

“Tips for the effective use of close range digital photogrammetry for the Earth sciences”

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1. Introduction

This document was developed by members of ISPRS V6 to provide simple guidance to new/less experienced users of close range digital photogrammetry, with a particular emphasis on application to Earth science applications. It does not enable a novice to produce or supply commercial products and services using close range photogrammetry. The guidance is provided with the best of intentions but clearly members cannot be held responsible for any actions arising from the information presented, although the utmost care has been taken to ensure its accuracy.

2. Start simple, start small

A recommendation that is not specific to digital photogrammetry but appropriate when introduced to any new technology is to start with simple and small applications. Only when a small project has been tackled successfully is it prudent to start working on larger and more ambitious schemes. This is particularly true when applying close range photogrammetry for the first time, and especially when an application is combined with using new and unfamiliar software. It is suggested that an initial project should consist of just a few frames acquired with a camera which has some form of camera calibration data.

It is always prudent to test equipment before you start a full project or even buy hardware/software. If you cannot solve a problem yourself, get support from experienced users. Small difficulties in the workflow may have large impacts!

Key stages which allow for accurate spatial measurement using digital cameras can be briefly identified:

- Test-field calibration to derive an approximate lens model (See “Tip 2”, below);
- Provide sufficient control for restitution and providing independent checks (See “Tip 5”, below);
- Obtain images for object recording using a convergent image pair configuration with an overlap of 90-95%. If multiple image pairs are combined to mosaics, an appropriate overlap between adjacent convergent pairs can be 5-10%;
- Spatial measurement using digital photogrammetry, including automated DEM acquisition.

These simple steps allow non-photogrammetrists using consumer-grade digital cameras to capture spatial data of sufficient accuracy for many applications.

Chandler, J.H., 1999. Effective application of automated digital photogrammetry for geomorphological research, *Earth Surface Processes and Landforms*, 24: 51-63.

<http://www3.interscience.wiley.com/journal/40005892/abstract>

Wackrow, R. and Chandler, J.H., 2008. A convergent image configuration for DEM extraction that minimises the systematic effects caused by an inaccurate lens model, *The Photogrammetric Record*, 23(121): 6-18.

<http://www3.interscience.wiley.com/journal/119395357/abstract>

3. Which camera?

An obvious and common question is “which camera should be used or purchased when applying close range photogrammetry to the Earth Sciences”? There is no simple answer, as project requirements should always dictate the design of any measuring system, which should include camera selection. Despite this, the following guidance/comments may be of value:

Digital SLR cameras tend to give better results than compact digital cameras. The number of megapixels is important with high resolutions providing more information, but if the lenses are of low quality, images will lack sharpness and clarity whatever the resolution. Digital SLR cameras are generally equipped with higher quality lenses than compact cameras and therefore give better results. In addition, digital SLR cameras normally provide more controls for image capture, so tend to be more versatile and hence capable of tackling more diverse problems (Chandler et al, 2003). Such cameras also offer the best high ISO performance - this allows working indoors without the need for a tripod or flash or to stop down aperture for increased depth of field.

Never purchase the "top of the range" digital camera, unless equipped with an **essential feature** that is necessary for the project. Camera technology evolves rapidly, and top of the range features frequently migrate into cheaper midrange series of the future.

Distortions associated with fixed focal length lenses are easier to model and maintain than the more common, variable zoom lens. However, variable zoom lenses (18-70mm on digital SLR's or more strictly APS-C “Advanced Photo System Type Classic”) cameras are more versatile and can, with care, be utilised for close range digital photogrammetry at medium accuracies (Wackrow and Chandler, 2008).

Although wide angle lenses typically allow for better triangulation results, avoid extremely wide angle lenses because radial lens distortion becomes excessive for these lenses, reducing the potential accuracy of a system. (e.g. For an APS-C size sensor, avoid focal lengths (fixed or variable zoom settings) of less than 20mm). Note also that Fisheye lenses cannot typically be handled by standard software.

