Test Field Material Effects of Camera Calibration (In Term of Photogrammetry)

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Abstract:- Both metric and non-metric cameras are used in photogrammetry, but the most common use is for non-metric cameras. Since its calibration is very important to calculate the internal orientation elements of the camera, the calibration method is very important. One of the most accurate methods is the pre-calibration method, in which a test field is usually used. There are many types of test fields, some of which are standard and some are locally made. Because of the cost and variety of applications, home-made is used. The test field industry involves many factors such as the quality of the points, their size, and the material the test field is made of. Several types of test fields were tried in this research. The best two models of these types were selected, and then the two models were compared in terms of the effect of the material from which they were made. The effect of the material and choosing the appropriate pattern gave calibration results that reached one-micron accuracy.

Keywords:- *Camera Calibration; Test Field; Pattern; Material.*

I. INTRODUCTION

The data processing results from the photogrammetry depend greatly on the accuracy and quality of the camera calibration (IOP), and the identification of the external orientation elements of the camera station (EOP), which includes linking the camera station coordinate system to the object coordinate system. This depends greatly on the quality of the control points used, their efficiency, and the accuracy of their coordinate system. There are three ways in which the point coordinate system can be measured, used in the process of preparing the camera for surveying. It is either the use of accurately manufactured points, which are covered by a manufacturing report and the amount of accuracy, or direct measurement by surveyors, or through direct measurement in vernier, for example, or by following methods of photogrammetry and image processing to calculate the coordinate system for a group of points.

II. MEASURING COORDINATES SYSTEM

A. Direct Measuring

Measurement is a cornerstone of photogrammetry engineering, and the accuracy of representation depends on this measurement. To link the image model to the coordinate system of objects, either the camera station is known to the coordinates, as in the case of permanent imaging stations, for example in permanent imagination systems .. or the distance between two camera stations is known to the distance, as in stereo systems. Or that there are sufficient ground control points within the imaging field. The accuracy of the measurements resulting from the model based on the geometry of the photogrammetry depends on many factors, the most important of. which is the accuracy of the measurements on which the construction of the aforementioned model depends. The permanent stations are far from the research objectives. Also, the basic distance between two camera stations because it takes us towards an imaginary stereo is not in the context of the search plan. Ground control points are measured accurately and suitable for building a measurement system in terms of accuracy and ease of reuse, making options limited to the target field. These goals are either measured using surveying devices such as theodolite or the total station, or lengths are measured with other direct measurement tools, such as a metal tape or a vernier.

This topic refers to the subject of the visualization, the effect of the observer's vision of the measurement gradations, and the accuracy of determining the measurement within a precision that may reach a few microns, this can be done by using auxiliary tools such as high-precision vernier as in the models of analogue or digital tools. Some of which reach the accuracy of one Micron, and with the help of the magnifiers, which should have a magnification of more than 500X, to make one micron appear to us as a half a millimetre. Of course, this is with regard to eye vision to match the measuring instrument with the measured part **Error! Reference source not found.**.

Personal errors include mistakes in reading the scale or in manipulating the dividers. They also include the personal equation of the observer, which is how a reading lying between the closest subdivisions of the scale is estimated visually(Maling, 1989).

