Aircraft Deformation Measurement using Industrial Photogrammetry

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Abstract : With industrial development, industrial products became more refined and upscale, resulting in increased necessity for manufacturers to come up with a method to check whether products have been produced to meet the needs of the customer. For thisreason, attention was drawn to industrial photogrammetry to obtain data rapidly without contacting the target object. In this study, the experiment has been conducted with the O-2A aircraft to determine the applicability of industrial photogrammetry.

Key Words : Industrial photogrammetry, O-2A aircraft, Check point, Point cloud

1. Introduction

With industrial development, industrial products became more refined and upscale, resulting in increased necessity for manufacturers to come up with a method of measurement to check whether or not the products have been produced correctly to meet customers' needs. In turn, significant attention was drawn to industrial photogrammetry to satisfy such needs. In the aviation industry, specifically, attempts are being made to apply industrial photogrammetry, as a new technology to improve the existing method of measurement, to the actual maintenance of aircraft. Since core technologies, such as design drawings of the aircraft have been classified as confidential, have not been revealed by countries and companies concerned, thus, they cannot be used in the maintenance of aircraft. Therefore, in case of breakdown of the aircraft, the method to measure the distance between check points of the aircraft is used to check for any failure in the aircraft, instead of using the aircraft's design drawings. This study presentsindustrial photogrammetry to ensure accurate and rapid acquisition of data, which is required in advanced precision industries, regarding the aircraft. For this, the 3-D coordinates of the check points of the aircraft wasmeasured to check the alignment condition of the aircraft by using the V-Stars system. The industrial photogrammetry system and the quantitative analysis regarding the deformation of the aircraft body wasanalyzed by using the

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Pro-Spot system in order to provide promptly the data necessary for the maintenance and failure analysis of the aircraft.

2. Industrial photogrammetry

Industrial photogrammetry enables the measurement of the object to which access is difficult, and also allows measuring the object, which is sensitive to human contact,without direct contact to the target object. The advantages of industrial photogrammetry in the precision measurement of the industrial products are as follows.

(1) Quickness

The photogrammetric precision measurement requires less time to obtain the required data than using other measurement methods. It only requires the time for target installation and image taking, and thus, minimizes its influence to the industrial process. Some systems currently can obtain the data almost in real time. Quickness in the environment, such as tunnel measurement, minimizes personal accidents and damages in property.

(2) Precision

Photogrammetry technology has the precision of about 1:20,000 ~ 1:1,000,000, the ratio of standard deviation of the point coordinate and the size of the target object. This ratio is widely used in industrial precision measurement due to the relative independency of the camera arrangement.

(3) Reliability

Since it uses a multi-bundle solution, any wrong measurement can be found by using the data of other images that are not used for obtaining the main data, and thus, its result is reliable.

(4) Verifiability

The results of photogrammetry provide detailed data for the target object. Since data that were unnecessary at the time of measurement can be obtained later, and the data necessary for other uses can be obtained, they can be utilized as pieces of evidence in various areas.

In order to reconstruct a coordinate of the target object into a 3-D image, it needs to be shown in at least two photos. If many coordinates are distributed widely, several photos must be matched. Multi-image matching determines the 3-D coordinate of the target object precisely by matching several photos through the geometrical principle of the photo.

In this study, V-STARS of GSI (Geodetic Systems, Inc.) has been used to obtain 3-D coordinate values for each orientation point through multi-image matching. V-STARS can processthe image data of the digital camera and all its processes, which have been performed manually,are performed automatically and rapidly. It also enables the processing of Automatch, Triangulation, and Bundle processes that are suitable for each condition,and performs automatic over-all data processing by using the Automeasure module, which integrates all these processes, to calculate the accurate 3-D coordinate value. The steps involved in multi-image matching in this study are shown in Figure 1.

Project setup
Project title

Camera selection
Camera calibration Data loading

Photo input
Specification of the image path

Bundle
Point coordinate creation

Scaling measurement
Input standard distance

3D viewer
Calculating the distance between points, vector quantity, average, deviation, etc.

Export file
IGES, VDA, 3D, AAT, XYZ, Text, EDDS.

Fig. 1 Flow chart for the multi-image matching system

3. Industrial Photogrammetry System

The industrial photogrammetry system consists of the measurementdigital camera to obtain the image, the various targets for automatic processing and obtaining the coordinate of the feature point, the Pro-Spot system to obtain point cloud, Auto bar for setting the reference coordinate, and the Scale bar for the selection of scale.

