IMAGE-BASED MODELLING OF ARCHITECTURAL SITES:
THE *iWitness* APPROACH

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ABSTRACT:

This paper discusses image-based modelling and the generation of textured 3D object models. The main focus of the presentation is upon a low-cost, easy-to-use photogrammetric system which can handle hidden object parts and model curves in object space. The concept includes the following stages: first, measurement of points, lines and curves; second, selection of a polygon which describes a potential object entity; and third, texturing the entity. The reconstruction of hidden object parts, through approximate measurement from constructed neighbourhood points in object space, is also considered. Additionally, features appearing in a single image can be accommodated. The potential of the image-based modelling concept presented, which has been integrated into the software package *iWitness,* along with its current development status are discussed. Finally, application of the concept is illustrated for a building façade, as an example recording of an architectural site, and a car to exemplify modelling of an industrial object.

1. INTRODUCTION

The modelling of architectural sites is increasingly being called upon to support cultural heritage documentation and preservation. In most applications, accurate data is necessary, e.g. to realize virtual museums or to replicate artefacts, objects and building façades. The acquisition of accurate data for this purpose includes the requirement to record geometric shape and radiometric colour information. There are a number of existing data acquisition and evaluation techniques, including close-range photogrammetry and terrestrial laser scanning (TLS).

1.1 Comparison of Photogrammetry and TLS

Close-range photogrammetry and TLS are two widely applied and often compared area-based 3D data acquisition techniques for cultural heritage recording and documentation (e.g. Böhler & Marbs, 2004). Laser scanning devices directly deliver the geometric shape of measured objects with an adequate resolution and accuracy. Besides measuring sensor-to-object ranges, most laser scanners provide an intensity image of the scanned surface, which can give the operator a first idea of the object's appearance. With regard to generating textured architectural models, this radiometric intensity information generally falls short of what is required to produce visually realistic models of sufficient resolution. Over recent years, laser scanner manufacturers have integrated a digital camera into

their systems to improve the quality of intensity data and to provide real colour.

A digital camera alone is used for data acquisition in close-range photogrammetry. The images provide both visual information of the object and also, indirectly, it's geometric shape. The parameters of the camera(s) and the geometry of the network of recorded images greatly influence 3D measurement accuracy. In instances where stereoscopic image matching is employed, favourable image quality and texture are necessary for reliable 3D surface extraction, and they are in turn also necessary for final texturing of the object model.

Architectural sites can be completely digitized with either technique. The TLS approach is more powerful in terms of automation than the solely photogrammetric method, and it can generally yield more data from each viewpoint. However, two disadvantages of TLS systems remain, these being the huge point cloud data sets which are produced, and the high hardware and software costs for data acquisition and processing.

1.2 Motivation

The motivation for the development of an image-based modelling technique was to provide a tool for the 3D documentation of architectural and other heritage sites using a very inexpensive data acquisition system which collected high-

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resolution data, real colour information and on-the-fly analysis for visualization and virtual reconstruction.

Consumer-grade cameras are being increasingly employed as low-cost data acquisition systems for photogrammetric measurement. Such cameras display limitations in regard to metric quality, but can nevertheless yield 3D measurement accuracy to levels which can be safely predicted in advance (e.g. Cronk et al., 2006; Al-Ajlouni & Fraser, 2006). In regard to radiometric quality, consumer-grade cameras and especially those in the digital SLR category display fewer restrictions and limitations.

Within the overall image-based modelling development, additional aims were:

- To provide the possibility to model hidden object parts for visualisation. It often happens that for large and complex architectural sites, parts or corners of objects are occluded and subsequently 'missed' in the object modelling. Neighbourhood points can be considered in the approximate reconstruction of hidden object parts, including those which appear in only a single image.

- To very rapidly generate object models.

- To keep the textured 3D models small enough through the combination of coarse and fine modelling aspects.

- To use 3D curves as border lines for the modelling of neighbouring object parts.

