GROUND SURFACE ESTIMATION IN DENSE FOREST

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ABSTRACT:

Usually, filtering is performed in order to extract a ground surface from laser points obtained with the airborne laser scanner. It mainly removes the laser points that were measured as trees surface. However, in the dense forest where trees are grown thick, we can see the part of the laser points has not reached to the ground surface. If it conducted the filtering that sorts out the laser points in such area, the ground surface is obtained as the laser points of only coarse interval theoretically. For this reason, a correct ground surface cannot be acquired with the ordinary filtering method in dense forest. In order to solve this problem, it analyzes paying attention to the tree height map obtained by laser measurement. In the dense forest where laser beams do not penetrate partically, trees height value becomes low rapidly and it appears as a gaping hole of local tree height map. Compensation processing which interpolate this gaping hole was performed and the tree height map was estimated. This report presents the ground surface estimation method by using the interpolated tree height map obtained by using the laser scanner in dense forest.

1. INTRODUCTION

In recent years, the request to the preservation of forest environment and the GIS base data maintenance in the erosion control are becoming large in forest. For this reason, the measurement technology of the correct ground surface shape in mountain area is becoming indispensable. However, measuring a vast mountain area in uniform quality requires a great labour. In order to solve this subject, the mapping that used the aerial photograph has been performed. Such mapping work in Japan has been performed based on the procedure indicated by "Working Regulation of Public Survey", and the data quality is secured. However, since person interpreted the ground surface by using the stereo model, it was difficult to measure correct ground surface where trees were very dense, and operator cannot see the ground enough from stereo model.

On the other hand, the Airborne Laser Scanner (following, ALS) is able to measure directly the ground surface shape that includes bare ground, trees and noises. Some filtering methods that extract the ground surface from measured data are proposed. Although this method can be regarded high objective measurement technique compared with the stereo mapping method with the aerial photograph, this method does not function enough, when there are extremely few laser points that have reached to the ground surface in the dense forest. Even in such a case, the adaptable technique that estimates the ground surface elevation from the upper surface of forest is proposed. This method estimates the tree height depending on the correlation between the horizontal distance from river line (gorge line) and real tree height. However, since this method requires the ground survey work, it lacks in flexibility.

In this research, the ground surface estimation is proposed utilizing a few points that are obtained as the ground surface from the ALS data in the dense forest. The verification experiment of proposed technique was conducted using three difference data sets where the characters of acquired laser points differ. Comparison and accuracy verification are performed, and their results are reported on this paper.

2. PRINCIPLE OF PROPOSED METHOD

2.1 Principle of Filtering Method

In this section, in order to clarify the difference from the proposed technique, the principle of filtering as former method is described briefly. The principle of filtering is shown in Figure 1. Here, Digital Elevation Models (DEM) was created in the following procedures.

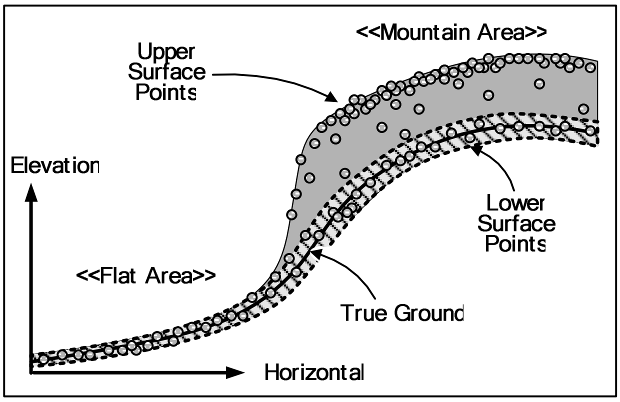

Figure 1. Principle of Filtering Method

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2.1.1 Lower Surface Extraction Filtering: The laser points include trees and noises as well as ground data. In the mountain area, it mainly consists of two layers, upper layer and lower layer. Lower surface extraction filtering sorts out lower layer points (hatching part in Figure 1) from the measured laser points that are distributing spatially. Here, the lower surface was approximated with the polynomial curved surface. And the ground surface points below a threshold value are extracted that depend on the height from the approximated curve surface.

2.1.2 Noise Removal Processing: In general, the result of lower surface extraction filtering contains some of noise points. Then, contour lines are utilized to detect where noise points still exists. When a contour line is generated, in the part where geographical feature is steep, the interval of contour lines will become dense. As this extreme example, there are circular contour lines of dense interval and short length around spike noise locally. Here, the laser points inside such dense contour lines are removed as a spike noise. Moreover, manual work (visual interpretation) removes the noise that cannot remove with this processing described above.

