Airborne Lidar Data Processing and Information Extraction

by Qi Chen

Lidar is changing the paradigm of terrain mapping and gaining popularity in many applications such as floodplain mapping, hydrology, geomorphology, forest inventory, urban planning, and landscape ecology. One of the major barriers for a wider application of lidar used to be the high cost of data acquisition. However, this problem has been greatly alleviated with the thrilling developments in hardware. The first commercial airborne lidar system was introduced just ten years ago (Flood, 2001). Now, the latest system is capable of transmitting 100,000 pulses per second from an altitude of up to 2km. The pulse repetition rate has reached a maximum of more than 150 kHz and has increased by about 10-fold within the last 5 years; correspondingly, the cost of data collection has decreased by about 10 times within the same time period. Nowadays users can obtain data with a density of >1 pulses per m2 for several hundred dollars per square mile. The dramatically decreasing cost of data collection encourages more and more users to embrace this innovative technology in their application and research. For example, North Carolina has collected statewide lidar to help the Federal Emergency Management Agency (FEMA) update their digital flood insurance rate maps (Stoker et al., 2006). A wealth of free lidar data are also accessible to the public from the websites maintained by governmental agencies such as the U.S. Geological Survey (the Center for Lidar Information, Coordination and Knowledge: CLICK), National Oceanic and Atmospheric Administration (Coastal Service Center), and U.S. Army Corps of Engineers (the Joint Airborne Lidar Bathymetry Technical Center of Expertise: JALBTCX).

Although lidar data has become more affordable for average users, how to effectively process the raw data and extract useful information remains a big challenge. Compared to image processing, lidar is appealing in many aspects. For example, the users do not have to worry about geometric, atmospheric, and radiometric corrections. However, lidar data have some characteristics that post new challenges. First of all, lidar is essentially a kind of vector data. Different from raster data, the spatial locations of laser points have to be explicitly stored, making the file size much larger than imagery given the same "nominal" spatial resolution. Second, how to extract useful information from these seemingly random points is a relatively new research topic. The generation of digital elevation models (bare earth) is the largest and fastest growing application of lidar data (Stoker et al., 2006). However, the research on automating the production of bare earth is still in its infancy. To make this situation worse, until recently, researchers tended not to publish their methods (Zhang et al., 2003, Chen et al., 2007). Besides terrain mapping, there is an endless list of areas where lidar has a potential application but they have not been adequately explored. I have developed a software (dubbed Tiffs: Toolbox for Lidar Data Filtering and Forest Studies) for processing lidar data and extracting bare earth and forest structure information. I will discuss the challenges and needs for lidar data distribution, management, and processing. I hope this article can shed light on the topic, not only for other software developers, but also for data providers and end users of lidar.

Tiffs: A Toolbox for Lidar Data Filtering and Forest Studies

Tiffs is a software dedicated to filtering point cloud, generating bare earth, and extracting individual tree structural information. It includes such functions as importing/exporting files, organizing the raw data into tiles, filtering point cloud, generating DEM, digital surface model (DSM), and canopy height model (CHM), isolating individual tree crowns, and extracting individual tree structural information including tree height, crown area, trunk height, biomass, etc. It also includes the function of simulating the waveforms from point cloud for the purpose of validating satellite GLAS (Geoscience Laser Altimeter System) data.

Tiling Lidar Data

Tiling means that the raw lidar data are reorganized and stored in contiguous regular tiles. There are at least two reasons for tiling the lidar data: 1) the raw lidar data files commonly have a size of several hundred Megabytes. There are some files in the CLICK website that are about 2 Gigabytes large, which are difficult to store in a computer's memory with a 32-bit Operation System (OS), and 2) the raw lidar data are recorded along the flight line when the data were collected. Therefore, the raw lidar data files usually contain narrow and long strips of points. Such a data format is inefficient for the subsequent data processing in terms of memory allocation and algorithm design. For example, if a grid is used to store a long strip of data, a very large matrix should be allocated in the computer and many elements of the matrix will have no values. Figure 1 shows the effects of tiling on managing raw lidar data.

Filtering Point Cloud

Filtering the point cloud into ground and non-ground returns is the core component of a lidar data processing software. Only if the point cloud is filtered it is possible to generate a bare earth and perform further analysis such as deriving the height information for trees and buildings. Unfortunately, only a few lidar softwares have the capability of filtering point cloud. The major problems with the current filtering methods are that 1) the processes are not automatic and they usually require parameter tuning and manual editing of

continued on page 110

continued from page 109

the filtering results, 2) most of the methods involve iterations and so they are computation intensive and time consuming, which is a serious problem for processing such a massive volume of data. The filtering method by Chen et al. (2007) is used in Tiffs. Since this method is grid-based, the filtering process is very fast. Chen et al. (2007) compared their method with the other eight algorithms provided by ISPRS using the benchmark dataset. It was found that their method achieved the best overall performance. In Chen et al. (2007), the classified ground returns were interpolated into a DEM with ArcGIS. Tiffs uses a different interpolation method to increase its speed. Figure 2 and the cover image show the interpolated DEM from the ground returns.

