Archaeology Guidelines Supplement

Photogrammetry

State Historic Preservation Office

Ohio History Connection
Columbus, Ohio
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Photogrammetry

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Photogrammetry

Introduction

Photogrammetry is the science of making precise measurements from photographs (Merriam- Webster.com Dictionary) and the earliest records of this practice date to the 1850s, nearly as far back as photography itself. The principles of photogrammetry are based on the calculation of perspective and projective geometry, which in turn draw upon the work of artists to paint perspective accurately. Pioneering work by Aimé Laussedat in 1849 demonstrated the application of photogrammetry to derive topography. In 1867, Laussedat displayed his topographic map of Paris generated from balloon-based aerial images at the Paris Exposition (Birdseye 1940). Generally, the advancement of photogrammetry can be classed into four main periods (Konecny 1985):

Plane table photogrammetry (1850 to 1900)
Analog photogrammetry (1900 to 1960)
Analytical photogrammetry (1960 to present)
Digital photogrammetry (1980 to present)

While the technologies involved have changed dramatically in the intervening 150 years since the Paris Exposition, the application and principles have not. Additional information regarding the development of photogrammetry can be found in Ghosh (1981).

Digital Photogrammetry, the most common type today, often refers to the production of a three- dimensional distribution of points (point cloud) from two-dimensional digital images using a specialized software package. These points are locations that are common between photographs, and they are where the spatial location has been calculated using a technique called structure from motion, or SfM (Historic England 2017). Output point clouds can then be turned into a surface or "mesh" and color or texture data from the photos can be added to the points or the surfaces of the mesh. Though each software package may use different terms/steps, the basic workflows are similar:

1. Take images,
2. Load images into photogrammetry software,
3. Calculate *tie points*,
4. Generate *dense point cloud*,
5. Generate *mesh*,
6. Add *texture* to mesh,
7. Export model/*DEM*/*orthophoto mosaic*

Figure 1 presents the primary components of a complete photogrammetry project workflow. Some of these steps are automatically performed in photogrammetry software, but troubleshooting issues with photogrammetry models may require intervention if the software allows adjustments.

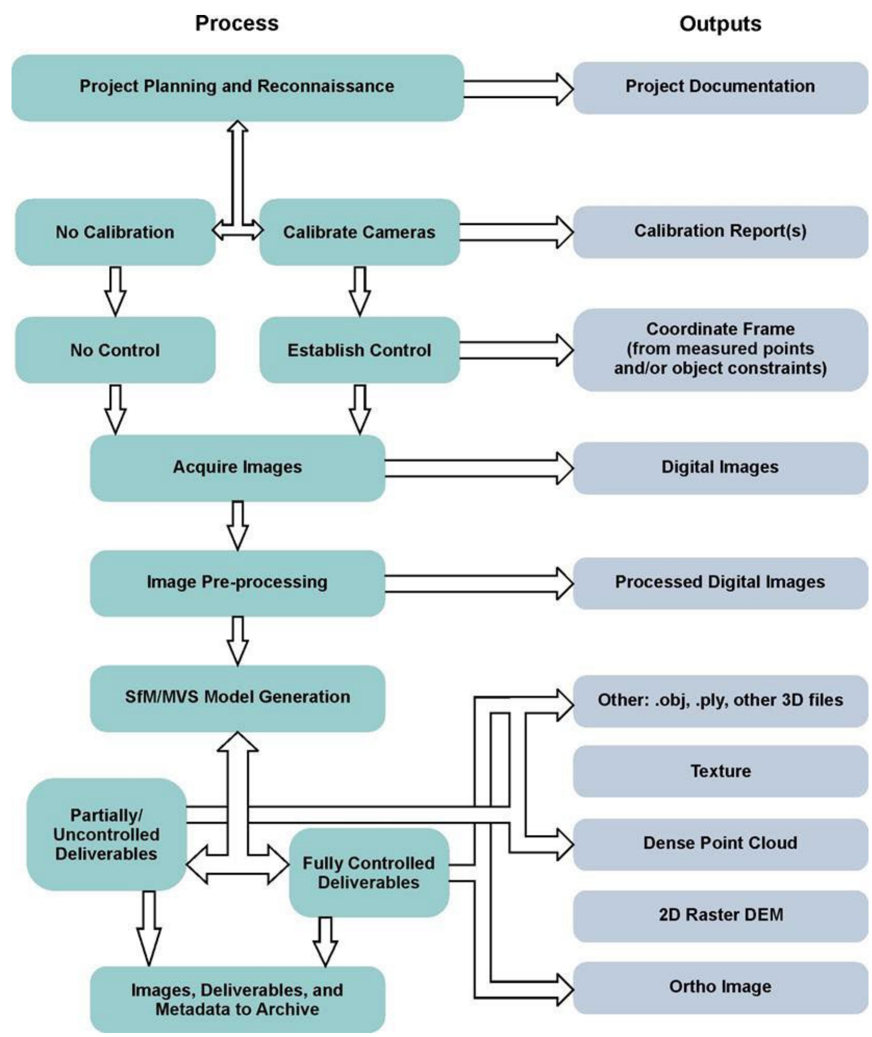

Figure 1. Examples of the processes and outputs for a photogrammetry workflow; outputs also include metadata that should be reported and archived (adapted from Historic England 2017).

How Does it Work

The structure from motion approach works by generating three-dimensional measurements from two-dimensional images. It is based on three primary assumptions (Historic England 2017):

The chief ray and the principles of intersection

A captured image represents the intersection of multiple light rays at a single point (Fryer et al. 2007). Photogrammetry is interested in the rays that reflect off the object/background, pass through the lens assembly, and are projected onto the image sensor in a straight line. These rays are called chief rays (Figure 2).

