HYBRID MEASUREMENT SCENARIOS IN AUTOMATED CLOSE-RANGE PHOTOGRAMMETRY

Simon Cronk, Clive S. Fraser

Department of Geomatics, University of Melbourne, Victoria 3010, Australia – (c.fraser, cronks)@unimelb.edu.au

Commission III, WG III/1 and TS 22

ABSTRACT:

Automated close-range photogrammetric measurement has traditionally been associated with expensive specialist cameras and usually requires highly controlled image illumination conditions. In the past few years, however, there has been a significant amount of research into the development of automated routines and algorithms that support the employment of consumer-grade colour digital cameras for everyday photogrammetric measurement tasks. These include, but are not limited to, fully automatic network orientation, image point correspondence determination and camera calibration. This paper discusses the further requirement of a hybrid-measurement approach, where automatic orientation routines are supported, as well as follow-up manual and semi-automatic operations such as natural feature point extraction, manual point measurement and operator-assisted surface definition via image matching. Control over image illumination is not critical; however the use of retro-reflective targeting ensures a high level of process automation prior to the manual phase of hybrid measurement. Topics discussed include the exploitation of colour from imagery and targeting, issues regarding automatic network orientation and image point correspondence determination in normally exposed imagery, operator-assisted surface extraction, and a special condition placed on the bundle adjustment to support both automatic and manual image measurements.

1. INTRODUCTION

At the heart of the success of digital close-range photogrammetry for industrial measurement has been the ability of vision metrology systems to measure 3D coordinates of targeted object point arrays fully automatically. In order to achieve this, a number of developments have been required in digital camera technology, in photogrammetric processing algorithms, and in object point targeting. Most notable in the point signalisation area has been the continued use of retro-reflective targeting techniques, which generally demand a controlled lighting environment, if fully automatic image measurement is to be successful. For practical and accuracy reasons, panchromatic imagery has been exclusively employed to date in high-end vision metrology systems (e.g. Ganci and Handley, 1998).

What is being witnessed today, however, is the increasing use of off-the-shelf, SLR-type digital cameras, which offer can significantly complicate the associated automatic network orientation stage. All phases of this process become more complex: (i) it is more difficult to robustly detect coded and other signalised points in the imagery; (ii) the subsequent image point correspondence problem is complicated by the much greater number of scanned 'targets', both real and erroneous; and (iii) there is a requirement for more robust blunder detection techniques within the network formation and bundle adjustment stages, because of the likely high number of plausible yet wrong image point matches, resulting from the correspondence determination stage. Aggravating these issues is the invariably less than favourable network geometry, which is often an unavoidable characteristic of measurement networks.

Developments to be discussed in the paper include: the merits of colour for codes in normally exposed imagery; fully

moderate to high metric performance at considerable cost savings over their dedicated photogrammetric counterparts. These sensors are exclusively colour, and so it has not been surprising to see the attributes of colour being adopted in close-range photogrammetric systems (Fraser et al., 2005; Cronk et al., 2006). More recently, colour retro-reflective targeting has found application in network configurations that incorporate both fully automatic and manual (unsignalised) point measurement (e.g. Fraser & Cronk, 2007). The attributes of colour imaging from consumer-grade cameras have greatly enhanced the prospects for productive 'hybrid measurement' in non-controlled environments, thus giving rise to some distinctly new application areas of close-range photogrammetry.

One of the often under-appreciated problems associated with utilising lighting conditions conducive to normally exposed imagery that is required to support manual digitizing, is that it

automatic network orientation; optional image point correspondence determination; and subsequent manual and semi-automatic hybrid measurement operations. *iWitnessPRO*, a newly-developed software package is also discussed (Photometrix, 2008). This paper also describes recent developments that have been undertaken to enhance the use of automated photogrammetric measurement in two new and quite distinct applications. These are the reverse engineering of often complex stairways to facilitate accurate design and installation of in-home stairlifts, and the deformation or so-called crush measurement of vehicles involved in traffic accidents to support accident reconstruction and analysis. A characteristic of both these systems is the requirement for fully automatic photogrammetric network orientation, coupled with subsequent manual 3D digitising of selected non-targeted features such as points and lines.

2. COLOUR

Traditional vision metrology employed panchromatic digital cameras and 'white' retro-reflective targets on a black background, to provide the necessary high-contrast bright targets against an underexposed dark background (e.g. Ganci and Handley, 1998). When recording normally-exposed imagery with consumer-grade digital cameras, which are typically colour and do not provide a high level of control over illumination, white retro-reflective targets are often indistinguishable from background noise and 'hot spots'. To overcome this issue, the authors have investigated alternative photogrammetric targeting materials, and have discovered one far better suited to the scanning of normally-exposed colour imagery and hybrid measurement.

