

MOVING OBJECT'S POSE ACQUISITION FROM IMAGE SEQUENCE

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ABSTRACT:

Acquisition of pose parameters of moving objects is an important problem in many fields. This paper proposed a method to obtain pose parameters of moving object (mainly aircraft) from image sequence under assumptions of monocular and perspective view as well as known 3D shape and initial pose parameters of objects. Firstly image sequence is captured by optical-electric phototheodolite. Based these images, a method for aircraft pose measurement from image sequence has been deeply studied from the view of photogrammetry and projective geometry. A novel idea, Parapoint Feedback Iteration, has been presented and used in aircraft pose measurement. Firstly, we derive nonlinear equations to estimate pose parameter with the correspondence between image feature and model feature. To solve the nonlinear equations, at first several frames several control points must be selected manually and a DLT (Direct Linear Transform) algorithm has been used to provide approximate value, in the following frames Kalman filter can be used to predict motion parameter of next frame as approximate value. To get the accurate parameters, Parapoint Feedback Iteration algorithm has been used. Several sets of data have been used to test the method and results show its reliability and robustness.

1 INTRODUCTION

It is a hot topic to study and measure motion pose of object in many fields. For example, motion pose of aircraft is important to evaluate capabilities of aircraft control system and provide key data for improvement of aircraft system design by analysis of its space location (X, Y, Z) and movement pose (φ, ω, κ) at different times. In photogrammetry, known motion pose of aircraft can be used to determine external parameters of aerial photography taken by aircraft so as to reduce workloads of locating GCPs (ground control point) in the field. Now normally there are two methods to measuring aircraft pose: one is to measure locations and poses of aircraft by use of GPS and IMU loaded in aircraft, the other is high speed tracking and recording moving objective by optical-electric phototheodolite, and then identifying poses of moving objective with image data and camera parameters. The former is called "interior measurement of object pose", now its prevalent means is identifying craft poses by using three high precision GPSs or IMU and correcting signals received by GPS. The measuring accuracy is restricted by GPS and IMU, as same as, flight height and high speed changing pose of craft may cause GPS signal to be lost, and IMU is very expensive and difficult to operate. The later is called "exterior measurement of object pose" and has some advantage over the former. Because such method doesn't need to directly contact flying objectives and can be used widely. The paper mainly studies techniques and means about "exterior measurement of motion object pose". Image sequence data obtained by optical-electric phototheodolite have such characteristics: Imaging background is simple, objective is single, geometry model data of object can be known beforehand, the image data captured is huge.

Due to simple image background, aircraft objectives can be extracted automatically from images sequences. However, due to longer distance between aircraft and camera (3 km~10 km), size of objective image is generally between about 100 and 1000 pixel, so that sometimes it is more difficult to determine flying pose of aircraft.

Now, there are many methods to measure objective pose by use of image sequence. For example, Wenhao Feng calculated objective pose by Direct Linear Transformation[1]. Horaud[7],etc proposed to calculate objective pose by four point perspective means. DeMenthon,D[8],etc proposed to calculate objective pose by a weak perspective camera mode. Ohta,Y[2,3],etc put forward that model pose can be calculated by parasperspective camera model.

However, it is necessary for methods mentioned above to collect at least 3 to 4 GCPs for the calculation of objective pose. In many cases it is very difficult to identity feature points on images when aircraft is so far and aircraft is so small in the image frame. To solve this question, we proposed a method of matching simulation image and real image to trace objective pose: First of all, the 3D model of aircraft is measured by use of close-range photogrammetry method, then a simulation system of optical-electric phototheodolite is set up which can produce simulation image of aircraft in different pose, finally aircraft pose at different times in image sequences are calculated by matching real images and simulation images. In this process, no GCP is needed and silhouette of aircraft is used in calculation to determine the pose parameter of aircraft. It is obvious that information in silhouette of aircraft is much more abundant than that in several GCPs and therefore the results are also much more reliable that can be seen in the experiment below.

