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Data Preprocess of Target guidance in the Mobile ATP System

YANG Song-hua[a*], MAO Yao[b]

[a]Institute of Automation,Southwest University,2 Rd. Tiansheng, Beibei, CQ, China, 400715

[b]Institute of Optics and Electronics,Chinese Academy of Sciences,Chengdu, China, 610209, e-mail:yoyo7802@yahoo.com.cn

Abstract. This paper described an approach of target guidance in the mobile system, which computes data to define recent position before guiding. The ATP system managed the position of the target, the position of the ATP system and the attitude of the platform by GPS devices. The recent position will be computed by the data above refer to coordinate system conversion. This is an easy managed method, and can be used in many areas.

Keywords: guidance, Strapdown Inertial Navigation System (SINS), laser, data preprocess, Cartesian coordinate systems, GPS devices

1. Introduction

The Acquisition, Tracking and Pointing (ATP) system is the key platform of free space optical communication, which directs the laser beam carrying the modulated data precisely to the other ATP system. The establishment of the link depends on the acquisition of the target. The ATP system must be guided to acquire the target in the field of view. In the guide mode, the guide sub-system computes the azimuth and elevation of the target, the drive sub-system drives the axis tracking the ordinate and the image processing sub-system tries to acquire the target from the real-time image.

Usually, the target sends its position to the guide sub-system. The measurement is achieved by Global Navigation Satellite System (GNSS), which including GPS, GLONASS, Compass and Galileo. The accuracy of GNSS can be centimeter and the business solutions are available.

The position of the ATP system is also measured by GNSS. And furthermore, the attitude must be also considered in the mobile ATP system. The accuracy of the attitude decides the accuracy of guide accuracy directly. Strapdown Inertial Navigation System (SINS) is a better choice than the star sensor because of the output frequency. The accuracy of the magnetic sensor cannot satisfy the accuracy requirement of the attitude measurement.

Data preprocess is necessary for guide sub-system. The original data from sensors and the target should be decoded and marked with timestamps, then measurement data should be checked for burst noises and error, and short time prediction should be made based on the recent measurement data. The detail is described as follow.

2. Theory of Target Guidance in Mobile ATP system

The position of the target in the earth-fixed coordinate system is (x_{te},y_{te},z_{te}), the position of the ATP system in the earth-fixed coordinate system is (x_{se},y_{se},z_{se}), and the attitude of the ATP system is a unit quaternion (p_1, p_2, p_3, p_4), which presents the rotation from the topocentric horizontal coordinate system to the

∗ Corresponding author
E-mail: yangsh@swu.edu.cn

topocentric coordinate system that fixed on the platform of the ATP system. Figure 1 demonstrates the relation of the target, the ATP system and the coordinate systems.

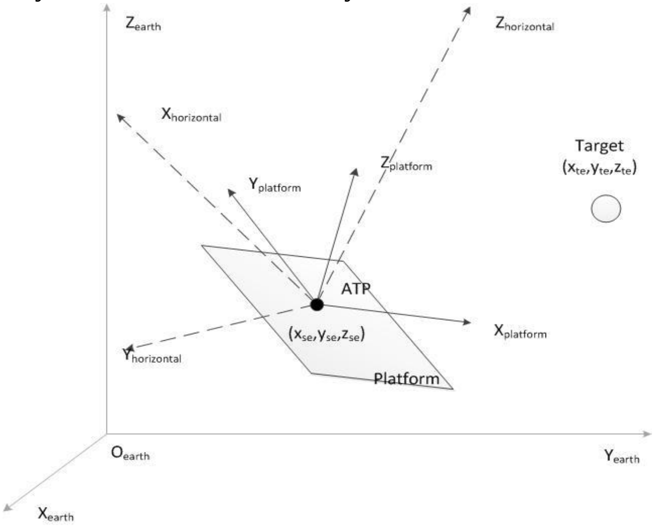

Figure 1. Target and platform of the mobile ATP system

There are three Cartesian coordinate systems: the earth-fixed coordinate system, the topocentric horizontal coordinate system and the topocentric platform coordinate system. For the earth-fixed coordinate system, the origin is the center of the earth, the Z axis is pointing to the north pole of the earth, the X axis is pointing to 0° longitude and the coordinate system are right-handed. For the topocentric horizontal coordinate system, the origin is the center of the ATP system, the Z axis is pointing to vertical up, the X and Y axes are in horizontal plane, the X axis is pointing to the north and the coordinate system are right-handed. For the topocentric platform coordinate system, the Z axis is pointing to the 90° elevation, the X axis is pointing to the 0° azimuth and the coordinate system are right-handed.

