

# AUTOMATIC TREE DATA REMOVAL METHOD FOR TOPOGRAPHY MEASUREMENT RESULT USING TERRESTRIAL LASER SCANNER

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## Commission II

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### ABSTRACT:

Recently, laser scanning has been receiving greater attention as a useful tool for real-time 3D data acquisition, and various applications such as city modelling, DTM generation and 3D modelling of cultural heritage sites have been proposed. And, former digital data processing were demanded in the past digital archive techniques for cultural heritage sites.

However, robust filtering method for distinguishing on- and off-terrain points by terrestrial laser scanner still have many issues. In the past investigation, former digital data processing using air-borne laser scanner were reported. Though, efficient tree removal methods from terrain points for the cultural heritage are not considered.

In this paper, authors describe a new robust filtering method for cultural heritage using terrestrial laser scanner with "the echo digital processing technology" as latest data processing techniques of terrestrial laser scanner.

## 1. INTRODUCTION

By the rapid development of the recent digital technology and image processing technology, and from the viewpoint of cultural assets restoration, digital archive for cultural heritage attracts attention. Actually, large survey projects are producing digital archive data in many countries. In conventional digital archive data producing, only the preparation of digital data about the configuration of cultural assets was demanded.

As well as the record of cultural assets using conventional 3D CG, with maintenance of the infrastructure and the technological advance of the processing system, utilization of the digital archive is considered in various fields (e.g. AR (Augmented Reality) or GIS). The additional data (e.g. the location and findings) for cooperation with AR or GIS are demanded. Furthermore, the data size increases every day. So, automatic work to reduce labour will be problem in the geometry data acquisition and 3D modelling. Especially, automatic data processing is expected in the 3D measurement work for archaeological sites.

Meanwhile, in the field of the recent topography measurement, the terrestrial laser scanner attracts attention as topography measurement technique. However, to make topography model from the 3D point cloud data, the tree part should be removed, and the earth surface should be detected effectively. In the automatic classification of point cloud data, various processing techniques are considering (Pirotti, 2013, Bordu, 2012, Kim, 2011, Lim, 2009). Though, at the place where tree and heavy irregularity topography are complicated intricately, the classification work will be difficult. Because experience and reference data are necessary. Moreover, the data classification includes false classification. So, revival method for the miss classified part is necessary.

In the past investigation, many data processing technique for forest using air-borne laser scanner were conducted. And some method using the terrestrial laser scanner are examined. For example, Measurement of the height of the tree, A vegetation classification, and the reproduction of the external form are considered (Schilling, 2012). However, the removal of the tree

from the terrestrial data for cultural assets is not researched. In the situation that removing trees from the measurement result of landform is demanded, automatic working to classify to flat area (surface of the earth or building wall surface) or non-flat area (a tree or undergrowth of weeds) will be needed. In past investigation, the classification method which using the flatness index of the plane to detect break line was reported (Yokoyama, 2006). In the method, micro field to classify the notice points to flat area or non-flat area was used. By using this flatness index method, the intense topography or irregularity trees will be classified easily. However, extraction of landform data from the landform data including big trees is not realized yet.

In this investigation, authors compared methods (Method using the flatness-related evaluation, Method using the quantity of edge characteristic, Method using the chief ingredient analysis) to automatically remove the data of trees from the point cloud data of remains.

Moreover, authors examined the method that revived of the landform data which were deleted by mistake.

## 2. AUTOMATIC REMOVAL OF TREE FROM LANDFORM MEASUREMENT DATA

About the making of digital archive data for remains, there is the need to record present conditions to prepare for deterioration or landform collapse by the secular variation. As one of the correspondence, detailed landform information and break line are recorded. About the record of the break line of cultural assets, the method using a total station, photogrammetry and the laser scanner were used. Recently, automation of the work is demanded.

With the recent laser scanner, "the echo digital processing technique" to analyse the reflection data of the laser to irradiate into instantly is utilized. Thus, figure1 shows the work flow about automatic removal of the tree (unnecessary data) using the terrestrial laser scanner above the landform information (remains and landform).