Autobar is the tool used in determining the reference coordinate for the target object and allows automatic processing.

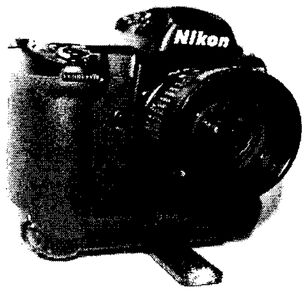

Fig. 2 Digital measurement camera

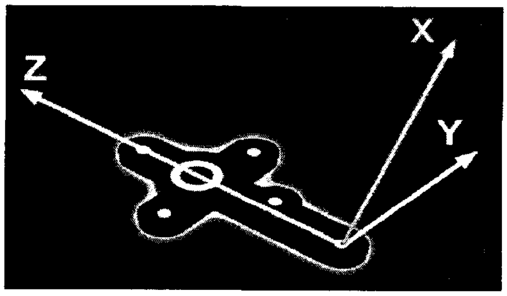

Fig 3 Auto bar

Coded target is the target for which the identification number is given by recognizing each unique pattern automatically in the program, and allows automatic matching processing between photos. Tape target is used in places where it is difficult to install the coded target, or in places that must be measured at regular intervals, and in which the identification number is randomly given through the system.

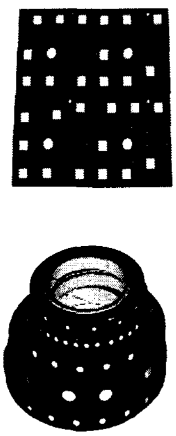

Fig. 4 Coded target and Tape target

Pro-Spot is used to create the point cloud, from which 6,000 to 22,000 projection targets are projected on the surface of the target object according to the type of slit. A random identification number is given to each projected point on the program. Pro-Spot is used to determine surface topography or deformation of the target object.

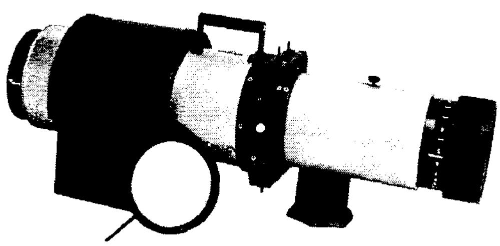

Fig. 5 Pro-spot system

Table1. Pro-spot system specification

Classification	Features
Accuracy	0.01～0.025mm per 1m of object size
Point number	6,000～22,000
Weight	5.0 Kg
Environments of temperature	0～40℃

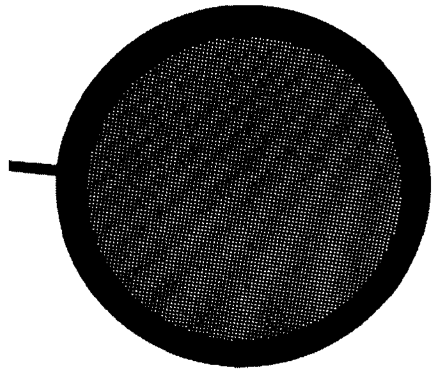

Fig. 6 Projection Target slit

4. Experimentation and the Analysis of the Results

In this study, O-2A aircraft that has been manufactured by Cessna was selected in order to measure the alignment condition of the aircraft.

Since design drawings are kept confidential in most aircraft, the alignment condition of the aircraft was checked by measuring the distance between the check points of the aircraft, not according to the design drawings of the aircraft.