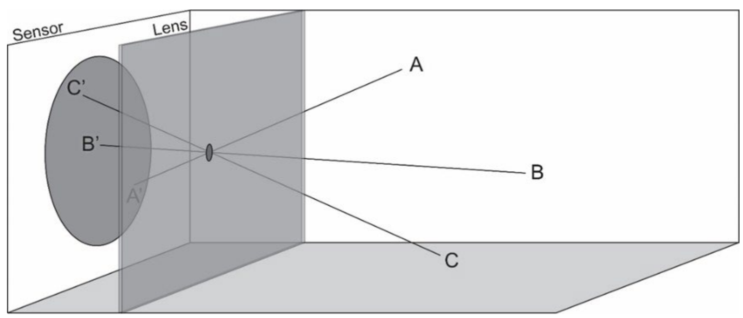

Figure 2. Example of chief rays, where A, B, C represent points in space, P is the lens, and A', B', C' represent the points on the image sensor (Historic England 2017).

The intersection of chief rays from multiple images of the same point on an object is known as the principles of intersection and defines the position of intersection in space (Figure 3; Historic England 2017).

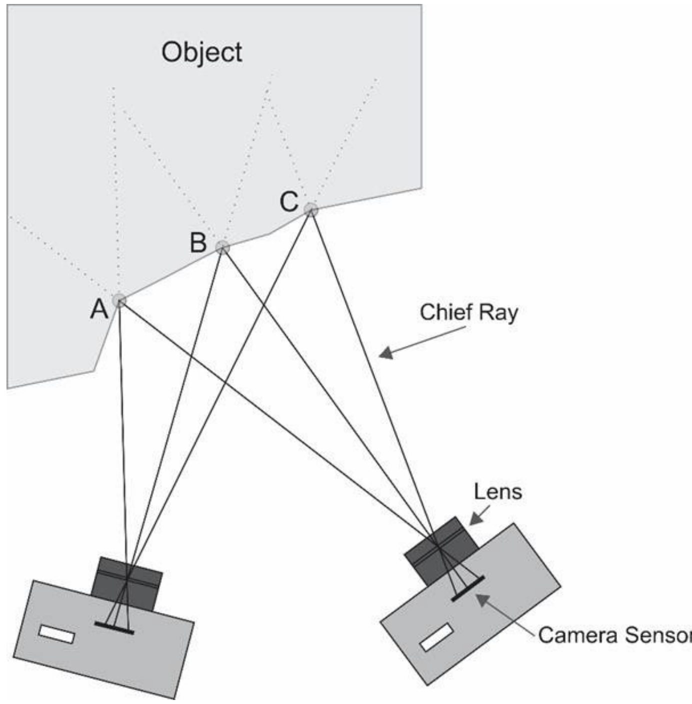

Figure 3. When chief rays from two images intersect (e.g., points A, B, and C), they allow for spatial relationships to be calculated—the foundation of photogrammetry (Historic England 2017).

Collinearity

In order to transform the two-dimensional coordinates of ray intersections into the three- dimensional coordinates of the ray origin, collinearity equations are used. Collinearity is when one predictor variable in a multiple regression model can be linearly predicted. For photogrammetry, these equations are based on a perfect camera, which has no geometric distortion (Historic England 2017).

Interior and exterior orientation/camera intrinsics

While the collinear equation assumes a perfect camera, the actual geometric properties of both the lens and the principal distance (the distance between the image plane and perspective center) are very important to generate precise three-dimensional coordinates for chief intersection points (Luhmann et al. 2006). Most photogrammetry software calculates these values automatically from a combination of the EXIF data embedded in each image and a process known as bundle adjustment (Historic England 2017).

In the end, the photogrammetric process creates several products that stay behind the scenes (e.g., Dense Point Cloud, Mesh) and are used for various end products (e.g., Mesh, Textured Mesh, Orthophoto-Mosaic) (Figure 4).

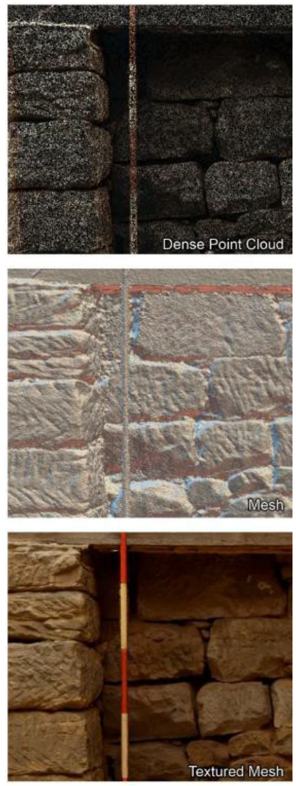

Figure 4. Some of the steps in the photogrammetry process.

Practical Limitations

There are a number of limiting factors to consider when preparing to document something using photogrammetry. Some sources are related to error you cannot control (e.g., they are inside your camera and lens), while others are related to the methodology and choices made when surveying. The following are a non-exhaustive list of sources of error likely to be encountered:

Visibility
Can the camera resolve the object being documented? Objects/features that are too small or far away may not appear in the final model. Likewise, overly reflective surfaces (e.g., window glass) or objects that are the same color as the background may be problematical.

Lighting conditions

Low light environments or areas of deep shadow in an otherwise brightly lit scene can be exceptionally problematic for photogrammetry and can introduce significant error.

Limited documentation

Structure from motion can only act on what appears in the photographs. Restricted viewing angles or insufficient overlap between images increases errors in the final product.

Accuracy/Control points

Manually setting control point locations and assigning their importance/weight is sometimes necessary to align images. Incorrect placement or weighting of the control points can generate significant error in the output model.

Incorrect lens or camera settings

Using the incorrect interior and exterior geometric properties of the camera will greatly increase noise/error in the output. Zoom lenses, cheap phone/camera sensors that are perpendicular to the lens axis, or incorrectly calculated interior and exterior orientation values can cause these types of error.

Photo or Video?

Though photogrammetry functions via photographs, certain software packages can extract still images from video (effectively turning video into hundreds or thousands of lower resolution photographs). One advantage of this methodology is the guarantee of sufficient overlap. Though the absolute resolution of the stills will be lower, the reconstructed geometry is likely to be of high quality. A blending of both photography and video (ideally taken from the same device) for objects with complicated geometry can be a very effective strategy, leveraging the resolution of the photographs (to be used in creating the textures) with the high overlap of the video-based stills for geometry.

Archaeological Applications

Archaeological applications of photogrammetry abound, and they can be broken down into three categories: objects, excavations/features/structures, and landscapes.