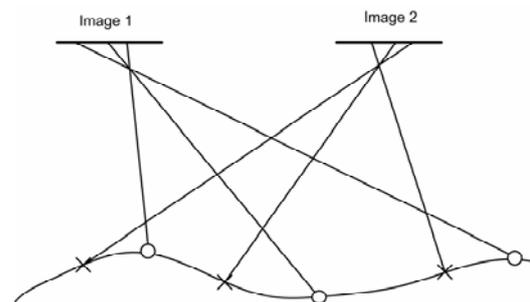## 2. THE *iWitness* SOFTWARE

2.1 General Features

For the modelling task, tools have been developed and implemented into the commercial software package *iWitness* (www.photometrix.com.au), which is a multi-image measurement system developed especially for the non-specialist user. Indeed, its primary application domain is traffic accident reconstruction and forensic measurement, where it is widely employed by traffic police (Fraser et al., 2005). The system is also ideal as a tool for various 3D measurement tasks in engineering, and for general digital model building, as well as in heritage recording.

iWitness is characterised by a high level of automation within many of its functions, while being very intuitive with easy-to-use modules for the operator. The system provides basic functionality for standard photogrammetric data analysis including automatic and manual image point measurement, automatic camera calibration and on-line exterior orientation, with the primary output being 3D object point coordinates (Fraser & Hanley, 2004; Cronk et al., 2006).
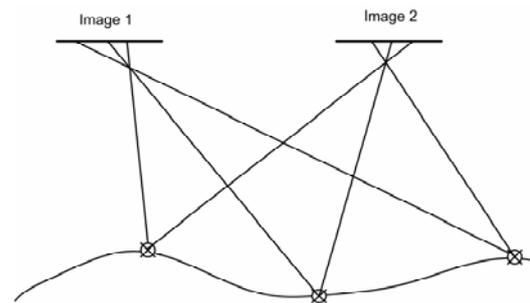
The graphical user interface of *iWitness* comprises a thumbnail view, an image view and a 3D graphics view to analyse the data of the actual project. The thumbnail view provides an overview of the project images, whereas in the 3D graphics view the computed data (points, lines, …) and further information in 3D object space are visualized using the Open Graphics Library (OpenGL) (e.g. Wright & Lipchak, 2004). Image measurement and other image-related functions are carried out within the image view.

2.2 Curve line measurement

Of interest in the context of image modelling is the capability to model 'free-form' and 'facet' 3D curves in object space, these being necessary to support the image-based modelling process. The term free-form implies that there is no need for homologous points in the construction of a single 3D curve line from multiple 2D projections of all or parts of that line into images within the network (Fig. 1a). The term facet curve line denotes the use of nodes which are themselves homologous points, the curve line being built interactively with operator-guidance (Fig. 1b). The measurement of free-form and facet 3D curve lines is an essential component for the modelling and texturing of objects without defined edges. The resulting 3D curved lines can be represented by non-linear interpolation functions, e.g. spline functions.

(a) free-form 3D curve

(b) facet 3D curve

Figure 1: 3D curve modelling in object space

3. CONCEPT OF IMAGE-BASED MODELLING

Based on the known orientation parameters of a set of images, coupled with standard photogrammetric data processing, tools and procedures have been developed for object modelling, including reconstruction and visualization. Besides points and lines, curve lines can also be measured in the images and adjusted in 3D object space.

