CONTRIBUTION OF VIDEOGRAMMETRY TO THE ARCHITECTURAL RESTITUTION
Results of the CIPA "O. Wagner Pavillion" test

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ABSTRACT:

Although there is an unchanged demand for the recording and documentation of the cultural heritage, modern acquisition and analysis techniques are rarely used. Improvements and new developments in the fields of sensor and computer technology have had a major impact on many fields including photogrammetry, while at the same time have led to the production of low-cost consumer products, like the camcorders, which today are considered to be "household items". Although camcorders are not intented for photogrammetric use, they excibit many useful characteristics (low-cost, universal use, portability, no need of special equipment, inexpensive means for storage of huge amount of data, etc) while previous studies have shown that with proper system calibration sufficient accuracy for architectural tasks can be obtained under normal practical situations.
The purpose of this work is to demonstrate the use of camcorders in architectural recordings, contributing thus to the CIPA test "O. Wagner Pavillion". The results are compared to the results obtained by other institutes, which have used conventional photogrammetric techniques. The accuracies of 1cm on the object which have been obtained are compatible to those derived by classical photogrammetry, while the unique characteristcs of Digital Photogrammetry (automation, computer compatibility, relaxation of expertise) give Videogrammetry distinct advantages.

1. INTRODUCTION

World-wide, only a small percentage of the buildings of cultural interest are documented, but many images are taken by architects, historians or others, who are interested in Architectural Photogrammetry or just in souvenir photography. There is a great potential for such imagery taken by accident, and it would be advantageous to use this resource in addition to professional photogrammetric imagery for the restitution of the world's heritage (Waldhauesl, Brunner, 1989).

Although there is an unchanged demand for the recording and documentation of the cultural heritage (Waldhauesl, 1992), modern acquisition and analysis techniques are rarely used. Improvements and new developments in the fields of sensor and computer technology have had a major impact on many fields including photogrammetry. On the other hand such technological advances have led to the production of low-cost consumer products, like the camcorders, today considered to be "household items".

In Digital Photogrammetry images are captured either with film-based cameras and subsequent digitization, or with cameras with solid-state sensors. Devices of the latter type can be standard solid-state cameras with a video recorder or a computer with a framegrabber, still-video cameras, video cameras, and several types of high resolution CCD cameras. Conventional film-based cameras still provide an unsurpassed photographic resolution, but the film must be developed and digitized before its data become available for photogrammetric processing. Solid-state cameras, on the other hand, provide immediate access to the image data, with the drawback of a coarser resolution. Today a variety of solid-state imaging systems, ranging from inexpensive camcorders to specialized high resolution systems, is available at the market (Luhmann, 1992).

Although camcorders are not intented for photogrammetric use, they excibit many useful characteristics. They are inexpensive and widely used for other pursposes as well, they are portable and free-hand, they need no special equipment, they offer the ability of on-site quality control. Furthermore they provide a very inexpensive means for storage of huge amount of data in video tapes. Their major disadvantage is their low resolution, which poses some limitation on the number of measurable details, and of course their geometrical instability. However, previous studies (Streilein, 1994, Streilein, et. al., 1993) have shown that with proper calibration sufficient accuracy for architectural tasks can be obtained under normal practical situations.

The purpose of this work is to demonstrate the use of camcorders in architectural recordings, contributing thus to the CIPA test "O. Wagner Pavillion". The results are compared to the results obtained by other institutes, which have used conventional photogrammetric techniques.

2. PROJECT DEFINITION

The idea and the initiative of the CIPA project belongs to Prof. P. Waldhausl (Technical University of Vienna, Austria) and the aim was to check the current state-of-the-art in Architectural Photogrammetry.

The test object chosen is one of the Otto Wagner's Stadtbahn Station buildings on the Karlplatz in Vienna, Austria. Its dimensions are $15x8x10m^3$. A 6-station surveying network has been established around the building and the polar coordinates of 44 non-signalized (but well defined in majority) control points have been measured. After the adjustment of the surveying measurements, the local cartesian coordinates of the control points have been determined with an rms values of 2mm. These points cover all four exterior facades.

Subsequently the object was photographically covered. During this campaign different cameras have been used like the Rollei 6006, the Hasselbland 500 EL/M, the Leica Elcovision, the Nikon FE2, the Pentax PAMS 645P and ME-Super totaling to more than 70 photographs.

The photographs have been measured by different measuring devices and the data processed by different software packages. In total 16 photogrammetric Institutes from 9 countries have participated to this campaign and the preliminary results are reported in (Patias, et. al., 1993, Waldhausl and Ogleby, 1994).