Close range photogrammetric work often involves exposed conditions, heavy use & taking photos perhaps days apart, which emphasizes the need for a very stable camera system, unlike aerial mapping where photos are taken in rapid succession. So, when choosing a camera, choose stability over anything else if accuracy is a major factor.

Only use cameras with fixed and stable sensors, it is not recommended to use those with anti-shake (image stabiliser) mechanisms or clip-on backs. Be cautious of new breeds of DSLRs with anti-shake

within the sensor or lens, in both cases the formation of a sharp image is being assisted by the compensatory movement of either the lens elements or the actual sensor. These types of features should be avoided in photogrammetric work, where each recorded pixel position must represent a repeatable measurement point.

Disable "automatic image orientation" in your camera. The photogrammetric image coordinate system assumes this to be fixed relative to the camera. If you cannot disable this feature, record the orientation of the camera manually for each image.

4. Camera calibration

To derive accurate spatial data using consumer grade digital cameras, it is necessary to define several critical parameters which model distinct geometric characteristics of the imaging system. The prime parameters normally recognised include:

- camera focal length (f)
- principal point offset (x_p, y_p)
- radial lens distortion (K_1, K_2, K_3)
- tangential distortion (P_1, P_2)

Unfortunately, no universal standards have been adopted and different software systems use slightly different combinations and many include additional parameters too. An additional difficulty is that the accuracy and number of parameters required depends upon a variety of factors, most notably the final desired accuracy of the data to be acquired from the imagery, which is often unknown. Fortunately, the desired accuracy for many earth science applications is generally an order lower than necessary for high precision industrial measurement, hence the opportunity for spatial measurement using consumer grade digital cameras. There are also a variety of cheap/free calibration software tools available, including: Matlab, PhotoModeler, iWitness, Camera Calibrator, LISA-FOTO which provide the required capability. Some understanding and experience in camera calibration is necessary for optimum results which should be verified by providing independent checks, (see Tip 3).

The camera system should be re-calibrated at least every 12 months; or:

- If the camera is heavily handled or knocked, or has been unattended during major transit;
- If the lens has been moved, or removed (ie. to clean the sensor);
- If the initial photo orientations become unstable;
- During, or prior to carrying out a major or crucial project ;
- in case of deliberate changes to camera/lens setting, i.e. new focus position.

Chandler, J. H., Fryer, J. G. and Jack, A. (2005), Metric capabilities of low-cost digital cameras for close range surface measurement. The Photogrammetric Record, 20: 12–26. doi: 10.1111/j.1477-9730.2005.00302.x
<http://onlinelibrary.wiley.com/doi/10.1111/j.1477-9730.2005.00302.x/abstract>

Clarke, T. A. and Fryer, J. G. (1998), The Development of Camera Calibration Methods and Models. The Photogrammetric Record, 16: 51–66. doi: 10.1111/0031-868X.00113

Tuominen, M.T., 2010. Datapix Pty Ltd, Australia

Wackrow, R. and Chandler, J.H., 2008. A convergent image configuration for DEM extraction that minimises the systematic effects caused by an inaccurate lens model, *The Photogrammetric Record*, 23(121): 6-18.

<http://onlinelibrary.wiley.com/doi/10.1111/j.1477-9730.2008.00467.x/abstract>

Rieke-Zapp, D., W. Tecklenburg, J. Peipe, H. Hastedt, C. Haig (2009). Evaluation of the geometric stability and the accuracy potential of digital cameras – Comparing mechanical stabilization versus parameterisation. *ISPRS Journal of Photogrammetry and Remote Sensing*, 64(3): 248-258.

5. Fieldwork

Planning/preparation

Where possible, visit the site or review the subject and take various test photos to study prior to planning. Spend time planning ALL photo locations & control points, estimate the time required for preparing the site (marking control targets etc.) taking photography & making field notes. Consider all possible working conditions & other site specifics: weather, visibility, sun/shadows, equipment, assistance, safety regulations & legal responsibilities. Most; if not all planimetric measurements derived photogrammetrically require elevated photos in order to see enough detail that is common to & can be identified in at least 2 or 3 photos. Common methods of obtaining elevated photos include: tall tripods, masts, cranes or elevating platforms, UAVs & helicopters.

