Interpolation Techniques for a LIDAR Profiler System

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Abstract : A nonuniform interpolation technique for use in a LIDAR profiler system is presented. The technique has been implemented to obtain the ground and canopy cover profiles from LIDAR profiling data containing ground and vegetation information, and it entails a two-stage process. In the first stage, the irregularly spaced data points are interpolated to regularize the data points. In the second stage, uniform interpolation is applied to the regularized data points to obtain the required profiles.

1. Introduction

For many years topographic mapping has been based on field measurements, which are both cost ineffective and time inefficient [1,2]. Thus, the impetus exists for developing airborne laser technologies for application to surveying and mapping. An airborne laser system offers opportunities for rapidly estimating tree heights, ground elevation, timber volume, and forest biomass over extensive areas [2-5].

This paper is concerned with nonuniform interpolation algorithms that can be used to obtain the ground and canopy cover profiles from data acquired using a LIDAR profiler system. A laser profiler mounted in a small twin-engine aircraft was used to measure the distance between the aircraft and the landscape surface as defined by any object reflecting the laser pulse (i.e., soil, rock, vegetation, man-made structure etc.). Elevation is calculated for each laser measurement based on known elevations along the flightlines.

From the irregularly spaced data points ground hits and vegetation top hits are identified. A new method of interpolation is used to obtain the ground and canopy cover profiles which are generated through an iterative scheme applied to the irregularly spaced data points, approximated by data points placed at dyadic rationals.

2. Problem formulation

Definition: A point on the variable axis is said to be a binary rational at scale j if it can be expressed as $k/2^j$ for some integers j and k.

The data values can be approximated by a set of binary rationals for a certain j and, therefore, the problem can be formulated as the task of finding a continuous-time function which interpolates on a set of binary rationals obtained from the given original set of data points. In our case, the generated set of binary rationals corresponds to the ground hits or the vegetation top hits.

3. Methodology

The LIDAR profile data contains ground hits, and may also contain vegetation top hits as well as hits from leaves of trees which may not be at the top. Thus to get a profile of the ground and the canopy cover, ground hits and vegetation top hits are first identified. After the ground hits and the vegetation top hits have been grouped, an interpolation technique is used to fit a smooth curve to denote the profile of the ground and the canopy cover. As the data points are irregularly spaced a nonuniform interpolation technique has been used to get the profiles.

A set of nonuniformly spaced data points can be approximated, within allowed error limits, with a set of data points placed at binary rationals. The new set of data points can then be considered as a set of regularly spaced data points with missing data points in between. The interpolation process for nonuniformly spaced data points can, therefore, be regarded as a two stage process. In the first stage, the missing data points are filled up with suitable data, using the local characteristics of the data set. This lays the foundation for a uniform interpolation of the data in the second stage.

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3.1. Pre-processing of data

The LIDAR profile data as provided by Terra Surveys Ltd. consists of Northing, Easting, elevation, and time. This data is processed to get just the elevation and time which is then considered to be the data for further analysis.

A moving window of certain length is selected and is moved over the 1-D data of elevation versus time. The data point having the minimum elevation value within the window is adjudged as a ground hit and the maximum elevation value within the window is adjudged as a vegetation top hit. The adjudged ground and vegetation top hits are grouped separately. The data points are then interpolated and a smooth curve is fitted to get the profile of the ground and the vegetation top individually.

3.2. Nonuniform interpolation

In a multiscale interpolation method one approximates the original set of irregularly spaced data points $\{t_k, k \in Z\}$ by a set of binary rationals denoted by $\{t'_k, k \in Z\}$. The problem for this case can thus be stated as finding a continuous-time function $\tilde{f}(t)$ with certain degree of smoothness such that for a given set of point values $\{v_k = f(t_k), k \in Z\}$, we have $\tilde{f}(t_k) = v_k$ for $k \in Z$.

The approximation used is justified by two reasons: for an arbitrary t_k and a given tolerance ϵ, there always exists a binary rational t'_k such that $\mid t_k - t'_k \mid < \epsilon$, and for a smooth $f(t)$ the error $\mid f(t_k) - f(t'_k) \mid$ can be made arbitrarily small with a binary rational t'_k.

Each t'_k can be expressed as $k'/2^j$ for some integer values k' and j. The maximum j for all t'_k is denoted by J. Each t'_k can be viewed as a binary rational at scale J.