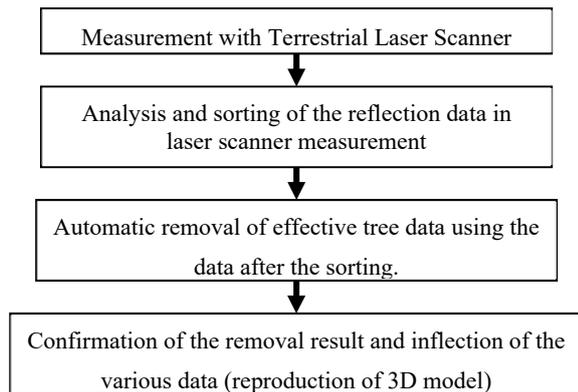


Figure1. Work flow about automatic removal of the tree using the terrestrial laser scanner above the ground

In the digital archive for remains, many trees have to be automatically removed from landform. When we check change of landform to remove trees, the landform (remains) which has gentle consecutive change and the trees which have sudden change will be confirmed. Therefore, the automatic classification about tree and landform are enabled by executing a flatness-related evaluation in consideration of notice point and the neighbouring shapes.

Moreover, "an echo digital processing technique" to analyse the reflection state of the laser is utilized by the recent terrestrial laser scanner. This technique is a data handling technology which used with air-borne laser scanner. This technique can classify the reflection signals of the laser for the object in First target, Last target, Others target, Single target, which shows in figure 2. In other words, plural reflection signals will be detected when a laser goes through the cavity of the leaf group like the part that a tree leaf is piled up. About these plural detected signals, the detected position as the first reflection is defined as First target, the position that is detected as the last reflection is defined as Last target, the reflection signal which is detected in the middle is defined as Others target. And the signal reflection such as the wall surface is defined as Single target.

In this paper, the automatic removal of tree was utilised these reflection data. Figure 3 (a) shows the colouring point cloud data which acquired by 0.04deg of angle pitch. Table 1 show the specifications of the terrestrial laser scanner that used to measure remains. The measurement range becomes about 190m in a horizontal direction.

Figure 3 (b) - (e) are measurement results by the reflection signals that measured the remain (landform) including tree. Leaves of tree are detected as first target in the measurement result. And, in the single target, the estimated data as the leaves of tree are existing. These data are estimated to be detected as single data by "A laser does not through by the leaf thickness" or "Data do not exist behind a leaf".

Therefore, part of leaves will be removed by examining only single target. In measurement data of figure 3, quantity of data of approximately 77% as for the single target of the whole, approximately 11% of first targets, approximately 10% of last targets, and the others target has the breakdown of approximately 2%.

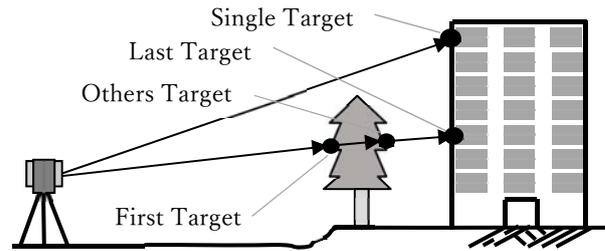
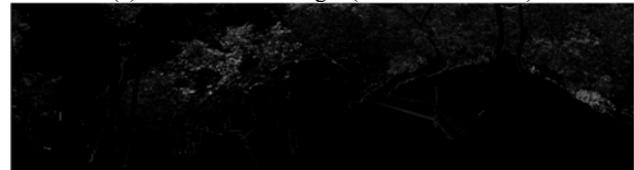


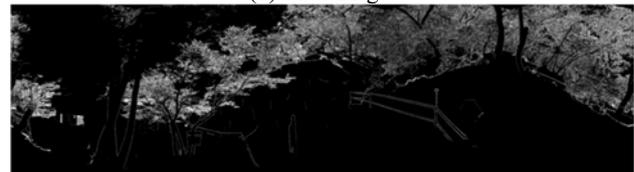
Figure2. Reflection signal classification image



(a) Measurement Target (Point Cloud Data)



(b) First Target



(c) Last Target



(d) Others Target



(e) Single Target

Figure3. Measurement results by the reflection signal

Model/ Maker	VZ-400/ Reigl
Measurement Range	~350m (Speed Mode)
Field of View	Vertical : -50deg~+50deg (100deg) Horizontal: -180deg~180deg(360deg)
Scanning Speed	122,000point/sec
Accuracy	5 mm
Size/Weight	308 mm(Length)xφ180 mm(Diameter) / 9.6kg

Table1. Laser scanner specifications

### 3. TREE REMOVAL METHOD FROM POINT CLOUD DATA

#### 3.1 Flatness index evaluation technique

By the measurement using the terrestrial laser scanner, the 3D point cloud data is acquired radially of the equipment. Therefore, points consistence changes by the distance from a laser scanner to the measurement points. As a result, if we set a mask of the constant size (pts) on range image, the real length of edge does not become the same size (real length).

