THE EXTRACTION OF LINEAR FEATURES FROM AIRBORNE FULL-WAVEFORM LIDAR

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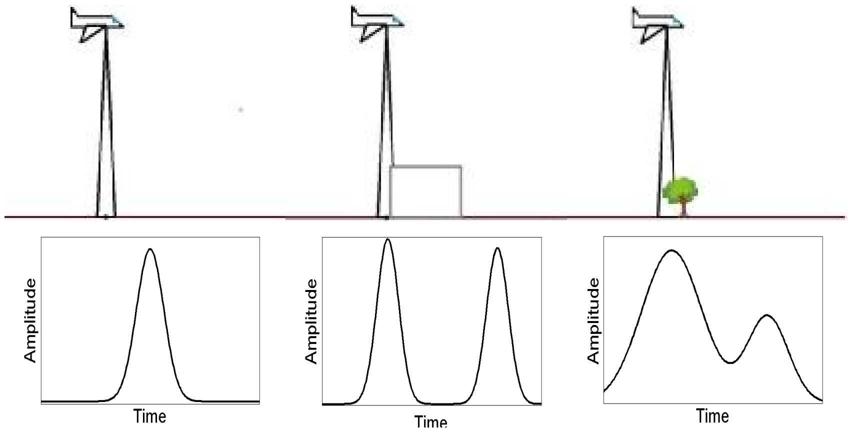
Abstract: Full-waveform (FWF) lidar is an advanced technology inlidar system development. Multi-echo (ME) lidar only provides 3-D point clouds and intensity, whereas FWF lidar provides entirereturned signals. The waveform attributesarethe useful information in feature extraction. However, discrete point clouds without waveform attributes are usually utilized for geometrical feature extraction.In this research, we use the waveform information to detect edges in urban area and to compare the result from discrete point clouds.The proposed method includes two major parts. First, we compute the separation distance of 3-D point clouds according to the height jump of edge points. When theseparation distances exceed the predefined threshold, we set them as the candidate edge points. Second, the different edges show different characteristics and waveform attributes. So we utilize the echo width and amplitude of the candidate edge points to remove the vegetation area. Moreover, the waveform attributes are used to discriminate the objects such as "buildings" and "power lines".The experimental data acquired by Riegl LMS-Q680i is located in Tainan city, the southern part of Taiwan.The experimental result indicates that the proposed method may separate the edge points from different objects when considering the waveform attributes.

1. INTRODUCTION

Full-waveform (FWF) lidar is anadvancedtechnologyinactive laser scanner system. The traditional discrete lidar only provides a direct and illuminated-independent distance to surface and provides 3-D point clouds and intensity of the points(Stillaand Jutzi, 2009). Currently, the development of full-waveformlidar offers more information about the structure of the illuminated objects.Comparing with discrete lidar, full-waveformlidar not only provides the range of the reflections but also digitalizes and records the received signal(Mallet andBretar, 2009). It can obtain more useful information afterwaveform analysis.Each returned signal represents the vertical characteristics of surface features (Beraldin et al., 2010).We can extract different surface attributes based on the shape of the received signals.These echoes include several parameters such as echo width, amplitude, echo number and other. Hence, full-waveform lidar nowadays is widely used for land-cover classification and feature extraction(Malle et al., 2011; Jutzi et al., 2005).

In the edge detection, discrete lidar only utilizes the characteristic of separation distance to extract edge points. It is not able to discriminate the land-cover type directly (Michelin et al., 2012).On the contrary, full waveform lidar provides more information of reflecting surface. The different reflecting surfaces provide different waveform patterns. Therefore, waveform parameters such as echo width and amplitude could be used to separate the different land-covers (Lin and Mills, 2010;Alexander et al.,2010). Depends on the shape and material, the echo width of the vegetated area is wider than man-made object, besides the amplitude of irregular vegetated area value is also smallerthan man-made object (fig. 1).Hence, waveform features are helpful informationin edge detection and edgetype determination.

In this research, we integrate geometric and waveform properties for the edge detection in urban area.According to the separation distance, we detect the candidate edge points firstly. Then we utilize the waveform features such as echo width and amplitude to generate accurate edge points and distinguish the different types of reflecting objects. The waveform parameters not only use to detect the location of edges but also discriminate the different types of reflecting objects.This research also compares the results of the edge detection between FWF lidar and ME lidar.



