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Image matching as a data source for forest inventory – Comparison of Semi-Global Matching and Next-Generation Automatic Terrain Extraction algorithms in a typical managed boreal forest environment

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ABSTRACT

Image matching is emerging as a compelling alternative to airborne laser scanning (ALS) as a data source for forest inventory and management. There is currently an open discussion in the forest inventory community about whether, and to what extent, the new method can be applied to practical inventory campaigns. This paper aims to contribute to this discussion by comparing two different image matching algorithms (Semi-Global Matching [SGM] and Next-Generation Automatic Terrain Extraction [NGATE]) and ALS in a typical managed boreal forest environment in southern Finland. Spectral features from unrectified aerial images were included in the modeling and the potential of image matching in areas without a high resolution digital terrain model (DTM) was also explored. Plot level predictions for total volume, stem number, basal area, height of basal area median tree and diameter of basal area median tree were modeled using an area-based approach. Plot level dominant tree species were predicted using a random forest algorithm, also using an area-based approach. The statistical difference between the error rates from different datasets was evaluated using a bootstrap method.

Results showed that ALS outperformed image matching with every forest attribute, even when a high resolution DTM was used for height normalization and spectral information from images was included. Dominant tree species classification with image matching achieved accuracy levels similar to ALS regardless of the resolution of the DTM when spectral metrics were used. Neither of the image matching algorithms consistently outperformed the other, but there were noticeably different error rates depending on the parameter configuration, spectral band, resolution of DTM, or response variable. This study showed that image matching provides reasonable point cloud data for forest inventory purposes, especially when a high resolution DTM is available and information from the understory is redundant.

1. Introduction

For more than 15 years, airborne laser scanning (ALS) has received considerable scientific and operational attention as a data source in stand level forest management inventory (Maltamo and Packalen, 2014; Næsset, 2014). ALS is a method where the distance between a laser pulse emitter and an object establish the primary information content (Nurminen et al., 2013). When the location and orientation of the ALS device is known, together with the speed of light, the coordinates of the returned pulses' echoes can be calculated (Vauhkonen et al., 2014). This ability to gain affordable and reliable three-dimensional information about forest structure has revolutionized forest inventory practices in many countries (Reutenbach et al., 2005; Evans et al., 2006).

Recently, the forest inventory community has shown an increasing interest in point clouds, which are similar to ALS datasets and created using an automated photogrammetric method known as *image matching* from aerial images. Many studies have been published regarding image matching as a data source for modeling forest attributes (Järnstedt et al., 2012; Bohlin et al., 2012; St-Onge et al., 2015; Puliti et al., 2016). Aerial image point clouds are considered as an attractive alternative due to advances in the fields of photogrammetry, algorithms, and the increased capacity of computers (White et al., 2013). Interest in such alternative methods can also be attributed to the lower acquisition cost, higher temporal resolution, the direct auxiliary spectral and textural information which may be obtained from image pixels, and historically established methods of using aerial images in forest inventories (Holopainen

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et al., 2015). The possibility for time-series analysis is likewise an interesting prospect with image point clouds.

Usually in (image) point cloud related research, only height metrics are utilized as predictor variables. Spectral values can be linked to image point clouds quite easily, but reliable linking of spectral information to ALS data can on the other hand be challenging due to different geometric properties. Adding spectral information from aerial images as auxiliary data in a point cloud inventory could enable the estimation of response variables that are traditionally difficult for point clouds to handle; e.g. age, health and species distribution (White et al., 2013).

While aerial image based point clouds may offer certain benefits over ALS point clouds, the inherent feature of an image to portray only the outermost layer of an object may be a considerable disadvantage from a forest inventory perspective. For this reason alone, image point clouds offer significantly less detailed information about the lower canopy layers, but have been proven to perform almost equally as well as ALS datasets with respect to several common forest attributes (Järnstedt et al., 2012; Nurminen et al., 2013). Similar performance can be attributed to the fact that in most cases, ALS based prediction only uses the first echoes of laser pulses, which correspond roughly to point clouds based on aerial images. Earlier study by White et al. (2015) provides valuable information about the similarities of variances of the metrics calculated from both ALS and image based point clouds. Although they found significant differences for most of the utilized metrics between the two datasets, White et al. (2015) also concluded that there is generally an increase in similarity between the datasets with increased canopy cover.