However, all the results obtained up to now are only refering to the use of analog cameras and analog measuring devices. The purpose of this test is to show the contribution of Digital Photogrammetric techniques in recording architectural objects.

For this reason the same control point information have been used but the acquired photography is in the form of digital imagery taken by a camcorder. The measurements of image coordinates have been performed on the computer screen using zooming on the images. The final results are compared to those obtained by the classical Photogrammetric means.

Figure 1. "O. Wagner Pavillion" test object. Superimposed are shown the check points of the first facade used in this test.

3. IMAGE ACQUISITION

3.1 The Imaging System

The JVC GR-S77E Camcorder is an inexpensive consumer product. It is a free-hand portable camera and the on-site control for the acquired imagery is achieved by the internal monitor. It incorporates a 1/2" (6.4mm x 4.8mm) color sensor with ca. 420.000 sensor elements. The imagery can be directly trasmitted to a frame grabber or recorded on a S-VHS C tape. The digitized images have a size of 728x568 pixel, which results in a pixel spacing of 8.5µm in the horizontal and 8.3µm in the vertical direction.

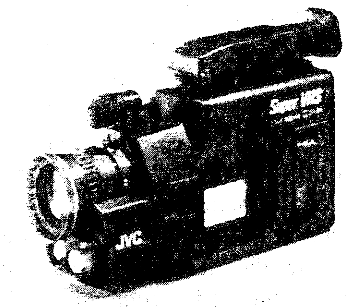

Figure 2. The JVC GR-S77E Camcorder

3.2 Photography

Using such an imaging system in Architectural Photogrammetry requires that most of the functions which are implemented for the convenience of the common user (eg. autofocus, zooming functions or image stabilizer) are disabled. In this test the autofocus was disabled and the zoom lens was fixed at its shortest focal length. This sytem does, however, offer the ability to store a huge amount of data on inexpensive video-tapes and allows on-site quality control for the acquired images.

Dealing with a low-cost camcorder instead of metric cameras, the problem of low sensor resolution must be faced. To obtain sufficient accuracy in object space with such an equipment, it is advisable to take as many images as is reasonable and to use multiple camera arrangements with convergent rays, instead of being restricted to special camera arrangements (eg. stereo pairs). On the other hand, the number of measurements increases rapidly with the number of images, but one of the advantages of Digital Photogrammetry is that it is possible to establish semi-automatic or automatic measurement routines.

The whole building was covered by 24 video images. However, for the purpose of this test only 4 images corresponding to the first facade have been used.

The average image scale of the used photographs is approximately 1:2300 (average object distance is approximately 20 m). All the object points are imaged in at least two images and at the average there are 3.3 rays corresponding to each object point.

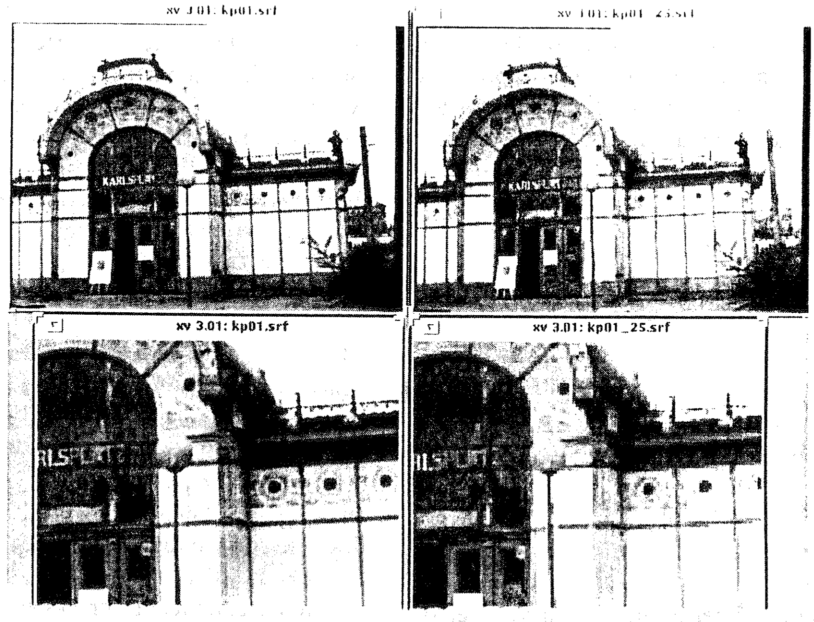

Figure 3. Measuring devices of 8.5ìm and 25ìm have been simulated by "blowing up" the pixel size from 8.5ìm(original photo) to 25ìm (derived photo).

