A LASER SCANNING VIDEOTHEODOLITE FOR 3D VISUALISATION AND METROLOGY

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ABSTRACT: This paper presents a novel terrestrial survey system that is developed to be used for collecting three dimensional data and images of the surrounding environment for the purposes of visualisation and metrology. The system is the product of integration of a motorised theodolite, a zoomable CCD camera and a laser range finder. The laser rotates with the theodolite and determines three dimensional coordinates of points using the bearing and distance principle. The camera provide visual interactive guide for the laser scanning operation and also captures images to be used for image-based rendering and, where necessary, stereo photogrammetric measurement. The paper gives details on the system configuration, calibration, 3D modelling, rendering and a quarry application module of the system.

1. INTRODUCTION

A variety of survey techniques are used to collect data for 3D modelling. The most outstanding ones are digital photogrammetry and laser scanning. The former has the unique advantage of providing image information for lifelike rendering whereas the latter provides direct 3D data with the extent of automation and reliability that the former will struggle to match for a few more years to come. The combination of the two techniques provides the best of both worlds and potentially more. Such combined systems have recently emerged for airborne platforms demonstrating huge potential. For terrestrial survey, this paper will present such a system, which combines a motorised theodolite (a precise pan-tilt device), a reflectorless laser range finder and a zoom lens CCD camera.

The system with patent applied is the subject of a joint project undertaken by University of East London and Measurement Devices Ltd. The aim of the project is to fully exploit the concept of laser, camera and theodolite combination for various terrestrial-surveying applications. The system developed is designed to provide a surveying tool that eases the territorial surveying and exhibits virtually the territory realistically and informatively. It will be a useful means for environmental planning, production of 3D games and films, quarry 3D face modelling, architectural preservation and reconstruction etc (Huang, 1998). The paper will first give detailed system architecture. It then focus on topics of system calibration, data acquisition, modelling, visualisation and customisation for one of the targeted applications - quarry survey.

2. SYSTEM CONFIGURATION

A zoom lens CCD camera and a laser reflectorless range finder are mounted on a motorised theodolite so that they can pan and tilt panoramically as shown in Fig.1. The zoom CCD camera used in the system is Sony EVI-371, which is designed for use in camcorders. The CCD chip is a 1/3 inch interline transfer chip with 752×582 image cells and the cell size is about 6.5(H)×6.25(V) microns. The lens can zoom from 5.4 to 64.2mm focal length in 12 optical settings. The frame grabber used for the system is creative Blaster IE500 imaging card. It digitises both fields of the composite video input and generates a digital image. The zoom lens and the focal length of the camera can be controlled by a desktop or laptop computer. Live image from the camera can be shown in real-time on the computer screen. The wide angle focal setting is mainly used for capturing image for image indexing and user interfacing purposing, and long focal settings are used for measurement and rendering purposes.

The laser and theodolite used in the system are based on an existing product – Quarryman ALS (Autoscanning

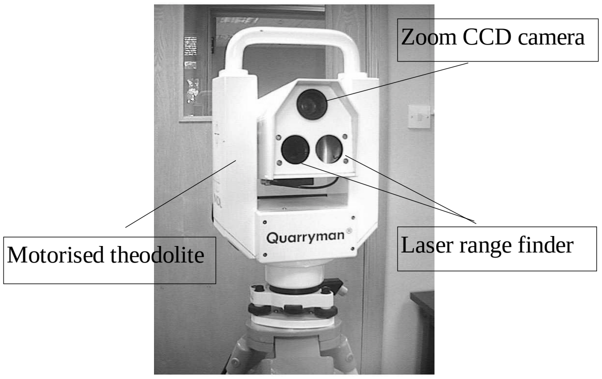


Fig.1 Configuration of a laser scanning videotheodolite

Laser System) originally designed for rock profiling and scanning. The laser range finder, the horizontal and vertical positions of the theodolite can be controlled by the computer via a RS232 port. At the same time, range, horizontal and vertical angles can be received by the computer. A control program has been comprehensively implemented to enable the operator to control the instrument and the camera from the computer.