Objects

The Objects category includes artifacts and other portable things, as well as headstones, smaller monuments, and statues. These things can have very complicated geometry and may require many photographs to ensure complete coverage with sufficient overlap.

a. *Artifacts*. It is possible to create high resolution photogrammetry models of artifacts (Figure 5). This works especially well on moderate- and large-sized objects, such as axes, whole pottery vessels, and megafauna bones. Smaller objects such as coins are more difficult, but macro lenses can help resolution. It may be necessary to create discrete models of two or more sides of small or very complex objects that can then be combined into a final, single model manually or with the help of control points. Not all software packages allow for this.

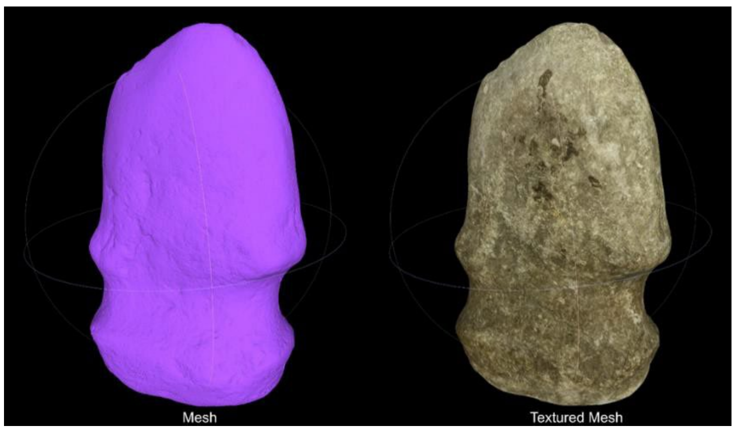

Figure 5. Example of an artifact modeled with photogrammetry. Note how a colorized mesh can make it easier to see shadows related to subtle relief on the object.

b. *Headstones and Monuments*. These are ideal objects for photogrammetry. Photographs are best taken with few shadows. If desired, background scenery can easily be clipped from the model. Three-dimensional models are an excellent way to improve the visibility of faint text on headstones or monument inscriptions (Figure 6). The mesh can be used to create a DEM, which can then be further processed (e.g., a local relief model) to extract or highlight very subtle surface topography.

Figure 6. Creating a DEM of a headstone fragment with faint lettering.

c. *Statues*. Statues are very complex objects that require more images to adequately cover their many different depressions, appendages, and textures (Figure 7). They also often are made with shiny metals or stone (e.g., polished marble) that can be problematic for photogrammetry software. One solution, if permissible (this may rarely be the case), is to cover the shiny surfaces with a matte (preferable) coating, such as baby powder (or any dust) or wax. A combination of photos with and without the coating may be necessary—photos without the coating would be used for the final texture.

Figure 7. Example of a statue as a textured mesh (left) and a dense point cloud (right).

Excavations/Features/Structures

a. *Excavations and Features*. The archaeological process can create very complicated three-dimensional features (i.e., excavations). These are typically documented with a limited number of static photographs and hand drawings made in the field. If the excavations are large or contain complicated features, such as with a foundation wall or a cooking pit with numerous pieces of fire-cracked rock (Figure 8), drawings can be very time consuming and require two or more people.

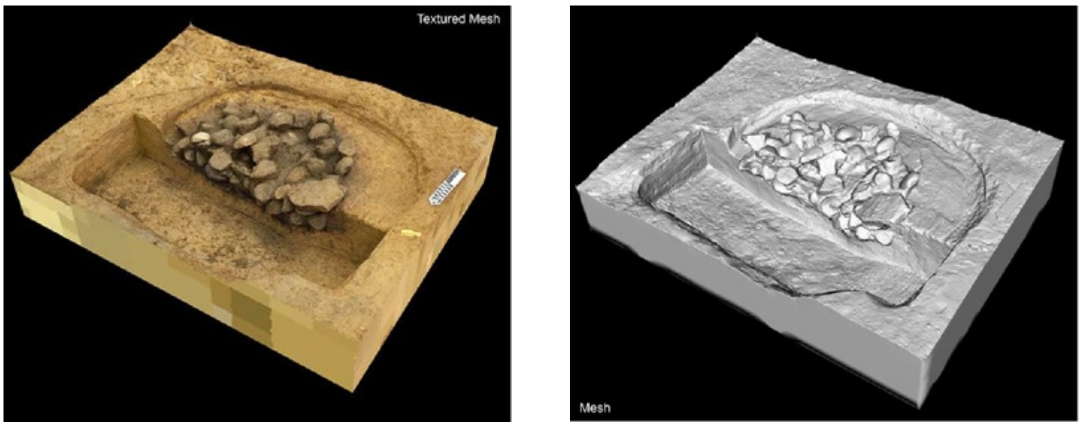

Figure 8. Using photogrammetry to create a full model of a feature under excavation.

The photogrammetry process can be completed more quickly and with just one person, and it can yield a much more accurate model, as well as an orthophotograph for use in creating line drawings or computing volumes. If properly archived, it would also be available well into the future for other uses.

Photogrammetry can also be used to make a high-resolution image of large or difficult to access surfaces, such as long excavation unit profiles or trench plan view photos from above (Figure 9).