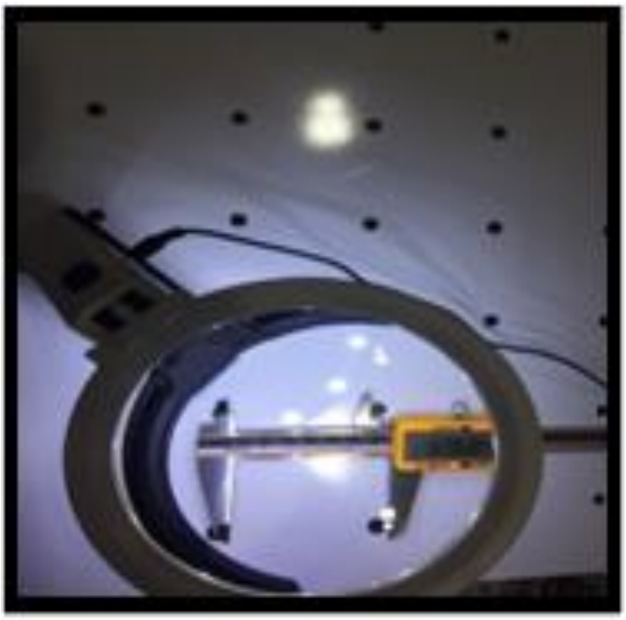
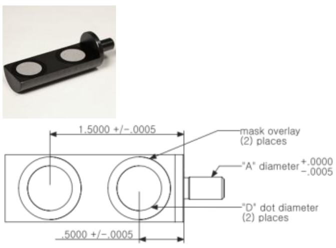
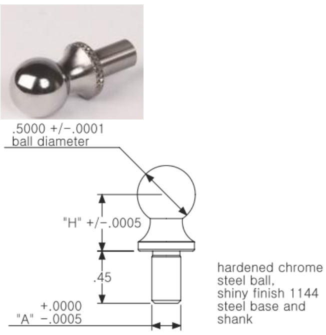


Figure 1 ***Set measurement points in the available ways, with zoom.***

B. Reported Test Field (Grid Points)

Target measurement methods are used to install the coordinate system used for the targets that the camera captures, either for building an object model or for calibration purposes. These methods of measurement, including those that are direct and common to the user, which we will mention in the next section, and some of them are in laboratory conditions and tools that produce features or points of specific accuracy and suitable for high-precision imaging scanning purposes such as calibration, for example. Some products for companies specializing in the manufacture of targets used for photogrammetry or videogrammetry or as accessories for surveying devices such as theodolite, total station or laser scanning station, which shows that each product has a description that includes the accuracy of measurement for the dimensions or centers of the circuits in it, which represent a high accuracy that qualifies Devices for producing accurate samples or surveys or calibrating them with high accuracy. Or, the accuracy of the equipment is at least with an accuracy that can be calculated and determined, which may very well be within the limits required for most delicate works. In the following table examples of that:-

Description	Accuracy
Used with photogrammetry to measure location an angularity of a hole. 1144 STEEL, BLACK OXIDE FINISH (standard)	Target dots are located within +/-.0005 on height (unless otherwise noted) or +/-.0005 in relationship of C/L of shank or body. Which is +/-0.0127 mm
	
All of are balls are welded to the shank. 1144 STEEL and HARDENED CHROME STEEL BALL	CB-.5000-.2500-.5000 & CB-.3125-.2500-.5000 will have a ball diameter tolerance of + .0000 / -.0003 Which is +/-0.0076 mm
	

ISSN No:-2456-2165

Table 1 ***Targets used in camera calibration and coordinates system referencing.*** **(*Hubbs Machine & Manufacturing*, n.d.).**

C. Retro Reflective targets

Retro Reflective targets have wide use in practice, especially in manufacturing applications. Retro Reflective material is the main material in the manufacture of this type of target, which is either painted in a black pattern or integrated with the target body. The shape of Retro Reflective targets is spherical or circular, or in various shapes, as in the Figure 2. Retro Reflective Primers consist of a material containing either small reflective spheres up to eighty micrometers in diameter or micro-reflective lines. In the case of high contrast, a ring flash attached to the camera is used to increase the clarity of retro-reflective targets. The most important feature of this type is that the incident rays are reflected parallel to the same direction, and the floatation of the measuring center may occur in some cases up to fifty microns, which requires programmatic treatment.

