Distortion impact on a stereo distance

Jernej Mrovlje[1], Damir Vrančić[2]

Abstract—**Stereoscopy is a technique used for recording and representing stereoscopic images. Information extracted from images and stereoscopic system data allow us to calculate the distance between the system and any object within the image. For this purpose, program called »Stedimat«, was recently developed. Our stereoscopic system consists of two cameras Canon PowerShot A640. For a cameras in this class, optical errors, especially distortion, is a common problem. Camera calibration procedure using Camera Calibration Toolbox for Matlab was done in order to determine the amount of distortion presented in the pictures. Further, using proposed distortion model, »distortion-correction function« was built as a part of the Stedimat. Four experiments have been conducted in order to evaluate distortion model and to test the effectiveness of the build-in function.**

I. INTRODUCTION

In comparison to a high precision photogrammetric cameras, where calibration is done using expensive specialised equipment, the use of consumer "non-metric" cameras in photometry requires applications of several calibration procedures. They are computationally inexpensive.

Most frequently used calibration procedures are radial distortion correction techniques. They use the polynomial approximation model, first proposed by Brown [2]. This approach relies on the fact that the straight lines must perspectively project to straight lines in the image. Furthermore, Kang suggested so-called "radial distortion snakes" to compute radial distortion parameters [9]. Becker and Bove introduced a technique to solve for radial and tangecial lens distortion directly from the results of vanishing point estimation [10]. Stein uses epipolar and trilinear constraints and searches for the amount of radial distortion that minimizes the errors in these constraints. Perš and Kovačič introduced a radial distortion model with a single parameter (the focal length) [5].

There are several types of optical aberrations. While chromatic and spherical aberration affect image quality only, tangential and radial distortion affect image geometry. The radial distortion causes an inward or outward displacement of a given image point from its ideal location. When image points get displaced from the original location to the position closer to the optical axes (negative radial displacement), barrel distortion occurs. In contrary, when image points get displaced from the original location to the position away from optical axes (positive radial displacement), pincushion distortion occurs. Barrel distortion is common for inexpensive cameras with wide-angle lenses. Effect of radial distortion on image geometry is illustrated in Fig. 1.

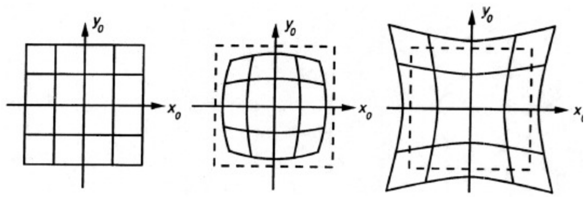

Figure 1. Barrel distortion (middle) and pincushion distortion (right).

Stereoscopic distance is calculated from differences between the position of selected object on the left and right image and additional technical data like focal length and distance between the cameras in the stereoscopic system. If the object in the image is misplaced due to distortion, the calculated distance is incorrect. Understanding distortion impact on image geometry is therefore significant for accurate 3D measurements.

II. DISTORTION AND CAMERA CALIBRATION

Distortion can be compensated mathematically, first by applying a parametric distortion model, estimating the distortion coefficients and then correcting the distortion. Polynomial approximation model of radial distortion is:

$$r_d = r + k_1 r^3 + k_2 r^5 + k_3 r^7 + \dots , \qquad (1)$$

where k_1, k_2, k_3... are radial distortion coefficients, r_d distorted radial distance ($r_d^2=x_d^2+y_d^2$), r undistorted radial distance ($r^2=x^2+y^2$), [x_d y_d] distorted point coordinates and [x y] undistorted point coordinates. Authors agree that the fifth order of polynomial is sufficient [8].

Calibration was done using »Camera Calibration Toolbox for Matlab [7]. For each camera in the system, a sequence of 20 images of the calibration board (with checkerboard pattern) was taken in different orientations. Six example calibration images are shown in Fig. 2. Within each image a set of known calibration points (intersections between white and black fields) were automatically identified (see Fig. 3). Using the coordinates of distorted and undistorted points, following parameters are calculated: focal distance (in

[1] Jernej Mrovlje is with Department of Systems and Control, J. Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia (e-mail: jernej.mrovlje@ijs.si).
[2] Damir Vrančić is with Department of Systems and Control, J. Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia (e-mail: damir.vrancic@ijs.si).

pixels), principle point, angle between the x and y sensor axes and distortion parameters k_c.

