QUALIFICATION OF CLOSE RANGE PHOTOGRAMMETRY CAMERAS BY AVERAGE IMAGE COORDINATES RMS ERROR VS. OBJECT DISTANCE FUNCTION

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ABSTRACT:

In this publication, the concept of image coordinate RMS error derived from average object side RMS is introduced. In the course of derivation, data on network geometry and redundancy were taken into consideration; thereby camera output for a given object distance was characterized by this quantity independent of the shooting arrangement. If this value is determined for several object distances, a function of average image coordinate RMS error vs. object distance is yielded, which, in our opinion, properly characterizes the photogrammetric potential of a given camera. This function was determined – using new measurement results – for a mobile phone with a camera and a digital camera frequently applied in our days; in addition, it was generated for a professional camera used in the 1990s, KODAK DCS, by using former results.

1. INTRODUCTION

Digital photography is widely used, nowadays more and more people have digital cameras or own a device which is capable to capture digital images, like mobile phones with built in camera or webcams etc. (Ebrahim, 2004.) Digital cameras became obligate in close range photogrammetry during the last decades. The wide assortment of digital cameras raise the question: is there any way to qualify digital cameras from photogrammetric aspect? In this paper we introduce a possible method based on a function of the average image coordinate RMS error and the object distance.

1.1 Image coordinate RMS error deducted from object side RMS error

Close range photogrammetric networks are substituted by their points. Determination of the network involves the determination of the coordinates of these points. Network qualification is linked to point-coordinates. When we look for a correlation between the accuracy of the object coordinates and the accuracy of the image coordinates, we will find direct proportionality, but it is easy to see that there must be other factors, too. In accordance with the literature on close range photogrammetry (Fraser, 1996; Mason, 1995) the main factors are image scale, network redundancy and a design factor expressing the strength of the network. An initial precision indicator can be given by the formula (Fraser, 1996):

$$\bar{\sigma}_c = \frac{q}{\sqrt{k}} S\sigma = \frac{q}{\sqrt{k}} d\sigma_a \qquad (1)$$

where $\bar{\sigma}_c$ = experimental error of object coordinates X,Y,Z;
S = scale of the image;
d = is the object distance,
σ = average error of image coordinates;
σ_a = average error of angle measurement,
q = design factor characteristic of the network,
k = ratio of independent perceptions and the number of images

For experimental close range photogrammetry design, the values of the factor q in formula (1) represent specific figures associated with each generic network of the network set, and they fall between 0.4 to 0.8 for favourable generic convergent multi-stage close range photogrammetric networks. The value k for a generic network is usually given as 1, and can be raised by adding more camera stations and/or multiple exposures, but the value can also be a fraction number depending on the correlation (Mason 1995).

Recasting equation (1) by expressing the object distance results in the following correlation:

$$d = \frac{\bar{\sigma}_c \sqrt{k}\ c}{q\ \sigma} \qquad (2)$$

This object distance can be considered as the maximum allowable camera-to-object distance keeping the required accuracy, because if the camera is placed farther away, the median errors of object-size point coordinates will also increase (Fraser, 1996).

Equation (1) in consideration of (2) provides an opportunity to classify a camera as a recording unit in certain ranges of object distance. In addition, there is a chance to make the precision indicator independent of q and k. Inspection of differently arranged networks allows eliminating the values related to the network geometry and redundancy, resulting in a function where the variable is the object distance. In this paper we present several qualification measures of different digital cameras. The classification method was the following: different objects with identified and measured points were captured, some of the points with known coordinates were used as control points, some of them were calculated as new points during the photogrammetric object space reconstruction process, so the average object side RMS error can be calculated from real errors. The standard deviation of coordinate differences gives

$$\sigma_X^2 = \frac{\sum_{i=1}^{n_X} \Delta X_i^2}{n_X}; \quad \sigma_Y^2 = \frac{\sum_{i=1}^{n_Y} \Delta Y_i^2}{n_Y}; \quad \sigma_Z^2 = \frac{\sum_{i=1}^{n_Z} \Delta Z_i^2}{n_Z} \qquad (3)$$

where σ_X^2, σ_Y^2, σ_Z^2 = variances,
ΔX, ΔY, ΔZ = coordinate differences,
n_X, n_Y, n_Z = number of differences.

The square root of the summed variances in (3) gives the required average object-side root means square error. Placing this value in equation (1) and rearranging the equation gives the average image-side root means square coordinate error, which is valid only at this object distance and recording unit.

