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In-flight photogrammetric camera calibration and validation via complementary lidar

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ABSTRACT

This research assumes lidar as a reference dataset against which in-flight camera system calibration and validation can be performed. The methodology utilises a robust least squares surface matching algorithm to align a dense network of photogrammetric points to the lidar reference surface, allowing for the automatic extraction of so-called lidar control points (LCPs). Adjustment of the photogrammetric data is then repeated using the extracted LCPs in a self-calibrating bundle adjustment with additional parameters. This methodology was tested using two different photogrammetric datasets, a Microsoft UltraCamX large format camera and an Applanix DSS322 medium format camera. Systematic sensitivity testing explored the influence of the number and weighting of LCPs. For both camera blocks it was found that when the number of control points increase, the accuracy improves regardless of point weighting. The calibration results were compared with those obtained using ground control points, with good agreement found between the two.

1. Introduction

The last decade witnessed the start of a new era for airborne photogrammetric camera systems, with various digital sensors introduced as equivalent replacements for existing analogue cameras. Amongst other advantages, these new digital camera systems have provided a simplified and cost-effective photogrammetric workflow (Petrie and Walker, 2007). Despite the considerable advantages afforded by modern large format cameras, smaller and more flexible cameras suited to cost effective mapping of limited spatial areas are also desirable (Grenzdörffer, 2010). The new breed of digital photogrammetric sensor systems can therefore be categorised as large format (including line and frame cameras) and medium to small format cameras (Heipke et al., 2006).

Before any imagery can be used for high precision measurement purposes in photogrammetry, there is a need to determine the geometric model of the sensing system used to capture it. This is described by the parameters of interior orientation, such as principal distance, principal point coordinates and lens distortion coefficients, that are determined via the process of camera calibration (Sandau, 2009). Camera calibration is usually initially conducted by the manufacturer, where the camera's interior orientation parameters are provided to the user in a calibration report. Under in-flight conditions however, camera parameters may change relative to the situation in the laboratory (Honkavaara et al., 2006; Jacobsen, 2007). Therefore, in-flight camera calibration parameters can be determined simultaneously using real datasets and accurate ground control points (GCPs) set in a permanent test field (Honkavaara, 2003). Since large format digital aerial cameras are specifically designed as robust metric cameras optimised for mapping purposes, in the vast majority of applications laboratory calibration by the manufacturer can be used with confidence (Habib et al., 2010), although in-flight validation is advisable. Lower cost cameras, however, are increasingly used in photogrammetric activities, perhaps for projects involving limited ground coverage or in conjunction with lidar systems. The calibration of such camera systems, and the stability of the calibration parameters in-flight, is considered a prerequisite (Habib et al., 2006).

Due to their complementary characteristics, the integration of photogrammetry with lidar can potentially reduce overall costs and improve accuracy in many mapping applications (Liu et al., 2007). Lidar provides direct and highly accurate 3D elevation information, which is both accurate and spatially dense (Postolov et al., 1999). Moreover, continued improvements in the accuracy of lidar systems have enabled the use of such data as a source of photogrammetric control (Habib et al., 2005). The usual methodology

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for integrating lidar and photogrammetric data includes defining common reference features, establishing a mathematical relationship with the corresponding model and undertaking a similarity assessment (Habib et al., 2005). Current registration methods are mainly based on the identification and extraction of common spatial features, such as points, lines and planar patches. This is followed by determining the parameters of the transformation required to align the two datasets, usually based on a 3D conformal transformation (Armenakis et al., 2013).

Reference targets from the lidar surface are usually extracted using classification and segmentation techniques (Wang and Tseng, 2011). Shin et al. (2007) identified and used straight lines, extracted either by intersecting two planes or through direct manual observation, as conjugate features in the registration process. Other methods have used planes as common features (Brenner et al., 2008). Surface-to-surface registration is also possible by interpolating both datasets into regular or irregular surfaces, with registration accomplished by minimising either the vertical or Euclidean distances between the two (Akca, 2007). The quality of registration is highly dependent on the process adopted, which can be classified as manual, semi-automatic or automatic (Rönnholm, 2011).

In many cases, registration is achieved by adapting the photogrammetric adjustment process to enable the introduction of the extracted feature type. Jaw (1999) and Jaw and Wu (2006), for example, extended the photogrammetric model by establishing a new relationship with planar surfaces. Habib et al. (2005) directly incorporated linear features as a source of control in the photogrammetric bundle adjustment. However, a large number of linear features with good spatial distribution are needed to achieve equivalent accuracy to conventional control point patterns in the photogrammetric block (Mitishita et al., 2008). For large photogrammetric blocks, significant numbers of well distributed linear reference targets may not be readily available.