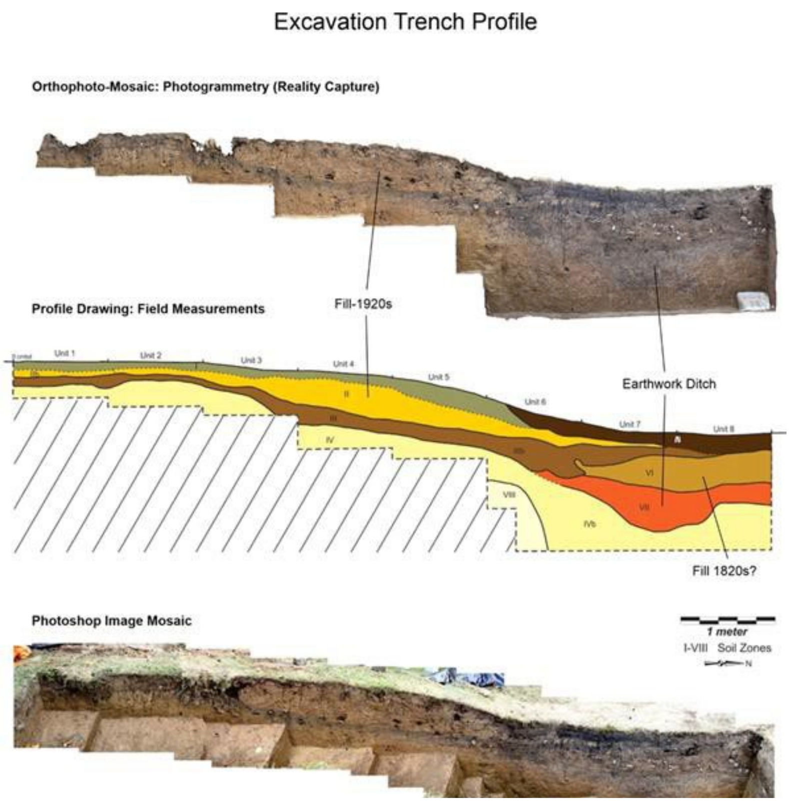

Figure 9. Using photogrammetry for specific tasks within an excavation, such as creating an orthophoto-mosaic of a trench excavation profile (an unrectified mosaic example from Photoshop for comparison).

a. These orthophoto mosaics can be created from numerous close-range orthogonal photographs taken from within the trench (to create a single trench profile image) or they can be created from overlapping oblique photos taken while standing at the edge of the trench (to create an orthogonal plan view image). Measured control points are recommended for best results.
b. *Structures*. Buildings and other structures are some of the most common subjects of photogrammetry modeling (Figure 10). Though sometimes large, thus requiring many photographs, they often have ideal surfaces for generating very high-density point

clouds that can be used for making precision models. These models can be used for analysis of hard-to reach areas, for taking measurements, and for producing ortho-rectified elevation photographs and drawings (by digitizing orthophotos). However, their height can require the use of a pole- or drone-mounted camera. They also contain many windows, which can be challenging to model. Attached or adjacent vegetation can also produce gaps in the model. Making the model in winter can help limit the effects of some vegetation.

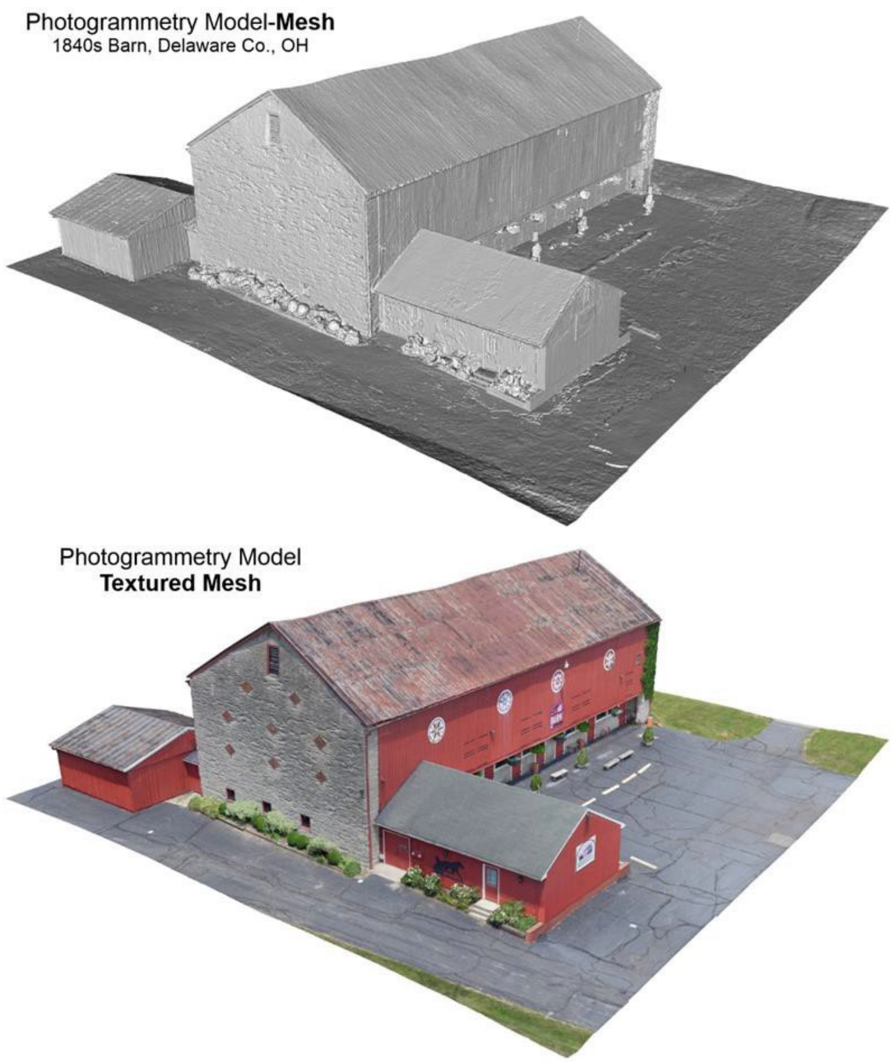

Figure 10. Mesh and textured mesh model of a 19th century barn.

Landscapes

a. Site *topographic maps* and up-to-date *orthophotographs*. In this age of state-wide LiDAR datasets, making topographic maps of archaeology sites with a transit is seemingly a thing of the past. However, landscapes can change rapidly while costly LiDAR datasets are infrequently updated. Photogrammetry represents a quick way to make highly detailed digital surface models (DSMs) (Figure 11).

