Image acquisition for digital photogrammetry: guidelines & best practice

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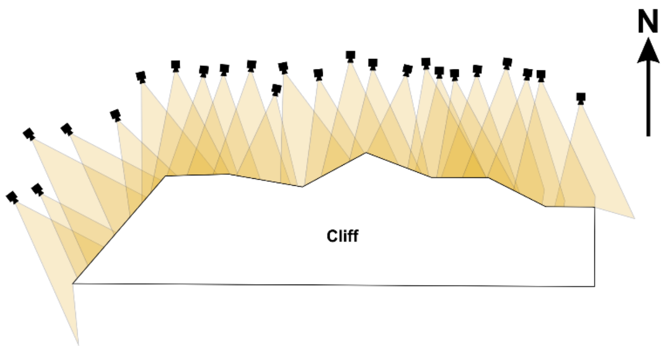
Digital photogrammetry of Structure-from-Motion (SfM) builds on the principles of traditional photogrammetry by resolving the location of photographed features in 3D space. Whereas traditional photogrammetry relies on precisely calibrated cameras and known camera locations and orientations, SfM follows an iterative process whereby feature locations are resolved from unstructured collections of images. In other words, images taken of an object from different distances and angles, in no particular order, can be used to resolve the 3D structure of an object. SfM is a useful, easy to use technique, but relies on a few key principles when acquiring data:

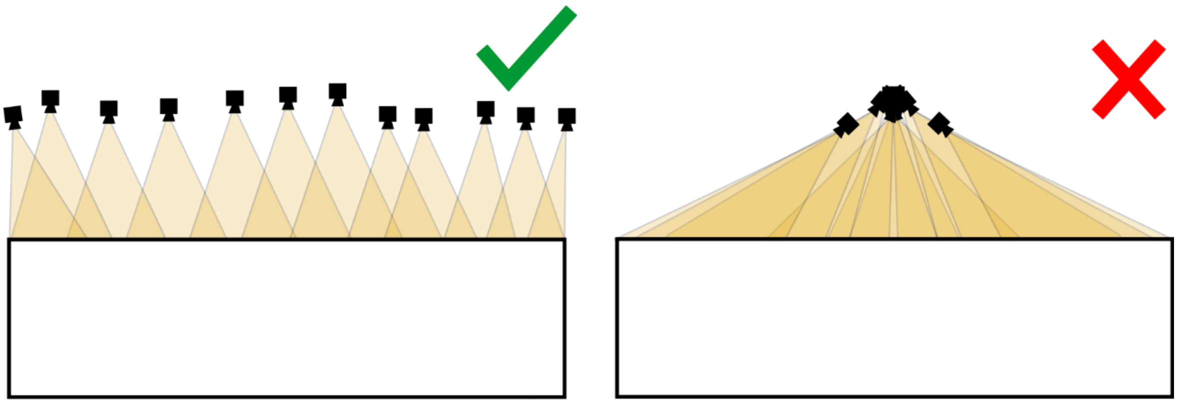
1. Image overlap

This is the single most important consideration during field acquisition. 60% overlap between images is recommended to obtain best results. Anything less will result in 3D models with holes in them or erroneous reconstruction of surfaces. Camera stations should be closely spaced to allow for multiple overlap of images, if possible.



2. Acquisition angle and the effects of occlusion

Camera angle with respect to object of interest is another important consideration. Where possible, the camera station should **be orthogonal to the object of interest**. This is not always possible due to local topography, particularly when cliffs are to be reconstructed from ground-based stations. While overlap of images is of primary importance, survey design should avoid images that are taken at high angle to the outcrop or sample, or a lack of spread in survey stations.



3. Shutter speeds and aperture

High F-stop values or blurry, out-of-focus images result in erroneous digital reconstructions and poor texturing results. During acquisition of images in the field, care should be taken to ensure images are not blurry and are taken at a high enough F-stop so that the scene is focussed at a range of distances. Automatic mode shooting in low-light conditions may result in low F-stop values (below 5) to compensate for shutter speed. **This should be avoided if possible**. Similarly, shutter speeds should be at **1/125 or faster** to avoid image blur. Where lighting conditions do not allow both of these conditions to be met, a tripod should be used to allow for longer shutter speeds. ISO values should also be as ow as possible to reduce the effects of camera sensor noise.

4. Focal length

The camera focal length **should not be changed** during acquisition. If you are using a camera with adjustable zoom, keep this set. Users of DSLRs with hand-adjustable zooms commonly use a piece of tape or similar to avoid mistakenly changing zoom.

