CALIBRATION OF DIGITAL CAMERA FOR MEDICAL PHOTOGRAMMETRY

Anuar Ahmad, Halim Setan, Zulkepli Majid & Albert Chong
Faculty of Geoinformation Science & Engineering
Universiti Teknologi Malaysia
81 310 UTM Skudai, Johor Bahru
MALAYSIA
Tel: 07-5530863; Fax: 07-5566163

Email: anuar@fksg.utm.my

KEYWORDS**:** Digital Close Range Photogrammetry (DCRP), low cost, medical photogrammetry, digital camera, test field

ABSTRACT

Today, there are several low cost softwares that are available in the market that could be used for digital close range photogrammetry applications such as for medical photogrammetry. Most softwares could be used to calibrate digital camera or other sensors and produce accurate results. This paper discusses about the experience of calibrating a consumer digital camera using low cost digital close range photogrammetric software. A test field was used to calibrate the digital cameras. Convergent images and retro-reflective targets were employed in the study. The process of photography and processing the photographs were carried out within short period of time. In this study, self-calibrating bundle adjustment embedded in the software was used to recover the camera calibration parameters of the consumer digital camera. Subsequently, the consumer digital camera was used to capture the photographs of human face for medical photogrammetry application. Output of calibrating the digital cameras include exterior orientation parameters, camera calibration parameters and the object space coordinates. The results showed that all the camera calibration parameters could be recovered without any difficulties and could be used to capture photographs or data for medical photogrammetry applications. Also the results from this study suggest that consumer digital camera is potential to be used in many close range photogrammetric applications and when the budget is limited.

1.0 Introduction

Close range photogrammetry has evolved rapidly and today it is known as Digital Close Range Photogrammetry (DCRP). In DCRP, the most important equipment is the digital sensor and it could be either a digital camera, CCD (*Charge Couple Device*) camera, video camera or others. Today there are various digital sensor types and models that are available in the market including digital camera. The digital camera could be in various form, cost, resolution and format. Therefore the user of digital camera should select the appropriate digital camera and it must be calibrated so that it could produce quality results. In DCRP, many studies have been carried out using digital camera which utilized 'Single Lens Reflex' (SLR) for various applications including study on the assessment of precision and accuracy aspect.

Close range photogrammetry has been reported used in diversified applications and different fields such as in various industrial applications, medical, archaeology, architecture, map revision and others. Close range photogrammetry has many advantages which include non-contact measurement, portable, precise, delivers the output in short period, cost saving and others. In close range photogrammetry, point measurement is the prime focus where the 3D coordinates of discrete points on the object or surround the object of interest will be determined (Fraser, 1996; 1997; Ahmad and Chandler, 1999). In many applications of close range photogrammetry, retro-reflective targets are often used and the targeted points together with the object are photographed using different type of sensor whether it is based on film or digital and the sensor could be of metric or non-metric types. Today, with the advent in computer technology and software, many studies have been reported where digital cameras were used. Quite often digital camera of Kodak series were reported used in close range photogrammetry such as the Kodak DCS200, Kodak DCS420 and Kodak DCS460. These digital cameras are of the "Single Lens Reflex" (SLR) types. However, digital cameras in the form of compact such as the Kodak DC40, DC50, DC120, DC210, DC220, DC280 and DC290 also have been reported used in close range photogrammetry (Miyatsuka, 1996; Litchi dan Chapman, 1997; Ahmad dan Chandler, 1999; Anuar and Siti Hamisah; 2001; Anuar *et. al.*, 2002a; 2002b).

In close range photogrammetry, the position of the targeted points could be measured automatically using program/software developed in-house or using commercial software that are available in the market. Subsequently, the data are processed using bundle adjustment program to determine 3D coordinates and to acquire camera calibration parameters. Examples of bundle adjustment program include General Adjustment Program (GAP) developed at City University, London, AUSTRALIS developed at University of Melbourne, Australia, PHOXY developed by Ingenieursbureau Geodelta bv, Delft and others. From the results of bundle adjustment, relative precision could be computed. This paper describes an experience of calibrating digital camera for acquisition of facial images. After the process of calibration, the results of calibration i.e the camera calibration parameters were used as data input into a digital photogrammetric system for data reduction of the acquired facial images.

