Shortcomings of Current 3D Data Acquisition Technologies for Graphical Recording of Archaeological Excavations

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Abstract. The many 3D data acquisition devices (or techniques, in the case of Photogrammetry) commercially available today employ a number of range-finding technologies. It is the view of the author that each technology, and the various commercial models of acquisition devices which employ them, have their strengths and weaknesses in respect of our goal in using them to replace drawing for "single context recording" of archaeological excavations. The author will draw attention to the shortcomings of the techniques and conclude that none of the currently available 3D data acquisition instruments are adequately suited to this task.

1. Introduction

In a previous paper (Avern, 2001) I expressed the view that archaeologists should be looking to replace drawing with 3D modelling for the recording of excavations, but that the greatest obstacle to this lay in the acquisition of the 3D data. Harris's "Vienna paper" (2002), which is seen by many as a watershed in the subject of recording of excavations using 3D modelling, offers a rationale and methodology for such recording. He advocates a 3D form of "single context recording", where surfaces of deposits and cut features are recorded as 3D surface models, and continues by exploring the visualisation and interpretation of such data using GIS. However, Harris gives virtually no consideration to the very real issues of acquiring such data on the excavation site. Indeed, it is not immediately obvious which instruments or techniques we might use which will provide data of a nature that fits Harris' concept since there are very few published examples of recording in 3D from which to draw upon. Barceló, de Castro, et al. (2002, 2003) experimented with the recording of archaeological deposits using total station theodolite and rectified photography to record, respectively, the topography and colour texture. While fine for experimental purposes, I consider that their topographical models were too crude (that is, they were simple polysurfaces based on too few points) to constitute a good quality archaeological record. What the experiment revealed, to my mind, is that it is an impractically large task to capture enough points with the total station to attain high quality topography in the resulting 3D model. To gain such data-dense models it would seem that we should turn to either photogrammetry or laser scanning.

Photogrammetry, I would suggest, covers a range of products using a fundamentally similar underlying technology. Of note is the photogrammetry reported in Pollefeys, Proesmans, et al. (2000) that uses a technique that gives pixel-by-pixel correspondence from uncalibrated images. It has been used to model buildings and the terrain of the entire site of Sagalassos in SW Turkey but not for recording single context excavations. While seeming to hold considerable potential for archaeology, it is unfortunate that this system is not yet commercially available.

In the last few years laser scanners have been employed in various aspects of archaeology on numerous occasions. Schaich (presented at CAA Vienna, 2003, but not published; also see Arctron website www.arctron.com) has used scanned time-of-flight for recording terrains and large excavation sites but, as far as I am aware, he has not used laser scanning for "single context recording" of excavations. Carty has used different forms of laser scanning on a number of projects to record objects (see Archaeoptics website www.archaeoptics.com) and also some forays into the scanning of surfaces during excavation (Carty, pers. comm., 2004.).

The only examples known to the author of systematic 3D recording of an excavation by making data-dense, full-colour, 3D surfaces of deposits and cut features have been by Doneus, Neubauer & Studnicka (2003) using time-of-flight scanner and rectified photography (recently combined in the one instrument; Doneus, pers. comm., 2004) and a total station. Having witnessed this system in operation, I have no doubts that it is currently the best means available for recording single context excavations in 3D (in terms of speed, simplicity and robustness). However, it shares with many other systems, the shortcomings discussed in this paper.

From this introduction it should be quite clear that the use of 3D data acquisition technologies for recording excavations dug by the "single context" method, as extolled by Harris, is a field very much in its infancy. Meanwhile, in the field of 3D captors there has been a veritable explosion in the number and type now available, which may suggest that rapid progress in our infant archaeological application is simply a matter of selecting the right 3D captor from this extensive range. However, in the light of the following discussion and reflection on the question "What are the characteristics of the terrain that we wish to record?" you may conclude, as I do, that all of the currently available 3D captors (whether instruments or techniques implemented in software), including those mentioned above, have shortcomings in relation to our specific needs for the recording of excavations.

2. Survey and Initial Cull

In March 2004, an Internet search revealed 190 models of 3D data acquisition instruments currently available, plus a small number of software programs purporting to construct 3D models from photographic data, in which we might include Photogrammetry (only 8 programs were found – I'm sure that there are more). As you might expect from such a large number, the instruments vary enormously in size, speed, range-finding techniques, etc, etc. We can immediately discount most of them, for our recording purposes, on the following grounds;

- Those based on the range-finding techniques of structured light or interferometry typically do not work in sunlight,
- Many require installation in stable and protected environments,
- A number are simply laser profiling units and are not, in themselves, 3D recorders,
- Many software for extracting "3D shape from Images" are only able to extract simple geometric forms (e.g. rectangular buildings),
- Desktop Photogrammetry programs are not yet (as far as I am aware) able to do truly automated feature recognition in order to provide the number of data points necessary for realistic modelling of complex surfaces, let alone pixel-by-pixel correspondences,
- Hand-held laser stripe scanners which use tracking systems have problems operating in our environment: electromagnetic tracking systems are reportedly effected by the presence of metal; sonar tracking systems are affected by climatic conditions; infra-red tracking systems have difficulties operating in daylight and require constant line-of-sight contact between emitters and receivers.