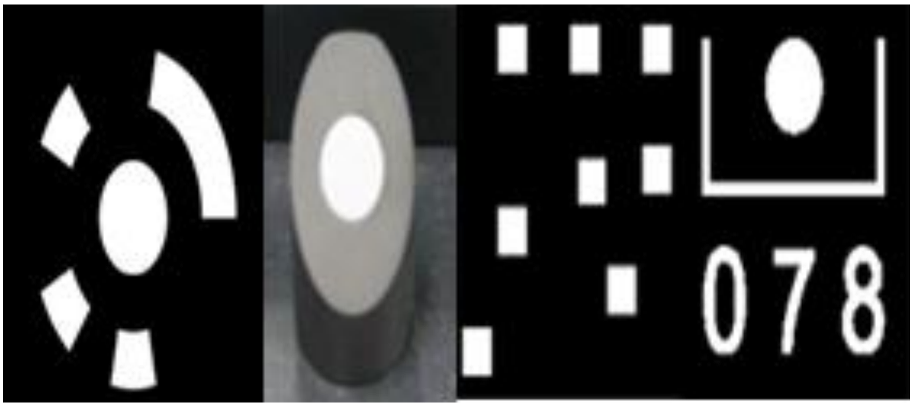


Figure 2 Examples of retro-reflective targets. Circular target with ring code, oblique circular, with area code and circular with point number (left to right).

III. PREVIOUS WORKS

(Udin & Ahmad, 2011) They calibrate three types of cameras which used to accurate measurement. They choose Rollei, Compact and SLR types. The calibration test fields was equipped with retro-reflective targets. They measure the points manually and determined their coordinates using intersection method by total station to use these values as reference coordinates system. The Table 2 shows the calibration results by three sizes of 3D test field with scale bar Figure 3 . So they find the SLR camera the best one.

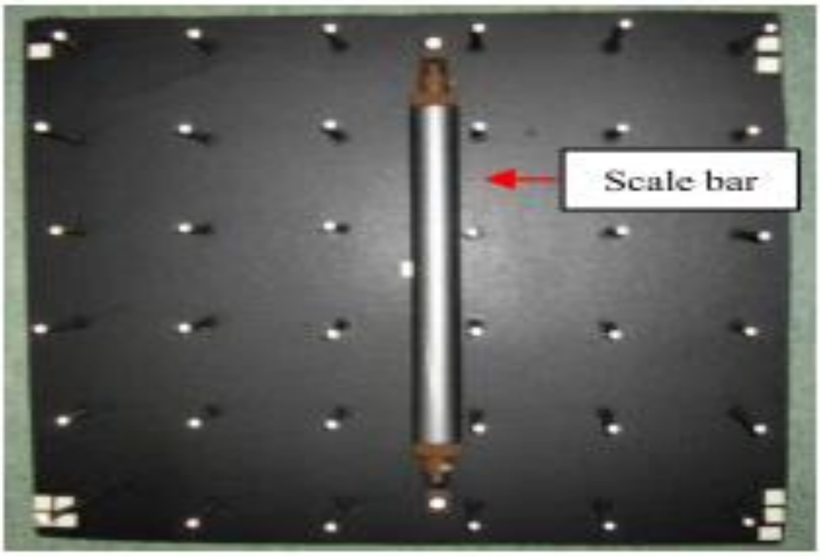


Figure 3 *Three dimensional test field calibration with scale bar and retro-reflective.*

(Tommaselli & Telles, 2006)They bundle block adjustment to calibrate non-metric digital camera by plump straight lines and grid points, they found that the discrepancies between photogrammetric derived coordinates and field true was 0.597±1.591 mm when use IOP come from straight lines and was 0.530±1.512 mm for IOP come from points test field calibration Table 2.

ISSN No:-2456-2165

Table 2 ***Camera calibration parameters and precision for test fields (0.4*0.4, 0.6*0.6 and 0.8*0.8) respectively from up to down.***