The optimum material found is red 3M^{TM} 3272 Engineering Grade Reflective Sheeting. Red provides the best colour response because typical outdoor scenes are dominated by green vegetation and blue sky, with very little naturally occurring red (Cronk, 2007). 3M^{TM} 3272 maintains the well-known benefits of retro-reflective material, with the added advantage of facilitating the exploitation of colour information within the recorded imagery. It is also highly durable, which is important for long life, and has a surface conducive to the screen-printing of black ink for masking out circular photogrammetric targets. This has long been an issue with normal 'white' retro-reflective material, where the black ink is printed directly on the tiny glass beads and is prone to scratching, which lowers coded target performance and longevity.

Scanning a colour image for colour targets is a three stage process. Firstly, potential target 'blobs' are identified, which is fundamentally a line-by-line algorithm that considers the brightness and colour saturation of pixels (in this case, the presence of red over and above green and blue). A target 'on/off' threshold value determines the start and end of a blob on each line, and then line sections are merged to form entire blobs. Secondly, each individual blob is refined. The initial identification of interest blobs reduces the effective search space dramatically, so blob refinement is locally intensive without compromising overall scan-time. The two primary functions are to split conjoined blobs, and to 'grow' tiny yet valid blobs so that as much information as possible is preserved. Finally, blobs are filtered in an effort to remove noise (i.e. non-targets) based on a series of radiometric and geometric tests involving shape, size, brightness and circularity. Remaining 'blobs' are considered valid targets, and their corresponding image measurements calculated via an intensity-weighted centroiding routine (e.g. Luhmann et al., 2006).

The authors have devised a new coded target system using the 3272 material. The design is based on a five point pattern forming a 'T' shape, with a subsequent three 'bits' occurring at various pre-defined locations on concentric circles around the bottom two points of the 'T'. A total of 165 unique code combinations exist. The last 20 are reserved as 'spinners', which are codes that can be 'spun' during image recording, without compromising the integrity of photogrammetric measurement. The adoption of spinners means that fewer codes are required to measure a complex network, for example when images must be taken around corners, because the essential codes that tie the network together will be 'seen' in enough images for automatic network orientation to take place. The new coded target design is illustrated in Figure 1.
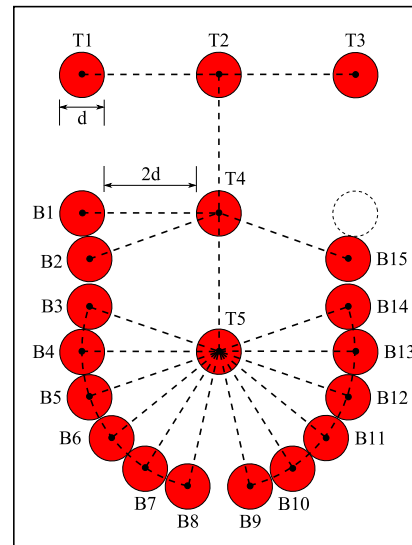

Figure 1. Red coded target design showing 5-point 'T' pattern and other code 'bit' locations.

3. AUTOMATIC NETWORK ORIENTATION & IMAGE POINT CORRESPONDENCE DETERMINATION

The newly designed red retro-reflective coded target system facilitates automatic homologous point determination in multi-image networks. The preliminary stage of this procedure is ideally based on automatic relative orientation (RO), or can also be achieved by the use of an exterior orientation (EO) device (Fraser & Cronk, 2007). The former approach is adopted by the *iWitnessPRO* system (Photometrix, 2008).

Selection of the image pair most suitable for initial RO is based on three main criteria: the number of common coded-targets seen by the candidate image pair; the perspective dissimilarity between both images; and finally the area coverage by points within each image (Cronk, 2007). Once the initial image pair has been oriented, it is then simply a matter of spatially resecting the remaining images in the photogrammetric network based on the coded-target locations in each image. The initial parameters required for bundle adjustment - station EOs and 3D point coordinates - are then known. Camera self-calibration can also take place at this stage, however this topic will not be discussed in this paper; instead the reader is directed, for example, to Cronk et al. (2006).

If the imagery only contains natural features of interest, then the sole purpose of this phase is to automatically orient each image in the photogrammetric network. Ongoing manual operations for hybrid measurement can then take place, because the EO for each station is known. If the imagery contains other targeted features, i.e. single red dots representing points of interest, then automatic detection and subsequent triangulation of these non-code object feature points can take place via image point correspondence determination. This is completely optional for hybrid measurement, which is one of its attractive benefits compared with traditional automated photogrammetry.

