INVESTIGATING OFF-LINE LOW COST PHOTOGRAMMETRY APPLIED TO SMALL AIRCRAFT QULAITY CONTROL

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Abstract

Today, reducing the time and cost of measurements keeping a certain level of accuracy and a certain degree of automation are amongst the desired properties of any industrial measurement system. Due to working limitations like complexity of object shapes and difficulty in getting access to them, designing proper systems of such becomes a difficult task. As a non-contact, flexible, and accurate technique, photogrammetry can be used to facilitate the measurements in various dimensional measurement applications.

This paper investigates the capability of low cost off-line industrial photogrammetry to determine deformations in small aircraft surfaces. In order to estimate the differences between the surfaces of two aircrafts, a number of targets were fixed on their noses and were imaged from several stations. The distances between the targets, on each plane, were measured and the corresponding ones were compared to reveal any difference between the two noses.

Having critically analyzed the results, 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 150μm in 3m object) can be achieved. Therefore, in addition to offering flexibility and convenience, photogrammetry can produce object measurements with a reasonable accuracy which may suit different quality control applications in aviation industry.

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 the noses of two similar aircrafts to reveal their difference is used.

It has been tried to keep the system as low cost as possible, by incorporating an ordinary digital camera and low-cost retro-reflective targets and scale bars. In the following, various steps taken to test the capability of photogrammetry in deformation analysis of the noses are described. In this regard, first, the characteristics of the aircraft noses, the test conditions, the components of the photogrammetric system, and the way the tests were carried out are briefly reviewed. The result 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 nose of two aircrafts (Figure 1) having very similar shape. Basically, due to producing procedure, environmental pressure and temperature, the shape of a small aircraft gets deformed. The aim of tests carried out here is to reveal these deformations. For simplicity, the

Figure 1: Test instruments: one of the noses (left), targets and scale bars (right)

aircraft nose was selected for measurements. In addition, as the original model of the aircraft was not available, the measurements were made on two aircrafts with those on one of them taken as the reference. In other words, noses of the two aircraft were measured and compared with each other to reveal any differences resulted from their deformations.

The camera used to acquire the images is a Canon Powershot Pro90 IS digital camera which is off-the-shelf and relatively cheap. This camera has a pixel size of nearly 4 μm. A number of plastic retro-reflective targets were also used to produce texture points on the noses. In addition, to scale the photogrammetric model, a few scale bars with known length were 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 cameras at each station. To estimate correct values of the camera's interior parameters, the calibration was carried out with self-calibration method.

Having defined the final interior orientation elements, the coordinates of the targets, fixed on the noses, were used to measure distances between some control targets having similar locations on each nose. The two sets of measured length were finally compared with each other to reveal any deformations in the noses surface.

3 Network Design and Image acquisition

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 noses in terms of shape and size of, of the process of network design for both noses is similar. The following conditions were considered in the network design:

- **Nose size:** each nose is about 3 meters long. Because the images can not be captured surrounding the whole surface of each nose, all targets are visible in each image.
- **Scale of Imaging:** if the mean deviation of X, Y and Z coordinates of the points is assumed to be 50 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 [2] and [3]:

$$S = \frac{\delta_c.\sqrt{k}}{\delta.q} = \frac{50 \times \sqrt{2}}{(0.04 \times 4) \times 0.7} = 630 \qquad (1)$$

In this equation, σ_c is the mean deviation of X, Y and Z coordinates of the object points, σ 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 is:

$$H = \frac{f}{S} = \frac{0.007}{\frac{1}{630}} = 4.41m \qquad (2)$$

In this equation 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 2.5 mm (0.004×630). However, in order to automatic the detection of the targets using the software used, the sizes of the targets need to be at least 5×5 to 8×8 pixels. For this reason, the physical diameter of the targets was set to 12mm.

- **Density and distribution of the scale bars:** To achieve metric distances on the objects, four scale bars were used on the surface of each nose (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, 13 stations for nose A and 10 stations were considered (figure 2). Two images were captured at each station, i.e. and a total of 26 images for nose A and 20 images for nose B.

