Investigation of Full-waveform Lidar Data Segmentation

A. Kimlei*, A. Barsi**
* Doctoral School of Applied Informatics and Applied Mathematics, Óbuda University, Budapest, Hungary
** Department of Photogrammetry and Geoinformatics, Budapest University of Technology and Economics, Budapest, Hungary
kimlei.annamaria@gmail.com, barsi@eik.bme.hu

***Abstract*— Many of the recent laser scanners are capable of digitizing the full waveform of the received signal. Full waveform laser scanners provide a lot of new opportunities. Analyzing the registered waveforms further geometric and material properties of the reflected surface can be derived. These waveforms can be used for multiple purposes. The full waveforms of backscattered signals are different when coming back from grass, canopy, road or oblique roof, so they can be used for classification tasks. Increased number of reflections can support classifying forested areas where the tree type or canopy size is to be determined. This technology leads to enormously increased data volume, which requires totally new processing methodologies. In this paper several processing techniques have been investigated that are able to provide remarkable results in segmentation. Obviously, these methods require further investigations to exploit their full potential.**

I. INTRODUCTION

Laser scanning is a dynamically developing part of remote sensing. We can get information about target objects without direct contact.

In the last few decades new airborne laser scanners appeared, which could measure not only discrete points, but the whole backscattered signal of every emitted pulse.

During the full waveform processing the whole backscattered pulse is computed with a given resolution, so the detailed vertical resolution of the backscattered pulse is produced. This new technology gives the opportunity to increase the reliability, accuracy, and resolution of the impulse-detection. These Lidar (Light Detection and Ranging) systems provide more possibilities to the users to determine physical properties.

A. History

In the 1980s the first full-waveform systems were designed to measure bathymetric data [2].

As an experimental system, topographic devices appeared in the middle of the 1990s, and have been commercially available for a few years later.

The first useful topographic system was designed by the NASA in 1999. It was called LVIS (Laser Vegetation Image Sensor); it was an improved version of the previous SLICER satellite system. The purpose of SLICER was to describe the vertical structure of the vegetation in huge areas.

The LVIS data processing proved the efficiency of characterizing wooded areas and measuring ground topography even beneath the vegetation.

The first commercial full wave-form system was released in 2004. Full wave-form topographic Lidar systems mainly differ in footprint size, pulse energy and repetition frequency (PRF). Small- and large footprint systems collect different information over the same area (Fig. 1):

- small-footprint system with higher PRF: high point density, accurate altimetric description. In the case of these systems tree tops are often missing, and it's difficult to determine ground points under dense vegetation.
- large footprint systems: the probability, that the impulse hits both the canopy top and the ground, is higher. The returned waveform gives the vertical distribution of the recorded surface, because none of the levels between the ground and the top are missing.

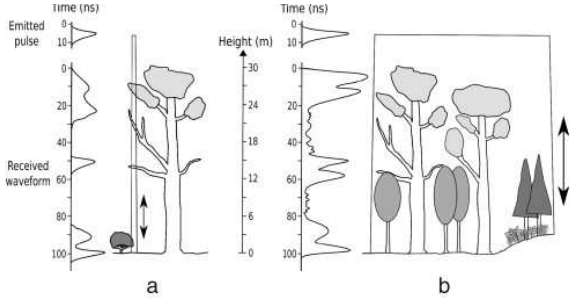

Figure 1. Emitted and returned pulses in the case of small and large footprints at wooded area [2]

B. Recording the data

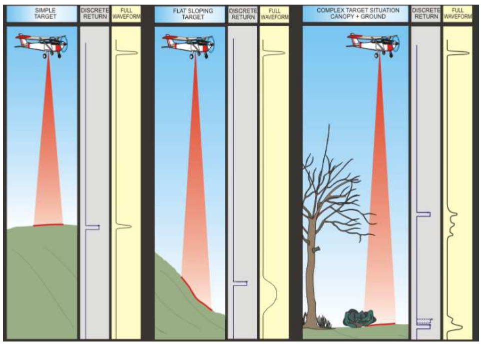

Figure 2. Recording the full waveform of different surfaces[1]

The recording of the backscattered waves is a function of time. The manufacturers of Lidar equipments have added digitization modules to their systems (for example Leica uses a separate digitization module, while Riegl has built it into the system).

The coordinates of the points, intensity values, number of all backscatters, direction of progress, scanning angle, GPS time, wave packet index, wave packet and the waveform are also recorded.

The waveform is characterized by the amplitude and width of the backscattered pulse. The amplitude depends on the signal intensity, which depends on the distance, atmospheric effects, and the reflection properties of the object. The width of the impulse depends on the height differences and the surface roughness of the object.

