Applying Close Range Photogrammetry to an Archaeological Investigation at Port Arthur Historic Site

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Abstract

This report describes how close range vertical photogrammetry has been applied to an archaeological investigation at Port Arthur Historic Site, Tasmania. Two very different approaches to obtain a merged visual record of an archaeological excavation have been tried and compared with respect to their spatial accuracies. The results indicate that for visually and spatially recording an archaeological excavation, the simpler, cheaper and faster technique of stitching photos together produced similar spatial accuracies to orthophoto production on a digital photogrammetric workstation.

Introduction

Archaeological excavations are destructive, and documentation of findings must often be performed quickly to maximise productivity of limited resources and to allow excavations to be filled in as soon as possible to minimise further degradation. Photographs acquired during a recent excavation at Port Arthur represent those routinely acquired upon uncovering cultural or natural features. Photographs are typically used during analysis to help identify the uncovered features in support of written documentation.

If images commonly taken on an archaeological excavation can be captured with sufficient resolution to identify the smallest relevant cultural detail, such as small nails, and the image can be geometrically corrected to represent a map like photo of the excavated site, then this orthophoto can later be used to identify trends in artefact scatter, ground-truth geophysical datasets, and possibly lead to a different understanding of the excavated findings.

Photogrammetry is the technique of acquiring reliable spatial information from photographs, usually overlapping stereo-photographs. To achieve certain measurement and coordinate accuracies it is necessary to correct for many effects and unknowns inherent in raw photography, including lens distortion, perspective distortions, film or CCD array errors, and camera orientations. Modern photogrammetry is performed on a digital photogrammetric workstation (DPW), which works with digital photographs of known dimension and distortion (Wolf and Dewitt 2000, p. 327).

Photogrammetry can be a useful technique for archaeological investigations, but is rarely used.

This project applied close range photogrammetry to an archaeological investigation at the Port Arthur Historic Site, Tasmania. An alternative solution of stitching photographs together with public domain software was also employed and the spatial accuracies compared with those of close range photogrammetry.

Methods

Camera calibration

Accurate photogrammetry requires a calibrated camera. A Canon 300D 6 mega pixel camera and USM 20mm AF lens was calibrated using a co-planar test range array of 64 targets attached to the eastern wall of the law building (UTAS). Each of the photo targets was already reliably coordinated in X and Y (estimated accuracy +/-3mm s.d.). Photographs were taken of the photo targets from nine directions at a 5 metre focus and f11 aperture.

Each 18MB tiff image was imported into ArcMap software in order to observe and record photo coordinates of the centroid of each target. This provided 1 pixel precision. Coordinates of each photo target in each image and in object space were input to calibration software.

The camera calibration was performed using six convergent photographs of the planar array of targets. A MATLAB toolbox based on the method of Heikkila and Silven (1997) which uses a direct linear transformation to solve for some of the parameters, followed with a Levenberg-Marquardt optimisation method to solve for all the parameters. The calibration software generated values for radial and asymmetric lens distortion, focal length, principal point and a scaling factor (Heikkila and Silven, 1997). All possible six-photo combinations were run through the calibration software.

The camera's radial symmetric lens distortions can be represented by the function:

$$\Delta r = k_1 r^3 + k_2 r^5 + k_3 r^7 \qquad \text{(Karara, 1989)}$$

Where: Δr = radial distortion at a distance r from the principle point
r = radial distance from the principal point
k_1 k_2 k_3 = parameters of the radial lens distortion

The camera's asymmetric lens distortions can be represented by the function:

$$\Delta x = P_1 \left[r^2 + 2(x - x_P)^2 \right] + 2P_2 (x - x_P)(y - y_P)$$

$$\Delta y = P_2 \left[r^2 + 2(y - y_P)^2 \right] + 2P_1 (x - x_P)(y - y_P) \qquad \text{(Karara, 1989)}$$

Where: Δx, Δy = asymmetric lens distortions
r = radial distance from the principal point
xp, yp = principal point coordinates
x, y = observed photo coordinates
P_1 P_2 = asymmetric lens distortion parameters

Photo Acquisition

Photographs were acquired of an archaeological excavation located at Port Arthur Historic Site during the 2004 summer archaeology program The excavation site was ideal for this investigation because the subject was relatively shallow (minimising relief distortion), well textured (to assist automatic image correlation techniques), well illuminated, and only a single strip of photography was required to adequately capture the whole of the excavation.