In general, in a point cloud based forest inventory context it is necessary to relate every point measurement to the bare earth surface in order to obtain aboveground heights. This is done by subtracting a digital terrain model (DTM) surface from the point cloud data. Because the ground surface is usually obscured by vegetation in a forest ecosystem, it is difficult to extract an accurate DTM from the image point cloud data in areas of dense canopy cover. Although Jensen and Mathews (2016) reported good results for DTM extraction from UAV (Unmanned Aerial Vehicle) aerial images, it is still uncertain how accurate the terrain model may be for a typical managed boreal forest environment when aerial images are captured from an airplane. This is potentially a major disadvantage for using image point cloud datasets in areas where an accurate DTM is unavailable, and could therefore restrict the method to areas where an ALS campaign has been conducted in the past.

Disregarding the differences between image matching algorithms, there are several factors that have a significant impact on the integrity and quality of resulting point clouds (White et al., 2013). Algorithm parameters, camera setup (sensor resolution, capture altitude, focal length), sun-angle, radial displacement due to change in viewing angle, shadows and occlusions can affect the functionality of image matching algorithms. While these problems may create differences in images that are easy for the human eye to distinguish, they are usually insurmountable for automated algorithms. In a forest inventory context, issues related to varying illumination conditions pose problems, especially in large inventory areas. A change in sun-angle affects the amount of shadow and could therefore produce an uneven presentation of canopy surface across the image area. Due to the irregular nature of the surface of the forest canopy, there is also a demand for exceedingly redundant imaging data to address the occlusions which may appear in the canopy (Haala et al., 2010).

The main research question is whether it is possible to improve the performance of forest attribute prediction with a combination of image point clouds and spectral features of images. This is a relatively unexplored field of study. The specific objectives were to: (1) evaluate the additional value of spectral information when used together with image point clouds for predicting tree species, volume, height, diameter, basal area and stem number; (2) evaluate the performance of image point cloud inventory in areas where a high spatial resolution DTM is not available; and (3) compare the results using two different image matching algorithms, Semi-Global Matching (SGM) (Hirschmüller, 2008) and Next-Generation Automatic Terrain Extraction (NGATE) (Zhang et al., 2007), and the sensitivity to the tuning parameters of these selected algorithms.

2. Materials and methods

2.1. Field measurements

A total of 173 field plots located in the southern Finland (north of the city of Hamina) were used in this study (Fig. 1). Fieldwork was carried out during the summer of 2013, and the study area consists of typical, pine dominated managed boreal forests, with downy birch being the dominant broadleaved species. The dominating tree species at plot level was determined as pine (127 plots), spruce (35 plots) or deciduous (11 plots). The field data was gathered by the Finnish Forest Centre.

The radius of the field plots was either 9.00 m or 12.62 m. The larger plot type was used in areas with sparse tree cover, such as seed-tree stands, in order to gain a larger sample of trees from the area. Diameter was measured for every tree with a diameter at breast height of at least 5 cm. Height was measured for a subset of trees. Heights for the remaining trees were calculated using the species specific function form of Näslund (1937). The locations of plot centers were measured with a high accuracy Trimble device supporting both the Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) satellites to enable linking to image and ALS data. Plot centers were determined by taking at least 1000 positions with an external antenna elevated up to 5 m and post-processed using virtual reference station (VRS) base stations. A number of forest attributes were calculated from the field data for each plot: stem number (N), basal-area (G), diameter of basal area median tree (DGM), height of basal area median tree (HGM), volume (V) and dominant tree species. The mean, range and standard deviation of these variables are presented in Table 1.

2.2. Remote sensing data

2.2.1. Data acquisition

ALS data were collected in leaf-on conditions by the National Land Survey of Finland (NLS) on 25 June 2013 using a Leica ALS70 laser scanning system. The study area was scanned from an altitude of 1900 m with a field of view of 20 degrees. This resulted in a nominal point density of 0.75 measurements per square meter.

Digital aerial images were also collected during leaf-on conditions by FM-International Oy FINNMAP on 12 June 2013 using a Microsoft Ultracam XP camera system. The images were taken at a flying altitude of 6000 m with a sidelap of 45% and endlap of 80%. This configuration resulted in a ground sample distance (GSD) of 35 cm. Three spectral bands were used in this study: near-infra red (680–980 nm), red (590– 720nm) and green (490–660 nm).

2.2.2. Image matching

Image matching is used to find corresponding image points from two or more overlapping stereo image pairs (Dall'Asta and Roncella, 2014). Modern image matching algorithms can be divided into two broad categories: area- and feature-based methods (Zitová and Flusser, 2003). Feature-based methods rely on simple cartographic units such as points and lines to find similarities between images. Area-based methods use the differences of pixels within a small moving window around the target observation to find matching points (Hirschmüller, 2008). A variant of the area-based method