Camera Calibration Toolbox uses Brown's distortion model also known as »Plumb Bob«:

$$\begin{bmatrix} x_d \\ y_d \end{bmatrix} = (1 + k_c(1)r^2 + k_c(2)r^4)\begin{bmatrix} x \\ y \end{bmatrix} + dx. \qquad (2)$$

where $r^2=x^2+y^2$ and dx is a tangential distortion vector:

$$dx = \begin{bmatrix} 2k_c(3)xy + k_c(4)(r^2 + 2x^2) \\ k_c(3)(r^2 + 2y^2) + 2k_c(4)xy \end{bmatrix}. \qquad (3)$$

The tangential distortion is due to imperfect centering of the lens components.

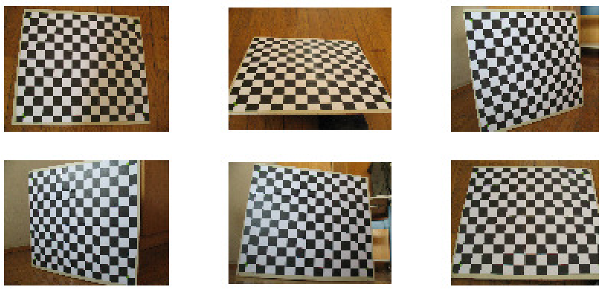

Figure 2. Calibration board taken in six different orientations.

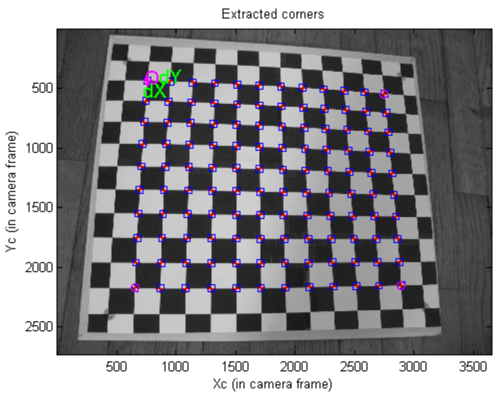

Figure 3. Automatic identification of calibration points within manually defined area on the calibration board.

Impact of the complete distortion model (2) on each pixel of the image for our cameras is shown in Figs. 4 and 5. Arrows represent the negative radial displacement of pixels introduced by the lens distortion. In the centre of the image, the size of displacement is up to 10 pixels, but it grows up to 100 pixels at the corners of the image. As expected, distortion impact is immense.

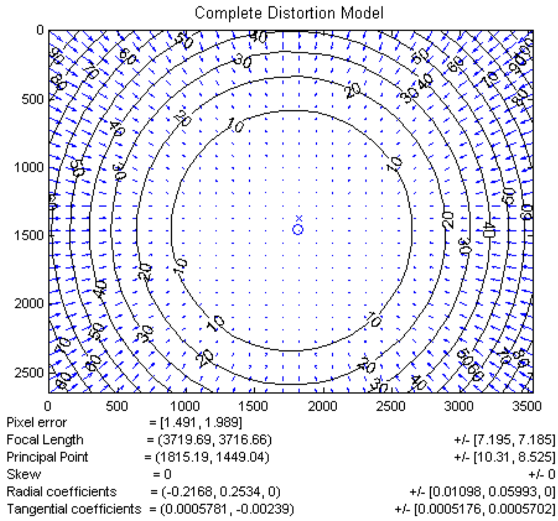

Figure 4. Visualized complete distortion model for left camera.

