DEVELOPMENTS IN CLOSE-RANGE PHOTOGRAMMETRY FOR
3D MODELLING: THE *iWitness* EXAMPLE

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Keywords: Close-range photogrammetry, automation, software systems, on-line processing, digital cameras

ABSTRACT:

Close-range photogrammetry is increasingly being employed for 3D measurement and modelling across a host of application areas. Consumer-grade digital cameras are becoming ubiquitous, and 'professional' digital cameras are becoming less expensive. Thus, access to suitable imaging technology for 3D measurement and subsequent model building and visualisation is now open to all. Access to suitable photogrammetric data processing systems is, however, still less than universal. Although there are a number of PC-based integrated image measurement and photogrammetric restitution systems available, for both multi-image processing and stereo configurations, most are either too specialised for the casual user, too expensive or too difficult to use without extensive training. This paper reports upon a new photogrammetric data processing system, *iWitness*, which has been especially developed for the non-specialist user. Indeed, its primary application domain is accident reconstruction and forensic measurement where it is used by police. The system is also ideal as a tool for many other 3D measurement tasks in engineering and architectural photogrammetry, as well as in general heritage recording.

The *iWitness* system is characterised by a new paradigm adopted within the image measurement and photogrammetric processes. This is centred upon fully automatic on-line photogrammetric processing, automatic recognition of the camera(s) from the imagery, extensive operator assistance as exemplified by guided referencing and interactive quality review, as well as exceptional ease of use. The paper describes *iWitness* and illustrates its flexibility and accuracy. The *iWitness* software is low cost, and offers the user the prospect of assembling a photogrammetric measurement system comprising camera and all necessary data processing software, which is capable of accuracies to about 1:20,000, for as little as $US 1500.

1. INTRODUCTION

Close-range photogrammetry has a long history as a useful tool for 3D measurement and modelling in support of heritage recording. Over the past half decade or so, we have witnessed a very significant growth in activity in this area, and indeed in close-range photogrammetric measurement in general. A number of trends account for the broadening use of this technology, especially by non-photogrammetrists. The first and very obvious trend is the increasing availability and indeed suitability of off-the-shelf, consumer grade digital cameras for photogrammetric applications. These cameras are ubiquitous, have ever higher resolutions and are quite suitable for medium accuracy measurement at, say, the 1:5000 to 1:20,000 level required in architectural and archaeological recording, forensic measurement, engineering documentation and in numerous other application domains. A second obvious trend, which is not a photogrammetric development per se, is the enhanced capabilities available in 3D modelling and visualisation, processes which benefit from more comprehensive measurement and imagery data. A third obvious trend relates to developments in photogrammetric data processing, including improved computational models, and the development of automated image measurement and photogrammetric orientation software systems designed for use with low-cost digital cameras.

This paper describes the features of a recently developed close-range photogrammetric system, *iWitness*, in order to illustrate the state of the art in highly flexible, robust, and easy-to-use software packages for integrated image measurement, orientation, subsequent photogrammetric triangulation and post-orientation processes.

The *iWitness* package is by no means the only modern close-range photogrammetry system available, and it follows on from such products as Photomodeler (EOS Systems, 2004) and ShapeCapture (ShapeQuest, 2004). As the newest such offering available, however, *iWitness* incorporates a number of very distinctive features which have been designed to extend the capability of the photogrammetric measurement process, to increase its ease of use, and to overcome what are perceived to be shortcomings with existing approaches. Thus, in the following sections, an account is given of some of the distinctive features of *iWitness*.

2. *iWitness* OVERVIEW

As a PC-based image measurement and data processing system for multi-image, close-range photogrammetric measurement, *iWitness* has the familiar features of 2D image mensuration for an essentially unlimited number of images, points and cameras. Moreover, it incorporates user interfaces and interaction that are designed to support maximum ease of use. There has been an attempt, successfully realised, to perform full photogrammetric measurement operations with just 'five toolbar buttons and mouse clicks'.