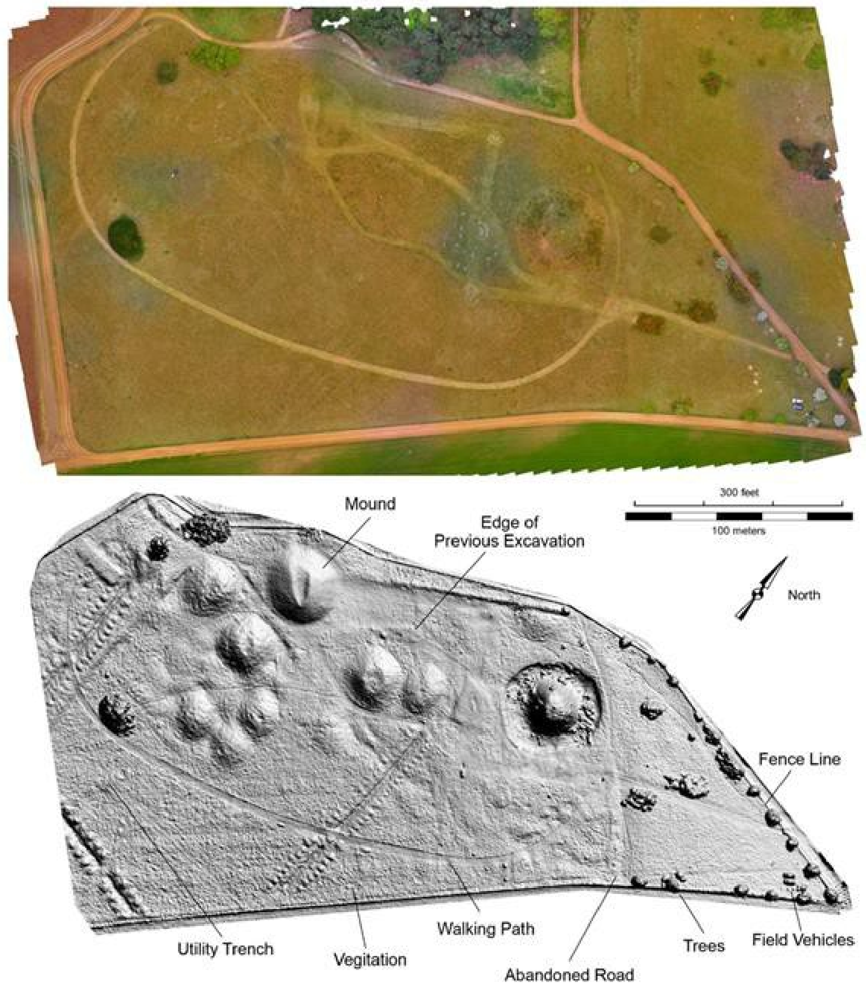

Figure 11. Creating a digital surface model to examine terrain; (top) the orthophoto-mosaic, (bottom) a shaded relief map created from the digital surface model.

a. The surfaces that are captured in these models represent what is visible in the photographs, which in most cases is the top of whatever vegetation is growing in the area. Photos taken in winter can be used to the ground surface in model wooded areas; trees are clipped out of the data to produce a LiDAR-like DSM. Using a drone-based camera, DSMs of very large areas can be created relative quickly with resolutions of 10 cm or better (i.e., an elevation data point every 10 cm).

b. *High-density models of select features*. In some cases, detailed models of select features of a site are desired, such as a mound (Figure 12). Images for these models can be captured with a handheld or pole-mounted camera, as well as drone-based imagery. Resolutions of 1-2 cm can be achieved with this technique.

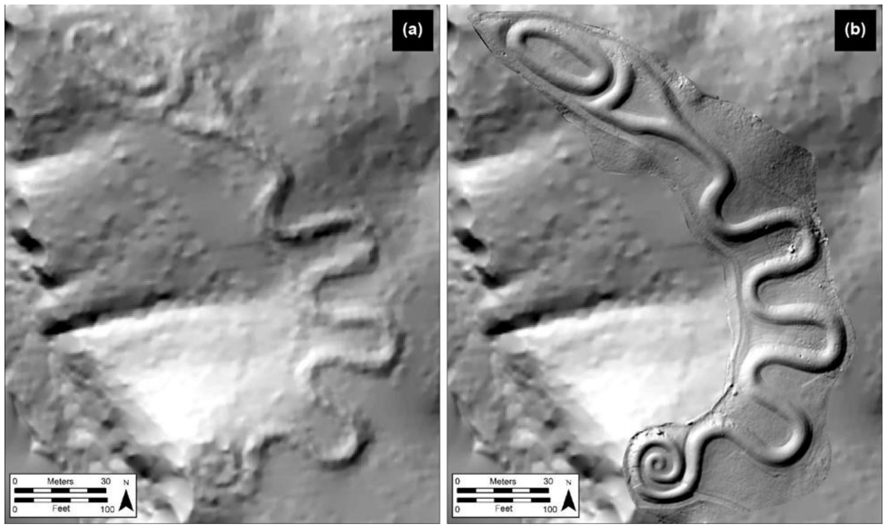

Figure 12. Shaded relief maps of Serpent Mound using (a) LiDAR data and (b) photogrammetry- based data.

c. *Site mapping*. Archaeologists spend a lot of time making maps of features present in their survey/work areas, such as trees, buildings, or headstones in a cemetery. When there are thousands of features to be precisely mapped, an orthorectified photo-mosaic, created with photographs from a drone or pole-mounted camera, can be used to digitize features of interest (Figure 13).

Figure 13. Using the orthophoto-mosaic to vectorize headstone location and size/shape in a large cemetery.

Section 106 of the National Historic Preservation Act

The three phases of cultural resource management archaeology can benefit from both terrestrial and airborne photogrammetry surveys.

Phase I: Finding Cultural Resources
Airborne based photogrammetry can be used to quickly assess a site, providing useful data on topography, surveyable landforms (which can aid in estimating shovel test numbers), and ground cover. If the project area is not too large, this can often be accomplished in a single flight. Depending on the precision required for the outputs, the internal GPS location for the UAS may be sufficient and ground control points may not be needed. This approach can be used to quickly delimit mounds and other subtle enclosures (made visible in a DSM), locate depressions perhaps marking grave locations (DSM), or identify possible cultural features as differential vegetation marks

or soil colors (photo-mosaic). While it is possible to take pictures of artifacts in the field for use in creating photogrammetry models (during projects that limit artifact collection), it can be very difficult in a field setting to take images with the necessary lighting and resolution for creating high-quality models.