2.0 Medical Photogrammetry

Over the last century, close range photogrammetric techniques have been used to record shape and size in studies relating to a wide range of areas of the human body such as torsos, heads, faces, limbs breasts, feet, skin, eyes and teeth. Some of these applications have been used for purpose of advancing anatomical studies while others have been related to the detection or treatment of diseases and other conditions. Although photogrammetric measurement is particularly relevant to orthopedics and anatomy, it can also contribute to ophthalmology, neurology, dentistry, occupational therapy, ergonomic studies and many other areas related to human health. The users of the results may be involved in health in various ways such as medical researchers, surgeons, clinicians, biomechanical engineers, occupational therapists and others.

According to Newton and Mitchell (1996), close range photogrammetry has a distinct values as a medical measurement tool since it uses photography which offers a quick, convenient and safe means of recording a condition at a particular point of time. It is not invasive and not touching the patient (non-contact measurement) with the risk of hurting or infecting. Further, photography does not distort the surface being measured. Close range photogrammetry can be contrasted with other external measurement techniques such as those involving electrogoniometers and accelerometers attached to the body for movement analysis which are not only uncomfortable but can interfere with the free movement of the patient. Medical photogrammetric measurement for the diagnosis and treatment of human conditions and for biomedical research, creates a class of close range photogrammetry with its own distinctive challenges and constraints. Some of the challenges and constraints are as follows:

- Medical measurement deals primarily with living human patients. Consequently, it is necessary to be concerned about their convenience, comfort, privacy and dignity. More importantly, human move continuously, even if imperceptibly over short periods of time and so quick, hence, fine synchronized imaging can be crucial.

- The measurement also involves interaction with the medical practitioner. This may require careful communication about the constraints and requirements of the measurement and the form of output. Indeed, one of the major challenges of medical photogrammetry is to provide information (e.g measurement and other information) which is appropriate, usable and medically meaningful.

- The cost of photogrammetric measurement usually needs to be kept low because the measurements are not normally crucial to saving life.

- The urgency with which the results need to be supplied to the client is very variable. For some clinical and even surgical applications, it is clear that immediate results are desirable. In other cases, a slow turnaround is acceptable.

In any close range photogrammetry application, the fundamental instrument or device is the camera type. The major decision in camera selection is between film and digital cameras. Today, most of the close range photogrammetric applications employ digital camera including medical photogrammetry. In medical photogrammetry, it must be remembered that the camera used requires synchronized photography since the state being measured normally is a dynamic one and this increases the number of cameras that are required.

3.0 Digital Camera

In close range photogrammetry, digital camera can be categorized as non-metric camera since it was not designed for photogrammetric purposes. Some of the characteristics of digital cameras are no fiducial mark, the camera calibration parameters are not stable, small format and others. The digital camera can also be categorized as (i) “Single Lens Reflex” (SLR) (i.e the lens of the camera is focusable and changeable) and (ii) compact. For SLR digital camera, the user has the full control on the camera such as controlling the focus, aperture and shutter speed. For compact digital camera, it uses the concept of point and shoot and it has the zoom facility.

According to Shortis and Beyer (1996), digital camera can be categorized as digital still camera (in short, digital camera) and analogue video camera. Digital camera could be used to acquire single image at a particular instance and the image could be stored in the camera on-board. For example, digital camera Kodak DC280 could store 32-245 images using internal storing card 20MB. For analogue video camera, it can be used to acquire continuous image as electronic signal at the rate of 30 frames per second. However, a frame grabber is required to transform the frame from analogue signal form into digital form. Both types of digital camera and analogue video camera could be used for close range photogrammetric applications. However, the use of digital camera is preferable since digital images could be obtained directly, digital images could be stored on-board, easy to operate and not necessary to use direct current. Today, there are many types of digital cameras available in the market. Any person could possess the camera either for personal use, producing report or for research and other purposes.

Digital cameras are manufactured with different sensor size and resolution. Sensor size is defined by width and height of sensor array in millimeter or inches. Sensor resolution can also be defined as the number of horizontal pixel multiplied by number of vertical pixel (Shortis and Beyer, 1996). A digital camera could be categorized as (i) low resolution if the number of pixels is less than 500,000; (2) medium resolution between 500,000 to 1.5 million and (3) high resolution if number of pixel is beyond 1.5 million (Shortis and Beyer, 1996). In this study, a compact digital camera known as CANON POWERSHOT S400 was used. This digital camera can be considered as high resolution compact digital camera (Resolution = 4.0 Megapixels). Figure 1 shows the CANON POWERSHOT S400 compact digital camera. The cost of this digital camera is much cheaper compared to digital camera of SLR type and high resolution. In close range photogrammetry, other makes of digital camera could also be used such as Fuji, Olympus and others, however, many Kodak digital cameras of different models has been reported used in many studies.

