DEFORMATION DETERMINATION OF AIRCRAFT PARTS BY PHOTOGRAMMETRY

A. Sh. Amini [a], M. Varshosaz [b], M. Saadatseresht [c]

[a] Dept. of Photogrammetry and Remote Sensing, Faculty of Surveying, K.N. Toosi University of Technology, Tehran, Iran. Email: amirshahrokh_amini@yahoo.com
[b] Dept. of Photogrammetry and Surveying, Faculty of Surveying, K.N. Toosi University of Technology, Tehran, Iran. Email: varshosazm@kntu.ac.ir
[c] Dept. of Surveying, University of Tehran, Tehran, Iran. Email: msaadat@ut.ac.ir

KEY WORDS: Deformation, Industrial photogrammetry, Modelling, Propeller, Quality control

ABSTRACT:

This paper investigates the precision and capability of low cost off-line industrial photogrammetry for determination of deformations in aircraft parts. The study concentrates on deformation analysis of an airplane propeller through standard photogrammetric procedures. In this regard, around 100 targets were fixed on the blades of the propeller and imaged from several stations. The left and right models of the blades were developed using the measured points. The two models were then compared with each other to reveal any deformations in the propeller. The results indicated a maximum of 2.5 mm deformation in the blades. The investigations carried out in this research, suggest that with an ordinary non-metric digital camera, low cost targets and scale bars, an accuracy of around 1:20,000 (up to 50µm in object measurements) can be achieved. In addition, compared to current quality control techniques used in aviation, photogrammetry offers more flexibility, convenience, and a reasonable accuracy suitable for different measurement applications.

1. INTRODUCTION

Today, high quality and low cost in production process and dimensional quality control is an important aspect of industrial measurements [1]. There are a number of parameters regarding such measurements which need to be considered. These include the amount of time and cost, degree of automation, accuracy, working limitations such as difficulty in access to objects in radioactive areas, and complexity of object shapes. As a non-contact, flexible, and accurate technique, photogrammetry is used to facilitate the measurements in various quality control applications.

In this paper, the application of a photogrammetry in dimensional measurement of a propeller to reveal its deformations is used. This object was selected, because usually the two blades are meant to be manufactured exactly the same. However, due to environmental pressure and temperature, the blades get deformed after a while.

It has been tried to keep the system as low cost as possible, by incorporating an ordinary digital camera and inexpensive retro-reflective targets and scale bars. In the following, various steps taken to test the capability of photogrammetry in deformation analysis of the propeller are described. In this regard, at first, the characteristics of the propeller and the test conditions, the components of the photogrammetric system, and the way the tests were carried out are briefly reviewed. The results obtained in each step are then closely examined and discussed in order to see how accurate the photogrammetric measurements can be, within the test conditions. Conclusions and suggestions for further investigations are finally mentioned.

2. SYSTEM COMPONENTS AND PROCEDURE

As mentioned above, the object selected for the measurements is the propeller of a small aircraft (Figure 1) having two blades of very similar shape. The camera used to acquire the images was a Canon Powershot Pro90 IS digital camera which is off-the-shelf and relatively cheap. This camera has a pixel size of 4 m. A number of plastic retro-reflective targets were also used to produce texture points on the propeller. In order to scale the photogrammetric model, a few scale bars with known length were also used.

The experiment was carried out in three main stages including network design and image acquisition, calibration, and deformation analysis. The network design was carried out in order to define a proper configuration for the images to be taken. The calibration stage aims to define the interior orientation parameters of the camera at each station. To estimate correct values of the camera's interior parameters, the calibration was carried out twice, i.e. pre-calibration and self-calibration.

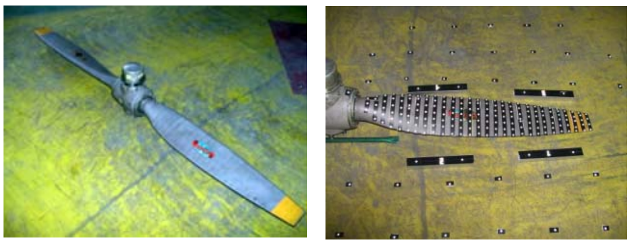

Figure 1. Test instruments: the propeller (on the left), targets and scale bars (on the right)

To study which one of the calibration techniques leads to better results, the coordinates of targets on the propeller were measured with their accuracy examined. Having defined the final interior orientation elements, the coordinates of the targets, fixed on the propeller, were used to develop individual models for each of the propeller's blades. The two models were finally compared with each other to reveal any deformations in the propeller's surface. The deformations were then examined to evaluate how well off-the shelf, low cost instruments can be used by photogrammetry in precise measurements like those used for analysis of deformations in aircraft parts. In the following, these steps are presented with the results of each discussed.