In this method, the rectangle mask (Size: 3\*3 dot) is set around the notice point as the first step. Figure4 shows concept of variable mask size. The smallest size mask is set on the range image which made based on 3D point cloud data. Then, real length of the rectangular mask size is checked using the 3D data of each point. And mask size on the range image is extended until the mask size becomes the predetermined length (0.3m \*0.3m).

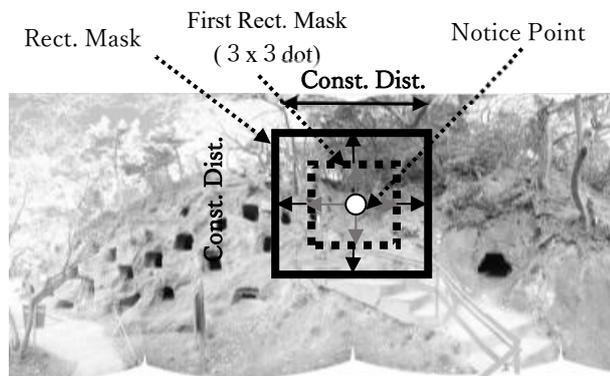


Figure4. Concept of variable mask size

Then, eight triangles are made by using 9 points data (4 corners point of the mask, circumference centre point of the mask and notice point located in the mask centre) in the rectangle. Normal vectors of each triangles are calculated using the 3D data of the triangular top. Synthetic normal vector is calculated by finding the average of calculated triangular normal vector. The calculated synthetic normal vector assumes the normal vector of the rectangular mask (reference field). By the way, the direction of the normal vector takes various directions. Therefore, coordinate transformation is performed around a notice point so that the direction of the normal vector for the mask is parallel to the Z-axis about all 3D point cloud data included within the mask. And The standard deviation for the irregularity of the plane is calculated from the Z value of all point cloud data included within the mask, after the direction of the plane assumed an approximately parallel state on XY plane. And the direction is aligned by a normal vector. The flatness index for the reference field is calculated after this process.

Images (range image, intensity image, flatness index image) that made based on a measurement result (figure 3 (a), remains as measurement result) are shown in figure 5. In the images, the unnecessary data such as leaves are expressed as the colour that is almost white.

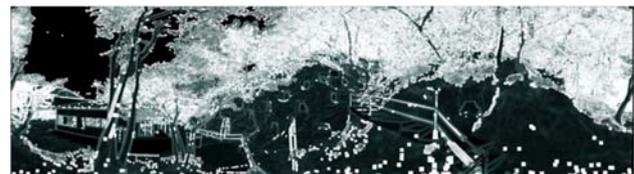
This technique was applied for the points that were confirmed in Single and Last target. As a result, the result that removed a tree is shown in figure 6. By this technique, the threshold to divide landform and a tree into was set as 0.030m. And the point that became more than the threshold was removed as a tree. However, the data of the tree are left in a removal result of figure 6. Therefore, the additional process for removal of the tree was confirmed.



(a) Range Image



(b) Intensity Image



(c) Flatness Index Image

Figure5. Measurement result for remain

Tree data is still staying.

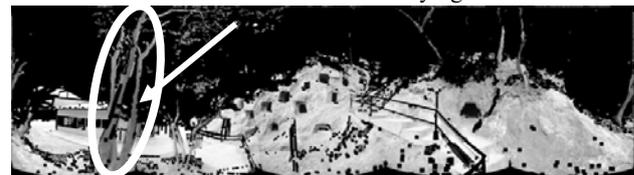


Figure6. Automatic removal result by the flatness index evaluation

In figure 6, the part of the big tree is not removed. So, the request of addition new process was confirmed. The details are shown to the next joint.

#### 3.2 Addition of the automatic removal method of the tree using the edge characteristic quantity

A new tree removal process was examined in addition to the combination of flatness index related evaluation and reflection data in this investigation. By the result of figure 6, the cylindrical shapes such as tree trunk or the branch are not removed. Therefore, near cylindrical shape data are removed. For a cylindrical shape, the direction of the local plane around the notice point is analysed, and a cylindrical change will be confirmed.

