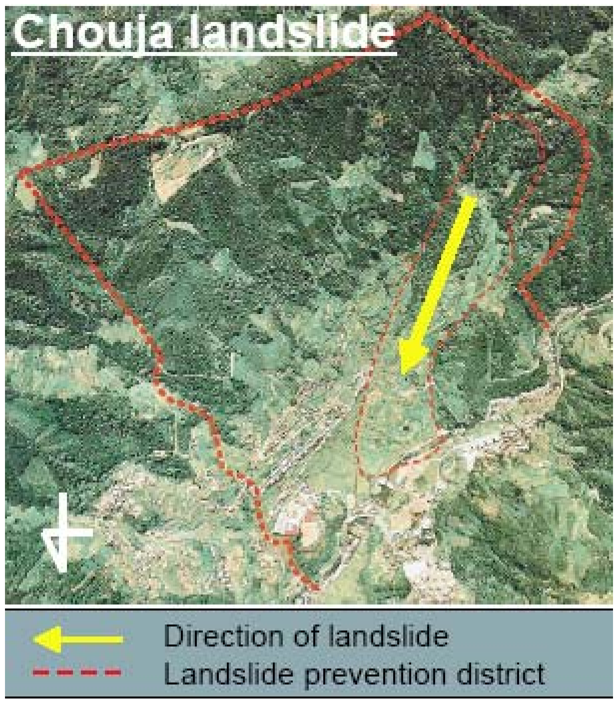

Figure 1-2 Choja landslide

1.4.1 Specification of Used Laser Scanner

In this study, LMS-Z210 produced by Riegl was used as laser scanner. Maximum measurement range by the laser scanner is 350m. Accuracy is about 2.5 centimeter in standard deviation. Table 1-1 shows Performances of measurement distance. Table 1-2 shows specification of Laser scanner.

Figure 1-3 Laser scanner

Table 1-1. 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 1-2. 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°)

1.4.2 Measurement Result Using Prism

In the observation, 5 prisms were set up and scanned 8 times. Table 1-3 shows acquisition precision of a control point which extracted automatically by bundle software. Standard deviation of control point coordinates were calculated from 8 times measurement. The coordinates of the same control point have 10 cm error in maximum. It was very big error comparing with laser range accuracy (2.5cm). Table 1-4 shows Root Mean Square Error of geometric transformations by using prism. GCP was measured by Total Station (3mm accuracy). The geometric transformation is low accuracy that it is difficult to detect the landslide displacement in current condition.

Table 1-3 Standard deviation of a coordinate of a prism

	x_c(m)	y_c(m)	z_c(m)
prism1	1.25E-01	3.52E-02	1.75E-02
prism2	5.94E-02	8.53E-02	9.82E-03
prism3	4.57E-03	7.90E-02	5.99E-03
prism4	8.51E-03	3.28E-02	3.16E-03
prism5	1.00E-01	5.43E-02	1.98E-02

Table 1-4 R.M.S.error (m) of geometric transformation

scan number	Prism
scan1	5.52E-02
scan2	2.02E-02
scan3	5.54E-02
scan4	5.87E-02
scan5	7.10E-02
scan6	2.54E-02
scan7	5.07E-02
scan8	3.33E-02

2. OBJECTIVES

This study is focusing on solving the problem in the acquisition of the accurate control points. Point measurement is very difficult by laser scanner because of no collimation telescope. The accurate measurement can be carried out by surface measurement. When three surfaces are measured, coordinates of the intersection with three surfaces can be calculated. This intersection can be used as control points of the laser coordinates. Objectives of this study are acquisition of accurate control points in laser scanner data by multi surface measurement and the evaluation. Accuracy for landslide monitoring is required less than 1cm in standard deviation. Therefore, accuracy of geometric transformation should be also less than 1cm.

3. Method for Measurement of Accurate Ground Control Points

The coordinates of the target by laser scanner is calculated by following equations.

$$x = r \sin\lambda \cos\phi$$
$$y = r \sin\lambda \sin\phi$$
$$z = r \cos\lambda$$

x, y, z : laser coordinates
r : range(m)
λ : polar angle (°)
ϕ : azimuth angle (°)

Following equations show estimated error of coordinates in standard deviation by low of error propagation. The error of an angle was assigned 1/10 of angle resolution in laser scanner.

$$\sigma_x = \sqrt{(\sin\lambda\cos\phi)^2{\sigma_r}^2 + (r\cos\lambda\cos\phi)^2{\sigma_\lambda}^2 + \{r\sin\lambda(-\sin\phi)\}^2{\sigma_\phi}^2}$$
$$\sigma_y = \sqrt{(\sin\lambda\sin\phi)^2{\sigma_r}^2 + (r\cos\lambda\sin\phi)^2{\sigma_\lambda}^2 + (r\sin\lambda\cos\phi)^2{\sigma_\phi}^2}$$
$$\sigma_z = \sqrt{\cos\lambda^2{\sigma_r}^2 + \{r(-\sin\lambda)\}^2\sigma_\lambda^2}$$