5. Cameras, image resolution and file formats

Camera resolution, sensor size and lens quality are all important considerations when taking photos for the purposes of digital photogrammetry. Passable results can be obtained on any camera, even those on your phone. As a guide, we currently use a Nikon D5300, an entry level DSLR which has the useful addition of an on-board GPS unit. There are many forum discussions about which camera model/make is best – ultimately this is a personal choice. Good practice in the field and consideration of the points outlined above will yield good results, even with a compact camera.

If you are using a DSLR and are able to change lenses, it is worth investigating a lens with a fixed focal length. These are generally made to a higher specification than similarly priced zoom lenses, and contain less distortion. They have the added benefit that you will not be able to adjust the zoom of the camera without noticing – which results in alignment problems when processing (see above).

Images taken in JPG format are generally sufficient for the purposes of virtual outcrops. Many users report little difference between RAW and JPG formats in final 3D models, though this is dependent on camera model and the degree of compression when converting to JPG. As a guide, we use the largest, highest resolution JPG option available on whichever camera we are using in the field.

6. How many photos should I take? How close to the outcrop?

There is no hard and fast rule for this – we have virtual outcrops generated from a range of image collections, with datasets comprising less than ten photos through to those with several thousand images. There will always be a trade-off between resolution and size of the 3D model – a virtual outcrop that covers several km^2 will probably not have sub-cm ground pixel resolution, given current limits to speed of processing and computer memory. Our largest models (>2000 images) took a number of weeks to process and resulted in a ground pixel resolution of 20cm. At this scale, the finer detail of the outcrop was not visible in digital form, and thus features such as small fractures and sedimentary structures were not resolvable. Theoretically, higher resolution would have been possible but not only would processing have taken longer, anyone wishing to view the virtual outcrop would have needed a computer with a powerful dedicated graphics card. From our experience, **less than 500 photos works best**, in terms of online rendering and efficiency of processing. Consideration of the need for **image overlap, suitable acquisition angle** and **desired resolution/coverage** for your chosen outcrop or sample should also take into account processing power and times. Very large virtual outcrops with sub-mm resolution are clearly desirable, but computer memory limitations currently make them unfeasible. The resolution of images used for 3D model construction generally undergo a 4x reduction in resolution in the final virtual outcrop. Thus images containing pixels equivalent to 1mm square on the ground will generate a virtual outcrop with 4mm ground pixel resolution. A rough approximation for image ground pixel resolution is provided by:

$$GPR = \frac{Sw \times D \times 100}{Fr \times imW}$$

GPR = ground pixel resolution; Sw = camera sensor width (mm); D = distance to outcrop (m); Fr = focal length of camera (mm); imW = image width (pixels).

7. Handheld camera or UAV?

A common question, with no easy answer. UAVs have the clear advantage in that they are able to cover a much larger area, particularly where access is difficult. Avoiding highly oblique images on high structures or sea-cliffs is near-unavoidable when working with a handheld camera. Similarly, surveys of large, planar areas are likely to be difficult with a handheld DSLR. UAVs capable of carrying high resolution cameras with large sensors, however, are very expensive and require specialist pilot skills and training. Some of our best results have been generated from handheld cameras and a tripod. Where local topography allows synoptic viewpoints onto the object of interest, handheld is often the best option. Higher camera resolution, greater control of the survey positions and in-situ quality checking of images are key advantages of the ground-based method. Ultimately, the choice of approach depends on the site characteristics and the balance between coverage and resolution.

8. Ground control points and georeferencing

While SfM is a useful technique for digitally reconstructing objects, it is important to remember that without known camera locations or GPS locations of known points within the reconstructed object, 3D models will contain no useful information regarding orientation, scale or location of points. An advantage of using UAVs for surveying is that location data is continuously recorded during acquisition – images are tagged with coordinates when taken. This allows *Photoscan* to estimate the location of the virtual outcrop in 3D space. This method is not perfect and errors in GPS locations can result in errors in final model orientations, scale and location in global coordinates. The best way to georeference an object is to include markers in your survey. The locations of these can be recorded by GPS and used to georeference the virtual outcrop. The higher the precision and accuracy of your GPS, the better the georeferencing of the final model will be. We use small cones and a differential GPS for our virtual outcrops when using them for research.

