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Automated planimetric quality control in high accuracy airborne laser scanning surveys

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ABSTRACT

With the increasing point densities of airborne laser scanning surveys, the applications of the generated point clouds have evolved from the production of digital terrain models to 3D modelling of a wide variety of objects. Likewise in quality control procedures criteria for height accuracy are extended with measures to describe the planimetric accuracy. This paper introduces a measure for the potential accuracy of outlining objects in a point cloud. It describes how this accuracy can be verified with the use of ridge lines of gable roofs in strip overlaps. Because of the high accuracy of modern laser scanning surveys, the influence of roof tiles onto the estimation of ridge lines is explicitly modelled. New selection criteria are introduced that allow an automated, reliable and accurate extraction of ridge lines from point clouds. The applicability of the procedure is demonstrated in a pilot project in an area covering 100,000 ha with around 20 billion points.

1. Introduction

In the last two decades airborne laser scanning has been adopted as the preferred technology for the acquisition of digital terrain models (Briese, 2010). Driven by application demands in the field of water or forestry management larger regional or even national laser scanning surveys have been conducted. As the height of the terrain or vegetation was seen as the most important information to be gathered, quality control procedures of these surveys typically had a strong, if not exclusive, focus on the evaluation of height accuracy (Crombaghs et al., 2000, 2002; Ahokas et al., 2003).

In the meantime the pulse frequencies of laser scanners continued to increase and nowadays reach up to 500 kHz. With this technology point clouds with 10–20 points/m^2 can be easily acquired from low speed aircrafts. The acquisition of such high density point clouds over large areas has therefore become feasible. The high point densities enable the use of point clouds for a much wider range of applications including building detection, outlining and 3D modelling (Verma et al., 2006; Sampath and Shan, 2007; Haala and Kada, 2010; Oude Elberink and Vosselman, 2011), 3D modelling of road networks (Hatger and Brenner, 2003; Clode et al., 2007; Oude Elberink and Vosselman, 2009a; Zhou and Vosselman, 2012), power line mapping (Jwa and Sohn, 2010) and monitoring of individual trees (Reitberger et al., 2009; Yu et al., 2011).

In the Netherlands the regional water authorities (Wikipedia, 2012) have been using this kind of high density laser scanning in corridor surveys for the management of water barriers and waterways next to lower density nationwide surveys for the determination of optimal ground water levels. Recognising the potential of mapping in high point density point clouds, in 2007 the regional water authorities, together with the (then) Ministry of Transport, Public Works and Water Management, decided to start a nationwide laser scanning survey with a point density of 8–10 points/m^2. The final flights have been conducted spring 2012. The complete dataset will consist of some 400–500 billion points.

For this project an extensive quality control procedure has been defined. As the point cloud should be suitable for 3D mapping the planimetric accuracy has to be considered, next to the height accuracy. A methodology has therefore been developed to assess the potential planimetric accuracy of mapping objects in a point cloud. This paper reports on the developed methodology for planimetric quality control and demonstrates the applicability to a large dataset.

In the next section the related literature is discussed. The larger part of this literature is about strip adjustment, where offsets between corresponding features in overlapping strips are used to estimate strip deformations or sensor calibration errors. Section 3 defines the requirement a point cloud should fulfil in order to enable mapping with a given maximum planimetric error. Calibration procedures typically make use of (locally) planar surfaces. While corresponding planar surfaces can be used to estimate 3D offsets

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between strips, it cannot be distinguished to what extent the remaining errors are caused by errors in height or errors in planimetry. Hence, one cannot estimate the noise in the planimetry. To define the planimetric mapping accuracy requirement we therefore make use of corresponding horizontal roof ridge lines in overlapping strips. The use of ridge lines for the estimation of strip offsets and sensor positioning noise is making use of earlier work reported in (Vosselman, 2002; 2008). This is extended in this paper to take into account the influence of roof tiles onto the accuracy of ridge line estimations. Without doing so offsets between ridge lines would incorrectly completely be attributed to sensor positioning noise, and thus to the planimetric point cloud accuracy. In case of roof faces with a limited number of points or with a small slope, the influence of the roof tile structure onto the ridge line offsets estimation may become very significant, in particular for high accuracy surveys. In Section 4 we describe the procedure to extract the ridge lines from the point cloud. Because of the project size, this procedure has to be largely automated. At the same time estimated ridge lines should be precise and reliable such that errors will not lead to overestimated standard deviations. In quality control procedures such overestimations would cause incorrect rejections of delivered point clouds. Therefore several new criteria are defined to ensure that selected ridge line pairs have been accurately extracted. Errors in the extraction process should be kept clearly smaller than the expected sensor positioning noise. In Section 5 the developed methodology is applied to a 20 billion point dataset that was acquired in 2007 in a pilot project to study the feasibility of the now acquired high point density nationwide point cloud. Results are analysed w.r.t. different strategies for ridge line selection and planimetric and height accuracy.