Figure 1: CANON POWERSHOT S400 compact digital camera

4.0 Methodology

In general, close range photogrammetry involves data acquisition of the object of interest and data reduction. For data acquisition, the sensor (either film or digital based) that will be used for photography needs to be calibrated so that accurate results can be obtained. For data reduction, the acquired photographs can be processed analytically or digitally using software or digital photogrammetric system.

4.1 Data Acquisition

4.1.1 Data Acquisition: Digital Camera Calibration

In this study, a calibration plate of dimension 0.5 x 0.5 m was built. This calibration plate is made of a piece of plywood with 36 screws drilled into it. Each screw has different height and on top of these screws retro-reflective target is stick on it. All the screws and the plywood are painted black. Also all the screws are in matrix arrangement as shown in Figure 2. Apart from the screws, a precise scale bar was also placed on the calibration plate. Before photography, the approximate 3D coordinates of all the screws are prepared in a file.

For the purpose of calibration, eight (8) photographs of the calibration plate were acquired from four (4) camera locations (Figure 3). At each location, two photographs were acquired where one is in landscape position and the other one is rotated 90 degree from it's original position i.e portrait position. During photography the camera flash is switched on, however, a piece of tissue paper was used to block the flash light so that not much light will be transmitted. If the flash is not covered then 'over saturated' will occur (too much light) which might cause deterioration of the calibration results. The object to camera distance is approximately 0.7 meter. Also during photography, convergent photographs were acquired where the optical axis of the digital camera always pointing towards the centre of the calibration plate and the dimension of the calibration plate should occupies as much as possible the format of the digital camera. Convergent configuration was employed since it will strengthen the geometry and with the purpose to recover focal length successfully (Fryer, 1996). Since two compact digital cameras of CANON POWERSHOT S400 will be used to acquire the stereoimage of human face both of them were calibrated using the calibration plate. Photography was done within short period of time for both digital cameras.