2.1.3 Grid Processing: Since the extracted ground surface points are random points, it is generally hard to handle. For this reason, the grid processing was performed and random points were changed into the DEM. The grid processing was performed with the linear interpolation by using the triangular irregular network (TIN) as the most ordinary method.

2.2 Problem of Filtering in Dense Forest

Next, the problem of filtering in the dense forest is shown. In order to explain the characteristic of the laser data in the dense forest, the conceptual cross section showing the spatial distribution of measured laser points is shown in Figure 2.

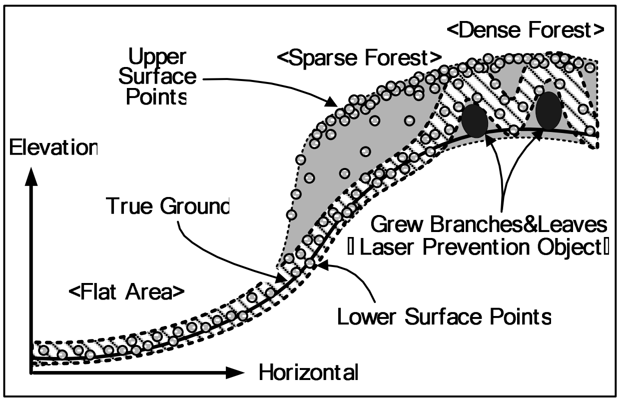


Figure 2. Characteristic of Laser Data in Dense Forest

The flat-plane part, the sparse forest and the dense forest are expressed from the left to right. The upper surface equivalent to the top of trees is stabilized and can be acquired in any area. However, about the ground surface, the character of measurement data differs according to the luxuriant growth situation of trees. In the sparse forest, since laser beams have fully penetrated to the ground surface, the lower surface of laser points are according with the true ground surface. However, in the dense forest, since the laser beams are interrupted by leafs and branches which grew thick and it has not reach to the ground, the lower surface extracted from the laser points catches near the upper surface of trees. And this result is usually higher than the true ground surface. Otherwise, the filtering removes the laser points that are catching the prevention object. In this case, the laser points of ground surface are extracted as coarse interval. Anyhow, when the filtering is used in the dense forest, the good results of ground surface shape can not be expected.

2.3 Principle of Proposed Ground Surface Estimation

In this research, the analysis technique for solving the difficulties of filtering mentioned above is proposed. The technique proposed here is henceforth called "Ground Surface Estimation", and the flow of the whole proposed method is shown in Figure 3. Moreover, the principle of individual processing is shown below.

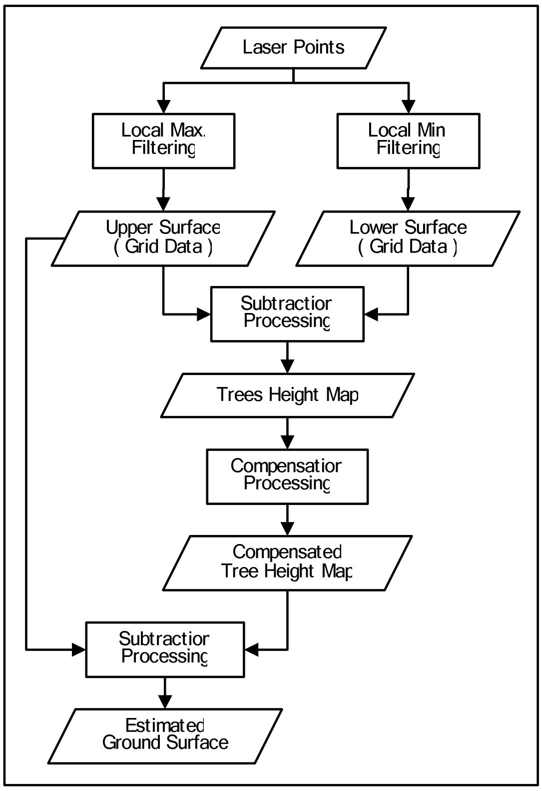


Figure 3. Flow of Proposed Method

2.3.1 Extraction of Upper and Lower Surface: In this section, the filtering for extracting an upper and lower surface from the measured laser points is performed, and the filtering extracts the local maximum and local minimum elevation. The "local" means the minimum unit that constitutes surface shape and it is defined as the horizontal square lattice (unit mesh) for facilities of analysis processing. Here, local maximum and minimum elevation filtering are performed for the maximum and minimum elevation in a unit mesh as a representation value of the mesh. Then, the grid data of an upper surface and a lower surface is obtained from this result.

