CLOSE-RANGE PHOTOGRAMMETRY IN TRAFFIC INCIDENT MANAGEMENT

Clive Fraser [a], Simon Cronk [a], Harry Hanley [b]

[a] Dept. of Geomatics, University of Melbourne, Vic 3010, Australia -(c.fraser, cronks)@unimelb.edu.au
[b] Geodetic Systems Inc., Melbourne, Florida, USA -harry.hanley@gmail.com

Commission V, WG V/1

KEY WORDS: Accident Reconstruction, On-Line Processing, Automated Close-Range Photogrammetry, Camera Calibration

ABSTRACT:

As a component of the overall traffic incident management process, 3D measurement for accident reconstruction has gained increasing importance over recent years. Digital close-range photogrammetry displays many attributes which make it a well-suited technology for this purpose. However, traditional close-range photogrammetric approaches can pose difficulties. These include the predominance of near-planar networks of generally very poor geometry that can complicate relative orientation; the economic and practical imperative of utilising inexpensive, non-metric consumer-grade cameras; and the need for the image recording and data processing phases to be carried out by non-photogrammetrists, indeed generally by police officers. This paper overviews recent developments undertaken to enhance the applicability of close-range photogrammetry and consumer-grade digital cameras to accident reconstruction. These include the implementation of robust on-line image orientation; a method for automatic camera calibration, which employs colour coded targets; and the adoption of a highly automated data processing workflow that exhibits maximum ease of use. These developments are exemplified through reference to both the *iWitness* and *iWitnessPRO* systems for close-range photogrammetry.

1. INTRODUCTION

Traffic incidents, including vehicle breakdowns, spilled loads, crashes, failure of critical infrastructure and natural disasters, affect human safety and add significant cost to the community, especially in terms of disruption to normal travel. Road infrastructure is reaching critical capacity and traffic congestion due to incidents is expected to increase rapidly in the near future. As a result, traffic incidents pose considerable challenges for both government agencies and road users alike. One of the ways to reduce the adverse consequences of traffic incidents is through fast and comprehensive dimensional recording of incident scenes for later forensic analysis and legal purposes; the goal being to minimise traffic disruption times.

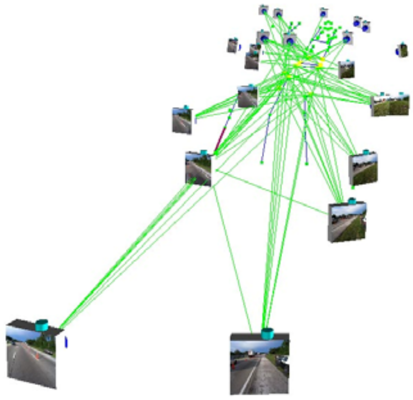
Dimensional characterisation of an incident is critical for a number of reasons, but primarily to provide evidence in any subsequent legal proceedings and to analyse the dynamics of the collision event(s), for example vehicle speed determination. The measurement data collected must be sufficiently comprehensive to allow post-examination of the event, which may occur several months later, but the immediate imperative is to gather the spatial information data as quickly as possible so as to minimize road clearance times. A technology that has recently found application in traffic incident reconstruction and forensic measurement is digital close-range photogrammetry (Fraser et al., 2005; Fraser, 2006). Inexpensive consumer-grade digital cameras are employed and the data acquisition phase (actual photography) is extremely fast. Captured imagery also provides an irrefutable and permanent visual record of the scene, and can be archived for later analysis and investigation.

The image that forms Figure 1a is from the network shown in Figure 1b. The camera station configuration, which was spread over 100 metres, was used to produce 3D data from which the 2D top-down ‘diagramming’ of the incident was carried out, as indicated in Figure 1c. The perspective view shown in Figure 1d is generated from a rendering of the 3D model, using Crash Zone (Cad Zone, 2008). It is noteworthy that limited sophistication is usually required in accident reconstruction, where the aim is generally to obtain a dimensionally accurate 2D or 3D representation of the scene, rather than a comprehensively rendered or textured model.

