EXPERIENCES WITH DIGITAL MICROSCOPE PHOTOGRAMMETRY

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ABSTRACT

Attempts have been made to use the automation offered by digital photogrammetry to measure small objects, in this case about 20 mm across, which had been photographed through a microscope. Using scanned 35mm film photographs originally taken through an Olympus microscope at its smallest magnification (2:1 scale), the VirtuoZo digital photogrammetric system could successfully create an accurate DTM, provided that a suitably textured object was chosen. While image matching proceeded remarkably well, various problems needed to be overcome, some due to the high level of automation of the digital system. The unusual image scales, the uncommon pixel sizes, and the unconventional and uncertain imaging geometry, all impeded automatic photogrammetric solutions. As with all microscope measurement, photographic problems with the microscope were also faced, attention to lighting being crucial. Moreover, control points and independent assess of the accuracy of results at these scales was also difficult, but an ADAM MPS analytical plotter could be utilised for both these purposes and to verify imaging geometry.

BACKGROUND TO MICROSCOPE PHOTOGRAMMETRY

Quantitative analysis through microscopes of various types is very useful in fields of study such as materials sciences and dentistry, and photogrammetry suggests itself as means of extracting three-dimensional measurements for such purposes. Indeed, microscope photogrammetry has been attempted in the past, for dentistry, (Mitchell *et al.*, 1989) and other purposes (Layton & Cox, 1982), but *digital* techniques have rarely been used so far. However, like all photogrammetry, microscope photogrammetry is of restricted functionality if manual measurement is needed, and so, as a matter of course, digital photogrammetry must be applied to the microscope. This paper reports experiments carried out to assess the viability of measurement through an optical microscope with digital photogrammetry, using a variety of objects.

Whether digital cameras or film cameras are used and whether digital or other photogrammetric data reduction is used, microscope photogrammetry poses special challenges. They arise from the unknown photogrammetric configuration and the size of the object, i.e.:

- The complex lens train of the microscope, which is often known only in a qualitative sense, causes a problem. The principal distance and the object distance and the nature of any lens distortion are usually unknown and are difficult to determine. (As the camera is used without any lens, at least this complication is removed).
- Obtaining stereoscopic coverage with acceptable ratios of base-to-object-distance is difficult because of the narrow field of view of the lens and the constrained object and camera positions.
- Obtaining accurate three-dimensional control in satisfactory locations at small scale size and, similarly, the checking of results on small objects can be difficult.

Some additional distinctive problems were encountered here with the use of the highly automated digital photogrammetric system. Although some of the following description must necessarily refer to microscope photogrammetry, the aim of the paper is to emphasise *digital photogrammetry* aspects of the microscope usage.

In the experiments reported here, 35 mm colour film images of three different objects, all about 20 mm across, were obtained through the optical microscope at a *large* scale setting. Developed film frames were then scanned on a film transparency scanner, capable of 1500 dots per inch, and then photogrammetrically processed using the VirtuoZo digital photogrammetric system, (VirtuoZo Systems International, Brisbane, Australia)

DESCRIPTION OF PHOTOGRAMMETRIC CONFIGURATION

A small piece of concrete at a break surface created during test to failure in a laboratory materials strength experiment was the main item under study, being of interest to materials engineers studying bond strengths of mortar materials used in masonry construction; (Diamond & Mindess, 1992, for example, express interest in microscope usage). The object was seen as having good radiometric texture but convoluted geometric texture at the very fine scale due to the highly grained surface.

Measurement was also, but less successfully, attempted on a short length of reinforcement rod, about 5 mm diameter, another object of genuine interest to engineers concerned with its bonding strength. The surface was smooth with little radiometric texture, and so it was expected to cause photographic problems. In addition, a casting of a set of human teeth was examined, being an object of extensive interest because of the value of examining tooth wear and decay. Relief on individual teeth was extreme and radiometric texture was very poor.