Shown in Figure 1 is an example of the graphical user interface of *iWitness*. As the system was primarily designed for traffic accident reconstruction and forensic measurement, its features are currently restricted to attributed point cloud generation, with the attributes primarily being line connections which are preserved in the export of XYZ point coordinate data in DXF format. *iWitness* is designed to interface with CAD and modelling packages, especially with CAD systems from The CAD Zone (2004).
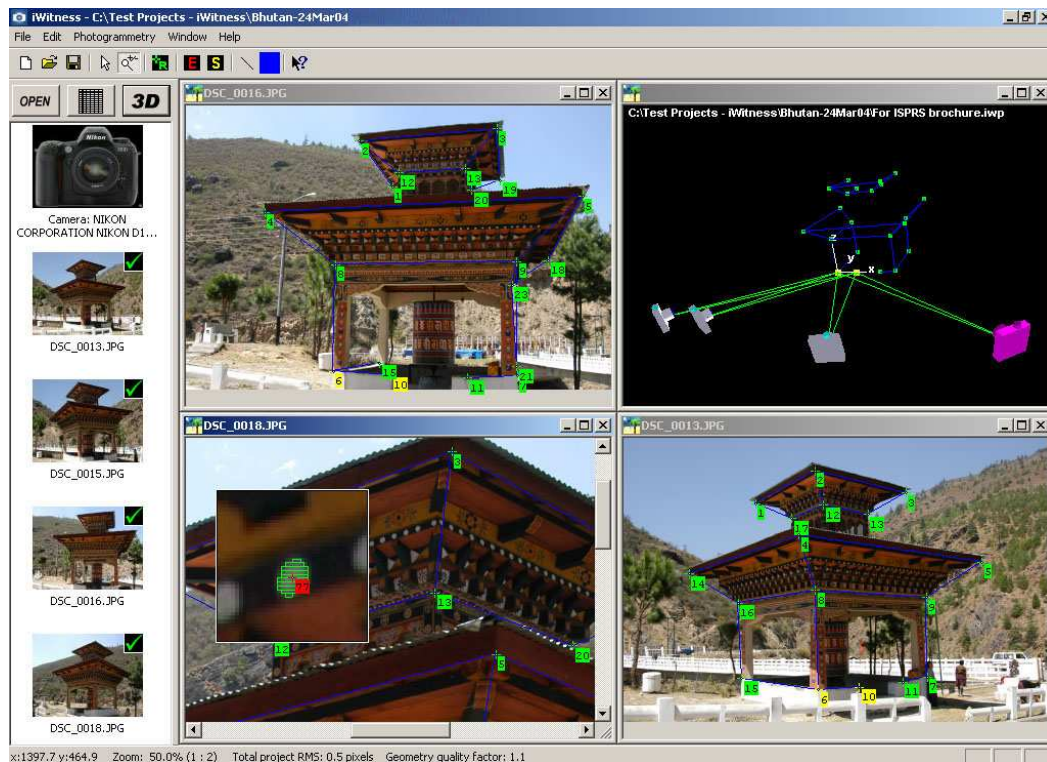
Figure 1. *iWitness* user interface.

While *iWitness* has a host of features that will be familiar to users of close-range photogrammetric systems, it also has some unique developments. These include the fully automatic initiation of all photogrammetric orientation functions, coupled with full on-line processing. Put simply, this means that *iWitness* will perform its orientation functions automatically, whenever it has enough measurement information to do so, and it will perform an updated orientation as every image point is referenced (i.e. with the measurement of a conjugate point pair).

A further feature is automatic recognition of the camera(s) and possibly its full calibration, via information contained within the EXIF header of the JPEG or TIFF images. A third feature of note is 'Review Mode', whereby it is possible to interactively review all image point observations and to adjust these where appropriate, again with on-line and immediate updating of the photogrammetric bundle orientation. These and other features will now be described, simply to highlight the contributions of *iWitness* to the current state of the art in image-based 3D measurement at close range.

