EXPLOITING THE CONTEMPORARY TOPCON IMAGING TOTAL STATION FOR CULTURAL HERITAGE RECORDING

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ABSTRACT:

The world's first total station to incorporate the very latest digital imaging technology to enhance Total Station fieldwork and extend the range of applications for the total station has been presented by Topcon just a few years ago. The implementation of imaging technology allows the image seen through the telescope to be viewed on the display screen of the instrument. This not only makes it easy to point the telescope to the required object for measurement, but instead of only the traditional map view of the surveyed points on the screen, you now see the measured points and lines appear on the real view of the area being measured. In addition you can now "Capture Reality" by storing the digital image along with the measurement data. In this paper the idea of photogrammetrically exploiting the images taken by this total station in conjunction to the recorded angles is thoroughly examined, as far as monoscopic images and plane objects is concerned for a start. An algorithm has been developed to produce rectified images without the need for any control points on the object. The implementation range and its limitations are examined and the results assessed for their accuracy

1. INTRODUCTION

1.1 A contemporary Photo-theodolite

Back in the analogue era of Photogrammetry various models of terrestrial metric cameras were available in the market. They were grouped mainly into single cameras, stereocameras and, of course, photo-theodolites. The purpose of the latter was to provide to the user exact information about the camera orientation, in order to facilitate the photogrammetric operations in the analogue instruments. It was a necessity for the terrestrial applications, as they presented special difficulties, as opposed to, more or less, straightforward aerial mapping.

Through the years this information became obsolete, as analytical procedures took over and the analogue instruments were gradually replaced by analytical -at first- and digital photogrammetric workstations (DPW) later. However information about the orientation of the digital camera is always useful, especially in the case of terrestrial applications, which still present the same difficulties as before. Hence the position and attitude of the digital camera is very often sought in terrestrial applications, mainly in order to serve as initial values for the photogrammetric computations.

The Topcon GPT 7000i Imaging total station, which appeared in the market about four years ago, incorporates a digital camera and offers the capability of recording its attitude, i.e. orientation angles, at any pointing direction. Although not boosted by the manufacturer, it is maintained that this revolutionary total station could be used as a modern version of a photo-theodolite. In the following the first investigations towards this exploitation are presented.

2. INSTRUMENT DESCRIPTION

During InterGEO 2004 in Stuttgart, Topcon unveiled a revolution in Surveying Instrumentation in the form of the GPT-7000i (Figure 1). This is the world's first Total station to incorporate the very latest digital imaging technology to enhance Total Station fieldwork and extend the range of applications for the total station. According to the manufacturers the implementation of imaging technology allows the image seen through the telescope to be viewed on the display screen of the instrument. This not only makes it easy to point the telescope to the required object for measurement, but instead of only the traditional map view of the surveyed points on the screen, the user now sees the measured points and lines appear on the real view of the area being measured. In addition one may now "Capture Reality" by storing the digital image along with the measurement data. However there is little reference to the metric exploitation of the digital images captured by the instrument (http://www.topconeurope.com).

Figure 1: The Topcon GPT 7000i Imaging total station

The **G**PT 7000i Series basic features include:
• Dual-view integrated CCD camera with 'wide and finder view'
• Windows CE.NET 4.2 operating system
• Extra-large QVGA LCD TFT colour display
• GUI (Graphical User Interface)
• Field images recorded with the field coordinate data
• TopSURV™ on-board data collection software
• Pinpoint reflectorless measuring up to 250m
• Single prism measuring up to 3000m
• By adding optional digital imaging software, like e.g. the Topcon PI3000, one can combine multiple job site photos and create 3D models and point clouds

Windows CE technology on the GPT-7000i imaging total station provides a bright graphic display, touch screen display, more functionality, better support for standard accessories like Bluetooth® wireless technology and more available software.

The instrument features two different digital cameras: One co-axial to the telescope, called finder view (f = 248.46mm), which records the details of the point measured each time, and a second one above the telescope axis, but within the same housing, called wide area view. The specifications of this latter camera are:

Image:	0.3M pixels CMOS Sensor
Number of effective pixels:	640 x 480 (VGA)
f :	8 mm
Digital zoom magnifications:	0.25, 0.5, 1.0, 2.0 x
Minimum focusing distance:	2 m

3. METHODOLOGY

3.1 Instrument Operation

While measuring points with the instrument, there are several options available to the user. Firstly, with each point recorded, the finder view camera acquires an image of the details around the recorded point. Optionally, the user may request the acquisition of an additional image with the wide area view camera. Depending on the distance of the object from the instrument, this latter image may be exploited for photogrammetric use. The first approach considered in this report, concerns the single image exploitation, i.e. the image rectification.