The microscope was a stereo Olympus model SZ6045TR, (Figure 1), of the Greenough pattern, which has two separate optical trains, convergent at 10°, but utilising a single objective lens. Photographs are taken down an optical train which by-passes the eyepiece lenses but which is still effectively not vertical. Even though the microscope permitted magnifications between 1.0 and 6.3, using zoom adjustment, for this work the lowest possible magnification of 1.0 was used, along with a further reduction provided by a 0.5 reducing lens. The nominal microscope magnification is not related to the camera attachment, and the scale of photography was finally found to be about 1.8:1, permitting an object about 20 mm long to be fitted on a 36 mm length of film frame.

Different options for achieving stereo photography were tried:

- Obtaining stereoscopic coverage through camera axis convergence by photographing down one optical train and then rotating body of microscope for a second photograph gave only a very small convergence angle, (and was seen as cumbersome and fairly painstaking and the rotation estimation was inaccurate).

- Shifting the object gave an unacceptably small base to object-distance ratio, as a result of the narrow field-of-view.

- Stereoscopic coverage achieved by tilting the object may be "inconvenient" given the small objects, especially if the angle of tilt is to be estimated, but despite the expected stereo-matching difficulty, this was most successful technique. Tilt can be estimated by various techniques, but most need considerable preparatory work. Here, slopes were estimated by a surveyor's Abney level mounted, along with the object, on a tilting stage intended for terrestrial survey equipment. It is necessary to ensure that the lighting remains consistent, so preferably the illumination would move with the tilting stage.

The camera was an Olympus TTL auto-exposure 35 mm SLR, and the film was Kodak 100 ASA Ektachrome colour slide film. Exposure times were found to be very long, around 40 seconds, because of the fibre optic lighting, the dark object and also the small object relative to the film frame size (magnification greater than one). A digital camera was not used because of the limited resolution of the available cameras, as well as the high resolution of the available scanner/film combination.

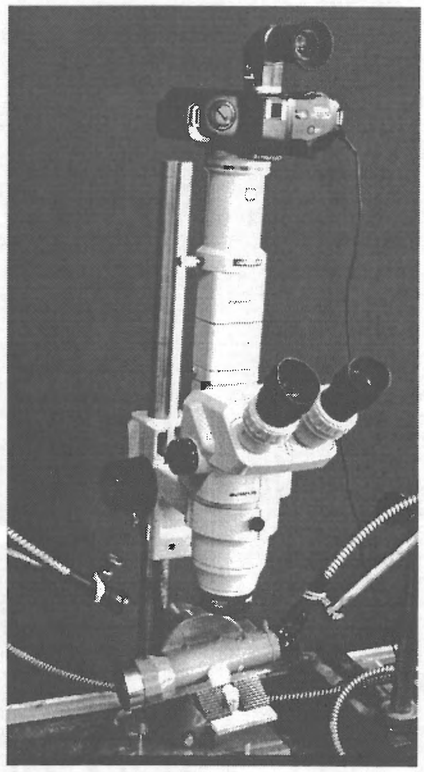

Figure 1: Olympus SZ6045TR microscope, with film camera in position.

Scanning was found to be a simple part of the overall procedure, and was carried out using a Nikon LS-4500AF 200mm scanner, which was set to digitise 35mm slide scenes at around 1500 pixels per inch (0.016 mm per pixel), creating BMP formatted images. Sample images appear in Figure 2.

Height control was provided by a control object with steps of known height, instead of control *points*, located in the field-of-view with the object of interest. For positional control, nine points were marked on the objects, and their positions were obtained by using the film frames in an ADAM Technology MPS-2 analytical stereo-plotter. This procedure was possible because the relative and absolute orientation procedures could be controlled by the operator of the analytical plotter, especially as various solution options could be selected.