3. NOTABLE FEATURES OF *iWitness*

3.1 Orientation

Shown in Figure 2 is a relatively oriented pair of images, with 7 object points. Note how all object points and the two camera stations are near co-planar. From a photogrammetric point of view, this is very, very poor geometry for relative orientation (RO). Indeed there are a number of plausible image orientations which go close to satisfying the coplanarity condition for this network geometry. Yet, this is a quite typical camera station and object point configuration for traffic accident reconstruction, and thus it is of paramount importance that RO solutions be readily obtainable for such geometries within the photogrammetric processing. Moreover, the solution of the non-

linear RO problem must be achieved in a robust manner, without the need to input any prior information regarding station or object point positions, and with an uncalibrated camera of roughly estimated focal length.

The reliable determination of RO for both poor geometries (Figure 2) and good (Figure 1) is a very favourable feature of *iWitness*. Indeed from a photogrammetric standpoint, this is probably the most difficult process to carry through to a robust solution. There are of course instances where it is not possible to achieve a unique solution, but fortunately these are rare. Effectively, the *iWitness* approach is to keep track of plausible RO solutions until such time that there can be some confidence as to which of the possible camera station configurations is the correct one. Thus, the operator continues to reference points in the two images until the system reports that a satisfactory RO has been obtained. A minimum of five conjugate points is of course required, but it may well be that some 7-10 points need to be referenced before a successful RO is reported. The computations occur automatically in the background with the RO being updated with every additional point referencing.

This same on-line processing concept is utilised in the resection operation for initial exterior orientation (EO) determination of the third and subsequent images. Once again, although a minimum of three points is required for space resection, some 5-7 might need to be referenced before a successful EO is indicated. This automatic on-line computational processing, which is also applied to bundle adjustment, provides a very powerful mechanism for blunder deflection, as gross errors are indicated as they occur. Also, the approach removes from the inexperienced user the need to know when to compute the orientations and bundle triangulation. These processes occur automatically whenever the required image measurement data is available, and with every image point referencing.
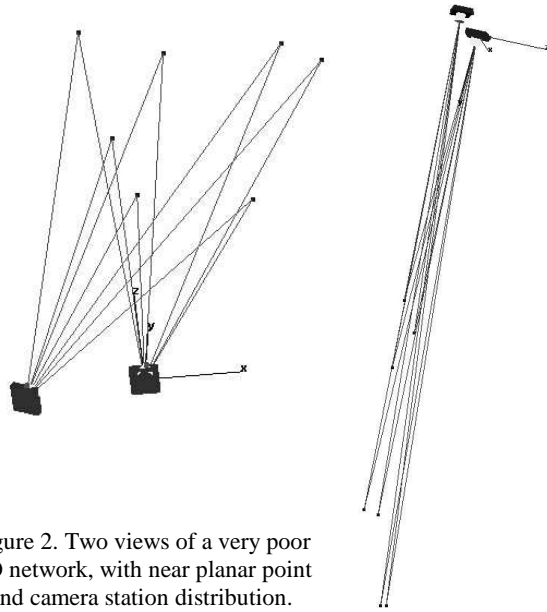
Figure 2. Two views of a very poor RO network, with near planar point and camera station distribution.

3.2 Automatic Camera Recognition

Nowadays, it can be anticipated that the JPEG and TIFF images created by any consumer digital camera will incorporate an Exchangeable Image File Format (EXIF) header. Within this header, there is a host of information pertaining to the camera and to the image. Of importance in a photogrammetric context are the camera make and model, the array size (real and pixel dimensions) and therefore, possibly and indirectly, the pixel size and also the focal length setting of the lens. Thus, it is possible to automatically identify the camera used, along with the value of certain camera parameters. *iWitness* reads such information and accesses internal and external camera databases to automatically assign the correct camera to the measurement project. Where the particular camera has been pre-calibrated, the user need take no action, whereas there may be a requirement to interactively input certain parameters in the event that the EXIF header information is not complete, or in cases where there is no EXIF header.