3.2 Image Rectification

Image rectification is a single-image photogrammetric process, which applies the projective transformation to images of planar objects, in order to produce orthogonal projections thereof. In the two dimensional image the third dimension "disappears" and the reversal of the process requires a second geometric locus of the point in 3D space (i.e. a second image in most cases). In the case of a two dimensional object, i.e. a planar object (like e.g. a building façade), there is no third dimension, hence the reversal of the process is possible using a single image. This process actually is a two dimensional projective transformation relating the two planes: The object and the image. This transformation is described as follows:

$$X = \frac{a_1 x + a_2 y + a_3}{a_7 x + a_8 y + 1} \quad Y = \frac{a_4 x + a_5 y + a_6}{a_7 x + a_8 y + 1}$$

where:

X, Y :	Co-ordinates on the object plane
x, y :	Co-ordinates on the image plane
$a_1 \div a_8$:	Projective transformation coefficients

Normally at least four points are required for the determination of the transformation parameters, with known co-ordinates in both planes (GCP's). However each transformation coefficient may be expressed with the help of the following parameters:

Xo, Yo, Zo :	The geodetic co-ordinates of the camera projection centre
xo, yo :	The principal point co-ordinates
c :	The camera constant
ω, φ, κ :	The basic rotations of the camera axis

It is obvious that a total station set-up over a point may provide part of the above information, i.e. the co-ordinates of the station point and the orientation of the telescope axis. Hence a methodology is sought to combine this available information with some additional image parameters (i.e. the co-ordinates of the principal point and the camera constant) in order to perform image rectification without the need for ground control points (GCP's).

3.3 Proposed methodology

The equations relating the eight coefficients of the projective transformation to the above parameters are (Kraus, 2003) :

$$a_1 = -\frac{X_o r_{13} - Z_o r_{11}}{x_o r_{13} + y_o r_{23} + c r_{33}} \quad a_2 = -\frac{X_o r_{23} - Z_o r_{21}}{x_o r_{13} + y_o r_{23} + c r_{33}}$$

$$a_3 = \frac{X_o (x_o r_{13} + y_o r_{23} + c r_{33}) - Z_o (x_o r_{11} + y_o r_{21} + c r_{31})}{x_o r_{13} + y_o r_{23} + c r_{33}}$$

$$a_4 = -\frac{Y_o r_{13} - Z_o r_{12}}{x_o r_{13} + y_o r_{23} + c r_{33}} \quad a_5 = -\frac{Y_o r_{23} - Z_o r_{22}}{x_o r_{13} + y_o r_{23} + c r_{33}}$$

$$a_6 = \frac{Y_o (x_o r_{13} + y_o r_{23} + c r_{33}) - Z_o (x_o r_{12} + y_o r_{22} + c r_{32})}{x_o r_{13} + y_o r_{23} + c r_{33}}$$

$$a_7 = -\frac{r_{13}}{x_o r_{13} + y_o r_{23} + c r_{33}} \quad a_8 = -\frac{r_{23}}{x_o r_{13} + y_o r_{23} + c r_{33}}$$

For these parameters to be determined analytically, camera calibration and total station orientation are needed, in order to establish exactly the position of the camera projection centre and the attitude of the camera axis in relation to the telescope axis and the position of the total station. Once these parameters are computed, the transformation between the two systems will be established and, consequently, any point measured on the image could be transformed to the geodetic system on the plane. The only presupposition is that the geodetic system should be defined on the planar object (Figure 2).

The above transformation may be executed for each pixel on the initial image. Thus the result will be a rectified image of the planar object, which obviously is an orthogonal projection.

3.4 Camera Calibration

For the determination of the interior orientation parameters of the camera of the image station, but also for the determination of the exact position of the camera's projection centre in relation to the total station's centre a standard camera calibration procedure was employed.

