

# COMPARATIVE CAMERA CALIBRATIONS OF SOME "OFF THE SHELF" DIGITAL CAMERAS SUITED TO ARCHAEOLOGICAL PURPOSES.

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## ABSTRACT :

The increasing availability and capability of "off the shelf" low cost digital cameras coupled with on-going advances in mobile computing technology offer great potential for on-site archaeological recording. In particular the user-friendliness and ready availability of these systems coupled with image orientated modelling software packages such as Photo Modeller and Photo Builder are providing systems that are increasingly suited to the requirements of on-site archaeological recording. However, whilst offering ease of use, the geometric performance and imaging stability of all "off the shelf" systems are extremely dependant on the manner in which they are used and the selection of an appropriate calibration method. This paper, through a series of calibration experiments, investigates the suitability and geometric stability of three such camera systems: a pair of Kodak DC210 cameras, a pair of Kodak DC260 cameras and a Canon DV1 digital video camcorder used in both still and video imaging modes.

The work undertaken demonstrates that all three systems are capable of attaining measurements to sub-pixel accuracy provided that the image acquisition methodology adopted for each camera takes into account and compensates for the particular design features of each system. In particular it is noted that some of the design features aimed at promoting ease of "snap shot" photography must be circumvented if camera internal geometry is to remain at best stable or at least reproducible.

## 1. INTRODUCTION

The last several years or so has seen the rapid development of digital still and video cameras for the mass or consumer market. The costs of these cameras, while still considerably more than that for equivalent film based cameras, are dropping very quickly whilst the image resolutions and storage capacities are increasing.

At the moment most recognised 35mm film-based camera manufacturers like Kodak, Nikon, Olympus, Minolta, Konica, Ricoh, Pentax and others now make a range of digital cameras (Kodak alone has over 10 models, for an overview of available cameras see Plug-in Systems 1999) aimed at the consumer market. In addition, computer/media companies like Sony and Kyocera also make digital cameras, indicating strong consumer interest in this technology. The resolution of the cameras varies greatly, as does control over the camera functions, both of which increase in specifications with increasing price.

Digital cameras offer limited advantages over film-based systems, on a cost benefit basis film-based cameras still offer a better photographic instrument for the money. However the use and popularity of digital cameras is increasing, and this popularity will mean that the cameras will find application in cultural monument documentation in general, and photogrammetric recording specifically. With the universal trend towards digital data, and the development of 'photogrammetric' solutions to artefact modelling for non-photogrammetrists, there is a need to evaluate the suitability of off-the-shelf digital cameras.

### 1.1 Photogrammetric Documentation of Cultural Heritage

Developments in the sciences of photogrammetry and image processing over the last decade or so, including the development of digital cameras and large format image digitisers, have seen an increase in the automation of the data collection process. These advances range from high-precision industrial applications (for example see (Brown 1995) and (Beyer 1995) for production systems) through to simple solutions for non-traditional users (for example 3D Builder (Patias 1998) and Photomodeler (Hanke 1997)). In addition systems that use imagery from consumer digital and analogue video systems (for example (Streilein 1998)), and sequences of images (Pollefeys et al, 1998), have almost automated the creation of 3D models (as has the development of 3d laser scanners, for example see (Minolta 1998)).

Within the photogrammetric and remote sensing community, there have been many papers presented at recent ISPRS Symposia presenting developments in the area of data acquisition for virtual reality and heritage, (for example (Gruen 1998)), and two of the working groups within the ISPRS Commission V are known as Scene Modelling for Visualisation and Virtual Reality, and World Cultural Heritage. At the ISPRS Commission V Symposium in Hakodate in 1998, 31 papers were presented specifically in the World Cultural Heritage section, and others in the other working groups used heritage sites or monuments in order to test their developments. In addition, the activities of the Comité

International de Photogrammétrie Architectural (CIPA, a liaison between ISPRS and the International Committee on Monuments and Sites) continue to produce an increasing number of publications in this discipline. Many of these applications use digital images, and with the increasing availability of medium resolution digital cameras, coupled with the growth of web based computer graphics tools one can expect increasing awareness of the possibility of generating visualisations appropriate to cultural heritage.

