ISPRS Journal of Photogrammetry and Remote Sensing 101 (2015) 193–208

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Digital stereo photogrammetry for grain-scale monitoring of fluvial surfaces: Error evaluation and workflow optimisation

Stephane Bertin [a,*], Heide Friedrich [a], Patrice Delmas [b], Edwin Chan [b], Georgy Gimel'farb [b]

[a] Department of Civil and Environmental Engineering, The University of Auckland, New Zealand
[b] Department of Computer Science, The University of Auckland, New Zealand

ARTICLE INFO

Article history:
Received 8 July 2014
Received in revised form 22 December 2014
Accepted 23 December 2014

Keywords:
Photogrammetry
Digital
Application
DEM/DTM
Close range
High resolution
Performance
Accuracy

ABSTRACT

Grain-scale monitoring of fluvial morphology is important for the evaluation of river system dynamics. Significant progress in remote sensing and computer performance allows rapid high-resolution data acquisition, however, applications in fluvial environments remain challenging. Even in a controlled environment, such as a laboratory, the extensive acquisition workflow is prone to the propagation of errors in digital elevation models (DEMs). This is valid for both of the common surface recording techniques: digital stereo photogrammetry and terrestrial laser scanning (TLS). The optimisation of the acquisition process, an effective way to reduce the occurrence of errors, is generally limited by the use of commercial software. Therefore, the removal of evident blunders during post processing is regarded as standard practice, although this may introduce new errors. This paper presents a detailed evaluation of a digital stereo-photogrammetric workflow developed for fluvial hydraulic applications. The introduced workflow is user-friendly and can be adapted to various close-range measurements: imagery is acquired with two Nikon D5100 cameras and processed using non-proprietary "on-the-job" calibration and dense scanline-based stereo matching algorithms. Novel ground truth evaluation studies were designed to identify the DEM errors, which resulted from a combination of calibration errors, inaccurate image rectifications and stereo-matching errors. To ensure optimum DEM quality, we show that systematic DEM errors must be minimised by ensuring a good distribution of control points throughout the image format during calibration. DEM quality is then largely dependent on the imagery utilised. We evaluated the open access multi-scale Retinex algorithm to facilitate the stereo matching, and quantified its influence on DEM quality. Occlusions, inherent to any roughness element, are still a major limiting factor to DEM accuracy. We show that a careful selection of the camera-to-object and baseline distance reduces errors in occluded areas and that realistic ground truths help to quantify those errors.

© 2015 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

1. Introduction

1.1. Fluvial morphology remote sensing

In situ characterisation of grain-scale fluvial morphology is challenging for hydraulic engineers and fluvial geomorphologists. In a riverine environment, the interactions between the sediment surface (characterised by the grain size distribution, the particle shapes and the arrangement of the particles) and the water flow significantly control the riverbed. Hence, an understanding of the river system dynamics, and associated habitats, relies on the ability to accurately describe the riverbed morphology.

Using 2.5D digital elevation models (DEMs) is increasingly becoming more common to represent the grain-scale surface morphology for gravel-bed rivers. This is enabled by the advent of new measurement techniques and improved PC performances. DEM analysis reveals the flow history (Mao et al., 2011; Ockelford and Haynes, 2013) and allows the parameterisation of the surface roughness for flow resistance equations (Smart et al., 2002; Aberle and Smart, 2003; Smith et al., 2011; Qin and Ng, 2012). DEMs are also essential for detailed computational fluid dynamics (CFD) simulations (Lane et al., 2002; Hardy, 2008; Hardy et al., 2009). In future, field collection of DEMs will help improve flood modelling by reducing the need to calibrate the surface roughness, a key parameter in flow simulations over rough surfaces.

* Corresponding author.
E-mail addresses: sber081@aucklanduni.ac.nz (S. Bertin), h.friedrich@auckland.ac.nz (H. Friedrich), p.delmas@auckland.ac.nz (P. Delmas), ycha171@aucklanduni.ac.nz (E. Chan), g.gimelfarb@auckland.ac.nz (G. Gimel'farb).

http://dx.doi.org/10.1016/j.isprsjprs.2014.12.019
0924-2716/© 2015 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

Whilst both digital stereo photogrammetry and terrestrial laser scanning (TLS) support high-resolution data aquisition, measurement errors, which can affect data reliability and subsequent findings (Lane et al., 2005; Hodge et al., 2009), remain a major issue. For this reason, the majority of previously surveyed close-range fluvial environments are exposed riverbeds in a controlled environment, such as the laboratory. At present, it is thus important to identify, quantify and reduce measurement error sources to improve the quality of grain-scale DEMs and allow using the techniques in more sophisticated experiments in future. For TLS applications, previous users scanned fluvial surfaces repeatedly to average out the errors (Hodge et al., 2009; Smith et al., 2012). However, there is still the need of significant post-processing in the form of filtering to obtain accurate metrics from exposed gravel beds in the field. Practical applications have shown that data post-processing should be avoided as it can introduce other errors (Hodge et al., 2009).

The most viable approach to minimise measurement errors is the optimisation of the data collection process. Workflow optimisation is of particular concern to stereo-photogrammetric users, as the DEM collection workflow is long, complex, and the source of various error types (Lane et al., 2000; Carbonneau et al., 2003; Bouratsis et al., 2013). However, improving data collection is generally limited by the use of commercial photogrammetric software.

To put the introduced workflow in context, we provide a review of previous hydraulic stereo-photogrammetric applications in the next Section. Attention is focused on the DEM collection workflow, the error sources and the solutions previously adopted.

