An improved method of individual tree detection using airborne LiDAR

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Abstract

The aim of this research is to improve a method to identify individual trees using airborne LiDAR. In our research, "Crown Shape Index" was invented to detect individual tree tops. The index is calculated based on unevenness of grid digital height model (DHM). And the authors devised a new method that extracts crown area surrounding tree top by referring to statistics theory. The authors applied the index and method to a Japanese cedar forest. Crown Shape Index applied to low density forests resulted in 80 to 90% detection accuracy. With the increase in tree density, the accuracy dropped by 10 to 20%. Further, in order to understand the accuracy of Crown Shape Index, the identification result was compared with that of aerial photo interpretation by human eyes. As the result of this comparison, it was found that the Crown Shape Index method could detect 80 – 100% of the detection numbers by aerial photos. From this result, individual tree identification by Crown Shape Index is considered to have the same level of accuracy with manual aerial photos interpretation method.

Keywords: individual trees detection, LiDAR, Crown Shape Index

1. Preface

Forests fix CO_2 and contribute to restrain the global warming. Forests can maintain water resources and conserve soil and also provide space and environment for outdoor recreation. Recently, these functions of forests are highly evaluated.

In order to preserve precious forests, they should be managed properly and for that purpose, it is required to know exact conditions of forests.

One of the most basic information on forest is the number of trees growing in forests. Traditionally, on-the-spot investigations have been the most popular method for countering number of trees. However, with the development of LiDAR technologies, application of LiDAR data for forest survey has been studied and now the technology has great potential in individual stand detection.

Most researches on individual stand identification by LiDAR data have used DHM (Digital Height Model), which is the difference between DSM and DEM, as a criterion for the detection and watershed algorism or local maximum filter as a method. [1,2,3,4] Also, there was a research to identify individual stands based on crown shape model using raw laser pulse data.[5]

Shape of crown, however, is very complex and particularly in dense forests DHM cannot give clear height difference between tree tops and edge of crowns. Thus, reliable detection of individual tree is difficult in dense forests.

In our research, we have invented a new index by processing DHM data of crown area to improve the individual trees detection result.

2. Study Area and Data Used

Study area is an artificial forest of Cryptomeria japonica (Japanese cedar) in Kosugi Village, Yamanashi Prefecture in central Japan. In the study area, square shaped plots whose size is almost equal to average tree height (20m) in the area were established and number of stands, DBH, tree height, slope angle, slope direction and coordinates of corner points of the plots were surveyed. GPS receiver was used to acquire the coordinates. Characteristics of the four plots are given on Table 1.

Table1: The forest state of investigation site

Plot_No	average tree height (m)	average DBH (cm)	stand tree density (trees/ha)
P1	20.8	27.0	860
P2	21.2	28.2	1176
P3	20.3	23.3	1964
P4	18.7	21.1	2435

LiDAR data used in the research was acquired on December 1, 2006. Specifications for the data acquisition are summarized as Table 2.

Table2: Specifications for data acquisition

sensor	leica ALS50-Ⅱ
laser pulse rate	100KHz
scan rate	62Hz
scan angle	±9°
average point density	4pts/m^2
Flying Height AGL	1890m
position accuracy	X,Y < 0.20m
elevation accuracy	Z < 0.11m
Laser classification	Class 4

From this dataset, two sets of data were made. First, abnormal data were removed. Then, the data were filtered. From the two sets of data TIN was made and 0.5 meter grid data, DSM (Digital Surface Model) and DEM (Digital Elevation Model) were generated. Further, DEM was subtracted from DSM to make DHM（Digital Height Model）.

3. Individual Tree Identification Method

3.1 Development of Crown Shape Index

In DHM height difference between tree tops and edges of crown is not large. Therefore, it is difficult to identify individual trees with DHM. To deal with this problem, the authors have developed an index named Ridge/Valley Index. [6] Its principle is as follows.

1) Prepare 0.5 meter grid DHM of canopy surface.
2) At First, "upper open degree" phi1 is calculated. This is an angle between a vertical line and a line which starts from each grid point of DHM and tangent to the crown surface, which is represented by DHM, within each search area.
3) Similarly, "lower open degree" phi2 is calculated.
4) Angle phi3 is calculated by the following formula:

Phi3 = (phi1 – phi2)/2

5) Total 8 phis are calculated for 8 directions for each DHM grid point and their average is computed. This average is named as the Crown Shape Index.

Ridge/Valley Index expresses the condition of canopy at each grid point. The authors could emphasize the shape of canopy surface by using this index.