Parameter	DIGITAL CAMERA					
	NIKON COOLPIX S560	Std Dev	NIKON D60 (SLR)	Std Dev	ROLLEI D30	Std Dev
c (mm)	7.7749	6.931E-03	21.2012	2.093E-02	10.6429	9.480E-03
x_p (mm)	-0.0649	7.359E-03	0.0836	1.891E-02	0.2783	1.062E-02
y_p (mm)	-0.1536	7.060E-03	0.1860	1.728E-02	-0.0498	1.061E-02
k_1	7.10100E-03	2.502E-04	1.83254E-04	9.243E-05	1.25882E-03	3.778E-03
k_2	-7.27032E-04	1.141E-04	-1.36159E-06	7.052E-06	2.81396E-05	3.692E-05
k_3	7.87930E-05	1.600E-05	3.59516E-08	1.721E-07	-2.91047E-06	2.938E-06
p_1	1.66967E-07	4.763E-05	-1.38283E-05	1.542E-05	-2.49500E-04	3.567E-05
p_2	1.32639E-04	4.654E-05	-1.49795E-05	1.515E-05	3.59760E-05	3.530E-05
b_1	3.16261E-04	1.109E-04	5.33903E-05	9.381E-05	5.23934E-05	1.208E-04
b_2	-1.34998E-04	1.292E-04	3.09247E-06	1.081E-04	9.42648E-05	1.383E-04

Parameter	DIGITAL CAMERA					
	NIKON COOLPIX S560	Std Dev	NIKON D60 (SLR)	Std Dev	ROLLEI D30	Std Dev
c (mm)	7.7938	7.035E-03	21.2423	1.024E-02	10.6712	6.716E-03
x_p (mm)	-0.0600	4.985E-03	0.0678	8.411E-03	0.2664	7.221E-03
y_p (mm)	-0.1378	5.094E-03	0.2171	8.111E-03	-0.0385	7.204E-03
k_1	5.89760E-03	1.661E-04	2.06302E-04	3.361E-05	1.30710E-03	1.026E-04
k_2	-1.92982E-04	4.843E-05	-9.61525E-07	1.265E-06	-8.10300E-07	1.832E-05
k_3	1.04475E-05	4.222E-06	1.93634E-08	1.440E-08	-5.90363E-07	9.997E-07
p_1	-1.66240E-05	3.005E-05	-1.36190E-05	6.624E-06	-2.62903E-04	2.304E-05
p_2	1.31673E-04	3.071E-05	-2.20261E-05	6.364E-06	3.98000E-06	2.282E-05
b_1	3.06344E-04	8.675E-05	1.24916E-04	4.985E-05	5.35382E-05	8.639E-05
b_2	-3.72817E-05	1.082E-04	-1.03768E-04	6.308E-05	-6.82402E-01	1.063E-04

Parameter	DIGITAL CAMERA					
	NIKON COOLPIX S560	Std Dev	NIKON D60 (SLR)	Std Dev	ROLLEI D30	Std Dev
c (mm)	7.7668	4.967E-03	21.2316	1.050E-02	10.4103	7.439E-03
x_p (mm)	-0.0700	1.195E+00	0.0974	7.660E-03	0.2667	5.638E-03
y_p (mm)	-0.1441	3.453E-03	0.2294	7.658E-03	-0.0449	5.844E-03
k_1	5.09189E-03	9.649E-05	1.74598E-04	1.699E-05	1.56250E-03	8.342E-05
k_2	1.16136E-05	1.596E-05	2.28916E-07	3.448E-07	-1.35557E-05	8.979E-06
k_3	-6.60092E-06	8.288E-07	-4.18695E-10	2.126E-09	-3.16953E-07	3.043E-07
p_1	-2.58613E-05	1.837E-05	-1.58766E-05	5.031E-06	-2.98044E-04	1.662E-05
p_2	2.63763E-04	1.860E-05	-3.19870E-05	5.036E-06	-3.85991E-06	1.672E-05
b_1	2.10634E-04	6.929E-05	9.41291E-05	5.556E-05	4.14820E-05	8.863E-05
b_2	-2.56598E-04	1.428E-04	3.22892E-05	1.300E-04	-4.68888E-04	1.808E-04

ISSN No:-2456-2165

Table 3 Calibration results using plump lines and points with their standard deviation.

