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## Research Article

## Defining the Relationship between the Diameters of the Points Used in 2D Test Platforms and the Parameters Obtained from Camera Calibration

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### Abstract

With the developing technology in recent years, there has been a significant increase in 3D spatial data needs and data production. 3D spatial data occupy an important place in almost every field. As a result, there is a need for 3D spatial data production and the produced data's reliability. Like all spatial measuring equipment, cameras, which are data production units used in photogrammetry, must also be calibrated to produce reliable data. Calibration for non-metric cameras is critical to ensure that the measurements are highly accurate and at standards acceptable to everyone. In this study, to determine the factors affecting the calibration, terrestrial photogrammetric images were taken with a Canon EOS 600D non-metric camera with different point diameters on the calibration paper. These images were evaluated in the camera calibration software, and the photogrammetric result accuracies were investigated. The effects of the point diameters on the camera calibration paper on the calibration results have been observed. A4, A3, A0 sizes were printed and calibrated for both calibration papers. As a result of the printouts, as can be predicted, the largest point sizes are A0, which has the largest paper size, and according to the results, it was seen that the highest accuracy was achieved in the A0 dimension. The Relationship between the accuracy obtained in the calibration process and the point diameters in the test area was examined in this study. When the 144-point test area presented by the software is printed in A0 size, the point diameters were measured 1.00 cm. In this study, calibration processes were performed as 1.00 cm, 1.20 cm, 1.40 cm, 1.60 cm, 1.80 cm, and 2.00 cm by enlarging the point diameters by 20%, and more accurate results were obtained more quickly than other paper sizes and calibration methods. As a result, since the calibration of the device to be used in the studies directly affects the model's accuracy to be obtained at the end of the study, it is necessary to take the maximum accuracy obtained in the calibration process. In this research, the calibration process's highest accuracy is aimed at and how the calibration process can be performed more effortlessly and more accurately by increasing the size of the point diameter on the test area.

**Keywords:** Accuracy Assessment, Interior Orientation Parameters, Radial Distortion, 2D Test Platform Camera Calibration

### Introduction

In order to keep up with the developments of our age and meet the requirements, high accuracy and precision are sought in the first place in the studies carried out in every field (Remondino, and Fraser, 2006; Cramer, 2004; Küçüköseleci and Uyargil, 2009). The studies carried out are desired to obtain highly accurate results at a low cost. In addition, it is everyone's main goal to carry out work easier and faster. In addition to high accuracy, the cost is an essential factor in the studies (Şenyay and Semerci, 1999). In terrestrial photogrammetry, before all known studies such as deformation analysis of historical artifacts, 3D modeling, documentation of cultural heritage, it is unavoidable to calibrate cameras, which are data production units (Tata and Eteje, 2022; Duran and Atik, 2021). Non-metric cameras, used instead of metric cameras due to high cost, must be calibrated by users. In the calibration report, the values that should be found are the Interior Orientation (IO) parameters ( $X_h$ ,  $Y_h$ ,  $f$ ) and the polynomial coefficients of the function expressing the lens distortion ( $K_1$ ,  $K_2$ ,  $K_3$ , and  $P_1$ ,  $P_2$ ) (Kılınç Kazar, et al., 2021; Khalaf and Yassin, 2016;

Zhang et. Al., 2010). Since the manufacturers do not report the IO parameters of non-metric cameras in the laboratory, camera calibration is needed. Different software often offers 2D test platforms to the users for the camera calibration process. How the calibration with the 2D test platforms will give more accurate results is an essential topic for researchers.

Image acquisition is performed directly from the computer monitor in some test platforms. Commonly performed is the calibration process, where the test platform is printed as hardcopy. The calibrations performed by printing out the test area are made by printing out the standard A4 paper size. However, users often confront errors in calibrations made on A4 paper size. In addition, the IO parameters obtained as a result of the calibration with A4 paper are not of high accuracy (Hold-Geoffroy, et. al., 2018).

In many previous studies, calibration was determined using different cameras or test platforms (2D and 3D) or lenses and how the results provide better accurate results. In addition, the camera calibration has been

studied with 2D test platforms for high reliability and high accuracy results. In studies where calibration is performed with different lenses, the parameters' accuracy has been studied, and similar studies have been carried out with both the 2D test area and the 3D test area (Kraszewski, 2011; Tagoe and Mantey, 2019). Another study has investigated how much the calibration will improve with video recording instead of image acquisition. In addition, it was investigated how much the calibration result would change with video recordings with different resolutions (4K and 1080p) (Teo, 2015). In another study was conducted on the results of single-stage and double-stage calibration. In the double-stage calibration, more accurate results were proposed by using images with distortion errors in the single-stage. As a result, it was concluded that the two-stage calibration is more reliable than the single-stage calibration method (Gašparović and Gajski, 2016). In another study, it was emphasized that calibration should be done in theory. The proposed research examined the results by taking images with certain vegetation areas, calibrated and uncalibrated cameras. The study considered what would happen if the calibration process was not done. As a result, it was determined that calibration is essential for accurate and reliable results in the experiment as in theory (Wackrow, et al., 2015). Although there are different methods and techniques for the calibration process, the primary purpose and main principles do not change. The objectives, such as determining the IO parameters of non-metric cameras, determining the principal point coordinates, obtaining the distortion parameters, endure similarly regardless of the method.