1.2. Stereo photogrammetry for hydraulic experiments

Stereo photogrammetry of fluvial environments covers a wide range of scales. DEM scales vary from several kilometres for the study of large braided rivers (Westaway et al., 2003), to several metres for mountainous streams (Bird et al., 2010) and to a mere metre for gravel-bed roughness characterisation (Butler et al., 2001; Bertin and Friedrich, 2014). The variety of stereo-photogrammetric applications is also reflected in the hardware and software/workflow selection for DEM reconstruction.

The advent of high-resolution digital cameras has led to the replacement of metric film cameras, allowing low-cost and versatile surveys (Chandler et al., 2001; Lane et al., 2001). Metric film cameras are provided with a calibration certificate that includes the parameters of the interior orientation (also called intrinsic parameters), although regular re-calibrations are recommended to ensure optimal accuracy (Cooper and Robson, 2001). Off-the-shelf digital cameras, as used in our experiments, require detailed calibration (see Section 3.4), if accurate metrics are to be extracted from imagery. In contrast, automatic stereo matching is now easier, which ensures an efficient DEM collection process and high data resolution. However, where a human operator previously ensured correct matching, automatic stereo matching now relies on image quality, and a lack thereof can result in additional errors (Lane, 2000). Very recently, multi-view stereo (MVS) and structure-from-motion (SfM) photogrammetry started to be implemented in medium to large scale experiments (Westoby et al., 2012; Javernick et al., 2014). Even though these novel methods have the potential to better capture occlusions, they are not discussed here, as the workflow departs substantially from the more conventional binocular stereo (also called two-view) photogrammetry.

To date, most environmental and fluvial applications of stereo photogrammetry have relied on proprietary stereo-photogrammetric products. OrthoMAX module of Erdas Imagine® (later Leica photogrammetry suite, LPS, now IMAGINE Photogrammetry) is the most used commercial software, with AICON 3D Systems® a more recent product (Schmocker, 2011). Other commercial software, such as Trimble Inpho®, Intergraph ImageStation® and BAE Systems SOCET SET®, enable DEM reconstruction from stereo images, and have been tested for civil engineering and geomorphic purposes (González-Díez et al., 2014; Murillo-García et al., 2014; Stoter et al., 2015). As noted by Chandler et al. (2001), the use of proprietary software constrains the photogrammetric design. OrthoMAX requires conventional photogrammetric control targets to be placed in the region of interest. The control targets' 3D coordinates are recorded separately, using an independent device, and registered within the stereo model by bundle adjustment. This was shown to be a potential source of errors (Carbonneau et al., 2003). The tangential distortion is ignored in OrthoMAX for the calibration, which may be tolerable for high quality lenses and medium accuracy work (Fraser, 1997; Chandler et al., 2001). Furthermore, OrthoMAX's DEM reconstruction algorithm is limited, with substantial surface smoothing and poor results over rough surfaces and in occlusions (Chandler et al., 2001; Carbonneau et al., 2003), as it relies on area-based stereo matching. Substantial post-processing is needed when using those proprietary stereo-photogrammetric products for fluvial roughness studies (Carbonneau et al., 2003).

Attempts to optimise the DEM reconstruction process in OrthoMAX were first made by varying the DEM collection parameters, such as the minimum threshold of normalised cross-correlation and the template size for area-based stereo matching (Butler et al., 1998; Gooch et al., 1999). Butler et al. (1998, 2002) also changed the camera settings to obtain optimal exposures with maximum contrast; however, the image quality effect on stereo matching was not evaluated. As outlined by Aber et al. (2010), low image noise is expected to increase the DEM accuracy, which has been tested in specific application areas, such as stereomicroscopy. In Chandler et al. (2001), two different methods to obtain the calibration parameters were tried: (i) an in situ self-calibration with GAP software and (ii) an "on-the-job" calibration with a 3D test field consisting of 70 retro-reflective targets, both resulting in similar DEM accuracy. Chandler et al. (2001) concluded that self-calibration is perhaps the preferable method, since it only requires the measurement of imagery used for the DEM extraction. However, the number and spatial arrangement of calibration control targets was found critical, with a need to have numerous (minimum of 15) and well-surveyed control targets evenly distributed throughout the x, y and z volume of the study site, which enables the recovery of reliable lens parameters (Chandler et al., 2001; Carbonneau et al., 2003).

More recently, stereo-photogrammetric solutions using non-proprietary algorithms are implemented in hydraulic experiments (e.g., Bouratsis et al. (2013) for the laboratory study of bridge pier scouring). The calibration parameters (including the tangential distortion) were obtained by using the freely accessible camera calibration toolbox for MATLAB® developed by Bouguet (2010). The stereo matching was performed on rectified images with a self-programmed correlation-based algorithm, using a window size of 35×35 pixels. Although a smooth surface was investigated, three geometrical filters were needed to process the data and remove blunders in a satisfactory manner. DEM errors were associated with the inadequate stereo setup design (baseline and the flying-height of cameras), which did result in substantial occlusions and thus stereo matching errors. Bouratsis et al. (2013) stressed the importance of image quality for stereo matching and suggested a structured light approach (whereby patterns are projected on the surface) to improve on the initially poor stereo matching results based on the riverbed texture only.

Download English Version:

https://daneshyari.com/en/article/6949510

Download Persian Version:

https://daneshyari.com/article/6949510

Daneshyari.com