Accuracy Control of Big-scale Space 3D Measurement System in Aircraft Digital Assembly

Yan Cheng*, Yuan-heng Xu, Xue-liang Huang and Lei Wang

Institute of Systems Engineering, CAEP, Mianyang 621999, Sichuan, China

*E-mail: 654803236@qq.com

Abstract. Large scale space measurement technology is one of the key technologies of aircraft assembly. The accuracy of measurement system affects the efficiency and quality of aircraft assembly directly. However, the accuracy of the measurement system depends on the process of constructing the measurement system. Therefore, this paper explores three principles of constructing high-precision large-scale space measurement system, through a large number of experiments and simulations.

1. Introduction

The rapid development of large-scale space measurement technology has changed the traditional aircraft design and manufacturing mode [1-2], which meets the requirements of large measurement range, high precision, high efficiency and high flexibility in the process of aircraft digital assembly. Constructing digital measurement system to locate the spatial position and posture of aircraft components accurately is the foundation and premise of modern aircraft digital assembly [3], therefore, the accuracy of measurement system affects the efficiency and quality of aircraft assembly directly. According to the current aircraft manufacturing process, the assembly accuracies at many stages are just above the minimum level, so the cumulative effect may even make that the final quality of aircraft assembly cannot satisfy the standard. Therefore, it is necessary to explore the large-scale space measurement technology, to control the accuracy of the measurement system effectively, and provide better support for the aircraft digital assembly.

2. Survey of large scale space measurement technology

Different from the traditional measurement technologies, large scale space measurement system consists of professional optical measuring equipment and target receiver. According to different principles, large scale measurement equipment can be divided into three types which are widely used in industry:

2.1. IGPS (Indoor GPS)

IGPS [4] is a concept of three-dimensional principle based on regional GPS technology, which is proposed in the early 21st century. The measuring principle of IGPS is similar to GPS, the infrared pulse laser transmitters are used as the satellite, and the indoor receiver receive the laser and time characteristic parameters passed by the transmitters. According to the angle and position characteristics of the receivers, the third-party measurement software calculates and gets the high-precision measurement results [5-6]. The main features of IGPS technology are as follows: the system...
has no limitation of measurement range, and it can expand the measurement range by increasing the number of transmitters; As long as there is no physical occlusion, there will be no light drop; IGPS can be used indefinitely after the location is calibrated without considering the station moving. However, the cost of deploying IGPS measurement system is high, and its location is inconvenient to move.

2.2. Laser radar
Laser radar is an instrument that can acquire 3D spatial target location data in real time. Combined with airborne system and remote sensing technology, Laser radar can achieve large scale and high-precision space measurement. Laser radar measurement system combines laser technology with photoelectric detection technology, which includes transmission system, receiving system, information processing system and other subsystems. When the measurement system works, the transmitters send a laser beam (detection signal) to the target, the receiving system receives the reflected signal and restores it to a kind of electrical pulse that can be analysed. The information processing system analyses the detected signal and the returned electrical pulse signal, calculating the spatial position information of the target, including distance, orientation, posture and external contour parameters, etc. The main features of the laser radar measurement system are as follows: the measuring speed is fast and the range is wide, which is suitable for the large-scale measured target; the measuring precision is high, the single point repetitive measuring accuracy is less than 0.05 mm, within five meters; but it is difficult to process the measuring data.

2.3. Laser Tracker
Laser tracker is a kind of high-precision and large-size measuring equipment in industrial measurement field, which is mainly used for real-time tracking and measurement of space moving targets. Laser tracker measurement system consists tracker host, controller, upper computer, target ball and some measurement accessories (such as T-probe, T-cam). When measuring, the laser beam is emitted from the main hole of the tracker and irradiated on a reflecting prism which can rotate around the horizontal axis; the main head of the mirror can rotate around the vertical direction. Thus, the laser beam can track all points in the measured space. The target ball is placed at the measured point, receiving the laser beam and reflecting the original laser beam back. The reflected beam is divided into two paths when passing through the spectroscope: one beam of laser light enters the laser interference system, forming the interference fringes, which can measure the linear distance between the target ball and the origin of the laser tracker; another laser light enters into two angle encoders, the optical elements convert and amplify the photoelectric signal, the encoder can measure the horizontal and vertical angle between the target ball and the laser tracker's rotation centre [7], and then calculate the relative spatial position of the target ball. The main features of the laser tracker measurement system are as follows: tracking the moving target automatically; the measuring precision is high and the absolute accuracy can be controlled within (+0.1mm); measuring instruments are easy to carry. And laser tracker can even measure the shading points and scan the contour of targets, with T-probe, T-scan and other accessories. But it’s inconvenient to transfer station, Overall, laser tracker measurement system has become the most popular large-scale space measurement method in the field of aircraft digital assembly.