The modelling within *iWitness* is a semi-automatic procedure. First, feature points have to be measured and/or selected in the images of interest. Points, lines and curve lines can also be selected in 3D object space within the 3D graphics view. Second, textured entities are generated. A textured entity is the smallest planar surface unit to be displayed and textured on the model. The texture is a rectified image approximating a true orthoimage. The operator can decide upon the level of detail

within the texturing process, so object parts of particular interest can be modelled meticulously whereas those of less interest can receive coarse texturing, which is still sufficient to assist in gaining a more complete visual representation. The full processing pipeline is shown in Fig. 2.
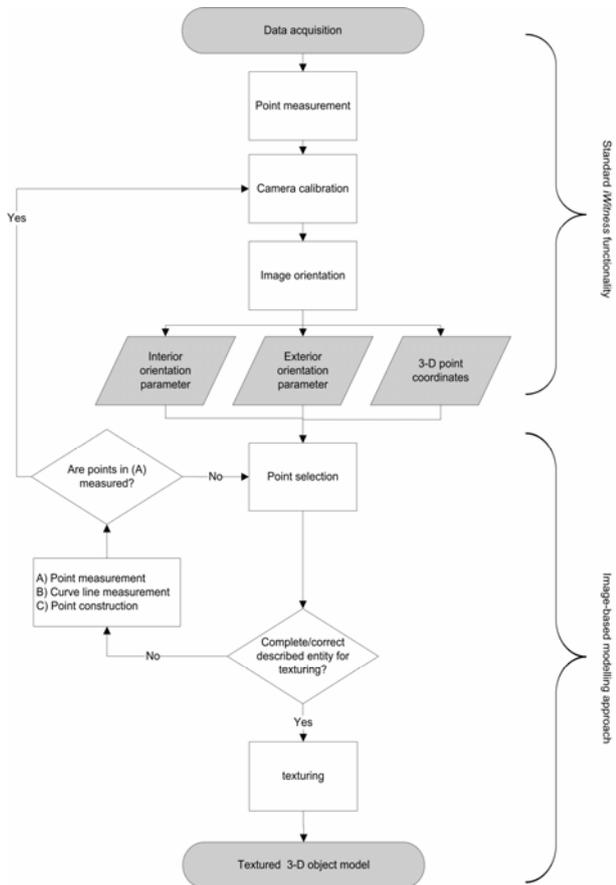

Figure 2: Processing steps for the image-based modelling concept.

Within the standard functionality of *iWitness*, target points or marker-free points are measured to process the camera calibration and image orientation. Based on the estimated interior and exterior orientation parameters, as well as selected already measured 3D point coordinates, the image-based modelling approach is then set up.

The main steps in the modelling approach are (1) point selection to provide a polygon, which may also involve curve line measurement and the generation of constructed points; (2) an inspection of the completeness and correctness of the selected polygon, along with additional measurements where necessary to complete the polygon; and (3) the texturing, which can be carried out in either automatic or operator-selected mode. The following sections describe the processing steps.

3.1 Point selection

At least three points or curve lines that contain at least three node points must be selected in order to create a textured entity in the 3D graphics view. The selection can be carried out either directly in the 3D graphics view or in an appropriate image view. The selected points should be near co-planar for the subsequent image patch rectification. Further, the points have to

be selected in a sequence that forms a convex boundary. Fig. 3a illustrates a valid selection, whereas Fig. 3b shows an invalid polygon selection. The entity boundary is drawn in the order of selection of the boundary points. To improve the visualisation quality, the entity borderline should run along radiometric or geometric edges.
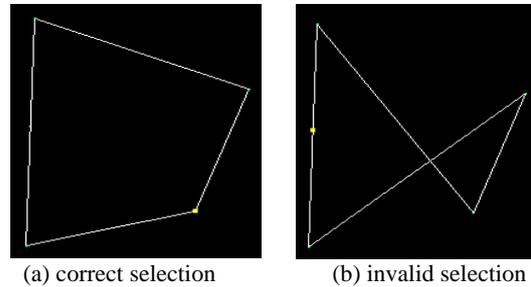

(a) correct selection (b) invalid selection

Figure 3: Selected boundaries for entity creation.

A curve line is internally stored as a sequence of 3D points. Therefore, a selected curve line can directly describe a boundary segment of a planar surface entity and the curve line can be selected in the same way as a single point. Additionally, it is possible to use only a subset of these points in the texture mapping process.