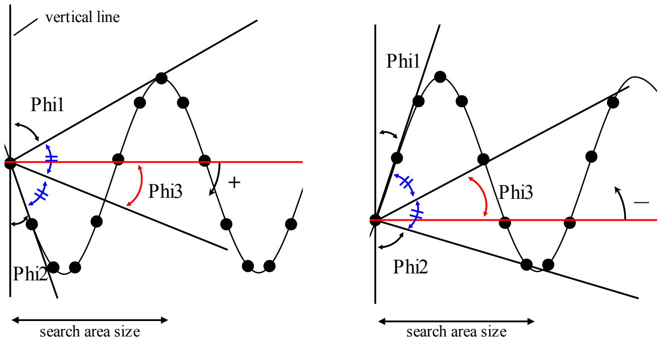

Figure1: Concept of Ridge/Valley Index（Cross section）

Difference in Ridge/Valley Index value of tree top and that of crown edge is larger than the difference given by DHM and also the index is almost the same for any tree top regardless of tree height. Since the index can represent outline of crown shape the authors assumed that it could be used for individual stand identification by using a uniform threshold value.

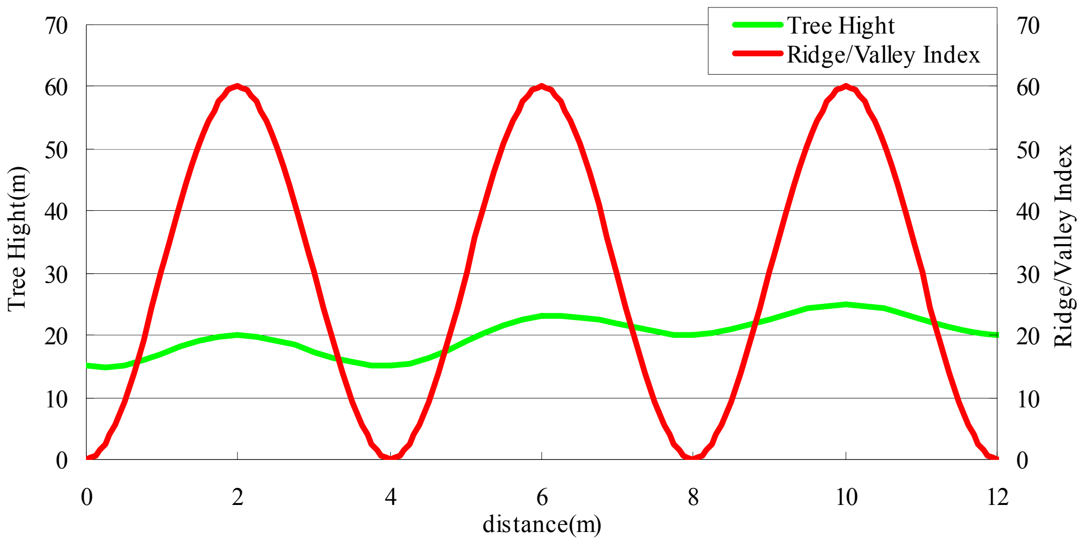

Figure2: Relation between Ridge/Valley Index and cross section of crown surface

It was found, however, that approximately only 70% of trees were identified by the index in low density forests (1000 stands/ha). This means there was much miss identification. Analysis of the results revealed that there were three issues which need to be dealt with.

1) Clarification of the shape of small crowns where height difference between tree tops and crown edge is small.（Although Ridge/Valley index can represent relatively flat crown area

better than DHM, small crowns were not represented well.)
2) Prevention of the index value becomes extremely large at crown edges.
3) Clarification of positions of tree tops

In order to solve these problems and to improve the accuracy of individual stand identification, the authors improved the Ridge/Valley Index.

Ridge/Valley Index can represent approximate shape of tree crowns by degrees. This index cannot work well in forests where crown surface is relatively flat.

To solve this problem a tree crown model was made based on the shape of ridge and valley formed by Upper Open Degree (phi1) and Lower Open Degree (phi2), and this model was defined as the Crown Shape Index. The principle of the Crown Shape Index is shown in Figure 3.

In Figure 3, relatively flat line represents the crown surface. Upper Open Degree and Lower Open Degree were switched to emphasize the undulation of crown surface. The lower undulated line is the result of this switching process.

