DECOMPOSITION TECHNIQUES FOR ICESAT/GLAS FULL-WAVEFORM DATA

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ABSTRACT:

The geoscience laser altimeter system (GLAS) on the board Ice, Cloud, and land Elevation Satellite (ICESat), is the first long-duration space borne full-waveform LiDAR for measuring the topography of the ice shelf and temporal variation, cloud and atmospheric characteristics. In order to extract the characteristic parameters of the waveform, the key step is to process the full waveform data. In this paper, the modified waveform decomposition method is proposed to extract the echo components from full-waveform. First, the initial parameter estimation is implemented through data preprocessing and waveform detection. Next, the waveform fitting is demonstrated using the Levenberg-Marquard (LM) optimization method. The results show that the modified waveform decomposition method can effectively extract the overlapped echo components and missing echo components compared with the results from GLA14 product. The echo components can also be extracted from the complex waveforms.

1. INTRODUCTION

Full-waveform light detection and ranging (LiDAR) is an active remote sensing technology, in which a laser source transmits short laser pulses towards objects. For each laser pulse, the echo waveform can be received by interaction between the laser beam and the objects within the laser footprint. The received waveform of a returned laser pulse is called a full-waveform echo. A full-waveform echo is the superposition of multiple echo components scattered by multiple objects or surfaces at different distances within one laser footprint (Xu et al., 2016). The first echo component is regard as the top of features (top of canopy), and the last echo component is usually regard as the ground. The echo components can be obtained by decomposing the full-waveform echo. After that, the geometric and physical properties of the objects can be obtained. Such as the elevations, roughness, slope, forest canopy structure metrics and so on. The waveform LiDAR can be classified as a large footprint system (larger than 10 m) such as the Laser Vegetation Imaging Sensor (LVIS) and the Geoscience Laser Altimeter System (GLAS) and a small footprint system (0.2-3 m) such as RIEGL LMS-Q560 and Optech ALTM3100 (Mallet and Bretar, 2009).

The GLAS on the board Ice, Cloud, and land Elevation Satellite (ICESat), which was launched on January 13, 2003, is the first long-duration space borne full-waveform LiDAR for measuring the topography of the ice shelf and temporal variation, cloud and atmospheric characteristics. The GLAS instrument used a laser with 1064 and 532 nm wavelengths, and the 1064 nm wavelength is used to detect the full-waveform of the surface. The entire full waveform is the sum of all the target signals encountered along the path of transmitting pulse, which can reflect the vertical distribution of the ground objects and reveal the geometric and physical properties of the ground objects. The main applications for GLAS are surface elevation, roughness, slope and vegetation height and land cover classification.

Space borne lidar has a unique advantage in the field of earth observation, since it can provide global observations of atmospheric and surface properties. A number of studies have focus on the estimation of the forest canopy height (Duncanson et al., 2010; Iqbal et al., 2013), leaf area index (Luo et al., 2013; Tian et al., 2016) and above-ground forest biomass (Baghdadi et al., 2013) by using GLAS full waveform data.

The GLAS full waveform data should be processed first. Waveform decomposition is a key step for waveform LiDAR data processing. There are three main methods for decomposing the GLAS full waveform data, such as the Gaussian decomposition, waveform deconvolution (Neuenschwander et al., 2008; Duong, 2010), and wavelet analysis method (Wang et al., 2013). The signal to noise ratio (SNR) of the spaceborne LiDAR system is much lower than that of airborne systems. In addition, the spaceborne LiDAR system has a large footprint that contains complex surface features. So the critical processing situations may occur in these regions. the overlapping echoes or weak echoes are hardly detectable from the background noise.

In order to effectively extract the echo components (especially for the overlapping echoes) from the complex waveforms, this study proposes a modified decomposition method to process the GLAS full waveform data. In Section 2 the methodology is presented. In Section 3 the experiments and analysis is discussed. Finally, the conclusion is presented in section 4.

2. METHODOLOGY

The decomposition technique for GLAS full waveform data has two main steps, the first step is to estimate the initiative parameters of full waveform, which include the data preprocessing and waveform detection, the second step is to decompose the full waveform, which is used for extracting the echo components.

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2.1 Initial parameter estimation

The initial parameter estimation contains two steps, the data preprocessing and waveform detection, the detail introduction is as below.