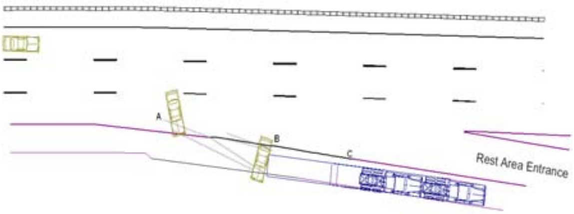
Over recent years, total stations and even laser scanners have been employed for incident scene dimensioning. These technologies can produce more accurate, and in the case of laser scanners, more comprehensive 3D models, but data acquisition at the scene is slow compared to the photogrammetric approach. Moreover, total stations and laser scanners are relatively expensive and complex for local police and traffic agencies to use, particularly in terms of on-scene set up requirements and subsequent data handling. Photogrammetry, on the other hand, provides a major advantage in terms of data acquisition speed, and is an easy-to-use, accurate and reliable measurement tool that incorporates a reasonable degree of process automation.

In order to illustrate some of the concepts involved in photogrammetric documentation of accident scenes, reference will be made in this paper to the *iWitness* software system (Photometrix, 2008). This close-range photogrammetry system has been designed for the non-specialist user and its primary application domain is accident reconstruction and forensic measurement, where it is now widely 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. *iWitnessPRO* is a newer and more sophisticated version of the classic *iWitness* system. It provides a much higher level of automation in network orientation through the use of coloured retro-reflective coded targets (Photometrix, 2008).

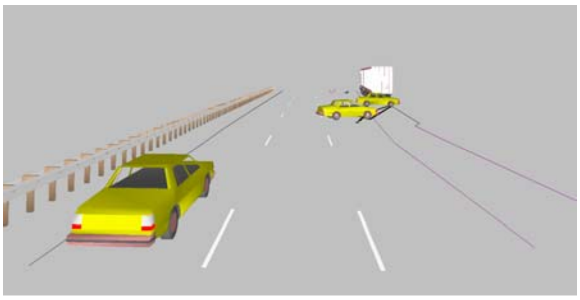
(a) Image recording



(b) Network of images



(c) CAD Model



(d) 3D reconstruction

Figure 1. Photogrammetric reconstruction of traffic incidents.

This short paper reports upon innovations in the photogrammetric recording and 3D documentation of traffic incident scenes through reference to the *iWitness* system. It highlights developments that have been necessary to ensure that photogrammetry is user-friendly for non-specialist operators such as traffic police. The developments discussed include a newly adopted paradigm for image measurement and photogrammetric processing, centred upon fully automatic camera calibration; automated on-line processing; automatic recognition of the camera(s) used for the imagery; and extensive operator assistance as exemplified by a guided point referencing mode and interactive quality review. The high level of automation has been achieved through the use of specialised targeting strategies, notably evidence markers placed on features of interest.

2. THE NETWORK GEOMETRY PROBLEM

A significant problem facing those who wish to apply photogrammetry to accident reconstruction is that, by and large, all feature points of interest tend to have a near-planar distribution, the majority being on or near the road surface. These long and thin, near-planar object point arrays constitute an undesirable geometric configuration for close-range photogrammetry, especially when the network spans a height range of only a few metres and a horizontal length of greater than 50m. As illustrated in Figure 2, which shows the same network as Figure 1, the camera stations also lie close to the same plane. This situation is typical, and constitutes a rather ill-posed mathematical problem, namely the recovery of 3D network orientation from an essentially 2D array of camera stations and object points. For the photogrammetric measurement to be successful, network orientation needs to be accomplished in the absence of control point information. This necessitates an initial relative orientation (RO) between any two selected images, followed by a sequential on-line building of the network via spatial resection and forward intersection, in turn followed by photogrammetric bundle adjustment (Ganci and Handley, 1998; Cronk, 2007). In the case of *iWitness*, these necessary stages occur automatically when enough points have been measured.

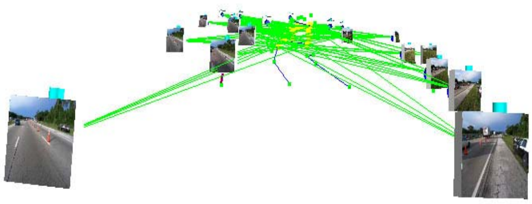


Figure 2. A view of an unfavourable, yet typical network geometry encountered in accident reconstruction.