Photos were acquired from as close to vertical as possible, with minimal shadowing, at a mid range aperture of f11 and at approximately 5 metre focus, as per the calibration. (The actual object distance was 6 metres as the photos were taken from a convenient adjacent wall, producing a photo scale of ~1:300).

Photos were taken so as to include 6 photo control targets in each photo, and to ensure that each stereo pair had an overlap of approximately 70%. This enabled each overlapping region (stereo image) to include at least 4 photo control targets.

Coordination of Photo Control Targets

A traverse from state permanent surveying control was conducted using a Nikon DTM700 theodolite, prism and tripod. Each photo target was observed in Face Left and Face Right from a single observation point using the 5 second calibrated theodolite and prism. Coordinates were computed for each photo target from the averaged observations.

Figure 1: An example of a photogrammetric control target used on the excavation.

Generation of an Orthophoto

Using the captured images, ground control coordinates of the photo control targets and the calibration parameters, an orthophoto mosaic was created using a Digital Photogrammetric Workstation (Virtuozo V3.5, Supresoft, Wuhan, China).

Generation of an orthophoto is performed in several steps. Ground control is used to firstly determine the position and orientation of each photo relative to its stereo pair and relative to the ground control coordinate system.

Each stereo pair must then be resampled using these orientation parameters in a process called epipolar resampling, which produces equivalent vertical photographs (Wolf and Dewitt 2000: 333-334).

A Digital Terrain Model (DTM) is also required for generation of orthophotography. To extract a DTM, an image matching algorithm correlates image patches in the left and right image of the stereo pair. This allows parallax to be measured and three-dimensional heights computed (Wolf and Dewitt 2000: 178-179).

An orthophotograph can then be generated for each stereo pair using the DTM derived from overlapping photographs and orientation. The DTM derived from each stereo pair must then be merged before a mosaic of all orthophotos can be generated.

In practice it was necessary to manually locate some additional conjugate image points where steep changes in Z (object distance) occurred, such as at the edge of walls, trench sides and brick edges (see Figure 2). These additional points assist the image matching routines, which otherwise fail to find matching points in each image, and inevitably match incorrect points.

Figure 2: Preparing for image matching by placing conjugate image points around features with large Z variation.

Figure 3: Output orthophoto with reduced image stretching

Generation of a Stitched Photo

Free software 'ZoomBrowser EX' provided with the Canon 300D camera included a photostitch algorithm, which merged up to four photographs together using unspecified routines. The software only requires the input of photos in some order, and the output is a stitched image.

Results

Camera Calibration

The adopted camera calibration results came from the combination of photographs with the highest roll angles (most convergent), which included more targets in each photograph and had better distribution of targets across each photo. The camera calibration data appears in Table 1.

Scale Factor	0.9997
Effective focal length(mm)	20.4224
Principle Point X (pixels)	1549.8027
Principle Point Y (pixels)	1016.0570
K1 Radial Distortion	2.2030E-04
K2 Radial Distortion	-4.0608E-07
T1 Tangential Distortion	3.7856E-06
T2 Tangential Distortion	1.6714E-05
Standard Error in pixels	1.1205
Max Asymmetric distortion (microns)	9.0918

Table1: Camera calibration parameters derived from multi-station planar calibration.