3. NETWORK DESING AND IMAGE AQUISITION

To achieve required accuracy, it is necessary to execute some constraints to network design to strengthen the imaging network. Due to the similarity of the blades in terms of shape and size, the process of network design for both blades is similar. The following conditions were considered in the network design:

- **Blade size:** each blade was about 1m long and the images should, thus, be captured in a way that the whole surface of the blade and the surrounding targets are visible in all images.
- **Scale of Imaging:** if the mean deviation of X, Y and Z coordinates of the points is assumed to be 10 µm, the accuracy of automatically measured points be 0.04 of a pixel, and there be three images captured at each station, the scale value would be:

$$S = \frac{\delta_c \cdot \sqrt{k}}{\delta . q} = \frac{10 \times \sqrt{3}}{(0.04 \times 4) \times 0.6} = 180 \quad (1)$$

In this equation, c is the mean deviation of X, Y and Z coordinates of the object points, . is the mean deviation of x, y image coordinates, q is the network factor and k is the number of captured images in each camera station. Consequently, according to lens distance, the optimum distance for foregone accuracy can be computed as:

$$H = \frac{f}{S} = \frac{0.007}{\frac{1}{180}} = 1.26m \quad (2)$$

where H is the distance between camera and object and f is the focal length.

- **Targeting:** based on the scale and the camera pixel size (4 µm), the size of each pixel on the object will be 0.72mm (0.004×180). However, in order to automate the detection of the targets using the software used (Australis in this case), the size of the targets needs to be at least 5×5 to 8×8 pixels. For this reason, the physical diameter of the targets was set to 4mm.
- **Density and distribution of the scale bars:** To achieve metric distances on the objects, four scale bars were used around the propeller (Figure 1). Two targets were fixed at the end of each scale bar, the distance between which was measured with an accurate clipper with an accuracy of 8µm.
- **Density and distribution of camera stations:** to capture the images, seven stations were considered. Three images were captured at each station, i.e. and a total of 20 images.

4. CALIBRATION

As mentioned above, the calibration was performed in two different ways, i.e. pre-calibration and self-calibration. For this, all targets fixed on the blades were measured and their accuracy was studied in both cases. In the following sections, in addition to how these steps are performed, their accuracy will be examined. The results would show which set of calibration parameters is to be used in the subsequent stage.

4.1 Pre-Calibration

In this stage, a testfield (Figure 2) was established, from which 8 convergent images were captured. The testfield included some 50 targets with unknown coordinates. The targets were then measured and the calibration parameters were then computed.

Figure 2. Pre-calibration testfield

Taking into account the conditions mentioned in the network design section above, the images were captured (Figure 3) and the points were measured.

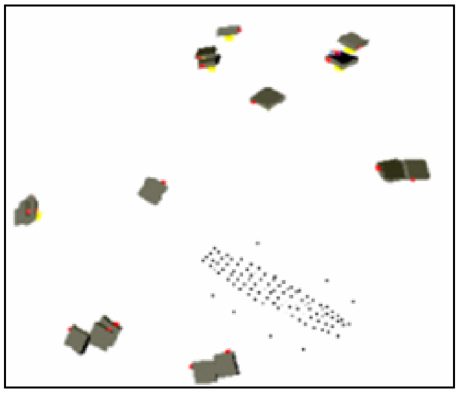

Figure 3. Images from the propeller

Scale Bar		Measured Length(mm)	Computed length(mm)	Difference(mm)
1	Blade A	174.009	174.013	-0.004
	Blade B		174.010	-0.001
2	Blade A	170.697	170.655	0.041
	Blade B		170.662	0.031
3	Blade A	171.315	171.354	-0.039
	Blade B		171.348	-0.033
4	Blade A	171.285	171.280	0.004
	Blade B		171.283	0.001

Table 1: measured and computed lengths of scale bars 1 and 4 as control length and scale bars 2 and 3 as check lengths in pre-calibration

The mean accuracy for propeller was obtained 52 m. As an external check to the measurements, the lengths of the scale bars were computed using the scale bar targets, and compared with their true lengths, measured by an accurate clipper. Table 1 shows the results of this step.