After discounting those instruments that will simply not work at all, we are left with only a dozen or so instruments/techniques that might do the job we require. They basically fall into 3 groups; traditional close-range photogrammetry (on photogrammetric stations), tripod-mounted laser stripe triangulation scanners and tripod-mounted time-of-flight laser scanners. I would argue that they all suffer from shortcomings in 3 main areas, as discussed below.

3. Problems due to Recording from a Fixed Position

3.1 Blind Spots/Holes

Tripod-mounted instruments and/or photography gather data at an angle oblique to the surface of the terrain. Topographical irregularities will mean that some of the surface will not be visible (Fig.1) which should(!) result in holes in the 3D record.

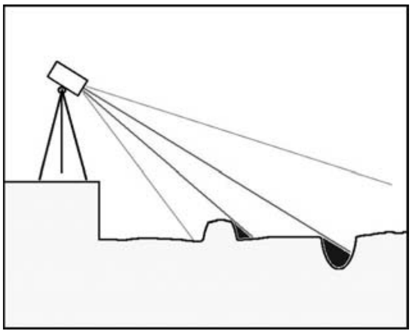

Fig. 1. Blind spots on the terrain when recording from fixed positions at oblique angles.

3.2 Resolution and Accuracy in Oblique Sampling

Figure 2 illustrates the change in data density as the sampling angle (angle between line-of-sight and the terrain) becomes smaller, which on flat terrain is a function of proximity to the recording instrument. An attendant problem is the effective elongation of the sampled surface at smaller sampling angles, that yields "stripes" of colour texture data and, theoretically, affecting accuracy in the calculation of point coordinates.

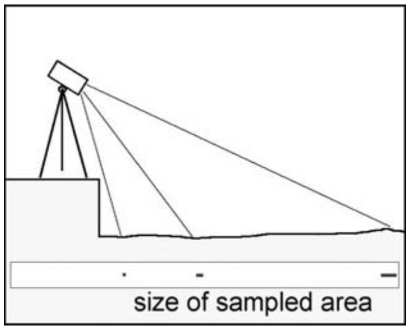

Fig. 2. Sampling areas become elongated when recording at an oblique angle.

One solution is to make supplementary records of the same terrain from different positions and merge the resulting 3D patches [where "patch" is a 3D modelled surface which forms only part of an object, or project, and which is destined to be joined, merged or fused with one or more other patches].

3.3 Vertical Recording

Another solution is to record vertically rather than obliquely. However, I would argue that the use of platforms, rigs or gantries to achieve this introduces additional complexities to the recording of excavations. It is not appropriate for many sites and is still no guarantee against blind spots or obliquely sampled surfaces, such as walls of pits.

To conclude this section, I would suggest that ensuring the capture of adequate 3D data to guarantee a high quality record with these instruments is not as simple and straightforward a process as the archaeological community would want (or, indeed, could be with different hardware design).

4. Post-Processing of Data

Post-processing of data will, of course, vary with different acquisition techniques and different modelling software. In general, the following steps are required;

- Initial modelling – point cloud to wireframe to rendered surface,
- Merging of any complementary data sets – merging 3D patches of the same terrain taken from different view-points; mapping of colour texture data to rendered surfaces,

- Making a line drawing – I do not believe that 3D models make drawings redundant, however, digital 3D drawings are preferable to 2D drawings on paper. Such a 3D drawing of the outline of the deposit or cut feature is, in any case, necessary step for the following action,
- Cropping an initial or composite model down to the limits of the deposit or cut feature being recorded,
- Spatial Referencing – at some point in the data capture or modelling process geo-referencing must be introduced to ensure correct registration of data sets within an overall excavation model.

For both types of laser instrument (stripe triangulation and scanned time-of-flight) and close-range photogrammetry, it is the post-processing that turns the data points into the archaeological record. However, this step is unlikely to be done sitting on the site with the subject directly in front of us, as we do when we draw. Thus there is a danger that the creation of the record becomes distanced, in location and in time, from the archaeology. As long as the distance and the time are both small, there is no great problem. But complicated software and the need for faster computing or special peripherals are likely to take post-processing off-site. Further, while every digger can make pencil drawings, post-processing removes 3D recording to the domain of the recording specialist and, in doing so, the record becomes personally distanced from the archaeology – the recorder is not the person who did the digging and who is, therefore, most familiar with it.

My general impression is that post-processing, with the systems we are considering here, is far too complicated a process for it to become widespread and routinely used on the archaeological site and that, to a large degree, it is not the underlying technology, but the ways they are currently implemented, which create this complexity.