2. Related literature

In the ideal case one would like to have many ground control points that can be accurately identified in the point cloud. Csanyi and Toth (2007) designed lidar specific ground targets. The circular plates were slightly elevated above the ground to allow straightforward identification. With a Hough transform-like approach the plate centre is estimated from the points on the plate. The plate centres could be identified with an accuracy of 10% of the point spacing if the plate contains 16 points. Instead of selecting points based on elevation, Anderson et al. (2010) investigated the use of lidar-activated phosphors and infrared retro-reflectors such that points on the target can be selected based on their reflectance strength. Experiments at different altitudes demonstrated that the targets could be very clearly distinguished from their background. To remove the need for lidar specific targets, Toth et al. (2008) introduced the use of road pavement markings for ground control. By estimating curves through points on markings that were selected based on reflectance strength, the markings could be measured with an accuracy of a few cm.

Ground control points are required for checking the absolute accuracy. Like in photogrammetric aerial triangulation the amount of ground control points has to be minimised to reduce costs. In most laser scanning surveys the discrepancies between corresponding locations in overlapping strips play an important role in the quality control, similar to the use of tie points in photogrammetry. Among others Latypov (2002) uses the height differences in strip overlaps to assess the relative height accuracy. He notes that the need for absolute accuracy checks will be strongly reduced if a good relative accuracy between strips can be confirmed. This holds likewise for height and planimetric accuracy control.

In literature planimetric errors in airborne laser scanning data have been primarily discussed in the context of strip adjustment procedures. Strip adjustment aims to estimate and remove systematic differences between overlapping strips of laser data. Initially strip adjustment has been defined as a method to estimate transformations between strip coordinate systems that minimise the discrepancies (Burman, 2000; Crombaghs et al., 2000; Kager, 2004). Later, Friess (2006) as well as Skaloud and Lichti (2006) defined strip adjustment as a sensor calibration problem that minimises discrepancies by estimating corrections to calibration parameters such as bore-sight angles and range offsets. In both cases planar features have been used as the basis for the formulation of the observation equations (Kager, 2004; Friess, 2006; Skaloud and Lichti, 2006; van der Sande et al., 2010). Whereas Kager (2004) and Friess (2006) first estimate plane parameters that are then kept fixed in the strip adjustment, Skaloud and Lichti (2006) simultaneously estimate plane and calibration parameters.

The extraction of corresponding planar surfaces for the purpose of strip adjustment is further discussed in (Pfeifer et al., 2005). They use a clustering in a space of feature vectors including the locally estimated normal surface vector. A region growing method is used to determine the extent of planar segments. This is required because co-planar segments will be mapped to the same location in the feature space. To select corresponding segments in overlapping strips the points of the point in a segment of one strip should be surrounding by points in the corresponding segment from the other strip. Furthermore the height difference between the two segments should be within a pre-set range. For the height adjustment in (Pfeifer et al., 2005) only near vertical segments with a limited number of points were used. In his selection of corresponding surfaces Kager (2004), aiming at a 3D strip adjustment, demanded a minimum slope of the selected segments and set further fixed thresholds on the deviations of points from the plane, the number of outliers (caused by chimneys and dormers), and the number of points in a segment.

In addition to planar features, Habib et al. (2008, 2010) and Kersting et al. (2008) also use linear features (ridge lines) in their strip adjustment. Corresponding linear features are selected based on distance between the lines, direction difference and overlap. The user of the strip adjustment method has to interactively confirm the correctness of the selected feature pairs.

3. Requirements to planimetric mapping accuracy

Technical specifications used in tendering and quality control procedures of laser scanning surveys often explicitly specify the minimum point density and point accuracy to be obtained. Point accuracy is usually split into a systematic error and a standard deviation of the points that may remain after the processing, e.g. a strip adjustment, by the data provider. The potential accuracy of outlining objects in a point cloud is determined by the point density and point accuracy together. Instead of specifying acceptance conditions for the various components of the planimetric mapping accuracy, the tender document for the Dutch national laser scanning survey only specified a requirement on the maximum error that may occur when outlining objects (with edges of at least 2 m in size) in a point cloud. In this project this maximum error was set to 0.50 m. It was left up to the surveying companies how to balance between point density and point accuracy. With a higher accuracy of the sensor positioning a company could lower the point density and still meet the planimetric mapping accuracy requirement. A lower point density would reduce the number of flight lines, an important factor in the survey costs.

In this section we work out the definition of this requirement and the way in which the requirement is verified. Section 3.1 reviews the components of the planimetric mapping accuracy and defines the requirement to be used in overlaps between strips. In Section 3.2 it is explained how ridge lines in strip overlaps are used for the accuracy verification. The influence of roof tiles onto the accuracy of ridge line locations is discussed in Section 3.3.