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Photo acquisition

Ultimately, the quality of the input (imagery) will greatly determine the quality of the output (data), so develop a refined photographic technique for photogrammetry. Develop your photographic skills to be able to take consistently sharp photos in all conditions, for clear and crisp photos that are suitable for use in photogrammetry. In summary:

- Find the sharpest aperture setting for your lens (often f/8) and calibrate with this setting;
- for most projects infinity focus can be used; keep the lens fixed to this focus & calibrate with the true infinity setting;
- Use the fastest shutter speed applicable to the conditions & available light;
- Increase ISO as necessary if additional sensitivity is needed in lower lighting conditions;
- If necessary in very low light, use a tripod and mirror-lockup to avoid any camera movement;
- Take extra images to increase data redundancy.

Low light conditions may also require a compromise of optimal exposure settings. Often, the lens aperture setting is predetermined given the pixel size of an image (see tip “Which camera?”) and an upper limit for the ISO setting has been established given the operator’s experience with a particular camera and the acceptable amount of image noise the operator is willing to tolerate. Generally, image noise reduces the detail preserved in an image (especially in areas of low contrast) and can reduce the success of image matching routines used in photogrammetric software. Although flash photography can be used, it is best to avoid utilising the “in-built” camera flash. Different and harsh

shadows are generated from different camera locations which can confuse automated DEM extraction algorithms.

In low light conditions, this often means that the shutter must be held open for a longer period to achieve proper exposure. A tripod avoids blurring due to "camera shake" but blurring of the image will occur if the subject is moving (e.g., flowing water or vegetation on a windy day) or if the camera is mounted to an unstable platform (e.g., unipod or balloon). Small amounts of image blur will reduce the apparent resolution of an image, while larger amounts will again reduce the success of image matching routines used in photogrammetric software.

To compensate for potential motion blur, the remaining option for the camera operator is to increase the aperture of the lens until the desired shutter speed is met. However, this can have the effect of producing a relatively shallow depth-of-field, blurring foreground and background objects within a scene. When a lens is focused at infinity, the hyperfocal distance can be used as a helpful tool to estimate the near-point (minimum distance an object must be from the lens before being interpreted as 'in focus') for a given focal length, aperture, and the expected resolution and magnification of media used to view the final image. If an object of interest is closer to the lens than that of the near-point, reducing the aperture, switching to a lens with a shorter focal length (but see tip "Which camera?" regarding the minimal recommended focal length), and/or increasing the flying height of the camera may produce acceptable results. Ultimately, compromise amongst these parameters is often required to obtain a properly exposed and sufficiently sharp image.

Bird, S., Hogan, D. and Schwab, J., 2010. Photogrammetric monitoring of small streams under a riparian forest canopy. *Earth Surface Processes and Landforms*, 35(8): 952-970.

<http://onlinelibrary.wiley.com/doi/10.1002/esp.2001/abstract>

Don't forget the photo control, put in extra to provide independent check data to assess "true" accuracy

Photo-control points are well-defined features which appear on the photographs and whose positions are known in relation to the desired coordinate reference system. Abundant photo-control is particularly desirable when using proprietary software packages, where it is often impossible to proceed unless a minimal amount of control is measured. It is useful for novices to distinguish between the effects of systematic errors - which are due to faults in our observation procedures, field techniques or calculations (therefore generally avoidable if we are competent) and random errors, which are small but unavoidable, and should have an average value of zero.