Solving the optical configuration: The objective lens forms a real image, from which a second lens combination creates a final image on the film plane. It is assumed that this optical train can be represented by an equivalent single lens, with principal distance (c) and object distance (Z, measured to the object base). However, c and Z are unknown. The ratio of c to Z is easily provided by the scale of photography, and, classically, ($c + Z$) can also be estimated, being the distance from object to film plane. However, this latter estimation assumes that principal planes of the lens system have zero separation, which is not true in the case of the microscope, so c and Z cannot easily be deduced. However, with a narrow field-of-view, the main effect of an incorrect c value is to cause an error in the Z scale, so the

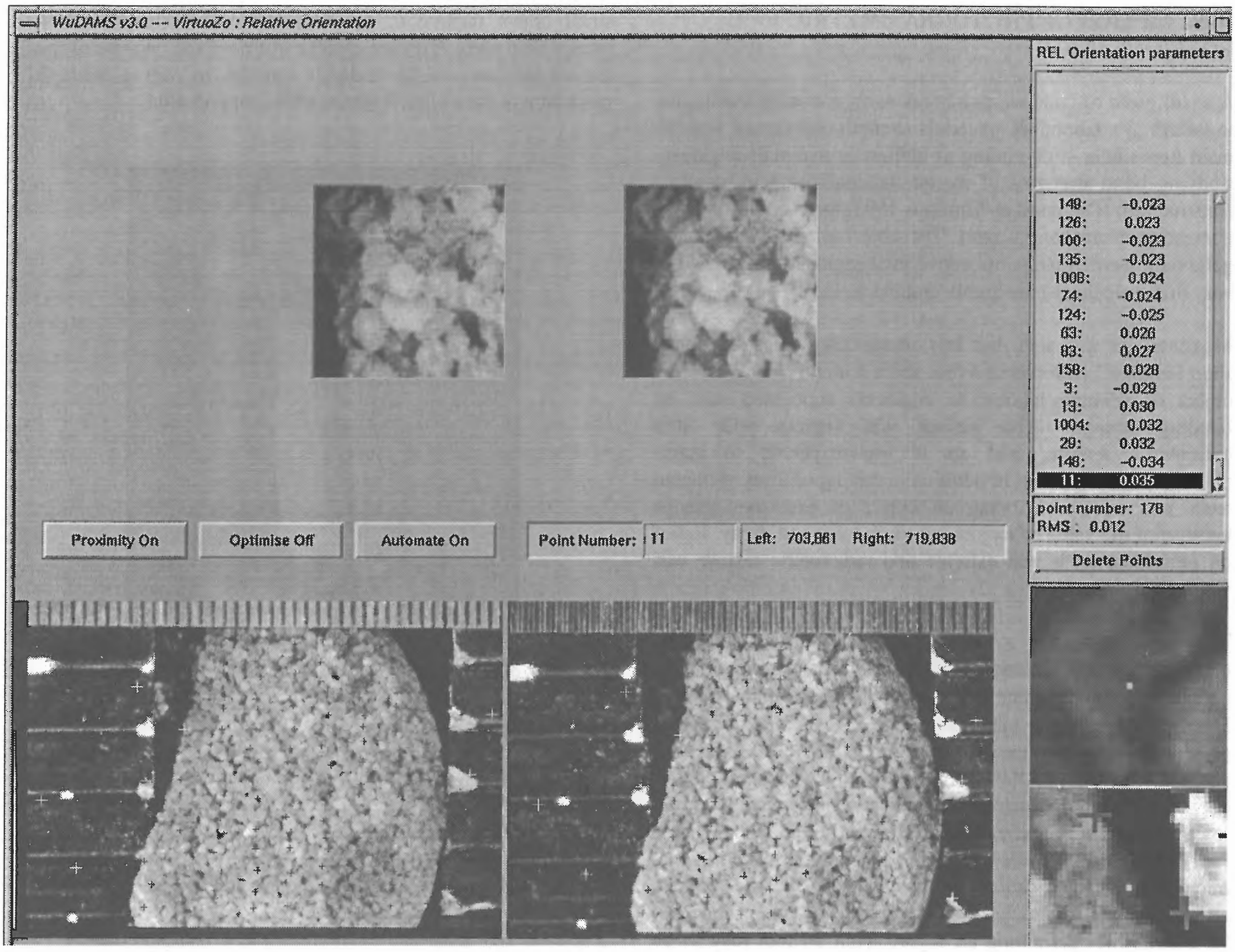

Figure 2:Screen display during relative orientation procedure with the VirtuoZo system. The scanned images the concrete break surface are shown, along with close-up views of windows surrounding a point being matched automatically.(The frames may be viewed stereoscopically under good conditions).