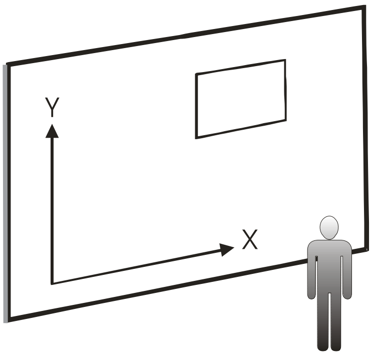

Figure 2: The geodetic reference system in the plane object

For this purpose several images of the indoor test field of the Metrology Centre of NTUA (Figure 3) were taken by the image station's camera. At the same time the exact position of the total station was determined with the help of a Leica TC 5005 theodolite with high accuracy.

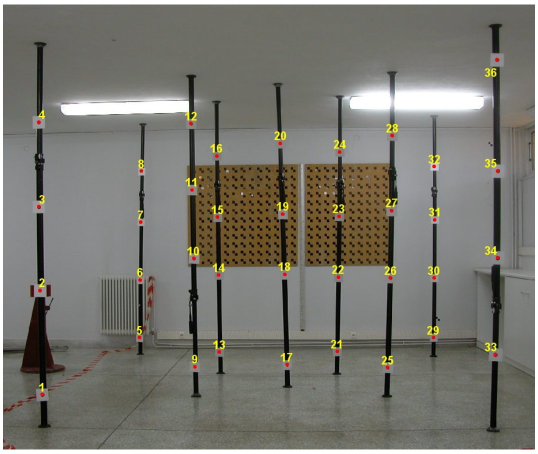

Figure 3: The indoor test field

A suitable camera calibration own developed software was employed. It actually performs a self calibrating bundle adjustment, thus determining both the exterior and interior orientation parameters of the camera. The calibration results are summarized in Table 1.

Principal point			
xo (pixel)	yo (pixel)	xo (mm)	yo (mm)
319,682	220,736	1,790	1,236

Camera constant		
c (pixel)	c (mm)	Nominal value (mm)
1430,485	8,010716	8

In addition, the calculations proved that the camera projection centre is located 45.2mm vertically above and 48.932mm to the front of the point of intersection of the main instrument axes. This is also indirectly verified by the manufacturer's brochure.

3.5 Direct Rectification

A first approach for acquiring a rectified image with the imaging total station is the following: Provided a planar object is being measured, the imaging station's telescope, and hence the incorporated camera may be oriented in such a way that its axis is perpendicular to the object's main plane. This may be achieved by calculating the plane's azimuth and calculating accordingly the value of the horizontal angle of the telescope. In this way a directly "rectified" image of the object is acquired, without the need for ground control points, as the calculation may be based on arbitrary points determined using the reflectorless ability of the imaging station.

4. SOFTWARE DEVELOPED

However, this may not always be possible, as a different orientation of the telescope may be required for the whole object of interest to be imaged. In this case a different approach is required and hence the proposed methodology is applied.

Suitable software has been developed using MATLAB® environment. This software uses the values of the calibration parameters, the co-ordinates of the point on which the imaging total station is set up and the values of the horizontal and vertical angles measured towards the planar object, in order to calculate the projective transformation parameters and perform the image transformation, thus producing a rectified image. The main steps of the software are the following:

- Input of the calibration parameters
- Input of the imaging station co-ordinates
- Read-in of the horizontal and vertical angles
- Determination of the eight parameters of the projective transformation
- Calculation of the parameters of the reverse projective transformation
- Resample original digital image to produce the rectified one, with pixel size defined by the user

A first implementation of the above described software was performed with images acquired in the Technological and Cultural Park of NTUA in Lavrio. The buildings of the old French Mining Company present mainly planar surfaces and interesting details (Figure 4). Several tests were performed during the field work including directly acquiring a rectified image (see par. 3.5) and rectifying images using the developed software.

Figure 4: The buildings in the Technological and Cultural Park of NTUA in Lavrio

Such an example involves the original image shown in Figure 5. It was acquired with the imaging total station from a point with known co-ordinates (X= 100, Y= 11.340, Z= 100) in a local co-ordinate system. The details of this particular image are:

- Horizontal angle = $221^g.8062$
- Vertical angle = $90^g.0006$

- Principal distance = 1430.485 pixels
- Principal point co-ordinates x_o=319.682, y_o=220.736 pixels

The last two result from the camera calibration procedure, which has been described before. With a suitable calculation from the above data the omega and phi rotations may be calculated, as they refer to a different co-ordinate system (Figure 2). Also the eccentricity of the camera projection centre referring to the theodolite's central point has been taken into account in order to determine the eight projective transformation parameters.