IOP	Method using straight lines		Bundle Method with points	
	Estimated Value	Standard Deviation	Estimated Value	Standard Deviation
c (mm)	34.96	2.4E-02	34.97	2.3E-02
x_0 (mm)	0.19	1.6E-02	0.19	1.7E-02
x_0 (mm)	0.31	1.5E-02	0.31	1.6E-02
K_1 (mm^{-2})	8.1E-06	3.3E-06	9.7E-06	3.2E-06
K_2 (mm^{-4})	7.6E-09	1.0E-08	2.7E-09	9.9E-09
K_3 (mm^{-6})	1.3E-12	1.0E-11	5.5E-12	9.7E-12
P_1 (mm^{-1})	2.5E-05	3.8E-06	2.6E-05	4.0E-06
P_2 (mm^{-1})	2.6E-05	3.4E-06	2.5E-05	4.0E-06

IV. CALIBRATION STRATEGIES

The purpose of camera calibration is to calculate the engineering camera model, which can be described by the internal rotation elements; spatial position of the center of the camera with the image coordinate system (Principle Distance and the coordinates of the image system of the Principle point) and items describing image distortion and sensor corrections.

In general, for a metric camera, the internal components are known and established through its laboratory calibration report. What needs calibration is mainly the imaging system, the partial metric camera, the commercial camera, or what is called the non-metric camera. As its elements change permanently with changing shooting settings.

In general, according to the reference object used, the time of its use, and its location, the calibration methods can be divided into two main methods Figure 4 with the presence of other methods other than the old methods (multicollimator and goniometer).

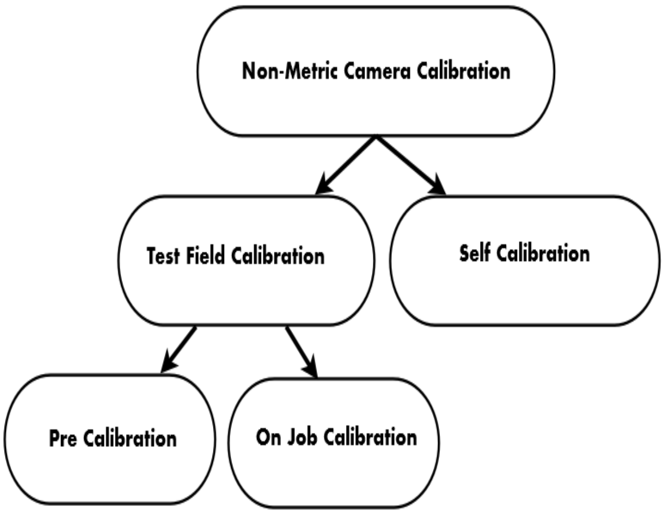


Figure 4 Non metric camera calibration main classification

V. TEST FIELD CALIBRATION

The calibration field is based on target points with a known coordinate system or known distances. The calibration field is photographed from several directions, ensuring good intersections and that the image is filled with the image. The calibration field can be fixed or movable, such as installed on a frame or wall. There is a distinction between a three-dimensional and two-dimensional calibration field, or in other words, the flat, such as a chessboard or raster, etc., and the spatial calibration field, or what is in three dimensions. Camera parameters are calculated as part of the Bundle Block Adjustment with which the external rotation elements and the 3D coordinates of the objects are calculated. Any distances or coordinates other information entered to contribute to the measurement. It is not necessary for the calibration field points to be reference points with a coordinate system and with high precision, but this reduces the efficiency of the calibration unless accurate measurements are taken to calculate the three-dimensional coordinates using the free grid Bundle Adjustment Scale Bar gives Bundle with an absolute scale. Where the camera elements can be calculated without scale information because the directions will be corrected and they are independent by scale.

Figure 5 shows a calibration field that accommodates at least eight images, but this type requires perpendicular and oblique images, and the relative angles are approximately 90 degrees around the optic axis.

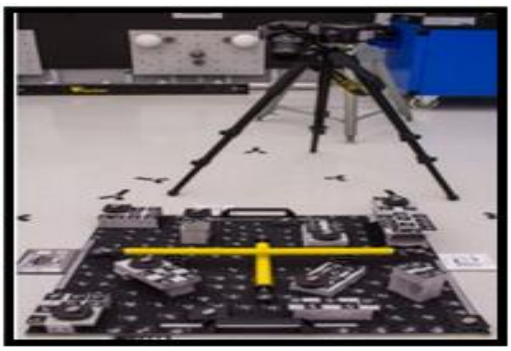


Figure 5 3D test object consisted of about 170 coded targets with a largest dimension of 900 mm.

