DEVELOPING A 3D WAVEFORM LIDAR SIMULATOR FOR FOREST

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ABSTRACT:

Waveform LiDAR systems is widely used in several fields such as terrain survey, disaster monitoring and forest monitoring. Especially, in forest research, using an echo signal is expected for understanding structural characteristics of the forest. However, an echo signal highly depends on the sensor configuration, the footprint size, the canopy structure, and terrain condition. Therefore, it is not easy to understand the forest attributes from the echo signal. In this paper, we describe the development and application of model which to simulate laser intersections within ideal forest environments and to visualize intersections. The developed model has three components. The first component was a creation of the forest environment as full polygon in 3DCG software. Characteristics of the forest was decided by individual trees which were generated by the plant growth model using species and planting years as the initial parameter. The second component was a simulation using a ray tracing to calculate intersections between the forest object and the modelled laser beam. In this study, a laser beam with a specific footprint and a pulse width was defined by spatiotemporal features. In point of view of spatial feature, numerous sub laser beams were generated within a specific footprint to make the laser beam hit the target uniformly. Each sub laser beam had the intensity which was calculated by both the distance from the center of laser beam and the TEM_{00}. On the other hand, in point of view of time feature, each sub laser beam was defined as several particles based on the sampling rate. Each particle had the intensity which was calculated by the pulse width and the sampling rate. The third component was a creation of an echo signal of a specific footprint using the calculated intersections and its intensity, reflectance of target at intersections and sampling rate. Moreover, the developed model had a view function that was able to show the calculated intersections on the surface of target object. As results of simulation of ideal forest environment scenarios, the developed model demonstrated that the model generated the echo signal of different environments well and the viewer function helped to understand the interactions between sub laser beams and target objects.

1. INTRODUCTION

Waveform data provides a valuable echo dataset for assessing forest structural attributes. However, it is not easy to interpret generation mechanisms of the echo signal of the forest. Because, the echo signal is dependent on the sensor configuration, the footprint size, the canopy structure and terrain condition. Many researchers have studied these influences using an actual data or a simulated data. Næasset (2004) demonstrated that differences in footprint size affected echo signal. Clark et al., (2004) showed that slope and vegetation density have been identified as variables which influence the accuracy of Digital Elevation Model (DEM) .

In order to understand the relationship between the echo signal and the sensor configuration and the target environment, a simulation model is useful. Sun and Randon (2000) developed the simulator for large footprint LiDAR that generated an echo signal using a forest 3D model and a radiative transfer model. Also, Goodwin et al., (2007) developed a simulator that generates an echo signal using the LITE model and a ray tracing approach. Overall, a definition of the forest structure is quite important in order to simulate an echo signal.

In this study, the development of new LiDAR waveform simulator using targets defined as full polygons discussed. The simulator used full polygons as the target environment to avoid an effect of gap probability. Intersections between the laser beam and the target was simulated by a ray tracing approach. An echo signal was calculated by intersections, reflectance at intersections, the pulse width, the sampling rate, and the intensity. In this paper, firstly, a detailed description about the developed model is given, and secondly, results of several scenarios are described.

2. FEATURES OF THE DEVELOPED MODEL

The developed model has several features. Firstly, targets such as the forest and terrain dataset are defined as full polygons in a 3DCG space. Secondly, phenology of the forest in the developed model is variable, since the plant growth model is used to generate the forest data. Thirdly, the illumination angle and the footprint size are variable. Fourthly, a laser beam is defined as sub laser beams with the intensity based on TEM_{00} in point of view of spatial feature. Also, sub laser beams are defined as particles in point of view of time feature. Numbers of particles are based on the sampling rate and the pulse width. Finally, intersections are visualized in 3DCG space to help understand an echo signal generation procedure.

3. DEVELOPMENT ENVIRONMENT

The development environment in this study shows as Table 1. Commercial 3DCG software was used to generate intersections using full polygons and a ray tracing approach. Matlab was used to generate an echo signal. Merits of using 3DCG software are the followings: using the commercial plant growth model software as add in for the 3DCG software, handling a large amount of polygons easily, calculating the angle between leaf inclination and the direction of laser beam easily and the availability of an external DEM dataset.

Programing languages for a ray tracing and for generation of an echo signal were Maxscript and Matlab language, respectively.

Hardware	OS: Win7 Professional. CPU: core i7, RAM:24GB, GPU:GeForce275 x 2	
Software	3ds Max 2011 x64 (Autodesk)	(3DCG space)
	natFX (Bionatics)	(Forest (tree) modeling)
	Maxscript (Autodesk)	(Ray tracing)
	Matlab 2010b (Mathworks)	(Echo signal simulation)

Table 1. The development environment

4. MODEL DEVELOPMENT

The developed simulator considers the following features: the sensor configurations, the laser beam definitions, the forest and terrain objects, the echo signal generation and the visualization of intersections.