The image point correspondence determination procedure begins by pairing oriented images and ranking them based on geometry and the number of commonly 'seen' coded target

points. Only those ranked above a pre-defined threshold are further considered where a third image is introduced to each pair, forming an image triplet. Valid correspondences are determined if candidate point triplets adhere to the coplanarity condition in the triplet. The subsequent triangulated 3D point is then back projected into remaining images and the relevant image measurements that form its observations are automatically gathered (Otepka et al., 2002; Cronk, 2007).

This procedure continues iteratively until the maximum number of object points has been established and all images and potential measurements exhausted. Images can be re-resected during each iteration, in an effort to stabilize their exterior orientation, improving the accuracy of the overall process. This is typically worthwhile until an image contains at least 20 well-distributed and valid measurements, after which its translation and orientation parameters are unlikely to change significantly. Photogrammetric bundle adjustments are also run periodically during this process, to aid in the automatic detection and possible rejection of outliers and to ensure image orientations and object point coordinates are always up-to-date.

As can be imagined, there is a substantial number of thresholds, tolerances and settings involved in this procedure, and a more detailed explanation of these is given in Cronk (2007) and Fraser & Cronk (2007). One notable example is the ability to set the minimum number of rays before a 3D point is deemed valid. Fortunately, a default set of values can usually be relied upon to deliver a robust and fully automatic final solution to the image point correspondence determination.

The complexity and sensitivity of image point correspondence determination for hybrid measurement is influenced by factors including network geometry, the number of images captured and to some extent the quality of imagery, including resolution & illumination.

4. MANUAL AND SEMI-AUTOMATIC PROCEDURES FOR HYBRID MEASUREMENT SCENARIOS

As mentioned, one of the primary motivations for the hybrid measurement approach is to facilitate the measurement of untargeted features within images forming the network. Once automatic network orientation and optional image point correspondence determination have taken place, ancillary manual and semi-automatic procedures can begin.

For manual point measurement, once a single measurement has been indicated within an image during interactive feature extraction, operator assisted measurement need only extend to projection of the corresponding epipolar line into other images. After the point's 3D position is determined from two images, its predicted position can be back-projected into all other images, to aid the operator in the manual identification of homologous points. The target location prediction is considerably enhanced in cases where either the camera has been pre-calibrated, or self-calibrated in the automatic network orientation phase. This process can be extended to the measurement of lines and polygons in the *iWitnessPRO* system. The successful measurement of untargeted features within an image network is clearly a function of the quality of the network orientation.

During the bundle adjustment procedure, it is required that the observational error detection take into account the anticipated five-fold or so difference in precision for the image coordinate

observations of targeted versus untargeted points, the former being of 0.1 pixel accuracy or better and the latter generally between 0.3 and 1 pixel accuracy. The majority of manually digitized points will be rejected, unless the error cutoff in the bundle adjustment accounts for this difference in precision.

It is widely recognised that automatic, full-scene 3D surface extraction via image matching is rarely feasible in close-range photogrammetry in situations where the objects and scenes are well distributed over three dimensions. The hybrid measurement approach, however, offers the prospect of a viable semi-automated approach, where the required initial model segmentation into surfaces amenable to measurement via feature- and area-based matching becomes an interactive operation. The process of surface generation is initiated by the operator interactively marking the surface area to be generated, as indicated in Figure 2a. Feature point detection can then occur in either all or selected images that 'see' the surface. This is followed by image point correspondence determination to effect multi-image feature-based matching, there being 13 images in this case. The resulting surface, which comprises 4000 points, is displayed in Figure 2b. Subsequent refinement by area-based matching is also a prospect when network geometry and image texture are suitable. However, the computational cost of least-squares matching, for example, can deprive the process of the timeliness needed for interactive operation.
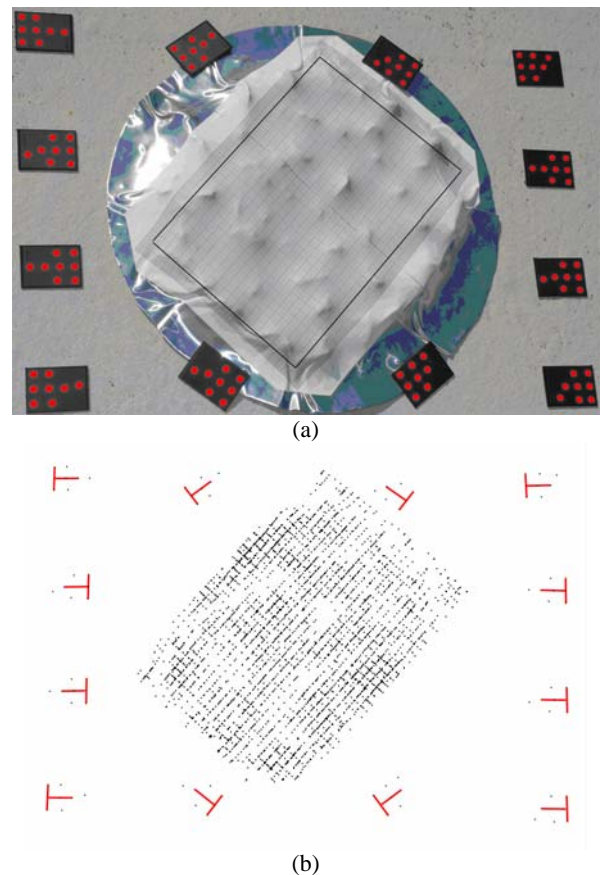

