

MINIMISING SYSTEMATIC ERRORS IN DEMS CAUSED BY AN INACCURATE LENS MODEL

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ABSTRACT

The use of consumer grade digital cameras for spatial measurement has rapidly increased over the past decade and is accepted in many industrial applications but also in diverse fields ranging from medical science to architectural work. Their uncertain internal geometry can be partially resolved by calibration. Research recent conducted at Loughborough University indicated the potential of consumer grade digital sensors to maintain their internal geometry but also identified residual systematic error surfaces, discernible in digital elevation models (DEM), which are caused by slightly inaccurately estimated lens distortion parameters. These remaining systematic errors degrade the accuracy of data that can be extracted. The stereopair configuration remains important for data extraction in photogrammetry, one that is employed by automated DEM extraction software. The aerial photogrammetric normal case is widely used, in which the camera base is parallel to the object plane and the camera axes intersect the object plane orthogonally. Initial results have demonstrated that using a convergent image configuration, where the optical camera axes intersect the object plane at the same point, minimises the residual systematic error surfaces in DEMs, even if extracted using inaccurately estimated lens distortion parameters. The developed methodology was tested using simulated data and verified by a practical test. However, such simple configurations are inflexible since almost every measurement task in close range photogrammetry, desires a unique image configuration, which is often oblique. This paper will demonstrate, how this simple constraint, which can be introduced to almost every stereopair configuration used for DEM generation, can minimise these systematic errors and may be suitable for many spatial measurement applications. A series of practical tests were conducted to verify the results from the simulation. In the first, accurate measurement and modelling of a flume bed surface, using digital photogrammetry, provided the opportunity to conduct a suitable case study in a semi-controlled environment. A flume or simulated river bed, located in a laboratory, needed to be measured. A series of images were acquired using a consumer grade digital camera (Canon EOS 10D). These included the normal case and a convergent configuration. Mosaic DEMs were extracted and this work and the accuracy achieved is presented. Flooding can cause loss of life and property and research activities in flood management are essential to determine accurately the flood conveyance. Accurate water surface elevation data are essential to develop computational flow models and a remote water surface measuring technique could be provided using digital photogrammetry. In the second case study, a photogrammetric method was developed to measure a dynamic water surface on a small river in Loughborough. A pair of synchronised Nikon D80 digital cameras were used to capture stereo image pairs (normal and convergent configuration) of the water surface. A fixed, horizontal survey staff located above the water surface, was used to access accuracy. This paper will demonstrate that a mildly convergent image configuration for DEM extraction, minimises residual systematic error surfaces caused by slightly inaccurately estimated lens distortion parameters. This approach effectively improves the accuracy achievable with non-metric sensors and provides an alternative approach to the need for an explicit and exact lens model.

1. INTRODUCTION

The use of consumer grade digital cameras for accurate spatial measurement is accepted in many industrial applications and also in diverse fields ranging from medical science to architectural work. Their uncertain internal geometry can be partially resolved by calibration; the approach normally adopted. Research recently conducted at Loughborough University indicated the potential of consumer grade digital sensors to maintain their internal geometry. It also identified residual systematic error surfaces, caused by slightly inaccurately estimated lens distortion parameters (Wackrow et al., 2007). These remaining systematic errors manifest themselves as domes and degrade the accuracy of data that can be extracted. Since almost every measurement task in close range photogrammetry desires a unique image configuration, a generally adequate geometric configuration cannot be defined (Luhmann et al., 2006). Particularly, measuring a dynamic

water surface on a river can require a extremely oblique image configuration. Therefore, a flexible methodology is needed, which minimises the systematic error surfaces in DEMs.

This paper describes a series of case studies conducted at Loughborough University, which demonstrate that for DEM extraction, a mildly convergent image configuration effectively improves the accuracy achievable with consumer grade digital cameras. Previous work related to image configuration is reviewed, before presenting two case studies. Results are discussed and this paper concludes with a brief summary.

2. IMAGE CONFIGURATION- PAST WORK

Appropriate network configurations for camera calibration through self-calibration have been well described in many publications (Fraser, 2006; Remondino and Fraser, 2006).

Gruen and Beyer (2001) investigated the determinability of self-calibration parameters under various network conditions (one frame up to eight frames). Of all configurations tested in this study, only an eight frame configuration (convergent, large horizontal base plus vertical base plus additional 90° rotation of frames) produced very good results. This work also indicated that of all interior orientation parameters, the radial distortion is the major source of image deformation.