(a) Ground (b) Building(c) Tree
Figure1. Surface characteristic and pulse form.

2. METHODOLOGY

2.1 Computation of separation distance

In this step, we extract the candidate edge pointsby examiningthe separation distanceof waveform. Edges could be divided into two cases: single echo and multiple echoes.When laser beams illuminate at a vertical plane (e.g. walls), the waveform only receivesa single echo. For the waveform contains two echoes in a laser beam, one echo is located on the top of the object and the other one is located on the bottom of the object. In this research, we use multiple echoes rather than single echo in edge detection. The height jump or height discontinuityis called "separation distance"in this study.The separation distanceis defined as the distance between two targetsin a pulse. Usually, the buildings create the larger separation distancewhen comparing to vegetated area (fig.2).In order to remove non edge points, wepredefine a threshold by examining the separation distance.If the distance of two targets exceeds the threshold, then, this pulse contains candidate edge points.

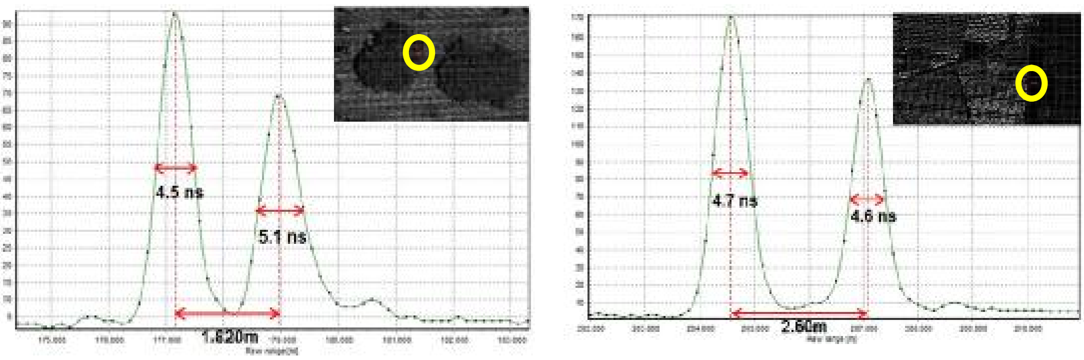


Figure2. Illustration of waveform's edges(Left: vegetated area, Right: building. The red circles on upper images are the location of the waveform.)

2.2 Analyzing the waveform attributes

To compare the discrete and waveformlidars, the additionalwaveform information in edge detection may offer more accurate edge points. The laser beam illuminated to different objects represents different waveform attributes. For example, figure 2 demonstratesthe echo of the vegetated area is wider than building and the amplitude is smaller than building. Because the extracted edges only consider the heightdiscontinuous, we intend to separate different kinds of edgesdepending on the waveform characteristics. This step includestwo major parts: training area selection and decision tree classification.

In the first part, we define thresholds of waveform parameters on the edges such as"echo width" and "amplitude". The parameters are defined by analyzing the waveform of different objects, i.e."vegetated area", "building" and "power line". This research selects training areas for three objects and obtains candidate edge points. In these training areas, the candidate edge points will be extracted with separation distance. And then we utilize the statistical technique to obtain the different ranges of the echo width and amplitude for different types of edges. According to the waveform characteristics, the parameters obtained above are used for discriminating the different objects.In the second part, we utilize the concepts of decision tree classification to classify the edges of the objects.We use the predefinedthresholds of waveform attributes to discriminate the objects. As shown in figure 3, we set thresholdforseparation distance. If the separation distance for the two targets exceeds the threshold, we indicatethis pulseincludingcandidate edge points,otherwise, we discard the points. We also use the echo width and amplitude parameters to classify the edge type.