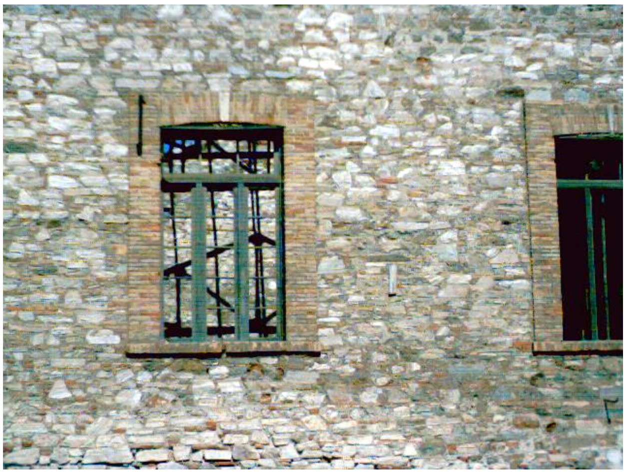

Figure 5: Original image taken with the Topcon 7000i Imaging Total Station

The same original image has been rectified both with the software developed and standard digital rectification software which requires the co-ordinates of control points on the objects planar surface. After the completion of the two procedures the two rectified images have been compared with a simple geodetic restitution of the object, which was performed with the imaging total station. The rectified images were also inserted in a CAD environment and overlaid with the vector restitution (Figures 6 and 7) with very promising results.

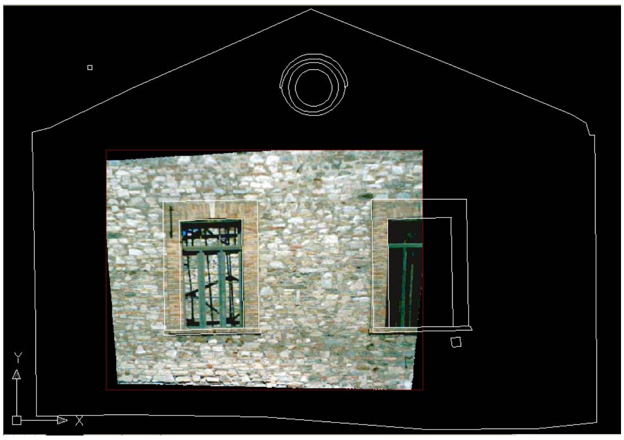

Figure 6: The rectified image with the rectification software overlaid with the vector restitution of the object

The first comparison calculations show that the two methods produce similar results in terms of accuracy and image quality. Of course further and more thorough tests are already underway and will be reported in due course.

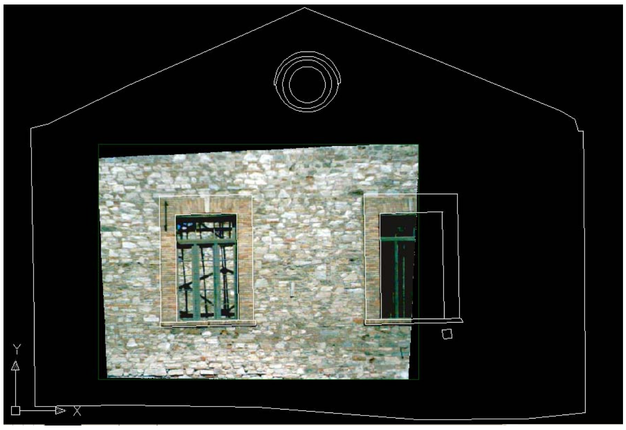

Figure 7: The rectified image with the developed software overlaid with the vector restitution of the object

5. EVALUATION & FUTURE OUTLOOK

It has been proven that the idea of direct rectifying images taken by the imaging total station is quite promising. It is for the first time that geodetic measurements and imaging procedure may be integrated into one action. Hence the idea of exploiting the simultaneously acquired data leads to improvement of speed and reduction of cost, as only one piece of instrumentation is required.

Moreover users are freed from the need of measuring and determining ground control points (GCP's), since the necessary information is recorded together with the image acquisition process.

However, the characteristics of the digital camera incorporated into the imaging station are still not entirely adequate for extended applications. It is believed that it is only a matter of time until they improve, i.e. increase the image spatial analysis, improve the camera constant or decrease the pixel size. They are all depending on technological advances which are inevitable in the near future.

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