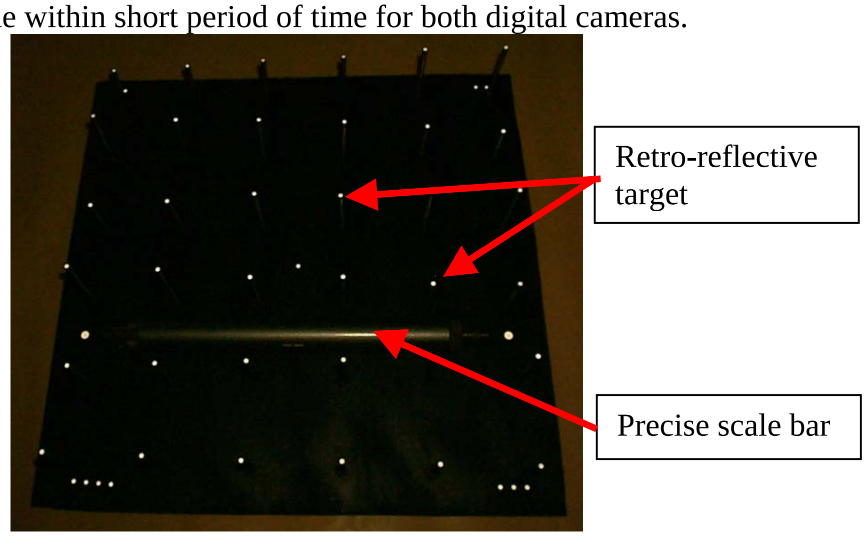

Figure 2: An image of calibration plate

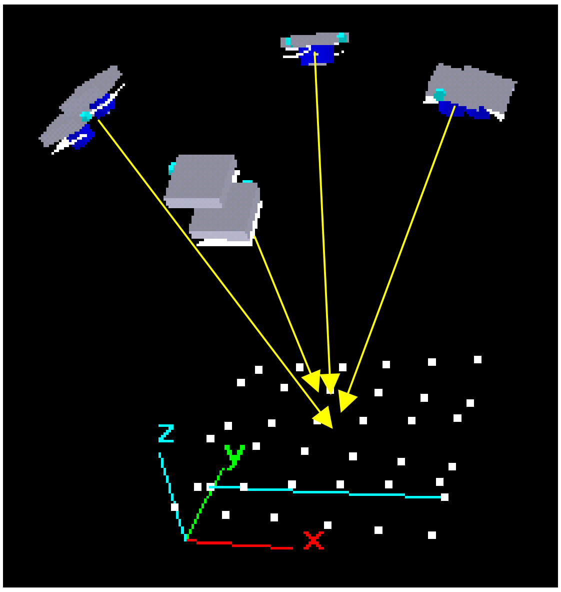

Figure 3: Location of the digital camera in space

4.1.2 Data Acquisition : Facial photography

In close range photogrammetry, normally convergent configuration is employed for photography. However, there are some applications that require the photographs in stereo form. In stereophotography, the optical axis of the camera normally pointing perpendicular towards the object of interest and should be parallel from one camera to another camera. In this study, both compact digital cameras were placed on a bar so that they can be positioned horizontally in front of the human face and both compact digital cameras were synchronized together. Figure 4 shows the two compact digital cameras placed on a bar.

Figure 4: Two compact digital cameras placed a on bar.

In this study, the two compact digital cameras were used to acquire a stereoimage of a human face. These compact digital cameras were placed 0.7 meter away from the centre of the human face. Before photography a control frame was placed with the human face. On this control frame, retro-reflective targets were placed at different depth and the coordinates of these targets were determined precisely using a software. Once the setup is ready, the synchronized compact digital cameras were used for data acquisition of a human face. Figure 5 shows an example of stereoimage of a human face.

Left image Right image

Figure 5: A stereoimage of a human face

4.2 Data Reduction

4.2.1 Data Reduction: Digital Camera Calibration

After all the photographs from both compact digital cameras have been downloaded individually into the computer, image measurement is carried out. All the photographs of the calibration plate were measured semi-automatically using a close range photogrammetric software known as AUSTRALIS. This software can be used to determine the 3D coordinates of the points on the object (i.e retro-reflective targets) and the camera calibration parameters. The coordinates for the centre of the retro-reflective targets of the calibration plate were determined using ‘weighted mean’ technique. The results of the camera calibration are tabulated in Section 5.1.

4.2.2 Data Reduction: Facial photography

After a stereoimage of a human face is acquired and downloaded into the computer, anthropometric measurements can be carried out. Before anthropometric measurement can be carried out, a replica of the 3D human face in a photogrammetric system should be setup and this replica is known as stereomodel. In this study, the stereomodel of the human face was setup using a digital photogrammetric system known as Digital Video plotter (DVP, developed in Canada). This system comprises of hardware (two monitors, a keyboard and one CPU) and software. Also this system requires a special glasses known as stereoscopic glasses for viewing the stereomodel in three dimensional (3D) mode. Figure 6 shows the digital photogrammetric system used for anthropometric measurement. In brief, a few processes should be carried out before the stereomodel can be setup. These processes are known as interior, relative and absolute orientation. After completing these three processes in sequence, the stereomodel is setup and ready for measurement. In this study, the distances between the anthropometric landmarks were measured manually using a caliper and DVP.

The distances between the anthropometric landmarks were measured three times (3x) and the mean is computed. The results of the anthropometric measurements in shown in Section 5.2

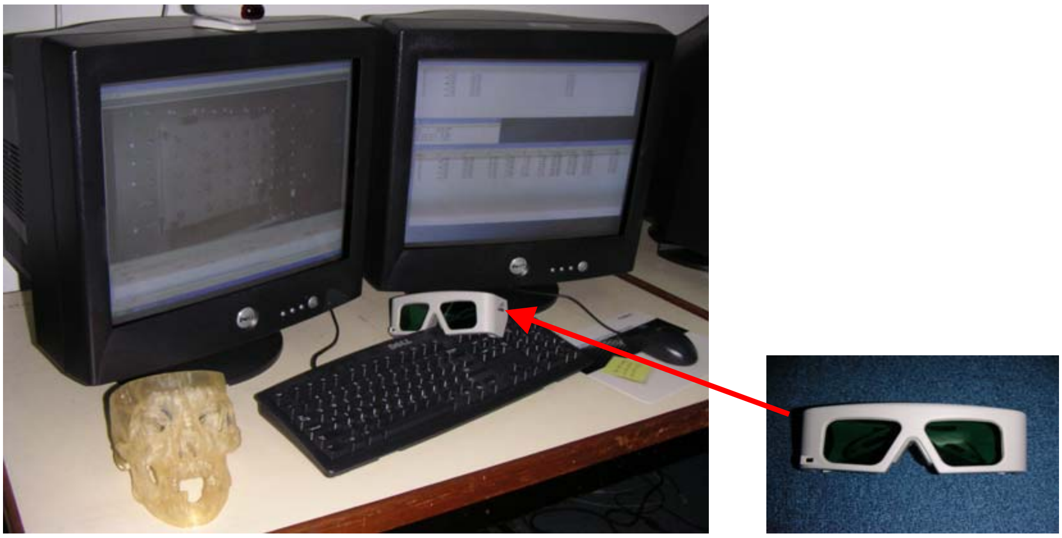

Figure 6: Digital Video Plotter (DVP)