Meanwhile, edge extraction is performed in the image processing by analysing the change of the colour (Sugiyama, et.al., 1995). One of this technique has a method to display quantity of edge characteristic in a vector.

By this method, the directionality of the edge of the notice point on the image is calculated using equation (1), and equation (1) calculates XY direction ingredients using equation (2).

$$\vec{h}(x, y) = (h_x(x, y), h_y(x, y)) \quad (1)$$

Here,  $\vec{h}(x, y)$ : Vector of edge in the notice point,

$h_x(x, y), h_y(x, y)$ :  $x, y$  component of the edge vector in the notice point

$$\begin{aligned} h_x(x, y) &= \int_{-\pi}^{\pi} \int_0^{\infty} f(x + r\cos\theta, y + r\sin\theta)w(r)\cos\theta drd\theta \\ h_y(x, y) &= \int_{-\pi}^{\pi} \int_0^{\infty} f(x + r\cos\theta, y + r\sin\theta)w(r)\sin\theta drd\theta \end{aligned} \quad (2)$$

Here,  $w(r)$ : Weight Function,  
 $r$ : Distance on the image from notice point

Moreover, equation (3) is established as an equation for calculating direction  $\theta(x,y)$  of the edge.

$$\theta(x, y) = \arctan(h_y(x, y)/h_x(x, y)) \quad (3)$$

By this technique, brightness data in the 2D image are used. However, point cloud data have 3D coordinate data. Therefore, this method cannot be applied, directly. Meanwhile, not only the 3D positional information but also other data can be added to each point in the range image that show in figure 5 (a). This method can be utilized by using each point in the range image and various point data. By this technique, the data of the near cylindrical shape can be removed as trees.

To remove the trees, the change of normal vector is attracted the attention in this paper. The normal vector changes in the axial direction where a branch reaches. Therefore, the change of the normal vector of each axis (the X-axis, the Y-axis) on the range image is considered. And the directionality of the change on the range image is confirmed.

Then, the change of the normal vector is considered about the neighbouring point of the right and left direction, when the lengthening direction of the tree confirmed on range image is a top and bottom direction. The change of the normal vector of the axis circumference is shown as the lengthening direction (top and bottom direction) of the tree. So, when the change of the normal vector of the axis circumference is bigger than two other axes, the notice point will be judged as part of tree.

As a result, the notice point judged as a part of tree is removed from measurement result. By using single target shown in figure 3, the applied result of flatness index evaluation technique is shown in figure 7.

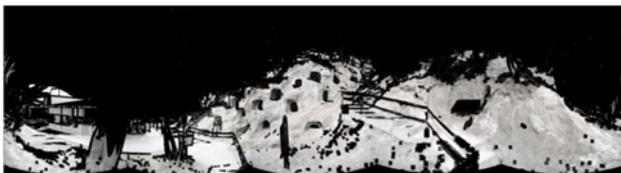


Figure7 Tree removal result using the method to express the characteristic of the edge in vector

Using flatness index evaluation technique to single data, the number of points for the processing is limited. Therefore, the automatic removal of the effective tree can be performed. However, any big trunk parts are still remaining. Therefore, not to be able to remove the further tree by this technique was judged.

### 3.3 Study of automatic tree removal method using component analysis

Trees are essentially aggregates of cylindrical shapes. Thus, it is possible to detect trees by analysing their positional relationships around notice points.

In the field of informatics, there is a method referred to as “component analysis” involving data trend analysis using statistical techniques. Component analysis is a technique included in multivariate analysis for statistical handling of variate data consisting of multiple result variables. A correlation

coefficient matrix R is computed from constituent data, and then a first main component  $z_1$  is computed from eigenvectors corresponding to a first eigenvalue (maximum eigenvalue)  $\lambda_1$ . Thereafter, the main components of all constituent multidimensional data are computed. Furthermore, the contribution ratio, cumulative contribution ratio and other ratios are computed for each main component, and then the various data ultimately computed is used to analyse trends in data.

The data handled in this study is 3D data, which requires a component analysis process in which there are three variables. In which case, first data is standardized according to formula (4).