The assignment of the Nikon D100 camera indicated by the icon at the top of the column of image thumbnails in Figure 1 occurs automatically at the time the images are imported into the project. It is also possible in *iWitness* to maintain multiple calibrations for the same camera/lens combination to account for usage at different focus or zoom settings. Camera calibration within *iWitness* is via self-calibration though this must be selected by the user; it does not occur automatically (by design). There is, however, a procedure for fully automatic camera calibration should this be desired (Photometrix, 2004).

3.3 Centroid Determination

The ability to automatically detect image points and determine their centroids is crucial to the success of industrial vision metrology (eg Fraser & Edmundson, 2000; Ganci & Hanley, 1998). To aid in this process, retroreflective targeting is employed, since it is much easier to automatically set an intensity threshold in underexposed near binary imagery, above which only valid target blobs will appear. The luxury of distinct targets in near binary images is generally not afforded in photogrammetric measurement for heritage recording or accident reconstruction, yet the ability to centroid on artificial

and even some natural targets is very desirable from an accuracy point of view. *iWitness* incorporates a centroiding feature which facilitates semi-automatic image point measurement to an accuracy of up to 0.03 pixels. Moreover, the centroiding function is very straightforward and it can accommodate light blobs on a dark background, or vice versa. Such a centroiding operation is illustrated in the lower left image in the main window of Figure 1.

The centroiding function is illustrated by the sequence of images in Figure 3. In the first the user selects the enlargement window via a keyboard key. By moving the cursor to the edge of the window the normal enlarged image of the target to be centroided is seen (Figure 3a). Then, as the cursor is moved within the window, the area to be centroided via an intensity-weighted centroid determination (ie. using the pixels with an intensity above the variable threshold) is highlighted and a cross indicates the computed centroid (Figure 3b). For a finite range of thresholds the cross will remain invariant in position, even though the target region is varying (Figure 3c). Once this invariance is experienced, the centroid is recorded with a left-mouse click (Figure 3d). This very simple procedure yields highly accurate centroid coordinates, which in turn leads to higher orientation (RO and EO) and object point accuracy.

(a)   (b)
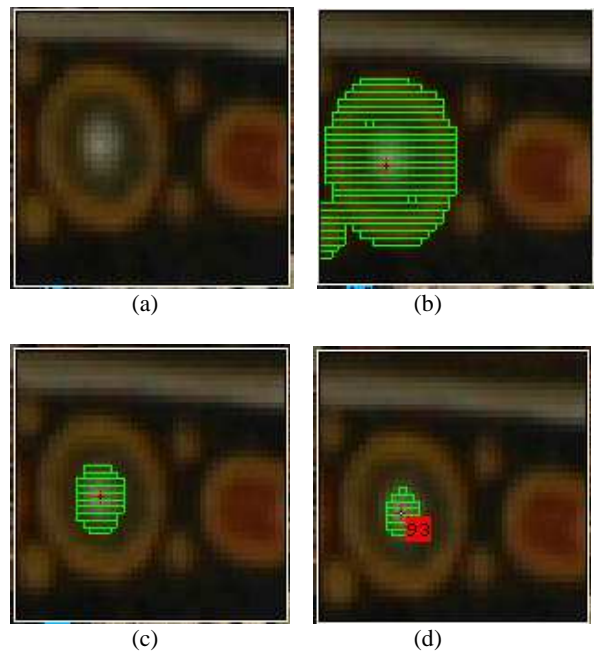
(c)   (d)

Figure 3. Illustration of the image blob centroiding process.