Three different types of digital cameras were selected for evaluation of their suitability for use in the photogrammetric documentation of cultural heritage. The cameras chosen represent a cross section of recent instruments, including digital video.

## 2. THE CAMERAS

There were a variety of solid state digital still cameras used in this exercise, two Kodak DC210 Zoom and three Kodak DC260 Zoom. Both of these cameras use CompactFlash cards for image storage, and provide several camera functions in common with 35mm auto focus cameras. The other cameras used in the exercise are a pair of Canon Digital Video cameras, both of the same make but of different ages and history of use. Photographs of the cameras and the specifications are

shown in Table 1.

### 2.1 The Kodak DC210

The reason this camera was chosen for assessment for suitability for calibration and photogrammetric applications was that it is typical of the *megapixel* consumer cameras, and it was readily available. It is typical of a 'class' of digital camera that has fixed focus, medium resolution and a zoom lens. The camera is relatively primitive as far as camera features go, there is no autofocus (although there is a macro setting) and no external synchronisation with additional flash units. There is also no control over the power of the flash, requiring masking of the camera flash unit during the calibration photography. The camera would cost one quarter of the digital price if the unit was film based, and apart from the 2x zoom feature represents the lowest level of medium resolution camera.

### 2.2 The Kodak DC260

The DC260 is a considerable advance on the DC210, offering many more camera features like multi-zone autofocus, screen based view finder, audio recording, 'burst' sequence capture and external flash sync. Additionally the camera can be controlled by software scripts that can modify camera settings, for example, disabling the autofocus and the function that automatically rotates an image

Camera Model	Kodak DC210	Kodak DC260	Canon DV1
Images obtained from the Canon and Kodak Web sites, see bibliography.			
<b>Maximum image resolution</b>	1152 x 864	1536 x 1024	720x576+/-PAL
<b>Sensor resolution</b>	1160 x 872	1548 x 1032	450,000 pixels
<b>Zoom range</b>	2:1 optical 29-58mm equiv	3:1 optical 2:1 digital 38-115mm equiv	14:1 optical 35:1 digital
<b>Focus type</b>	Fixed	Automatic, manual override	Automatic, manual override
<b>Exposure</b>	Automatic	Automatic with manual override and additional control by scripts	Automatic aperture and shutter priority, manual override
<b>Image storage medium</b>	Kodak Digital Science Picture card	Kodak Digital Science Picture card	Digital Video cassette
<b>Data output</b>	RS232, Flash Card	RS232, Flash Card	IEEE 1394 (Firewire), Pinnacle Systems MiroDV1000 board
<b>Video out</b>	Analogue PAL & NTSC	Analogue PAL & NTSC	Composite video, S-Video
<b>Image file format</b>	FlashPix or JPEG	FlashPix or JPEG	Digital video, BMP for single frames and AVI for video
<b>Other Features</b>		Camera control possible through scripts, external flash sync.	Camera can be used in video and 'SLR' mode, flash sync in SLR mode

Note: Many of the names, file formats, models and processes mentioned above are registered trademarks

Table 1: A Comparison between the Kodak and Canon Cameras

to the upright position (auto-rotate). It offers a larger zoom range than the DC210, but in this exercise the zoom on both cameras was used at the widest field of view.

### 2.3 The Canon MV1

The Canon MV1 Digital video camera differs in many ways from the solid state cameras, not least in that the storage medium is a digital video cassette. The camera is a PAL or NTSC video standard camera, and therefore has a limited frame or image size corresponding to the PAL or NTSC standard (in this case 720x576 PAL). The camera uses a progressive scan CCD array so that the alternate fields found on conventional video cameras are acquired at the same time when the camera is used in this mode. This provides a full frame image without the striping or motion blur common to interlaced pictures, improving the image quality substantially and therefore enabling a higher accuracy of target definition for calibration.