2. DATA GATHERING

2.1 Cameras used in the experiments

Three different types of camera were used in our experiments:

1. A relatively cheap mobile phone (*Samsung SGH-D600E*) with built-in 2 megapixel f=3.35mm CMOS 2M digital camera with 4x zoom (Fig 1.),
2. A *Kodak DCS-420* camera, which was one of the first digital single-lens-reflect cameras. It was mounted on a Nikon body and has a resolution of 1.3 megapixels. A Nikon 50mm F1.8 lens was used with it. The international literature in the '90s refers to this camera as an extraordinary good one. Obviously, the qualification of this camera was based on re-using photographs taken by this camera formerly.(Fekete, 1996)
3. A *Sony DSC-R1* camera. It has a 10.3 megapixel CMOS unit and Carl-Zeiss 24-120mm F2.8-4.8 lenses. (Fig 2.)
4.

Figure 1. Samsung SGH-D600E

Figure 2. Sony DSC-R1

2.2 Test fields used

We used three different sized test-fields. In the field of close range photogrammetry, where objects of some tens of centimeters or smaller are surveyed, the usual survey procedure is to build a precise network of high stability, measure it precisely, place various small-sized objects into this pre-fabricated network then take images and specify the geometric parameters required. Such a test-field – termed as a Manhattan-type test field in the literature frequently – was built at the Department of Photogrammetry and Geoinformatics at the Budapest University of Technology and Economics. (Fig 3.) Up till now the construction of this test-field and the related researches were published in Hungarian only. This small mobile test field was used during the project published in this paper where the camera parameters of some ten centimeters were gathered. The camera positions were similar to the optimal configuration for generic networks given by Mason (Mason, 1995). The camera parameters for 2 to 4 meters of camera-to-object distance were determined using a larger test field built up in a room of the department. (Fig. 4.) The camera configuration network was the same as above.

For the examination of taking images from greater distances a ground test-field was set up in the yard of the Budapest University of Technology and Economics (BME). (Fig. 5.) This test-field was oriented by geodetic means, that is, the points previously specified were provided with 3D coordinates. The location of the points enables us to select and assign control points of an appropriate number and accuracy and proper differences in depth, which are spread evenly in the images. The camera configuration network followed the arrangement by Schlögelhofer (Schlögenhofer, 1989).

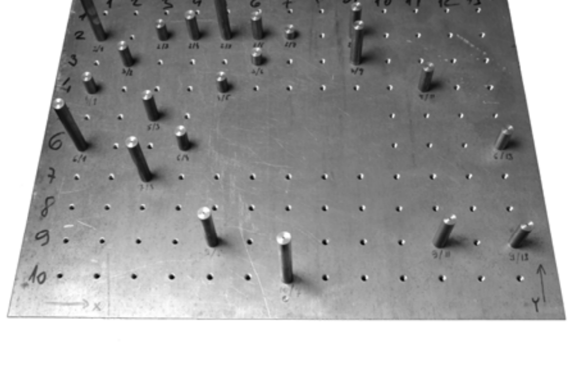

Figure 3. Manhattan-type test-field

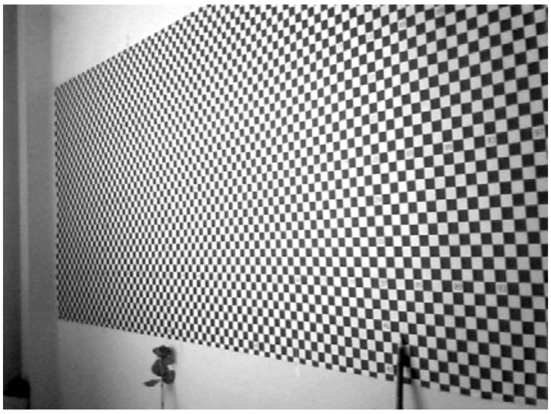

Figure 4. Mid-distance test-field

Figure 5. Ground test-field

3. IMAGE COORDINATE DETERMINATION AND OBJECT-SIDE RECONSTRUCTION

Photogrammetric measurements are not performed on the object itself but on the images taken thereof. The images generated by cameras are handled as digital files by the computer. 2D measurements of digital files are mainly performed on a computer display. Today's measurement technologies allow that the determination of image coordinates is not equal to specifying pixel indices; more accurate ones are also feasible.

In order to increase measurement accuracy, literature references (i.e. Luhman, 2000) emphasize the importance of point specifications. In the event of manual evaluation, the standard deviation of a measurement was examined using wedge-shaped marking in the course of our experiments. Having used images produced from several distances and several directions, this value always remained under 0.3 pixel, therefore this value is going to be used when qualifying image coordinates.