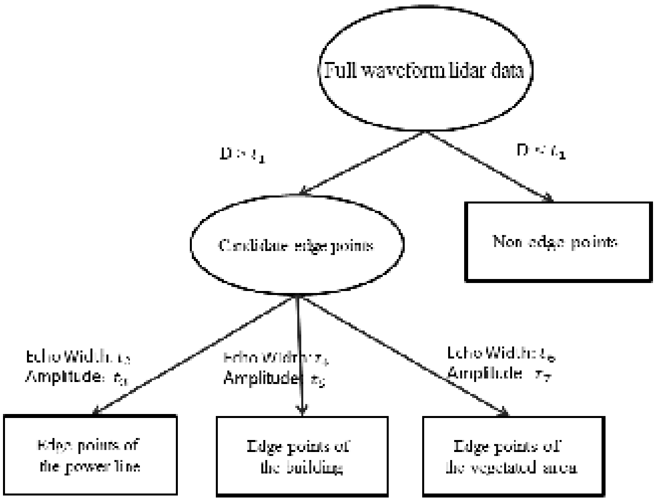


Figure 3. Decision tree classification

3. EXPPERIMENTAL RESULTS

The experimental data is acquired by Riegl LMS-Q680i. It is located at Tainan of Taiwan. In the training data selection, we subset three small regions(i.e. vegetated area, building and power line) as shown in figure 4.Then,we apply the parameters from training to a larger area as shown in figure 5.

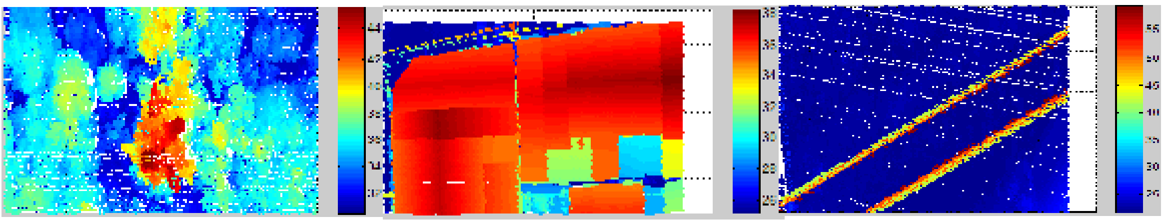


Figure 4.Training area, point clouds with elevation. (Left: vegetated area (50m*20m), Middle: building (50m*35m), Right: power line (10m*23m))

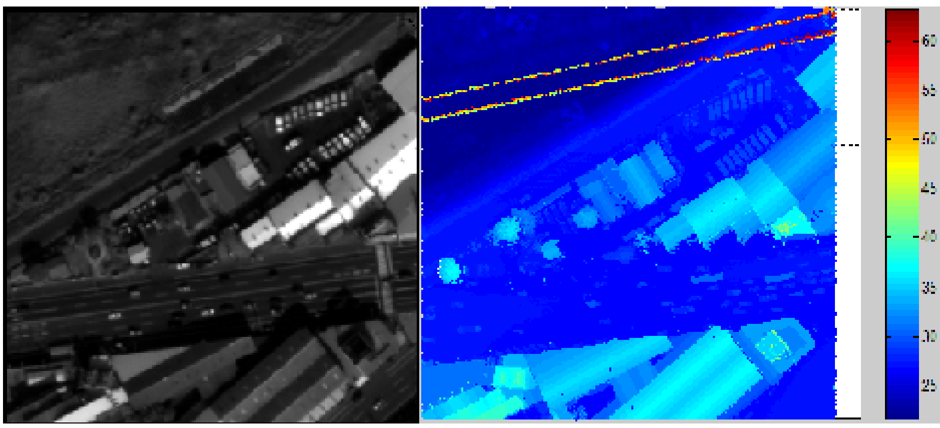


Figure 5. Test area.(Size: 150m*150m, Left: ortho-image, Right: point clouds with elevation)

3.1 Waveform attributes from different objects

The edge points as shown in figure 6 were extracted according toseparation distance. The threshold of separation distance was 2.25m. The threshold is set by theoretically minimal height of buildings. When the separation distance exceeds the threshold, we regard it as edges. Then, we analyze the waveform parameters from candidate edge points. The histogram is shown as figure 7. Table1summarized the results. Table 1 indicates that the echo width of power line is the smallest and the vegetated area is the largest. On the other hand, the distribution of echo widths in the vegetated area is more dispersive. When it comes to amplitude, the building is the largest and the power line is the smallest. Comparing with echo width, the distribution of the amplitude is more dispersive.