Without lose of generality it is assumed that $\cdots < t'_k < t'_{k+1} < \cdots$ t'_k can be expressed as $t'_k = i(k)/2^J$ where *i(k)* is an integer dependent on k and $\cdots < i(k) < i(k+1) < \cdots$. Thus the problem can be considered as that of finding a contnuous-time function $\tilde{f}(t)$ with some degree of smoothness, given a set of point values $\{v_k = f[i(k)/2^J], k \in Z\}$, such that $\tilde{f}[i(k)/2^J] = v_k$ for $k \in Z$.

The multiscale technique starts at the highest scale J. At this scale, attempt is made to fill in as many data points as possible using a $D = 2L + 1$ polynomial interpolation process. The process starts with identifying a missing data point which may be placed at $(k + 1/2)/2^J$ for some arbitrary integer k. $D + 1$ valid data points are then identified at $(k-L)/2^J, (k-L+1)/2^J, \cdots k/2^J, \cdots (k+L+1)/2^J$. A polynomial of order D is then fitted using the data values at these points and, therefore, the value at $(k + 1/2)/2^J$ can be interpolated using the fitted polynomial. However, if data is missing at any of these points, the interpolation cannot be carried out at $(k + 1/2)/2^J$ and so the next missing data point is identified. If all the missing data points cannot be interpolated at scale J, the process is repeated for a coarser scale $J - 1$. If necessary this process is repeated at a coarser scale and so on until the coarsest scale is reached. If some data points are still missing, the whole process is repeated starting from the highest scale J. This is repeated until no data points are missing. The foundation is thus laid for interpolation of uniformly spaced data.

3.3. The Deslauriers-Dubuc interpolation process

The Deslauriers-Dubuc (DD) interpolation is a multiscale refinement technique for interpolating uniformly sampled discrete data points [6,7]. With data points given at binary rationals $k/2^j, K_1 \leq k \leq K_2, j \geq 0, \quad k, j \in Z$, the DD process estimates the interpolating values of function $f(t)$ at binary rationals $(k+1/2)/2^j, K_1 \leq k < K_2, \quad j \geq 0, \quad k, j \in Z$. In other words, it finds the values of $\tilde{f}(t)$ at all points halfway between previously defined points. For an integer D=$2L$+1, D+1 values of $\tilde{f}(t)$ at $(k - L)/2^j, (k-L+1)/2^j, \cdots, k/2^j, \cdots, (k+L+1)/2^j$ are used to determine a polynomial of order D, denoted as $P_{j,k}(t)$ such that the values of $P_{j,k}(t)$ at the above points are identical. The data at $(k+1/2)/2^j$ can be interpolated as $\tilde{f}[(k+1/2)/2^j] = P_{j,k}[(k+1/2)/2^j]$ using the polynomial. This is repeated for all k, $K_1 \leq k < K_2$. The whole process is repeated for a higher scale $j+1$ and so on until $\tilde{f}(t)$ is defined at a desired scale J.

4. Results

The algorithms developed were implemented using data provided by Terra Surveys Ltd. One-dimensional analysis was considered with discrete elevation values at different time intervals. Results were obtained for different values of D, the lowest scale of interpolation J, number of iterations in uni-

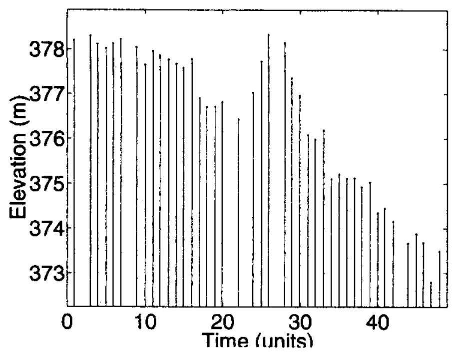

Fig. 1. Original data

form interpolation technique I, and window length W. The data is considered to be at scale 0 (i.e., data points are located at $t_k, k \in Z$).

Figure 1 shows the plot of a small part of the original data set. The elevation values of the laser hits were plotted at corresponding time instances. The implementation results are shown in Figure 2. The plots show the grouping of ground hits and vegetation top hits and the corresponding profiles drawn after interpolation of the data. The plots indicate the presence of vegetation which can be infered after comparison of the ground profile and the vegetation profile.