The three-dimensional calibration field increases accuracy and reduces correlation between parameters. The number of points and their distribution is important, and the focus, zoom, sharpness, and focal length should not be changed during the calibration process.

VI. CAMERA CALIBRATION

Camera calibration is a key issue in photography. Mostly the techniques for solving a calibration problem use the collinearity equations (1) to compute the interior and exterior parameters and parameters of the lens distortion of the camera lens system. Calculation of interior parameters is what the term camera calibration means, just as it is the calculation of external orientation elements which is the meaning of the term camera orientation. The camera calibration is usually combined with the Orientation in Simultaneous Solutions for the coordinates of targets in the Bundle block adjustments method of collinearity equations.

Because the collinearity equations include additive elements of lens distortion which are nonlinear, so the iteration method for the least squares is the specific method. As is evident in the equations (1) the internal (C, X, and Y) is embedded in it. And it is very clear the strength of correlation between exterior parameters and interior parameters, so it was suggested by (C. S. Fraser, 2001)(C. Fraser, 1989) to use multiple camera stations with a varied scale and from different angles (portrait and landscape) and that the points be well distributed and preferably distributed in three dimensions to achieve a geometrical distribution that will improve the properties of the Normal equation. (collinearity equation) and improves results.

$$x_{p'}=x_o - f\frac{m_{11}(X_p-X_o)+m_{12}(Y_p-Y_o)+m_{13}(Z_p-Z_o)}{m_{31}(X_p-X_o)+m_{32}(Y_p-Y_o)+m_{33}(Z_p-Z_o)}$$

(1)

$$y_{p'}=y_o - f\frac{m_{21}(X_p-X_o)+m_{22}(Y_p-Y_o)+m_{23}(Z_p-Z_o)}{m_{31}(X_p-X_o)+m_{32}(Y_p-Y_o)+m_{33}(Z_p-Z_o)}$$

The DLT method presented by(Abdel-Aziz & Karara, 2015) is usually an effective way to give the initial values of the camera parameters, but unlike the collinearity it is a linear method where the optical distortion is neglected, so it is a simplified method, but gives a linear solution to a nonlinear problem, it can be used to give initial values to the solution.

Initial values for the solution can be obtained through the known calibration field for the used program, as is the case in the Photo Modeler program. The calibration field used is defined by the program, whether the product manufactured by the company itself or the electronic version prepared for printing with dimensions defined by the program. But of course, printing the electronic version is much less accurate than the product because it is subject to the accuracy of the printer and the quality of the material on which it will be printed. Then, through these known points, the elements of external guidance are calculated, and then the solution in the bundle block adjustments method is the real-time solution for all elements.

VII. MEASUREMENT OF SINGLE POINT FEATURE

The center of the dot pattern is concerned with measurement and identification, which can be found by manually positioning the center of the point. However, this method will not be of adequate accuracy to the research plan we are considering. As the minimum movement of the mouse cursor will be around half a pixel, this is in the best case, otherwise it could be more than twice as easily and easily, especially since the matter is subject to the user's eyesight, screen display accuracy, and other reasons. There must be a mathematical method to determine the center of the point.

If the point whose center is to be calculated has similar grey values around the center, as is the case for circular or similar points usually. The weighted pixel rate value can be adopted in the implementation window as follows:

$$x_m = \frac{\sum_{i=1}^{n}(X_i.T.g_i)}{\sum_{i=1}^{n}(T.g_i)}$$

(2)

$$y_m = \frac{\sum_{i=1}^{n}(y_i.T.g_i)}{\sum_{i=1}^{n}(T.g_i)}$$

Where:-

x_m , y_m : weighted mean of pixel coordinates

x_i , y_i : pixel coordinates of points in process window

g_i : grey value at the pixel position (x_i , y_i)

T : the decision function to decide whether pixel use to calculation, which can be defined by threshold .