The MV1 cameras acquire either 25 or 30 full frames of video per second when in progressive scan mode, with a colour saturation and signal-to-noise ratio similar to professional broadcast quality cameras. With the potential to supply image sequences very easily, and the recent advances in the use of image sequences for measuring and modelling, the camera was reviewed with regard to its stability of calibration. The video sequences or still frames are acquired from the camera using a Pinnacle Systems Miro DV100 *Firewire* 'frame grabber' board.

## 3. CALIBRATION

The cameras have been calibrated at both The University of Melbourne and at the University College London, using different software packages and different test-ranges. This procedure determines the stability of the cameras after travelling across the planet, which reproduces a typical 'work' environment and even that of the occasional tourist.

Figure 1 shows the test range in London, Figure 2 shows the exposure level needed for calibration. Figure 3 shows the arrangement in Melbourne and Figure 4 shows a close range configuration used to self-calibrate the Canon MV1 on a modelling project.

### 3.1 Calibration Model

The model used for the calibrations is based on a mixture of primary physical terms and additional empirical terms which model the systematic errors in the perspective projection. Despite the mix of physical and additional terms, the calibration model is commonly known as an additional parameter model. The most widely used block-invariant additional parameter model based on physical terms (Fryer, 1996) is adopted as follows:

<i>Parameter Name</i>	<i>Parameters and/or Model</i>
Position of the principal point	$x_p, y_p$
Principal distance	$p_d$
Radial lens distortion	$\Delta r = k_1 r^3 + k_2 r^5 + k_3 r^7 + \dots$
Decentering lens distortion	$\Delta x = p_1(r^2 + 2x^2) + p_2(2xy)$ $\Delta y = p_1(2xy) + p_2(r^2 + 2y^2)$
Orthogonality and affinity	$\Delta x = a_1 x + a_2 y$

$x, y$  = image co-ordinates with respect to the principal point

$r$  = radial distance with respect to the principal point

The additional parameter model is adopted as block-invariant as it applies to every image in a network. The implication of this adoption is that the camera has a stable calibration and is used at a constant focus.

### 3.2 The Calibration Procedure

The processing of all cases employed self calibration, free networks and a targeted test range approach. The purpose built array at UCL comprises 95 targets on a wall with the addition of approximately 55 targets on metal rods and invar scale bars in the foreground. The purpose built array at the University of Melbourne is similar, comprising 48 targets on a planar wall and 24 targets in the foreground, either fixed or on a moveable fixture. Although the planar array plus moveable fixture is a less than an ideal case, it is convenient as the requirement for permanent physical space in a laboratory is minimised.

Calibrations using the purpose built test arrays employed networks of eight camera stations with convergent photography. Dual (0° and 90° rolls) or quad (0°, 90°, 180° and -90°) roll strategies were used at each station to simulate the typical practice in close range photogrammetry for minimisation of parameter correlations. Typical practice also decrees, for the sake of efficiency, that each camera station is visited only once and two or four exposures are taken. Between each roll the camera is moved slightly to randomise the location, and therefore randomise any systematic dependencies on station position (Fraser and Shortis, 1995). In all cases, the target images were measured by intensity-weighted centroids (Trinder, 1989) using the VMS software suite, a digital image processing package developed jointly by the University of Melbourne and University College London as a research tool.



Figure 1: UCL Test Range



Figure 2: UCL Test Range Exposed for calibration

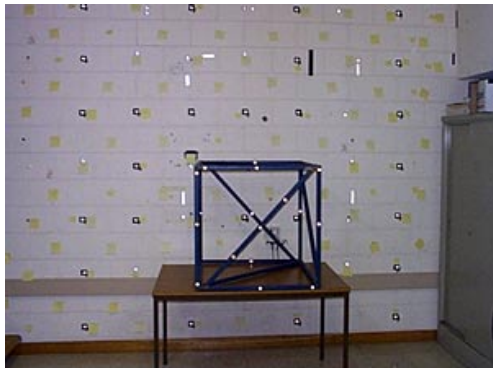


Figure 3: The University of Melbourne Calibration Range



Figure 4: Close-range Calibration array for Canon MV1  
Still frame grabbed from sequence.