$\sigma_x, \sigma_y, \sigma_z$: estimated error of coodinate
σ_r : assigned error of range $= 2.5$ cm
σ_λ : assigned error of azimuth angle $= 0.0036$ °
σ_ϕ : assigned error of polarangle $= 0.0018$ °

3.1 Measurement Object

The measurement object must be a flat surface. So the two kind of flat boards were prepared as flat surface. The board's size was 1.37*1.525m, and 1.20*1.65m. The 3 boards were set up for one control point (Figure 3-1). Figure 3-2 shows location of measurement board. Test area was divided into 4 blocks. There were 3 boards in each block. Laser scanner measurements were repeated 8 times in same condition.

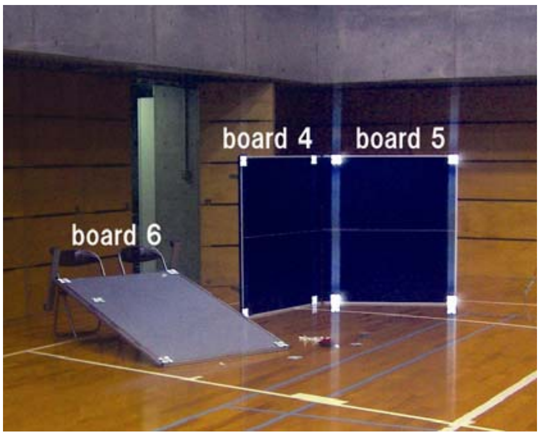

Figure 3-1 Picture of measurement board

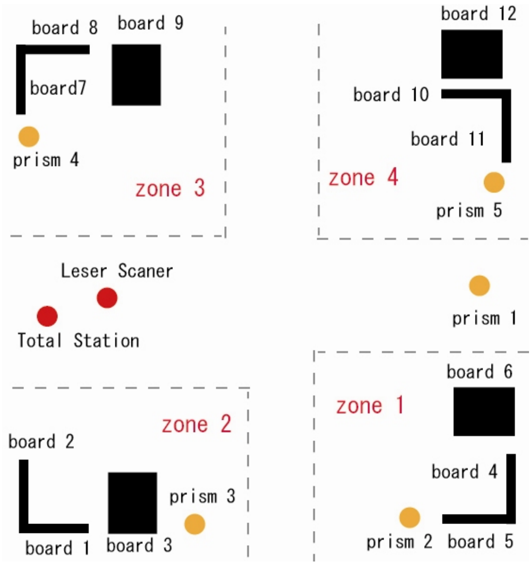

Figure 3-2 Location in test area

4. METHOD FOR ACCURATE CONTROL POINT

4.1 Establishing Equation of Planes in Laser Coordinates

The derived equation of plane will be accurate position of the surface. Following equation is equation of plane in three dimensions.

$$ax + by + cz = 1$$

$$a, b, c : \text{ unknown coefficients}$$

The equation of plane can be derived using many measurement points by least square method. Number of measurement point will influence to accuracy of the derived equation. The unknown coefficient can be calculated by following equation.

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} \Sigma x_i^2 & \Sigma x_i y_i & \Sigma x_i z_i \\ \Sigma x_i y_i & \Sigma y_i^2 & \Sigma y_i z_i \\ \Sigma x_i z_i & \Sigma y_i z_i & \Sigma z_i^2 \end{pmatrix}^{-1} \begin{pmatrix} \Sigma x_i \\ \Sigma y_i \\ \Sigma z_i \end{pmatrix}$$

$$x_i, y_i, z_i : \text{ laser scanner data}$$

Estimated error can be also calculated by low of error propagation as follows;

$$\sigma_a{}^2 = \left(\sum_{i=1}^{n} \frac{\partial a}{\partial x_i}\right)^2 \sigma_x{}^2 + \left(\sum_{i=1}^{n} \frac{\partial a}{\partial y_i}\right)^2 \sigma_y{}^2 + \left(\sum_{i=1}^{n} \frac{\partial a}{\partial z_i}\right)^2 \sigma_z{}^2$$
$$\sigma_b{}^2 = \left(\sum_{i=1}^{n} \frac{\partial b}{\partial x_i}\right)^2 \sigma_x{}^2 + \left(\sum_{i=1}^{n} \frac{\partial b}{\partial y_i}\right)^2 \sigma_y{}^2 + \left(\sum_{i=1}^{n} \frac{\partial a}{\partial z_i}\right)^2 \sigma_z{}^2$$
$$\sigma_c{}^2 = \left(\sum_{i=1}^{n} \frac{\partial c}{\partial x_i}\right)^2 \sigma_x{}^2 + \left(\sum_{i=1}^{n} \frac{\partial c}{\partial y_i}\right)^2 \sigma_y{}^2 + \left(\sum_{i=1}^{n} \frac{\partial a}{\partial z_i}\right)^2 \sigma_z{}^2$$

$$\sigma_a, \sigma_b, \sigma_c : \text{ error of coefficients}$$

Table 4-1 shows estimated error and result of experiment. Result of experiment shows higher accuracy than estimated error.