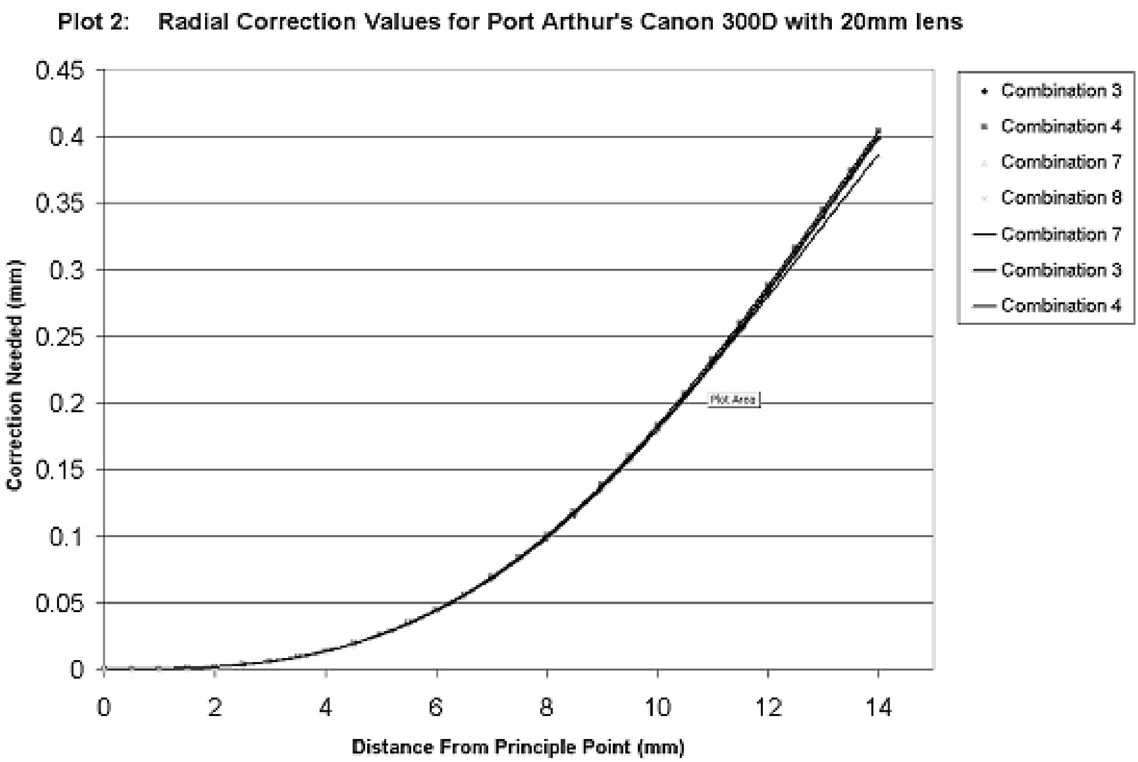

Figure 4: Radial lens distortion - correction values for the Canon 300D with 20mm lens.

The consistency of the radial lens distortion functions, illustrated in Figure 4, reflects the strength of the calibration solution, indicating sufficient redundancy exists to compute a reliable solution.