When looking at the researches done so far, it is seen that the most accurate result is desired by performing

changes either on the camera used or in the environment where the images are acquired. It is seen that nothing has been done about the points on the test area. This research is aimed to maximize the accuracy obtained as a result of the calibration process. Changes are made on the test area regardless of how the images are obtained and the device used. The points on the test platforms are presented to the user by the software. The software identifies these points and performs the calibration process automatically. By gradually increasing the point diameters on the test area by 20%, calibration processes were carried out, including the common test platform presented to the user by the software. The software's calibration test platform output presented to the user was taken in A4, A3, and A0 sizes. The calibration was performed, and the most accurate results were obtained in the A0 format, where the point sizes are the largest. Therefore, beginning from this result, the point diameters on the calibration test platform, which are firstly presented by the software with a total of 144 points, the point sizes measured as 1.00 cm in the test platform A0 Paper size are enlarged by 20%, respectively, 1.20 cm, 1.40 cm, 1.60 cm, 1.80 cm, 2.00 cm and step by step calibration was carried out. It is aimed to perform the calibration process, which will directly affect the accuracy of the work to be carried out in the fastest and most accurate way.

**Materials and Methods**

This section explains the camera, workflow, and methods used in the study. In addition, the camera and lens used in the study, the test platforms where the investigations were carried out, and the procedures for calculating the camera IOs were explained, respectively.

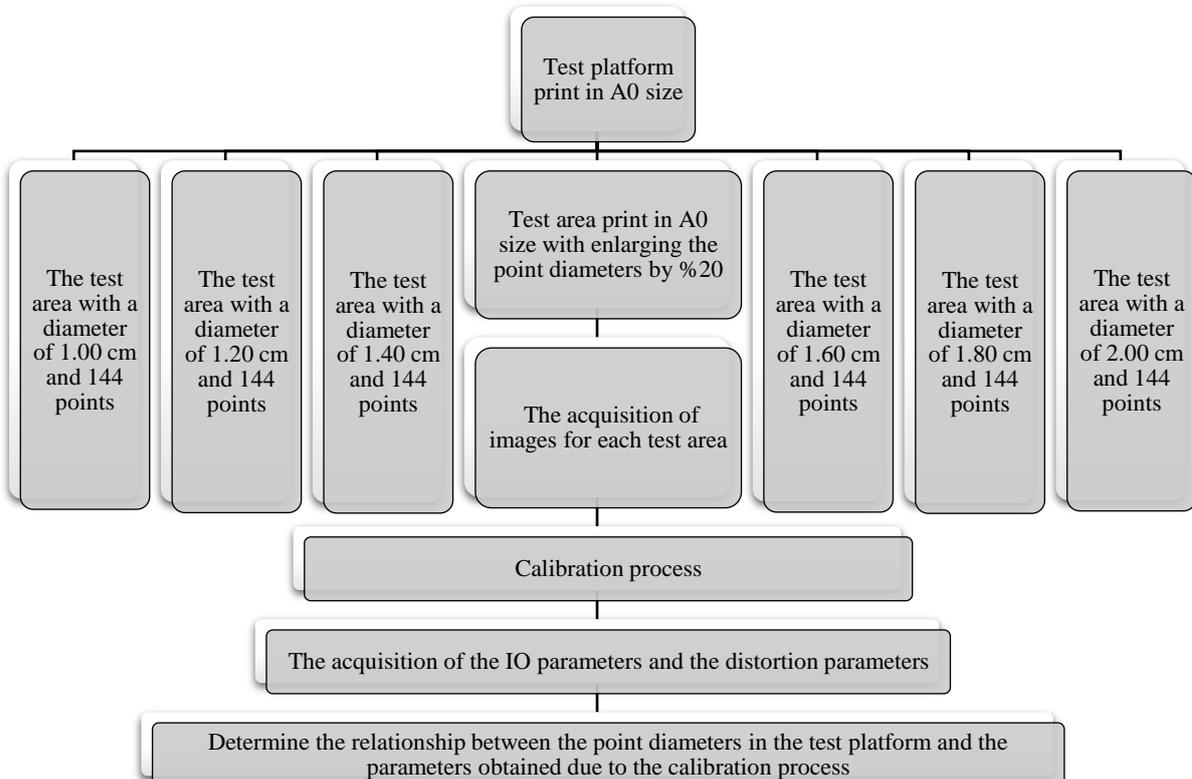


Fig. 1. The chart of workflow

**Camera and Test Platforms Used in The Study**

The workflow (Figure 1) was carried out in this research as follows. First, hardcopy copies of the different 2D test platforms were printed. Then, the following steps have been done to acquire images from different angles with the camera and determine the distortion coefficients of other polynomials with calculations

**Calibration Method**

The process performed to determine the difference between the actual and measured values is called calibration (Akdağ, 2018). Camera calibration has always been an essential part of photogrammetric measurement. Self-calibration is an integrated and routinely applied process within photogrammetric triangulation, especially in high-precision close-range measurements (Remondino and Fraser, 2005)

The calibration process used in photogrammetric studies is to obtain the IO parameters of the camera. All lenses used in cameras have negative physical effects on the image (Makineci et al., 2020). Distortion is a deviation from rectilinear projection optically. It is a sort of optical peculiarity. Theories such as how close the model to be created are with the real, how well the model's parameters are calculated to have an important place to obtain an accurate result. Therefore, considering that the cameras consist of lenses that enable the transformation between the object space and the image space, it is impossible for this conversion to be fully realized due to distortion errors (Clarke and Fryer, 1998). With the camera calibration, the effect of this distortion on the image coordinate system is determined (Makineci et al., 2020). In order to obtain the 3D model of the object, environment, or part of the earth whose three-dimensional model is desired to be obtained with the expected sensitivity and accuracy, the calibration process of the cameras, which is the data production unit, is performed as a priority. An example 2D test platform image is given in Figure 2. There are 144 points, with four control points on the test platform in total.