2.3.2 Extraction of Tree Height Map: In this section, in order to obtain the tree height map, subtraction is calculated between the grid data of an upper surface and a lower surface. Here, the concept of the extraction method of a tree height map is shown in Figure 4. Although a locally correct tree height map is obtained in the sparse forest, the "gaping hole" resulting from laser beams having not reached to the ground surface is seen in the dense forest.

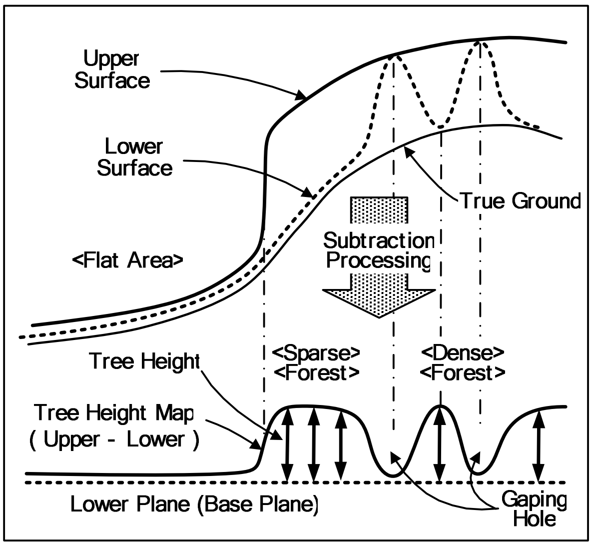


Figure 4. Extraction of Tree Height Map

2.3.3 Compensation of Tree Height Map: Here, compensation processing is carried out so that the "gaping hole" obtained with the tree height map may be filled. At this time, the data depicts tree surface shape should not be affected as much as possible. Since the smoothing method of a moving average and the median filter that are the general image-processing technique has a possibility of affecting the whole tree height map, it cannot be regarded suitable processing. Then, compensation processing of a tree height map by using the contour line is performed in this method. The concept of this compensation processing is shown in Figure 5.

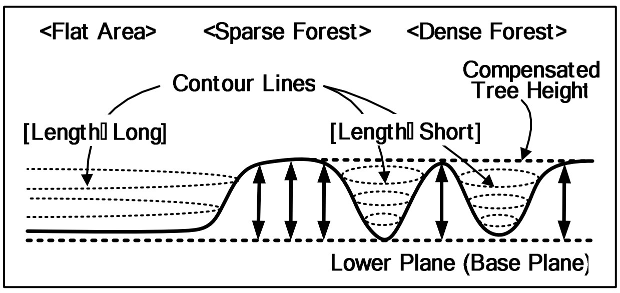


Figure 5. Compensation of Tree Height Map

Short contour lines are extracted from the all contour lines that are created from the tree height map. The "area" and "depth" of a gaping hole are computed from the extracted contour line. When these values are less than a threshold, the grid points of tree height that exists inside the short contour line is deleted, and the linear interpolation is performed by using TIN method. This method can compensate only the part of gaping hole in the tree height map.

2.3.4 Estimation of Ground Surface: The tree height map after compensation is used for estimation of the ground surface. Subtraction is carried out between the upper surface and the compensated tree height map in the grid, and the ground surface is estimated. The concept of ground surface estimation is shown in Figure 6.

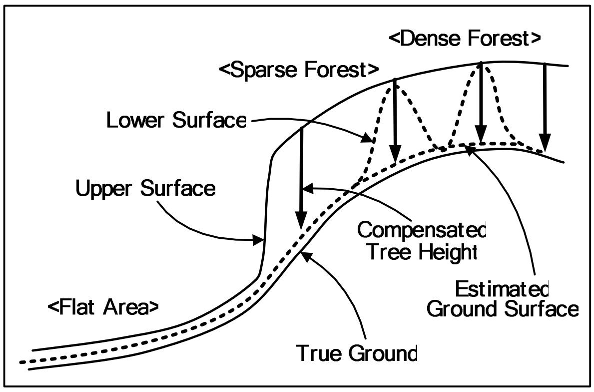


Figure 6. Estimation of Ground Surface

The deficit part is filled in the tree height map after compensation. For this reason, by subtracting the tree height map after compensation from the upper surface data, the estimated ground surface near true ground can be acquired without depending on the height of a lower surface data.