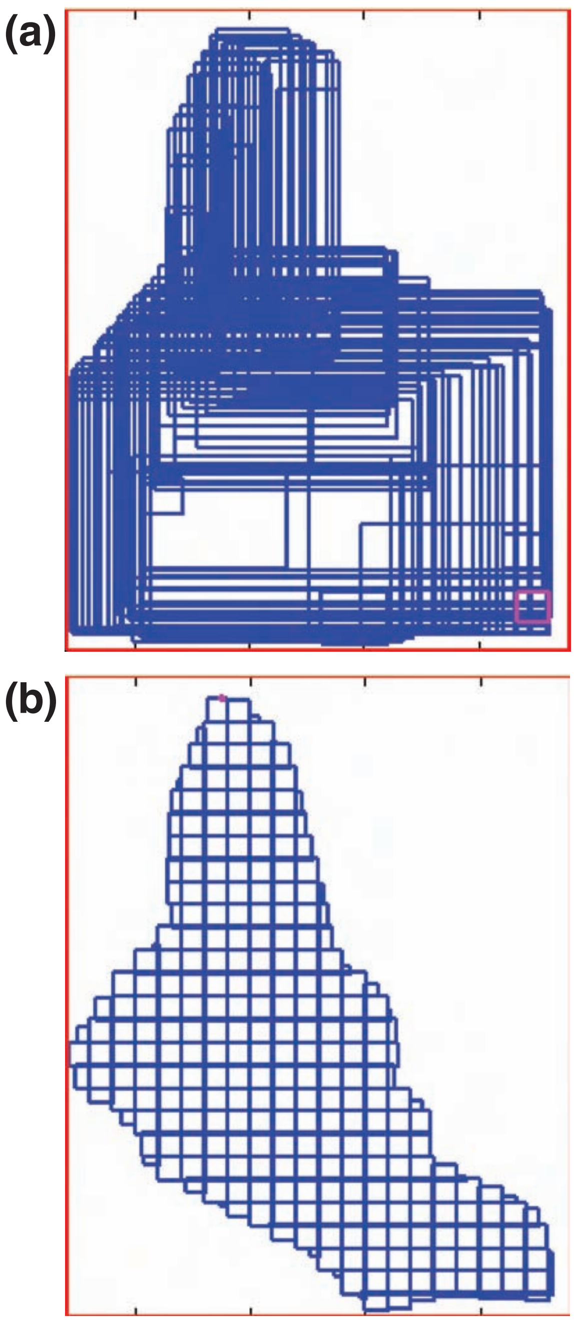

Figure 1. Tiling the raw LIDAR data to more effectively manage the data. Each rectangle represents the minimum rectangular that encircles the data in that file. (a) and (b) show the rectangles that encircles the files before and after tiling, respectively.

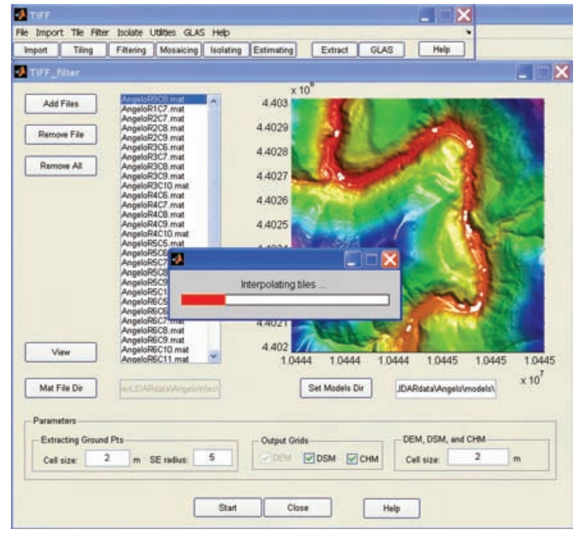

Figure 2. Tiffs is running for filtering point cloud and generating DEM, DSM, and CHM. The white spots in the image are the areas with missing data caused by the water in the river.

Isolating Individual Trees

Tiffs was originally developed to facilitate the extraction of individual tree structural information from discrete-return lidar data for spatially explicit ecological modeling. Trees are isolated using a marker-controlled watershed segmentation method (Chen et al., 2006). The key for the success of tree isolation is to find the proper treetops from the canopy height model derived from lidar data. Chen et al. (2006) proposed a treetop detection method that can minimize both commission and omission errors simultaneously. Tiffs used an improved method so that the trees can be isolated with a short period (It typically takes 10-20 seconds to isolate trees within an area of 1 square kilometer). Figure 3 is an individual-tree map based on the tree isolation results for a savanna woodland in California.