4.1 Sensor configuration

The illumination angle, the footprint shape and wavelength of laser beam as the sensor configuration were considered. The illumination angle was variable. The footprint shape above the target was defined as a round with specific diameter. The illumination angle was rotated to Y axis. Therefore, the footprint shape on the ground depended on both the illumination angle of the laser beam and the shape of terrain surface. In this study, the beam divergence wasn't considered. The effect of wavelength of laser beam was considered as reflectance of the target at a specific wavelength.

4.2 Laser beam definition

Laser beam was considered in two features. One was spatial feature, the other was time feature. In point of view of spatial feature, a laser beam was defined as multiple sub laser beams. Spatial density of sub laser beams was $1/0.09m^2$ as default. In order to decide the value of spatial density, gap distributions were examined using a tree model of full polygons before. As a result, this value was reasonable in point of view of uniformly hitting sub laser beams to objects. Moreover, the intensity on cross section of laser beam also was considered. The intensity of the edge of footprint was defined as $1/e^2$ (TEM_{00}), since an actual distribution of intensity on cross section of laser beam was Gaussian distribution. On the other hand, in point of view of time feature, sub laser beams were defined as multiple particles based on the sampling rate and the pulse width. Each particle had different value of intensity based on an actual pulse intensity.

4.3 Forest and terrain objects

The forest consisted of several trees, and these trees created by the plant growth model (natFX). Each tree was full polygons in order to avoid the effect of a gap function. Each tree was created by initial parameters which are species and planting year. If tree shape is needed to fit an actual shape, its shape is able to be modified to any shape in 3DCG software. On the other hand, distribution of trees was able to be located based on an ideal condition or an actual condition by manual.

There are two ways to deal with terrain data in the developed simulator. One way is automatically generating a plane object under forest object as the ideal condition. The other way is importing an external DEM data of DXF format.

Furthermore, each object had a specific reflectance derived from literatures or actual hyperspectral data.

4.4 Echo signal generation

Echo signal was generated by synthesizing wave propagation of each sub laser beam. At first, multiple cells were generated by using number of the sampling and a range of each cell had the distance calculated by light speed and the sampling rate. Secondly, the start position of cell number corresponding to particles of sub laser beam was calculated by using initial positions of sub laser beams and its intersections. And the intensity at each cell was calculated by using both the intensity of particles and the reflectance of target. The echo signal was generated by the summation of each value at cells.

4.5 Visualization of intersections

In order to understand the interaction between sub laser beams and targets, the developed simulator implemented visualization function. The position the particle with highest intensity hit against was visualized to understand the interactions between sub laser beam and targets.

5. SIMULATION METHODOLOGY

The echo signal was simulated by the following two steps: (1) the calculation of intersections and (2) the generation of echo signal.

5.1 Input and output parameters

In order to calculate intersections, initial input variables were the diameter of footprint (m), the illumination angle (degree against Y axis) and the Z value at the center of the forest object (m). The illumination angle defined the direction vector of laser beam. The diameter of footprint and the illumination angle defined the initial the position of each sub laser beams. The Z value defined an adjustment value to fix a viewpoint, in order to compare results from any simulation at several illumination angles. Output parameters in this procedure were the followings: the initial position of each sub laser beam, intersections between each sub laser beam and the target, the intensity of each sub laser beam and a flag of target type. Next, in order to generate an echo signal, input variables were the sampling rate and the reflectance of target based on the flag. Output parameters in this procedure were a csv file of echo signal and display of a graph of png format.

5.2 Simulation flow

The echo signal was generated by the following steps. The flow chart was a case of using a plane object as the ground.
-Calculation of intersections-
(1) Creation of the forest object using natFX in 3DCG software.
(2) Input of the diameter of footprint size, the illumination angle and the Z value at the center of the forest object, as initial parameters.
(3) Generation of initial points of sub laser beams with in the footprint area.
(4) Calculation of the intensity of each initial point based on TEM_{00}.
(6) Rotation of initial points to Y axis using the illumination angle and moving it to above the forest object.
(7) Creation of the ground plane object under the forest object.

(8) Adjustment of the position of the forest and the ground object to fix viewpoint.
(9) Execution of a ray tracing between the objects and the initial points.
(10) Output of the position of initial points, intersections, the intensity and the flag of object type.

- Generation of echo signal-
(1) Read of the output file.
(2) Input of the reflectance of each object, the sapling rate and the illumination angle.
(3) Generation of cells using the sampling rate and the illumination angle.
(4) Calculation of intensity of each particle using its intensity and the reflectance of target type.
(5) Decision of the start position of particle of a sub laser beam using the distance between initial positions of each laser beam and the intersection.
(6) Summation of the intensity at cells.
(7) Output of the echo signal as csv format and display of the graph of the echo signal.