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2 TO MEASURE AIRCRAFT POSE BASED WITH PARAPOINT FEEDBACK ITERATION

2.1 Imaging model of optical-electric phototheodolite

It records distances from central of camera to aircraft and photography orientation of camera expressed by a vertical angle β and a horizontal angle α while optical-electric phototheodolite takes photos of aircraft (see Figure1).

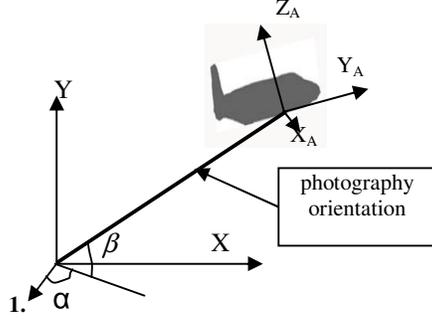


Figure 1 Imaging model of optical-electric phototheodolite



Figure 2 Coordinate system of airplane model

Suppose local Coordinate system of aircraft model likes figure 2 and distance between aircraft and camera to be D , then when aircraft is in position like figure 1 during its flight, position $[X_m \ Y_m \ Z_m]$ of aircraft in ground coordinate will is:

$$\begin{aligned} X_m &= D \times \cos(\beta) \times \sin(\alpha) \\ Y_m &= D \times \sin(\beta) \\ Z_m &= D \times \cos(\beta) \times \cos(\alpha) \end{aligned} \quad (1)$$

Coordinate $[X'Y'Z']$ of any surface point of aircraft in ground coordinate can be described in expression (2):

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = R' \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} \quad (2)$$

where: R' is a rotation matrix between airplane coordinate system and ground coordinate system;

$[X \ Y \ Z]$ is coordinate of aircraft surface point in aircraft coordinate system.

The relation between coordinate of points on the aircraft in ground coordinate system and coordinate of pixels on the

photos can be expressed by photogrammetry collinear equation:

$$\begin{aligned} x - x_0 &= -f \frac{a_1(X' - X_s) + b_1(Y' - Y_s) + c_1(Z' - Z_s)}{a_3(X' - X_s) + b_3(Y' - Y_s) + c_3(Z' - Z_s)} \\ y - y_0 &= -f \frac{a_2(X' - X_s) + b_2(Y' - Y_s) + c_2(Z' - Z_s)}{a_3(X' - X_s) + b_3(Y' - Y_s) + c_3(Z' - Z_s)} \end{aligned}$$

For derivation convenience below, collinear equation can be written as expression (3).

$$x - x_0 = -f \frac{\bar{X}}{\bar{Z}} \quad y - y_0 = -f \frac{\bar{Y}}{\bar{Z}} \quad (3)$$

$\bar{X}, \bar{Y}, \bar{Z}$ can be described as following form:

$$\begin{bmatrix} \bar{X} \\ \bar{Y} \\ \bar{Z} \end{bmatrix} = R^{-1} \cdot R' \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + R^{-1} \cdot \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} - R^{-1} \cdot \begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} \quad (4)$$

where:

$$R = \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} \quad \text{is rotation matrix of camera,}$$

$$R' = \begin{bmatrix} a'_1 & a'_2 & a'_3 \\ b'_1 & b'_2 & b'_3 \\ c'_1 & c'_2 & c'_3 \end{bmatrix} \quad \text{is rotation matrix of aircraft itself.}$$

Formula (3) can be linearized to be following form:

$$\begin{aligned} F_x &= F_{x_0} + \frac{\partial F_x}{\partial \varphi} d\varphi + \frac{\partial F_x}{\partial \omega} d\omega + \frac{\partial F_x}{\partial \kappa} d\kappa + \frac{\partial F_x}{\partial X_m} dX_m + \frac{\partial F_x}{\partial Y_m} dY_m + \frac{\partial F_x}{\partial Z_m} dZ_m \\ F_y &= F_{y_0} + \frac{\partial F_y}{\partial \varphi} d\varphi + \frac{\partial F_y}{\partial \omega} d\omega + \frac{\partial F_y}{\partial \kappa} d\kappa + \frac{\partial F_y}{\partial X_m} dX_m + \frac{\partial F_y}{\partial Y_m} dY_m + \frac{\partial F_y}{\partial Z_m} dZ_m \end{aligned}$$