Phase II: Assessing Sites

Phase II work often involves determining site integrity and delimiting site boundaries. Photogrammetry could be used on these projects to document the extent of features (e.g., building foundations, graves, subtle topography related to mounds and enclosures) in photo-mosaics and DSMs. Likewise, up-to-date topographic maps are useful at the Phase II level to delimit landform boundaries and locate disturbed ground (e.g., from utility lines or the creation of garden terraces around a historic house).

Phase III: Data Recovery

a. Thoroughly document a site before excavation/destruction with a high-resolution DSM and photo-mosaic.
b. Accurately map and record archaeological features. Data recovery work often results in the destruction of the cultural resource. Creating photogrammetry models of excavation units and exposed features can produce precise spatial data for use in later applications, such as studies of feature form and volume. It is also an excellent way to quickly document very complex features, such as building foundations or exposed skeletal material. The models can then later be used to produce detailed plan drawings.
c. Estimate volume of excavations.
d. Create virtual museum collections of recovered artifacts.

These are but a small selection of many possible applications of photogrammetry in NHPA-related projects.

Expectations and Best Practices

There are several best practice rules to follow when attempting to generate a three-dimensional model with the smallest level of error. Some rules are general and apply to all applications, while others are more specific to certain applications. The following list will highlight the most important of these. Further examples can be found in

Photogrammetric Applications for Cultural Heritage (Historic England 2017) and many other photogrammetric manuals, such as *Manual of Photogrammetry* (McGlone and Lee 2013).

Camera

a. Use a camera that is suited to the survey. In reality, any camera can be used— DSLR, phone camera, drone-based cameras. But camera choice will greatly impact outcome.
    i. Consider weight, battery life, resolution, lens, sensor size. A large camera with a high resolution may be bulky and ill-suited to tight spaces or mounting on a pole/drone. A small camera with a low resolution may be unable to capture the detail necessary to produce a precise model.

b. Shoot in RAW if possible, though compressed file types (e.g., jpeg) can work, too.

c. Avoid images/settings with a shallow depth of field (use the appropriate f-stop). It is best if everything within the image is in focus. Out-of-focus images will be hard or impossible to align when making the model, and they produce blurry areas in textures.

d. Turn off auto-focus, image stabilization, HDR, and any other digital modifications that might alter the image. The photogrammetry software my not be able to determine important geometry variables in modified images.

Survey Strategy

Tip #1. Typically, take more photos than you think you will need. Overlapping photos are the key. Attempt roughly 75% side overlap and 80% forward overlap for both airborne and terrestrial surveys (Figure 14).

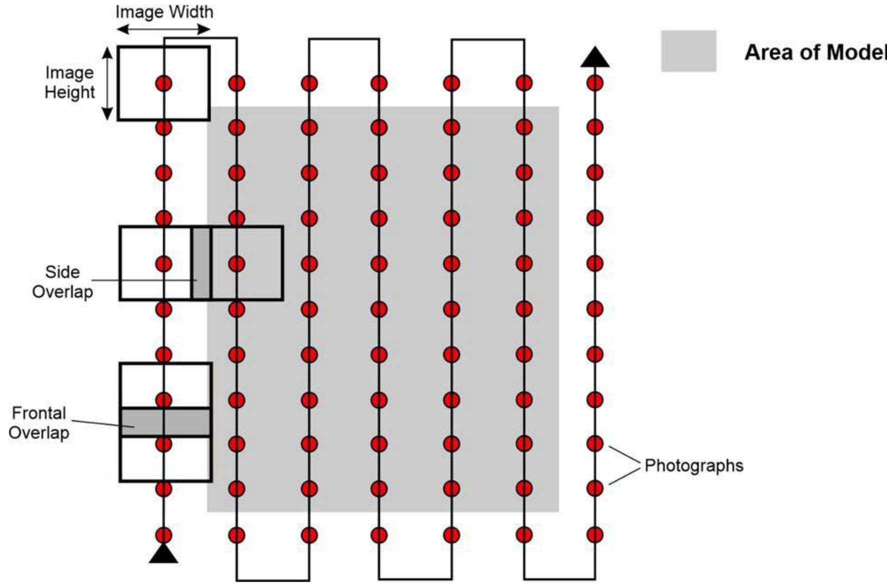

Figure 14. Example of flown photogrammetry survey pattern illustrating side and frontal image overlap over the area of interest (adapted from Pix4D 2019).

Tip #2. Take photos beyond the edge of the subject, to ensure the edges are properly documented.

Tip #3. Consider camera angle. Many photogrammetry software packages prefer photos taken orthogonal to the subject matter. However, oblique can work well with other software. Thus, it is best to capture both kinds of imagery, but be sure to have good overlap (Figure 15).