It is wise to always withhold a sample of the photo-control points for use as "check-points". Comparing the photogrammetrically derived coordinates with the accepted survey derived values provides the only true indicator of accuracy of any photogrammetric restitution. Use of such redundant data is particularly important if a high resolution digital elevation model (DEM) is to be derived using automated DEM extraction software carry out automated DEM extraction (common packages include: LPS/Imagemaster, Socet Set, Image Station, Match-T, LISA-FOTO, 3DM Analyst). There can be the dangerous presumption that accurate data is being generated simply because sophisticated and automated techniques are being used. In such cases, it is recommended to

compare extracted elevations derived at many (100+) accepted checkpoints. Traditionally, this has been summarised by a single parameter known as the root mean square error (r.m.s.e.). However, experience has shown that it is more informative to derive **mean error** and **standard deviation of error** from these differences, which can be assumed to be random variables. If the mean of the check point errors is not zero, it suggests the existence of “*systematic errors*”, which then can be hopefully identified and removed. The standard deviation is unaffected by the mean error and therefore provides a useful measure of “*random error*”. These two statistics therefore distinguish between unwanted systematic errors and the more expected and tolerable random errors.

Automatic DEM extraction requires ground coverage per pixel larger than the desired DEM resolution because DEM generation is based on a comparison of pixel clusters not individual pixels. The DEM resolution should be at least three times less than pixel resolution at the object. (This will actually increase the number of images required for DEM extraction, but also reduces demands on camera and camera orientation procedures.

Finally, it is also important to realise that automated DEM generation procedures will generate a DEM that represents the visible surface, which may not characterise the desired surface. For example, if grass, trees or bushes are present in the imagery then the elevation estimates within the DEM will represent the top of the vegetative canopy, not the underlying terrain. If the true ground surface is desired then vegetation heights need to be estimated or measured and appropriate corrections applied.

Chandler, J.H., 1999. Effective application of automated digital photogrammetry for geomorphological research, *Earth Surface Processes and Landforms*, 24: 51-63.
<http://www3.interscience.wiley.com/journal/40005892/abstract>

Chandler, J.H., Fryer, J.G. and Jack, A., 2005. Metric capabilities of low-cost digital cameras for close range surface measurement, *The Photogrammetric Record*, 20(109): 12-26.
<http://www3.interscience.wiley.com/journal/120703951/abstract>

Control points need not be heavily distributed throughout a well configured photogrammetric project, as long as the basic minimums are established according to the particular requirements of the software. The very basic requirements usually constitute 3 control points around the bounds of the project (along with sufficient check points). Even projects comprising of many well configured photos can still be oriented using limited bounding control points at intervals around its perimeter, the internal structure of the model is held together by Block Adjustment (also referred to as Photogrammetric Triangulation¹) which uses the camera calibration geometry to establish interpolated or secondary photo control.

The control points need to be adequately targeted with disks, chequer plates or similar that are large enough to be defined in the most distant photo that is planned to be used with that control point. An appropriate minimum target size in an image is about 10 pixels in width.

¹ Allan, A.L., 2007. Principles of geospatial surveying, *Whittles Publishing / CRC Press*: 401-402.

6. Data-processing

Close-range photogrammetric processing is a step-by-step procedure

Current (2010) close-range photogrammetry software entails quite a bit of manual intervention from the user. Until fully automated image-matching processes are released, each photo needs to be added & oriented in a more or less manual fashion (except in some small-scale industrial situations where automatic target recognition can be pre-planned, but this does not really apply in medium to larger scale earth science applications).

It is important in any photogrammetric project to begin with the basics to form the initial framework of the model, rather than trying to process everything at once. A good core technique is to setup initial photo orientations with no more than 4 photos with strong angles that cover the entire project area (it will become apparent that larger sites or subjects may need to be split into sub-projects). Process and evaluate the integrity of this initial model and refine as necessary using all available quality indicators, prior to adding further fill-in photos. Addition of further photos can then commence, whilst keeping constant watch on the project's quality indicators, refining as necessary. It is best to apply automatic orientation point indication strategies after these types of pre-processing have been performed.

