BUILDING DETECTION USING AIRBORNE FULL-WAVEFORM LiDAR DATA

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Abstract: Different from the traditional discrete airborne laser scanning (ALS) systems, the latest airborne full-waveform laser scanning is capable of recording complete waveform of backscattering pulses. Through this property, it becomes more possible to detect objects lying on the path of laser pulse and capture additional information about targets, and therefore such system has been applied to detect objects covered by thick forests or vegetation. In this study we focus on extracting buildings from laser point clouds in forest areas. To this purpose, we firstly indicated possible position of buildings from first echo data. Waveform indicators were subsequently applied to classify points of buildings from all points. The waveform indicators we took into account were the amplitude, the echo width and the backscatter cross-section. At last, a classification strategy using the information derived from full-waveform LiDAR data was developed to distinguish building and vegetation points. The overall building points were derived.

1 INTRODUCTION

Airborne laser scanning, also referred as LiDAR (Light Detection and Ranging) is a rapidly developed technology that is widely used for obtaining the geometric structure of the Earth's surface (Lehner et al., 2010).Most of the ALS systems are based on time-of-flight techniques to determine the distances between the sensor and targets. After integrating with exterior orientation, point clouds with 3D coordinates and also pulse amplitude are produced for further utilization. Although ALS has been applied widely, some limitations were found when such technique is used:

(1) Traditional discrete ALS systems normally record up to five returns within a laser signal.
(2) The method of detecting pulse used in traditional ALS systems was unclear (Amann et al., 2001; Katzenbeisser, 2003). Therefore users are unable to determine the correctness and errors caused by the pulse detection methods. As a result, inaccurate range determination may occur and reduce the 3D position accuracy of scanned points.
(3) The ability to detect close objects occurred on a single laser beam is limited using traditional ALS systems. That is the spatial resolution is limited along the scanning direction (Katzenbeisser, 2003).

The full-waveform LiDAR system capable of recording the entire waveform of each backscattered laser pulse was developed and has great potential to overcome these limitations. Figure 1 shows an example of the returned pulses recorded along the path of a laser signal. The X_i (i=1,2,3,4,5…)represents the time in which the pulse is captured, the red curve line indicates the pulse detected. Each peak (red points) represents a possible object occurring along the laser path. Due to the capability, it becomes possible to detect additional objects on each laser travel path (Lin and Mills, 2010). In addition, as the full-waveform data are recorded, users are able to apply their own pulse detection method to improve the performance and further extract waveform components, such as pulse width, amplitude, and etc. (Lin et al., 2009). Another feature of full-waveform system is the advanced scan rate. As a result, more points can be acquired, and it is more possible to detect buildings hidden below vegetation and also to determine terrain surface. To examine the feasibility, we focus on extracting buildings located in forest areas using full-waveform laser scanned data. The test site selected in this study, methodology performed for building extraction, and the results of the preliminary test are shown in following sections.

2 TEST AREA & DATA REVIEW

The test area selected in this paper was the Dabang Village in Mountain Ali area, which is in the center part of Taiwan (see Figure 3). As shown in Figure 3, land cover of the area is mixed with different types of vegetation and buildings. In this paper, we firstly aimed to detect all buildings and, if any of them were mixed with or existed underneath vegetation, then distinguish such buildings using full-waveform information. The characteristics of the waveform data employed in this paper and their interactions with the scanned objects are described below in detail.

(1) First echo: First echo is the first return backscattered to the receiver. It usually represents the nearest surface of object on the path of laser signal.
(2) Single echo: Single echo is the only one return backscattered to the receiver of a pulse signal. It was found normally they represent uncovered objects like building surface.
(3) Pulse amplitude: As shown in Figure 2, A_4 is the amplitude of the returned echo4. Different materials of target surface (for example metal and wood) can lead to apparent value difference. As shown in Figure 6, the amplitude is high in most part of buildings and relatively low in vegetation area in the test area.
(4) Pulse width (PW): PW is the width of the fitted pulse. As reported in many studies, the pulse width of vegetation is generally larger than that of terrain points (see Figure 3). Therefore the PW is a useful value for separating vegetation from terrain points. (Persson et al., 2005; Wagner et al., 2008). The phenomenon can be observed in Figure 7, in which the PW is lower in terrain (road) area.
(5) Backscatter cross-Section: The backscatter cross-section is the effective area of collision of the laser beam and targets. As it takes into account the shape of the scatter, as well as its reflectivity and the directions of the incident and backscattered waves (Jelalian, 1992), it is of potential to be used to differentiate vegetation from buildings . In the test area, it was observed that backscatter cross-section values provide apparent contrast between buildings and vegetation (Figure 8).