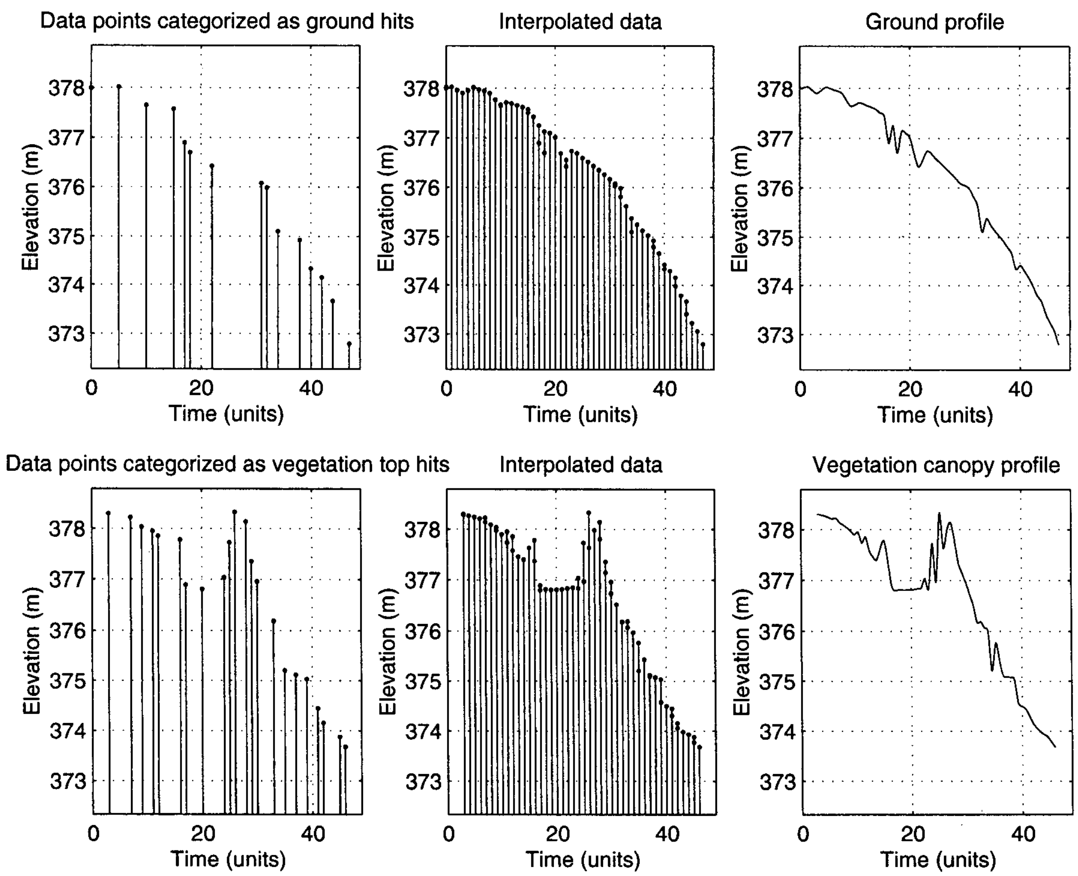

Fig. 2. Processing of data to obtain ground and canopy cover profiles (D=3, J=-4, I=4)

5. Discussion and conclusions

The problem of finding the ground and canopy profiles from the elevation data obtained from a laser profiler system has been described. The problem extends to finding the data points which correspond to ground hits and vegetation top hits. As the data points are irregularly spaced, nonuniform interpolation techniques have been implemented to identify the ground and canopy profiles.

As the ground is expected to be smoother than the vegetation canopy, a comparatively larger window length is considered for the ground than that considered for the vegetation. The frequency of the laser hits is required to be high in order to obtain enough vegetation top hits to accurately draw the canopy profile. If the data points are not dense enough, the interpolation would not be accurate.

The interpolation of the irregularly spaced data points has been performed in two steps. In the first step the irregularly data points have been regularized using a nonuniform interpolation technique and in the second step, a uniform interpolation technique has been used to interpolate intermediate data points to a certain level so that a smooth curve can be fitted through the data points to obtain the profiles.

The value of D should be chosen judiciously. A large D value is not recommended as that would interpolate using data that is not local for that point which is not desired for interpolation. On the other hand, a low D value means that the order of the polynomial used for interpolation is low, which is not good either. Hence a compromise value of D is obtained. The lowest scale at which interpolation is performed at each level is also desired to be low so that the interpolation is done using local characteristics of the data. When all the missing data points have been interpolated using the nonuniform interpolation technique described, the stage is set for uniform interpolation.

The uniform interpolation can be considered as a special case of the nonuniform process. Here data is interpolated at all the middle locations of the present data points. This process is repeated until a predefined lowest scale is reached.

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