MPS-2 analytical plotter again was used to measure height differences with different settings for c, which finally enabled *c* (and hence *Z* also) to be deduced. The estimated values for *c* were 500 mm and *Z* 320 mm. Once determined, these values should be usable for measurenments on other microscope imagery without re-determination. The analytical plotter was used to confirm the photogrammetric geometry overall and to provide a check against gross error in results in the DTM.

Lens distortion effects have been ignored in these experiments.

DIGITAL PHOTOGRAMMETRIC PROCESSING

Digital photogrammetric processing was carried out using the VirtuoZo system (version 3) running on a Silicon Graphics Indy workstation, using the images reformatted into the VirtuoZo format by VirtuoZo from the scanner's BMP format.

As explained above, achieving stereoscopy by shifting the object was found to be ineffective, as, although relatively oriented models were achieved by the digital system, they were generally not sensible: all base direction movements ("x-parallax") were absorbed as an axis convergence parameter ("φ rotation"). Such a computational result was not surprising, especially given the narrow field-of-view. More interestingly, this incorrect solution indicates one of the drawbacks of a highly automated system with limited opportunity for operator intervention. Because the small base solution failed, subsequent descriptions and results refer only to the tilting stage technique. And, as greatest success was obtained with the concrete specimen, the following discussion of procedures refers only to it.

In normal processing, once relevant data files have been read, the VirtuoZo software implements photogrammetric processing (essentially, image orientation, object measurement and DTM generation) according to the following menu settings:

- *Orientation*
- *Image Matching*
- *Display/Edit*
- *Create DTM*
- *Create Orthoimage*
- *Create Contour Image*
- *Orthoimage + Contours*

The Orientation menu has options

Interior
Relative (which includes, among others
Define Area
Epipolar Images)
Absolute

The experiments can most informatively be reported according to each of these VirtuoZo settings.

Interior Orientation: The VirtuoZo interior orientation procedure, which is used with fiducial marks on aerial photographs, is not needed for non-metric imagery, for which a DLT solution is followed.

Relative orientation: For the fully automated relative orientation solution, there were generally no problems even with smooth textured objects, due at times to the texture of surrounding control objects. A large number of points, typically about 150, were automatically chosen and matched, with an r.m.s. of 0.12 mm. The relative orientation included the absolute orientation control points.

Absolute orientation created difficulties , mainly because of the unavoidability of using control points, whose co-ordinates cannot be determined easily at this scale. The co-ordinates of control points were determined using the analytical plotter, as described earlier.

Epipolar images were created without apparent difficulty.

Image matching, the stage at which points are automatically matched across the entire surface, ran without fault.