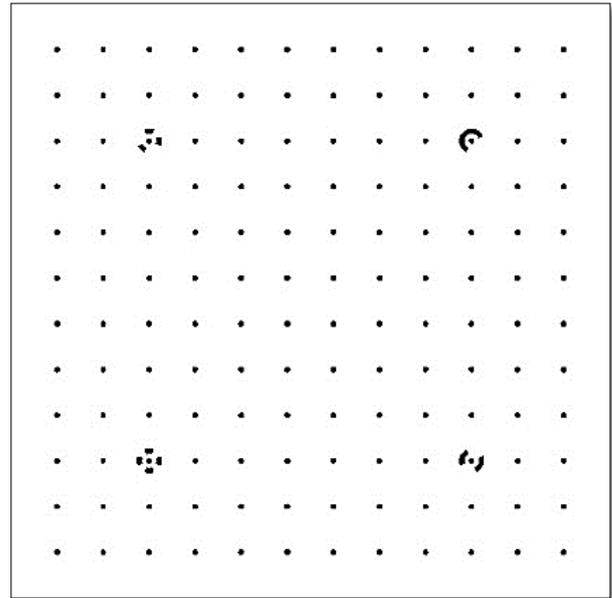


Fig. 2. The test area image provided by the software

**Lens Defects**

The lens systems used in photogrammetry are based on the central projection principle. The central projection is the projection of the beam spread from the object points onto the photographic plane by gathering at a projection center. As a result, the beam refracted by the lens system causes differences in the desired reflection positions. These differences are called aberrations. Generally, the five common types of aberration are known; one of Seidel's five aberrations, also referred to as monochromatic aberration, is the distortion effect on images (Yaşayan and et al., 2018). The distortion is minimized by obtaining the distortion parameters on the camera done by calibrating before a photogrammetric process.

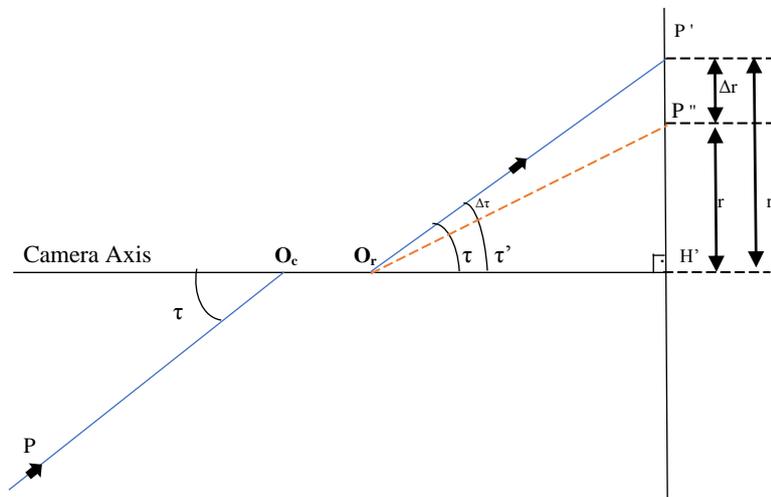


Fig. 3. Distortion influence

**Distortion**

Distortion is the refraction of beams inclined to the optical axis differently by hitting surfaces with different refractive indices. For example, while the beam coming from a P point makes an angle  $\tau$  with the camera axis, it emerges by making an angle  $\tau'$  in the photographic space due to the defects in the camera lens system. As a result, the image of the P point is formed at the P' point, instead of the (P') point, in a different position by  $\Delta r$  than it should be (figure 3) (Yaşayan and ark., 2018).

Distortion is an error that affects the image geometry and causes the object's position on the photo to change. Therefore, geometric distortion is significant negatively in photogrammetry. In addition, it must be taken into account in applications where any metric measurement process will be made on the photograph and should be eliminated by the geometric calibration of the camera.

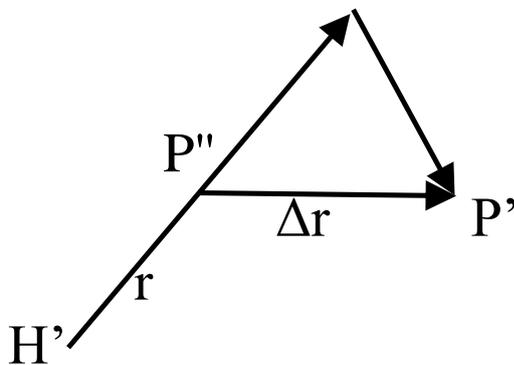


Fig.4. Radial and tangential distortion

Table 1. Camera Specs

Camera	CANON EOS 600d
Image Size	5184 X 3456 piksel
Camera Resolution	18.0 Mp
Sensor Size	22.3 mm x 14.9 mm
Focal Length	18 mm
Pixel Size	4.3 $\mu$

**Specs of Camera**

Canon EOS 600d camera, an industrial, compact, digital camera, was used in the research. Values such as the number of pixels and focal length of the camera are given in Table 1—Canon EOS 600d with body and integrated lens as in Figure 6.