During the full waveform processing the whole backscattered pulse is computed with a given resolution, so the detailed vertical resolution of the backscattered pulse is produced.

The intensity values have no units, the intensity of the emitted and the backscattered pulse is between 0-255.

The waveforms are digitized on 8 bit, which means 2^8 (0-255) wave samples are stored for each points. It can be done by other sampling rates, but this option needs to be given before the data recording [2].

The digitization sampling period is between 1 and 10 ns, which is the time between the consecutive waveforms.

The main limit of full waveform Lidar recording is the storage capacity. The instruments record a few million points on each flying. The general frequency of sampling is 50-100 kHz. If the whole backscattered pulse to each emitted signal has been stored, the storage need could increase highly. (For example: one minute of full waveform laser-scanning about 4 million of recorded waveforms means 580 MByte data besides the 460 MByte of navigation data (GPS time, latitude, longitude, elevation, pitch, roll, direction, etc.). It can be easily computed that a 3 hour long data recording means 180 GByte of data to be stored) [3].

C. *Data proccessing*

There are two approaches to process the vertical profiles. According to the first one, the waveform is decomposed into components or echoes to analyze the different objects hit by the laser.

The goal of this method is to maximize the detection efficiency of the relevant peaks, to generate a denser 3D point cloud, and to optimize the processing capabilities by supporting information extraction from raw data. The increasing number of 3D points is important for e.g. forestry applications. More extracted information can be useful for segmentation and classification in both wooded and urban areas. Beside the more accurate determination of peaks the density of the point cloud can be increased and previously not found local maximums in the merging waveforms with more backscattered pulses can be determined.

On the other hand, the whole waveform is preserved, information is gathered from the full waveform by spatio-temporal analysis. This method is useful at urban areas, where the geometry is regular.

The last opportunity has been barely investigated, most researches have their focus on 3D point cloud processing [2].

II. METHODOLOGY

A. *Data*

The raw data (4 flight bands with 4-bit sampling, full waveform data at every second impulse) was given by the Remote Sensing Research Institute of the Károly Róbert Collage. The recording was taken by a CESSNA C-206 “Skywagon” aircraft, and covered the center of Mátrafüred. A Leica AL70-HP scanner was used for the airborne laser scanning. It is a specially designed instrument for general topographic surveys at high altitude with high accuracy. With a WDM65 digitization module attached the full waveforms of the impulses can be stored. Furthermore, this system contains a Leica RCD30 camera with 60 MPixel resolution to take pictures at the same time.

The four flight bands contain too much points, therefore the processing was done by a smaller cutoff area to shorten the processing time.

Properties of the cutoff area:

- Area: 22 000 m^2,
- Number of points: 300 000,
- Number of full waveform points: 94 624,
- Rate of full waveform points: 31,5%
- Average point density: 13,6 points/ m^2,
- Density of full waveform points: 4,3 points/ m^2.

B. *Proccessing*

There are basic differences between the backscattered waveforms depending on the reflective surface, but the most important distinction is the number of backscatters. The waveforms are very different, but probably there is correlation between the waveform and the material of the reflective surface, thus the form of the wave backscattered from grassy area is different than from an urban area.

In this case, the task is clustering using the full waveform data (with Matlab) followed by a classification of the results.

Many of the researches deals with decomposing the waveforms to echoes using Gaussian function [2]. This method is used not just to increase the efficiency of peak detection, but to distinguish between vegetation and non-vegetation using Gaussian parameters (like amplitude).

In the study [5] Authors have fit Gaussian functions to the backscattered waveforms. In another Article [6] it was used generalized Gaussian and lognormal functions to model the signals.

In the study [3] Researchers have compared different peak detection methods to find more peaks (backscatters) in the full waveform data during the post-processing. It has a dual purpose: the first one is to increase the accuracy of the point cloud definition, the second one is to support the later classification tasks. Peak detection methods are indispensable for determining return time. Because of that, there are several existing peak detection techniques. The simplest methods are looking for the maximum values of intensity, but only the detection of one peak is possible. Another frequently used method is the fix threshold technique: if the backscattered signal is uprising to the threshold, a peak detection occurs (highly depending on the amplitude of the waveform). A better choice is, when the threshold is not a fix value, but it is set at the half of the actual maximum amplitude. There are several solutions to determine the center of the returning wave: correlation technique, first derivatives based filters, or fitting a function can determine the peaks of the returning wave. Function fitting is the most efficient algorithm; it can find the most number of peaks. Great advantage of this method is serving with the parameters (like width, flattening) being useful information for the later classification.

In the study [4] Authors could successfully do the segmentation of vegetation and built environment using full waveforms, but they didn't get satisfying results in the case of the sidewalks and roofs. They have determined that identifying roofs depend on the material and slope.