Furthermore, limits need to be placed on eigenvectors when calculating main components. Therefore, the following formulas (conditions) (5) and (6) are established.

$$u_1 = \frac{x_1 - \bar{x}_1}{s_1}, u_2 = \frac{x_2 - \bar{x}_2}{s_2}, u_3 = \frac{x_3 - \bar{x}_3}{s_3} \quad (4)$$

Here,  $u$ = Standardization data,  $x$ = Variable,  
 $\bar{x}$ =Average of Variable,  $s$ = Standard deviation of the variable

$$z_1 = a_1u_1 + a_2u_2 + a_3u_3 \quad (5)$$

Here,  $a$ = Characteristic vector

$$a_1^2 + a_2^2 + a_3^2 = 1 \quad (6)$$

Using the above equation (5) and equation (6), if the first main component is  $z_1$ , then  $[a_1, a_2, a_3]$  is calculated wherein  $V_{z_1}$  is at maximum. However, the solution is an eigenvector corresponding to the first eigenvalue  $\lambda_1$  of correlation coefficient matrix R shown by equation (7). In component analysis of the three variables, a second eigenvalue  $\lambda_2$  is computed as an eigenvector corresponding to the second eigenvalue of R, and a third eigenvalue  $\lambda_3$  is similarly computed. Furthermore, component analysis is performed for 3D point cloud data.

$$R = \begin{bmatrix} 1 & r_{x_1x_2} & r_{x_1x_3} \\ r_{x_2x_1} & 1 & r_{x_2x_3} \\ r_{x_3x_1} & r_{x_3x_2} & 1 \end{bmatrix} \quad (7)$$

Here,  $r$ = Coefficient of correlation

In other words, characteristic value  $\lambda$  is calculated based on the following equation (8) and equation (6).

$$\begin{bmatrix} 1 & r_{x_1x_2} & r_{x_1x_3} \\ r_{x_2x_1} & 1 & r_{x_2x_3} \\ r_{x_3x_1} & r_{x_3x_2} & 1 \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} = \lambda \cdot \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \quad (8)$$

With regards to this eigenvalue, compared to the data irregularities in the X-axis and Y-axis directions in columnar points as shown in Figure8(a), data irregularities in the Z-axis direction are large. That is, fluctuations become larger only in one axial direction. Hence, only the first eigenvalue  $\lambda_1$  is computed as a large value. On the other hand, with points on a flat plane, unlike the previous columnar points, the data irregularities in the X-axis and Y-axis directions are largely the same. However, the data irregularities in the Z-axis direction become extremely small. That is, in order for there to be a larger fluctuation width in the two axial directions, computations are done as the result of first and second eigenvalues  $\lambda_1$  and  $\lambda_2$  being the same.

Point in Pillar :  $\lambda_1 \gg \lambda_2 \approx \lambda_3$   
 Point in Plane :  $\lambda_1 \approx \lambda_2 \gg \lambda_3$   
 Other Point :  $\lambda_1 \approx \lambda_2 \approx \lambda_3$

Here,  $\lambda_1 \geq \lambda_2 \geq \lambda_3$

On the other hand, the third eigenvalue  $\lambda_3$  is computed as a small value. Furthermore, other points are in a state in which the data irregularities in each axial direction (X, Y and Z) are equal. Hence, unlike with columnar points or points on a flat plane, the fluctuation width is in a state of being equal. As a result, results are computed wherein the results between eigenvalues do not have large differences.