## 4. RESULTS

Results for the calibrations are shown in Table 2 on the following page.

The Kodak DC210 and DC260 cameras were calibrated in their widest zoom position. With the DC210 this position could be maintained as the camera has no autofocus feature so there was no further movement of the lens system following boot. The DC260 on the other hand would attempt to focus on the test range unless the autofocus facility was disabled, either by accessing the menu commands on the camera or through the use of a camera control script.

The images for the calibration of the MV1 were acquired using a video light mounted close to the lens, so that the retro-reflective targets could be illuminated. Again, it was necessary to 'stop-down' the exposure so that the targets were illuminated rather than the entire scene. The camera was focussed onto the target range and then the focus setting was locked. The camera was also used on the widest zoom setting on each occasion.

The table shows the principal distances or focal lengths for the cameras, the location of the principal point, two terms of radial distortion and two terms of decentring distortion for each of two DC210 cameras, three DC260 cameras and two MV1 digital video cameras.

All cameras show an internal image precision of approximately one quarter to one tenth of a pixel for the retro-target measurements. The exception to this is the DC260 in the zoomed position, which may be attributable to movement of the lens in the extended position. Whilst the Kodak cameras are otherwise consistent within the models, the MV1 shows a factor of two difference in precision. The poorer result emanates from an older, well-used camera, whilst the better result comes from a camera which was almost brand new.

### 4.1 Implications for Archaeology

There are two scenarios where these type of cameras would be used in the context of archaeological research; one is where they are used principally for a photogrammetric recording project, and the other is where imagery resulting from 'snapshot' photography may be used at a later stage for recording or reconstruction.

In the first instance it is possible to set the camera to a predefined focus and level of zoom, and carry the calibration from a previous epoch as known parameters in the photogrammetric solution. The DC210 is a fixed focus camera, and tests to date show that the lens returns closely to its boot position each time the camera is activated, so it could be used as a semi-metric camera in most applications. The DC260 can have the focus set to

Comparison of Calibration:

Camera and Epoch	DC210A UCL	DC210B UCL	DC260A UCL	DC260B UCL	DC260A zoomed	DC260C UM	MV1#1 UM	MV1#2 UM
PD	8.724	8.731	15.317	15.351	19.022	15.415	5.642	5.571
PPx	-0.014	0.127	0.093	0.083	0.168	0.005	0.035	0.076
PPy	0.043	0.061	-0.122	-0.098	-0.071	0.235	-0.022	-0.012
R1	-1.813E-3	-1.838E-3	-4.706E-4	-4.633E-4	-2.832E-4	-4.724E-4	-6.412E-3	-6.546E-3
R2	3.442E-5	3.327E-5	3.908E-6	4.404E-6	5.216E-6	3.567E-6	2.618E-4	2.421E-4
T1	1.967E-5	8.759E-5	1.532E-4	1.592E-4	1.732E-4	8.284E-6	1.271E-4	1.158E-4
T2	-1.617E-4	-8.341E-6	4.881E-5	2.373E-5	7.547E-5	2.311E-4	1.899E-4	5.288E-5
RMS	1.09	1.42	0.72	0.69	1.87	0.86	1.61	0.75
Camera ID	UCLCam	CLOCam	SRCam1	SRCam2	SRCam2	IDBCam	CLOMV1	MRSMV1

Table 2: Results of the Calibration

a predetermined position and then de-activated, as can the MV1 although this can only be performed optically for each camera. The best solution, rather than relying on pre-determined calibrations, is to self-calibrate the camera as part of the photogrammetric project.