Since a bundle adjustment is classically a point-based observation process, a number of different methods have been developed to extract point-based reference control from lidar data for subsequent use in aerial triangulation. Kwak et al. (2006) and Mitishita et al. (2008), for example, used centroids of rectangular building roofs as a single control point in the aerial triangulation process. Habib et al. (2005), Liu et al. (2007) and Yastikli and Toth (2007) all used manual extraction of control points from lidar point clouds, whilst James et al. (2006) used high resolution shaded lidar DEMs to manually extract reference control points for use in establishing a photogrammetric model. Deriving point-based control from lidar is, however, hindered by the difficulty in finding the corresponding point in the lidar dataset (Baltsavias, 1999).

The research presented herein describes the development of a methodology to integrate airborne photogrammetric and lidar data with the aim of validating and/or refining camera calibration parameters. The methodology, presented in Section 2, is assessed using both large format and medium format imagery, with results summarised in Sections 3 and 4 respectively. Discussion leads to the conclusions drawn in Section 5.

2. Methodology

2.1. Overview

The camera calibration approach implemented, as preliminarily described in (Gneeniss et al., 2013), is based on the automatic registration of a dense network of photogrammetric points and a reference lidar digital terrain model (DTM), the extraction of corresponding point features and their use in a subsequent self-calibrating bundle adjustment. The main advantages of the methodology are as follows: Firstly, no dedicated calibration test field, or even ground control, is necessary. Secondly, all photogrammetric tie points are measured using commercial off-the-shelf software (BAE Systems SOCET Set in this research) using an automatic image matching technique, providing point measurement precision up to 0.1 pixel (Alamús and Kornus, 2008). Thirdly, any residual shifts, rotations or scale errors in the photogrammetric point clouds, caused for example by changes in camera parameters or errors in the GNSS/IMU data, will be (at least partly) recovered by the surface matching registration procedure. Fourthly, the surface matching procedure is based on the global 3D surface matching approach between the photogrammetric block and the reference lidar surface. This provides an optimised alignment to the lidar surface and the 3D coordinates of each tie point can subsequently be used, thereby providing an advantage over other methods that adopt only vertical coordinates, e.g. Jaw (1999), Jaw and Wu (2006). Finally, all extracted features are in point form, meaning data can be directly introduced into a bundle adjustment using any existing triangulation software, in this case Leibniz Universität Hannover's BLUH software (Jacobsen, 2008).

The general workflow of the research methodology is illustrated in Fig. 1. The main steps comprise: (a) a combined adjustment of the GNSS/IMU data together with image coordinates, but without any GCPs (known as an integrated sensor orientation (ISO) process (Jacobsen, 2004)), to determine the initial coordinates of the photogrammetric point cloud; (b) the registration of the photogrammetric point cloud to the reference lidar surface using the least squares surface matching method; (c) the automatic extraction of reference lidar control points (LCPs); (d) the refinement of camera calibration parameters using the derived LCPs and the GNSS/IMU data in a full aerial triangulation. The whole procedure is performed in a semi-automated manner using an algorithm developed to bridge between BLUH and the surface matching algorithm.

2.2. Photogrammetric point cloud and lidar data processing

The methodology begins with automatic dense tie point measurement of the photogrammetric block. This step was performed using BAE Systems SocetSet 5.4.1. Automatic image measurement provides higher measurement precision than manual observation,

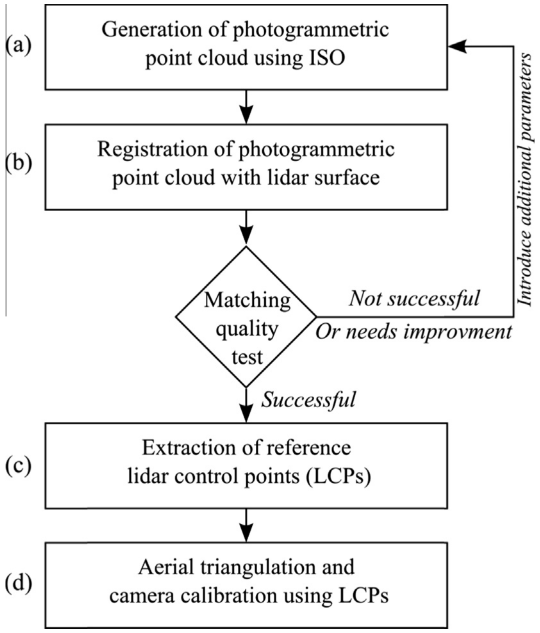

Fig. 1. Main steps of the research methodology.

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