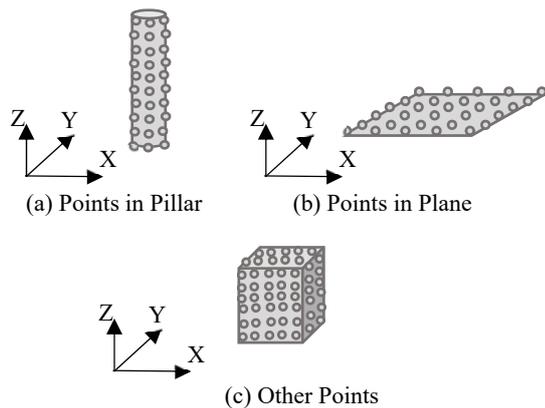


Figure8. Tendency of the characteristic value

In this study, we computed differences in eigenvalues from measurement data, including terrain and parts of the trunks of trees. If component analysis is used to remove a tree, then there is a problem of classifying focal points into columnar points, points on a flat plane or other points. It is possible to manually determine the threshold, but the rationale is called into question. Hence, in this study, we examined a technique for automatically setting a threshold. In searching for the threshold, it is necessary to set three types of thresholds:  $\lambda_1$ ,  $\lambda_2$ ,  $\lambda_3$ . However, if columnar points corresponding to a tree are classified, then the same values are set for  $\lambda_2$  and  $\lambda_3$  as the threshold. Hence, we automatically searched for real “ $\lambda_1$ ” and two types of thresholds “ $\lambda_2$  and  $\lambda_3$ .” When a component analysis is performed, the number of data points confirmed by light receiving intensity images is changed by changing the three types of thresholds  $\lambda_1$ ,  $\lambda_2$  and  $\lambda_3$ . Hence, it is possible to trace changes in the number of data points by gradually changing the threshold. This time, we searched for two types of thresholds, but it was difficult to search for thresholds simultaneously. In order to search for thresholds, we first fixed “ $\lambda_2$  and  $\lambda_3$ ,” and then searched for thresholds wherein changes in “ $\lambda_1$ ” were stable. Afterward, we fixed the searched “ $\lambda_1$ ,” and searched for thresholds wherein changes in “ $\lambda_2$  and  $\lambda_3$ ” were stable. Afterward, we repeatedly fixed “ $\lambda_2$  and  $\lambda_3$ ” and “ $\lambda_1$ ,” and repeatedly searched until there were no changes in both thresholds. Figure9 shows the results of component analysis involving automatic search techniques for thresholds. If a tree is removed by component analysis, certain sections of some tree trunks and roots are not recognized as columnar sections as a result of shape and terrain sections. Therefore, tree roots need to be removed from records of terrain information. In this investigation, we looked for points adjacent to focal points in the horizontal direction on depth maps in order to remove such sections. Afterward, we recognized points where the distance

between points was within a prescribed distance as contiguous point groups, and then decided to ascertain the shape of these contiguous point groups.

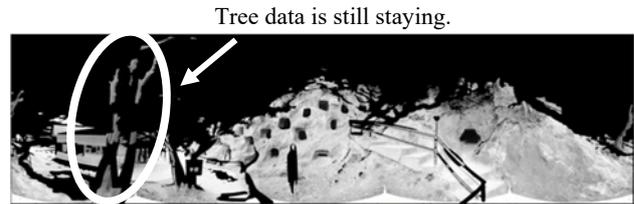


Figure9. Tree removal result by component analysis

In this study, in computing the distance between points, we focused upon radiating laser light in a radiating direction wherein laser scanner measurement was at a fixed angle. That is, we initially computed the distance from the laser scanner to focal points as shown in Figure10. Afterward, we computed the ideal distance to focal points when contiguous places are measured using the oscillation angle of laser light and equation (9). Next, we compared the distance between points adjacent to focal points computed from measurement data and the ideal distance between points. Based on the results, if it was deemed that there was no difference in distance, then the adjacent points were deemed to be mis-removed data. Furthermore, if used in a comparison of the supposed distance between two points and the actual distance between two points, places present in places having a 45-degree angle in the depth direction seen from a state in which the positional distance between two points was face to face were included. Hence, we decided to recognize points at a distance up to 1.5 times the distance between presumed ideal points to be a contiguous point group.

Condition to judge as a neighbouring point:

$$\Delta r < (\Delta r_i \times 1.5)$$

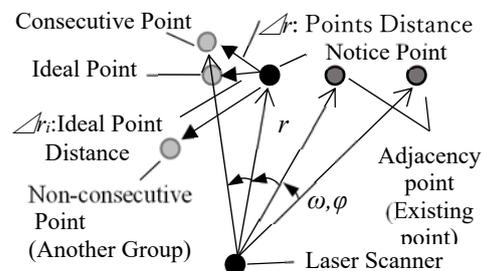


Figure10. Position relations examination conception diagram

$$\begin{aligned} \Delta r_z &= r \times \tan \phi \\ \Delta r_x &= r \times \cos \phi \times \cos \omega \\ \Delta r_y &= r \times \cos \phi \times \sin \omega \\ \Delta r &= (\Delta r_x^2 + \Delta r_y^2 + \Delta r_z^2)^{1/2} \end{aligned} \quad (9)$$