3. Spatial distribution of common reference points and accuracy of measurement System
Measurement field must be constructed to calibrate the position of aircraft components in each coordinate system, and transform it with the aircraft design coordinate system to describe the spatial position and posture of the aircraft components accurately, before aircraft digital assembly. Therefore, the accuracy of the measurement field determines the final accuracy of aircraft assembly directly, while the essence of constructing measurement field is the process of measuring ERS points and transferring station to create an enhanced coordinate system, which accuracy is related to the spatial distribution of the common reference points (ERS points) directly. Therefore, this paper explores the relationship between the spatial position distribution of ERS points and the accuracy of measurement
system through a large number of laser tracker measurement experiments, hoping to provide some valuable reference for the accuracy control of large-scale spatial measurement system in aircraft digital assembly.

3.1. Enveloping property of ERS points and accuracy control

Enveloping property refers to whether the measurement field constructed by ERS points envelops all the OTP (Optical Tooling Points).

Experiment process: keep the position of the laser tracker and ERS points fixed, configure four different OTP spatial distribution schemes. Spatial envelope relationship between OTP groups and ERS points are shown in figure 1 to figure 4, the spherical centre is the position of the laser tracker, ERS points envelope a sphere with a radius of 6000 mm, four groups of OTP are scattered irregularly on the spherical surface with radius of 3000 mm, 7500 mm, 9400 mm and 14000 mm. As shown in Figure 1, the first group of OTP are located within the enveloping region of the measurement field, while the spatial distribution of the second, the third and the fourth groups of OTP have exceeded the region of measurement field, and the distance is getting farther and farther, as shown in Figure 2 to Figure 4. According to the measured coordinates and the theoretical coordinates in aircraft coordinates of the four groups of OTP to calculate the measurement errors, which represent the accuracy of the measurement field.

The results of the transformation errors between the four groups of OTP and the ERS points are shown in Figure 5. The measurement errors of the first group of OTP enveloped in the inner region of ERS points are almost the same as the transformation errors. Because of the uncertainty of the spatial position, the measurement errors of each optical tooling point have a little difference, but the error values are fluctuating within the maximum transformation error. The measurement errors of the other three groups of OTP, which are distributed outside the region of ERS points, cannot be controlled within the transformation errors. Therefore, when constructing the measurement system, ERS points envelope all the points to be measured is helpful to control the measurement accuracy. If the actual condition is limited, the points to be measured should be put closer to the measurement field.

![Spatial distribution of the first group of OTP](image1)

**Figure 1.** Spatial envelope relation between the first group of OTP and ERS points.

![Spatial distribution of the second group of OTP](image2)

**Figure 2.** Spatial envelope relation between the second group of OTP and ERS points.
3.2. The number of ERS points with accuracy control
Measuring different number of ERS points in the same measurement area (10m × 10m × 3m), to explore the relationship between the number of ERS points and the measurement accuracy.

Experiment process: keep the position of laser tracker and the point P to be measured fixed, measuring ERS points to transfer station, and the number of ERS points participating in transferring station increases one by one. Then measuring the point P and calculating the measurement error of point P at different numbers of ERS Points participating in transferring stations. The spatial distribution of point P, laser tracker and all ERS points is shown in Figure 6. The transformation errors of ERS point with different number are shown in Figure 7, Figure 8 and Figure 9. The measurement errors of point P are shown in Figure 10.

As shown in these figures, when the number of ERS is three or four, the transformation errors are zero, but the measurement error of point P is very large; when the number of ERS points increases from five points, the transformation errors tend to be normal, and the measurement errors of point P decrease with the increase of the number of ERS points; when the number of ERS points is 7 or more than 7, the transformation errors of ERS points are small, and tend to be stable with the increase of the number of ERS points, the measurement errors of point P are stable; when the number of ERS points
is more than 11, the transformation errors of ERS points increase slightly, and the measurement errors of point P also increase slightly. Theoretically, the more the ERS points are, the higher the accuracy of the measurement filed will be. However, due to the interference of many external factors in the actual measuring process, ERS points have measurement errors, therefore, the more ERS points are, the more factors affecting the transformation accuracy, so, the number of ERS points increases while the transformation accuracy decreases. The results of experiments show that it is appropriate to keep the number of ERS points at 7–11. If the region of measurement field is large, the number of ERS points can be increased appropriately.