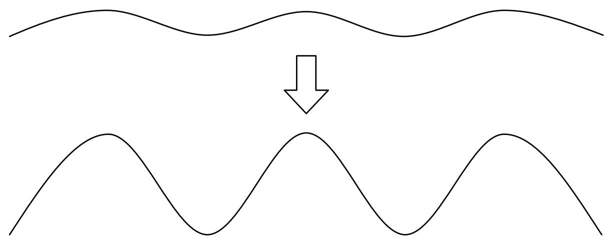

Figure3: Principle of Crown Shape Index

The Crown Shape Index is calculated as follows:

1) Upper and lower open degrees are replaced with pre-fixed values according to the following 5 criteria.

1. 150≦phi1 ⇒ phi1=150、
   phi2≦30 ⇒ phi2=30
   (To prevent extreme values at crown edges)
2. 90≦phi1＜150 ⇒ phi1=150、
   30＜phi2≦90 ⇒ phi2=30
   (To emphasize convex part of crown shape)
3. 30≦phi1＜90 ⇒ phi1=30、
   90＜phi2≦150 ⇒ phi2=150
   (To emphasize convex part of crown shape)
4. phi1＜30 ⇒ phi1=phi1、
   150<phi2 ⇒ phi2=phi2
5. If DHM values of the surrounding 8 directions are higher than the DHM value of a grid point then 179.9 is assigned to phi1 while 0.1 is assigned to phi2.
   (To emphasize the position of crown tops)

2) By using the Upper and Lower open degree value assigned according to the above 5 criteria, phi3 is calculated by the same method with Ridge/Valley Index.

3) Average of phi3 for 8 directions is computed. And this average is Crown Shape Index for that particular grid point.

Larger Crown Shape Index value represents convex area while smaller index represent concave areas.

3.2 Development of a method of individual stand identification

In individual stand identification using Ridge/Valley index, a uniform threshold value was used to extract crown area of each tree. However, since a uniform threshold value was used, if the index value is lower than the threshold value, the area cannot be identified as crown area even if the area is actually crown area.

To solve this problem, the authors tried to set a threshold value for each crown individually. For this purpose it is necessary to establish individual crown area for each tree. Individual crown area should be clearly separated from adjacent crown areas. If more than two crown areas are connected, they are regarded as belonging to one single tree and this result in smaller number of individual stand identified.

Therefore, the size of individual crown area for individual stand identification should be approximately half of the size of actual crown.
Relation with crown area and the smaller crown area surrounding tree top are shown in Figure 4.

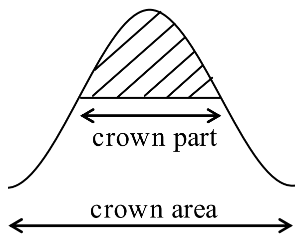

Figure 4: Crown area and area near tree top

Table 3 shows the ratio of crown part near tree top to the size of crown area for four cases of different pixel sizes. Average percentage of the crown top area against crown area is approximately 16% on Table 3.

Table3: Ratio of crown part

unit:pixel

crown part	1×1	2×2	3×3	4×4
	1	4	9	16
crown area	3×3	5×5	7×7	9×9
	9	25	49	81
crown part ratio	11.1%	16.0%	18.4%	19.8%
average	16.3%			

The authors pondered if optional 9 pixels (3×3) are chosen, the 9 pixels will be regarded as normal distribution, because Crown Shape Index is regarded as normal distribution (in figure 5 left histogram). And we extracted the crown part by referring to statistics theory. When value is normal distribution, in statistics theory a range of +-1 σ of the mean occupies 68% of total (figure 5). We exploited the theory and detected crown parts.

In order to detection the crown top area (crown part), we decide the threshold every local domain (crown area size). The threshold is the value that added standard deviation (σ) to the mean (μ) of Crown Shape Index of a domain. Centre value of the domain was compared with the threshold, and if centre value is bigger than the threshold, centre pixels form crown area surrounding tree top.

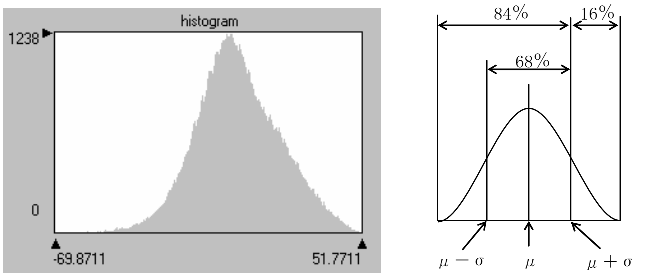

Figure 5: Histogram of Crown Shape Index and principle of determining threshold value

3.3 Flow of individual stand identification

Flow of individual stand identification where 0.5 meter grid DSM and DEM are used to compute Crown Shape Index is shown in Figure 6.