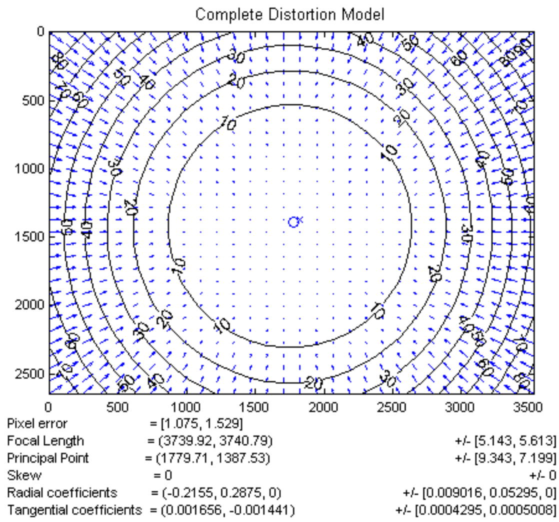

Figure 5. Visualized complete distortion model for right camera.

Application STEDIMAT (Stereo Distance Measuring Tool) to calculate the distance between the stereoscopic system and selected object within the image was developed recently [4]. It was written in program package Matlab and compiled with Matlab Compiler. The distance D to the object is calculated by using the following equation:

$$D = \frac{Bx_0}{2\tan\left(\frac{\varphi_0}{2}\right)(x_L - x_D)}, \qquad (4)$$

where B is a distance between cameras in the system, x_0 horizontal image resolution, φ_0 camera's horizontal angle of view and x_L-x_D difference between location of the object in left and right image.

Distortion model presented in (2) was used to build »distortion-correction function« (DCF) as a part of the

Stedimat. For every distance calculated, DCF has to be applied only twice - for two distorted image points. First distorted image point is the location of the selected object in the left image (x_L) and second is the location of the object found in the right image (x_D).

III. EXPERIMENTAL RESULTS

In order to evaluate distortion model and test the effectiveness of the built-in DCF, four sets of images were taken. Seven test objects (panel boards) were positioned at the distance D from the stereoscopic system as shown schematically in Fig. 6 and then photographed. Images were taken manually at distances 30, 40, 50 and 60 meters. For each distance test objects were rearranged accordingly, so they covered whole field of view of stereoscopic system. Detailed view of a sample stereoscopic pair of image is shown in Fig. 7.

Distance to each test object was calculated twice:

1. using distorted image points of the object's location,

2. using distortion-free image points of the object's location (using DCF).

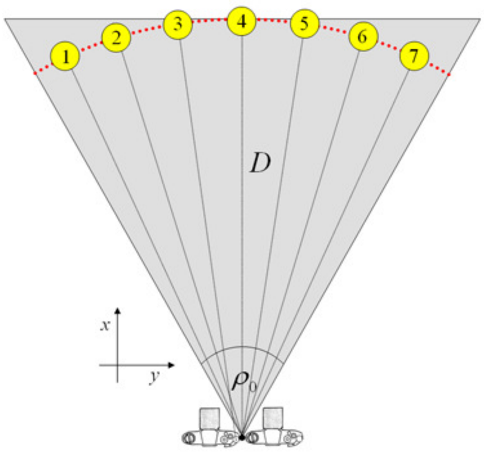

Figure 6. Schematic arrangements of test objects.

Figure 7. Detailed view of a sample stereoscopic pair of image (top: left image, bottom: right image)

Results are shown in Tables1-4 and graphically in Figures 8-11.

TABLE I
CALCULATED DISTANCES FOR TEST OBJECTS AT 30 METERS

Test object No.	Distorted image points $D_1 \pm \Delta D_1$ [m]	Distortion-free image points $D_1 \pm \Delta D_1$ [m]
1	28,71±0,38	29,55±0,40
2	28,71±0,38	29,00±0,39
3	29,13±0,39	29,34±0,40
4	30,00±0,42	30,00±0,42
5	30,93±0,44	29,86±0,41
6	31,91±0,47	29,66±0,41
7	33,51±0,52	28,42±0,37

TABLE II

CALCULATED DISTANCES FOR TEST OBJECTS AT 40 METERS

Test object No.	Distorted image points $D_2 \pm \Delta D_2$ [m]	Distortion-free image points $D_2 \pm \Delta D_2$ [m]
1	38,46±0,68	40,22±0,75
2	38,47±0,68	39,29±0,71
3	38,47±1,68	39,01+0,70
4	40,00±0,74	40,00±0,74
5	42,55±0,84	40,75±0,77
6	43,47±0,87	39,31±0,71
7	46,49±1,00	36,79±0,62