The accuracy of this computed centroid can be computed by the following equations:

$$\sigma_{x_m} = \frac{\sigma_g}{\sum g_i}\sqrt{\sum(x_i - x_m)^2}$$

(3)

$$\sigma_{y_m} = \frac{\sigma_g}{\sum g_i}\sqrt{\sum(y_i - y_m)^2}$$

These calculation repeated in all the image to find pattern recognition, the good contrast between targets and background help to minimize the iterations. Using least square method to find radiometric and geometric correlation between reference image and concerned image **Error! Reference source not found.**.

ISSN No:-2456-2165

VIII. EXPERIMENTAL WORK AND RESULTS

Several types of test field plate were used, square, spot, encrypted, and patched between coded and doted. More than ten practical experiments were made for this species, for each type a different shape and size, and each experiment was processed in several ways, and we had many results. We mention the best cases and compare between them.

It was the doted and the square did not give convergence in the solution. As for the coded and the mix dots and coded, they gave convergence from one trial to another. we cited here two cases of those multiple experiences. One is for coded points and one for mixed points. We find, as in Figure 1, that the encoded points gave a very high root mean square 679 pixels, of course there were fewer numbers for other experiments of this type, but it did not improve much to reach the level of the second type of points, which is the mixed encoded and doted.

Table 4 show the work of the experiment in this type. Mention these two experiments here to demonstrate the quality of this type of point, in addition to showing the effect of the quality of the material on which the dots are printed. The importance of the material lies in preserving the tropical painting and the good contrast between the points and its background. The equatorial effect is not for the purpose of standardizing the dimensions between the points, because this objective is only useful in the case of relying on entering the dimensions measured directly from the panel. But the purpose of equatorially is to give higher efficiency in determining the center of the point and thus higher efficiency in making matching between points. Which, in turn, gives a more stable position in the calculations for any solution or treatment process, giving better accuracy. We note that the overall RMS is 0.161pixels for a lower quality material and 0.0782 pixels for a higher quality material Table 4.

Table 4 Three types of test fields, two materials

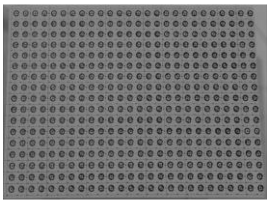
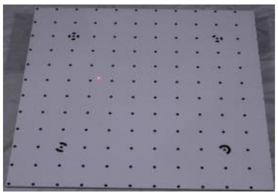
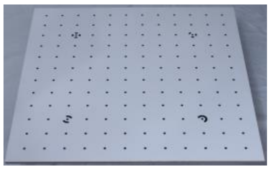
Number	Description	Sample
1	coded points test field	
2	Mixed coded and doted points test field MDF wood type1 with 1.25 cm thickness	
3	Mixed coded and doted points test field MDF wood type2 with 2.0 cm thickness	

Table 5 Sub-pixel marking results of the three types of test field.

Test field type	Count	Maximum residual	Overall RMS residual
coded points test field	349	1.4e+03	679
Mixed coded and doted points test field MDF wood type1	132	3.9	0.161
Mixed coded and doted points test field MDF wood type2	144	0.38	0.0782

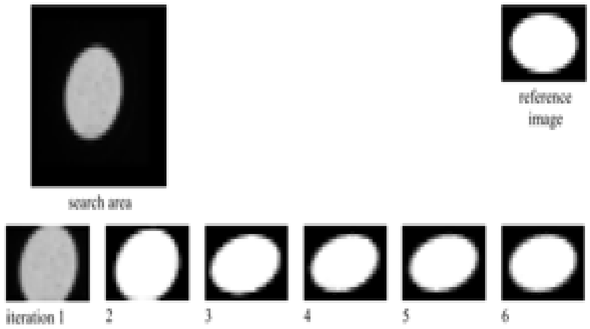


Figure 6 Iterative least square method to find concerned pattern.