3. CALIBRATION OF THE CAMERA

The automatic calibration of the interior parameters and the exterior parameters of the camera is one of the fundamental tasks for the development of the system. The calibration precision determines the accuracy of the measurement and the realisticity of 3D rendering on the computer screen. The calibration includes three interior parameters and six camera-to-theodolite parameters at various focus settings within the range of zoom.

A rigorous and precise calibration based on the camera-on-theodolite calibration method(Huang 1990, 1999) was implemented for the manufacturer's use. The method uses two artificial targets and is not yet fully automated.

In order for the user to easily conduct the calibration on site, a simple, fully automatic but less precise method was designed and programmed. It is mainly for calibration of the principal point and the principal distance by using image-processing techniques.

1.1 The Principal Point

It is assumed that the optical axis of the camera is straight so that the principal point for all zoom lenses falls at one point on the image. When the camera zooms in, the targets on the image move towards the centre of the image. The intersection of all target paths, while zooming, is considered as the principal point. The control program was implemented to enable the operator to click targets while zooming in and out. The computer calculates the average of the intersections of all target paths, which is considered as the principal point. The principal point needs to be calibrated several times and the average is taken. For the current camera used in the system, the principal point is at (3.1, 13.0) from the centre of the image (y downward is positive) with image size (800×600).

1.2 The Principal Distance

The principal distance varies with zoom lenses. At each zoom position, the calibration starts with pointing the camera/theodolite so that the central part of the image is filled with featured scene. This central part of image is shown in Fig. 2 as a rectangle and it is called the interest image in the paper. The angular readings of the theodolite are recorded in the mean time. A pixel with the most unique surrounding features within the interest image is chosen as the target point and its image coordinates are recorded. Normally this point has the most features and relatively easy to be matched. The theodolite is then rotated to 5 positions along four directions: left, right, up and down. At each position, a corresponding image is grabbed and the angular settings of the theodolite are recorded. The interest image is moved to enclose the moved target point by best estimate from previous calibration data. The target point is then searched and located with sub-pixel precision by area based matching techniques. A very strict check including back matching etc is performed to discard some unreliable matchings. If both horizontal and vertical directions have 4 matches discarded, re-calibration is suggested. At least 7 sets of locations of the target (including the initial target location) with respect to the angular settings of the theodolite can be obtained along the horizontal and vertical directions. Consider the horizontal direction, the following relationship between the target location and the horizontal angle exists (Wolf, 1983):

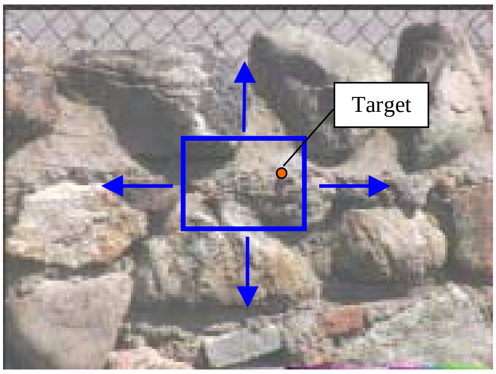


Fig .2 The target and The principle image

$$x - x_0 = f \tan(\theta - \theta_0) \qquad (1)$$

where

x ---- target location in x direction,

x_0 ---- Initial location of the target in x direction,

f ---- Principal distance in pixels

θ ---- Horizontal angle of the theodolite

θ_0 ---- Initial horizontal angle of the theodolite associated with x_0

x_0, θ_0 and f are unknown. A set of x and θ have been recorded. The least squares method is used to fit the equation (1) to solve x_0, θ_0 and f . Because the value of f (the principal distance in pixels) depends on the image dimension, the horizontal view angle θ_H is calculated and stored instead,

$$\theta_H = 2\tan^{-1}\left(\frac{HR}{2f}\right) \qquad (2)$$

where HR is the horizontal dimension of the digital image in pixels. The horizontal view angle can also be obtained from the calculation of the vertical direction. If the calibration results for both horizontal and vertical directions are valid, the average value is taken. A further check on the reliability of the matching can be conducted on the basis of the least squares solution.

Table1 shows some results of calibration carried out during the research. Each value has been calibrated three or four times and the average value is calculated. It compares the view angles with those values provided by the manufacturer. The comparison indicates that the specification provided by the manufacturer is far from the use in the digital photogrammetry.