Based on the above observation of the three waveform indicators in different land cover, it was understood that pulse width value can be applied to filter terrain points from other points and backscatter cross-section and amplitude might be useful for separating building points from vegetation points. These observations were further introduced in the approach for building detection and extraction proposed in the next Section.

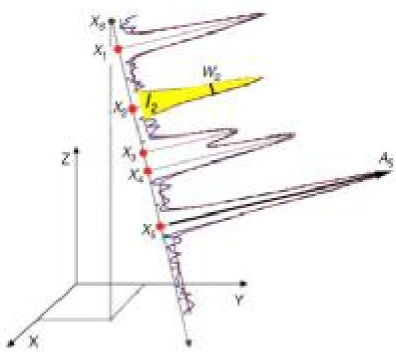

Figure 1: Returned pulses recoded in full-waveform system.

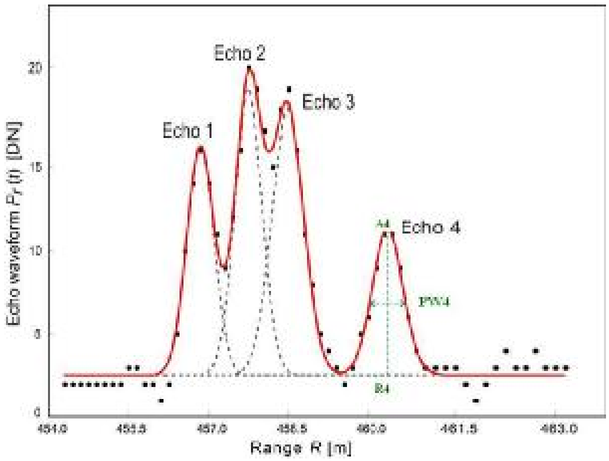

Figure 2: Waveform pulses fitted to individual Gaussian function (from Wagner et al., 2006).

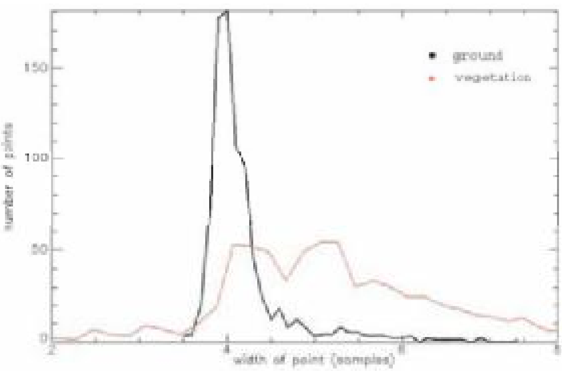

Figure 3: Histogram of pulse width of terrain points and vegetation points.

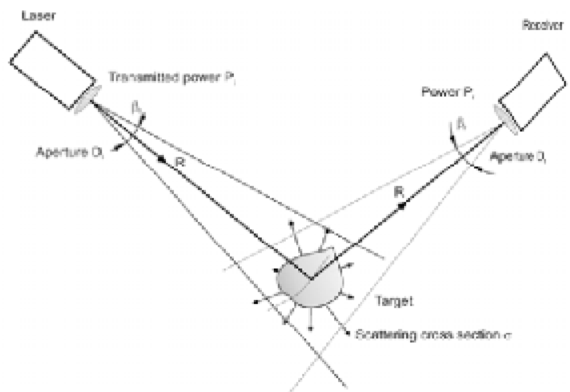

Figure 4: Representation of signal scatter.

Figure 5: Test area over Dabang Village.

