METHOD OF LANDSLIDE MEASUREMENT BY GROUND BASED LIDAR

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ABSTRACT:

Landslide is a phenomenon of mass movement of terrain. In order to prevent landslide, understanding the behavior of the landslide is important. The behavior of the landslide is usually measured by extensometer, inclinometer or GPS (global positioning system). These equipments are measuring some points or along the lines; it is difficult to measure the whole landslide area. Currently, it is expected that ground based LiDAR can be used to monitor the whole landslide area, because the LiDAR can acquire three-dimensional data of wide area in a short time.
The acquired time series data should be analyzed to measure the land movement to understand the behaviour of the landslide. Author report the method of landslide measurement with a LiDAR based on the best past results of the research.
For accurate measurement, surface of flat plane should be used. At least 256 points or more points are used in surface measurement, the error margin produced less than 1cm. When, the object surface is small, repeat measurement will be effective.
Next, materials or GCP were evaluated. The result showed reflector sheets had accurate than the prism.
Acquisition of the vicinity of the center of coordinates in the method used the averaging weight of reflection strength in selection of GCP.
When the position of the LiDAR was setup on a fixed place, the transformation model must be fit to the situation and it is established.
Method of the object matching for landslide monitoring is developed using these data, and the displacement extraction of the landslide will be able to present in future.

1. INTRODUCTION

1.1. Observation of Landslide

A landslide is a phenomenon of mass movement, which moves 0.01mm~10mm per day in wide area. Current monitoring systems are using extensometer, inclinometer or GPS. The monitoring systems for landslide displacement can measure at some points or along the lines. It is difficult to measure whole landslide area. Currently, LiDAR is expected to monitor the whole area of landslide. LiDAR can acquire three-dimensional data in a short time in wide area. The LiDAR is a kind of electro-optical distance measurement without prism. Finally, distance and angles to the targets, reflection intensity of the targets and the color information are detected. For the extraction of landslide displacement by using LiDAR, millimeter accuracy is required.

Figure 1.1. Shore-protection blocks and test surface

In this study, Choja landslide in Shikoku, Japan was selected as the test area. Authors observed the landslide using LiDAR since ten years ago. The target of measurement is shore-protection blocks which are located on the edge of landslide (Figure 1-1). The distance between shore-protection blocks and LiDAR is about 50 meters.

1.2. LiDAR Data

In this study, LMS-Z210 produce by Riegl is used as LiDAR. Maximum measurement range of the LiDAR is 350 meters. Accuracy is about 2.5 centimeter in the standard deviation. Table 1 shows specifications of LiDAR and table 2 shows performances of measurement distance.

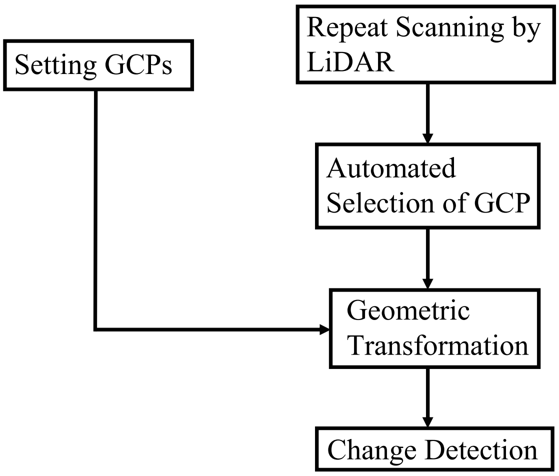
Table 1. Specification of the LiDAR

	Frame scan (Vertical direction)	Line scan (Horizon direction)
Pixel (max)	1106 pixels	4621 pixel
Angle Range	± 40 °	0 ° ～333 °
Scan speed(/s)	5 lines ～ 52	line 1 ° ～15 °
Angle step	0.24 °	0.24 °
Angle resolution	0.036 ° (actual 0.072 °)	0.018 ° (actual 0.072 °)

Table 2. Performances of measurement using LiDAR

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

1.3. Objectives



Figur1.2. Flow of LiDAR measurement for landslide monitoring

The research on landslide monitoring in Choja area is doing over ten years ago. Thus, the laboratory has many time series datasets. The flow diagram (figure 1.2) shows that process of LiDAR measurement. Firstly, LiDAR measurement should be carried out. At that time, repeated measurements are needed to do on high density data. The LiDAR datasets are required to transform geometrically. Therefore, the required ground control points (GCPs) were observed by total station. Geometric transformation coefficients (p_0, p_1, ..., p_8) are calculated using GCP (x_i, y_i, z_i) and the corresponding point (u_i, v_i, w_i) of LiDAR data. Finally, the change detection will be carried out. The method to keep required accuracy should be established in each process. Objective of this study is establishment of methodology for landslide monitoring by LiDAR. Ideal process of LiDAR measurement is suggested.