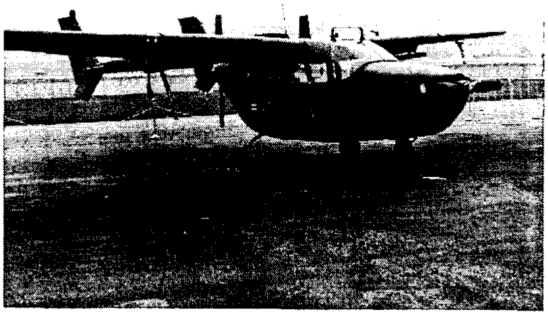

Fig. 7 Aircraft O-2A

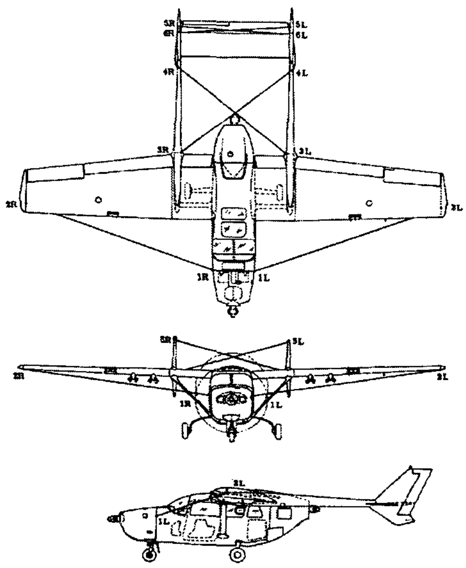

Fig. 8 Aircraft check point diagram

There are a total of 12 check points for the O-2A aircraft, as shown in Fig. 8, and the alignment condition of the aircraft is checked by the distances between check points. The distance between check points was based on the values of the TO (Technical Order) of the aircraft, as shown in Table 2.

Table 2. Distance range of check point (unit : mm)

check point	Toleration range
1L to 2L 1R to 2R	5442.712~5465.064
3L to 4R 3R to 4L	3868.674~3887.978
5L to 6R 6R to 6L	2911.348~2930.652

In this study, targets were attached at the check points to measure the distance between the aircraft's check points, and 10 coded targets were attached between check points for the automation of the processing. The locations of the coded targets were selected by considering the overlapping of photos, and the accuracy of the Autobar, which sets up the scale (degree: +/-0.003mm) and the reference coordinate, was enhanced by the collinear alignment of the check points.

Nikon D1H, a measurement camera, was used for photography, and the photo was taken by using the free convergent method that considers overlapping of photos.

Fig. 9 shows targets installed at each check point and coded targets, and Fig. 10 shows the Autobar and scale.

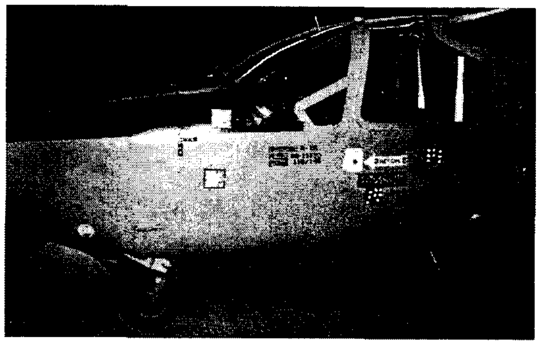

Fig. 9 Tape target and coded target

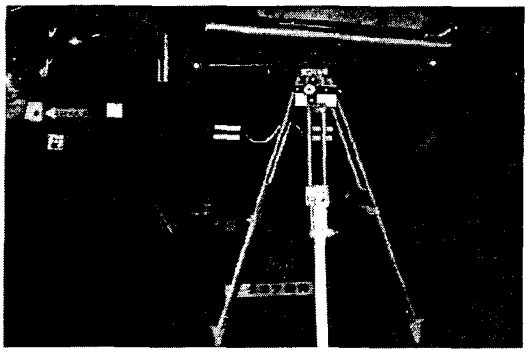

Fig. 10 Auto bar and Scale bar

The distance between check points was determined by V-STARS that can extract 3-D coordinates. Coded target, scale, and Auto bar were recognized automatically, each of the photos were matched, and bundle adjustment was performed by using Auto-matching for the input images to obtain the 3-D point coordinate as shown *in Fig. 12*.