Its error equations are as following :

$$\begin{aligned} v_x &= a_{11}\Delta\varphi + a_{12}\Delta\omega + a_{13}\Delta\kappa + a_{14}\Delta X_m + a_{15}\Delta Y_m + a_{16}\Delta Z_m - l_x \\ v_y &= a_{21}\Delta\varphi + a_{22}\Delta\omega + a_{23}\Delta\kappa + a_{24}\Delta X_m + a_{25}\Delta Y_m + a_{26}\Delta Z_m - l_y \end{aligned} \quad (5)$$

Formula (1), (3) and (5) constitutes imaging model of optical-electric phototheodolite and its error question.

2.2 Para-point and Parapoint Feedback Iteration Algorithm

To measure aircraft pose during its flight by using image sequences produced by optical-electric phototheodolite, it is relatively perfect measurement method to compare real images with simulation images, the work steps of the method is as following: first of all, high accurate aircraft model is established by using close-range photogrammetry method; then a simulation imaging system of optical-electric phototheodolite is established which can produce simulate aircraft images in any flying pose of aircraft; finally taking real image obtained by optical-electric phototheodolite as base image, the

simulation system is driven to produce images which outline is compared with that of base images until the outline is consistent with the base image, at this time the aircraft pose in last simulation image are deem the final pose of aircraft. So as to solve match between simulation image and real image, we proposed the Method of Least Squares base on Parapoint Feedback Iteration (PFI). PFI adjust dynamically boundaries of simulation image by use of least square method according to difference between outline edge of image to be approached and outline edge of objective, to make simulation image to approach real image rapidly.

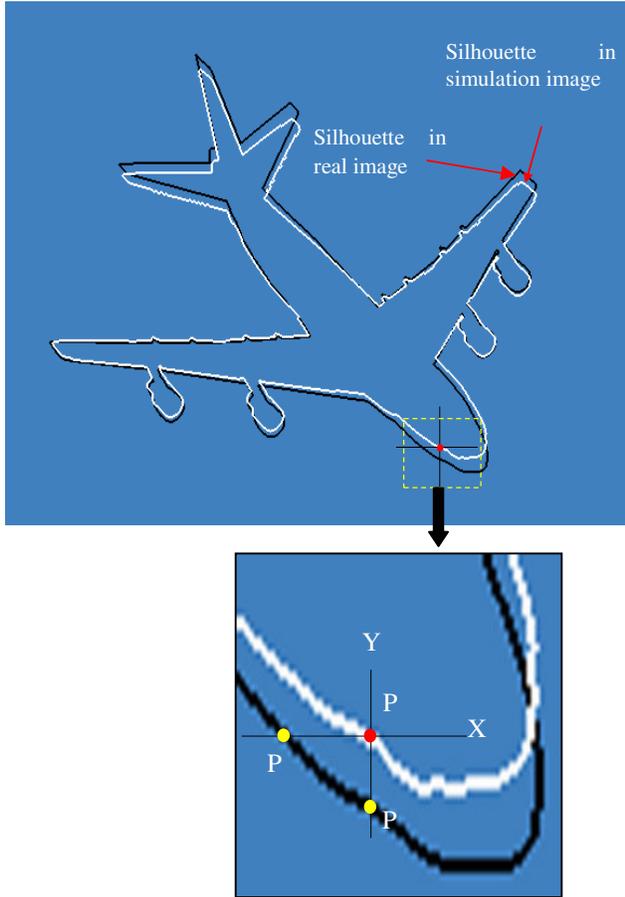


Figure 3 The Sketch map of the plane's outline and the ParaPoint.