2. DATA ACQUISITION BY REPEAT SCANNING

Figure 2.1 shows Digital Surface Model (DSM) of smooth flat board which measured by LiDAR. The DSM is represented by Triangulated Irregular Network. The TIN is added by shading effect for easy understanding. In this DSM, the measured points seemed including random errors. Therefore, the noise reduction system should be developed for accurate measurement.

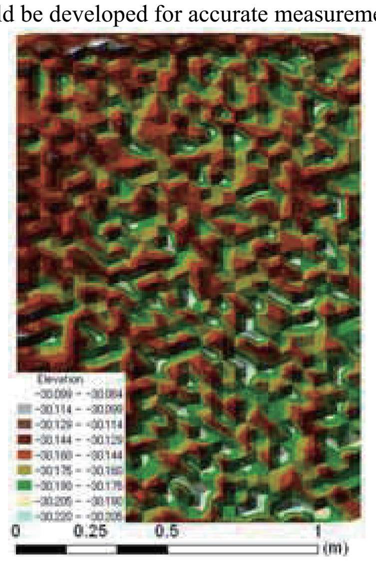


Figure 2.1. Sample of LiDAR data in the case of 30m distance

LiDAR measurement is repeated to 100 times in the same condition. The total numbers of points in 100 times observations are 1,562,500 points. In this study, 49.6 cm (125 points) by 49.6 cm (125 points) are extracted from the center of observation board in the LiDAR data to generate validation data. Validation plane was derived by using measurement points. Coefficients for the plane equation are calculated by least squares method. Next, distance between validation plane and each measurement points are calculated. Then, the histogram of the distance and the normal distribution are drawn in the same graph (Figure 2.2). Figure 2.2 showed the LiDAR measurement points had contained random errors.

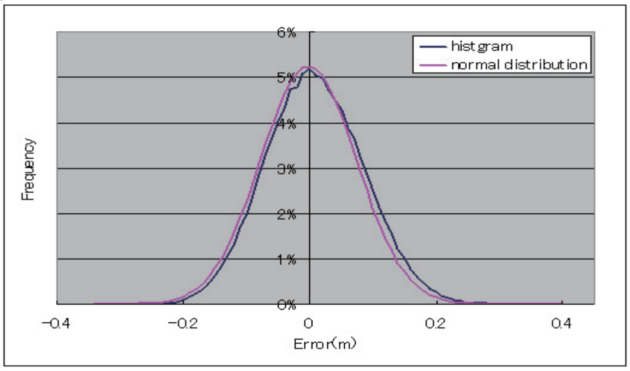


Figure 2.2. Normal distribution and histogram of validation data

Flat surface measurement will be effected to eliminate random error. It is necessary to know the least number of points to measure the surface accurately by indoor experiment. The measurement points are used from 4 to 4096 points. The number of points is corresponded to width of the flat surface. By using each measurement points, equation of plane is derived by least squares method. The distance between each derived plane and the validation plane are calculated, which direction is center of LiDAR to the measurement points. The distance means the error of derived plane. Figure 2.3 showed relationship between the error and number of points.

In figure 2.3, the error shows less than 1 centimeter when at least 256 points are used.