Table 6 shows the IOP parameters quality by standard deviation of every parameter. The process report explain there were no a significant correlation between the parameters, except the omega-kappa correlation. If compare with (Udin & Ahmad, 2011) work we found the results in this research more better. Although that (Udin & Ahmad, 2011) used a standard 3D test field.

Table 6 IOP camera parameters quality, by calibration.

Number of photos oriented: 12 Number of Processing Iterations: 5 Camera Calibration Canon EOS 500D		
IOP Items	Value	Standard Deviations
Focal Length	26.483993 mm	0.001 mm
principal point x	1.160557 mm	0.001 mm
principal point y	7.513021 mm	0.001 mm
format width	22.587934 mm	2.7e-04 mm
format height	15.062200 mm	------
K1	9.970e-05	4.3e-07
K2	-6.508e-07	4.6e-09
K3	0.000e+00	-------
P1	-6.229e-05	5.5e-07
P2	6.066e-05	6.3e-07

IX. CONCLISIONS AND RCOMENDATIONS

Several experiments were conducted to test a number of test fields of different types, sizes and types of points they contain, starting from small and medium sizes in Table 4 to the large sizes used, such as those used in this research Figures 5.8 and Table 4 type2 The points vary from dot to the coded points in Table 4 type1, or the mixed points in Fig. 5.8 and Fig. 5.9. The size of the test field varies according to its purpose, as the small size is usually suitable for small focal lengths. The large size is usually suitable for relatively large focal lengths, in the case of single and not multiple focal lengths. The dimensions of test field, which the research settled upon after several experiments, are test field s with dimensions of 36 * 36 inches, which are defined for the program used by Photomodeler. There are two types of test field, the first is the one that is prepared by companies and specialized laboratories for the production of such products, and a report of calibration and quality of points in test field is attached with it, and it is executed with high accuracy and gives very accurate results. The second type that was used in this research is the product in a non-discreet manner, as it was printed on one of the materials available in the market and using the available printers for that.

But in this case, the effect on the accuracy of test field is the accuracy of the printer used and the accuracy of the execution of the points, which by its nature is unknown accuracy, but there is some variation in the accuracy of the printing as shown in the direct measurement of points and indirect measurement using photogrammetric intersection. In addition to the quality of the material on which the points are printed. This gives an unreliable test field to the accuracy, or at least the points that are not precisely the same, and their interlayer dimensions are not the same. But this does not prevent it from being used according to the available possibility. The test field that was used and approved by the research was using more than one material, then the research settled on a material of pressed wood with a thickness of 1.8 cm and with glossy semi-glossy faces. The points that have been printed are mixed dot and coded points, and this choice of points is according to the image processing method and the ability of the PhotoModeler program to determine the centers of the points and match them as the program knows them and the values of the dimensions between the points are known primarily to the program.

ISSN No:-2456-2165

Test field gave a very good accuracy by determining the centers of the image points as in Table 5, where the marking ranged from points marking residuals(0.0658-0.38) pixels, and the largest value for the end points in test field, shown in Table 5.5, overall RMS is 0.0801 pixels. Figure 6 shows the magnitudes of residuals, which are magnified 1000 times. We note that the relatively large values are for the end points except for a mid-perpendicular line for the points from point number 20 to point number 102, and some points where residuals of test field depends on several factors, factors related to optical deformation factors and factors related to the quality of the points, which affects the quality of the matching in the program between the points through the images. This indirectly indicates the poor quality of the printer being used.

We conclude from the above that the quality of test field is highly dependent on its type, meaning that it is approved by a specialized body, as is the case in companies and laboratories specialized in this field and have such products. Or it is locally manufactured, as in the case of the used in this research. But those which manufactured locally can fulfil the purpose if the photogrammetric processing is good, as in the case of identifying points centers and matching them and applying methods and photogrammetric equations. Table 6 shows the calibration parameters, whose quality gives to some extent an indication of the quality of the calibration. The resolution of focal length and principle point is one micron, which is very good for reference test field and for processing software.

Figure 6 *First photo of the twelve camera calibration images, with largest residuals of points magnified 1000 times.*

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