The points with the possibility to select the tree top are extracted by using a local maximum filter. A local maximum filter was applied to Crown Shape Index. In this case, the filtered domain was fixed to 3 pixels by 3 pixels. The filter replaces the value of the center point with the maximum value in the domain.

Crown Shape Index values before and after the process are compared. If the two values are equal, that point is identified as a possible tree top.

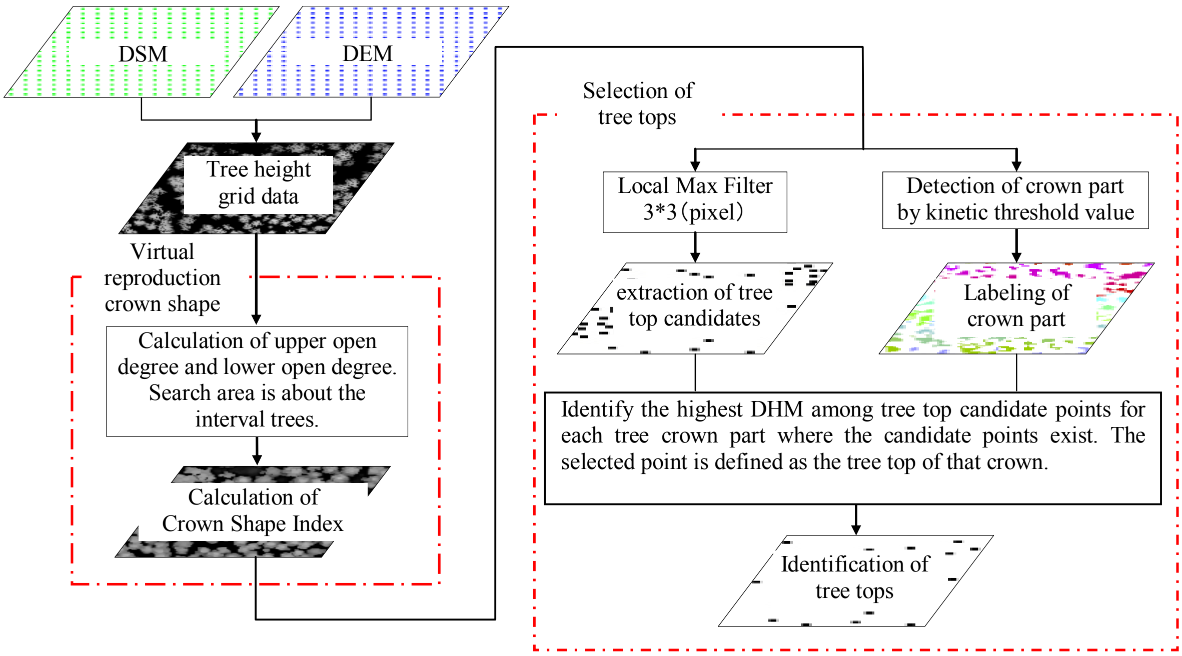

Figure 6: Flow of individual stand identifications using Crown Shape Index

4. Result

The result of the process described in Figure 6 is shown in Figure 7.