In the second scenario, with the focus setting and level of zoom as unknown parameters it would be somewhat more difficult to assume a focal length (although the results tend to suggest a good approximation could be made for the principal point). Ideally the camera could be 'calibrated' if there were sufficient photographs of the object, otherwise the camera can only be treated as non-metric in all calibration parameters.

One benefit resulting from the digital video camera is that if the camera has moved around the object, or the object appears in several scenes from different camera positions, then single frames from the sequences can be acquired and a bundle solution for the parameters can be determined.

## 5. CONCLUSIONS

### 5.1 The Cameras' Suitability for Archaeological Applications

As the title of this paper suggests these cameras will be analysed with respect to their suitability for applications in archaeology. One aspect of this is the 'metric' quality of the camera, which will be addressed in the next section. The other aspect must be a review of the functionality of the camera itself as a photographic instrument.

The Kodak DC210 camera represent a typical *megapixel*

consumer camera released mid 1998. It has an acceptable image quality, which on the high resolution setting gives 13 images on a 4Mb CompactFlash card, and 28 at standard resolution. There is limited control over the exposure, no external flash sync, and only a 2x optical zoom over the range of wide to normal angle. It does have a macro focus setting, and only on this setting is it possible to preview the image on the screen. In all other cases the image is framed through the view finder. For the cost of the camera, which seems to vary greatly with location and month, one could purchase a 35mm SLR camera with interchangeable lenses, good exposure control and compensation, and the various attachments which make these cameras so versatile.

The Kodak DC260 represents a considerable improvement over the DC210 in terms of its features, as well as increased resolution. The camera has a larger zoom range, making it suitable for photographing artefacts with less visual distortion being noticeable in the image. There is also an external flash connection, offering considerably more control over the lighting of a scene and for the enhancement of texture for example when photographing rock engravings or sculpture.

The Canon MV1 video camera represents a very different camera concept, a video camera capable of broadcast quality full frame image acquisition at 30 frames per second, limited by the resolution of the PAL and NTSC television systems. From the point of view of the camera functions, the MV1 offers all the automatic features of a video camera as well as an SLR camera, with a high level of control over exposure, level of zoom and even synchronisation with external flash units in picture mode.

## 5.2 The Calibrations

The Kodak cameras exhibit signs of being well designed and constructed, with decentring distortions and principal point locations substantially smaller than many CCTV cameras used in photogrammetry. The tests to date show results consistent to what would be expected from cameras of this type, and certainly the cameras are capable of consistent accuracy and precision. The principal distance and radial distortion is quite consistent for cameras of the same model, indicating that nominal values could be used to process images acquired by an uncalibrated camera (if the level of zoom was known).

The Canon MV1 also shows good results for the principal point location and decentring distortion, and is capable of achieving acceptable metric results. As for the Kodak cameras, the principal distance and radial distortion is consistent for the two cameras calibrated for this research. The limitation of this type of digital video camera is ultimately the image resolution, however the ease of use of the instrument for both moving and still imagery means that there will be applications for digital video in archaeology for many reasons, and the fact that the images can be used for photogrammetric purposes is a bonus.

## 5.3 Future Developments

Digital still and video cameras will have application in archaeology and architecture, the increasing popularity of the digital medium will ensure that there will be a migration to this camera type.

The recent advances in the display of digital panorama, instigated by the Apple Computer Corporation with the QuickTime Virtual Reality (QTVR) but now supported on multiple platforms by a variety of software companies, has meant that many archaeological sites are represented in this way, both as they are and as they may have been (Ogleby 1997). It is totally feasible to incorporate the panoramic software stitching program in the camera, so that instead of merely acquiring a series of images and down-loading them into additional software packages, the camera may supply the panorama directly.

It is also entirely feasible that digital cameras may offer automatic creation of three dimensional models of objects from either convergent photographs or image sequences, functions that are currently performed off-line but may very well be incorporated into camera processing chips. Packages like that discussed by Polleyfeys (1998) and others under development could feasibly be incorporated into camera software, and the scripting ability of the DC260 suggests that this may well be a distinct possibility.