The curve line can be 'shortened' from each end for texturing. Points of the curve line are highlighted to aid in this process. The start and end points are coloured green and red, respectively. Points can then be sequentially deleted, as indicated by the new start (green) and end (red) points, as shown in Fig. 4. Further selected points of other elements can be attached to the two new end points of the curve line segment.
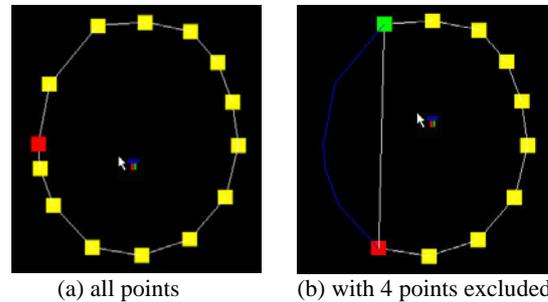

(a) all points (b) with 4 points excluded

Figure 4: Selected points of a curve line.

3.2 Constructed Points

The main purposes of 3D 'Constructed Points' is to enable the definition of additional sub-entities, which then allows further texturing within an existing planar entity. Constructed points can also be used to generate points in hidden areas to complete the textured 3D model and to improve visual appearance.

3D constructed points can be created in a special mode in *iWitness* in combination with an existing entity, as follows:

a) Through the direct intersection of a chosen image ray and a planar entity in the 3D graphics view (Fig. 5a). The entity does not have to be selected. In the case of overlapping entities, the entity on the top level will be used.

b) The entity is initially selected through the intersection of a chosen image ray and the selected planar entity in the 3D graphics view. In contrast to the first approach, the image

ray can be chosen outside of the borderline of the entity and also in the appropriate image view(s) (Fig. 5b). In the case of overlapping entities, the selected entity will be used.

The resulting 3D constructed points are automatically selected for later texturing.
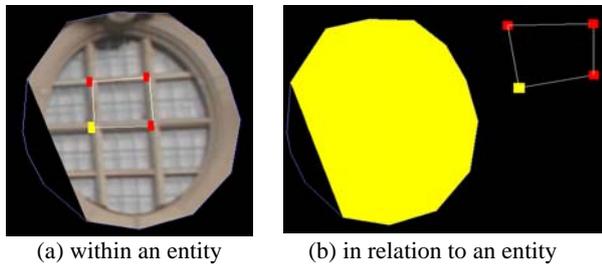

(a) within an entity   (b) in relation to an entity

Figure 5: 3D constructed points

The utilization of 3D constructed points is very useful for model refinement, e.g. to provide texture to cover obstructions and occlusions. This is indicated in Fig. 6 by the effective removal of the pole (Fig. 6a) standing several metres in front of the building from the texture mapped façade section (Fig 6b). Along the radiometric borderline of the pole, 3D points are directly constructed in the 3D model within the 3D graphics view in order to split the existing entity into two. The entity including the pole is then retextured with the texture from an alternative, occlusion-free image.

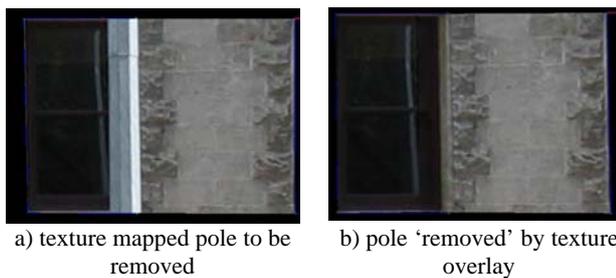a) texture mapped pole to be removed   b) pole 'removed' by texture overlay

Figure 6: Texture mapping via constructed points.

Another example is point construction in hidden areas. In terms of photogrammetric processing, hidden areas are object parts that appear in either one image or none of the images. In hidden areas no photogrammetric point measurement is possible. However, for textured 3D models it could be very useful to complete the visual appearance even though such areas might not have reliable geometric integrity.