**Figure 6.** The spatial distribution of point P, laser tracker and all ERS points.

**Figure 7.** Transformation errors of 3-7 ERS points.

**Figure 8.** Transformation errors of 8-12 ERS points.

**Figure 9.** Transformation errors of 12-16 ERS points.
3.3. Flat distribution of ERS points with accuracy control

The spatial distribution of ERS points is flat on a certain coordinate, the measurement accuracy will be affected on this certain coordinate direction.

Experiment process: in the same measuring area, first, measuring two groups of ERS points with the same number, then measuring the same point q and analysing the measurement errors of point q in three coordinate directions, after establishing the measurement field. The spatial distribution of the first group of ERS points is very small in the vertical direction, while the spatial distribution of ERS points in the second group is relatively uniform in these three coordinate directions.

As shown in Figure 11, ignoring the single-point transformation errors, transformation errors of these two groups of ERS points are almost the same. However, as shown in Figure 12, comparing the measurement results, the measurement errors of point q in the Y (vertical) direction appear a mutation, in the measurement field established by the first group of ERS points. Because of the consistency of measurement environment, instruments and coverage area, it can be inferred that the measurement errors in single direction (vertical) are caused by the difference of spatial distribution of ERS points. The spatial distribution of the first group of ERS points is relatively flat; the difference in the Y direction is small, while the spatial distribution of the second group of ERS points is relatively stereoscopic, there are obvious differences in the three coordinate directions. This spatial distribution difference is consistent with the performance of the final measurement errors of point q. Therefore, it is considered that ERS points should be distributed evenly in space, avoiding flat in a certain direction, which is helpful to improve the accuracy of the measurement system.

Figure 10. Measurement errors of point P.
4. Conclusions
The rapid development of aircraft digital assembly technology has put forward higher demand for accuracy control of digital measurement system. Many factors, such as measuring instruments, measuring environment, coordinate transformation parameter solving algorithm, spatial distribution of ERS points, will affect the measurement accuracy. Based on the digital measurement system of laser tracker, this paper studies the relationship between spatial distribution of ERS points and system accuracy control, hoping to provide some theoretical suggestions for building high-precision digital measurement system to improve the accuracy of aircraft digital assembly. The main conclusions are as follows:
- All the OTP points are enveloped in the region formed by ERS points can help to garant the measurement accuracy.
- There should be no less than 7 ERS points for the establishing measurement field, and the number of ERS points can be increased appropriately when the measuring area is large.
- The spatial distribution of ERS points should ensure uniformity instead of flatty.

References
[1] Corbett J, Naing S. Feature based design for jigless assembly[J]. Cranfield University, 2004.
[2] Weber, A. Aerospace prepares to soar again [J]. Assembly Magazine, 2003, 46(6):58-59.
[3] Zhao Lele. Research on Construction Technology of Digital Measurement Field for Aircraft Large Component Assembly [D]. Nanjing University of Aeronautics and Astronautics, 2013.
[4] Wang Z, Mastrogiacomo L, Franceschini F, et al. Experimental comparison of dynamic tracking performance of iGPS and laser tracker[J]. International Journal of Advanced Manufacturing Technology, 2011, 56(56):205-213.
[5] Wire B. Arc Second, Inc. Announces Technology Partnerships with ROMER CimCore and Other Metrology Industry Leaders; Facility-wide indoor GPS Gains Acceptance[J]. Business Wire, 2004, 24(1-3): 29-35.
[6] Norman A R, Schönberg A, Gorlach I A, et al. Validation of iGPS as an external measurement system for cooperative robot positioning[J]. The International Journal of Advanced Manufacturing Technology, 2013, 64(1-4): 427-446.
[7] Aguado S, Samper D, Santolaria J, et al. Identification strategy of error parameter in volumetric error compensation of machine tool based on laser tracker measurements[J]. International Journal of Machine Tools and Manufacture, 2012, 53(1): 160-169.