Figure 1 Simulated river bed in a laboratory, University of Western Ontario, Canada

Karara and Aziz (1974) investigated accuracies in object-space coordinates for four non-metric cameras and a metric camera, using the Direct Linear Transformation. Image pairs were taken with each of the cameras with the camera axis approximately horizontal and with a convergence angle of about 30°. Somewhat surprisingly, Karara and Aziz (1974) stated that a strong association between increasing the convergence angle of an image pair and improving precision was not found. The authors concluded that the most desirable configuration is the normal case. Should the normal case not be feasible, the angle of convergence should be kept as small as possible. This result is contrary to the finding described in this paper.

The use of mildly convergent image configurations for DEM generation is less frequently reported in the literature. The reason might be that the photogrammetric normal case is widely used in automated DEM extraction software. However, an approach using a convergent stereo pair for modelling tooth replicas was reported in the field of medical science (Grenness et al., 2005). A semi-metric camera was used to capture multiple convergent images (5°, 10°, 15°, 20° and 25°) of a planar array and used for camera calibration. The estimated camera parameters and digitised images of tooth replicas were imported into a commercial digital photogrammetric software package and DEMs were generated. However, the results are unclear and suggest no association between increasing the convergence angle of the image pairs and increasing precision.

Using a mildly convergent image configuration for DEM generation, in which the camera axes intersect the object plane at the same point was reported in Wackrow et al. (2008). Simulated data were used to demonstrate that this image configuration minimises systematic error surfaces in DEMs caused by slightly inaccurate lens distortion parameters. The results were verified through a practical test using a Nikon D80 digital camera. The author's concluded that these results are significant for DEM generation using low-cost digital sensors,

where a mildly convergent image configuration can reduce the need for an accurate lens model.

This review of previous work identified some uncertainties, suggesting the need for further investigation in the use of convergent imagery for DEM extraction. The work presented by the authors (Wackrow et al., 2008) also required more thorough testing in field applications, particularly for the oblique configuration.

3. THE CASE STUDIES

Two case studies were conducted at Loughborough University to verify and further investigate the issues. The first case study demonstrates accurate measurement of a flume or simulated river bed, situated in a laboratory, using both the normal and convergent image configuration. In the second case study, a photogrammetric method is described to measure a dynamic water surface on a small river in Loughborough, which required an extremely oblique image configuration.

3.1 Measurement of a flume bed surface

Figure 1 depicts a flume bed surface located at the University of Western Ontario, Canada, simulating the fluvial process in a braided river system, which needed to be measured using digital photogrammetry. Previous work conducted on a similar flume (Stojic et al., 1998) had demonstrated the potential of digital photogrammetry for measuring the bed forms and their development. The dimensions of this flume are 18.6 × 3.0m. Photogrammetric control targets (88) were fixed alongside both walls as well as in two, almost straight, rows along the flume bed and coordinated by theodolite intersection. These target points provided sufficient control for photogrammetric processing, as well as providing check point data to access accuracy.

A Canon EOS 10D digital camera (6 Mega-pixel) with a Canon 20mm fixed lens was pre-calibrated at Loughborough University. A 3D and planar testfield, used for camera calibration in Chandler et al. (2005), Wackrow et al. (2007) and Wackrow and Chandler (2008), was employed once again for this purpose. The 8 calibration frames were processed using the Leica Photogrammetry Suite (LPS) software, whilst the external self-calibrating bundle adjustment GAP (Chandler and Clark, 1992) was used to estimate the camera parameters. These camera parameters were then used for surface measurements of the flume.

A overhead gantry was mounted lengthwise, approximately 2.9m above the flume, which provided the opportunity to position the camera along the flume bed. Firstly, a series of images of the flume were captured using the aerial photogrammetric normal case, where the camera base is parallel to the object and the camera axes intersect the object plane orthogonally. The overlapping area of adjacent images were approximately 60%. For processing the flight strip in LPS, it was essential to measure control points manually, before 100 tie points were measured using fully automated methods.

Afterwards, a mosaic DEM describing the entire flume was extracted using the DEM generation algorithm of LPS. A representative selected area of the mosaic DEM is represented in Figure 2.