3.3 Texturing

The texturing step follows immediately after the planar surface entity is generated. The image patch to be rectified onto the planar surface entity will be automatically selected based on the geometry of the images forming the network. Normally, the best image is that whose pointing direction is most normal to the entity surface. Only images from the same side of the object as the operator's viewpoint within the 3D graphics view are considered.

As an alternative to automatic texture selection, the user can specify a given image from which the texture is to be taken. In this case, which will occur quite frequently because the automatic selection might not be the optimal choice because of occlusions or image quality reasons, the user can simply choose

the desired image view, or select a thumbnail image within the thumbnail view.

The texture mapping of the entity will result in one of three outcomes. In the first, a texture will be mapped to the surface in the 3D graphics view (Fig 7a). In the second, a plain-colour fill will appear, along with a message that there is no texture available. This could occur, for example, when the selected entity is being viewed from the backside in the 3D graphics view. In the third, a default texture is assigned to indicate that the entity spans more than one image, i.e. the entity is not contained within a single image (Fig 7b).

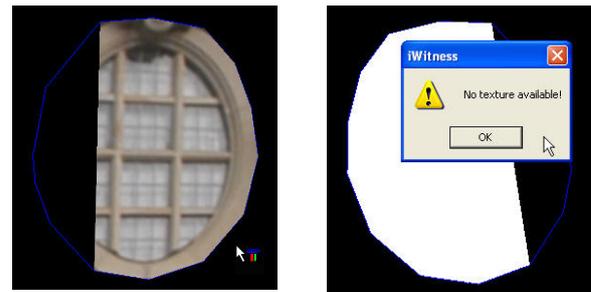a) textured entity   b) no texture available; default texture assigned

Figure 7: Two of three possible texturing outcomes.

Also, there will be situations where the automatically selected texture for an entity does not produce the optimal texturing. In these cases, the entity can be re-textured either from the project image of choice or by using artificial texture. It is also possible to both texture map an entity 'from behind', i.e. to have the texture visible from the opposite direction, and to make the entity visible from both sides. Finally, after the texture modelling is completed, the model can be exported in VRML format. The individual rectified texture elements are also saved as JPEG files.
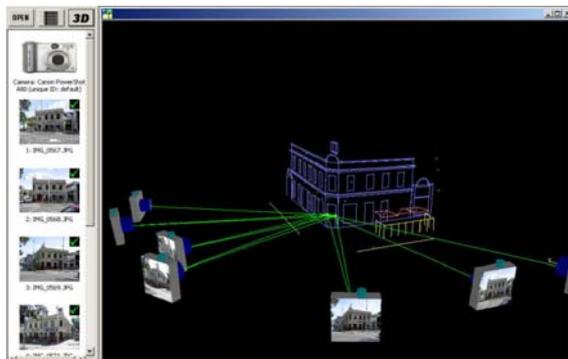
At this stage of development the process is sequential. The user needs to select and measure the borderlines of each textured entity. The texture is then directly mapped from the automatically or manually selected project image. Therefore, entities have to be contained completely within a single image. Otherwise, larger entities need first to be divided into several parts. There is no radiometric adjustment at present between the textures of neighbouring rectified image entities.
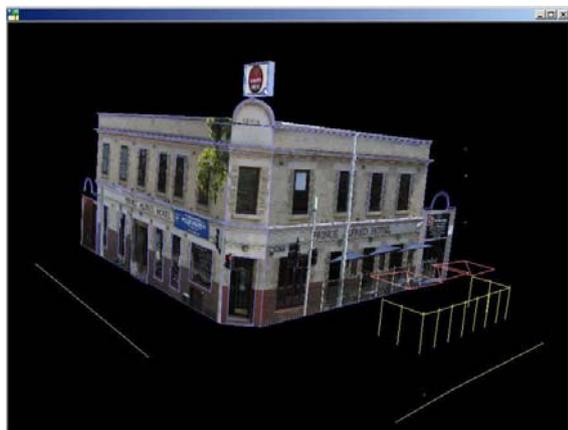
4. EXAMPLES

Two examples of texture mapping with *iWitness* are illustrated in Figs. 8 and 9. The first is an architectural application, a building comprising mainly planar elements, whereas the second is a sports car with complex curved surfaces (at least 'complex' in the context of texturing via rectification to planar surface entities). In each case, part (a) of the respective figure shows the points and lines (straight lines and curves) and part (b) shows the textured model within the 3D graphics view. The network of images is also displayed in Fig. 8a.