3.4 Review Mode

The Review Mode is a distinctive feature which allows the quality of individual image point markings and referencing to be assessed. As indicated in Figure 4, the user individually steps through the network point by point (or 'drives' to a particular point). All image point observations are then displayed for the particular point. The operator can now interactively adjust any observation or re-centroid if desired. As any image observation is made, the bundle adjustment for the entire network is immediately updated, again automatically and on line. A quality measure indicates any improvement or degradation in the spatial intersection accuracy as this review process is being undertaken, thus providing a powerful and effective error detection and correction capability.
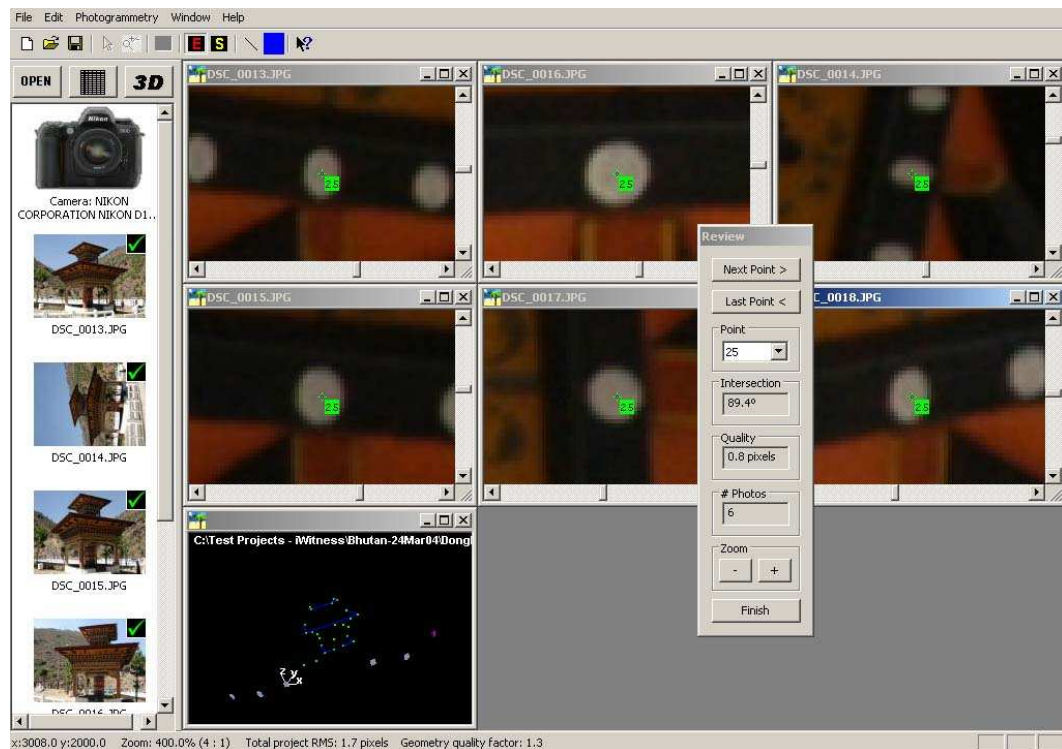
Figure 4. Illustration of Review Mode in iWitness.

As well as being able to adjust image point observations, it is also possible to make measurements to points which have not previously been measured in certain images. The Review Mode shows the predicted locations of such points in all applicable images. Although this edit/review process can be invoked at any time, it is recommended that it be the last step undertaken within the *iWitness* data processing operation, since it provides such a practical final QA function.

4. CONCLUDING REMARKS

In addition to the four highlighted, *iWitness* displays many other notable features. These include the capability of fully automatic camera calibration; the generation of full statistical measures (variances/covariances) for all photogrammetric parameters; the flexibility to interactively set and change the XYZ reference coordinate system, both with and without control points; a guided referencing mode which shows predicted image point locations, thus allowing faster single-image referencing; the ability to add point-to-point lines which are retained in the DXF output; and extensive image manipulation tools for zooming, panning, tiling, etc. These make *iWitness* a very comprehensive yet extremely easy-to-use, low-cost system for general purpose 3D measurement with digital cameras. Moreover, because of the intuitive nature of the

image referencing and computational processes utilised in *iWitness*, the system is an ideal teaching tool for close-range photogrammetry. Here it has been possible to give only a broad overview of the *iWitness* software package and for further information the reader is referred to www.photometrix.com.au.

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