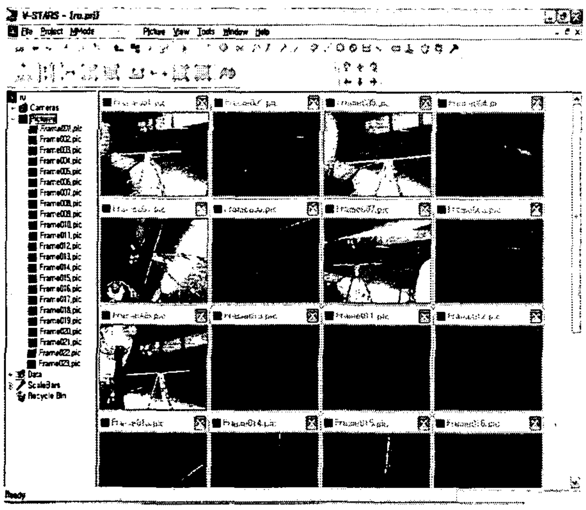

Fig. 11 image processing

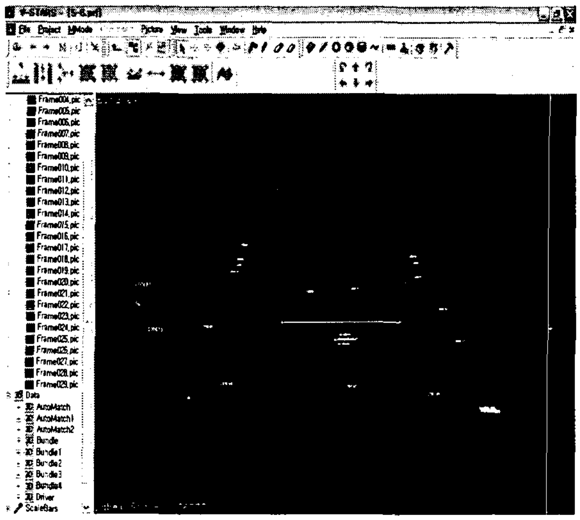

Fig. 12 measured 3-D points

The distances between each point of stable aircraft and unstable aircraft were calculated using such method and are shown in Table 3.

Table 3. Result of check point measurement (unit : mm)

check point	unstable aircraft	stable aircraft
1L to 2L	5443.378	5445.247
1R to 2R	5451.242	5451.872
3L to 4R	3868.926	3873.259
3R to 4L	3877.438	3877.016
5L to 6R	2923.540	2915.310
5R to 6L	2932.278	2918.180

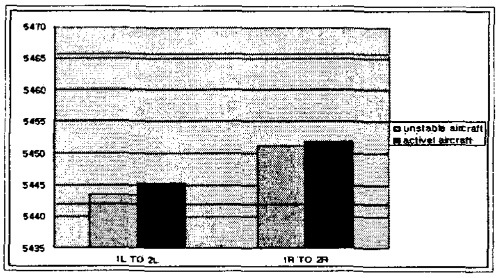

Fig. 13 Bar graph of check point 1to2 distance

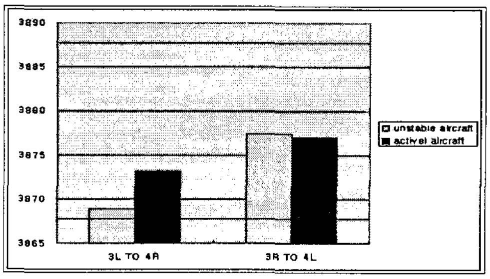

Fig. 14 Bar graph of check point 3to4 distance

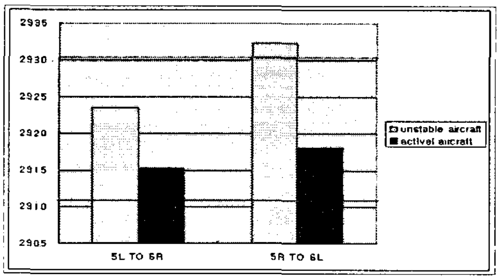

Fig. 15 Bar graph of check point 5to6 distance

The distance between #5 and #6 of the unstable aircraft exceeded the allowable tolerance as shown in Fig. 15. The unstable aircraft generally had more deviation in the distance in both sides.

The required time to check the alignment condition of the aircraft was about 15 minutes, 10 minutes for target installation, 2 minutes for photography, and 2 minutes for image processing.

Appearance measurement for the tail boom was also performed for the aircraft that was considered unstable in order to check for any deformation in the aircraft. Identical part of the stable aircraft and the unstable aircraft were measured and compared since there was no exact aircraft design data.

Point cloud was generated for the tail boom of each aircraft by using Pro-spot and photos taken by the measurement camera. The length of the boom was about 4.5 m, and photos were taken by dividing the boom into three parts for the Autobar.

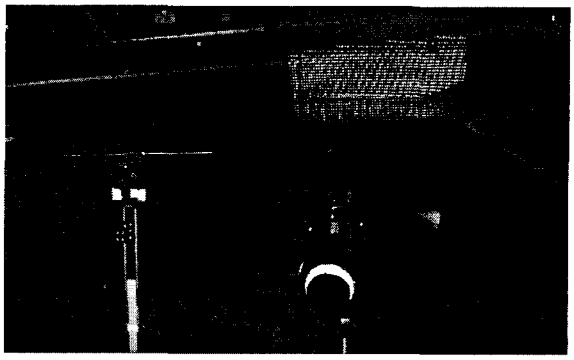

Fig. 16 Boom measurement using Pro-spot

With the obtained images, coordinate calculation was performed for the point cloud by using the same photography system. The automatically recognized point cloud was projected onto the reference surface by using target points located at the four corners of the boom, and the distance from the projected reference surface to the measuring points were calculated to compare differences in the appearance of both aircraft.