2.1.1 Data preprocessing

The GLA01 product and GLA14 product are employed for the decomposition and analysis of GLAS full waveform data. The full waveform data is including in GLA01 product, while the GLA14 product contains the waveform parameters extracted by GLAS algorithm. The data preprocessing for GLAS full waveform should be done first, such as count to volt conversion, waveform normalization, smoothing the waveform. The GLA01 data is matched with GLA14 data according to the same index and shot number of each laser footprint.

2.1.2 Waveform detection

The waveform detection includes the peak detection and overlapping echoes detection. To avoid small and noisy peaks, a search window of 5 neighbouring height bins is applied through the entire waveform to estimate peak locations. In addition, the inflexion detection is also applied to help locating the single echoes and overlapping echoes. The overlapping echoes detection is more complex than peak detection. In this study, the inflection points are found through the entire received waveform. Then, a pair of inflection points is used to find the overlapping echoes at the left or right side of visible peaks within the received waveform. To avoid false overlapping echoes, the overlapping echoes should be no more than 1 for both sides of visible peaks.

2.2 Waveform fitting

The waveform received by a LiDAR system is assumed as the sum of Gaussian components (Hofton et al., 2000)

$$y = f(\mathrm{t}) = \sum_{i=1}^{k} A_i \exp\left(-\frac{(\mathrm{t}-\mu_i)^2}{2\sigma_i^2}\right) + \varepsilon \tag{1}$$

where y is the approximated waveform, k is the number of Gaussian components, A_i is the amplitude of the i th Gaussian component, μ_i is the position of the i th Gaussian peak, σ_i is the standard deviation of the i th Gaussian component, ε is the bias .

The Levenberg-Marquard (LM) optimization method is chose as the least squares method to perform the Gaussian fitting and compute the model parameters. In order to find the missing echo components, the residual of Gaussian fitting is further checked. The value of residual threshold of Gaussian fitting is set as the sum of the background noise and 4 times the standard deviation. If the residual of Gaussian fitting beyond the threshold, a missed echo component is found at the location of the maximum residual.

In order to eliminate the invalid waveforms and maintain the accuracy of the decomposition results, some constraint conditions are added to the Gaussian fitting, such as the number of the echo components is limited to six, the minimum distance between neighbouring peaks is set to 1.5 m, the minimum amplitude of an individual peak is set to the noise threshold value, and the minimum sigma width of an individual peak is set to 30 cm (Duong et al., 2010).

3. EXPERIMENTS AND ANALYSIS

In order to verify the waveform decomposition method proposed in this study, some typical GLAS data were processed using the above methods including initial parameter estimation and waveform decomposition method. The experimental results were compared with the waveform parameters of GLA14 products.

The results show that, compared with the waveform parameters from GLA14, the decomposition method proposed in this study effectively extracted the overlapped echo components of received waveform, especially for the echo components corresponding with high degree of waveform overlapping (Figure 1 and Figure 2), the quantitative statistic of the comparison results in figure 1 and figure 2 are given by table 1 and table 2 respectively. In addition, the decomposition technique can also effectively extract the missing echo components (Figure 3), the quantitative statistic of the comparison results is given by table 3. Besides that, the modified waveform decomposition method can effectively extract the echo components from complex waveform (Figure 4), the quantitative statistic of the comparison results is given by table 4.

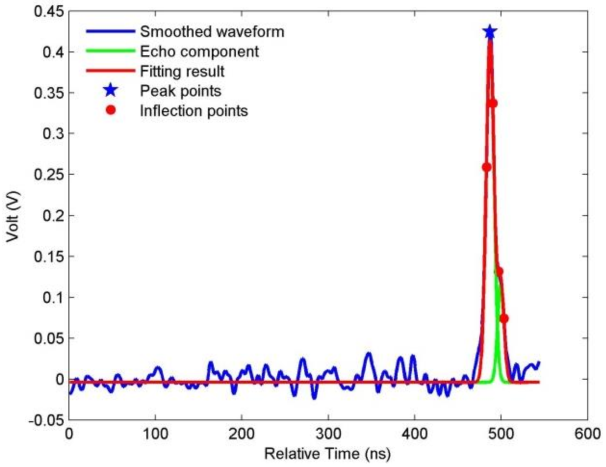

Figure 1. Example of waveform decomposition

Decomposition result	Paper		GLA14
A_i (V)	0.42	0.12	0.43
σ_i (ns)	4.44	3.66	4.47

Table 1. The quantitative statistic of the comparison results of waveform parameters from the decomposition technique in this study and GLA14