Table 1 Horizontal view angles of the camera

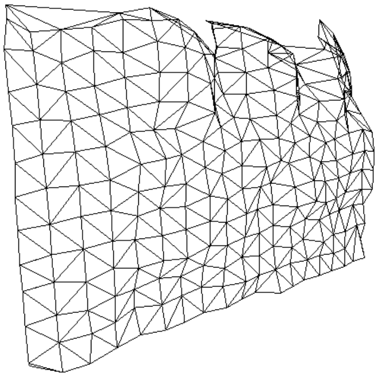
Zoom lens	Horizontal view angle(°)	
	manufacturer	Values calibrated
1	48.0	47.08
2	40.0	40.779
3	34.4	34.807
4	28.7	29.095
5	23.3	23.846
6	18.8	19.051
7	14.9	14.823
8	11.2	11.234
9	8.4	8.275
10	6.2	6.043
11	4.6	4.321
12	4.5	4.283

This calibration method can be conducted automatically without the need of setting special targets, which enables the user to carry out the procedure at any time necessary. It is designed for regular instrument check-up purpose. The automation without the set of targets greatly reduces the cost of the calibration and considerably increases the ease of the use of the calibration utility.

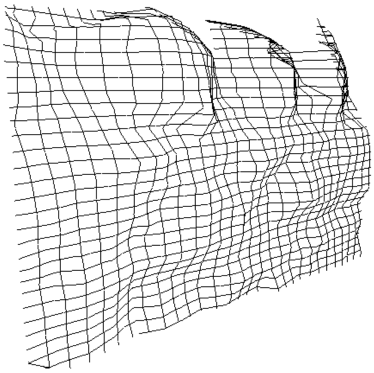
4. GENERATION OF 3D MODELS

An algorithm was developed to detect the laser spot on the live image when firing the laser by considering the offset of the laser and the camera optical axis and the calibration result. A method of calculating the angular settings of the theodolite from pixel co-ordinates on the image was derived. That means whenever the operator clicks one point on the computer screen, the theodolite can pan and tilt to shoot the target clicked. An algorithm was also developed to find the laser spot associated with a specific image. Those algorithms enable the operator to define an irregular polygonal area to be scanned by using mouse (Fig.3a). Internal points are generated by the computer according to the scanning density defined. The instrument will automatically carry out the scanning procedure, grab the image, and collect 3D data with corresponding location on the grabbed image. Algorithms and programs were also developed for the construction of a triangulated irregular network (TIN) model from the collected 3D points. This model can accept randomly scattered points and an irregular polygonal scanning area with convex or concave boundary. The 3D triangular wireframe model of an example scanned together with an interpolated orthogonal wireframe are shown in perspective projection in Fig.3(b) and (c).

(a)



(b)



(c)

Fig.3 Generation of 3D models (a) Definition of an irregular polygon by clicking mouse
(b) Triangular wireframe (c) Orthogonal wireframe

5. VISUALISATION OF 3D SCENES

For each 3D scanned point, the 3D co-ordinates and the location of the point on the grabbed image are recorded, and saved in a file for off-line visualisation. The grabbed image, at the same time, is saved as a bitmap file format. The off-line visualisation program reads the data set together with the bitmap image file to generate the 3D triangulated model, wrap the real image on the wireframe. The OpenGL utility is used to provide fast texture mapping and rendering. The off-line visualisation has been implemented to visualise 3D scenes in variable ways such as wireframe, false colour image with Gauroud shading, and real image wrapping etc. The visualisation package has made it possible to edit or delete interactively some false points such as those shot in windows or in the air. The 3D image with real photo wrapping greatly enhanced the visual effect and enables the 3D scene to be presented vividly on the computer screen. The 3D-object model can be viewed from different directions just by roaming the mouse. Fig.4 shows the same example with 3D real image from two view angles;

the 3D model is, however, much more attractive on a computer screen than on these prints. In addition to the visualisation functions, the fully programmed package enables the operator to manipulate the image and extract useful information. For example, the horizontal and vertical profiles passing through any point, any directional profiles passing through any two points defined by clicking mouse can be drawn quickly in 2D and 3D with or without image. Contour maps, slope distribution with colour indication, range distribution and depth colour map etc. can be quickly displayed on the computer screen.