By taking scale bars 2 and 3 as check length, as can be seen, the mentioned lengths didn't have notable differences.

4.2 Self-Calibration

In a self-calibration method, calibration parameters are estimated along all other parameters and point coordinates simultaneously, so it is necessary to use some tie targets around the propeller to obtain the parameters accurately (figure 1). A new set of images were, therefore, captured from the propeller and the corresponding targets. It should be noted that, in this case, a number additional targets were added around the propeller in order to make sure that there is a good distribution of targets all around the images.

In this case, the mean accuracy for blade A was 96 m with that of the blade B equal to 75 m. Again, similar to the pre-calibration, as an external check the length of the scale bars was computed can compared with the measured ones as shown in table 2.

Scale Bar		Measured Length(mm)	Computed length(mm)	Difference(mm)
1	Blade A	174.009	174.012	-0.003
	Blade B		174.012	-0.003
2	Blade A	170.697	170.623	0.073
	Blade B		170.656	0.040
3	Blade A	171.315	171.364	-0.049
	Blade B		171.379	-0.064
4	Blade A	171.285	171.281	0.004
	Blade B		171.281	0.004

Table 2: measured and computed lengths for scale bars 1 and 4 as control and scale bars 2 and 3 as check length in self-calibration

As can be seen, the measurement differences for scale bars 1 and 4 are both around 4 ṃ with those of the other two scale bars being around 70 m. As can be seen in table 2, the mentioned lengths didn't have notable differences.

5. DEFORMATION ANALYSIS: COMPARING THE PROPELLER BLADES

As mentioned above, due to working conditions, the propeller's blades get deformed after a while which needs to be revealed. In order to control the dimension similarity of the blades, the surface of blades need to be compared. The surface of each blade is formed using its target points. A question to answer is which set of target coordinates to use, i.e. those obtained using the pre or the self calibration parameters. As the results obtained, the mean RMSE of both blades is smaller in the pre-calibration case. Therefore, the coordinates obtained using the pre-calibration parameters were used for the deformation analysis.

Before we are able to find the deformation, two steps were carried out which are coordinate system transformation and surface modeling.

5.1 Coordinate systems transformation

To compare the blades, the two data sets are to be registered. For this a number of targets fixed on the blades were used as tie points. Samples of such points are shown in figure 4.

The mean error of coordinates obtained in the transformation was 201 m.

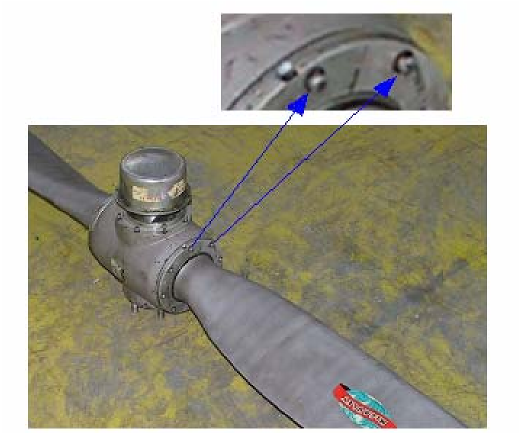

Figure 4. Sample control points used to register coordinate systems of measurements for both blades

5.2 Surface Modeling

Once the coordinate systems of both blades were registered, because of difference between the positions and the number of targets on each blade, the comparison of two blades was not yet possible. Therefore, the surface of the blade A must be modeled and the elevation of this surface in the position of target points of the blade B must be determined, by comparing which the deformations of two blades are obtained. In this research, a Global Polynomial was used to model the blade surface, i.e.

$$Z = f(X,Y) = a_0 + a_1 X + a_2 Y + a_3 X^2 + a_4 XY + ... \quad (3)$$

All the blade points including control and check points were used to determine the polynomial terms. Table 3 shows the examination of various terms of the polynomials used. As can be seen, the polynomial with 11 terms has the minimum RMSE. So final coefficients were determined again by using all control and check points using a polynomial with 11 terms. The mean error of surface modeling was estimated 94m.