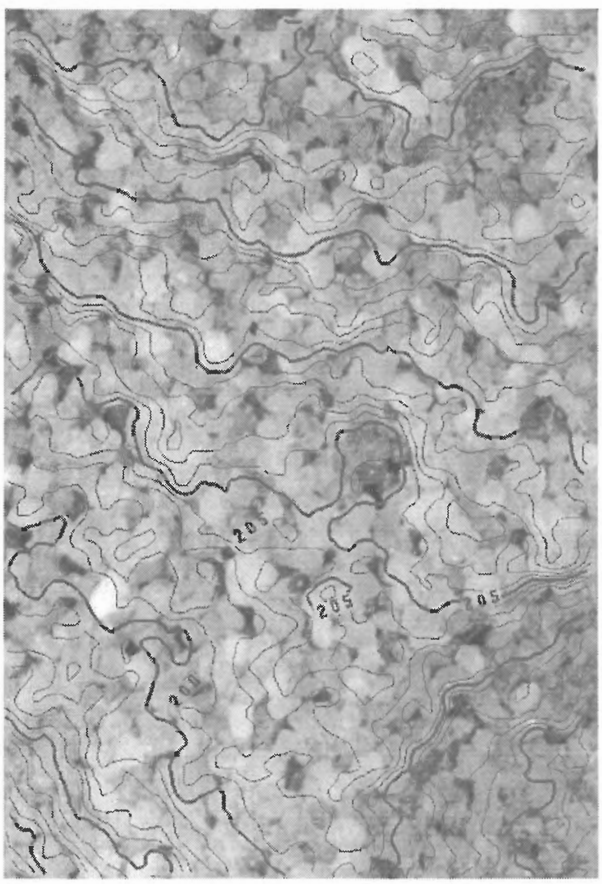

Figure 3: Contoured stereo-model at Display/Edit stage of VirtuoZo system processing, during measurement of concrete surface.

Results of image matching were examined at the *Display/Edit* stage, and it was apparent that even with the fine grained surface, contours closely followed the minute particles. Figure 3 shows the surface created from the matched points (not in DTM form at this stage, as it has not been referred to the ground co-ordinate system).

Create DTM: This step derives the DTM in object space with characteristics set by operator-defined parameters. Assorted problems of parameter settings were faced before a satisfactory DTM was obtained. For example, VirtuoZo requires integer values for the DTM spacing. But it only proceeds if a "large" number of points are to be created for a DTM. Since the number of millimetres across the object is small, the two requirements are incompatible in this case. The solution was to input object dimensions in tenths of millimetres, which has repercussions on other settings, such as for c and Z. Pixel sizes had to input 10 times larger than they really were. (The r.m.s. figure shown in Figure 2 is therefore a false value of 0.012, not the correct value of 0.12, as reported earlier this page.)

The time lost in the DTM generation should not be under-estimated. Most problems were overcome by some experimenting. However, once overcome, they should not recur in similar projects involving microscope images. Many of the small problems which were encountered relate specifically to this work and this photogrammetric system, and are not of general photogrammetric interest, and so will not be reported here in detail, but they do indicate the difficulties which can be faced by highly automated systems.

Eventually, a DTM of the concrete break-surface was created. The co-ordinates of ten DTM points which could be located on the images were determined using the model created in the analytical plotter, and found to be in agreement with a mean of 0.01mm and an r.m.s. of only 0.15 mm.

With the reinforcement rod and the tooth, the relative and absolute orientations proceeded well, thanks largely to the surrounding control objects; the objects themselves had inadequate texture. While some success was achieved with the metal rod, the contours on the tooth replica were clearly invalid, for which the photogrammetric system cannot be blamed.

CONCLUSIONS

Some of the experiences gathered by the writers relate to microscope usage, to microscope photogrammetry, and to photogrammetry in general, rather than to digital photogrammetry with a microscope. For example, good photography or good imaging is a challenge in all photogrammetry, and failures here due to this source disclose little that is not already familiar to photogrammetrists. In terms of digital photogrammetry with a microscope, there are two main conclusions:

1. The digital system carried out automated correlation of the convergent microscope imagery remarkably successfully, considering especially that the particle nature of the concrete surface made it a rather abnormal object, as figures 2 and 3 show. The final DTM appeared to be of good precision.

2. The fixed nature of parameter settings, presumably intended by the manufacturers to simplify processing by limiting the necessary amounts of human intervention, meant that success was initially slow to

achieve and indeed was achieved only with good understanding of photogrammetric principles, and with some unusual tactics including the assistance of an analytical plotter.

Both conclusions suggest that, once mastered, repeat uses of the microscope in conjunction with the digital software for similar measurements would be straight-forward. As a result of lessons learnt, greater attention would be paid to control requirements, in terms of selecting recognisable points, located in suitable positions, and to their co-ordination to an accuracy better than the photogrammetric measurement of other points, i.e. to about 0.01 mm. Nevertheless, measurement would be expected to proceed with the rapidity and therefore savings expected from digital procedures.

The film camera and scanner combination was seen as a simple and adequate, and inexpensive given the resolution available, and would be used again without hesitation.

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