4. MEASURING DEVICE

The DIPAD system (Digital Photogrammetry and Architectural Design) devoped in ETH (Streilein, 1994) has been used in this test. DIPAD consists of a Digital Photogrammetric Station (DIPS, (Gruen and Beyer, 1990)) and a Computer Aided Architectural Design (CAAD) module) and allows for automatic and semi-automatic measurement of image coordinates (template matching (Gruen, 1985)), or manual measurements.

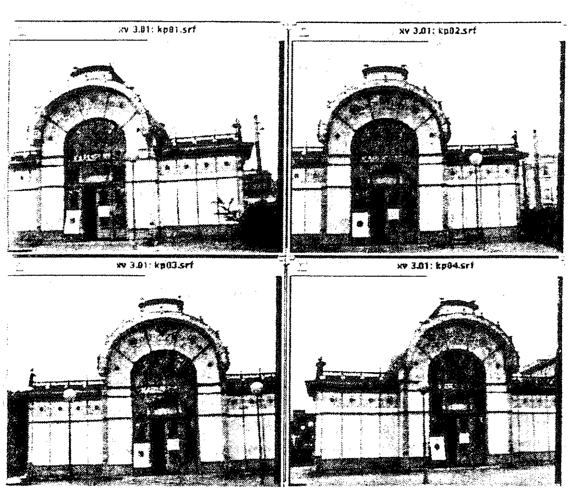

Figure 4. The four photos used in the test

Since all the control points used in this campaign were not signalized ones, only manual measurements on the zoomed images have been used in the course of this test. This gives the ability to sub-pixel pointing precision, the pixel size of the original image being approximately 8.5ìm.

This measurement resolution is of the order of the analytical systems used by other participants. Other institutes have either used measurement devices of lower accuracies or used digitizers (50-100ì m pointing accuracies) with enlarged photographs. In order to simulate such devices, the original photos were also blown up so that the derived image had a pixel size of 25ì m. Such a resolution judged to be rather extreme since many details started to be too small to be recognized and measured any more.

5. DATA PROCESSING

5.1 System calibration

It is typical for low-cost non-metric imaging sensors to suffer from systematic errors. This is especially so for the camcorders (like the one used in this test) employing off-the-self CCTV-type lenses with large distortion. Previous tests (Beyer, et. al., 1992) have shown that only the radial symmetric distortion of the lens and the adapter used with the JVC camcorder can reach 50 pixels at the image corners. Aside of that, the location of the principal point and the camera constant must be determined. Furthermore, imperfections in the specifications of the sensor element spacing cause a differentiation in scale along the two axes of the image.

In order to enhance the geometric quality of the results, all the above problems should be solved with appropriate system calibration. The calibration model used in this test is shown in eqs (1) and described fully in (Beyer, 1992).

$$\Delta x = \Delta x_p - \frac{\bar{x}}{c}\Delta c - \bar{x}\, s_x + \bar{y}\, a + \bar{x}\, r^2 K_1 + \bar{x}\, r^4 K_2 +$$
$$+ \bar{x}\, r^6 K_3 + (r^2 + 2\bar{x}^2) P_1 + 2\,\bar{x}\,\bar{y}\, P_2 \tag{1}$$
$$\Delta y = \Delta y_p - \frac{\bar{y}}{c}\Delta c - 0 + \bar{x}\, a + \bar{y}\, r^2 K_1 + \bar{y}\, r^4 K_2 +$$
$$+ \bar{y}\, r^6 K_3 + 2\,\bar{x}\,\bar{y}\, P_1 + (r^2 + 2\bar{y}^2) P_2$$

where:

Δx_p, Δy_p, Δc	Change of interior orientation parameters
s_x	Scale factor in x direction
a	Shear factor (affinity)
K_1, K_2, K_3	First three parameters for radial lens distortion
P_1, P_2	First two parameters for decentering lens distortion

$$\bar{x} = x - x_p$$

$$\bar{y} = y - y_p$$

$$r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

CAMERA CALIBRATION CHARACTERISTICS	
Nominal values	
x_p	0.029 mm (384.00 pixels)
y_p	- 0.129 mm (287.50 pixels)
c	8.959 mm
Additional Parameters	
Δx_p	$-4.51\ 10^{-3}$ mm
Δy_p	$5.53\ 10^{-4}$ mm
Δc	$1.18\ 10^{-4}$ mm
s_x	$-2.09\ 10^{-6}$
a	$-3.05\ 10^{-4}$
K_1	$-1.46\ 10^{-3}$
K_2	$5.78\ 10^{-5}$
K_3	0
P_1	$-3.56\ 10^{-4}$
P_2	$1.92\ 10^{-4}$

To obtain precise calibration parameters for the camcorder, a testfiled calibration was performed. The 3-D testfield spans 2.6x2.0x1.1 m^3 and contains 162 targets. Two images at each of four camera stations were taken, one image being acquired with the camera in upright position and the other with the camera rotated 90^o around its optical axis. The above described set of 10 additional parameters was used for the calibration, in order to compensate the effects of systematic errors introduced by the non-ideal geometric characteristics of the imaging system. The camcorder has been calibrated using the above described ETH calibration testfield (Beyer, et. al., 1992) and the values of the additional parameters entering the above calibration model have been estimated as shown below with a precision of several micrometers.