(a)

(b)

Figure 2. Surface measurement: (a) Surface area to be modelled, and (b) extracted surface points.

5. EXAMPLE HYBRID MEASUREMENT SCENARIOS

5.1 Stairway Measurement

Hybrid measurement is particularly suitable for carrying out 3D reverse engineering of stairways for stairlift design, fabrication

and installation. The physical structure of stairways can range from typical straight-run examples, to quite complex, curved, multi-level structures that can even double or triple back on themselves. All stairways present a geometrical challenge for photogrammetry, due to the narrow fields of view and obvious physical constraints that are placed on possible imaging locations.

Traditional automated photogrammetric techniques using white retro targets and highly controlled image exposure are generally not suitable for stairway measurement. Firstly, it is near-impossible to place targets exactly on the points and features of interest, such as straight line edges of stair intersections; risers, which are the vertical portions of each step; and winders, which are steps narrower on one side to facilitate a change of direction in a stairway. Hybrid measurement helps by allowing automatic network orientation via the use of coded targets, and then the subsequent manual and semi-automatic measurement of important stair features in the normally exposed imagery. The stairway will still be clearly visible in each photograph, allowing the user to see and therefore measure the necessary elements. This is illustrated in Figure 3. In the left image, the photogrammetric network is shown, with approximately 30 images and 40 coded targets, measured fully automatically. The right image shows examples of the manual measurement that has taken place, including points at the intersection of each step and the walls either side, and also some semi-automatic measurement, including scale bars, lines to represent each step, and 'stair-plates' which are linked to a user-defined database for ease of implementation.

In a hybrid measurement context, verifiable accuracies of about 1:50,000 have been achieved for the automatic component of stairway measurement, using a 12 megapixel Nikon D200 with fixed-focus 18mm lens. Achievable accuracy levels for manually measured untargeted features are roughly an order of magnitude lower, yet certainly fall within the required tolerance for stairlift design and installation.
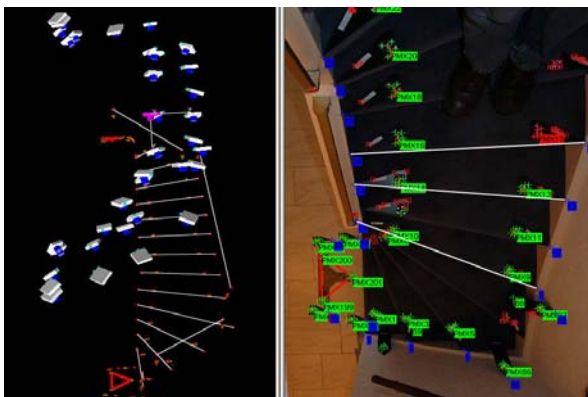

Figure 3. Hybrid measurement of a stairway for lift installation.

5.2 Vehicle Crush Measurement

Another application particularly suited to hybrid measurement is the accurate reconstruction of traffic accidents, and especially the measurement of damaged vehicles. Normally exposed images are required so that the operator can manually digitize unsignalized features, which typically constitute the primary features of interest, such as skid marks; debris on the road; surrounding buildings; traffic signs; road markings, and so on.