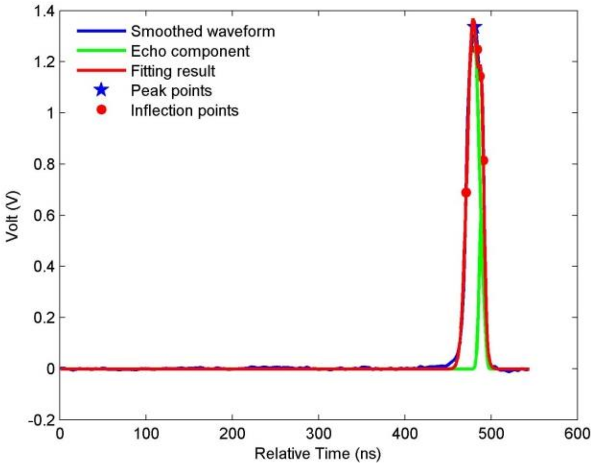

Figure 2. Example of waveform decomposition

Decomposition result	Paper		GLA14
A_i (V)	1.37	0.61	1.47
σ_i (ns)	6.84	2.76	7.77

Table 2. The quantitative statistic of the comparison results of waveform parameters from the decomposition technique in this study and GLA14

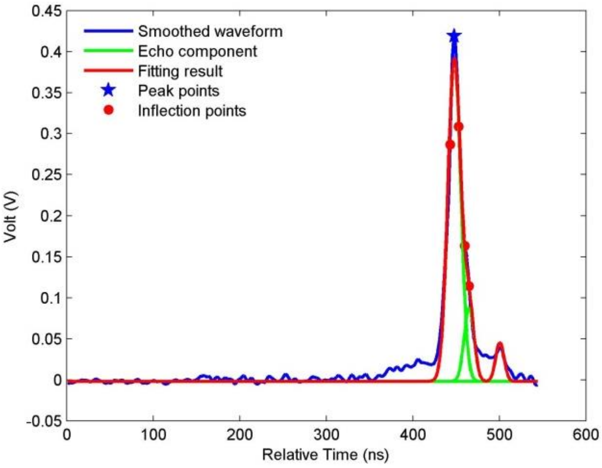

Figure 3. Example of waveform decomposition

Decomposition result	Paper			GLA14	
A_i (V)	0.39	0.09	0.05	0.41	0.10
σ_i (ns)	7.31	5.67	4.79	6.36	3.92

Table 3. The quantitative statistic of the comparison results of waveform parameters from the decomposition technique in this study and GLA14

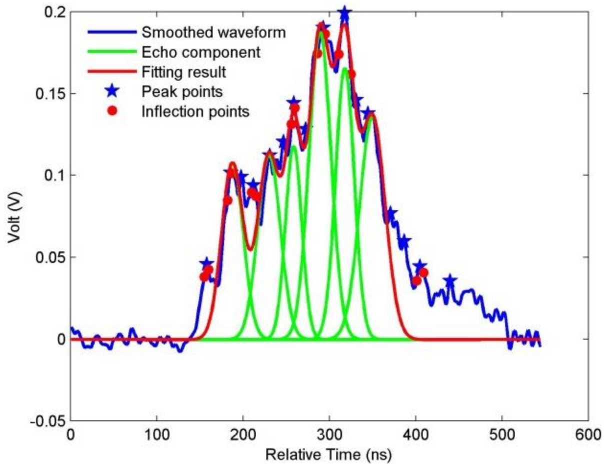

Figure 4. Example of waveform decomposition

Decomposition result	Paper					
A_i (V)	0.11	0.11	0.12	0.19	0.17	0.14
σ_i (ns)	12.47	12.98	9.40	12.65	10.73	14.69
	GLA14					
A_i (V)	0.07	0.05	0.02	0.17	0.03	0.01
σ_i (ns)	18.73	10.03	4.32	45.2	4.34	11.50

Table 4. The quantitative statistic of the comparison results of waveform parameters from the decomposition technique in this study and GLA14

4. CONCLUSION

The decomposition results show that the modified waveform decomposition method proposed in this paper can effectively extract the overlapped echo components, especially in the case of high degree of waveform overlapping. The modified waveform decomposition method can not only effectively extract the echo components which have far distance or low degree of waveform overlapping, but also effectively extract the echo components corresponding with high degree of waveform overlapping. Furthermore, in the general process of decomposing the full-waveform, it is easy to miss the echo component. The decomposition technique proposed in this paper can effectively extract the missing echo components.

But due to the complexity of surface properties, a large number of experiments should be conducted to test the effectivity of the decomposition technique, especially for the complex waveforms. In addition, more effective methods are needed to verify the accuracy of the decomposition results.

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