3. VERIFICATION EXPERIMENT

3.1 Target Area

The situations of vegetation growth differ depending on weather conditions, soil types, type of trees, seasons and so on in each area. The ground surface was measured by using the ALS. The verification experiment was conducted in three areas (Hokkaido, Shimane and Wakayama) that have different characteristic of laser data. The position of selected target area is shown in Figure 7.

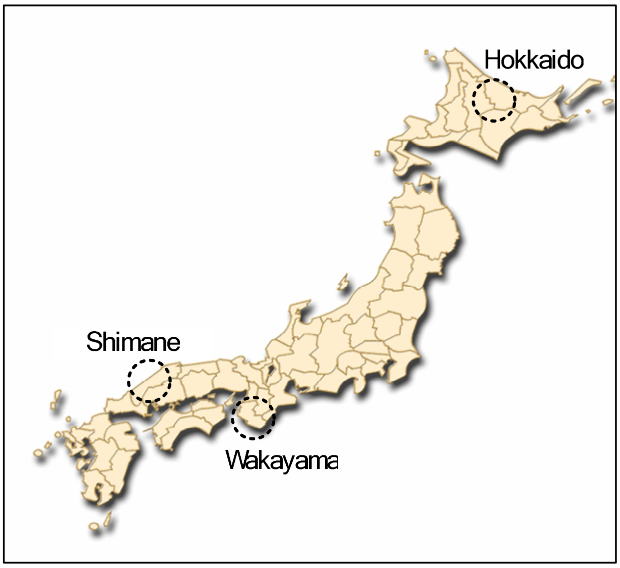


Figure 7. Position of Target Area

3.2 Measurement Instruments

In this verification experiment, measurement was conducted by using the ALS for a mountain area. The specification of the instruments (Laser Scanner) used in experiment is shown in Table 1.

Measurement Instruments	Laser Scanner
Laser Type	Near Infrared (Length□0.7-1.3um)
Laser Specification	Class4 Laser Product
Positioning Error	Horizontal:30cm / Vertical:15cm

Table 1. Specification of Measurement Instruments

Here, the measurement conditions when the laser data were acquired are shown in Table 2. These measurement data was obtained as the library collection data sets. The notable point is the measurement season that influences the measurement data according to a situation of vegetation growth along with the characteristic of area.

Target Area	Hokkaido	Shimane	Wakayama
Measurement Period	2002.10	2002.12	2003.8
Measurement Times	2	2	3
Pulse Frequency[kHz]	24.0	15.0	24.0
Flight Altitude[m]	1800	1200	1800
Flight Speed[km/h]	200	200	200
Scanning Angle[deg]	18.0	10.0	17.0
Scanning Freq. [Hz]	27.0	23.0	28.0

Table 2. Measurement Conditions

3.3 Character of Target Area from Measurement Data

The character of each target area from laser points obtained by ALS is described in this section. The example of the cross section of each area is shown in Figure 8.

In the Hokkaido area, it can be seen from each cross section that the sufficient quantity of laser point at the lower layer exists in spite of measurement in autumn (October). On the other hand, although the Shimane area was measured in winter (December), the rate of the laser points in the lower layer seems to be few compared with the Hokkaido area. Moreover, since the Wakayama area was measured in summer (August), a laser point hardly exists in the lower layer in several areas. Here, the specification of measurement data is shown in Table 3.

First, "Processing Area" was computed as an area of extent that conducted the processing. Next, "Laser Points Density" was computed as number of points per unit area ($1m^2$). And "Filtering Rate" was computed as proportion (%) of the after filtering points numbers to the original laser points numbers.