TABLE III

CALCULATED DISTANCES FOR TEST OBJECTS AT 50 METERS

Test object No.	Distorted image points $D_3 \pm \Delta D_3$ [m]	Distortion-free image points $D_3 \pm \Delta D_3$ [m]
1	46,52±1,00	49,06±1,11
2	46,52±1,00	47,79±1,05
3	47,62±1,05	48,52±1,07
4	50,00±1,15	50,00±1,15
5	54,04±1,35	51,42±1,22
6	57,12±1,51	50,53±1,18
7	64,47±1,92	48,83±1,10

TABLE IV

CALCULATED DISTANCES FOR TEST OBJECTS AT 60 METERS

Test object No.	Distorted image points $D_4 \pm \Delta D_4$ [m]	Distortion-free image points $D_4 \pm \Delta D_4$ [m]
1	56,61±1,48	60,32±1,68
2	56,61±1,48	59,04±1,61
3	56,61±1,48	58,14±1,56
4	60,00±1,66	60,00±1,66
5	63,82±1,88	60,28±1,68
6	70,56±2,30	60,70±1,70
7	78,89±2,87	57,99±1,55

Experiment results show that there is a bigger distortion impact on the right side of the image, while on the left side of the image, distortion is not noticeable. Using distorted image points results in distance error up to 5 pixels. When DCF is used (to get undistorted image points), distance error is significantly reduced. Brown's distortion model proves to be quite accurate. Nevertheless there is still some systematic error present on the right side of the images, when using DCF. The reason for the error is not known yet, but it is assumed to be the keystone distortion. In Tables V-VI, an absolute distance error in pixels is presented.