Therefore, equation 1 for distortion error  $\Delta r$  from Figure 3 is embraced.

$$\Delta r = r' - r = r' - ctan(\tau) \tag{1}$$

Line segment  $\Delta r$  connecting the point P' and P'' in Figure 3, vectorial error; could be divided into two components in radial and tangential direction. The diametrical direction (in the "r" direction) is called radial distortion, and the other is called tangential distortion. Tangential distortion is so insignificant that it is practically disregarded. Therefore, for lenses, only diametrical distortion is considered. The illustration of diametrical and tangential distortion is as in figure 4 (Yıldız and ark., 2005).

The calculated  $\Delta r$  values differences with the required  $r'$  are shown on an axis. The aforementioned is called a distortion curve (figure 5).

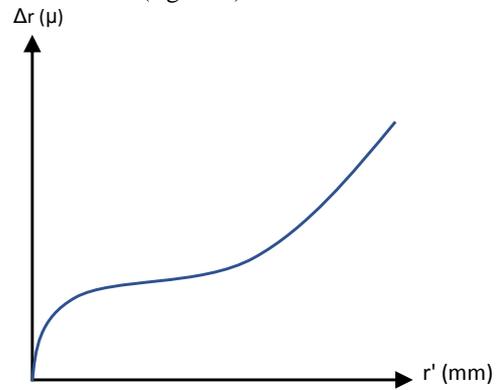


Fig. 5. Distortion Curve



Fig. 6. Canon EOS 600D camera body and 18 x 55 lens

**Distortion Curve and IO Parameters of Camera**

The post-calibration radial and tangential distortion values for the Canon EOS 600D camera presented in Figure 6 are shown in Figure 7 and Figure 8, respectively. In addition, IO parameters and distortion parameters are as seen in Table 2 and Table 3, respectively.

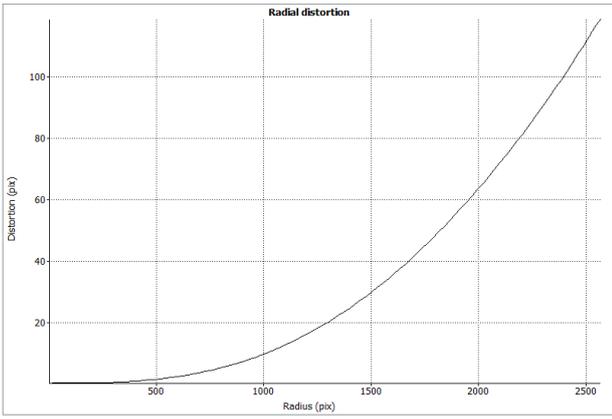


Fig. 7. Radial distortion graphs of the device used in study

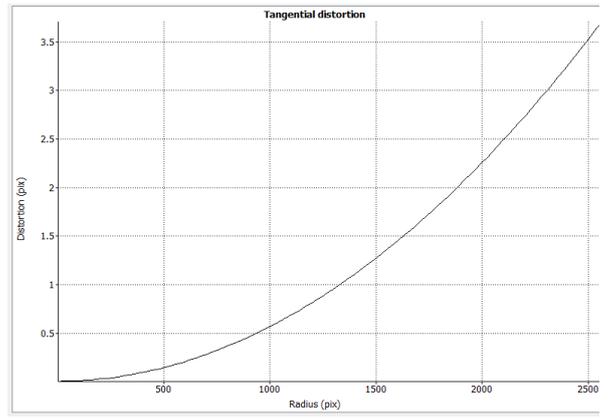


Fig. 8. The tangential distortion graphs of the device used in study

Table 2. The IO parameters of the device used in study

Param.	Radial				Tangential	
	K1	K2	K3	K4	P1	P2
Value	-0.1802	0.2119	-0.1705	0.1049	0.0023	0.000

Table 3. The distortion parameters of the device used in study

Parameters	f (mm)	X <sub>h</sub> (μm)	Y <sub>h</sub> (μm)
Value	18	0.5260	0.4163

**Formulation of Lens Distortion**

In general, four-parameter standard lens distortion equations, which are sub-examples of the parameter set, are used in camera calibration (Duane, 1971). The following equations 2 and 3 show how the software used applies distortion corrections (Wiggenhagen, 2012).

$$X_c = x + \Delta r_x + \Delta p_x \tag{2}$$

$$Y_c = y + \Delta r_y + \Delta p_y \tag{3}$$

Values are shown as X<sub>c</sub>, Y<sub>c</sub> in Equations 2 and 3 denote "Corrected image points", Δr<sub>x</sub> component correction of radial lens distortion, - Δr<sub>y</sub> component correction of radial lens distortion, Δp<sub>x</sub> component correction of central lens distortion, Δp<sub>y</sub> is expressed as the y-component correction of the central lens distortion.