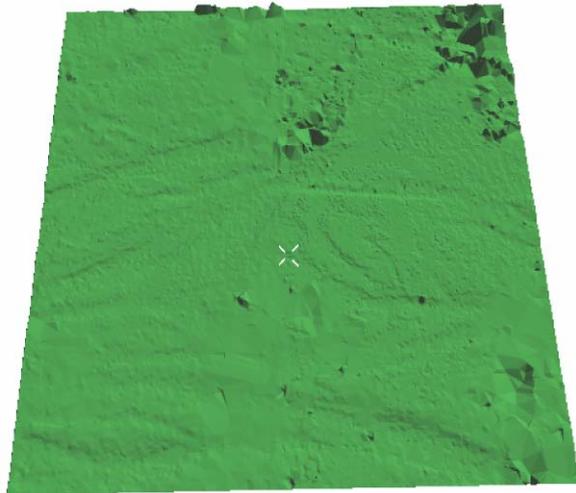


Figure 2 DEM using normal configuration

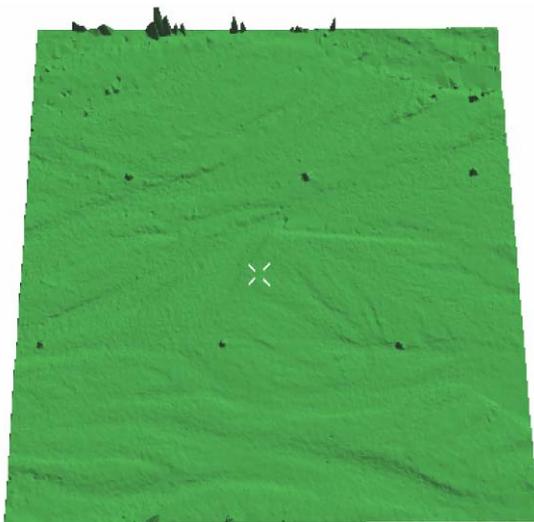


Figure 3 DEM using convergent configuration

Secondly, two additional image strips were captured using a convergent configuration. The camera axes of image pairs intersected the object plane at the same point describing an angle of approximately 18° between them. The overlapping area of adjacent image pairs was 60% and the same set of control points were used for photogrammetric processing. Using the mildly convergent image configuration, a mosaic DEM of the flume was extracted also. Figure 3 represents an area of the mosaic DEM extracted using the mildly convergent image configuration. This area shown is identical to the area represented in Figure 2. It is apparent visually that the areas exhibiting gross errors has reduced significantly, emphasising the location of the photo control targets.

3.2 Measurement of a dynamic water surface

A small river situated in Loughborough was identified to conduct a case study to measure a dynamic water surface. This was to support the development of a system to measure the topographic surface of a flooding river in Farnham, Surrey. This work is the subject of a related Congress paper (Chandler et al., 2008). Temporary photogrammetric target points were distributed along the river banks to provide conventional

photogrammetric control. For accuracy assessment, a survey staff was positioned horizontally close to the water surface. Both, the photogrammetric target points and the major staff graduations were coordinated using a reflectorless Total Station (Figure 4).

A pair of Nikon D80 digital cameras (10 Mega-pixel) were used to capture image pairs of the river, both equipped as standard with a variable zoom lens (18 – 70mm). These cameras were pre-calibrated at Loughborough University with the focal length of each lens fixed to 24mm using electrical tape. A bridge across the river provided an ideal platform to position the cameras, mounted on standard tripods (Figure 5). The camera to object distance was approximately 8m. The synchronisation problem was solved using two cables connected via a single relay operated switch. An oblique image pair of the river surface was captured using the normal configuration, whilst a second image pair was derived using a mildly convergent image configuration with an angle of approximately 10° between the optical camera axes. The camera axes intersected the object plane at approximately the same point. Both image pairs were processed in LPS using control provided by the photogrammetric target points. In addition, the position of the major staff graduations for both image configurations were determined using photogrammetry. Coordinates derived using the Total Station were compared with estimates established by photogrammetry, which provide the opportunity to assess accuracies achieved using either the normal or the convergent image pairs.