5. Collecting Colour Data

The acquisition of colour data is perhaps the most problematic issue facing the recording of excavations in 3D. Many captors from our original survey list do not capture any colour data and so are excluded from our consideration. Of those that do capture colour data, almost all capture ambient light reflected from the subject. Consequently, this data is subject to all the vagaries and artefacts of ambient light, making the acquisition of meaningful data and its interpretation difficult (Marchant, Tillet & Onyango, 2004) or even impossible, as we will consider below.

5.1 Variation in Intensity of Light.

Shadows are the obvious problem. Archaeologists identify a deposit as an area of homogeneous colour and/or texture and the record we make of an excavation reflect this identification. However, shadows affect our data by altering reflectance values from the terrain at a number of scales. Large shadows of buildings, trees, posts, etc can be cast across the site, with the result that a single context may be in part shade and so not of a homogeneous appearance.

A context that has a rough surface will cast shadows at a smaller scale, where the changing position of the sun throughout the day will change both the amount and the direction of such "textural" shadow. At a smaller scale again, when the physical roughness of the surface is smaller than the resolution of the colour recording system, shadows will affect the Intensity of the colour rather than texture, making a coarse deposit appear darker at low angles of illumination than the actual colour of the soil components. Ideally, any record we make of the terrain should be free from any shadows.

Finally, we should recall the physical law that tells us that intensity of light is inversely proportional to the distance it travels. When recording colour information of large areas from a single point (e.g. photography), the colour data from the background will have a lower Intensity value than that from the foreground.

5.2 Variations in Hue and Saturation of Colour.

The Hue of light reflected from our terrain is affected by the amount of direct sunlight, by atmospheric and meteorological conditions and even, at very close range, by the clothing worn by those in proximity.

The colour Saturation of the light reflected from soils is affected by their moisture content, as all archaeologists know.

5.3 Variability in Colour Recorders.

In addition to the variability of light reflected from the terrain that we wish to record, we should also consider the inherent variability in the functioning of the hardware we use. Many of the current 3D captors employ CCD chips that will automatically determine an optimal average exposure level and dynamic range, while also offering optional Auto White Balance. We should be alert to the very great difficulty of capturing replicable colour data and be mindful of the importance of calibrating cameras to a Commision Inernationale de l'Eclairage colour standard (CIE, 1986).

N.B. An exception to those 3D captors which capture ambient reflected light is the Hymarc HyScan 45C, which I believe is now used in the Arius 3D captor (www.arius3d.com). This unit uses tri-chromatic laser capture, that is, 3 laser beams of different, known wavelengths. The intensity of reflected laser light that is captured at each of the 3 wavelengths is converted (by a calibration factor) into RGB data.

5.4 Other Attributes of Refected Light

Thus far I have not considered some of the more complex aspects of sampling reflected light. 3D modellers will be familiar with the other attributes of diffuse reflectance, specular reflectance, specular roughness, anisotropy and translucency. The Bidirectional Reflectance Distribution Function (BRDF) is the expression of each of these factors at each pixel/voxel/unit. Sampling methods for calculating BRDF are relatively new and still being developed (e.g. Gardner, Tchou, et al, 2003; Claustres, Paulin & Boucher, 2003), the amount of data they create is enormous (this by 3D modelling standards!) and none of the instruments or techniques discussed here will address colour data in these terms.

At this point the reader may be despairing at the apparent impossibility of making an accurate record of colour in the field. However, there are certainly grounds for compromise for the recording of archaeological excavations. For example, given that the materials we record (soil, stone, charcoal, corroded metals) are rarely shiny, perhaps we can ignore specular reflectance, anisotropy, etc (unlike those who model finds and artefacts) and only concern ourselves with diffuse reflectance data, which is obtainable using the tri-chromatic laser (and, indeed, by other means which are not yet available in 3D captors). And since the archaeologist is more concerned with the relative contrast (in colour & texture) between deposits than their precise colour values, we might even question the basic assertion that we need to capture accurate colour. Certainly, I believe that archaeologists would benefit from close examination and discussion of exactly what are the physical characteristics of the archaeological remains they should be trying to record in 3D models.

6. Summary

Unlike the many other instruments and techniques that were dismissed at the beginning of the paper, 3 techniques for 3D data capture (laser stripe triangulation scanners, laser time-of-flight scanners and close-range photogrammetry) can yield reasonable results when used for recording archaeological excavations. These results will be obtained in far less time than recording by hand drawing and will yield a much more data-dense and generally more accurate record.

The purpose of this critique was to highlight the fact to the excavating archaeologist that, despite these results, all 3 have fundamental shortcomings for the 3D recording of excavations. These shortcomings and the high costs of buying into these recording techniques will, I am confident, limit their acceptance and use by the archaeological community, at least in the immediate future. An encouraging thought, however, is that the shortcomings considered above are not so much shortcomings of the underlying technology but of its current implementation in hardware and software – better recording systems for 3D recording of excavations are possible.

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