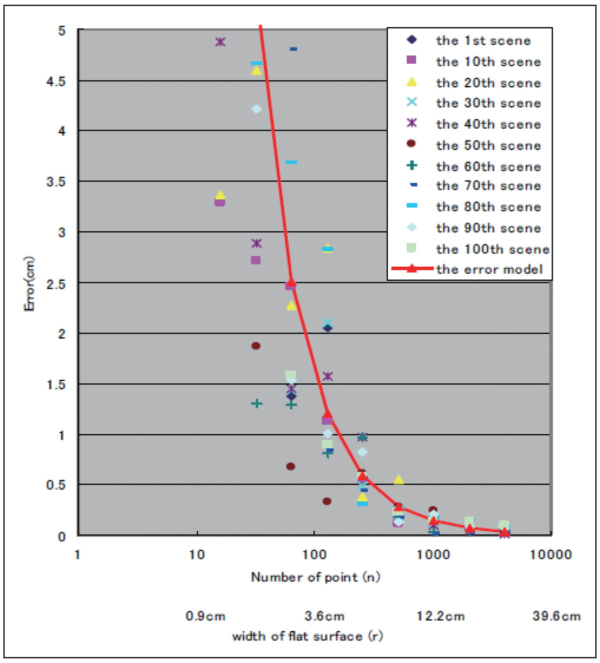


Figure 2.3. Relation of the number of point and the error

256 points are necessary to measure accurate the surface. Actually, 256 points from the surface of the shore-protection block cannot be acquired because the distance between LiDAR and the shore-protection block is too far to obtain 256 points. Only 100 point could be obtained. Therefore, data integration is necessary to keep enough accuracy for smaller surface. The high density data can be made by integrating repeat scanning. When 10 scenes were prepared, 10 times density data will be acquired. For example, very narrow surface which consisted with 4 points data will become 40 points data by integrating 10 scenes data. When data integration 8 time repeat scanning is applied, at least 2.8 cm width of flat surface could be satisfied by the experiment.

3. GROUND CONTROL POINT

3.1. Materials of GCP

Time series data must be prepared for monitoring landslide. Each data should be geometrically transformed in order to become same coordinate system for comparing each other. Therefore, control point must be setup in the test field. Figure 3.1 shows materials of the control point which are prisms and reflector sheets.

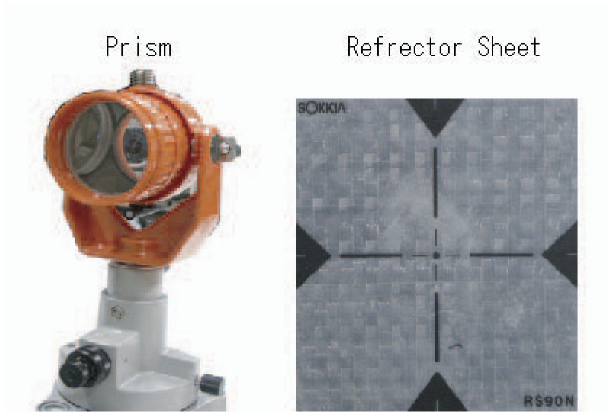


Figure 3.1. Materials of the control point

The prisms are often used as a control points. The prism can be strongly reflected laser light and that can be setup in very far place such as about 300 meters in range.
However, it is difficult to use a lot of prisms because it is expensive. Therefore, a lot of reflector sheets are expected to use. Though the reflection strength of reflector sheet is lower than the prism, the sheet must be setup within 100 meters distance.

3.1.1. Indoor Experiment

Firstly, indoor experiment was carried out to evaluate each material. Figure 3.2 shows location of control points. The prisms are setup at the four corners. Moreover, 12 reflector sheets are put on each corner. Thus, total 48 reflector sheets are used. Validation point is set in the center. LiDAR measurements are repeated 8 times in the same condition.