The problems associated with poor geometry are alleviated to some extent via the use of special targeting schemes, the most common being back-to-back targets, referred to as evidence markers. These targets, which are shown in Figure 3, can be sighted from opposite directions and they can be semi-automatically measured in *iWitness* via an operator-assisted centroiding function. The near-planar object point distribution can be overcome by placing some of the markers at higher locations, such as on the vehicles involved, on traffic cones or even on tripods. However, the fact remains, that from a photogrammetric perspective, the most challenging phase of accident reconstruction is the network orientation. Coupled with the typically highly-convergent imagery are object point geometries generally unsuitable for RO and spatial resection. Innovative orientation procedures have been developed to handle this problem, and these have been successfully implemented in the *iWitness* and *iWitnessPRO* systems (Photometrix, 2008).

Figure 3. 'Evidence markers' placed on features of interest, note the large letters for easy identification.

3. ON-LINE PHOTOGRAMMETRIC PROCESSING

There are basically two different mathematical models used for sensor orientation: RO, based on the photogrammetric coplanarity condition; and the collinearity equations, which are essential for spatial resection, exterior orientation (EO), forward intersection (point triangulation) and multi-image bundle adjustment, with or without camera self-calibration. Both models are parametric and are solved in their linearized form via an iterative least-squares adjustment of initial parameter values. In the on-line computational process of *iWitness*, where the bundle adjustment is updated every time a new observation is made, it is imperative that the initial EO parameters are determined with sufficient accuracy to ensure solution convergence.

Two approaches have traditionally been adopted for the determination of preliminary exterior orientation. The first of these involves the use of object space control points; with known or assigned XYZ coordinate values. Nowadays, the use of EO devices is popular in industrial vision metrology systems as a practical means of providing the necessary 3D control points for automated initial EO. A second approach, which has not been widely adopted, is initial RO. The attractiveness of RO is simply that it requires absolutely no object space coordinate data. Moreover, it is well suited to image measurement scenarios where conjugate points are 'referenced' between two images, point by point, as is the case with the *iWitness* system (Photometrix, 2008).

It is well known that for a given image pair, a minimum of five referenced points are required to solve for the unknown parameters in a dependent RO via the coplanarity model (Mikhail et al., 2001). For convergent imaging geometry, good initial parameter approximations are again required to ensure convergence of the RO solution. This can be achieved using a Monte Carlo style approach, whereby a large number of plausible combinations are assessed for the available conjugate image points (Cronk et al., 2006; Cronk, 2007). This method involves establishing the first camera station at the origin of the object space coordinate system with orientation coincident with the three major axes. The second camera station's EO is then simulated at varying locations on an imaginary sphere (with arbitrary radius) around the first station. The simulated position for the second camera station is more critical than its simulated orientation, in fact, as long as it is 'looking the same way' as the first camera station, this is generally sufficient. Each set of fictitious EO parameters provides approximate values to the RO, which is solved via least squares. The RO with the lowest RMSE after convergence is taken as the real solution. One further check is to perform the RO with five conjugate points and then again with six conjugate points (and so on). Then, if the result of both ROs is essentially the same, it has assuredly been successful. After intial RO, third and subsequent images are introduced into the photogrammetric network via spatial resection from referenced points in the image overlap areas, calculated in 3D using point triangulation. Bundle adjustments should be run periodically to ensure the network is up-to-date and this also provides the means to automatically determine blunders in image point measurement. Optional post-bundle 3D network transformation into the coordinate system of control points can also then take place.

4. *iWitness* AND *iWitnessPRO* OVERVIEWS

4.1 The *iWitness* System

This short overview of *iWitness* is presented to partially explain how the issues of difficult network geometry, on-line orientation and automatic camera calibration have been accommodated, and partly to give an indication of what other functions are needed in a photogrammetric system intended for accident reconstruction applications.

iWitness generates attributed point clouds, with the attributes primarily being lines which are preserved in the export of object coordinate data in DXF and/or KML formats. The system is designed to interface with CAD and modelling packages, the graphical user interface being shown in Figure 4. Some notable features are automatic recognition of the camera(s) used via information contained within the EXIF header of the JPEG imagery; fully automatic initiation of all computational functions (i.e. computations occur automatically in the background); and a point 'review mode', whereby it is possible to interactively review and adjust any necessary image observations. Semi-automatic image point measurement of artificial and even some natural targets via centroiding to an accuracy of up to 0.05 pixels is also available, as is the ability to plot free-form polylines from both homologous and non-homologous image points. As an aid to visualisation, photo-realistic texturing of planar facets in the 3D model is also supported.