Once the polynomial equations were computed, by putting the X and Y coordinate of each point on blade B in equations of blade A, and comparing the result with initial Z of the point, the deformation of two blades in the direction of Z in that point was determined. These deformations are shown in figure 5 as vector plots.

As mentioned, the errors of system transformation and surface modeling obtained 201 m and 94 m. Taking into the account the coordinate's error, i.e. 50 m, the final error with %67 confidence equals:

$$\delta = \sqrt{50^2 + 201^2 + 94^2} = 227\mu \qquad (4)$$

Now, with a 2.5 to give %95 confidence, the deformation is more than 570 m, two blades have deformation and for less value, the values are at least in the error zone and we can't say certainly they are deformations.

Number of terms	RMSE(μm)	Number of terms	RMSE(μm)
3	9067	13	413
4	6920	14	445
5	2483	15	984
6	1008	16	1270
7	474	17	3124
8	838	18	5583
9	125	19	5803
10	103	20	11225
11	94	21	23998
12	311		

Table 3. The values of RMSE according to the number of the terms of the polynomial

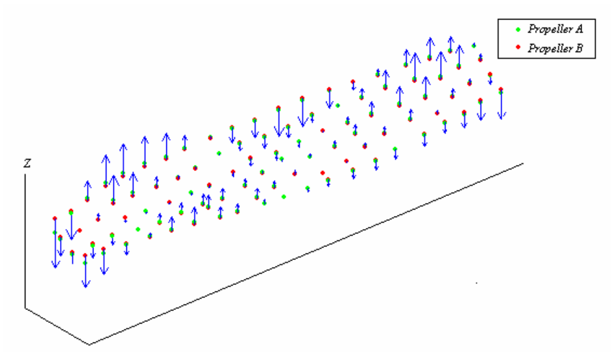

Figure 5. Vector plots of deformations of two blades

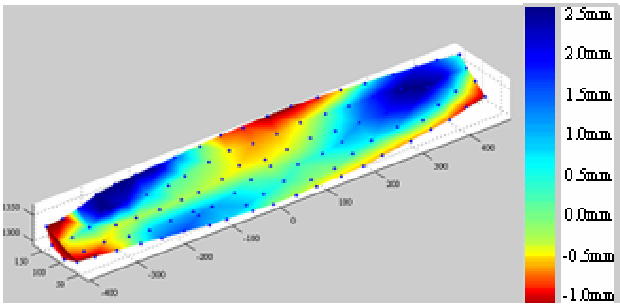

Figure 6. Graphic displaying of the deformation of two blade surfaces

6. CONCLUSIONS

The main purpose of the paper was to investigate the precision and capability of low cost off-line industrial photogrammetry in dimensional quality control and determination of deformations on aircraft parts. Based on the results of this paper, photogrammetry can be used as a metrology technique in aerospace applications, especially because of its exclusive characteristics such as being non-contact, flexible, and low cost. The observations and results in the tests carried out are:

1. Considering the better accuracy obtained from pre-calibration method versus self-calibration method in measuring the propeller, to reach high accuracy in self-calibration method, strong network design, appropriate quantity and distributions of targets and scale bars with appropriate precise and length is needed.

2. Achievement to accuracy of 10 micron for propeller with length of one meter equivalent relative accuracy of 1:100,000, was not possible. It seems the most important reasons were: using non-metric camera, weak network design, scale bars with short and imprecise length and targets with imprecise geometry. The attainable accuracy, in this paper was around 1:20,000.

3. Considering the obtained accuracy of 1:20,000, dimensional controlling of the industrial parts and equipments can be done with accuracy of 1:20,000 size of object with mentioned facilities. Also, with considering the time of six hours for targeting, imaging and calculations and the low cost of used camera, Industrial photogrammetry can be use as a relatively precise, cheap and flexible method in industrial metrology and dimensional controls.

REFERENCES

Amini, A. Sh., 2006: The Investigation of Dimensional Quality Control of Industrial Equipments with Close Range Photogrammetry Method. Master Science Thesis of Photogrammetry, Department of Photogrammetry Engineering, Faculty of Geomatics Engineering, K.N. Toosi University of Technology, Tehran, Iran

Fraser, C., 1999: Automated Vision Metrology for Precise 3D Engineering and Industrial Surveying. Department of Geomatics, the University of Melbourne Parkville VIC 3052

Fraser, C., 1996: Industrial Measurement Applications. Whittles Publishing.