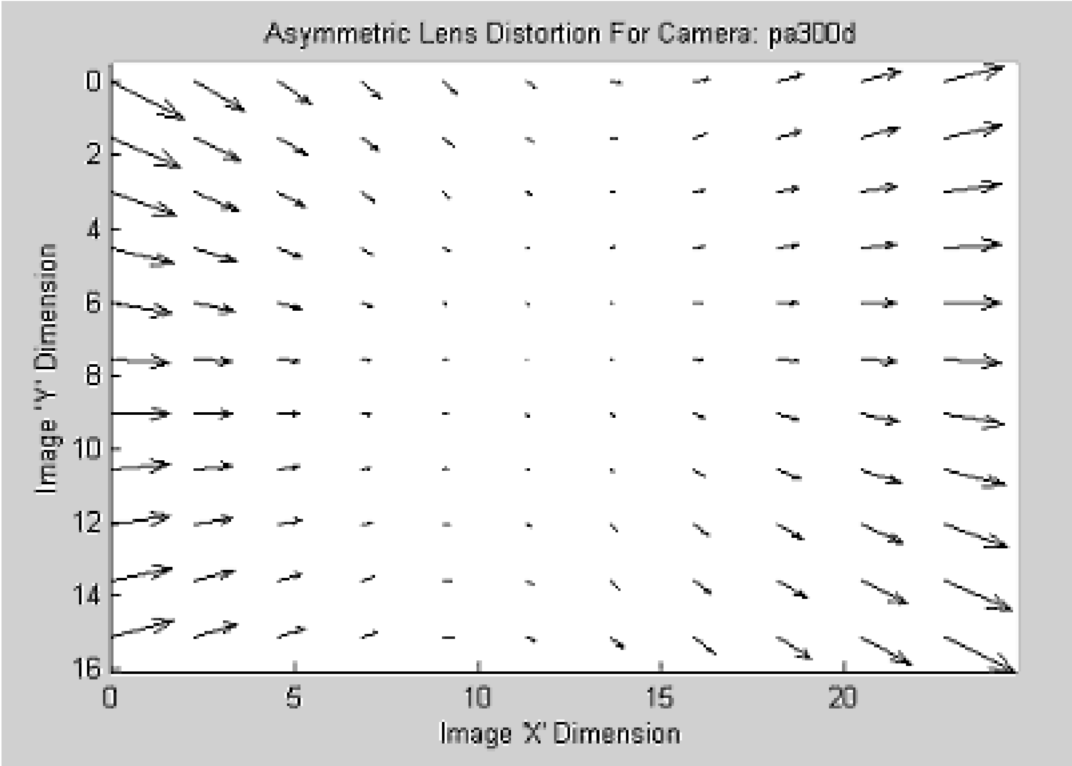

Figure 5: Asymmetric lens distortion for the Canon 300D with 20mm lens (maximum vector is 9 pixels).

Stereomodel Orientation
Interior, relative and absolute orientation was completed on the digital photogrammetric workstation. Image space residuals for the relative orientation were less than 7 microns; object space residuals on photo control for the absolute orientation were less than 5mm, indicating a reliable stereomodel.

Merging of the DTM
In merging the Digital Terrain Models, all of the points in the excavated area (excepting some of those around vertical 'wall' features) were calculated to agree to within one standard deviation of $\sigma = 0.084$ metres.

Achieved Accuracy
A test of the accuracy achieved was conducted by geo-referencing the orthophoto mosaic to the original photo control on a GIS using a 1st order algorithm. The root mean square (RMS) error of the transformation was 0.053 metres. Two of the targets used in the transformation were close to 0.09metres. Additional measurements on a GIS showed an approximate worst case error of 0.14 metres at a location where severe overlapping of features occurred.

These results indicate that, while the stereomodel was accurate, the automatic image correlation algorithms had generated a DTM that contained significant errors. These propagate into the orthophoto because it relies on an accurate DTM.

Accuracies obtained by geo-referencing the photo-stitched image were comparable to those of the orthophoto. An RMS error of 0.049 metres was calculated for the same 1st order transformation.

Figure 6: A region of particularly bad accuracy in the output orthophoto mosaic.

Discussion

Expected Accuracy

Expected accuracies were computed using the method of Karara (1989). Given an object distance of 6 m, a camera base of 1.2 m, a focal length of 20.42 mm, and an image space pointing accuracy of 20 μm, the expected precision in X/Y is +/-6 mm and in Z +/-42 mm.

Expected accuracies were not achieved in this application. The reliable orientations indicate that errors relate to DTM extraction, rather than the quality of the stereomodel, and that the DTM errors were due to unsuccessful image matching by the automatic image correlation techniques.

In comparing the orthophoto to the stitched photo the most obvious difference is the severe image stretching occurring in the orthophoto in regions of relatively large Z displacement. The automatic image matching techniques used to generate the orthophoto match points correctly on the higher and lower features, but the region between correctly matched points is noticeably stretched. Failure at these regions is attributed to perspective distortion.

Perspective distortions are particularly problematic in regions of large variation in Z relative to the object distance, such as around the walls and sides of the excavated trench. Severe stretching of these vertical features occurs as indicated in Figure 7.

The problem caused by viewing angle and perspective distortion remains as the primary obstacle with close range photogrammetry in this project. The extent of this problem can be minimised by editing the image prior to image matching (Figure 2). Placing points on conjugate features in each photograph of a stereo pair at regions where automatic image matching techniques fail did improve correlation. The automatic image matching techniques could then correctly locate conjugate points near the manually selected points where it otherwise had failed.

Overlapping features in the orthophoto occurred during the generation of the orthophoto mosaic. The photogrammetric software provided very little functionality to select areas of each stereo pair to be merged. The result was inclusion in the DTM of poorly matched regions. Improved capacity within the software to specify regions to be included and regions to be excluded from the DTM would alleviate this problem.