To perform these calculations, a software written in Turbo Pascal with a Graphical User Interface, developed by the Department of Photogrammetry of BME was used. (Schrott, 2005) The software is not capable to measure image coordinates; this task must be tackled separately. The DLT software calculates the object-side coordinates of unknown points from the image coordinates already determined and using the list of coordinates of points with known coordinates, providing results in the form of both a list of coordinates and a DXF file suitable for further processing by a CAD programme.

4. RESULTS

Our experimental results published here are the functions described above (Fig. 6,7,8) for these cameras. Easy to see that the mobile phone camera produces not just the worst values, but the tendency of the function is almost exponential.

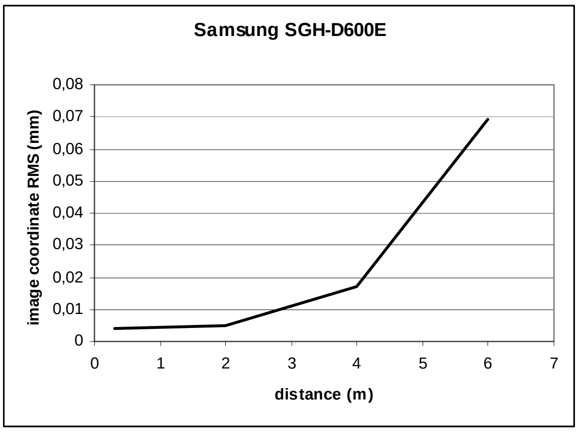

Figure 6. Samsung SGH-D600E

Both the other cameras produced linearly worsening values.

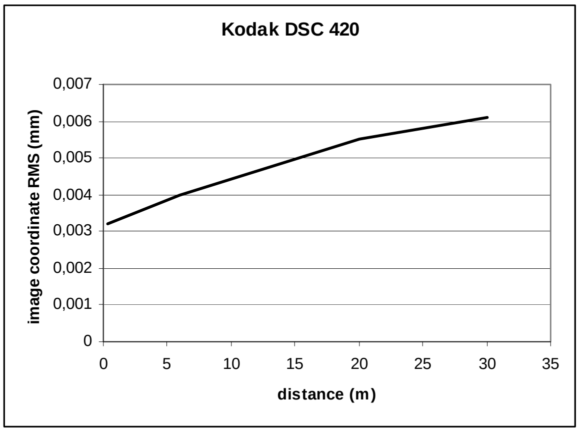

Figure 7. Kodak DSC 420

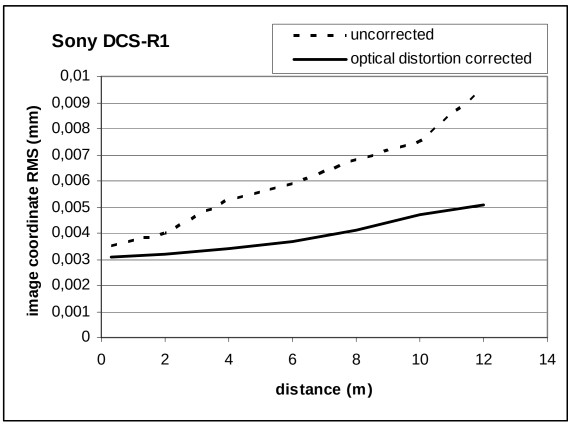

Figure 8. Sony DSC R-1

We present two functions for the Sony camera. If we use image coordinates directly as measurement results in our calculations, the results are inferior to those of the old Kodak camera. This is due to the optical distortion of the lenses, as upon measuring and correcting for these distortions, the measurements taking it into account result in a much better camera function.

5. CONCLUSION

In our opinion, average image coordinate RMS error vs. object distance function properly characterizes the photogrammetric capability of a recording unit.

Object-side data of relatively high and homogeneous accuracy can be gained by mobile phones' even simpler built-in cameras if the picture is taken from a few decimetres off. It was proven during our experiments that the homogeneity of object-side data can only be assured by four pictures in a geometrically appropriate arrangement and an adequate level of redundancy in control points. To increase precision, it is more important to acquire more images than to acquire more control points. The relationship between redundancy and the accuracy gained is not linear: above a certain level of redundancy, a marked decline in gain can be observed.

Our function for the Kodak DCS camera is in agreement with the excellent qualifications found in literature for years. Only using the optical distortion-corrected Sony images could result in better camera function than the KODAK DCS in our experiments.

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