Here,

$r$  : Diagonal distance from a laser scanner to the notice point

$\omega$  : Vertical swing angle,  $\phi$ : Horizontal swing angle

$\Delta r_x, \Delta r_y, \Delta r_z$  : Distance between x, y, z axial points

$\Delta r$  : Ideal distance to notice point and neighbouring point

We computed the radius of circles for groups of points considered contiguous groups using the  $x$  and  $y$  coordinate data of each constituent point and a least squares method. Next, if a contiguous group was within a fixed radius, then this group was

a point group representing a section of a tree trunk, and we selected it for deletion. In this study, we set the radius of a tree for a section of root (threshold) at 0.2 m (diameter: 0.4 m) from actual measurements of a real tree. Point group data presumed to be a radius of the threshold or less was removed from measurement results. Figure 11 shows the results.

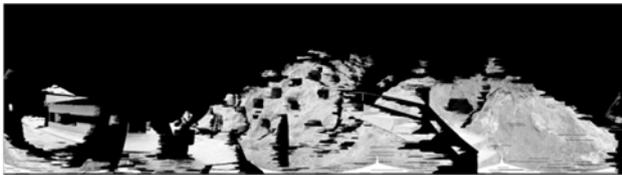


Figure 11. The new removal result that the removal process of the circle part was added

Compared to the results in Figure 7, since removal went up to the roots of trees, the effectiveness of a tree removal technique combining component analysis and a circle part removal process is confirmed. However, since some terrain is removed, it is desirable to restore the removed terrain in some form, if for the purpose of recording terrain.

#### 4. RESTORATION METHOD OF FALSE REMOVAL DATA

In the case of the method using the flatness index, the part which the corner of the building and slopes with varying depth will be removed by mistake. Because a flatness index is easy to growing. Meanwhile, when the method that combined the removal process of the chief ingredient analysis and circular part is used, by a tendency of the eigenvalue and the threshold to be set, there are part deleted by mistake. About this false removal, the interpolation data making is supposed by data interpolation method using neighbouring measurement results.

However, the measurement result exists. Therefore, the revival of original data before the false removal is desirable. In this investigation, the method to judge by the position relations of the adjacency point using the distance between points to idealize was utilized to perform the revival of the landform part removed mistakenly. Figure 10 shows the position relations of the adjacency point to idealize. In this method, a point meaning landform on range image is searched, first.

Then, in neighbouring points, a deleted point will be searched. When the distance between a point as meaning landform and a deleted point becomes less than a constant value, the deleted point revives as the point that was deleted mistakenly. And, about the threshold of the distance between the points, we decided to revive a neighbouring point in distance less than 1.5 times of the distance between the ideal point. In addition, when the position relations of the point were searched for, the upper part direction of the notice point in the image distance does not search. This is a measure not to bring back a tree growing from the surface of the earth. Figure 12 shows the revival result of false removal data using this technique with the data of figure 11.

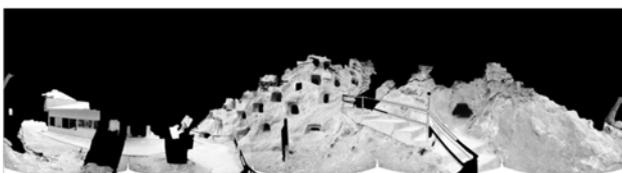


Figure 12. Revival result of false removal data

By an application of this technique, there were some exceptions, but almost all tree parts were automatically removed. As a result,

a record of the good landform information was realized, and the effectiveness of this technique was confirmed.

#### 5. CONCLUSIONS

In this investigation, authors examined methods to automatically remove data except the topography from the measurement result of the remains using the terrestrial laser scanner for the purpose of rationalization of the making for digital documentation data. Combination of the technique using the flatness-related evaluation and the technique using edge characteristic, and the method using the chief ingredient analysis were considered to perform the automatic removal of the tree.

The automatic removal of the tree was performed by combining the technique using the chief ingredient analysis and circular recognition technique using the least-squares method. Moreover, we confirmed that a record of the large amount topography information was enabled by restoring topography data using the distance between the ideal point.

Utilization to the digital documentation of cultural assets is expected by the topography measurement result using the terrestrial laser above the ground by performing the automatic removal of the tree. Moreover, the application to many aspects is expected, too. We will think that improvement of the removal accuracy and improvement of the efficiency, the establishment of the interpolation method of the topography of the high accuracy after the removal of the tree are necessary in future.

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