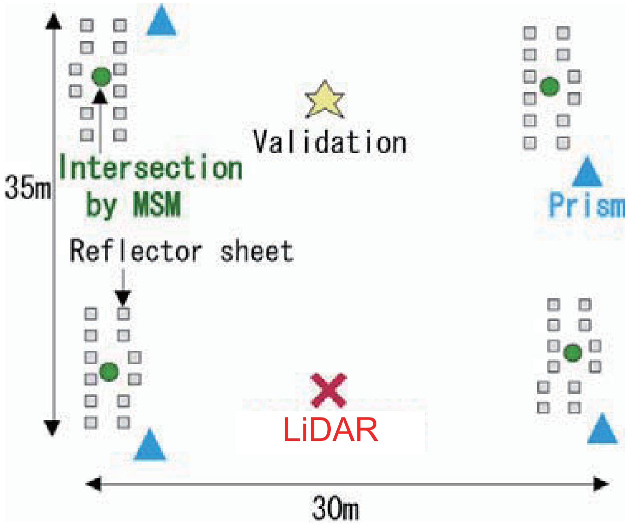


Figure 3.2. Situation of indoor experiment

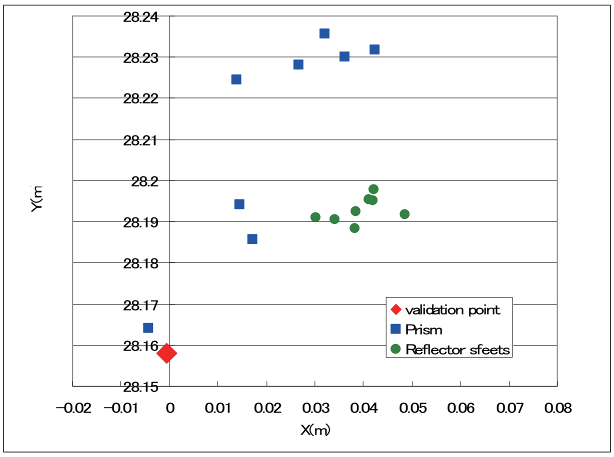


Figure 3.3. Validation point coordinates by each control point

Geometric transformation by reflector sheets produced higher accuracy than the prism. The compared errors became 2/3. However, systematic errors were included in the each control point. The systematic error might be come from special distribution of control point.

3.2. Spatial Distribution of GCP in Test Area

Figure 3.4 shows the location of GCPs in test area. Prisms and reflector sheets are combined to use in this study. 6 prisms are widely setup around the landslide site. 16 Reflector sheets are setup in about 80 meters range from LiDAR. One validation point of the geometric transformation is set up on the edge of landslide area.

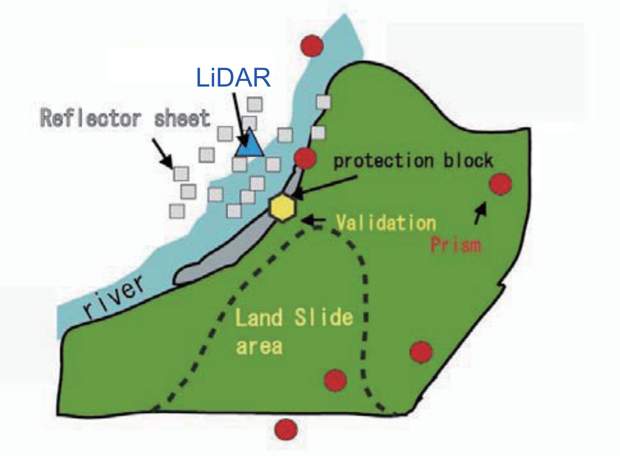


Figure 3.4. Location of GCPs in test field

3.3. Selection Method Laser Coordinate at GCP

Ground coordinates of GCPs are accurately measured by the total station which has only 1 mm error.
Corresponding laser GCPs coordinates should be extracted for geometric transformation. The strength of reflectance of GCPs showed very high. Then, finding GCPs can be extracted automatically.
However, accurate laser coordinates of GCPs are difficult to calculate; high reflected points are clustered. It means that there are several high reflected points around the center of GCP.
Therefore, the center of gravity of the reference point should be calculated for extracting accurate coordinates. Following equations express calculation of the center of gravity.

$$U = \frac{\sum u k_i}{\sum k_i} \tag{1}$$

$$V = \frac{\sum v k_i}{\sum k_i} \tag{2}$$

$$W = \frac{\sum w k_i}{\sum k_i} \tag{3}$$

k : Reflection strength value

u_i, v_i, w_i : Reference point coordinates(LiDAR coordinates)

4. GEOMETRIC TRANSFORMATION

4.1. General Model

The geometric transformation can be applied 3D affine transformation. The conversion equation shows below.

$$\begin{pmatrix} X_i \\ Y_i \\ Z_i \end{pmatrix} = \begin{pmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & p_8 \end{pmatrix} \begin{pmatrix} u_i \\ v_i \\ w_i \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix} \tag{4}$$

X_i, Y_i, Z_i: Ground coordinates
u_i, v_i, w_i: LiDAR coordinates
X_0, Y_0, Z_0: Coordinate of LiDAR
$p_0 \ldots p_8$: Coefficients of transformation

The coefficients of transformation model can be calculated by least squares method using control point data which are (X_i, Y_i, Z_i) and (ui, vi, wi) .The position of LiDAR (X_0, Y_0, Z_0) can be calculated by this geometric transformation.
LiDAR measurement in the test area carried out since 2005 to 2009. LiDAR was always setup on same point. All LiDAR data were transformed geometrically using GCPs.
This figure 4.1 plotted the position of the LiDAR in each measurement. This figure showed position of LiDAR is scattered. It means the calculated transformation included errors. Therefore, geometric model should be revised.