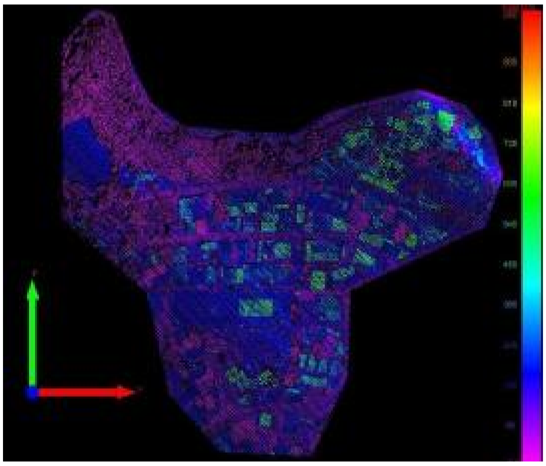

Figure 6: Colorized amplitude data over test area.

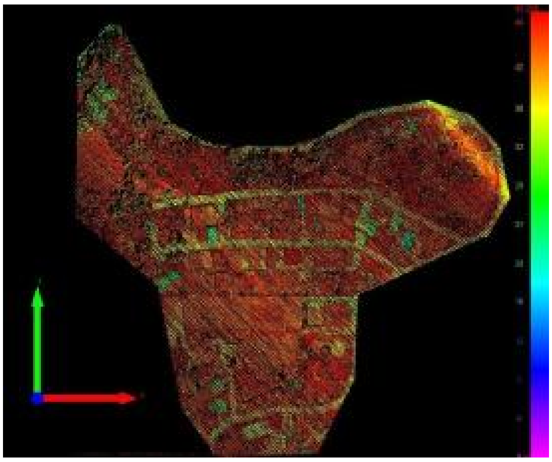

Figure 7: Colorized pulse-width data over test area.

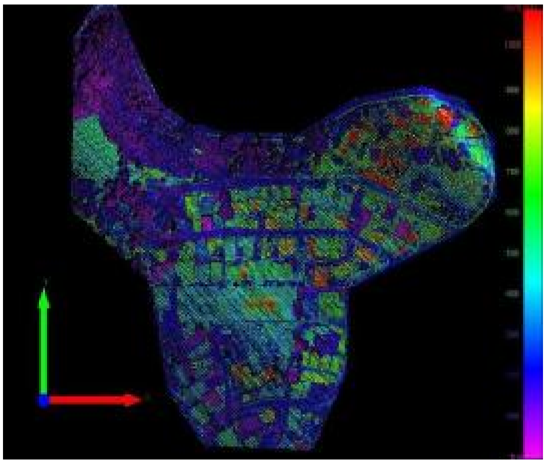

Figure 8: Colorized backscatter cross-section data over test area.

3 METHOD & RESULTS

3.1 BUILDING DETECTION

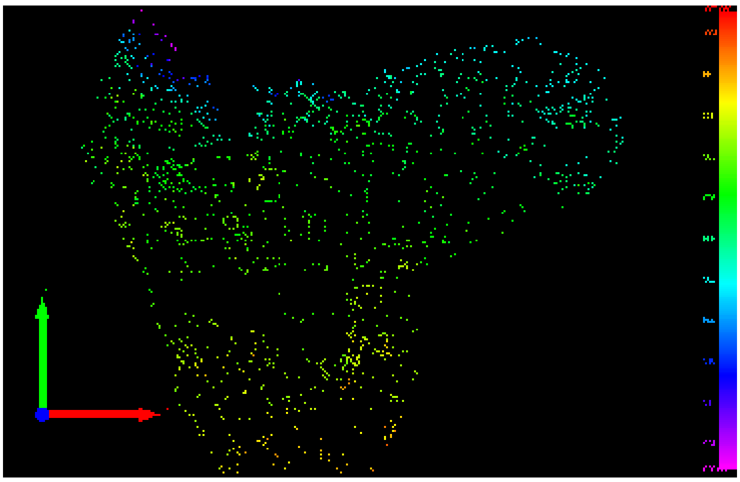

Figure 9: First echo data of test area

In order to extract buildings from the overall points, the first task is to determine the boundary of each building. After investigating the data, it was found that most of the first echo points located on the edges of the buildings (see Figure 9). Hence the general building detection strategy in this paper is to search approximate position of buildings using first echo data. To this end, the first echo points were selected and used to produce contour lines (Teo and Chen, 2006). As the location and shape of the buildings were identified based on the close polygons, the contours lines were then used as a reference extent to clip the entire test area point clouds. The extracted points were treated as points forming buildings (refer to Figure 10). As shown in Figure 11, most of building points (purple dots) are located within the boundary of first echo points (yellow dots). However it was observed that there are some buildings partly mixed with vegetation. Therefore, waveform data were subsequently used to separate these buildings from vegetation and are introduced in the next section.