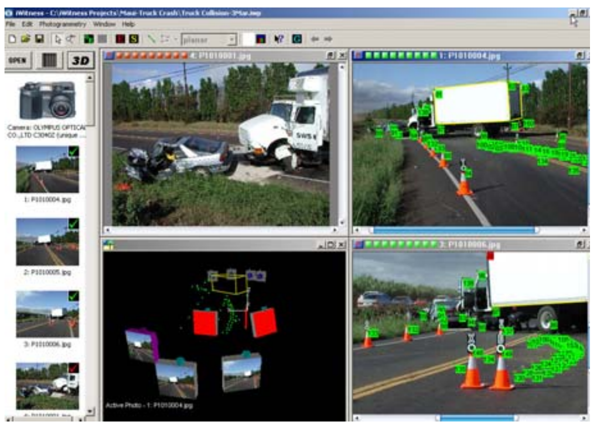


Figure 4. *iWitness* user interface.

iWitness also supports fully automatic camera calibration via the use of colour coded targets (Cronk et al., 2006), and can solve for any of the familiar camera parameters, including focal length, principal point offset, and radial and decentring distortion. This is a necessary requirement for consumer grade digital cameras to be used for photogrammetric measurement.

4.2 The *iWitnessPRO* System

The *iWitnessPRO* system incorporates all the developments of classic *iWitness*, with some other advantages (Fraser and Cronk, 2008; Photometrix, 2008). Firstly, it employs coloured retro-reflective targeting material, as opposed to the reflectively passive targeting material for classic *iWitness*. The choice of colour is red, in preference to green or blue, as red is the least naturally occurring colour in typical imagery. It supports a larger number of coded target combinations, which are used for fully automatic network orientation, one of *iWitnessPRO's* defining features. Finally, *iWitnessPRO* supports automatic image point correspondence determination and thus 3D measurement of single targeted non-code points. For traffic incident measurement, the automatic network orientation feature of *iWitnessPRO* is certainly invaluable, because, as previously mentioned, network orientation is normally the most challenging phase.

5. CONCLUDING REMARKS

The main aim of traffic incident measurement is to reconstruct motor vehicle collision scenes. Whether the final requirements of the process are to assist in calculations, such as vehicle speed; to analyse the dynamics of the collision event; to provide evidence in a subsequent court case; or for some other purpose, the essential first step is to accurately characterise the dimensions of the accident scene.

The most attractive attributes of the photogrammetric approach to accident reconstruction are that the scene can be recorded in a very short time and that the imagery provides a permanent archival record that will support further measurement after the accident. Inexpensive, consumer-grade digital cameras are all that are needed, and these can be automatically calibrated using the *iWitness* and *iWitnessPRO* systems (Photometrix, 2008). This user-friendly photogrammetric technology - as distinct from the skill intensive processes of traditional stereo photogrammetry - is now employed routinely for accident reconstruction, especially within the highway patrols of US states (DeChant, 2008), and the recent release of *iWitnessPRO* will further improve the applicability of close-range photogrammetry for traffic incident management.

REFERENCES

CAD Zone, 2008. http://www.cadzone.com [Web site accessed April 29th, 2008].

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

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

DeChant Consulting Services – DCS Inc., 2008. http://www.photomeasure.com [Web site accessed April 29th, 2008].

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

Fraser, C.S. 2006. Accident Reconstruction via, Digital Close-Range Photogrammetry. ASPRS Annual Conference Reno, Nevada, USA.

Fraser, C.S. and Cronk, S., 2008. A Hybrid Measurement Approach for Close-Range Photogrammetry. *Submitted to ISPRS Journal of Photogrammetry & Remote Sensing*, March.

Ganci, G. and Handley, H.B., 1998. Automation in Videogrammetry. International Archives of Photogrammetry and Remote Sensing, Vol. 32, No. 5, pp. 53-58.

Mikhail, E.M., Bethel, J. and McGlone, J.C., 2001. Introduction to Modern Photogrammetry. John Wiley and Sons, Inc., 479 pages.

Photometrix Pty. Ltd., 2008. http://www.photometrix.com.au [Accessed April 29th, 2008].