The coordinate (x_{th},y_{th},z_{th}) of the target in the topocentric horizontal coordinate system can be solved as (1).

$$\begin{pmatrix} x_{th} \\ y_{th} \\ z_{th} \end{pmatrix} = M_{eh} \cdot \left[\begin{pmatrix} x_{te} \\ y_{te} \\ z_{te} \end{pmatrix} - \begin{pmatrix} x_{se} \\ y_{se} \\ z_{se} \end{pmatrix} \right] \tag{1}$$

M_{eh} is the rotate matrix which rotates the earth-fixed frame to the topocentric horizontal frame and can be computed as (2).

$$M_{eh} = R_y\left(B - \frac{\pi}{2}\right) \cdot R_z(L - \pi) \tag{2}$$

L and B are the longitude and latitude respectively of the ATP system, and the rotate matrixes R_y and R_z are defined as (3) and (4).

$$R_y(\theta) = \begin{bmatrix} \cos(\theta) & 0 & -\sin(\theta) \\ 0 & 1 & 0 \\ \sin(\theta) & 0 & \cos(\theta) \end{bmatrix} \tag{3}$$

$$R_z(\theta) = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

The rotation from the topocentric horizontal coordinate system to the topocentric coordinate system that fixed on the platform of the ATP system can be done by multiplying the rotate matrix from (p_1, p_2, p_3, p_4) as (5) shows.

$$\begin{pmatrix} x_{tp} \\ y_{tp} \\ z_{tp} \end{pmatrix} = \begin{bmatrix} p_1^2 + p_2^2 - p_3^2 - p_4^2 & 2(p_2p_3 - p_1p_4) & 2(p_2p_4 + p_1p_3) \\ 2(p_2p_3 + p_1p_4) & p_1^2 - p_2^2 + p_3^2 - p_4^2 & 2(p_1p_2 - p_3p_4) \\ 2(p_2p_4 - p_1p_3) & 2(p_1p_2 + p_3p_4) & p_1^2 - p_2^2 - p_3^2 + p_4^2 \end{bmatrix}^T \cdot \begin{pmatrix} x_{th} \\ y_{th} \\ z_{th} \end{pmatrix} \tag{5}$$

Finally, the azimuth and elevation (A,E) can be solved from (x_{tp},y_{tp},z_{tp}) as (6) shows.

$$\rho = \sqrt{x_{tp}^2 + y_{tp}^2 + z_{tp}^2}$$

$$E = \arcsin(\frac{z_{tp}}{\rho})$$

$$A = \begin{cases} \arccos(\sqrt{\frac{x_{tp}^2}{\rho^2 - z_{tp}^2}}) & (y_{tp} \geq 0) \\ 2\pi - \arccos(\sqrt{\frac{x_{tp}^2}{\rho^2 - z_{tp}^2}}) & (y_{tp} < 0) \end{cases} \quad (6)$$

3. Data Preprocess

The guide sub-system of the ATP system collects three kinds of data to compute the guide data: the position of the target, the position of the ATP system and the attitude of the platform. The position data is measured by GPS devices. However, GPS data normally outputs data with rate of 1-10 Hz maximally depends on the GPS device. The attitude of the platform is measured by SINS and SINS outputs data with rate of 400-1000Hz because of the vibration of the platform during the movement of the mobile ATP system. Though the high frequency part of the vibration is filtered by the passive damping structure of the mechanism under the platform, high sample frequency can prevent the attitude data from reducing the accuracy.

The moment corresponding to the guide data which is sent to the drive sub-system is not the moment of the newest sampling time. Prediction of a little time ahead of the newest sampling time is necessary, which can minimize the delay in the control loop of the drive sub-system.

The theory of the target guidance of the mobile ATP system descripted above is purely geometrical, which requires all data measured at same time and produce the result of the same time. The prediction should be done to all measured data to apply the theory.

All measurement data have timestamps by hardware. GPS provide not only position and velocity data, but also the UTC time with high accuracy. Timestamp is in format of year, month, day, hour, minute, second and millisecond, and timestamp is converted to Julian days before data preprocess.

The output is in rate of 50Hz. Adaptive filters are considered to produce the prediction of each kind of data. The unscented Kalman filter (UKF) is applied to signal processing recent years, which improves the accuracy of non-linear system. A non-linear current statistical model is used and adaptive UKF is applied to preprocess.

Both the earth-fixed coordinate and the longitude/latitude of the ATP system are needed. GPS device outputs the longitude L, latitude B and geodetic height H. The earth-fixed coordinate can be calculated as (7).

$$e^2 = 2f - f^2$$

$$N = \frac{a_e}{\sqrt{1 - e^2 \sin^2(B)}}$$

$$x = (N + H)\cos B \cos L$$

$$y = (N + H)\cos B \sin L$$

$$z = (N(1 - e^2) + H)\sin B \quad (7)$$

a_e and f are the radius and the flattening of the earth respectively.