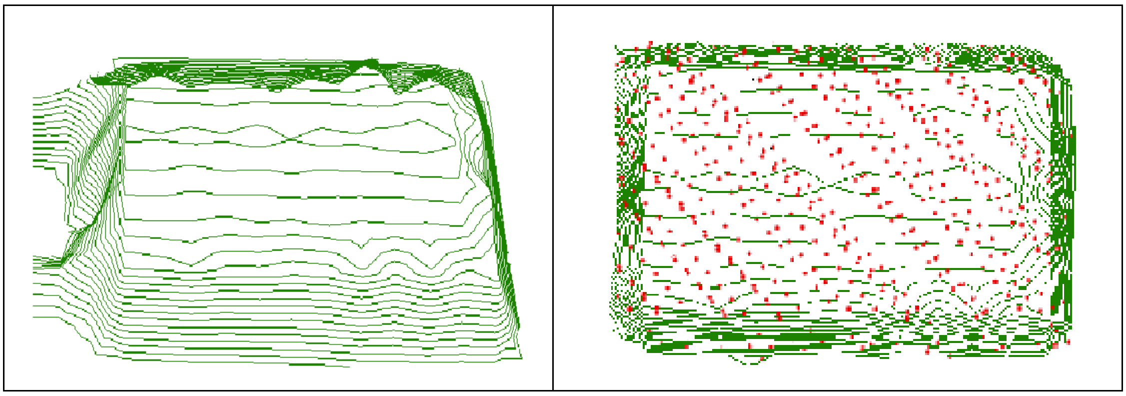

Figure 10: Building contour line and points fall within the close polygon.

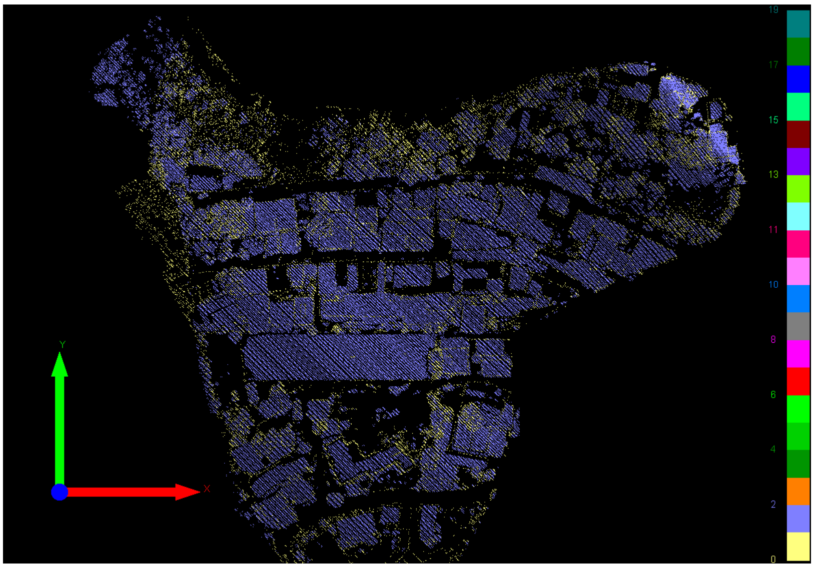

Figure 11: Extracted building points after clip processing.

3.2 WAVEFORM DATA EMPLOYMENT

Since the buildings were detected, the next task was to extract building from mixed vegetation. As introduced in Section 2, the application of waveform indicators (pulse amplitude, pulse width and backscatter cross-section) was capable of distinguishing building points from vegetation and terrain points. The waveform information was therefore introduced in this task. In order to classify the three land cover types (i.e. building, vegetation and terrain) using waveform information, appropriate threshold range of each waveform indicator was required. To this end, points of sample sites of building, vegetation and terrain were extracted. Then the frequency distribution of each waveform indicator derived from each extracted sample points was performed. The threshold range of each waveform indicator representing each land cover was computed based on the median value. In this study it was suggested that the threshold range should cover 70% of number of points. Therefore the range was determined using median value +/- 35% of number of points recorded in the table of frequency distribution. As a result, the threshold range of each waveform indicator representing each land cover type was listed in Table 1.