The building façade of Fig. 8 was digitized through point, line and curve measurements, whereas the sports car in Fig. 9 was digitized mainly through 3D curve line measurements. In both figures the typical borderlines representing geometric edges for object modelling are shown. In the 3D model texturing, adequate entities were selected according to the criteria of being

approximately planar, convex, being fully contained within a single project image and, if possible, having borderlines along radiometric or geometric edges. The particular images employed for texturing the entities were primarily chosen via the automatic image selection algorithm. Thus, in Fig. 8b some image clutter occurs in the radiometric appearance on the façade. Brightness differences occurring between the textures of different perspective images can also be seen on the car body in Fig. 9b.

(a) Measured 3D points and lines.

(b) Textured 3-D object.

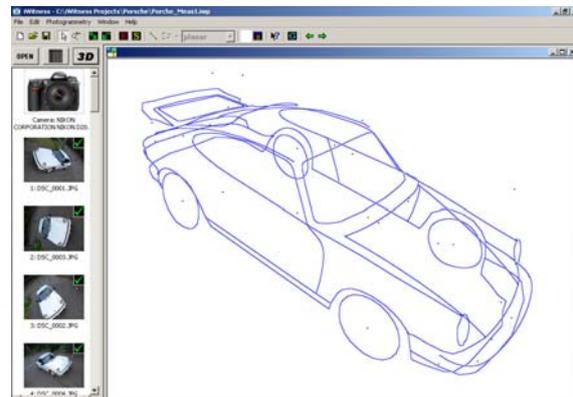Figure 8: 3D model generation of Prince Alfred Hotel site.

5. CONCLUDING REMARKS

With the *iWitness* approach, an image-based modelling tool is available to generate textured 3D models using images from consumer-grade cameras. In this concept, free-form surfaces as well as surfaces with corners and edges can be modelled. The resulting models are usually small and only the parts of interest are generally modelled in detail. Background parts can be modelled coarsely to provide a reasonable overview of the scene.
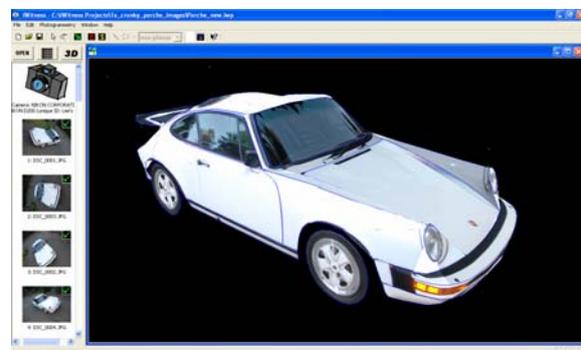
Depending upon the texture of the surface displayed in the images, the generation of a detailed surface model is possible. Especially in the case of cultural heritage objects, free-form surfaces that cannot be represented adequately through points can still be modelled.

A planned enhancement of the image-based modelling process and the software is to reconstruct the surface within each user-selected entity via an automated image matching approach. The assumption of planarity of the entity surface will thus be removed and orthorectification will be employed in the

texturing. In the context of object-based image matching algorithms, further parameters of the surface function can be included to estimate the adjusted radiometry in object space (e.g. Helava,1988).

(a) Measured points and free-form curved lines.

(b) Textured 3D model.

Figure 9: 3D model generation of sports car.

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