**Correction of Radial Distortion**

The main lens distortion influence is affected by the radial lens distortion. (Equations 4 and 5)

$$X_c = x \times \left(1 + \frac{\Delta r_b}{r}\right) \tag{4}$$

$$Y_c = y \times \left(1 + \frac{\Delta r_b}{r}\right) \tag{5}$$

If r is divided into the radial distortion formulas, the following results are obtained (Equations 6,7 and 8):

$$\Delta r = \frac{\Delta r_b}{r} \tag{6}$$

$$X_c = X \times (1 + \Delta r) \tag{7}$$

$$Y_c = Y \times (1 + \Delta r) \tag{8}$$

The "r" obtained for the lens used in the study is as in equation 9.

$$\Delta r = K_1 \times r^2 + K_2 \times r^4 \rightarrow r^2 = x^2 + y^2 \tag{9}$$

The standard form for radial lens distortion is Equation 10.

$$\Delta r = A_0 + A_1 \times r^2 + A_2 \times r_4 \tag{10}$$

The formula used to convert the standard form to the non-standard formula of the software used is as shown in Equations 11, 12, 13 and 14.

$$s = (1 - A_0) \tag{11}$$

$$f = \left(\frac{f_2}{s}\right) \tag{12}$$

$$K_1 = \left(\frac{A_1}{s}\right) \tag{13}$$

$$K_2 = \left(\frac{A_2}{s}\right) \tag{14}$$

Here "f<sub>2</sub>" is the actual focal length of the camera, and "f" is the focal length to be used in the software.

In order to standardize the non-standard formula of the software, it is required to determine the adjustment point defined by r<sub>0</sub> (Figures 15,16,17,18 and 19).

$$A_0 = -(K_1 \times r_0^2 + K_2 \times r_0^4) \tag{15}$$

$$s = (1 - A_0) \tag{16}$$

$$f_2 = f \times s \tag{17}$$

$$A_1 = K_1 \times s \tag{18}$$

$$A_2 = K_2 \times s \tag{19}$$

**Central Lens Distortion**

Because central lens distortion is insignificant compared to radial distortion, it is not usually modeled but should be considered if the highest accuracy is desired. The formulas used in the study to determine the central distortion are as follows (figures 20 and 21).

$$\Delta p_x = P_1 \times (r^2 + 2 \times x^2) + 2 \times P_2 \times x \times y \quad (20)$$

$$\Delta p_y = P_2 \times (r^2 + 2 \times y^2) + 2 \times P_1 \times x \times y \quad (21)$$

**Application of Research**

Regardless of the method used to obtain the most accurate and reliable results, no matter what type of camera is used, the calibration process of these cameras is carried out so that non-metric cameras should make more accurate analyses of the images (Kraszewski, 2011). While calibrating the CANON EOS 600d device, which is used in working with the camera calibration software, there are two papers with 100 points and 144 points, four of which are control points, both of which are presented to the user of the software. A4, A3, and A0 paper sizes were printed for calibration papers, and images were obtained with three different devices. One of these devices is a single-camera phone, the other is a

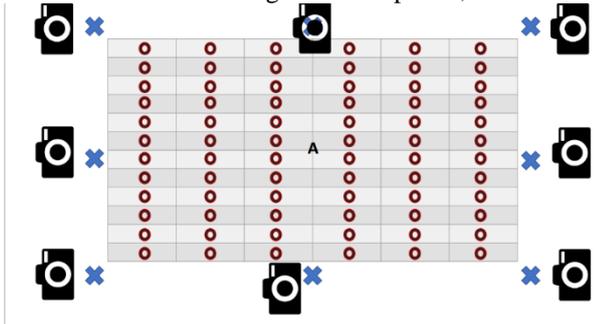


Fig. 9. The first camera angles in the acquisition of images for test area

If the focal length of the device used while obtaining these images is changed, the software will detect this. It will not accept those with different focal lengths in the images obtained because the focal length is extra in the photographs. Before a new image acquires, the camera's distance to the calibration paper should not be changed during the image acquisition process. The software detects changes in this distance and appears as an error during the calibration phase, and calibration cannot be performed. Although the calibration process related to the software used here varies, some software printed out the test area. In some programs, the image is taken directly on the computer monitor. Thus, the printouts of the test area image were taken. These printouts were fixed on a plain white background, and images were obtained when the camera was horizontal and vertical, as seen in Figures 9 and 10.

First, there are two test platforms presented to the user by the software. A 100-point test platform with four control points is one of these test areas. The second is a test platform with 144 points with four control points.

dual-camera phone, and the third is a digital camera. According to the results obtained, when paper sizes and devices were compared, it was seen that there was no noticeable difference in the accuracy values obtained. Still, much better results were obtained in A0 paper size. Getting more accurate results on A0 paper size raises the question of whether the accuracy obtained in the calibration process has anything to do with the dot sizes because the calibration papers given by the software were printed on different paper sizes, and the largest dot sizes were obtained on the A0 paper size as expected. For this reason, calibration papers with a point diameter of 1.00 cm, 1.20 cm, 1.40 cm, 1.60 cm, 1.80 cm, and 2.00 cm were produced by enlarging the 1.00 cm point diameter offered by the software by 20%, and their A0 size printouts were taken, and calibration processes were performed. In order to find the most accurate result, to ensure that our measurements are consistent, in other words, they are close to each other, the most appropriate images of the calibration paper in the camera calibration software used in the application are obtained from eight different angles at a distance of 25-30 cm, and eight photographs for each point diameter are uploaded to the software carried out separately. The image regarding the acquisition of images is shared in Figure 9 and Figure 10.