Operator-assisted surface extraction may also assist in vehicle 'crush' analysis. The number of image stations illustrated in Figures 4a highlights the need for fully automatic network orientation, while the abundance of natural features to be measured, including the curves shown in Figure 4b, illustrates the need for well exposed imagery. This is not generally conducive to automatic image scanning and multi-image orientation as it places an extra burden on these processes in terms of complexity and required computation time.
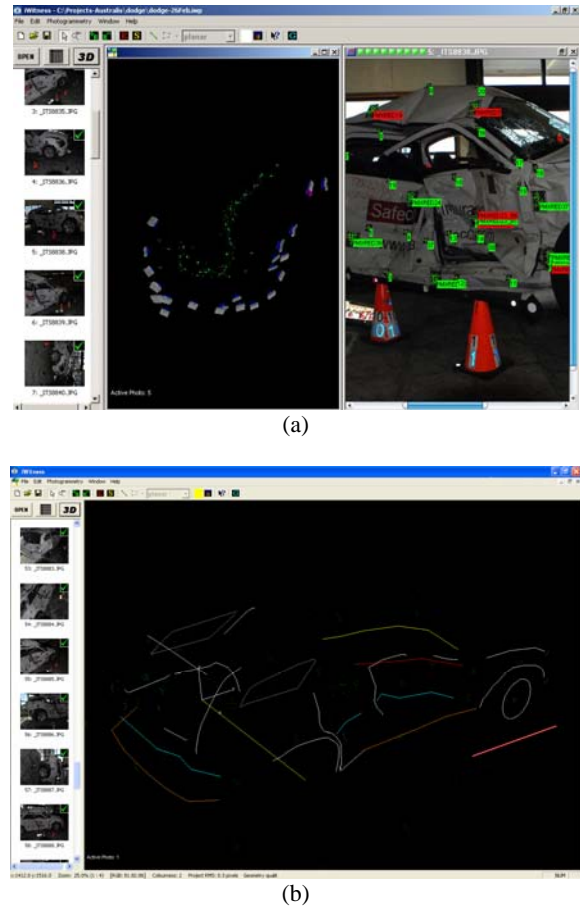

(a)

(b)

Figure 4. Vehicle crush measurement, illustrating: (a) automatic orientation and (b) manual feature dimensioning.

6. CONCLUDING REMARKS

There are a growing number of photogrammetric measurement tasks which can substantially benefit from fully automatic network orientation and 3D target point determination, coupled with the ability for subsequent semi-automatic and manual feature extraction from normally exposed imagery. The authors have dubbed this all-encompassing approach 'hybrid measurement'. Potential users include law enforcement agencies performing traffic accident reconstruction and forensic or crime scene measurement, architects interested in modelling buildings for which no CAD models exist, and ship building companies.

The practical developments of hybrid measurement reported in this paper, namely the adoption of red retro-reflective targeting; the new system of coded-targets, fully automatic network orientation and image point correspondence determination, as

well as subsequent manual operations, have all been successfully implemented in the new *iWitnessPRO* software system (Photometrix, 2008).

REFERENCES

Cronk, S., 2007. Automated Methods in Digital Close-Range Photogrammetry. *Thesis (PhD)*, Department of Geomatics, University of Melbourne, Australia, 142pp. Record ID 41969442, National Library of Australia.

Cronk, S., Fraser, C.S., Hanley, H.B., 2006. Automated Metric Calibration of Colour Digital Cameras. *Photogrammetric Record*, Vol. 21, No. 116, pp 355-372.

Fraser, C.S., Cronk S., 2007. Automated Close-Range Photogrammetry: Accommodation of Non-Controlled Measurement Environments. *Optical 3D Measurements*, VIII, (Gruen, A./Kahmen, H., Eds), Zurich, Switzerland, Vol. 1, pp. 49-55.

Fraser, C.S., Hanley, H.B., Cronk, S., 2005. Close-Range Photogrammetry for Accident Reconstruction. *Optical 3D Measurements*, VII, (Gruen, A./Kahmen, H., Eds), Tech. Univ. of Vienna, Vol. 2, pp. 115-123.

Ganci, G., Handley, H.B., 1998. Automation in Video-grammetry. *International Archives of Photogrammetry & Remote Sensing.* Hakodate, 32(5), pp. 53-59.

Luhmann, T., Robson, S., Kyle, S., Harley, I., 2006. *Close Range Photogrammetry: Principles, Methods and Applications.* Whittles, Scotland, 510 pages.

Otepka, J.O., Hanley, H.B., Fraser, C.S., 2002. Algorithm Developments for Automated Off-Line Vision Metrology. *International Archives of Photogrammetry and Remote Sensing*. 5(34), pp. 60-67.

Photometrix, 2008. http://www.photometrix.com.au [accessed 26th April 2008]