5.2 Bundle adjustment

All the measured image coordinates entered the bundle adjustment for a minimum constrained solution (only 7 parameters for the datum definition are assumed fixed). In the first set of adjustments, only the object coordinates are assumed unknown, whereas the systematic errors are taken care by a pre-calibration using the calibration model described above together with the obtained values for the parameters. For the second set of adjustments the additional parameters for systematic error compensation are also assumed unkown, using their known values only as approximate ones. In the latter case the minimum number of constraints needed for the datum definition are 17 (10 are attributed to the A.P's).

From the 15 known points (their coordinates are known from surveying measurements) in the first facade, the minimum number are kept fixed as control points and the rest serve as check points.

5.3 Transformation to a common frame

In order for the above results to be compatible to the results obtained by the other participants in this CIPA test, the minimum constrained solutions obtained so far should be transfered to the same reference frame with the rest of the solutions. This reference frame (Patias, et. al., 1993) is uniquely defined, it provides the minimum norm and it is obtained by the free-network adjustment.

The transformation of the minimum constrained solution to a free-network solution requires a Helmert transformation. The points kept fixed (base points) during this transformation are the same as those used by the other participants. The coordinates and the respective variance-covariance matrix are then transferred to their free-network respectives.

In order to access the accuracy of the adjusted coordinates we computed a number of criteria, ranging from local criteria (characterizing individual points) to global criteria (characterizing the whole solution). It should be pointed out that all these are accuracy criteria since they refer to the actually known (from surveying measurements) object coordinates of the witheld from the adjustment check points.

Dataset	Adjustment Type	$\hat{\sigma}_0$ (µm)	$\hat{\sigma}_X$ (mm)	$\hat{\sigma}_Y$ (mm)	$\hat{\sigma}_Z$ (mm)	$\bar{v}_x$ (µm)	$\bar{v}_y$ (µm)
I	a	2.65	14.23	26.02	6.16	1.33	1.89
I	b	2.58	8.32	4.67	9.18	1.46	1.65
II	a	8.37	42.43	78.29	16.78	5.01	5.30
II	b	6.70	25.52	38.52	13.39	6.89	5.94

I *measuring device of 8.5 µm* a *pre-calibration*
II *measuring device of 25 µm* b *self-calibration*

$\hat{\sigma}_0$ *a-posteriori standard deviation of unit weight*

$\hat{\sigma}_X$, $\hat{\sigma}_Y$, $\hat{\sigma}_Z$ *theoretical precision of check points coordinates in object space*

$\bar{v}_x$, $\bar{v}_y$ *rms values of image coordinates residuals*

5.3.1 Local Criteria

Local criteria are the Mean Square Error σ_i of a point i, the volume of the error ellipsoid, and the characteristics of the error ellipsoid (lengths of the axes, etc).

$$\sigma_i = \sqrt{\frac{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}{3}}$$

5.3.2 Global Criteria

Although the use of the local criteria is useful for each individual solution, for checking the accuracies in different areas of the object, they are of little help in drawing overall conclusions. Therefore additional global type of criteria have to be defined and computed for each solution.

Such global criteria can be the RMS value corresponding to the mean variance D_2, the Mean Standard Deviation D_1, and the Maximum Standard Deviation D_{max}.

$$D_2 = \sqrt{\frac{\sum_{i=1}^{k} \sigma_i^2}{k}}$$

$$D_1 = \frac{\sum_{i=1}^{k} \sqrt{\sigma_i^2}}{k}$$

$$D_{max} = \max \sqrt{\sigma_i^2}$$

5.3.3 Graphical presentations

In order to graphically present the results, the following plots have been prepared for each solution:

- *Projections of the error ellipsoid* of every point onto the X-Y, Y-Z, Z-X planes.
- *Discrepancy vector* plot, showing the differences between the the point coordinates obtained through the prior adjustemnts and those obtained after the S-transform. These discrepancies can be used to determine possible misfit between the individual dataset and the common reference frame used for the comparisons.

