LiDAR Review for the Sierra Nevada Adaptive Management Project (SNAMP)

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Background

Although the use and popularity of LiDAR (light detection and ranging) is currently on a remarkable rise in the scientific, commercial and government communities, the concept has been developed and used for nearly a century. Advancements in laser and sensor technologies as well as increased availability of computing power and access to the storage required to analyze such data have contributed to increased use of laser data in remote sensing.

As the advantages of LiDAR became clear, the commercial sector took note and made the technology marketable and, effectively, more accessible. Despite the availability of technology, the cost of acquiring laser data over large extents was mostly prohibitive until recently. Although the data is still expensive in comparison to other remotely sensed products such as high-resolution imagery, the cost has dropped enough to make its acquisition possible. Currently, LiDAR data is used for a range of applications including railroad and electric grid mapping, atmospheric sensing, accurate topography and bathymetry of the earth and other planets, landscape architecture, and analysis of forest structure. This summary will concentrate on the analysis of forest structure. We will also be using LiDAR data for watershed analysis. We briefly describe LiDAR's basic principles, review its uses in previous studies, and indicate its significance in the Sierra-Nevada Adaptive Management Project. This document will continue to be developed, and forms part of a chapter in Marek Jakubowski's dissertation research. All comments can be directed to Maggi Kelly at maggi@berkeley.edu.

Technology and Basics

LiDAR system works by "sounding" light against a target in a similar way to sonar or radar. The actual concept that makes LiDAR work is quite simple. First, the system generates a short pulse of electromagnetic energy at a specific wavelength (i.e. a laser pulse) and directs it towards a target. In our case, the sensor is attached to the underside of an aircraft and the laser is directed towards the ground. The wavelengths used are typically in the visible or near infrared region of the electromagnetic spectrum, mostly because the production of such lasers is inexpensive. The laser pulse propagates towards the earth and interacts with material; light can be reflected, absorbed or transmitted by material. A portion of the light is then reflected back towards the airborne sensor where it is detected and recorded. The time between sending the pulse out and its collection is measured and converted to distance by using the speed of light. Simultaneously, the aircraft's exact position and orientation is measured by an on-board global positioning system (GPS) and inertial measurement unit (IMU). The combination of all the above measurements allows us to backtrack and calculate the elevation at which the light pulse was reflected.

In the simplest case, light is reflected from the earth back to the airborne sensor where it is measured and converted to ground elevation. In a more complex situation, for example over a forest, the light can be reflected either by the ground, by the top of a tree, or it can be scattered by the branches and leaves before returning to the sensor. In a more realistic situation, the light can also undergo more convoluted behaviors such as scattering by the atmosphere and reflecting from a target towards a completely different direction, in which case it is never detected. We will ignore such cases for the purposes of this summary. The above process is repeated many times at a high frequency (up to hundreds of thousands times per second) to map out the surface structure below. Clearly, this collection method quickly leads to immense number of measurements over a relatively small area. Large file size is one of the challenges of processing and storing LiDAR data. This predicament is compounded by the fact that we can have multiple measurements for any sensed light pulse, as described below.

Initially, laser systems were capable of simply detecting a returned pulse (or "a return"). Better understanding of the laser ranging system and improvements in technology led to more comprehensive measurements. Many commercial LiDAR systems are now capable of collecting four or more returns *and* their intensities for each sent pulse – that is eight recorded values for every sensed location. Although this significantly increases the size of data and slows down its analysis, the additional information is very valuable.

In a forest setting, multiple returns are fractions of the primary laser pulse reflected by the many parts of tree crown, branches, shrubbery, or the understory. Their significance comes in the ability to describe forest structure as opposed to simply the average elevation of an area. The pulses' returns can be recoded in addition. The intensity of a pulse is related to the reflectance (i.e. albedo) of the target material – high intensity indicates a highly reflective material such as white paint or bright sand.