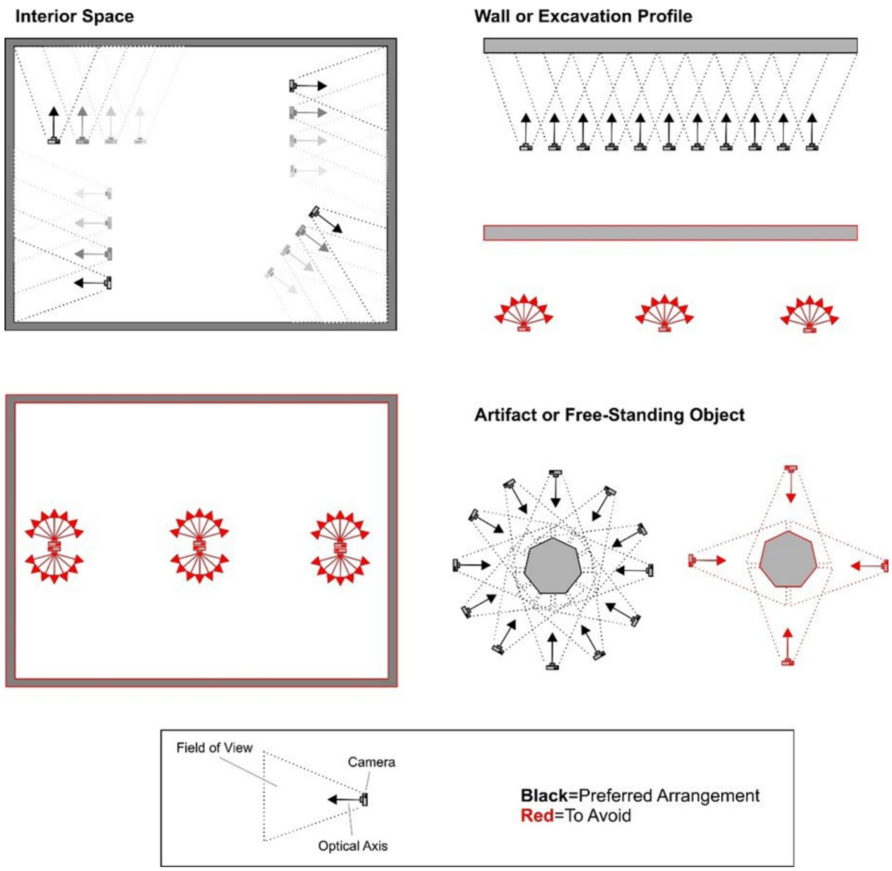

Figure 15. Idealized strategies for taking photos to model (clockwise from upper left to lower right) interior spaces, a flat surface such as a wall or building façade, and an object such as a statue.

Tip #5. Try to use the same camera/sensor for the entire survey.

Tip #6. Try to document an object by rotating around it, or by rotating it while the camera is stationary.

Tip #7. For Drone-based imagery, determine ideal flight elevation for survey and calculate the appropriate ground sampling distance (GSD).

- 3DFZephyr has a free GSD calculator (https://www.3dflow.net/ground-sampling-distance- calculator/)
- Pix4D has a free GSD calculator that can be saved locally (https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-calculator)

Tip #8. Attempt to document using a uniform light source.

- For aerial photographs, overcast days are preferable to sunny. This reduces the amount of noise created by shadows.
- For laboratory photographs, a light box or controlled external light sources are preferable.

Tip #9. Use control points. Photogrammetry calculates the spatial coordinates for points on a local scale (i.e., the scale of the pixels from the images). It therefore cannot, in isolation, be used to generate real world measurements. Some cameras are equipped with an internal GPS and while they are sufficient for quick models, they lack the precision necessary to generate real coordinates and measurements. Control must be readily visible in your images. Consider color and shape of targets when deciding on what to use. Make sure control points are widely spaced across the target area (Figure 16).

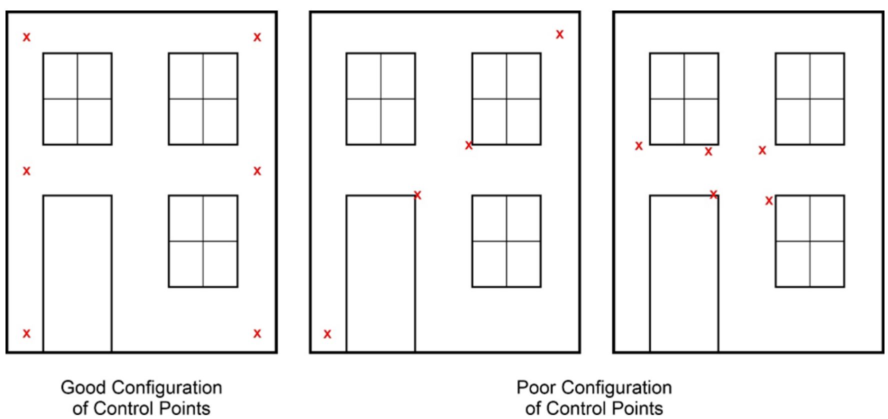

Figure 16. Examples of good control point distribution on the left and poor distribution on the right (adapted from Historic England 2017).

Software

Tip #1. A variety of software packages exist and many of them offer free or demo versions, which can be an excellent way to test software.

- Wikipedia maintains a publicly generated comparison of the various photogrammetry software packages available. It is a useful starting point for users looking to understand what software is available.

(https://en.wikipedia.org/wiki/Comparison_of_photogrammetry_software)

Tip#2. It is not uncommon for the specific workflow of a software package to be different than the workflow of others. As a result, many photogrammetry software webpages have tutorials for how get the best results from their software. These are some examples:

- **Pix4D** has a useful "example datasets" directory where a user can download the inputs, including images and settings used, and the output model (https://support.pix4d.com/hc/en-us/articles/360000235126-Example-projects#label2).
- **Reality Capture** has a tutorials directory with detailed videos of how to produce accurate models step by step (https://www.capturingreality.com/RealityCapture-Tutorials).
- **Metashape** has a beginner level tutorials page that will walk the user through the steps necessary to produce accurate models in their software (https://www.agisoft.com/support/tutorials/beginner-level/).

Minimum Standards

If real measurements are being derived from a model, control points must be used. The internal GPS on your camera is not likely accurate enough to produce sufficiently precise locations for the photographs. Control for the model should come from either a total station or a RTK GNSS (real- time kinematic global navigation satellite system). If a total station is used, and geographic coordinates are desired, the total station data should be tied in using a sub meter GNSS system (decimeter accuracy or better preferred).

Objects should be documented with at least two scales, one in the X and one in the Y orientation to control for skewing of the model.

Reporting

A methods section or appendix should be included with any report presenting photogrammetric results, if these results are a necessary product of the project. Details to be recorded include kind of camera and lens (if changeable), whether images are stills or extracted from video, software used to create model-based products, number of images used for the model, whether ground control points used and how many, equipment used to record control point locations, results of checks to verify quality of the final model (e.g., field measurements compared to model measurements).

Follow standard mapping procedures when presenting two dimensional images of results. Indicate whether an image is ortho-rectified or perspective. For ortho-rectified images, include a scale and north arrow. With perspective views, provide a three-axis north arrow. While useful scales are harder to include in perspective views, consider reporting the dimensions of the image's bounding box.

Archiving

Care should be taken to preserve the original, unaltered images and associated control points. Create a directory containing all images used for processing and a text file containing a list of control points from the software used for the project.

Ideally, a final textured model should be included in the archive. The open nature of .obj or .ply file formats make them ideal for archival use and such files can be natively viewed in many three- dimensional object viewers. Consider also including the dense point cloud as an XYZ file and the final texture as .tiff, .jpg, or .png files.