Relying on these statements the determination of the Gaussian curve parameters to each waveform was done. The exact value and position of the peak were important. After the peak detection the Gaussian function was fitted based on the environment of the peaks.

The used generalized Gaussian function was:

$$y = f(x) = a * \exp\left(\frac{-x^2}{b}\right) + c \tag{1}$$

An indirect measurement based adjustment has been used to determine the parameters.

The Gaussian function determines only the parameters of the highest peak of each wave.

First the Gaussian parameters to each point (each waveform) were calculated, then a SOM (self-organizing-map) neural network was used with them as inputs. In the first approach of SOM network a 4×4 neuron matrix with hexagonal-cell topology was used. The input data set was extended by other parameters like elevation, waveform or intensity.

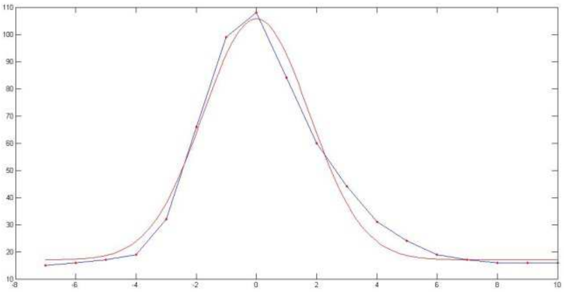

Figure 3. Fitting Gaussian function to a waveform

There were several segmentation attempts using the following parameters:

1. Only Gaussian parameters (a, b, c),
2. Height and Gaussian parameters (a, b, c),
3. Height and Gaussian parameters (a, b),
4. Height, the first 80 wave samples, Gaussian parameters (a, b, c),
5. Height, the first 10 wave samples, Gaussian parameters (a, b, c),
6. Intensity, Gaussian parameters (a, b, c).

C. Results

Fig. 4-9 show the results of the segmentations of the aforementioned parametrizations. Every figure shows the first 8 output images. One can notice that the output in cases 1-5 can't be ordered to any class. There are some results, which could be identified almost as a class (e.g. street in Fig. 5/2.), but accepting these are still not possible because of wrong identified points. Using intensity values in input data set results (dataset 6) outlining object contours (see Fig. 9). At Fig. 9/6, the points of the segmented image are mostly wooded area.

As a control, image 9/6. was acceptable; we have checked the result on a raster image in QGIS (Fig. 10).

It shows that the function can almost separate trees from other objects. Of course, there are mistakes between the points (e.g. misinterpretations on roofs), but the rate of wrongly identified points are small.

Of course, this method needs further researches and tests. Neither of the classes could be separated clearly. It could have different reasons:

- Gaussian parameters was assigned to a wrong data;
- The full waveforms should be proccessed not from the first wave sample or,
- A bigger radiometric resolution results different or better output.

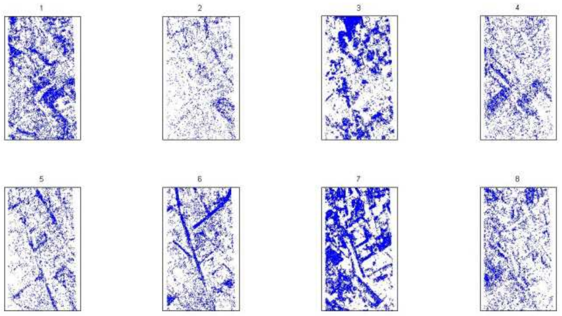

Figure 4. Segmentation by only Gaussian parameters (a, b, c)

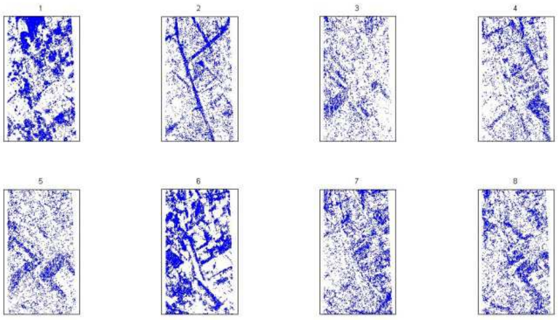

Figure 5. Using Height and Gaussian parameters (a, b, c)

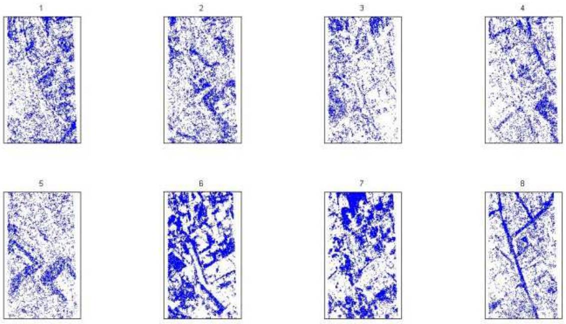

Figure 6. Using Height and Gaussian parameters (a, b)