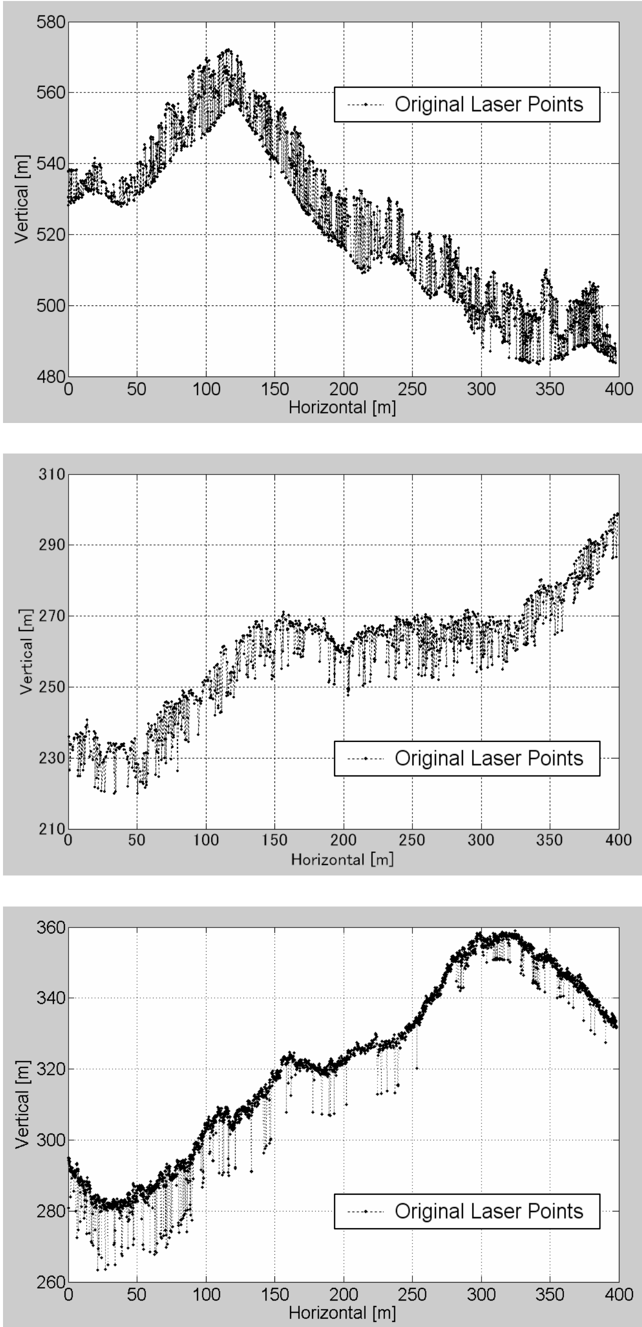


Figure 8. Cross Section of Measurement Data
(Upper: Hokkaido / Middle: Shimane / Lower: Wakayama)

Target Area	Hokkaido (Sparse)	Shimane (Medium)	Wakayama (Dense)
Processing Area [km^2]	2.69	4.74	16.13
Points Density [$1/m^2$]	2.35	1.02	3.11
Filtering Rate [%]	46.2	13.7	5.4

Table 3. Specifications of Measurement Data

Henceforth, each area is defined as "Sparse Forest (Hokkaido)", "Medium Forest (Shimane)" and "Dense Forest (Wakayama)", and it is considered paying attention to the difference in the character of measurement data. Points Density was the highest in Wakayama (dense forest). And the Filtering Rate of Hokkaido is nearly 50 percent, and it corresponds with the tendency shown in Figure 8. In Shimane (medium forest) and Wakayama (dense forest), as the Filtering Rate is small compared with Hokkaido (sparse forest), it turns out that laser points has not reached to the ground. These phenomena are generated by the difference in the vegetation growth situation of each area.

3.4 Analysis Conditions

3.4.1 Parameter of Filtering: Analysis processing was performed based on the "Principle of Filtering" mentioned earlier. The parameter used on the analysis is shown in Table 4.

No	Parameters	1st	2nd	3rd
1	Block Size [m]	50x50	25x25	15x15
2	Height Threshold [m]	5	3	1
3	Contour Line Step [m]	1		
4	Contour Line Length Threshold [m]	5		
5	Output Grid Size [m]	2		

Table 4. Parameters of Filtering

No=1,2 in Table 4 are the parameters of "Lower Surface Extraction Filtering", and No=3,4 are the parameters of "Noise Removal Processing" and No=5 is the parameter of "Grid Processing". In the Lower Surface Extraction Filtering, the processing was performed three times, changing a parameter using different "block size". Here, in order to raise the accuracy of curved surface estimation, points on large tree features were removed first with large tile size and the large threshold value. And block size was gradually made smaller and local ground points were extracted. In the Noise Removal Processing using the contour lines, the interval of contour lines were set to 1m, and only laser points which fall inside a contour line with length of less than 5m were removed. Next, TIN was generated from random points of the ground surface obtained finally, and 2m grid data was created in the Grid Processing.