Image post-processing and optimization

It may seem tempting to use general image enhancement functions to restore clarity & definition to your photos, however be aware that most techniques will actually degrade your image at the pixel-level creating numerous types of artefacts. The results may appear to show visual improvement, but often falsely so. The only basic enhancements that should be done are brightness/contrast, which should be applied during conversion from raw to 8-bit data; and if required, some unsharp masking (keeping well below the threshold before any ringing artefacts appear when viewed at 200%). These basic enhancements, when used minimally, will retain the relative values of the pixel structures in a consistent manner without causing loss of information or introduction of artefacts.

Don't be tempted by using multi-shot super-resolution (S.R.) techniques to gain increased resolution. Analysis has found variations between final output super-resolution imagery & the single input images, leading to the conclusion that the results are not consistent enough for photogrammetric use (this is due to apparent movement in the scene caused by the slightest parallax induced shift between near & far objects during the capture of the multiple photos required for S.R.). Until precise sensor-based multi-shot hardware is created in the consumer market, we are restricted in digital photogrammetry to the number of mega-pixels that the sensor can natively provide.

There are however a couple of advanced true enhancement techniques that are popular in scientific imagery, these are Deconvolution of the Point Spread Function (PSF) & Histogram Equalization.

The PSF is a representation of the inability of the camera system to provide a pin-sharp image of a single distant point, and the process of Deconvolution is a method of resampling the image to account for and reduce the 'blurring' effect of the PSF. As the PSF of the camera systems worsens, so does the spatial resolution of distinguishable features that can be resolved within the image, known as the Rayleigh Limit ². The latest version of Adobe Photoshop™ has a feature called 'Smart Sharpen'

and using its 'Lens Blur' option can greatly reduce the image softness induced by the PSF and can improve actual image quality.

Histogram Equalization is a powerful technique also known as micro-contrast, which can extract 'hidden' detail from images. It should only be used for images that will be used in manual photogrammetric digitizing and not in those images destined for automated DTM processing or image matching. Histogram Equalization works on the principal of redistributing gray-scale values of pixels to spread out and maximize all possible brightness levels within the image based on the histogram, thus aiding the human eye to judge otherwise indistinguishable features³. In automated processes however; the pixel values need to remain integral, the software is able to detect any slight variations without any exaggeration being applied; which would only degrade the automated results. The latest versions of Adobe Photoshop™ contain an image processing function called 'Shadows/Highlights' which essentially performs a variation of Histogram Equalization.

Tuominen, M.T., 2010. Datapix Pty Ltd, Australia

² Graham, R., 2005. The digital image, *Whittles Publishing*: 37-39.

³ Russ, J.C., 2007. The image processing handbook, 5th edn. *CRC Press, London*: 274-281.

7. Other points/comments

Convergent image geometry removes the need for an accurate lens model

A key source of systematic errors in the object space is caused by inaccurately estimated lens distortion parameters. Although deriving the perfect lens model through self-calibration can be difficult to achieve, it is worth establishing the most accurate lens model possible for a camera. Therefore, prior to their use for spatial measurement, digital cameras should be calibrated, ideally using the test-field calibration method.

Having derived an approximate lens model for the camera lens system, it is strongly recommended to acquire image pairs obtained using a convergent image configuration, rather than the "normal case" traditionally used for aerial photography. Critically, recent research (Wackrow, 2008; Wackrow and Chandler, 2008; 2011) demonstrated that a convergent image configuration minimises residual systematic error surfaces caused by slightly inaccurately estimated lens distortion parameters. There are other benefits. The convergent image configuration provides 100% overlap of image pairs and hence more efficient coverage of the object, compared to the traditional coverage methodologies used for aerial photogrammetry. Most notably, full stereo coverage can be obtained more easily using "pairs" rather than in adopting "60% overlapping strips", which is particularly useful for complex sites.