As shown in Figure 3, there are differences between outline edges L1 of real aircraft image and outline edges L2 of aircraft produced by simulation system because they are not matched completely. The difference shows in X direction and Y direction. For instance, the different distance between P point and real image in X direction $dx = -PP1$, in Y direction $dy = -PP2$, P point is any point in simulation image, it is a projection reproduced in simulation image plane from aircraft model. Object-space coordinate (X, Y, Z) of P point corresponding to aircraft model can be calculated, but we don't know the coordinate of the corresponding point (P') of P point in real image, the main aim of this method is to eliminate dx and dy gradually, finally, to obtain position of P point in real image. In fact, the point position of outline edges vary with pose changes of simulation aircraft, therefore, while iteration eliminates dx and dy gradually, it is not to adjust difference of one point in the model, but is to adjust changing trend to whole simulation model. We call outline edge points used in adjustment

calculation Parapoint. There are two reasons for this name: one reason is that position of P' calculated by us is very different from position of P on the model at the beginning of calculation, during the process of iteration, it is not to eliminate errors of P point located in outline of simulation images, but to approach outline edge of real image; the other reason is that when we conduct calculation by using these outline points, we use all outline points not only one point, and we carry out calculation by use of only the smaller of distances in X and Y direction. The whole process of FPE method can be divided into several steps as following:

Step1: first of all, a piece of clear image is found out at the beginning of the image sequences, then several feature points (for example, aircraft head, aircraft wing and aircraft trail, etc) are selected manually. Finally using these feature points' image-space coordinates and its corresponding object-space coordinates, initial values of aircraft pose are measured by DLT.

Step2: Outline points collection {S0} of aircraft objectives in this frame of image sequences is extracted, and the gross points in outline points collection {S0} are removed by use of RANSAC, local spline fitting is conduct to produce new outline points collection {S1}.

Step3: Initial values of aircraft pose are input into simulation system to produce a simulation image with OpenGL. Then aircraft outline point collection {S2} is extracted in this simulation image.

Step4: Distance dx in X direction and distance dy in Y direction between each point in points collection S2 and its corresponding point in {S1}, that is, to calculate the coordinate(X, Y, Z) of P point in three dimension model, then establish error equation are established with formula (5), so two error equations can be established in X and Y direction for each point, here according to the amount of $|dx|$ and $|dy|$, only one error equation whose correction is smaller are used to conduct calculation of least square iteration.

Step5: New pose of aircraft is obtained by solving the equations.

Step6: if correction values between aircraft pose and space position is larger than the set threshold values, to return step3 to start a new loop, otherwise go to next step.

Step7 To output pose data of current images, to judge if there are also image to be conducted in image sequence, if NO, to quit the calculation, otherwise, to get next image in image sequence to carry out the calculation. Two kinds of methods can be used to identify initial values of aircraft pose in next image. When frame number of image sequence conducted is less than three, the calculation value of former aircraft pose can be taken as initial values of aircraft pose in current frame of image. When frame number is greater than three, initial values of aircraft pose in new frame of image can be estimated by using KALMAN filter, then return to step2 to calculate aircraft pose in current frame of image.

PEI method established by using parapoint solved successfully rapid match between image in simulation model and real image. It is a new application of traditional least square in the field of photogrammetry and computer vision. The method also can be applied to pose measurement of other crafts except of aircraft and check the quality of industry parts which geometry model data is known, etc.

2.3 Calculation of image point coordinates

It is necessary to know object-space coordinates of outline point of simulation image during pose of aircraft model is measured by using PFI method. Though outline points of aircraft in simulation image are acquired by projection of three

dimension model, the deepness calculation of each point during projection spend not only a lot of EMS memory, but also a lot of time to calculate visibility of each point. So it is necessary to calculate dynamically three dimension point corresponded to outline points that is used in adjustment calculation.