Figure 4 Experimental setup to measure a dynamic water surface on a small river at Loughborough



Figure 5 Camera setup at Loughborough River

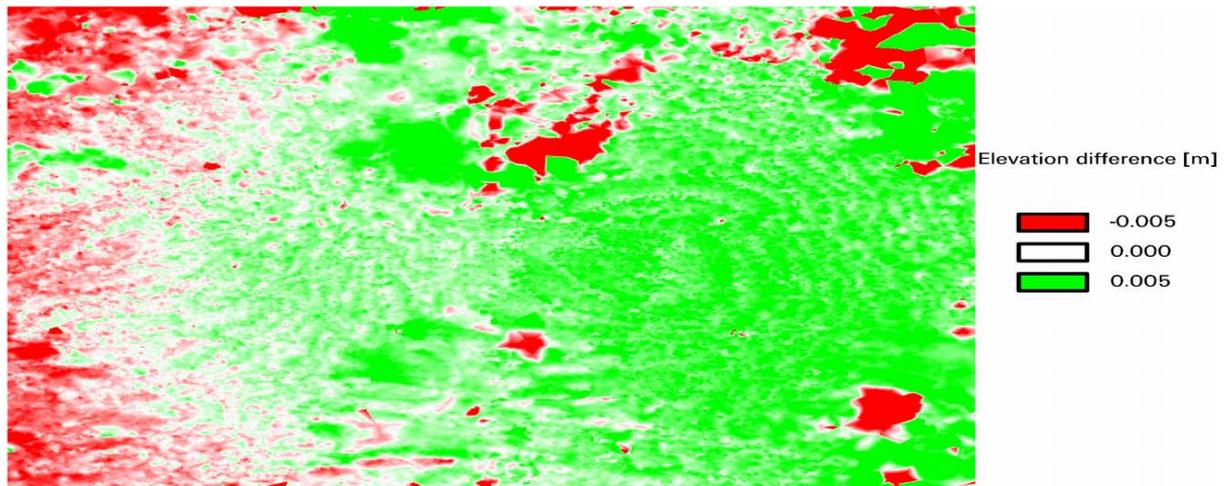


Figure 6 DEM of difference of the flume

4. DISCUSSION

4.1 Data accuracy of the laboratory flume

The quality of photogrammetric processing can be assessed in different ways and the self-calibrating bundle adjustment provides a diversity of criteria. The residuals of control points can be used as an initial indication of the quality of the restitution. These reflect differences between measured and determined coordinate values, utilising measured photo coordinates and estimated interior and exterior orientation. Unfortunately, these criteria are not independent measures of accuracy of a photogrammetric network. However, rms errors of “check points”, not used to compute the restitution of a photogrammetric network, can provide independent measures of accuracy in the object space.

Image Configuration	Check point rms error [mm]		
	X	Y	Z
normal	0.2	0.4	1.7
convergent	0.2	0.3	0.2

Table I Check point rms error (best possible lens model)

Accuracies in the object space, achieved by using a set of “check points” using the normal and convergent image configuration, are summarised in Table I. These statistics indicate significant improvement in accuracy, particularly in the direction of the camera axis (rms error 1.7 mm improves to 0.2 mm) using the convergent configuration. This result is not surprising since it can be assumed that extracted data using the normal case are disturbed by remaining residual lens induced systematic errors, whilst these have been minimised using the convergent configuration (Wackrow et al., 2008). To emphasise the benefit of a convergent image configuration, Table II summarises the check point rms errors for both image configurations in which the lens model used for the Canon EOS 10D camera was deliberately degraded. As expected, a significant change in accuracy in Z (rms error 6.6 mm) using the normal configuration could be observed. Surprisingly, the accuracy achieved using the mildly convergent case was also affected. However, investigating the convergent image

configuration further, it was established that the optical camera axes did not exactly intersect the object plane at the same point but 8-22 mm below the flume bed, which perhaps explains this anomaly. Overall, the accuracy improvement achieved using the convergent configuration exceeded expectations. Comparing the

Image Configuration	Check point rms error [mm]		
	X	Y	Z
normal	0.4	0.6	6.6
convergent	0.2	0.6	2.0

Table II Check point rms error (inaccurate lens model)

accuracy statistics achieved for check points using both configurations, results certainly demonstrate the potential of the mildly convergent configuration to minimise residual systematic errors, even though a significantly inaccurate lens model was used.