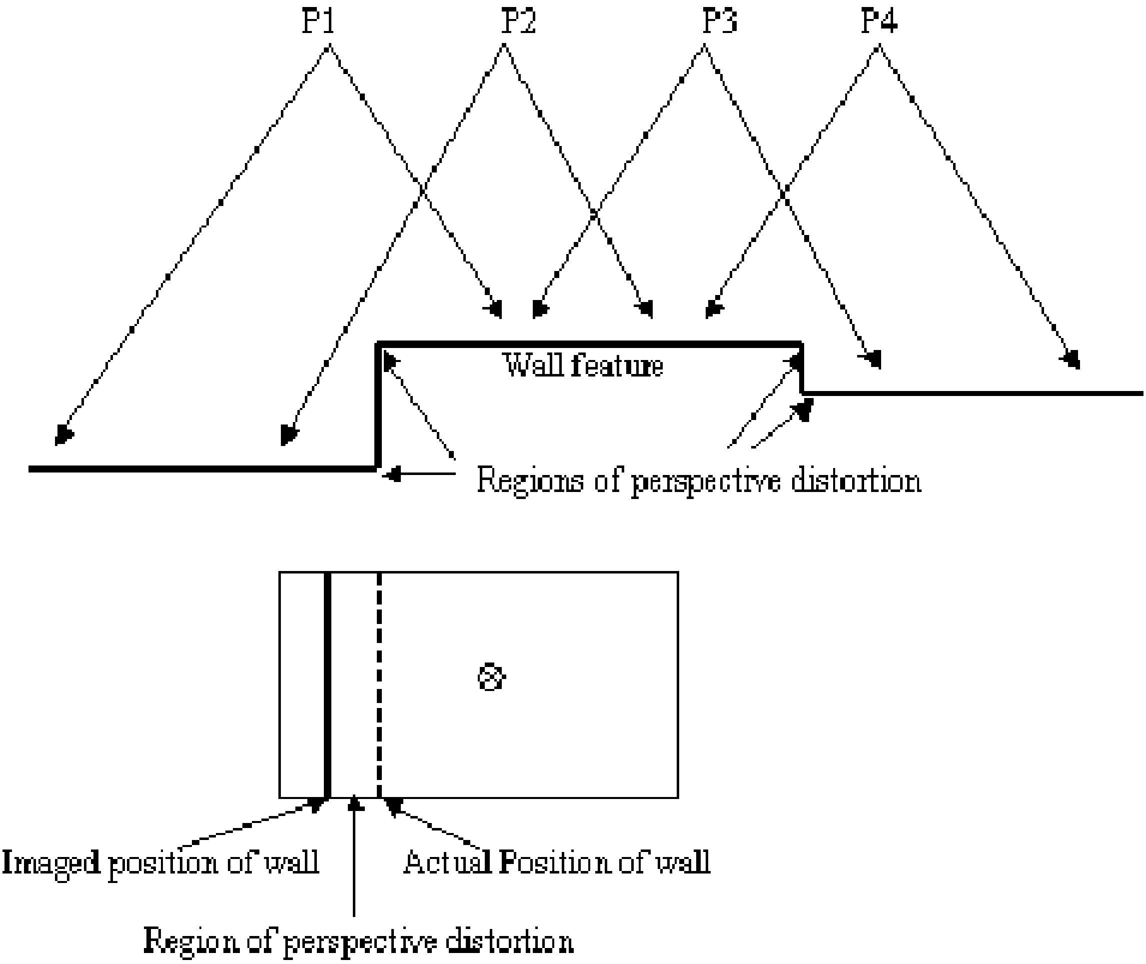

Figure 7: A strip of close range vertical photography of a wall shows how perspective distortions cause the wall imaged in photo 2 (P2) to be displaced outward from the centre of the photograph.

A comparison of the photostitched imagery and the orthophoto imagery is shown in Figure 9 below. It can clearly be seen that the orthophoto produces undesirable overlapping of features and image stretching. Both these problems are avoided by the photo-stitched image, which also produced slightly lower spatial errors. It is however important to note that there is no control over the stitching process just as there is no control over the orthophoto mosaic process, so there is no way of interrogating the internal accuracies of either process.

An additional feature offered by photogrammetry is the capacity to view the stereomodel (using a 3D-enabled computer monitor) and so to extract reliable 3-dimensional vector data, and also the capacity to drape an orthophotograph over a DTM for visualisation. Using the previously generated DTM, it is possible to overlay an image of known orientation and distortion and view the image in 3D. The practical application of this feature was not explored in this project, however it may assist archaeological investigation by providing additional information and high quality visualisation. An example is shown in Figure 8.

Figure 8 Imagery draped over a DTM.

Conclusion

Both photogrammetry and photo stitching produce a visual record suitable for archaeological investigations at Port Arthur. Equally poor accuracies were achieved by each technique, however an improved digital terrain model is likely to greatly improve the accuracy of orthophotography and its usefulness to archaeological investigation.