Suppose coordinate of photography center is (X_s, Y_s, Z_s) and the coordinate of image point is $(x, y, -f)$, the beam vector \vec{V}^p crossing photography center can be expressed as :

$$\vec{V}^p = (X_s - x, Y_s - y, Z_s + f) \quad (6)$$

Suppose rotation matrix of optical-electric phototheodolite camera is R and rotation matrix of aircraft is R' , the beam \vec{V}^p is transform to coordinate system of aircraft model, so

$$\vec{V}^{p'} = R'^{-1} R^{-1} \vec{V}^p \quad (7)$$

Normally aircraft model is expressed by triangular irregular net (TIN). First of all, the data collection of parallel projection between beam vector and triangle net on aircraft model surface in three plane space are produced, then triangles intersecting with projection beam are calculated so as to remove a lot of triangle that don't intersect beam. Large amount of intersection calculation can be avoided; then, intersection point of spatial triangle net extracted and projection beam are calculated by using rapid intersection algorithm proposed by Tomas Moller etc. [10].

Suppose $O(X, Y, Z)$ is one point in beam and D is direction vector of beam, beam equation is:

$$V(t) = O + tD \quad (8)$$

Suppose three vertex coordinates of triangle is $V_1(X_1, Y_1, Z_1)$, $V_2(X_2, Y_2, Z_2)$, $V_3(X_3, Y_3, Z_3)$, ϵ coordinate of each point in triangle can be expressed follow as by parameter variable u and v :

$$T(u, v) = (1 - u - v)V_0 + uV_1 + vV_2 \quad (9)$$

where: (u, v) is central coordinate of triangle that meet: $u \geq 0, v \geq 0, (u + v) \leq 1$ because beam intersect triangle, there are $V(t) = T(u, v)$, combination between(8)and (9) is :

$$\begin{bmatrix} -D & V_1 - V_0 & V_2 - V_0 \end{bmatrix} \begin{bmatrix} t \\ u \\ v \end{bmatrix} = O - V_0 \quad (10)$$

Defining: $E_1 = V_1 - V_0, E_2 = V_2 - V_0, T = O - V_0$

There are :

$$\begin{bmatrix} t \\ u \\ v \end{bmatrix} = \frac{1}{(D \times E_2) \bullet E_1} \begin{bmatrix} (T \times E_1) \bullet E_2 \\ (D \times E_2) \bullet T \\ (T \times E_1) \bullet D \end{bmatrix} \quad (11)$$

If coordinates of three points in every triangle are input into formula (11), parameter coordinate of intersection point between beam and triangle $[t \ u \ v]$ can be calculated, then $[t \ u \ v]$ is input into formula (9), intersection point coordinate between beam and triangle is obtained.

3 EXPERIMENT

At the beginning of the experiment, consecutive image sequences of aircraft flying are captured by optical-electric phototheodolite camera. Images and corresponding TIN model are shown in Figure 4.

If aircraft pose in the first frame of image sequence is taken as known values, due to shooting at the speed of 1000 frames per second by high speed camera, it is possible that aircraft pose of former frame are taken as initial value of next frame to calculate final aircraft pose by using PFI method. Table 1 is the result of simulation image pose and the result of aircraft pose produced by using PFI method.