Table 1: Threshold range of each waveform indicator representing each land cover type.

Land cover	Amplitude (DN)	Pulse-width (ns)	Backscatter cross-section(m^2)
Building	78~412	20~36	0.258~1.401
Vegetation	25~209	44~63	0.075~0.733
Terrain	87~332	31~50	0.249~1.075

As shown in Table 1, it is observed that the amplitude and backscatter cross-section of vegetation are significantly different from those values of building and terrain. These two waveform indicators were applied to all points derived from Section 3.1 to distinguish building and vegetation. The results are demonstrated in Figures 12 and 13, in which the purple points are detected buildings, while the orange points are the vegetation points.

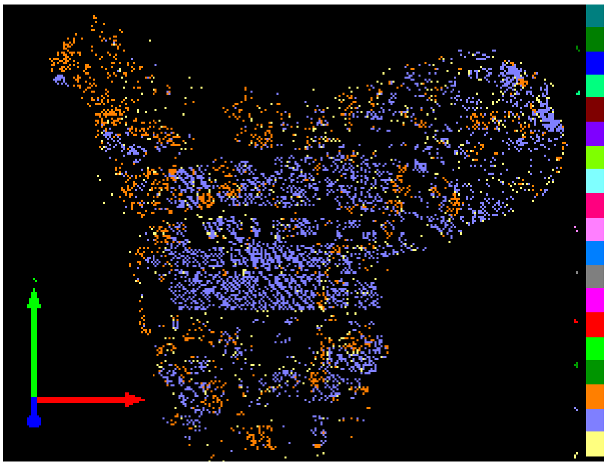

Figure 12: The points data after waveform data processing.

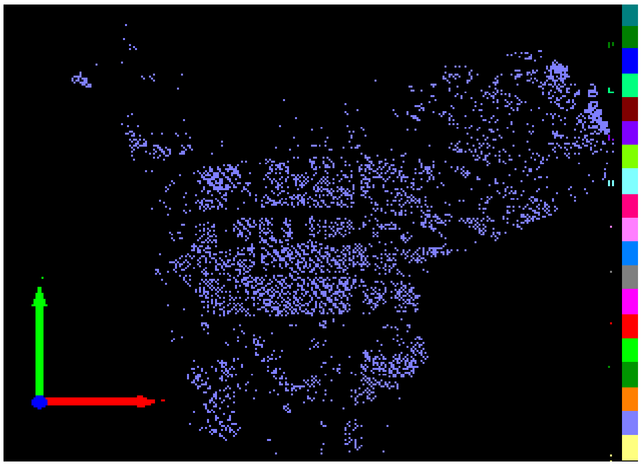

Figure 13: Extracted building points.

To show the performance of the method proposed in this paper, the numbers of buildings located in the test area, detected and missing buildings after processing were counted manually and listed in Table 2. The success rate of correct building extraction achieves 88.7%.

Table 2: Assessment of building extraction.

Type	Number	Percentage
Lost Building	7	11.3%
Detected Buildings	55	88.7%
Total Buildings	62	100%

4 SUMMARY & RECOMMENDATIONS

In summary, the application of full-waveform data was feasible to detect locations of buildings and also to determine buildings partly covered by vegetation. To accomplish this, as demonstrated in this paper, the most important task is to determine the boundary of each building. The method used is to derive building contour lines from LiDAR data and then make it an independent close polygon individually. Although most of the buildings were detected, image-based method is further integrated to improve the performance of boundary detection and extraction.

Regarding the extraction of building mixed with vegetation, the proposed method was capable of distinguishing such buildings. However, it was also found that a number of buildings were not detected. This was mainly due to similar amplitude, pulse width and backscatter cross-section values between building surface and vegetation. Further research is carried on to develop an advanced approach to address the issue, and also to determine the materials of the building surface.

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