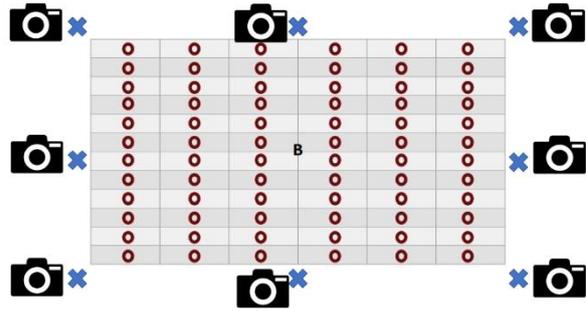


Fig. 10. The second camera angles in the acquisition of images for test area

Both 100-point and 144-point test platforms were printed out in A4, A3, and A0 sizes, and calibration processes were performed. As a result of these processes, other calibration results except A0 size were close. Still, it was seen that the calibration result made on A0 paper size gave the most accurate result for both the 100-point test area and the 144-point test area, unlike other paper sizes. In addition, as expected, the point diameters on the test platform printed on A0 paper size are more significant than other paper sizes. In this context, starting from the question of whether the point diameters on the test platform affect the calibration process, the point diameter, which is 1.00 cm on the printout on A0 paper size, is enlarged by 20% and 1.00cm, 1.20cm, 1.40cm, 1.60cm, 1.80cm, and 2.00cm respectively. Calibration papers with a point diameter of 144 points, four control points were produced, A0 size printouts were taken, and calibration processes were performed. The effect of point diameters on calibration was investigated.

There are 144 points on the calibration paper, and four of these points are control points in total. If any of these

four control points are not detected by the software during the calibration, the undetected photograph is canceled and not used in the calibration process. In addition, after the calibration process is completed, the brand of the device used, the focal length, the IO

parameters ( $X_h, Y_h, f$ ), and the polynomial coefficients of the function expressing the lens distortion ( $K_1, K_2, K_3$ , and  $P_1, P_2$ ) photo dimensions Important values such as software are displayed to the user after the calibration process (Table 4).

Table 4. The acquisition of the IO parameters after the calibration process for each test area

Point Diameters	Focal Length	Format Size	Principal Point	Image Size	Radial Lens Distortion ( $K_1$ )	Radial Lens Distortion ( $K_2$ )	Tangential Lens Distortion ( $P_1$ )	Tangential Lens Distorsiyon ( $P_2$ )	The RMSE (pixel)
1.00 cm	18.6700	W:22.6844 H: 15.1130	X:11.4736 Y:7.8129	W:5184 H:3456	$5.114 \times 10^{-4}$	$-9.700 \times 10^{-7}$	$-2.146 \times 10^{-5}$	$1.112 \times 10^{-4}$	0.7095
1.20 cm	18.6950	W:22.6740 H: 15.1130	X:11.4784 Y:7.8251	W:5184 H:3456	$5.115 \times 10^{-4}$	$-1.075 \times 10^{-6}$	$-3.464 \times 10^{-5}$	$1.704 \times 10^{-4}$	0.6846
1.40 cm	18.7729	W:22.6731 H: 15.1130	X:11.4972 Y:7.8096	W:5184 H:3456	$5.183 \times 10^{-4}$	$-1.101 \times 10^{-6}$	$-4.252 \times 10^{-5}$	$1.670 \times 10^{-4}$	0.7311
1.60 cm	18.8969	W:22.6711 H: 15.1130	X:11.5218 Y:7.7068	W:5184 H:3456	$4.973 \times 10^{-4}$	$-1.020 \times 10^{-6}$	$-7.218 \times 10^{-5}$	$1.334 \times 10^{-4}$	0.9019
1.80 cm	18.3460	W:22.7058 H: 15.1130	X:11.4856 Y:8.0393	W:5184 H:3456	$4.786 \times 10^{-4}$	$-7.735 \times 10^{-7}$	$-3.271 \times 10^{-5}$	0.00E+00	0.8144
2.00 cm	18.4123	W:22.7125 H: 15.1130	X:11.4683 Y:8.0476	W:5184 H:3456	$4.721 \times 10^{-4}$	$-6.874 \times 10^{-7}$	$-2.053 \times 10^{-5}$	0.00E+00	0.6634

**Acquired Images from Test Platforms**

2D test area consisting of 144 points in total, four of which are control points, were printed on A0 paper size for each point diameter.

**Test Platforms Including Different Point Diameters**

As mentioned before, the diameter of the points on the calibration paper is 1.00 cm in A0 paper size. Therefore, the calibration process was carried out by increasing the point sizes by 20%, respectively. Figure 12 is the image of the test area with a diameter of 1.00 cm and 144 points presented by the software. The points with a diameter of 1.00 cm, which are in A0 paper size offered

by the software, are enlarged by 20% to 1.20 cm, 1.40 cm, 1.60 cm, 1.80 cm, respectively, and 2.00 cm diameter points were produced. Thus, the calibration process was carried out on these test platforms. In Figure 11, the IO parameters calculated by the software after the calibration process and presented to the user are in the metric system. While obtaining the test platform images, one image from eight different angles was accepted. Therefore, the calibration process was carried out for each point diameter test area on a total of eight images. For an exemplary calibration process, the test platform image mosaic is shared in Figure 13.