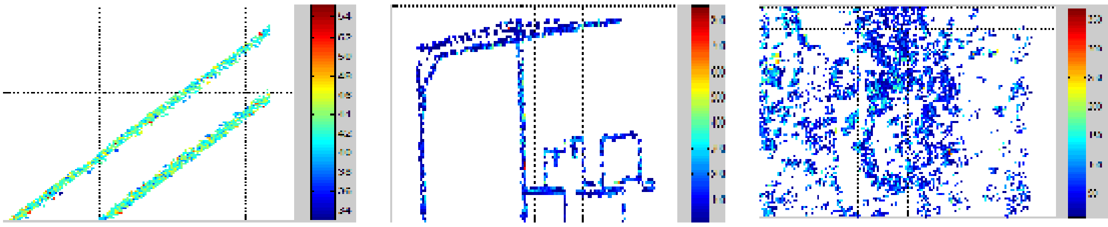


Figure 6.Edge points with echo width. (Left: vegetated area, Middle: building, Right: power line)

Echo widthAmplitude

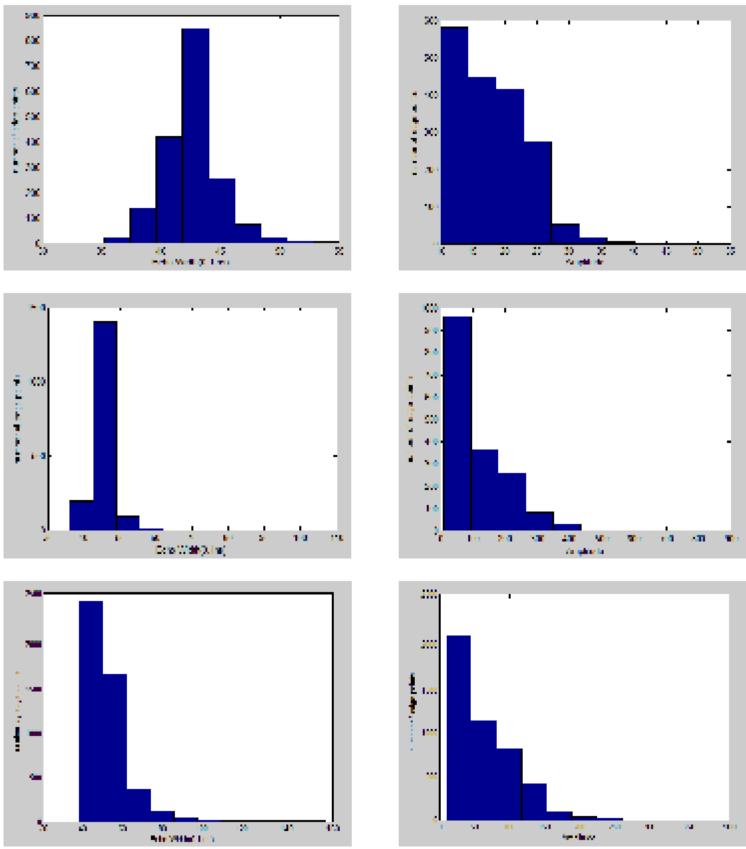


Figure 7.Histograms of echo width and amplitude. (Up: power line,Middle: building,Down: vegetated area)

Table1. Echo width and amplitude of three different objects

	Amplitude				Width (ns)			
	min	**max**	**mean**	**STD**	**min**	**max**	**mean**	**STD**
Power line	10	53	17.8	5.33	3.3	5.5	4.26	0.26
Building	10	859	110.45	99.88	3.6	10.1	4.51	0.35
Vegetated area	10	369	62.53	44.35	3.8	15.7	5.20	0.96

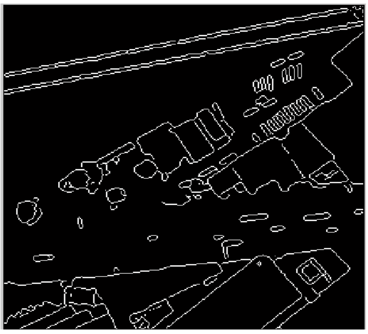
3.2 Comparing edge points extracted from discrete point cloudswith waveform data

Table 2.Predefined threshold for three objects

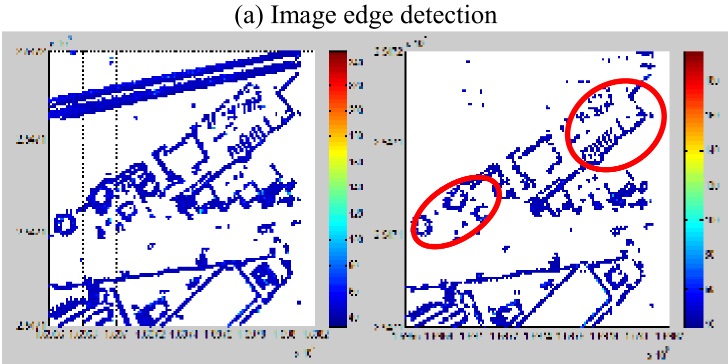
	Separation distance (m)	Echo width (ns)	Amplitude
Power line	2.25m	< 4.5	< 30
Building		4-5	> 40
Vegetated area		>5	<150