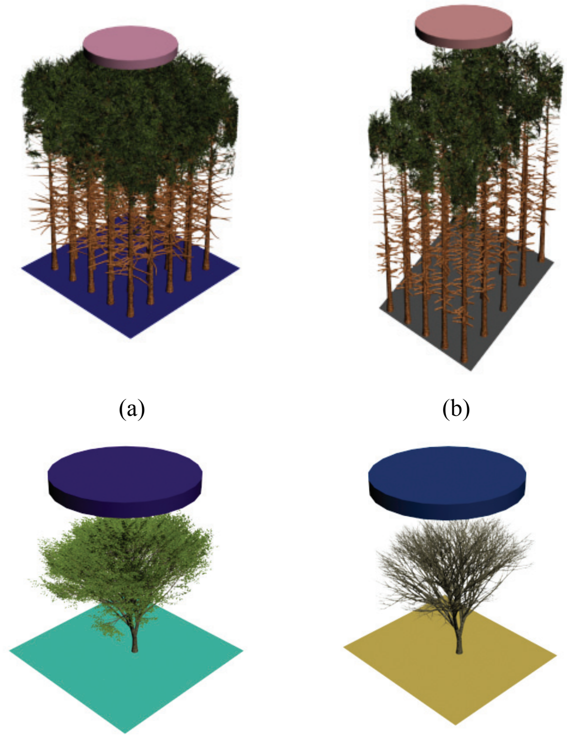
6. SIMULATION SCENARIOS

Several simulation cases were tested in order to examine a performance of the developed simulator. Table 2 shows lists of simulation cases. The footprint size and the reflectance of target types used common values in all simulation cases. The footprint size was 10m. The reflectance of the forest and the ground were 0.5% and 0.3%, respectively.

No.	Species	Tree density	Phenology	Illumination angle (degree)	The ground slope angle (degree)
1	*Japanese cedar*	low	summer	0	0
2	*Japanese cedar*	low	summer	6	0
3	*Japanese cedar*	low	summer	0	30
4	*Japanese cedar*	low	summer	0	-30
5	*Japanese cedar*	low	summer	6	30
6	*Japanese cedar*	low	summer	6	-30
7	*Japanese cedar*	high	summer	0	0
8	*Japanese cedar*	high	summer	6	0
9	*Japanese cedar*	high	summer	0	30
10	*Japanese cedar*	high	summer	0	-30
11	*Japanese cedar*	high	summer	6	30
12	*Japanese cedar*	high	summer	6	-30
13	*Zelkova serrata*	isolated	summer	0	0
14	*Zelkova serrata*	isolated	winter	0	0

Table 2. The list of simulation cases

Figure 1 shows several samples of initial conditions of the simulated scenarios. Figure 1 (a), (b), (c) and (d) stands for corresponding to scenario no.1, no.3, no.13 and no.14, respectively. The discus object above the forest or the tree object stands for an irradiated area of a laser beam. The plane object under the forest and the tree object stands for the ground. In case of these simulations, the ground plane was generated automatically.



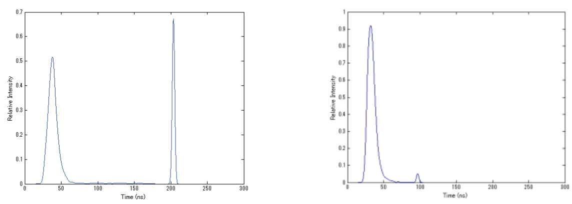
(a) (b) (c) (d)

Figure 1. Overview of several samples of initial conditions of the simulated scenarios. (a), (b), (c) and (d) stands for corresponding to scenario number 1, 3, 13 and 14, respectively.

7. RESULTS AND DISCUSSIONS

7.1 The difference of echo signals between conical shaped and bowl shaped canopy.

Figure 2 is the echo signals of scenario no.1 and no.13, respectively. As a result of analysis of the echo signals, the first peak corresponded to surface of object and the second peak corresponded to the ground.



(a) (b)

Figure 2. The simulated echo signals of scenario no.1 (a) and no.13 (b)

In comparison with echo signals between *Japanese cedar* and Zelkova *serrata*, the initial slope of the first peak of *Zelkova serrata* was steeper than that of *Japanese cedar*. Crown shapes of *Japanese cedar* and *Zelkova serrata* are the conical- and the bowled-shaped, respectively. We considered that the reason of the difference was the shape of crown. As the results, we considered that the developed simulator was able to simulate the difference of shape of crown well.