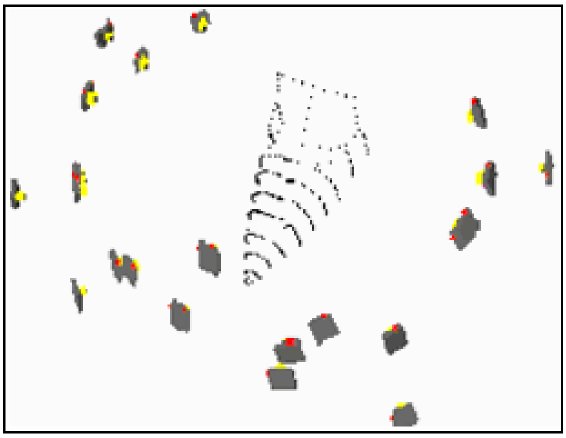

Figure 2: Location of imaging stations for nose A

4 Calibration

As mentioned above, the calibration was performed with self-calibration method. In a self-calibration method, calibration parameters are estimated with all other parameters and point coordinates simultaneously. In this case, there are 10 constraints including 4 scale bars length and 6 parameters of ZOD (Zero order design. Specifications of self-calibration for noses are given in table (1).

Table 1: Specifications of bundle adjustment self-calibration for noses

	Points	Observations	Unknowns	Constraints	Freedom
Nose A	246	5704	904	10	4810
Nose B	217	3496	781	10	2725

4.1. Investigating correlation between calibration parameters

The calibration parameters for nose A and B are given in table (2). As can be seen in this table, the parameters are not having notable differences, so the validity of the obtained parameters is confirmed.

Table 2: Calibration parameters values and their difference percentage for two noses

Parameters	Nose A	Nose B	Difference percentage
C	8.1946	8.1991	0.05
Xp	-0.0272	-0.0257	8.19
Yp	-0.0991	-0.0991	0.00
K1	3.13E-03	3.18E-03	1.60
B1	-1.86E-04	-1.72E-04	7.53
B2	5.34E-04	4.92E-04	7.87

4.2. Investigating the precision of coordinates obtained for the noses points

The accuracy of coordinates of target points are shown inflated as ellipse errors in figure (3). As can be seen, the middle points on the noses have the best accuracy which is due to the visibility of these targets in many images,

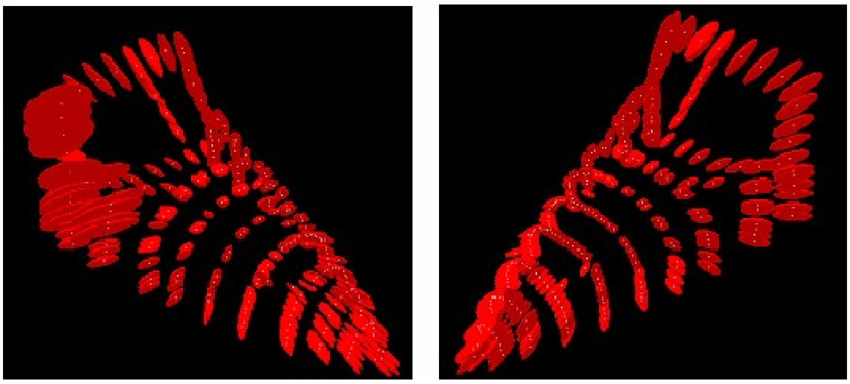

Figure 3: Ellipse error of points of nose A (right) and nose B (left)

good network and symmetry of the rays of these points. But edging points have less abundance and weak network design. The RMSE of points coordinates including mean, maximum and minimum values are given in table (3). The mean accuracy for nose A is 147µm and for nose B is 238µm. Good accuracy of coordinates shows the validity of results.

Table 3: Coordinates accuracy of self-calibration method

RMSE(mm)	Nose A	Nose B
MEAN	0.1465	0.2381
MIN	0.0591	0.0799
MAX	0.3232	0.4024

4.3 Investigating the validity of network by controlling scale bars length

By computing the length of the scale bars, and comparing them with those measured, the validity of the results can be investigated. As can be seen in Table (4) and selecting scale bars number 2 and 3 as check for nose A and scale bars number 1 and 3 as check for nose B, the mentioned lengths did not have notable difference; thus the validity of results is confirmed.