The ideal digital camera for archaeology may well be one that operates simply, gives an image quality as good as a medium format film-based camera, and can produce

virtual reality representations of buildings and artefacts complete with texture maps on-board the camera.

From the point of view of 'amateur' photogrammetry or monument recording from 'snapshots' (a Working Group of CIPA) a major problem arises in that digital images are not treated the same way as photographs, and their long term existence is in doubt. The likelihood of finding a box of pictures of a now destroyed monument in a museum collection or even a deceased relative's estate has become somewhat reduced. One could always hope to find a box of floppy disks, or CD-ROM, or Zip disks and hope that there is a machine somewhere that is still capable of reading the image medium and format.

This paper has shown that off-the-shelf digital cameras are capable of achieving internal accuracies suitable for photogrammetric applications. The cameras do not as yet represent the same value for money as a film-based camera from the perspective of the features offered and the level of control over the final image, however the price of digital still cameras is dropping so fast that by the time this paper is published there will be far better cameras available for the price. Off the shelf digital cameras are currently suitable for photogrammetric applications in archaeology, future enhancements are most likely only going to increase the suitability.

## 6. REFERENCES AND BIBLIOGRAPHY

- BEYER, H. A., UFFENKAMP, V. and van der VLUGT, G. 1995. *Quality Control in Industry with Digital Photogrammetry*. Optical 3D Measurement III, (Eds A. Gruen and H. Karara), Wichmann, Heidelberg. 533p, p29-38.
- BROWN, J., J. DOLD, 1995. *V-STARs: A System for Digital Industrial Photogrammetry*. Optical 3D Measurement III, (Eds A. Gruen and H. Karara), Wichmann, Heidelberg. 533p, p12-21.
- CANON, 1999. <http://www.canon.co.uk/> 28th May 1999
- FRASER, C.S. and SHORTIS, M. R., 1995. Metric exploitation of still video imagery. *Photogrammetric Record*, 15(85) : 107-122.
- FRYER, J. G., 1996. Camera calibration. In : *Close Range Photogrammetry and Machine Vision*, K. B. Atkinson (Editor). Whittles Publishing, Caithness, U.K. 371 pages.
- HANKE, K. and EBRAHIM, M. A-B. 1997. *A Low Cost 3D Measurement Tool for Architectural and Archaeological Applications*. *International Archives of Photogrammetry and Remote Sensing* 32(5C1B): 113-120.
- KODAK, 1999

<http://www.kodak.com/US/en/digital/genInfo/dc210.shtml> and [dc260.shtml](http://www.kodak.com/US/en/digital/genInfo/dc260.shtml), 28th May 1999

MINOLTA 1998. VI-700 3D Laser Scanner, [www.3dscanner.ch](http://www.3dscanner.ch). 15 April 1999.

OGLEBY, C.L. 1997. From Rubble to Virtual Reality: A reconstruction of the Ancient City of Ayutthaya Using Modern Photogrammetric Techniques. IAPRS 32(5C1B): 75-80.

PATIAS, P., E. STYLIANIDIS and C. TERZITANOS (1998). *Comparison of Simple Off-the-shelf and of Wide-Use 3D Modelling Software to Strict Photogrammetric Procedures for Close range Applications*. IAPRS 32(5): 628-632.

PLUG-IN Systems 1999. <http://www.plugin.com/digitalcameraguide/> 31 May 1999

POLLEFEYS, M., KOCH, R., VERGAUWEN, M., and Van GOOL L. 1998. "Virtualising Archaeological Sites". *Future Fusion: Application realities for the virtual age*. Proceedings of the 4th International Conference of Virtual Systems and Multimedia, November 1998, Ogaki, Japan. VSMM. p600-605

TRINDER, J. C., 1989. Precision of digital target location. *Photogrammetric Engineering and Remote Sensing*, 55 (6) : 883-886.