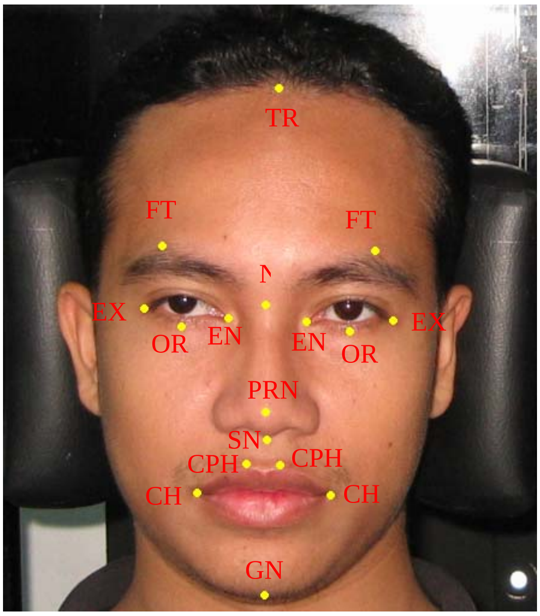

Figure 7: Location of the anthropometric landmarks

5.0 Results

From this study, two sets of results were produced. The first results are the camera calibration parameters obtained from calibrating the digital camera and the second results are anthropometric measurements obtained from the digital photogrammetric system.

5.1 Camera Calibration Parameters

Table 1 shows the estimated parameters together with their standard deviation of camera calibration parameters of one of the calibrated compact digital camera. The camera calibration parameters consist of the focal length (c), principal point offset (x_p, y_p), radial (k_1, k_2, k_3) and tangential (p_1, p_2, p_3) lens distortion, "affinity"(b_1) and different in scale factor (b_1). The other compact digital camera has the same camera calibration parameters but the values are not the same.

Table 1 : Camera calibration parameters of one of the compact digital camera

DIGITAL	CAMERA CANON	POWERSHOT S400
Parameter		**Std. Deviation**
c (mm)	7.2602	1.547e-016
x_P (mm)	0.0025	1.544e-004
y_P (mm)	0.0018	1.545e-004
k_1	2.15690e-003	1.390e-005
k_2	-1.13033e-025	1.547e-016
k_3	-1.42507e-024	1.547e-016
p_1	3.58962e-025	1.547e-016
p_2	4.76467e-025	1.547e-016
b_1	2.32331e-028	1.547e-016
b_2	-6.60168e-027	1.547e-016

5.2 Anthrophometric Measurement Of Human Face

Table 2 shows the distances between the anthropometric landmarks of a human face. As mentioned in Section 4.2.2, the distances between the anthropometric landmarks were measured 3x using both the caliper and DVP. In this paper, only one stereoimage was acquired from the front of the human face. From the table, the greatest distance difference is between TR-N. This difference arise due to the problem of identifying the exact position of point N. Consequently, the distance between N-SN is also affected. If this point can be located correctly then there is possible that the distance difference will be less. Hence, the operator of the digital photogrammetric system need the assistant of a doctor or surgeon in locating this point correctly since no artificial target was used to represent this point.

For future work, another two more stereoimages will be acquired, setup the model in same manner as in this study and carry out the anthropometric measurement. These two stereoimages will be acquired from the left and the right sides of the human face. After all the necessary anthropometric measurements are carried out, these data can be used for the development of craniofacial database. Also in future, more stereoimages of human face will be acquired, processed and measured perhaps based on races, gender, age group and others.

Table 2: Anthropometric measurement (distances) of human face

Anthropometric Landmarks	Caliper Distance(mm)	DVP Distance(mm)	Differences DVP-Caliper(mm)
EX - EX	97.067	98.736	1.669
EN - EN	35.033	33.490	-1.543
TR - N	65.050	69.195	4.145
N - SN	55.067	58.695	3.628
SN - GN	62.850	65.159	2.309
CH - CH	55.133	54.084	-1.049
FT - FT	83.467	85.433	1.966
CPH - CPH	11.383	10.065	1.318
PRN - N	48.817	45.427	3.390
OR - OR	64.183	65.962	1.779

5.0 Conclusion

From this study, it was found that the compact digital camera CANON POWERSHOT S400 could be calibrated within short period of time and all the camera calibration parameters could be recovered. These parameters were then used to rectify the stereoimage in the digital photogrammetric system, DVP. Not all the parameters were used. The parameters used for the system comprise of the focal length (c) and the principal point offset (x_p, y_p). The other parameters were not used since their values are too small and not significant.