The SINS measure system output Euler angles of the platform: yaw ψ, roll φ and pitch θ. The quaternion (p_1, p_2, p_3, p_4) can be calculated as (8).

$$\begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \end{bmatrix} = \begin{bmatrix} \cos\frac{\varphi}{2}\cos\frac{\theta}{2}\cos\frac{\psi}{2} + \sin\frac{\varphi}{2}\sin\frac{\theta}{2}\sin\frac{\psi}{2} \\ \sin\frac{\varphi}{2}\cos\frac{\theta}{2}\cos\frac{\psi}{2} - \cos\frac{\varphi}{2}\sin\frac{\theta}{2}\sin\frac{\psi}{2} \\ \cos\frac{\varphi}{2}\sin\frac{\theta}{2}\cos\frac{\psi}{2} + \sin\frac{\varphi}{2}\cos\frac{\theta}{2}\sin\frac{\psi}{2} \\ \cos\frac{\varphi}{2}\cos\frac{\theta}{2}\sin\frac{\psi}{2} + \sin\frac{\varphi}{2}\sin\frac{\theta}{2}\cos\frac{\psi}{2} \end{bmatrix} \tag{8}$$

The burst noise is harmful for data preprocess and must be cleared before the filter. If the measure data is far from the average of last several data, then it must be a burst noise. The burst noise is replaced by last prediction. The average is used as criterion because of the stability of numerical.

4. Experiment result

The data preprocess descripted above has been applied in some mobile ATP prototype system. Figure 2 shows the azimuth and elevation error of the prediction in experiments. There are systematic errors because of the misalignment between the SINS sub-system and the platform. The amplitude of the prediction error is less than 0.1° . This accuracy is benefit from the data preprocess and satisfies the requirement of the mobile ATP system in acquisition.

5. Conclusion

Data preprocess is important to the guidance of the mobile ATP system. Timestamp and adaptive filters are used to produce the prediction from guide sub-system to drive sub-system. Detecting and replace algorithm is applied to prevent the burst noise. These data preprocess steps have been applied to some mobile ATP prototype system, and the result of experiments implies that the data preprocess works well.

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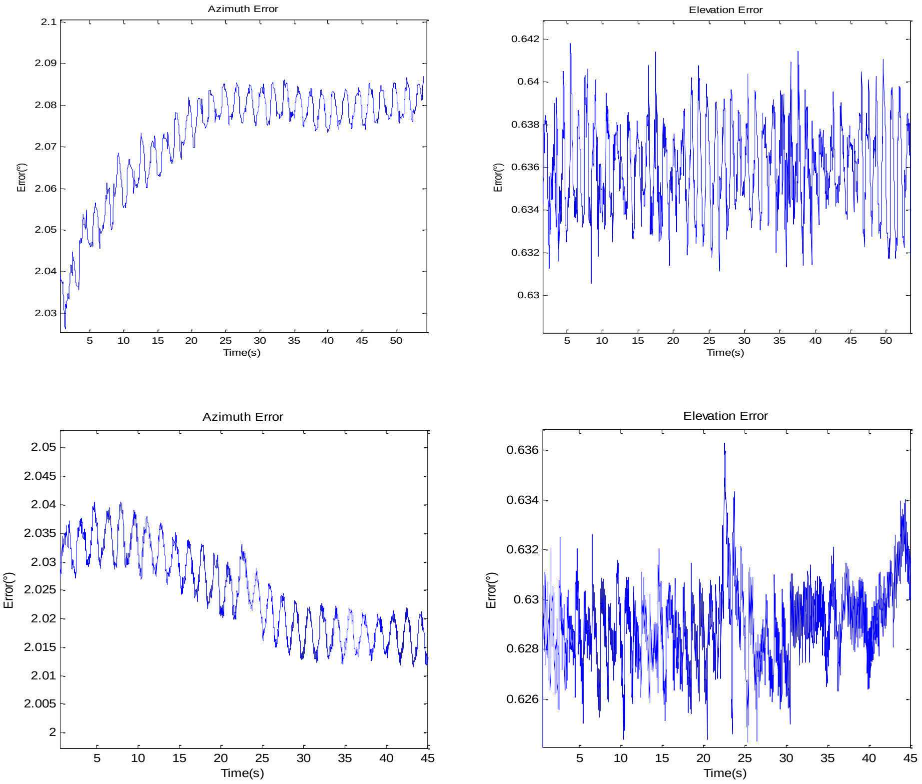

Figure 2. Experiment data