There are currently two common types of LiDAR systems: full waveform and discrete, small footprint pulse. Thus far, we have only described a discrete pulse system. The major difference between waveform and discrete system can be attributed to their characterization of vertical structure of measurement – where a pulse system collects, say, four vertical points at a location, the waveform system completely describes the vertical characteristic. In that sense, waveform LiDAR can provide much better description of forest structure than a discrete system. On the other hand, the footprint and spatial resolution of a waveform system is typically much larger and therefore does not provide as much detail about the forest system as a discrete system. The spatial team feels that the benefits and efficacy of a discrete system outweigh currently available waveform LiDAR and therefore this is the system we will be using in SNAMP.

Another important aspect of LiDAR data is its point density, usually specified in number of points per unit of area. There are a number of aspects that influence the density of laser data. From the physical perspective, point density depends on the aircraft's altitude or above ground level (AGL). The closer the sensor is to the ground, the higher the density of the data. Conversely, as AGL decreases, the aircraft must stay in the air for a longer time to cover the same amount of area, which significantly increases the acquisition costs. Point density also depends on the technical aspects of the sensor. For a while, systems collected data at about one pulse per square meter, although this figure varies from project to project and, on average, increases over time. Our data has been collected at nine points per square meter.

Utilizing LiDAR

LiDAR is used to produce a number of valuable spatial information. New innovative uses are constantly reported in scientific journals and conferences as laser altimetry is currently a very active research area. We will summarize a few common uses of LiDAR below.

LiDAR data is typically delivered as a "point cloud," a collection of elevations and their intensities that can be projected in a three-dimensional space. One of the most common uses of laser altimetry, and typically the first step in analyses, is to transform the data into a bare earth model. The bare earth model is an approximation of the ground if all objects above surface were removed. Kraus and Pfeifer (1998) show one way to obtain this goal in their 1998 study. Currently, nearly all software packages that process laser altimetry data can estimate what such a surface would look like and output a detailed digital elevation model, or DEM. After the DEM is estimated and validated, it is relatively a straightforward task to convert the product into slope and aspect, both important characteristic in vegetation analyses. Naturally, we are interested in more than just the topography of our study sites. Scientists have begun to use LiDAR data to extract information not just concerning the ground surface but also what is above it. Most of such information extraction is possible due to either the waveform or the multiple-return nature of laser data.

Another typical step in processing LiDAR data is to extract individual trees. There have been a number of studies that accomplished this with a reasonable degree of precision. Chen (2006) isolated individual trees with 64% absolute accuracy at a study area located near Ione, CA, which was covered in a savannah woodland mostly composed of separated blue oaks. The project used similar point spacing to the data recently collected for SNAMP. Other research shows that it is more feasible – or more accurate – to isolate trees by combining laser altimetry with remotely sensed imagery. For instance, Leckie et al. were able to separate trees with "80-90% good correspondence" with ground truth by combining LiDAR data with multispectral imagery.

Some of the parameters extracted in the recent literature include estimates of forest structure critical in fire research. Andersen et al. (2005) and Riano et al. (2003) provide good examples where such parameters are derived. For instance, Andersen et al. (2005) derives stand height, canopy cover, canopy bulk density, and canopy base height. The parameters are correlated with ground truth data based on height quintile estimators of the laser data. The reported accuracies ranged between r^2=0.77 and r^2=0.98, with canopy height being most accurate and canopy base height the least accurate. This study is particularly interesting because its objectives are similar to ours: they were deriving input parameters for Finney's FARSITE wildfire model.

LiDAR in SNAMP

Currently, LiDAR is the most critical spatial data collected over study sites for SNAMP. As the science team, we look forward to analyzing this data to better understand the tree structure of our forests and to improve fire modeling in our studies. We anticipate the data to be very useful in analyzing our sites and are investigating new techniques to extract information from the data. At the same time, we would like to acknowledge that although LiDAR data collected by NCALM is expected to be of great quality, it may not explain the whole picture needed for a thorough analysis of the forest composition. Either high spatial resolution imagery or hyperspectral imagery is expected to greatly improve our analysis capabilities. At this point, we are still investigating the most useful, efficient, and cost-effective path to meet our goals.

This summary is still at a beginning stage of a more detailed and sophisticated review of current LiDAR data and techniques. The more refined version is expected to be prepared before 2008 Q4 SNAMP meeting.

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