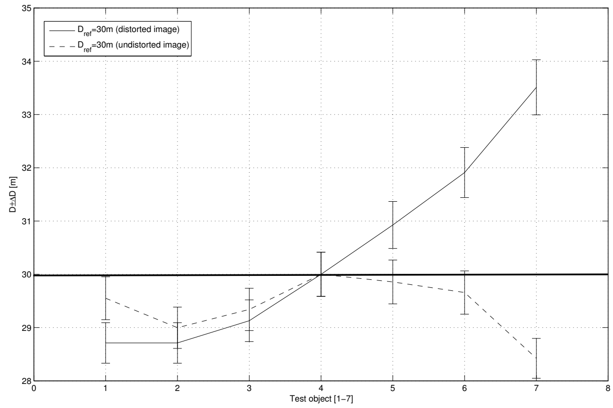

Figure 8. Calculated distances for test objects at 30 meters

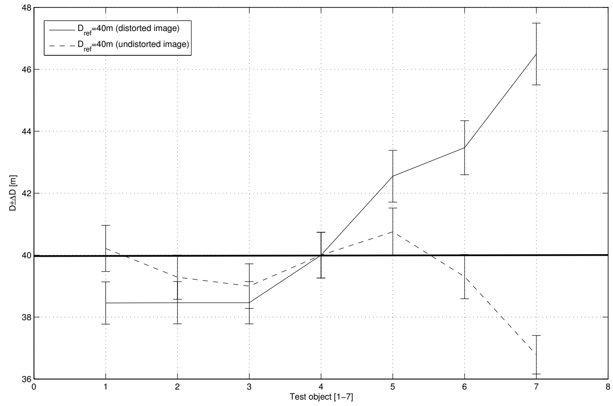

Figure 9. Calculated distances for test objects at 40 meters

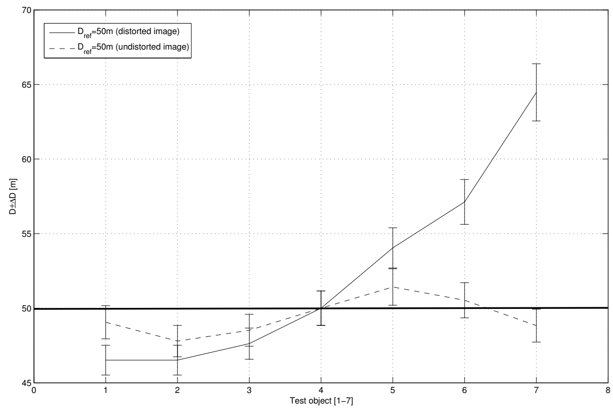

Figure 10. Calculated distances for test objects at 50 meters

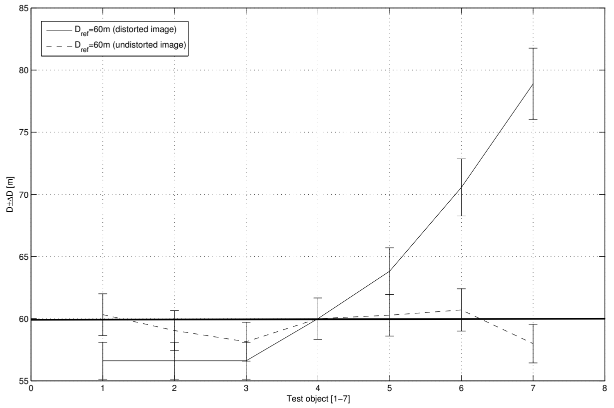

Figure 11. Calculated distances for test objects at 60 meters

TABLE V

ABSOLUTE DISTANCE ERROR FOR DISTORTED IMAGES (IN PIXELS)

Test object No.	D_{ref}=30m	D_{ref}=40m	D_{ref}=50m	D_{ref}=60m
1	3,4	2,3	3,5	2,3
2	3,4	2,2	3,5	2,3
3	2,2	2,2	2,3	2,3
4	0,0	0,0	0,0	0,0
5	2,1	3,1	3,0	2,0
6	4,1	4,0	4,7	4,6
7	6,8	6,5	7,5	6,6

Test object No.4 – reference point

TABLE VI

ABSOLUTE DISTANCE ERROR FOR UNDISTORTED IMAGES (IN PIXELS)

Test object No.	D_{ref}=30m	D_{ref}=40m	D_{ref}=50m	D_{ref}=60m
1	1,1	0,3	0,8	0,2
2	2,6	1,0	2,1	0,6
3	1,7	1,4	1,4	1,2
4	0,0	0,0	0,0	0,0
5	0,4	1,0	1,2	0,2
6	0,8	1,0	0,5	0,4
7	4,2	5,2	1,1	1,3

Test object No.4 – reference point

REFERENCES

[1] D. Schulte: Welt der stereoskopie. Available: http://www.stereoskopie.com. [viewed 20.5.2009].

[2] D.C. Brown, "Decentering Distortion of Lenses," Photogrammetric Eng., vol. 32, no. 3, pp. 444-462, May 1966.

[3] J. Carnicelli: Stereo vision: measuring object distance using pixel offset. Available: http://www.alexandria.nu/ai/blog/entry.asp?E=32. [viewed 26.5.2009].

[4] J. Mrovlje, D. Vrančić (2008): Distance measuring based on stereoscopic pictures, in Proceedings of the 9th International PhD Workshop on Systems and Control: young generation viewpoint. Izola, Slovenia: October 2008.

[5] J. Perš, S. Kovačič (2002): Nonparametric, Model-Based Radial Lens Distortion Correction Using Tilted Camera Assumption, in Proceedings of the Computer Vision Winter Workshop, 2002. Bad Aussee, Austria. pp.286-295.

[6] T. Luhmann, H. Hastedt, W. Tecklenburg, (2006): Modelling of chromatic aberration for high precision photogrammetry, in ISPRS Symposium Commission V. Dresden: September 2006.

[7] J.-Y. Bouguet: Camera Calibration Toolbox for Matlab. Available: http://www.vision.caltech.edu/bouguetj/calib_doc. [viewed 22.4.2009].

[8] L. Ma, Y. Chen, K. L. Moore (2003): A New Analytical Radial Distortion Model for Camera Calibration. CoRR cs.CV/0307046: (2003).

[9] S.B. Kang, (1997): Semi-Automatic Methods for Recovering Radial Distortion Parameters from a Single Image, Technical Reports Series CRL 97/3, DEC, Cambridge Research Labs, May 1997.

[10] S. Becker, V. Bove (1995): Semi-automatic 3D model extraction from uncalibrated 2D camera views, in Visual Data Exploration and Analysis II, Proc. SPIE 1898, 447–461 (1995).