Wackrow, R., 2008. Spatial measurement with consumer grade digital cameras, *PhD Thesis*.
<https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/3827>

Wackrow, R. and Chandler, J.H., 2008. [A convergent image configuration for DEM extraction that minimises the systematic effects caused by an inaccurate lens model](http://onlinelibrary.wiley.com/doi/10.1111/j.1477-9730.2008.00467.x/abstract), *The Photogrammetric Record*, 23(121): 6-18.
<http://onlinelibrary.wiley.com/doi/10.1111/j.1477-9730.2008.00467.x/abstract>

Wackrow, R. and Chandler, J.H., 2011. An oblique convergent image configuration to minimise systematic error surfaces in digital elevation models, *The Photogrammetric Record*, under revision.

Consider stereo viewing of close-range imagery

The emphasis of close range photogrammetry is often placed on the production of a digital elevation model (DEM) and an orthorectified image of a scene. However, with additional care taken during image acquisition, close range imagery may also be viewed and interpreted in three-dimensions (3D) using either a simple mirror stereoscope or a more sophisticated digital stereoplotter (similar to techniques used in traditional aerial photography). With the addition of a model describing the orientation of the camera (amongst other parameters), a digital stereoplotter can also extract precise 3D coordinates of a given point found in an image pair.

The ability to view imagery in stereo allows for several advantages, including improved qualitative interpretation of low relief features, manual extraction of breaklines for creating triangulated irregular networks (TINs), DEM error checking, and accurate feature extraction by manually tracing a 3D polygon representing a given feature class. In addition, the precision of 3D coordinates derived from a stereo model are generally higher than those derived from the combination of a DEM and orthoimage given uncertainties in the DEM surface and subsequent displacement in the orthoimage. However, extracting data from a stereo model is labour intensive and forgoes many of the automated routines available for the analysis and post-processing of DEMs and classification of orthoimages.

Often, it is useful to increase the vertical exaggeration of an image pair to better interpret a scene characterised by relatively low relief. This can be done by either increasing the horizontal distance between subsequent images in the stereo model, or by switching to a lens with a shorter focal length. However, increasing the vertical exaggeration generally reduces the overlap (or convergence) between images, and can increase the magnitude of systematic errors in the data (see tip “Convergent image geometry removes the need for an accurate lens model”). As an alternative, you may consider obtaining a highly convergent stereo triplet to model the lens and then omit the middle image from the stereo model.

Bird, S., Hogan, D. and Schwab, J., 2010. Photogrammetric monitoring of small streams under a riparian forest canopy. *Earth Surface Processes and Landforms*, 35(8): 952-970.

<http://onlinelibrary.wiley.com/doi/10.1002/esp.2001/abstract>

8. Other points

- Don't extrapolate the photogrammetric model outside the braced control network, unless for non-crucial measurements (and therefore indicated as 'approximate only').
- Only mark points on photos where the features are defined by enough pixel resolution so that the marking precision on that feature is greater than the expected accuracy to be obtained. Once features become too pixelated; they can no longer be used in primary measurement (due to being out of range).
- Perform gross checks against any available comparative data (field measurements, scaled maps or drawings, or preferably checkpoints). One option is to obtain surveyed cross-sections across the width of the project.

- Save separate backup copies of the project at key milestones; these can be reverted back to if necessary.
- Make sure that your software workflow is based on the same calibration parameters, units and orientation settings. Transferring calibration or perhaps orientation results from one software package to another is not always straightforward.

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9. Finally!

For an overview of photogrammetric theory and an introduction to photogrammetric practices, see Chapter 2, Fundamentals of Photogrammetry, in:

Fryer, J.G., Mitchell, H.L. and Chandler, J.H. (eds.), 2007. Applications of 3D Measurement from images. *Whittles Publishing*, ISBN 978-1870325-69-1.

Also useful:

Linder, W. 2006. Digital photogrammetry: a practical course. Springer, ISBN-10 3-540-29152-0.

T Luhmann, S Robson, S Kyle, I Harley, 2006. Close range photogrammetry: principles, methods and applications. Whittles Publishing, ISBN 1-870325-50-8.