Table 4-1 Error in plane equation

	estimated error			error of experiment		
	a	b	c	a	b	c
board1	2.77E-03	5.26E-03	2.79E-03	8.30E-05	1.55E-05	9.06E-05
board2	8.24E-03	2.14E-03	2.64E-03	1.22E-04	3.69E-05	9.96E-05
board3	6.90E-03	6.19E-03	5.69E-02	1.17E-04	4.59E-05	2.14E-04

4.2 Intersection Point by Three Planes as Virtual GCPs

Coordinate of intersection can be calculated using three equations of planes by following equation.

$$\begin{pmatrix} x_c \\ y_c \\ z_c \end{pmatrix} = \begin{pmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{pmatrix}^{-1} \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$

$$x_c, y_c, z_c : \text{ coordinates of intersection}$$
$$a_1, b_1, c_1 : \text{ coefficient in board1}$$
$$a_2, b_2, c_2 : \text{ coefficient in board2}$$
$$a_3, b_3, c_3 : \text{ coefficient in board3}$$

Estimated error of coordinate of intersection can be calculated following equation.

$$\sigma_{x_c}^2 = \left(\frac{\partial x_c}{\partial a_1}\right)^2 \sigma_{a_1}^2 + \left(\frac{\partial x_c}{\partial a_2}\right)^2 \sigma_{a_2}^2 + \left(\frac{\partial x_c}{\partial a_3}\right)^2 \sigma_{a_3}^2 + \left(\frac{\partial x_c}{\partial b_1}\right)^2 \sigma_{b_1}^2 + \left(\frac{\partial x_c}{\partial b_2}\right)^2 \sigma_{b_2}^2 + \left(\frac{\partial x_c}{\partial b_3}\right)^2 \sigma_{b_3}^2$$
$$+ \left(\frac{\partial x_c}{\partial c_1}\right)^2 \sigma_{c_1}^2 + \left(\frac{\partial x_c}{\partial c_2}\right)^2 \sigma_{c_2}^2 + \left(\frac{\partial x_c}{\partial c_3}\right)^2 \sigma_{c_3}^2$$

$$\sigma_{x_c}: \text{ estimated error of coordinate of intersection}$$

Table 4-2 shows estimated error and result of experiment in coordinates of intersection. The error of coordinates of in the experiment has maximum 2 cm in Z-axis. Because value of Z-coordinate in control point was almost same in each block. Then accuracy in Z-axis might be lower.

Table 4-2 Acquisition precision of a reference point by three planes

	estimated error			error of experiment		
	xc(m)	yc(m)	zc(m)	xc(m)	yc(m)	zc(m)
Block1	5.20E-02	5.09E-02	2.86E-02	4.40E-03	6.08E-03	1.15E-02
Block2	9.47E-03	5.64E-03	5.26E-03	4.08E-03	1.97E-03	5.73E-03
Block3	9.91E-03	3.15E-03	5.39E-03	4.04E-03	1.43E-03	2.67E-03
Block4	5.02E-02	4.24E-02	2.49E-02	3.93E-03	7.97E-03	1.80E-02

3 dimensional affine transformation was applied for geometric transformation as follows;

$$\begin{pmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & p_8 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

X, Y, Z : Coordinate of reference point acquired by laser scanner
x, y, z : Coordinate of reference point acquired by total station
X_0, Y_0, Z_0 : Coordinate of laser scanner point
$p_0 \cdots p_8$: Transform parameters

GCP was measured by Total Station (standard deviation 3mm). The reflector sheets which put at the corner on the board was measured by Total Station. Equation of plane and the intersection was calculated as well as laser scanner data. Table 4-3 shows R.M.S.error of geometric transformations by using prism, and by using the intersection of three planes.

Table 4-3 R.M.S.error (m) of geometric transformation

scan number	Prism	Intersection
scan1	2.64E-02	7.48E-03
scan2	1.36E-01	8.85E-03
scan3	5.61E-02	8.39E-03
scan4	9.75E-02	7.70E-03
scan5	5.61E-02	1.11E-02
scan6	1.01E-01	7.96E-03
scan7	8.42E-02	7.28E-03
scan8	1.31E-01	9.17E-03

As for the geometric transformation by the intersection of three planes, precision showed higher accuracy that error showed less than 1.0 cm.

5. CONCLUSIONS

Geometric transformation by multi surfaces measurement was higher accuracy than geometric transformation by a prism. And, the accuracy of R.M.S.Error showed less than 1cm. However the result of estimated error showed lower than experiment. The estimation by low of error propagation is checking now. Movement of a landslide should be detected by surface measurement. This method is difficult to set up twelve boards on the landslide area. Portable multi surface boards should be made in near future.

6. REFERENCES

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