9. Case study

The image below comes from our open-access article of 2017 which addresses some of the points covered above:

Cawood, A.J., Bond, C.E., Howell, J.A., Butler, R.W. and Totake, Y., 2017. LiDAR, UAV or compass-clinometer? Accuracy, coverage and the effects on structural models. *Journal of Structural Geology*, *98*, pp.67-82. https://doi.org/10.1016/j.jsg.2017.04.004

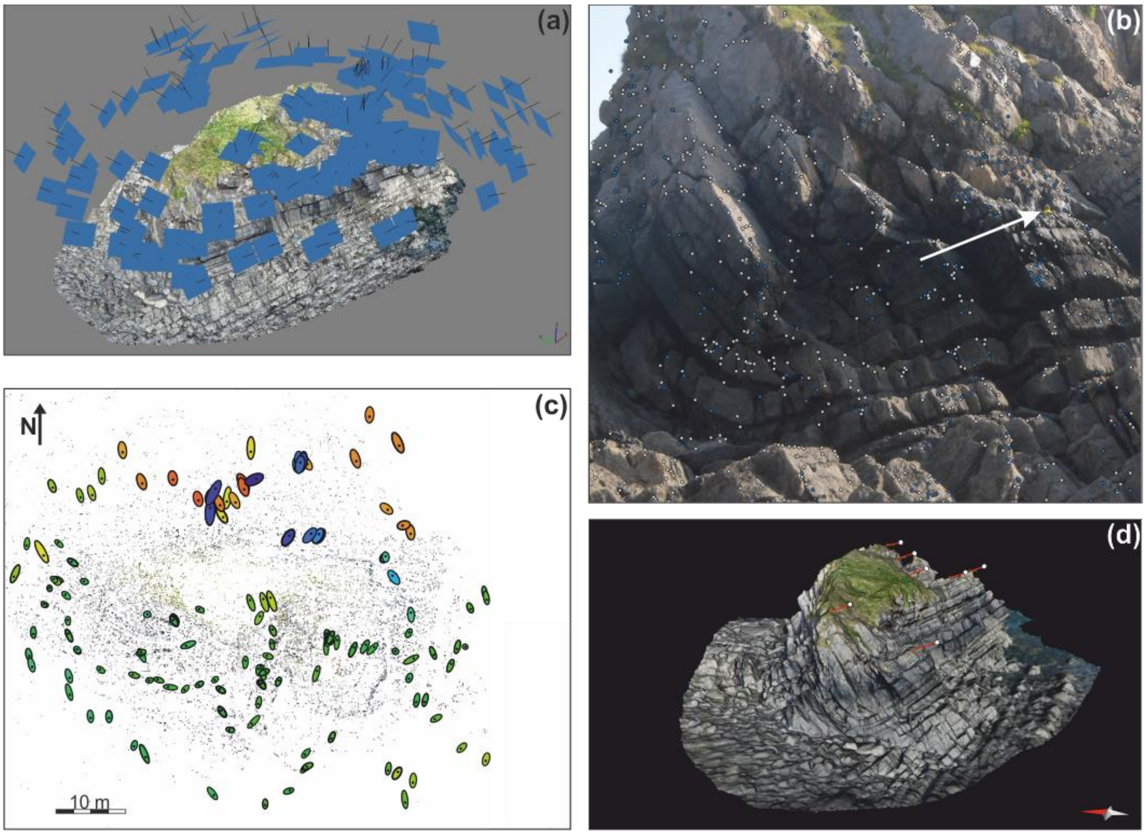


Fig. 2. SfM acquisition and processing steps. **(a)** Image acquisition points for a single UAV flight, highlighting the ability to obtain convergent imagery of Stackpole Quay syncline. Image coordinates recorded during acquisition, with camera orientations estimated during ASfM processing stage (Section 4.1.2). **(b)** Features automatically detected during TSfM processing in *Photoscan*, from which 3D coordinates may be estimated. Features used to construct 3D tie point network marked by dark circles; lighter grey points not used for reconstruction. White arrow marks position of ground control point laid out and recorded during acquistion of TSfM imagery. See section 3.2.2 and 4.1.2 for details of acquisition and processing. **(c)** Estimated camera locations and error estimates from UAV acquisition. X and Y errors represented by size and shape of ellipses. **(d)** Visual representation of required corrections to georeferencing of ASfM virtual outcrop. Spheres represent RTK dGPS measurement points; applied translation vectors of virtual outcrop shown by lines (Section 4.3.1).

We hope this guide is a useful starting point for image acquisition and generation of virtual outcrops. Please direct any questions or corrections to adam.cawood@abdn.ac.uk

Adam Cawood, 29/1/2017