Without an improved digital terrain model steep surfaces will continue to be problematic for close range orthophotogrammetry. For extracting reliable spatial information in X and Y dimensions from photographs containing steep variation in Z, it seems that the simple and cheap technique of georeferencing stitched photographs is appropriate for archaeological investigation.

References

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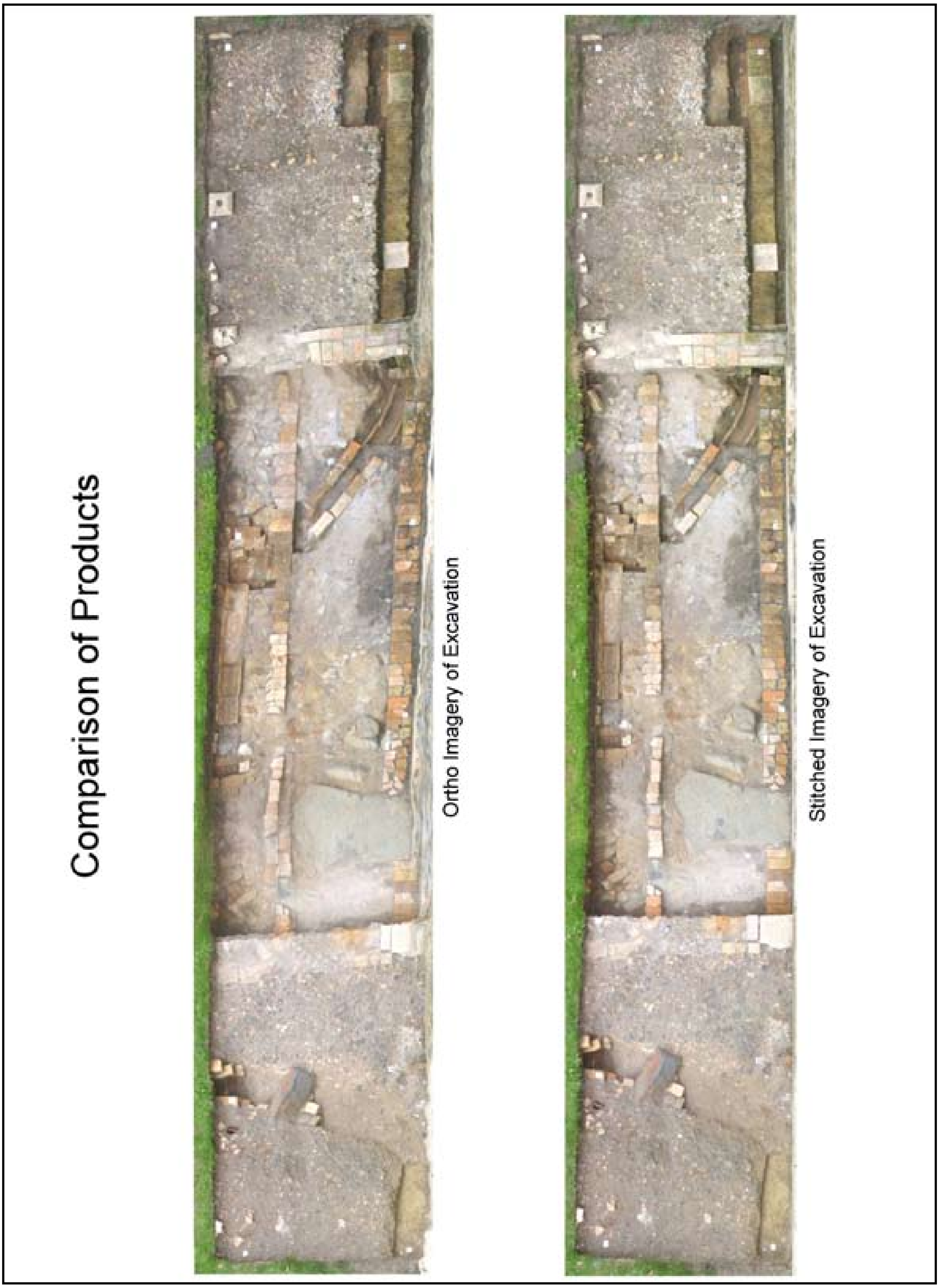

Figure 9: A comparison of the two products: an orthophotograph and stitched photographs.