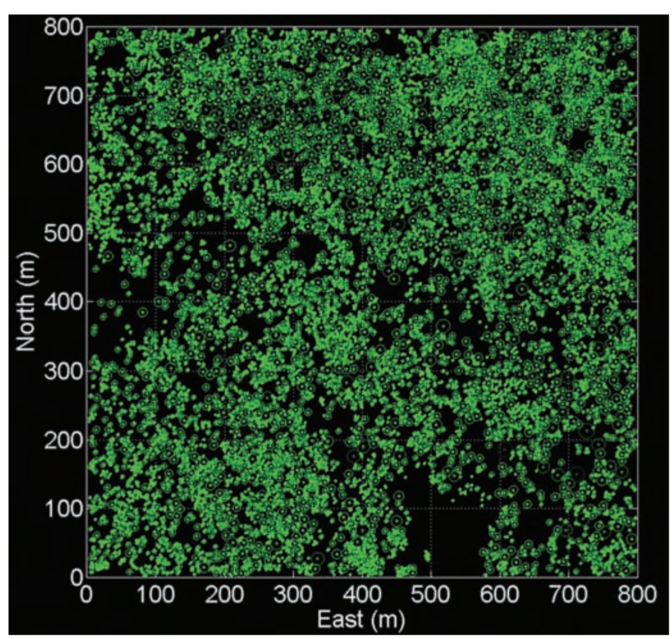

Figure 3. An individual-tree map based on the tree isolation results from Tiffs. The dot within each circle indicates the treetop locations.

Extracting Individual-tree Structural Parameters

Although lots of research has been done to extract canopy structural information, only a few have focused on it at the individual level. Tiffs can extract not only individual-tree height, crown area, and trunk height but also basal area, biomass, and leaf area. The extraction is based on the theory presented by Chen et al. (in press), which showed that the estimation of structural information such as basal area and biomass is the least affected by the tree isolation results when the prediction is based on a metric called canopy geometric volume. The canopy geometric volume is the volume encircled by the outer surface of the crown, which can be easily derived by combing the canopy height model and individual-tree crown map. Figure 4 shows the 3D display of individual-trees at the savanna woodland site, where the color of the individual tree is related to the leaf area of each tree.

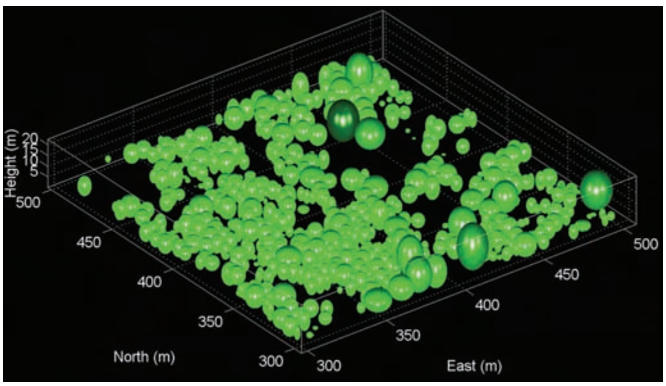

Figure 4. A 3D display of the individual trees based on the structural information estimated by Tiffs. The color of each tree is related to its leaf area.

Providing "Ground-truth" for Other Data

Due to the high accuracy of height measurements and small footprints of discrete-return lidar, the point cloud and its derived products can potentially act as the ground truth for many applications. For example, it is arguably true that the discrete-return lidar can achieve better accuracy of height measurements at the individual tree and stand levels than field methods. Tiffs provides a function of simulating satellite GLAS waveforms from airborne lidar data (Figure 5). The comparison of simulated waveforms with measured waveforms can help reveal the effects of such factors as terrain slope and canopy cover on the estimation of canopy height from satellite waveforms. We are doing research to map the global canopy height from GLAS data. The validation of height estimation globally is a demanding task if tree height has to be measured in the field. We are using the tree height derived from airborne lidar data as the replacement of the field measurements for validation. It is expected that airborne lidar data can be the ground truth for many other purposes such as validating canopy cover, biomass, and leaf area index derived from imagery.

In general, Tiffs has a user-friendly interface and convenient visualization functions. The algorithms used in the software typically require only a few input parameters, which can be easily set up. Speed and accuracy were the two major concerns when the software was designed. For an area of 1 square kilometer with a pulse density of 5 points per m2, it commonly takes 1-2 minutes to filter the point cloud, generate DEM, CHM, and CSM, isolate individual trees and extract their structural information on a personal computer.