FAQs: Frequently Asked Questions

(1) What is photogrammetry used for?

It is a relatively quick, inexpensive way to make 3D digital models of objects, buildings, and landscapes. It also produces high-resolution orthophoto mosaics (e.g., orthogonal aerial photographs) that, if properly georeferenced, can be used to digitize the locations of anything visible in the photograph. It is not unusual for these models and orthophoto mosaics to have a precision of 1-2 cm.

(2) Do I have to use a drone to take the photographs?

No, photographs from any camera can be used to create photogrammetry models. For many low-altitude needs, a pole-mounted camera can be used instead of a camera mounted on a drone.

(3) How many photographs are needed?

This will depend on the photogrammetry software and the desired resolution of the final products. Typically, more photographs are better as long as they are good (e.g., in focus) photographs. Also, images need to overlap about 75 percent to produce good results.

(4) What kind of camera should be used?

Any camera can be used to take images, though it's best if the same camera, or lens, is used for all images related to a particular project. Some, but not all, photogrammetry software can adjust for multiple lens/camera parameters. The type of camera (e.g., digital SLR, phone camera, drone-mounted camera) only matters as it impacts the quality of the final products. To produce a high-resolution orthophoto mosaic, for example, one must begin with high resolution images.

(5) Are ground control points necessary?

Ground control points help properly anchor and scale photogrammetry models of landscape features. While they are not required in all cases, they will help produce a better product. If making precision measurements on the photomosaic or 3D model is desired, then ground control points are necessary.

(6) What software is needed to make a photogrammetry model?

There are a variety of free or license-based software packages for making photogrammetry products. Many can make adequate products, depending on the goals of the photogrammetry work. However, some of the free software comes with limitations on the numbers of input images or on what, if anything, can be exported.

(7) Can photogrammetry be used to make a topographic map?

Sometimes. The photogrammetry process produces surface models of whatever is visible in the photographs. Most of the time, this means that the surface of the vegetation is being used to create the model. If the vegetation is short and consistent in height (e.g., mowed grass), then the surface model will be a close approximation to a bare earth model. If the vegetation is tall or varied in height, the surface model may differ markedly from the ground surface. In some cases, it is possible to remove trees or other sparse vegetation from the point clouds without creating large gaps in the model.

(8) What can be documented with a photogrammetry model?

Anything that can be photographed can be modeled with photogrammetry: ground surface, headstones and other monuments in cemeteries, statues, buildings, and objects of any size.

(9) Can I take precise distance and volume measurements from a photogrammetry model?

Yes, but only if control points and/or adequate scales are used in creating the model.

(10) When will photogrammetry not work?

To be included in the photogrammetry model or orthophoto mosaic, an object or surface of a building must occur in several of the overlapping images used to generate the model. Obstructing vegetation is a problem for creating complete models of buildings. Shiny objects (e.g., glass windows) and large surfaces of one color are difficult to properly capture in photogrammetry. Also, things that move from one photograph to the next (e.g., flags, leaves, vehicles, and people) will not be properly rendered in the 3D model or orthophoto mosaic.

(11) When should photogrammetry be used?

Photogrammetry can be a useful tool on Phase I, II, and III projects. It is quick to take images in the field; the office can be relatively quick or time consuming depending on the number of images and the desired output quality.

(12) Can photogrammetry be used to map the ground surface or features within a wooded area?

Yes, when the leaves are off the plants and if the ground surface, or very near the ground surface, is visible. Too much underbrush or material lying on the surface may result in gaps in the model or an overly rough surface.

Glossary

Dense Point Cloud. The common points found between a set of overlapping photographs of a place or object produced through a process called bundle adjustment. This is a step beyond the production of tie points (i.e., the sparse point cloud).

Digital Elevation Model (DEM). A three-dimensional representation of ground terrain based on data points collected through physical mapping (e.g., with a transit or global navigation satellite system), LiDAR, or photogrammetry. Also known as *Bare Earth Model* or *Digital Terrain Model.*

Digital Surface Model (DSM). A three-dimensional representation of the ground or another surface based on data points collected through physical mapping (e.g., with a transit or global navigation satellite system), LiDAR, or photogrammetry. This model includes data points on the bare earth as well as on the top surfaces of vegetation, buildings, or other features that extend above the surface. Technically, all LiDAR and photogrammetry models are DSMs because they include other surfaces in addition to the ground. LiDAR data can be filtered to produce a DEM. Photogrammetry-based data can only be considered as a DEM if no vegetation is present within the survey area. Also known as *Bare Earth Model of Digital Terrain Model.*

Ground Control Points (GCP). Marked (e.g., with a target) or identified points within a series of photographs, not necessarily on the ground, that are used for scaling the final model. These can have local, arbitrary coordinates or they can be tied into a geographic coordinate system, such as Universal Transverse Mercator (UTM) or State Plane.

Ground Sample Distance (GSD). The smallest visible element within a photogrammetry model or orthophoto mosaic.

Mesh. The three-dimensional architecture or skeleton of the model created most commonly by joining the points in the dense point could with triangles.

Orthophoto. Also known as *ortho-rectified image* or *orthophoto mosaic*. An image that has been made flat, or planimetrically accurate, by correcting for distortions caused by image tilt, the camera lens, changing local relief, and curvature of the earth. Once corrected, an orthophoto can be used for digitizing vector features, such as roads, building locations, etc.

Photogrammetry. The process of creating a three-dimensional model of objects and surfaces that appear in a set of photographs, which can include images from handheld cameras, airborne cameras, or satellite images.

Texture. Colors applied to a mesh, usually during the last step in making a photogrammetry model. Colors are derived from pixels sampled from the photographs used to create the model. The latter approach is used when making a realistic three-dimensional rendering of the scene captured in the photographs.

Tie Points. Common points between one or more overlapping images used to link the images together in space when building a photogrammetry model. These are automatically created by the photogrammetry software and are critical for aligning the images to create a 3D model.

Unmanned Aerial Vehicle (UAV). Also known as a drone. An airborne, remotely operated vehicle on which cameras can be mounted for taking images to use in producing photogrammetric models.

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