According to the results as mentioned before, we define the threshold to discriminate power line, building, and tree. Table 2 summarized the threshold for decision tree classification. In the first step, we used the threshold of the separation distance to obtain the candidate edge points as shown in figure 8 (b). Then, we discriminate three different objects according the characteristics of the pulse echo on the candidate edge points. The results are shown in figure 8 (c) to8(e). Figure 8(a) is the result of Canny edge detection frominterpolated digital surface model. The parameters of Cannyoperator are low threshold: 1.2; high threshold: 2.4; standard deviation of the Gaussian filter: 1. The result of the image edge detection shows the location of height jump. This method could detect all locations existing height jump but also cannot distinguish the type of edges. We can overlap figure 8(a) and other results to check the edges.

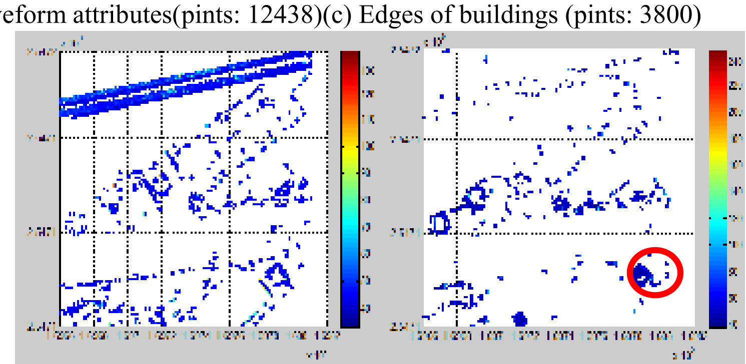
The edges of the building include some non-building edges. It is mainly caused by trees and trucks in test area shown as figure8 (c). If the threshold of theseparation distance for the building exceeds 3 m, the noise points caused by trucks can be removed. Because some edges on roof area create narrower echoes, the edges of the power line may include some building edges in the lower part of figure 8 (d). For vegetated area, some noise points aredetected due to wider echoes.



(a) Image edge detection



(b) Non-waveform attributes(pints: 12438)(c) Edges of buildings (pints: 3800)



(d) Edges of power lines(points: 4389)(e) Edges of vegetated area (points:918)

Figure 8.Results of the edge detection

3.3 Accuracy assessment

For accuracy assessment, we check the correctness of the detected edge points. In this part, we remove the edge points manually. The edge points are divided into two cases: “true” and “false”as shown in table 3.The correctness of the building is the highest one while the vegetated area is the lowest one. The correctness of the power lineand building exceeds 70%.For the edge detection in vegetated area, the main reason of low correctness is caused by large amount edge points of signboard. For the results of building edge detection, the detected trees and trucks influence the correctness. For the power line area, the false points are mainly caused by edge points of the buildings. That is because the echo of the building is narrower. Overall,the purpose of the edge detection of the vegetated area is to remove the trees.

Table3.Correctness of the edge points

Points	Power line	Building	Vegetated area
Total	4389	3800	918
True	3116	2814	490
False	1273	986	428
Correctness	70.99%	74.05%	53.38%

4. CONCLUSIONS

Traditionally, discrete point clouds are usually utilized for geometric feature extraction according to the separation distance. However, all kinds of edge points will be detected and cannot be distinguished. This researchuses statistical technique to define the range of the waveform parameters for different edge types.To compare the extracted edge from discrete and waveform lidars, waveform lidar may obtain more accurate edge points and discriminate the different edge points of the objects.The correctness of the power line and building are exceed 70% in urban area. Besides, the echo width and amplitude can be used to remove the vegetated area.But as shown in results, some noise points exist. In the future work, we will apply more parameters such as ratio of amplitude,ratio of echo width, number of echo to improve the results. Moreover,we will utilize the geometric characteristic and the spatial relationship between waveforms to obtain the accurate edge information and extract the line segments from detected edge points.

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