From the stereoimage, the stereomodel of the human face could be setup also within a short period of time with appropriate camera calibration data obtained from the process of camera calibration and control points from the control frame. Also the anthropometric measurements could also be measured easily after the formation of the stereomeodel of the human face since not many anthropometric landmarks were used. Finally, the results from this study can be used in developing the craniofacial database of Malaysia.

Acknowledgement

This research is part of a prioritised research IRPA Vot 74537 sponsored by Ministry of Science, Technology & Innovation (MOSTI), Malaysia. The authors would like to thank MOSTI for funding the research.

6.0 References and Bibliography

Anuar Ahmad, 2000. *Kemampuan kamera berdigit : Berpotensi digunakan dalam berbagai aplikasi*. Malaysian Science and Technology Congress (MSTC 2000), 7-9 November, 2000, Genting Highlands, Pahang.

Anuar Ahmad and Siti Hamisah Tapsir, 2001. *First Malaysian fullscale fire test of steel structure: Detection of beam deflection using non-contact measurement* Malaysian Science and Technology Congress (MSTC 2001), Riviera Bay Resort, Melaka, 8-10 Oktober 2001.

Anuar Ahmad, Ibrahim Busu and Ghazali Desa, 2002. *Assessment of the impact of digital camera's resolution on accuracy and precision of targeted points.* International Symposium and Exhibition on Geoinformation 2002, 22-24 October 2002, Kuala Lumpur, MALAYSIA.

Anuar Ahmad, Zulkepli Majid and Eileen Yap Chin Yueng, 2002. *Digital camera calibration using low cost software*. International Symposium and Exhibition on Geoinformation 2002, 22-24 October 2002, Kuala Lumpur, MALAYSIA.

Ahmad, A and Chandler, J.H., 1999. *Photogrammetric capabilities of the Kodak DC40, DCS420 and DCS460 digital cameras*. Photogrammetric Record, 16(94): 601-615.

Cooper, M.A.R. and Robson, S., 1996. *Theory of close range photogrammetry*. Close range photogrammetry and machine vision (Ed. K.B. Atkinson). Whittles Publishing, Caithness, Scotland, U.K. 371 pages: 9-51.

Fraser, C.S. and Shortis, M.R., 1995. *Metric exploitation of still video imagery*. Photogrammetric Record, 15(85): 107-122.

Fraser, C.S., 1996. *Industrial measurement applications*. Close range photogrammetry and machine vision (Ed. K.B. Atkinson). Whittles Publishing, Caithness, Scotland, U.K. 371 pages: 329-361.

Fraser, C.S., 1997. *Digital camera self-calibration*. ISPRS Journal of Photogrammetry & Remote Sensing. Vol. 52 :149-159.

Fryer, J.G., 1996. *Camera calibration*. Close range photogrammetry and machine vision (Ed. K.B. Atkinson). Whittles Publishing, Caithness, Scotland, U.K. 371 pages: 156-179.

Litchti, D.D. and Chapman, M.A., 1997. *Contrained FEM self-calibration.* Photogrammetric Engineering & Remote Sensing, Vol. 63 (9):111-1120.

Miyatsuka, Y., 1996. *Archeological real-time photogrammetric system using digital still camera.* International Archives of Photogrammetry and Remote Sensing, 31(B5):374-375.

Newton, I. and Mitchell, H.L., 1996. *Medical photogrammetry*. Close range photogrammetry and machine vision (Ed. K.B. Atkinson). Whittles Publishing, Caithness, Scotland, U.K. 371 pages: 303-327.

Shortis, M.R. and Beyer, H.A., 1996. *Sensor technology for digital photogrammetry and machine vision*. Close range photogrammetry and machine vision (Ed. K.B. Atkinson). Whittles Publishing, Caithness, Scotland, U.K. 371 pages: 106-155.

Warner, W.S. and Slaattelid, B.R., 1997. *Multiplotting with images from the Kodak DCS 420 digital camera*. Photogrammetric Record, 15(89):665-672.

Wolf, P.R., 1983. *Element of Photogrammetry*.