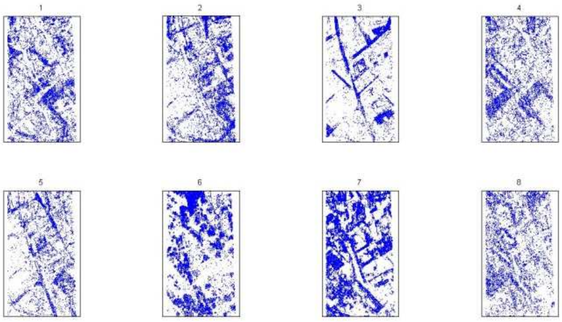

Figure 7. Using Height, the first 80 samples of the wave and Gaussian parameters (a, b, c)

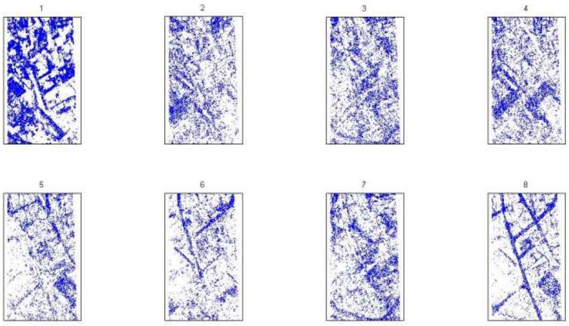

Figure 8. Using Height, the first 10 samples of the wave and Gaussian parameters (a, b, c)

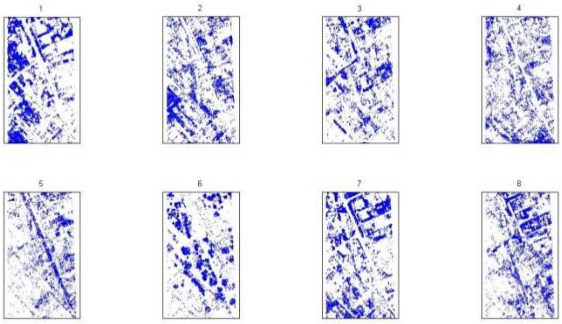

Figure 9. Using Intensity and Gaussian parameters (a, b, c)

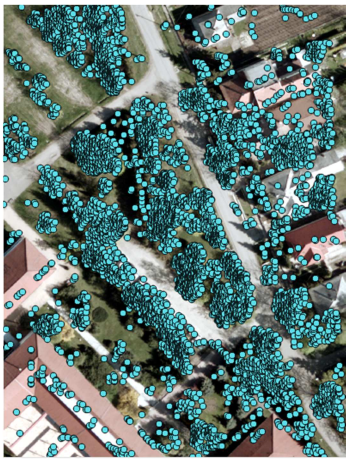

Figure 10. Segmented results in QGIS

III. CONCLUSIONS

In this paper the full waveform laser scanning and its possible usage have been shown. As an example the properties and classification possibilities of the full waveform data were analyzed.

The extremely high amount of data was the biggest difficulty during the processing, therefore a cutoff area was created and the methodology was applied there.

The processing of the full waveform Lidar data is not an easy task, because well-established methods with exact and accurate results are failing. Thus the main task was to achieve the best result from the received data. As a future research it should be worthy to investigate, whether a bigger radiometric resolution of waveforms results increased accuracy or not, and further analysis with additional parameters is recommended.

REFERENCES

[1] Verőné Wojtaszek M. (2010): Fotointerpretáció és távérzékelés, Tankönyvtár.

[2] Clément Mallet, Frédéric Bretar (2009): Full-waveform topographic lidar: State-of-the-art, ISPRS Journal of Photogrammetry and Remote Sensing http://recherche.ign.fr/labos/matis/pdf/articles_revues/mallet_IJPRS09.pdf

[3] Zaletnyik P., Laky S., Charles K. Tóth (2011): Csúcskeresési eljárások teljes hullámalakos lézerszkenner adatok feldolgozásához, Geomatikai közlemények XIV/1

[4] Bodon F. - Adatbányászati algoritmusok tanulmány

[5] Wagner, W., Ullrich, A., Ducic, V., Melzer, T., Studnicka, N., (2006): Gaussian decomposition and calibration of novel small-footprint full-waveform digitizing airborne laser scanner. ISPRS Journal of Photogrammetry & Remote Sensing 60 (2), 100-112.

[6] Chauve, A., Mallet, C., Bretar, F., Durrieu, S., Pierrot-Deseilligny, M., Puech, W. (2007): Processing full-waveform lidar data: Modelling raw signals. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 36 (Part 3/W52), 102-107.