The automatically extracted mosaic DEMs (Figure 2 and 3) using the camera parameters determined by self-calibration, were compared by interpolation and subtraction to produce a DEM of difference (Figure 6). Areas with elevations less than -5 mm are illustrated by solid red, while solid green regions indicate height differences greater than 5 mm and white areas represent areas of no height differences. A remaining systematic error surface can be clearly identified, slightly shifted to the right of the centre of the difference image. The results, represented in the DEM of difference (Figure 6) and Table 1 and 2, demonstrate that residual systematic effects arising by slightly inaccurate estimated lens distortion parameters certainly degrade achieved accuracies with a sensor using the normal image configuration. However, findings also indicate the potential of a mildly convergent configuration to minimise these effects. These results correspond closely with the findings in Wackrow et al. (2008).

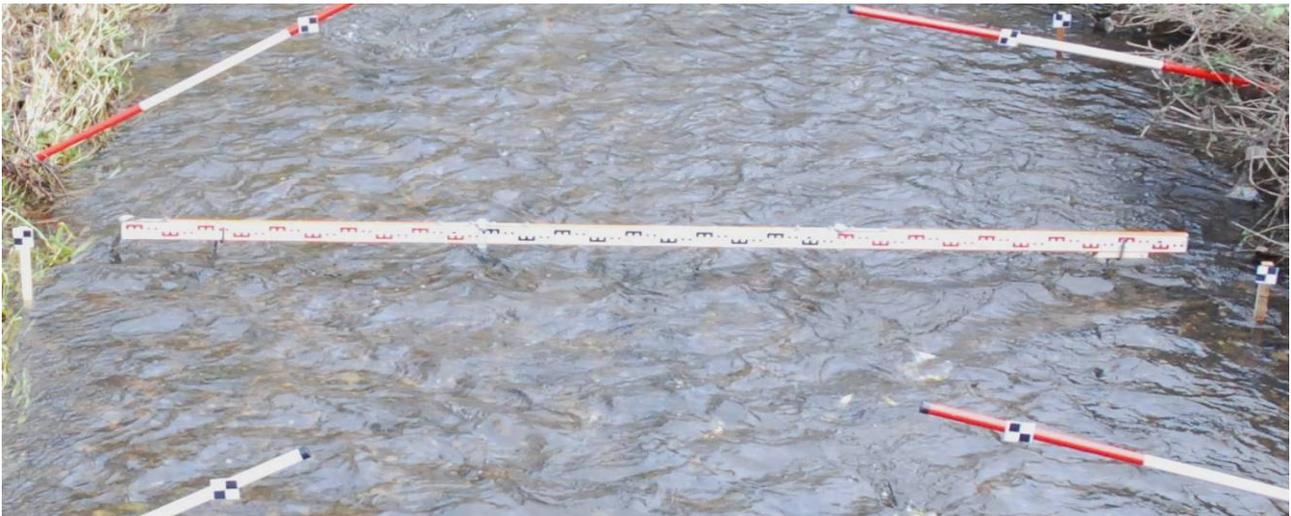


Figure 7 Survey staff positioned close to the water surfaces

4.2 Data accuracy of the dynamic water surface

Evaluating the accuracy in the object space of a dynamic water surface was identified as a main issue in this study. Analysing the residuals of the control points provides a first indication of the accuracy of the network restitution but is not independent. Generating DEMs of the water surface using an oblique image pair derived using the normal and convergent image configuration and comparing these surfaces by subtraction and interpolation is obviously not meaningful because of the dynamic nature of the water surface. However, using independent check point data would provide a viable means of assessing accuracy. Unfortunately, distributing an appropriate number of check points close to the water surface of the running river would be difficult. The solution involved placing a survey staff across the river located close to the water surface. The staff graduations could provide suitable check points and was considered effective (Figure 7). The staff graduations were coordinated using a reflectorless Total Station and these could be compared with values derived for the normal and convergent configuration. Initial results indicate that water surface elevation can be determined to an accuracy of $\pm 5\text{mm}$ using the normal configuration. It is believed that these accuracies can be improved by adopting a convergent image configuration. Further tests including simulated data have to be conducted to finalise the findings of this case study. It is hoped that these results can be presented in a future publication.

5. CONCLUSION

The work presented in this paper has successfully demonstrated that using a mildly convergent image configuration for DEM extraction, minimises systematic error surfaces caused by inaccurate lens distortion parameters. This result is significant for DEM generation using consumer grade digital sensors, where a mildly convergent image configuration can reduce the need for an accurate lens model. Furthermore, a case study to measure a dynamic water surfaces has been introduced, which hopefully will demonstrate that this technique can be also used for oblique image pairs and thus will be suitable for various applications in close range photogrammetry.

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