3.4.2 Parameter of Ground Surface Estimation: The ground surface estimation was carried out based on the "Principle of Proposed Method" mentioned earlier. The parameter used on the analysis is shown in Table 5.

No	Parameters	Value
1	Grid Size of Tree Height Map[m]	5
2	Threshold of Gaping Hole Area [m^2]	2500
3	Threshold of Gaping Hole Depth [m]	3
4	Output Grid Size [m]	2

Table 5. Parameters of Ground Surface Estimation

In order to obtain the stable tree height map, it is important to acquire the upper and lower surface in smooth shape. For this reason, "Grid Size" influences a tree height map greatly. In the case of 10m grid, a ridge and a gorge line have become too smooth. Moreover, in the case of 2m grid, surface shape became complicated, and the stable result was not obtained. So 5m grid was adopted that stabilized result comparatively without losing topographical feature. Next, about deficit compensation of a tree height map, 2,500m^2 was adopted as the threshold value of "gaping hole in area" so that it could respond to the gaping hole of the size approximately 50m square. Moreover, in order to keep a loose tree height map, the threshold value of "gaping hole in depth" was set to 3m. "Output Grid Size" was set to 2m which could catch the feature of an upper surface shape enough.

4. ANALYSIS RESULT AND ITS CONSIDERATION

4.1 Comparison of Geographical Feature in Sparse Forest

Based on the proposed technique mentioned earlier, the estimation processing of ground surface was performed to the measured data of Hokkaido (sparse forest). Here, comparison of the ground surface estimation result and the filtering result was performed. First of all, a contour line shape having created from the both results are shown in Figure 9.

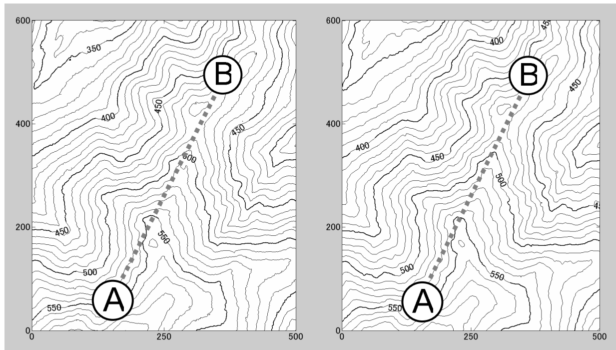


Figure 9. Contour Line Comparison in Hokkaido(Sparse Forest)

The significant difference was not recognized concerning the contour line shape when the filtering result was compared with the ground surface estimation result. Next, the cross section of measured laser points, the filtering result and the ground surface estimation result in the line segment AB shown in Figure 9 is shown in Figure 10 (Horizontal Position of A=0m / B=400m).

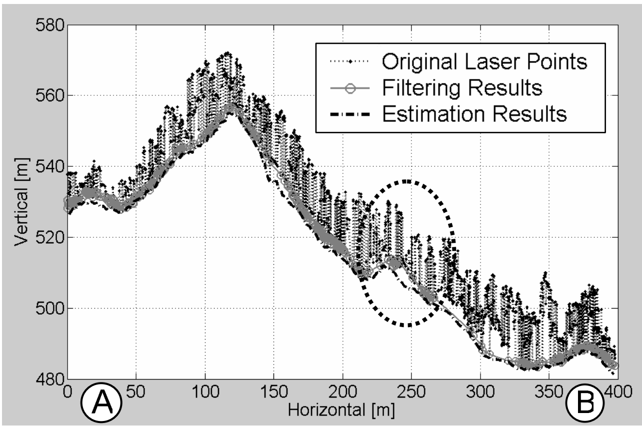


Figure 10. Cross Section in Hokkaido (Sparse Forest)