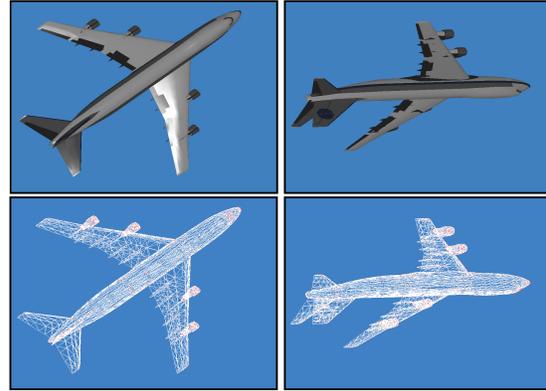


Figure 4 Textured Model and Wireframe Model of Airplane in frame 1 and frame 16

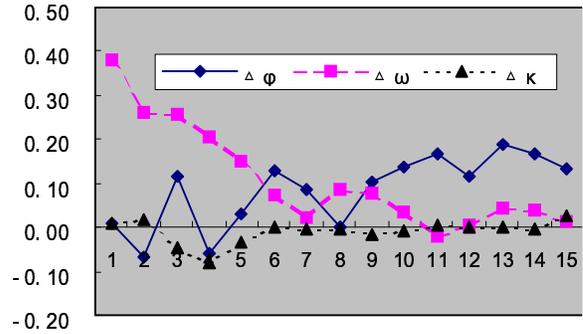


Figure 5 Absolute error curve of pose measurement

Figure 5 shows the curve of difference between known real pose angle and pose angle calculated by PFI method. It can be seen from the curve that the accuracy of angle Kapa is highest and that of angle ω is lowest. The reason is that at current pose, the range of aircraft objective on image is wider in its X direction and Y direction and rotation angle around Z axis greatly affects change of outline while change of angle ω affects outline little. Generally it can be said that the result is correlated closely with the pose of simulation image sequence.

4 CONCLUSION

The paper proposed a new measurement method of aircraft

pose based on image sequence. Based on the analysis of all existing measurement methods of aircraft pose, we proposed the measurement method using Parapoint Feedback Iteration. Experiments have been conducted and the results show the validity of PFI method. PFI method is extension of traditional least square method, it is dynamic approximation process. The method can be applied to other rigid moving body.

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Table 1: Table for result of pose on image sequence produced by PFI method

| Group NO | Theory φ | theory ω | theory κ | Measure-ment φ | measurement ω | measurement κ | $\Delta \varphi$ | $\Delta \omega$ | $\Delta \kappa$ |
|------------------|------------------|-----------------|-----------------|------------------------|----------------------|----------------------|------------------|-----------------|-----------------|
| 0 | 10.00 | -13.00 | -26.00 | | | | | | |
| 1 | 13.00 | -14.30 | -28.60 | 13.01 | -13.92 | -28.59 | 0.01 | 0.38 | 0.01 |
| 2 | 15.99 | -15.59 | -31.19 | 15.92 | -15.33 | -31.17 | -0.07 | 0.26 | 0.02 |
| 3 | 18.98 | -16.88 | -33.78 | 19.09 | -16.62 | -33.83 | 0.11 | 0.26 | -0.05 |
| 4 | 21.97 | -18.17 | -36.37 | 21.91 | -17.97 | -36.45 | -0.06 | 0.20 | -0.08 |
| 5 | 24.96 | -19.46 | -38.96 | 24.99 | -19.31 | -38.99 | 0.03 | 0.15 | -0.03 |
| 6 | 27.95 | -20.75 | -41.55 | 28.08 | -20.68 | -41.55 | 0.13 | 0.07 | 0.00 |
| 7 | 30.94 | -22.04 | -44.14 | 31.02 | -22.02 | -44.14 | 0.08 | 0.02 | 0.00 |
| 8 | 33.93 | -23.33 | -46.73 | 33.93 | -23.24 | -46.73 | 0.00 | 0.09 | 0.00 |
| 9 | 36.92 | -24.62 | -49.32 | 37.02 | -24.54 | -49.34 | 0.10 | 0.08 | -0.02 |
| 10 | 39.90 | -25.91 | -51.90 | 40.04 | -25.88 | -51.91 | 0.14 | 0.03 | -0.01 |
| 11 | 42.88 | -27.20 | -54.48 | 43.05 | -27.22 | -54.47 | 0.17 | -0.02 | 0.01 |
| 12 | 45.86 | -28.49 | -57.06 | 45.97 | -28.48 | -57.06 | 0.11 | 0.01 | 0.00 |
| 13 | 48.83 | -29.78 | -59.64 | 49.02 | -29.74 | -59.64 | 0.19 | 0.04 | 0.00 |
| 14 | 51.80 | -31.06 | -62.21 | 51.97 | -31.02 | -62.21 | 0.17 | 0.04 | 0.00 |
| 15 | 54.77 | -32.34 | -64.78 | 54.90 | -32.33 | -64.75 | 0.13 | 0.01 | 0.03 |
| Standard error : | | | | | | | 0.082 | 0.117 | 0.027 |

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