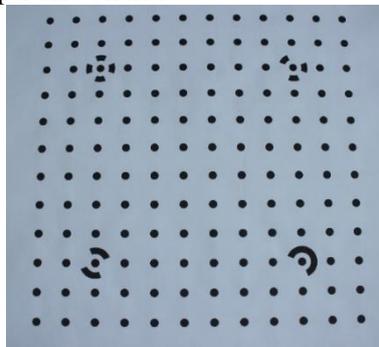


Fig. 12. The image of the test area with a diameter of 1.00 cm and 144 points presented by the software.

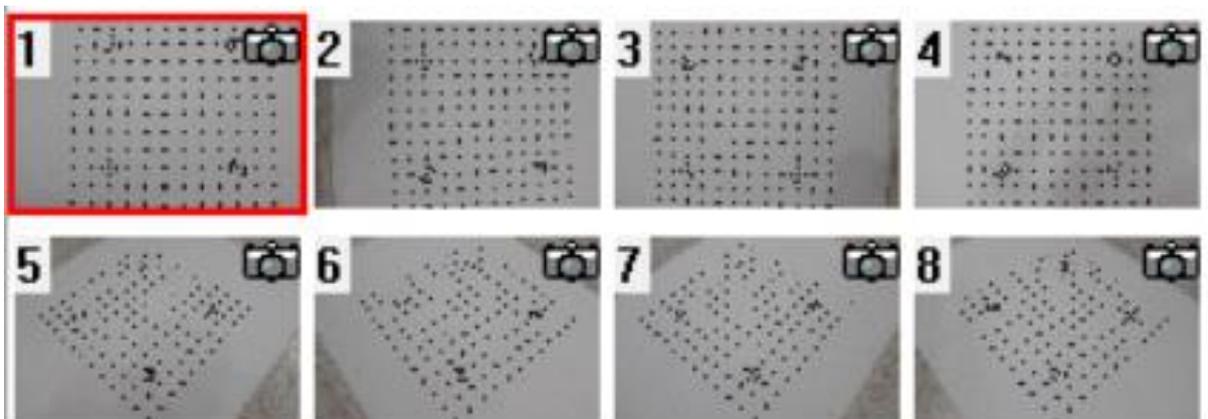


Fig. 13. Test area image mosaic for the exemplary calibration process

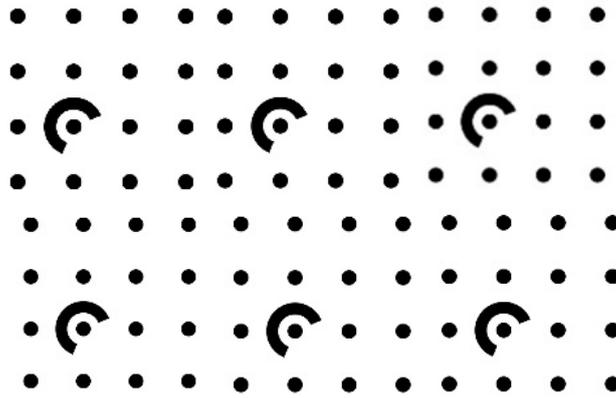


Fig. 14. The test area with a diameter of: A: 1.00 cm B: 1.20 cm, C: 1.40 cm, D: 1.60 cm, E: 1.80 cm, F: 2.00 cm

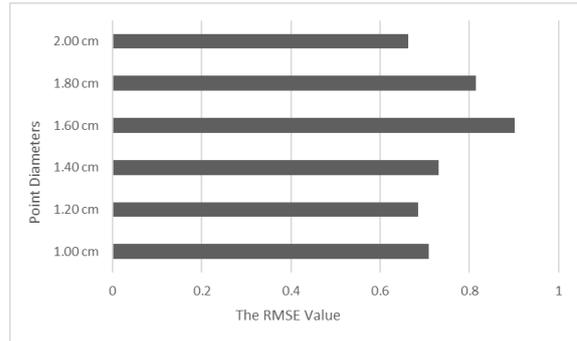
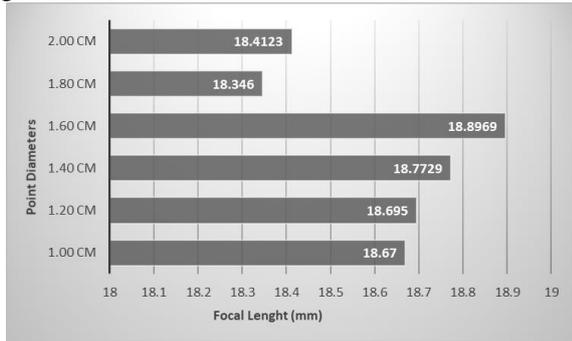


Fig. 15. The focal lengths calculated after the calibration process with a 20% enlarged point diameter

Fig. 16. The RMSE value calculated after the calibration process with a 20% enlarged point diameter