Table 4: measured and computed lengths for scale bars 1 and 4 as control for nose A and scale bars 2 and 4 as control for nose B

Scale Bar		Measured Length(mm)	Computed length(mm)	Difference(mm)
1	Nose A	174.009	174.010	-0.001
	Nose B		174.080	-0.071
2	Nose A	170.697	170.586	0.111
	Nose B		170.699	-0.002
3	Nose A	171.315	171.243	0.072
	Nose B		171.427	-0.112
4	Nose A	171.285	171.284	0.001
	Nose B		171.283	0.002

5 Deformation analysis: comparing the measurements on aircraft noses

As mentioned above, due to working conditions, the noses get deformed after a while. This deformation needs to be revealed, or the plane may crash. In order to control the dimension similarity of the noses, the surface of noses need to be compared. To find the deformation between the noses, dimensional control of two noses in sections between definite points was done. There are some screws on the noses of the planes that have similar and fix positions on their surfaces, and distances between these screws can be compared as length control of the noses. For this reason, 11 identical screws were selected on their bodies as shown in figure (4). The coordinates of these points are determined with other targets in bundle adjustment self-calibration.

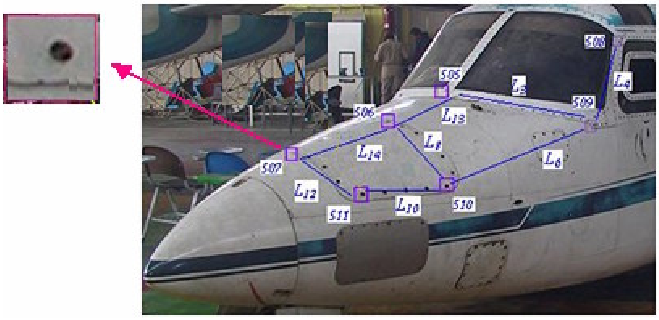

Figure 4: Instances screws selected on the bodies of the noses and distances between them

Fourteen distances, from L_1 to L_{14} were considered between these screws and their lengths were computed according their obtained coordinates from bundle adjustment. According the results of table (3) and the minimum accuracy of 240 micron for targets coordinates in %67 reliance area, by considering the value of 2.5δ in %95 3D reliance area, if the difference of the similar lengths on two noses are more than 600 micron (0.6 mm), two noses have deformation in that direction. So according to the table (5), we can say the lengths of L_9, L_{10} and L_{12} are in the error zone and we can't say certainly they are deformations. But other deviations are deformations.

Table 5: Analogous lengths between the screws on the noses and their difference

Length	Begin-End	Nose A (mm)	Nose B (mm)	Difference (mm)
L_1	501-502	529.927	526.360	3.567
L_2	502-505	752.906	758.255	-5.349
L_3	505-509	777.835	784.565	-6.729
L_4	508-509	530.968	523.111	7.856
L_5	502-503	994.704	992.716	1.987
L_6	509-510	990.307	994.880	-4.573
L_7	503-506	562.303	563.840	-1.537
L_8	506-510	564.788	562.882	1.906
L_9	503-504	405.209	405.420	-0.210
L_{10}	510-511	405.349	403.582	0.766
L_{11}	504-507	391.931	389.599	2.331
L_{12}	507-511	390.058	389.387	0.470
L_{13}	505-506	542.135	542.452	-0.316
L_{14}	506-507	511.501	513.219	-1.717

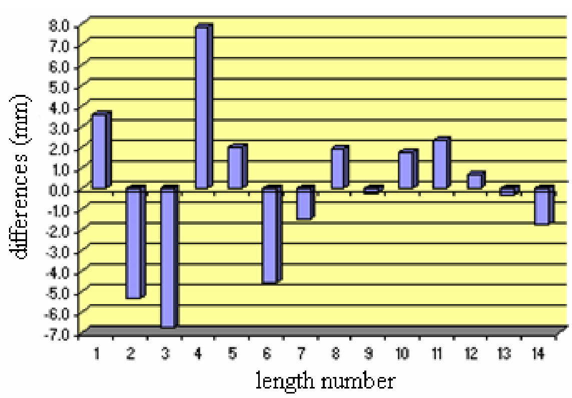

Figure 5: The differences between analogous lengths on two noses

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. In summary it can be said:

1. The low accuracy of measurements on the noses is due to the complexity of nose surface and the difficulty in taking images from over and below of the noses. The accuracy, therefore, could be improved by partial imaging, strengthening the imaging network, and taking images from more stations.
2. It was observed that the accuracy of 50 micron for noses within a 3m space equals an accuracy of 1:60,000 could not be achieved. 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. The tests showed, if measurements of accuracy no better than 1:20,000 are acceptable, photogrammetry can be reasonably used as the measurement tool. In addition, photogrammetry offered a quick (eight hours for targeting, imaging and calculations), low cost (cheap camera and targets), and flexible solution for making such measurements.

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