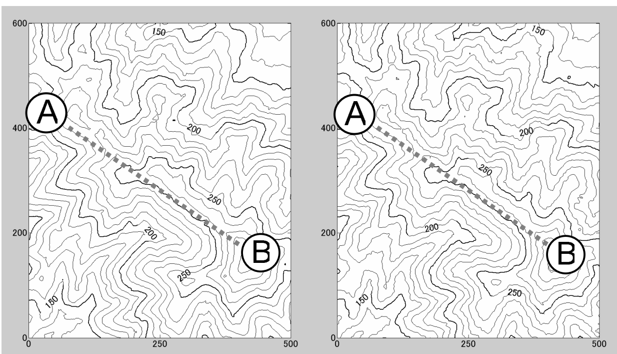
In comparison of a cross section line, although the result of ground surface estimation did not have the large difference compared with the result of filtering, the results of ground surface estimation became a little lower. This is a place where assumption was not suitable that the tree height map is locally fixed. The upper surface shape has fallen rapidly in the part enclosed with the circle of a dotted line. The rapid falling of upper surface is appeared as the gaping hole in tree height map. The gaping hole here is filled with compensation processing as same as the case that the ground surface points does not exist. And the ground surface estimation is performed that subtract the compensated tree height map from the upper surface shape. As a result, the ground surface estimation result is considered to have become a little lower.

In this area, since laser points have fully reached to the ground surface as mentioned earlier, it can be said that the reliability of the ground surface extracted by filtering is high. As the average of differential value of filtering result and ground surface estimation result was -1.72m, and the standard deviation was 0.941m. It could be said that there was no large variation, and the result was obtained that the ground surface estimation was a little lower. Measurement data has few points on upper surface, and extracted surface points vary widely, since it is considered as the cause that the smoothed upper surface became low on the whole.

Accordingly, it is thought that the ground surface estimation computed by the subtraction processing basis on an upper surface became low on the whole. For this reason, in such a non-dense forest area, it is considered that the filtering is suitable than the ground surface estimation.

4.2 Comparison of Graphical Feature in Medium Forest

In this section, a contour line and a cross section line are created in Shimane (medium forest), and the ground surface estimation result is compared with the filtering result. First, the comparison result using the contour line is shown in Figure 11.



Filtering Result Estimation Result

Figure 11. Contour Line Comparison in Shimane (Medium Forest)

Although there was a detailed difference locally, the significant difference was not recognized on the whole in the result of a contour line. The result that created the cross section to the line segment AB shown in Figure 11 is shown in Figure 12 (Horizontal Position of A=0m / B=400m).

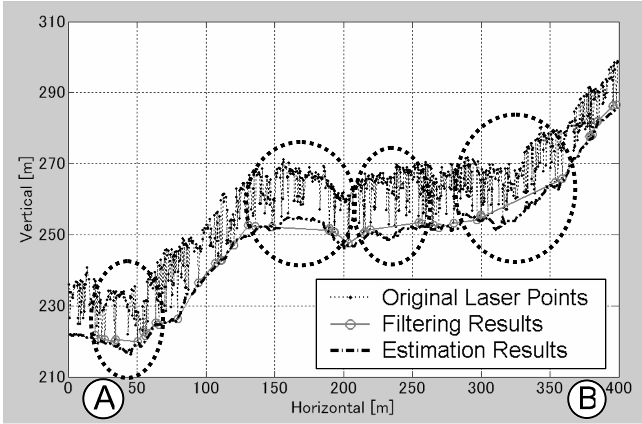


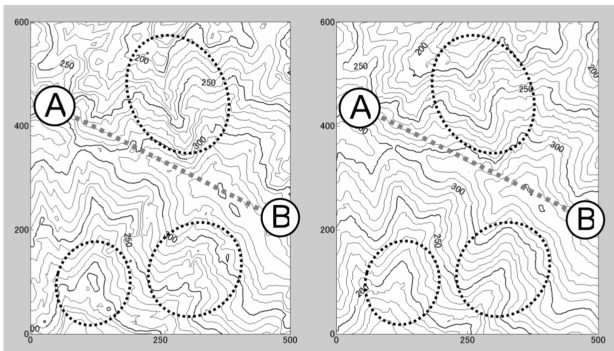
Figure 12. Cross Section in Shimane (Medium Forest)

In comparison of a cross section line, although the result of ground surface estimation was not difference greatly compared with the result of filtering, some deficit parts were able to be seen in the result of filtering. This originates in having had little laser points penetrated to the ground surface like the part enclosed with the circle of a dotted line. Even in such a case, the good result was obtained through the ground surface estimation based on assumption that the tree height map were fixed locally.

In this area, the average of differential value of a filtering result and the ground surface estimation result was -0.65m, and the standard deviation was 1.472m, and there was no significant difference compared with other areas. However it seems that the ground surface estimation is a little excellent in geographical feature reproducibility.