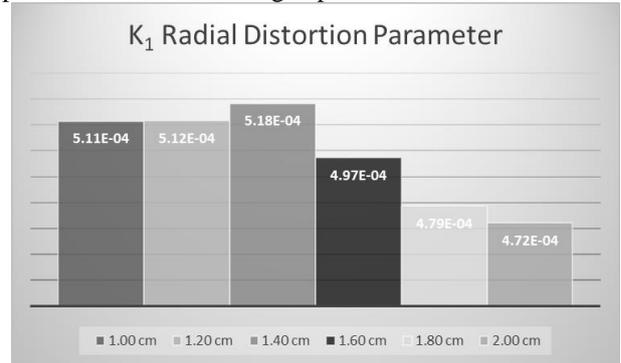
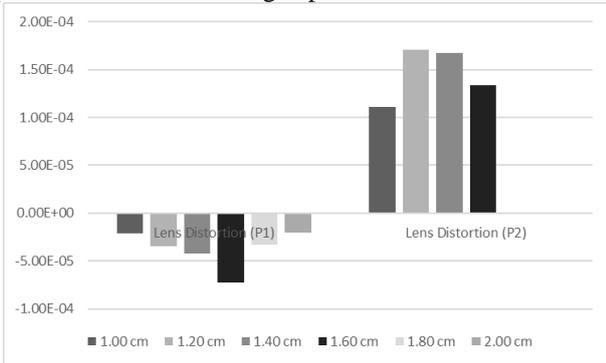


Fig. 17. The tangential distortion parameters P<sub>1</sub>, P<sub>2</sub> calculated after the calibration process with a 20% enlarged point diameter

Fig. 18. The K<sub>1</sub> radial distortion parameter calculated after the calibration process with a 20% enlarged point diameter

**Distortion Parameters from Camera Calibration Process**

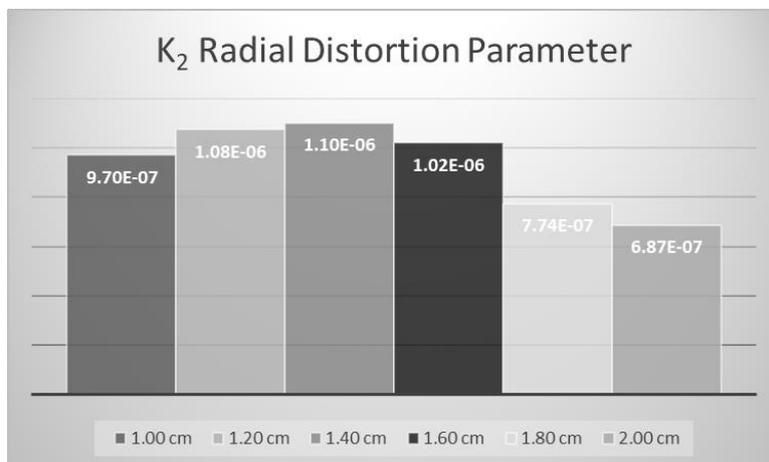


Fig. 19. The K<sub>2</sub> radial distortion parameter calculated after the calibration process with a 20% enlarged point diameter

## Results and Discussions

Calibration processes were carried out with point diameters enlarged by 20%, and the parameters obtained as a result of the calibration were explained with the graphics. In these graphs, the columns represent the point diameters; rows represent calculated values.

### Focal Length Parameters from Camera Calibration Process

As a result of the calibration process, the focal lengths calculated for the test platforms with a 20% enlarged point diameter are shown in Figure 15. The focal length given by the producer is 18 mm.

### Conclusions

The IO parameters of the camera used in every operation with non-metric cameras should be obtained because the results obtained after the application are expected to be of a standard acceptable to everyone and high accuracy in photogrammetry. Furthermore, camera calibration is a fundamental process since it is necessary to eliminate the effects of geometric and radiometric deformations arising from the characteristics of optical imaging systems and the IO parameters of the device to be used in researches where high accuracy and precision are required (Kılınç Kazar, et al., 2021). Thus, different mathematical models and methods for the calibration process must be done before every operation where high accuracy and precision are required. For example, in the calibrations performed by taking the printout of the test area, calibrations are made by printing out the standard A4 paper size. Still, errors are frequently encountered in the calibrations made in the A4 paper size, and the parameters obtained as a result of the calibration are not in the expected accuracy (Hold-Geoffroy, et al., 2018). It is understood from previous studies that the IO parameters are known, the pixel coordinates, the size of the lens distortion, this will be more in wide-angle cameras, and the effects of lens distortion have not changed. When looking at the studies done so far, it is seen that the most accurate result is by neither making changes either on the device used or in the environment where the images are obtained. It has been seen that nothing has been done about the points on the test area. In order to maximize the accuracy obtained as a result of the calibration process, changes were made on the test platform regardless of the environment in which the images were obtained and the camera used in this analysis. It was investigated to get high reliability and accuracy and make them more accurate and reliable than the results we will receive. The 2D test area image presented to the user by the software was printed out in A4, A3, and A0 sizes, and calibration processes were carried out separately with three different devices. As a result of these processes, it was seen that there was no significant difference in A4 and A3 paper sizes. Still, the calibration process results on the A0 paper size with the largest point diameter gave much more accurate and desired outcomes than A4 and A3 paper sizes. Then, the relationship of the point diameters on the 2D test area

image presented by the software with the data obtained after the calibration process was examined. When the test area image provided by the software is printed on A0 paper size, the point diameters are 1.00 cm measured. 1.00 cm point diameters with a 20% ratio are 1.20 cm, 1.40 cm, 1.60 cm, 1.80 cm, respectively, and 2.00 cm. By generating a new 2D test platform with point diameters, calibration processes were performed again. As a result of these calibration processes, the relationship between the point diameters in the test platform and the parameters obtained due to the calibration process is seen. In order to get an objective result at the end of the study, the calibration processes were carried out with the same camera, in the same conditions, and by adhering to the same external conditions as possible.

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