6. RESULTS

The results of the free-network sdjustment are shown below. Plots of the discrepancy vectors and the projections of the error ellipsoids are also shown.

As shown by the discrepancy vectors, the transformation has been with no problems, which means that the two data sets (the AUT and the ETH ones) are compatible and no blunders exist. With respect to accuracy the more conservative criterion D_2 showed a good agreement with the more optimistic criterion of D_1.

Pre-calibration give rather good results of 1.5cm in object space corresponding to about 6.5µm or 76% of the pixel size in image space, when the original images of 8.5µm pixel size is used. When the pixel size was blown up to 25µm the results of course are getting worse and reach the level of 4.5cm in object space or 19.5µm in image space. It is obvious that the obtained results are directly related to the pixel size. That is 3-times bigger pixel will give 3-times worse results.

Self-calibration improves the results by 30-40% relatively to pre-calibration. Accuracies are getting better than 1cm in object space corresponding to 4µm or abour 50% of the pixel size in image space, when the original images of 8.5µm pixel size is used. When the pixel size was blown up to 25µm the results of course are getting worse but still better than 3cm in object space or about 1/2 a pixel (13µm) in image space.

The obtained results are compatible with those from the other participants. These participants have used regular photography. The best results obtained by them are of the order of 1cm (highly accurate measuring device + self calibration). The worst ones are of the order of 3cm (digitizer + self calibration).

Data set	Adjust. Type	D_2 (cm)	D_1 (cm)	D_{max} (cm)	M_2 ìm (pixel)
I	a	1.48	1.38	2.06	6.43 (0.76)
I	b	0.92	0.79	1.58	4.00 (0.47)
II	a	4.47	4.13	6.18	19.43(0.78)
II	b	2.96	2.40	4.65	12.87(0.51)

D_2 *RMS value corresponding to the mean variance of the check points coordinates(object space)*
D_1 *Mean Standard Deviation of the check points coordinates (object space)*
D_{max} *Maximum Standard Deviation of the check points coordinates (object space)*
M_2 *RMS value corresponding to the mean variance, calculated with respect to* D_2 *(image space)*

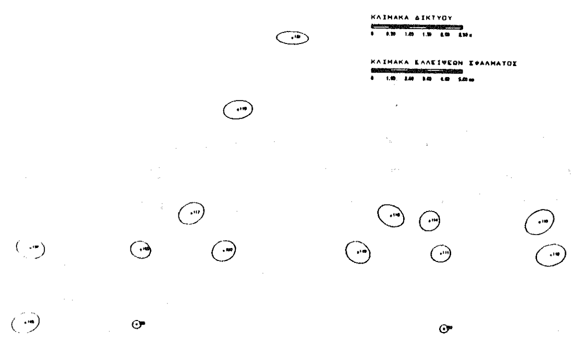

Figure 5. Projections of error ellipsoids for solution Ib.

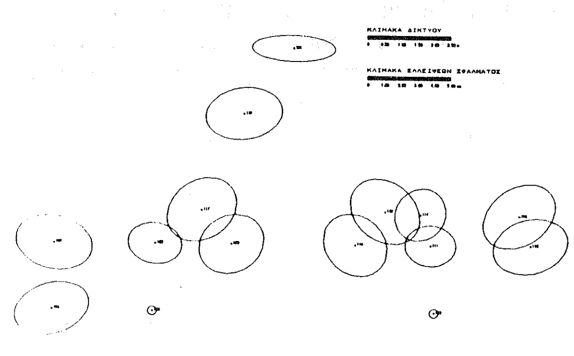

Figure 6. Projections of error ellipsoids for solutions Iib.

7. CONCLUSIONS

Many images of buildings of cultural interest are taken by architects, historians or others, who are interested in Architectural Photogrammetry or just in souvenir photography. There is a great potential for such imagery taken by accident, and it would be advantageous to use this resource in addition to professional photogrammetric imagery for the restitution of the world's heritage. Many such images are acquired today by low-cost consumer products, like camcorders.

Although camcorders are not intented for photogrammetric use, they excibit many useful characteristics (low-cost, universal use, portability, no need of special equipment, inexpensive means for storage of huge amount of data, etc) while previous studies have shown that with proper system calibration sufficient accuracy for architectural tasks can be otained under practical situations.

The aim of this work is to contribute to the CIPA test "O. Wagner Pavillion" with the purpose to describe the state-of-the-art in Architectural Photogrammetry. This contribution consists of demonstrating the user of camcorders in architectural recording. It is shown that even such low-cost, low-resolution, and low-geometrical-stability systems can give results compatible to those obtained under conventional photogrammetric techniques. The accuracies obtained is 1 cm with minimal ground control.

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