Fig .4 3D model viewed from different locations

6. APPLICATION OF THE SYSTEM IN QUARRY SITES

The first application of the system has been successfully made in a quarry site for rocking and scanning, which is considered as an aid to “Flyrock” control during blast. The system has been customised to facilitate computer interactive borehole design. The rock surface to be blasted is first scanned by the laser and imaged by the camera. A photo realistic 3D model is then generated and displayed on the computer screen, which can be manipulated interactively in a 3D manner with 3D coordinates of the cursor shown in real-time. The borehole parameters including positions, depths, angles, intervals, designed burden etc. can be input via the keyboard or the mouse. The burden distribution is then computed and shown as colour map for assessment as in Fig. 5(d). The burden shown in green colour is on par with the designed, in red is under and in blue is over. Querries can be made for parameters such as the minimum and maximum burdens, the area of each cross-section (the area between a borehole and the corresponding profile), and the volume of the whole blasting area. Relative position of the boreholes to the 3D-quarry face can be

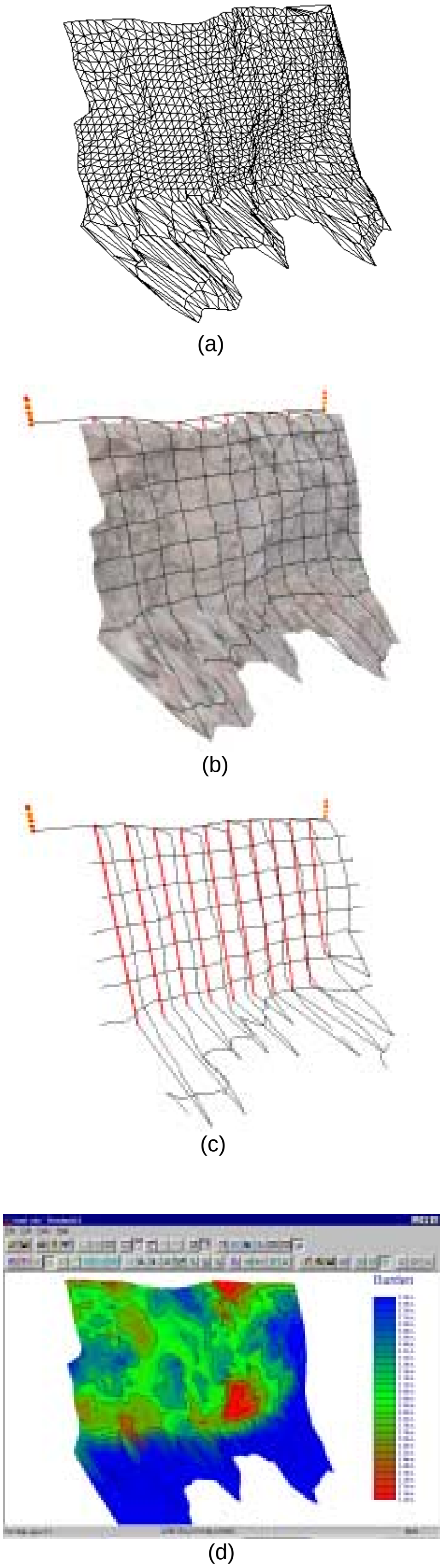


Fig .5 Application in a quarry site (a) Wireframe, (b) Horizontal and vertical and profiles with image superimposing, (c) Boreholes, horizontal and vertical profiles, (d) Burden colour map vividly presented in the 3D space. The burden colour map of a quarry face provides a useful means of assessment for the design of boreholes for the user. The application of the system in quarry sites helps not only control blasting costs and efficiency, but also maintain the safety of explosion. Fig 5 shows the images of various stages of the operation of the system.

7. CONCLUSIONS

The system developed in the joint project covered in this paper has exploited the great benefits of the combination of laser theodolite with videogrammetry. It has demonstrated a capability of providing direct 3D data as well as abundant image information for lifelike visualisation and precise metrology. Since it was put in test use, the system has been receiving much positive feedback from the quarry industry. Development for other application modules of the system is now underway. The full potential of this integratioin will continued to be exploited for visualisation and metrology.

8. ACKNOWLEDGEMENT

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