4.3 Comparison of Graphical Feature in Dense Forest

Here, a contour line and a cross section line are created in Wakayama (dense forest), and the ground surface estimation result is compared with the filtering result. First, the comparison result using the contour line is shown in Figure 13.



Filtering Result Estimation Result

Figure 13. Contour Line Comparison in Wakayama (Dense Forest)

As a whole tendency, although it was in agreement in general, some mismatching was seen like the area locally shown with the circle in a figure. The result that created the cross section to the line segment AB shown in Figure 13 is shown in Figure 14 (Horizontal Position of A=0m / B=400m).

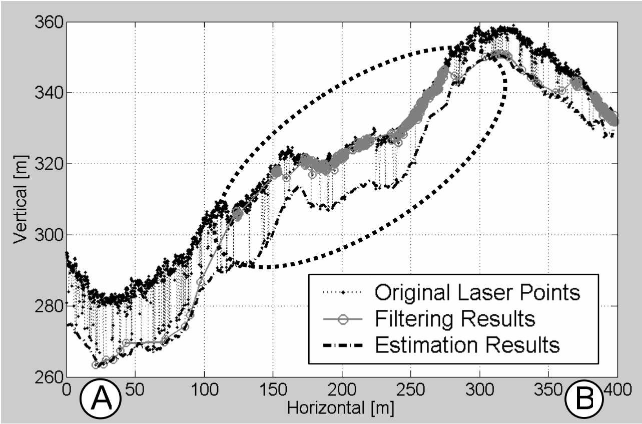


Figure 14. Cross Section in Wakayama (Dense Forest)

Here, the significant difference to the filtering result and the ground surface estimation result was seen. Although the target area was covered by dense trees, the point near a surface mostly remains without removing in the filtering results. It is mentioned as the reason that the approximation curved surface by the polynomial has suited the upper surface, since there were extremely few laser points that reached to the ground surface.

In this area, the average of differential value of the filtering result and the ground surface estimation result was -4.81m, and the difference appeared greatly compared with other two areas. When this carried out the cross section line check by several places, many phenomena of errors by the filtering were seen (shown in Figure 14).

In such a place, the filtering result had become approximately 10 to 20m higher compared with the ground surface estimation. Since this result was analyzed statistically, it is thought to appear as such a significant difference. Even in such case, the result of ground surface estimation was able to use a small number of laser points penetrated to ground surface as the circle of the dotted line in Figure 14, and it was able to presume the ground surface side effectively.

4.4 Accuracy Verification using Survey Data

In this section, the accuracy verification of ground surface estimation result was performed using the survey data acquired there. Since it was only Shimane (medium forest), that survey data was obtained for accuracy verification in this area. Here, the 1st order control points in four were generated from the electronic control point, and height was attached by levelling from a 1st grade bench mark, respectively. The survey data of 384 points were created by the traverse survey from those 1st grade control points. The result that carried out accuracy verification using the survey data is shown in Table 6.

Verification Items	Filtering	Estimation
Subtraction Ave.[m]	-0.05	-0.41
Standard Deviation[m]	2.28	1.61
RMSE [m]	2.28	1.66

Table 6. Accuracy Verification Result in Shimane (Medium Forest)

The ground surface estimation brought a good result than the filtering. As a reason that filtering brought larger RMSE value, as shown in the cross section (Figure 12), it is thought that it originates in a partial deficit part. Moreover, the result of ground surface estimation was a little lower at comparison with the survey data on the whole. As this reason, it is considered as the cause of the influence of gradient that the tree height map became a little higher. It can be improved by adjustment of the tree height map using a local gradient. However, it can be said that it was obtained the good results on the whole.

5. CONCLUSION

In this research, "Ground Surface Estimation" was shown as new algorithm for presuming ground surface elevation from the laser measurement data in the dense forest. And an analysis processing using the actual laser data was carried out along with "filtering" which has mainly used. The qualitative comparison using the contour line and the cross section, and the quantitative verification using the ground survey data were carried out to these analysis results. In the qualitative comparison, the result of ground surface estimation found signs that natural geographical feature shape in spite of the part from which the filtering result has obtained the error clearly. Moreover, in the quantitative verification, RMSE was smaller than the filtering result and the good result was obtained.

In the future work, the cause of a place where estimation went wrong needs to be investigated to raise the stability of processing. And carry out examination that performed collation with much more verification data in order to utilize this method. Moreover, the technology of compounding selectively for each place will be also needed, harnessing the mutual merits of a filtering result and a ground surface estimation result.

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