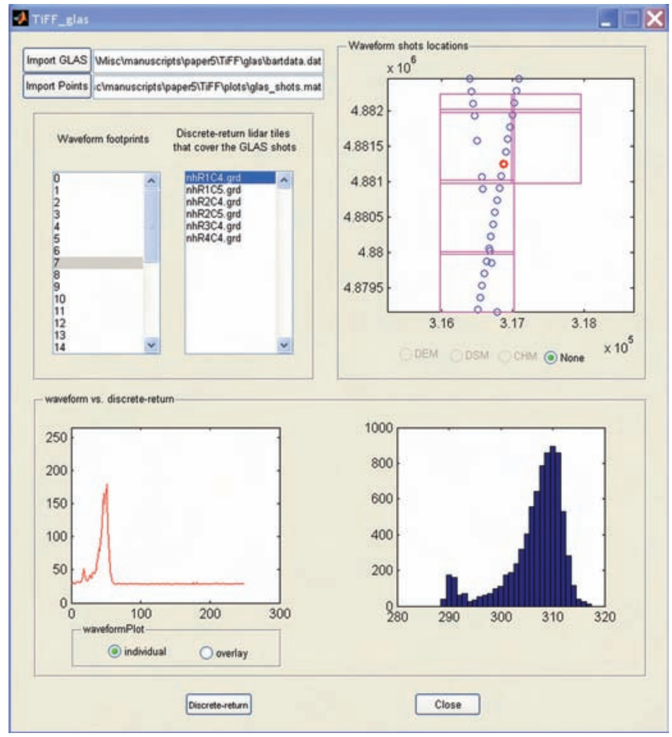

Figure 5. The interface of Tiffs for simulating waveforms from point cloud.

Discussion

Pre- and post-processing Software

Lidar software can be divided into two categories: pre-processing software and post-processing software. The pre-processing software is mainly used by data providers. This kind of software should have the capability of visualizing point cloud quickly and intuitively, transforming geoid and coordinate systems flexibly, and supporting a variety of output formats. The post-processing software is supposed to have diverse data processing and information extraction functions; however, the core function is filtering the point cloud into ground and non-ground returns. After the points are classified, the ground returns can be used to generating a DEM. The canopy returns can be used to extract forest structural information; and the building returns can be used to model the building shapes.

Tiffs is mainly a post-processing software. An important function in Tiffs is tiling the raw data. However, it is also essential for the developers to be aware of the usefulness of such a function in the pre-processing software. If the data provider distributes a tiled dataset over a website such as CLICK, it will save the efforts of every user of the dataset to tile the dataset by him/herself.

Data Exchange Format

The raw lidar data are usually exchanged with either a LAS binary format or an ASCII format. LAS format is a standard data exchange format proposed by the ASPRS Lidar Subcommittee. However, there is no standard format defined for exchanging lidar data in an ASCII format. For example, for the lidar data collected with a multiple return system, the several returns for the pulse can be recorded in one single row or several rows with one return per row.

There are potential advantages to storing the returns from the same pulse into a single row in an ASCII file. In so doing, it is easy

continued on page 112

continued from page 111

to find the several returns from one pulse. The spatial relationship among the returns could be useful for many purposes. For example, if a pulse hits the ground, the distance between first and last returns should be very small; however, if a pulse hits the canopy, the distance is usually large. Such information can be used for filtering point cloud. Moreover, the analysis of the penetration probability of a laser pulse within a canopy provides the possibility of deriving canopy structure information, such as leaf area index, based on radiative transfer models. An alterative of linking the multiple returns is to add a field that indicates the pulse number, which may be considered in the design of LAS version 2.0.

From the perspective of software design, the developer should consider the variety of raw data format and make the software work in all possible cases. From the perspective of making a contract with commercial vendors, users should be aware of the strengths and weaknesses of different data formats in order to order the appropriate data.

Fusion with Imagery

The major limitation of an airborne lidar system is that it mainly consists of the coordinates and has limited spectral information about the surface. It was recognized many years ago that it is, in many cases, impossible to interpret lidar data unless oriented images are available (Axelsson, 1999). However, even today most of the airborne lidar data are distributed without the accompanying images. This makes it difficult to validate the results from various information extraction methods. Airborne lidar data and imagery are highly complementary. The images can validate the filtering accuracy while the elevation information from lidar can be used to orthorectify images. In the future software, it is in great demand to include the functions of seamlessly integrating these two types of data. But at this stage it is important, at least for the end-users, to understand the importance of images when ordering their data and for the data providers to distribute their images.

In summary, lidar is a fast-growing field that changes quickly. To make more people benefit from this innovative technology, it is essential to let users learn what lidar can do. Also, it is crucial for the commercial vendors and researchers to understand the needs of users so that we can provide the best products to maximize the usage of lidar.

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