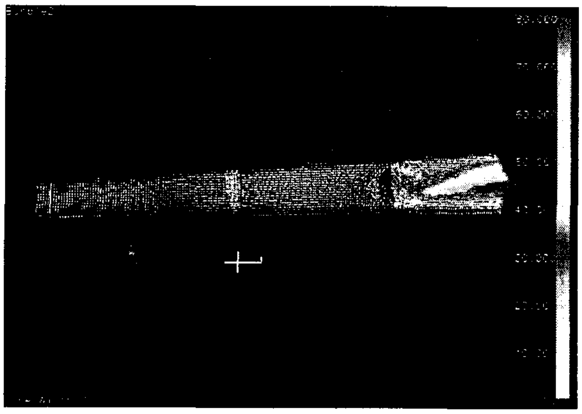

Fig. 17 Pro-spot result of stable aircraft

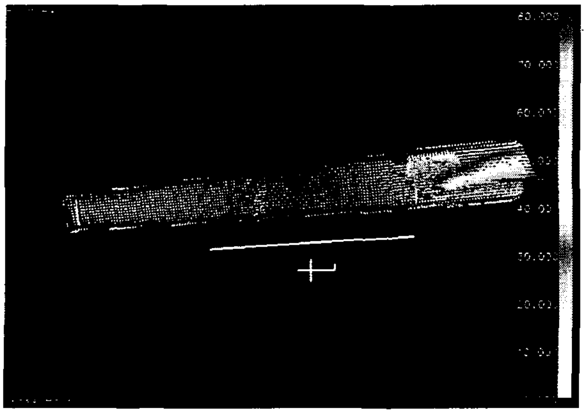

Fig. 18 Pro-spot result of unstable aircraft

The following results were obtained by the measurement of the alignment condition of the aircraft.

Fig. 17 and 18 show the distances from the virtual reference surface to the measuring points as the measurement results for the tail boom of the aircraft. According to the measurement, the height from reference surface at the connection of the boom and the body of the aircraft was shorter in the unstable aircraft than in the stable aircraft.

5. Conclusions

The alignment condition of the aircraft was measured by using industrial photogrammetry and the deformed part was measured by using the point cloud. The conclusions obtained are as follows.

1. The required time for checking the alignment condition of the aircraft was about 15 minutes, 10 minutes for target installation, 2 minutes for photography, and 2 minutes for image processing. It is advantageous that the required time for the 3-D measurement of the measuring points is almost constant in industrial photogrammetry, regardless of the number of measuring points and the size of the aircraft, because the 3-D coordinates of the measuring points are generated collectively after the completion of the processing, while it increases as the number of the measuring points increases in conventional measurement methods.
2. According to the comparison of the 3-D distance of each check point, the distance between #5 and #6 of the unstable aircraft exceeded the allowable tolerance by 1.626 mm.
3. According to the quantitative analysis used in the comparison of the check points'distances by each section, distance deviation was more significant in the unstable aircraft than in the stable aircraft. This means that the alignment was deformed in the unstable aircraft.

Reference

1. Pazar, R. E., (1999), Small-Scale Digital Photogrammetry in a Cryogenic Vacuum Environment, NASA CONFERENCE PUBLICATION, Vol.-No.208598.
2. Kooyman, T. (2000), Verifying Aircraft Assembly with Real-Time Digital Photogrammetry. Sensors, Vol.17 No.6.
3. International Archives of Photogrammetry and Remote Sensing, "Hough transform for interior orientation in digital photogrammetry", Vol.33 No.3/2, 2000.
4. H. M. Karara., (1989). Non-Topographic Photogrammetry, American society for photogrammetry and remote sensing 2nd ed, pp. 349~355.
5. Sanjib K. Ghosh. (1988) Analytical Photo-

grammetry. 2nd, Pergamon-press, pp. 187～195.

6. Paul R. Wolf., Elements of Photogrammetry, 3nd ed, McGraw-Hill Inc. pp. 384～390, 551～556.

7. Edward M. Mikhail., James S. Bethel., J. Chris McGlone., "Introduction Modern Photogrammetry", John Wiley &Sons Inc., pp. 247～275.

8. V-STARS, www.gsi.com