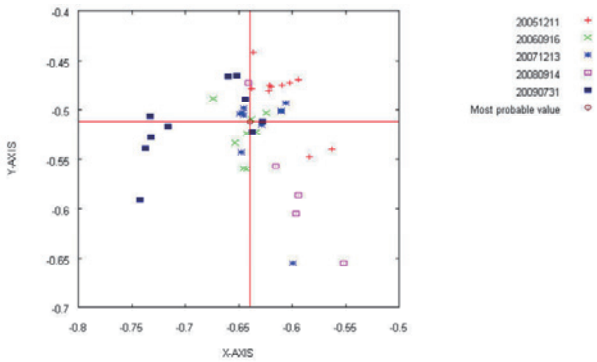


Figure 4.1. Gap at position of LiDAR counted backward

4.2. Fixed Position Model

In this study, fixed position model is suggested for landslide monitoring.
Coordinates X_0 and Y_0 must be constant always, X_0 and Y_0 should be input observed coordinate which surveyed by total station.
Table 3 shows the observed coordinate. This model might be decreased the error in geometric transformation.

$$\begin{pmatrix} X_i \\ Y_i \\ Z_i \end{pmatrix} = \begin{pmatrix} p_0 & p_1 & p_2 \\ p_3 & p_4 & p_5 \\ p_6 & p_7 & p_8 \end{pmatrix} \begin{pmatrix} u_i \\ v_i \\ w_i \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix} \tag{5}$$

Fixed (X_0, Y_0)
Unknown ($p_0 \ldots p_8$, Z_0)

X_i, Y_i, Z_i: Ground coordinates
u_i, v_i, w_i: LiDAR coordinates
X_0, Y_0, Z_0: Coordinate of LiDAR
$p_0 \ldots p_8$: Coefficients of transformation

Table 3. Position where LiDAR is setup

X0(m)	Y0(m)
-0.6397	-0.5119

5. CHANGE DETECTION METHOD

In this study, object matching is suggested as change detection method. In the test area, target of measurement is shore protection blocks on the landslide field. Thus, the shore-protection blocks become the object to measure.

One of shore-protection blocks (figure 5.1) is measured by a tape measurement to make supervised data. Next, three-dimensional object model (figure 5.2) is generated by CAD. This model is used for matching with LiDAR data.

Figure 5.1. Selected object

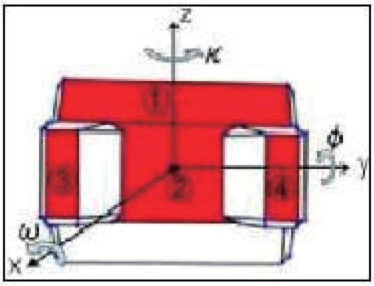


Figure 5.2. Object model

The location of the object model is calculated as shown in equation 6. The center of the surface in figure 5 is selected by visual interpretation of LiDAR data. Points are extracted 20 points around the center. Following equation of the surface from extracted points is established by least squares method.

$$aX + bY + cZ = 1 \cdots\cdots \cdot \quad (6)$$

X, Y, Z : Ground coordinates of LiDAR
a, b, c : Coefficients

By this equation, the distance from each point of LiDAR data to the surface can be calculated. When the distance showed within 0.05 m, the points are extracted to calculate accurately. Finally the accurate location (Xg, Yg, Zg) of object is calculated by averaging the coordinate of the extracted points. Primary attitude (ω, ϕ, κ) of the object is calculated by following equation using coefficients (a, b, c) of the surface equation. After that, each shore protection block will be tracked to detect displacement of Landslide.

$$\begin{cases} \phi = sin^{-1}\left(\frac{c}{r}\right) & r = \sqrt{a^2 + b^2 + c^2} \\ \kappa = tan^{-1}\left(\frac{b}{a}\right) \\ \omega = 0 \end{cases} \quad (7)$$

6. CONCLUSIONS

In this study, methodologies of Landslide monitoring by LiDAR are established.
For accurate measurement, surface of flat plane should be used. At least 256 points or more points are used in surface measurement, the error margin produced less than 1cm. When, the object surface is small, repeat measurement will be effective. Next, materials or GCP are evaluated. The result showed reflector sheets had accurate than the prism.
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