7.2 The effects of the illumination angle and the slope of the ground

Figure 3 is the effect of the illumination angle and the slope of the ground. Figure (a), (b), (c) and (d) stands for scenario no.1, no.2, no.3 and no.5, respectively. Full width half maximum (FWHM) of (b) became wider than that of (a), since optical paths between these were changed. In comparison with between (a) and (c), the echo signal of (c) differed significantly from (a). FWHM of the first peak of (c) was wider and the second peak had two peaks. On the other hand, in case of (d), the two peaks of the second peak in (c) disappeared in (d).

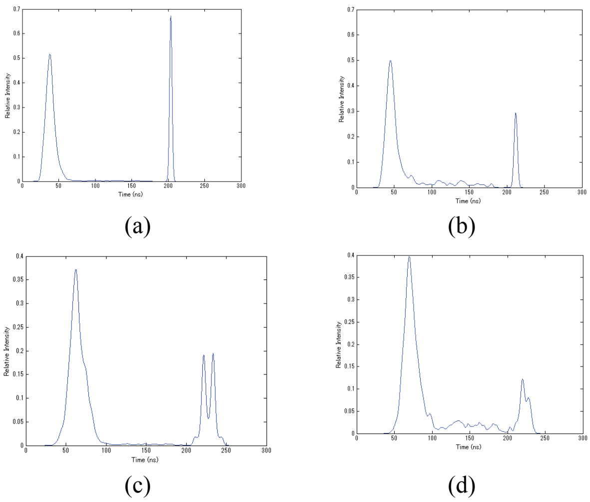


Figure 3. The effect of the illumination angle and the slope of the ground. (a), (b), (c) and (d) stands for scenario no.1, no.2, no.3 and no.5, respectively.

7.3 Comprehend of the elementary process of the generation of echo signal using the visualization tool

It is difficult to understand the elementary process between the laser beams and the object using only the results of the echo signal. For example, in case of scenario no.3, the second peak had two. However, in case of scenario no.5, two peaks disappeared. Then, the reason was considered using the visualization tool. Figure 4 shows the results of visualization of intersections derived from scenario no.2 (a) and no.5 (b). Sub windows stands for view at different directions, respectively. The upper left window is top view, the upper right window is left view, the bottom left window is right view and the bottom right window is perspective view. Dot symbol is intersections between sub laser beams and objects. As a result of analysis of intersections on the objects, two peaks corresponded to the distribution of intersections (bottom left view of (a)). There were two areas which had high density intersections on the surface of the ground. On the other hand, in case of figure 4 (b), high density area was one (bottom left view of (a)). The visualization tool was able to help to comprehend the elementary process of the generation of echo signal.

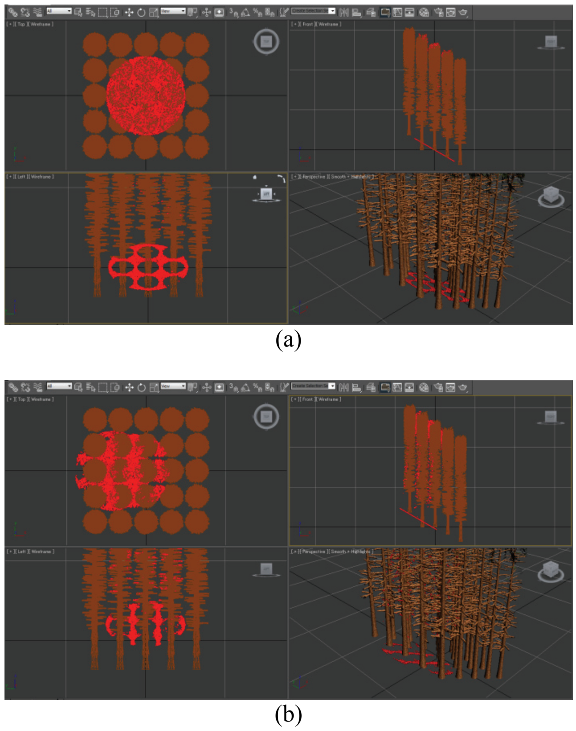


Figure 4. The results of visualization of intersections derived from scenario no.2 (a) and no.5 (b)

8. CONCLUSIONS

A waveform simulation model for complex forest environments using 3D object was presented in this paper. Since the echo signal depends on the sensor configuration, the target structure and terrain condition, we implemented these features in the simulator. According to the simulation using scenarios, these results indicated that the simulator was able to generate the echo signal under various conditions. Moreover, the visualization tool indicated that it was quite useful for understanding the elementary process of the generation of echo signal.

However, the simulator is preliminary result and we have not evaluated the simulator by an actual data yet. Moreover, an effect of noise has not been validated.

In our future work, we plan to evaluate the simulator by using an actual data.

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