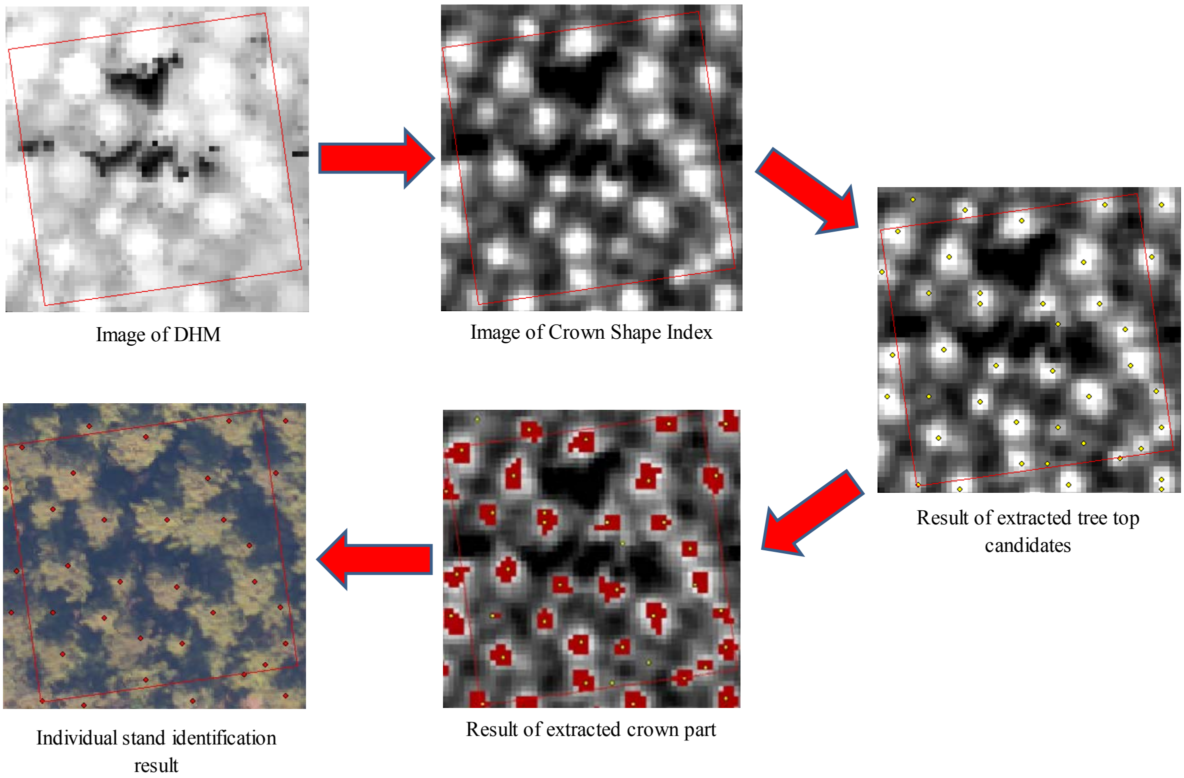

Figure 7: Individual stand identification result

Verification of the identification result was carried out by comparing with the result of field tree counting and tree counting by stereo view of aerial photos.

In order to increase the number of verification sites, more than one plot is established in P1, P2 and P4 stand and number of trees was counted in such plots. Verification result is summarized on Table 4.

Table 4: The rate of individual tree detection

		P1-1	P1-2	P2-1	P2-2	P-3	P4-1	P4-2
Stand tree density (tree/ha)		860		1176		1964	2435	
The number of actual trees		30	28	67	76	64	69	63
Aerial Photos	The number of detected tree tops	28	27	55	70	53	47	54
	The accuracy of detected trees	93%	96%	82%	92%	83%	68%	86%
LiDAR data	The number of detected tree tops	24	25	58	68	45	48	45
	The accuracy of detected trees	80%	89%	87%	89%	70%	70%	71%
The comparison of aerial photos and LiDAR data		86%	93%	105%	97%	85%	102%	83%

In low density forests (P1 and P2) 90 to 100 % of trees were identified on stereo view of aerial photos. In dense forests, the accuracy drops by nearly 20%. In dense forests, number of suppressed tree increases and their small crowns are not easily identified by human eyes on aerial photos.

Crown Shape Index applied to low density forests resulted in 80 to 90% identification accuracy. With the increase in tree density, the accuracy dropped by 10 to 20%. This means that Crown Shape Index method showed similar accuracy dropping tendency with visual photo interpretation method with the increase in tree density. This may further indicate that LiDAR data could not detect small crowns of suppressed trees.

From the above results, the authors conclude that the accuracy of individual tree identification in low density forests increased from 70% of the Ridge/Valley Index method by using improved Crown Shape Index.
However, in dense forests, the accuracy is not high enough and further research is required.

Further, in order to understand the accuracy of Crown Shape Index, the identification result was compared with that of aerial photo interpretation by human eyes. The comparison result is summarized as the last row of Table 4. As the result of this comparison, it was found that the Crown Shape Index method identified 80 – 100% of the detection by aerial photos. From this result, individual tree identification by Crown Shape Index is considered to have the same level of accuracy with manual aerial photos interpretation method.

5. Conclusion

In this research, individual trees in forest were identified by using a newly developed Crown Shape Index which clearly represents tree crown shape.

It was confirmed that the Crown Shape Index had a great potential in individual stand identification at the same level of accuracy with aerial photo interpretation.
However, number of identified trees tends to be less than actual number of trees and further improvement of the index is required.

Further, the authors plan to apply the method to forest of other species in order to make the method applicable to various types of forests.

A system to calculate crown size and tree density from identified tree top and to select areas which require maintenance will also be developed to contribute to better forest management.

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