The Synchronization Technique of Data Fusion for Integrated Navigation Systems

WANG Wei
School of Instrument Science & Opt-electronics Engineering
Beijing University of Aeronautics and Astronautics
Beijing, China

LIU Zong-yu
Beijing Institute of Control Engineering
Beijing, China

Abstract—**For the data fusion of integrated navigation system, the different data-updating rate of each navigation subsystem will cause the loss of information and introduce the new error source. Therefore the data synchronization of all navigation subsystems should be carried out before effective data fusion. In this paper, the data synchronization technique of INS/GNSS/TAN integrated navigation system is investigated in time and space level respectively. And the synchronization algorithm based on analytical extrapolation and position transformation is proposed. The practical applications validate that this synchronization algorithm is effective.**

Keywords—**integrated navigation system, data fusion, time synchronization, space synchronization**

I. INTRODUCTION

With the development of the navigation technology, more and more sensors are available to provide vehicle position information. Each class operates by using different principles, as thus each has its own advantages and weaknesses. The integrated navigation system, which consists of one primary subsystem and several aided subsystems, can fuse the information of various navigation subsystems and then overcome the shortcomings and exploit advantages of the individual subsystems, hence enhancing the precision and reliability of entire system[1,2]. Presently, the integrated navigation system for aircraft usually employs laser strapdown inertial navigation system (LINS) as the primary navigation system, meanwhile fuse the information from global navigation satellite system (GNSS), terrain aided navigation (TAN), radio altimeter (RA) and air data system (ADS).

On designing data fusion system, one premise is that the navigation data used for fusion should be uniform in both time and space. That means that only when the synchronization problem of real-time data from various subsystems is solved, is the design of the integrated navigation practically meaningful. Since in the integrated navigation system, the individual subsystems update the data at different rate, there definitely exist the time drifts and computation and communication delays of subsystems, and the different settings of subsystems in the vehicle will results in the differences of the measurement data in space, the study on the effective data synchronization in time and space is of importance in practical design.

The remainder of this article is organized as follows. In the next section, the architecture and data synchronization of the integrated navigation system are described. And the time synchronization and space synchronization approaches for the integrated navigation system are presented in section III and IV respectively. Finally, in Section V the concluding remarks are offered.

II. THE ARCHITECTURE AND DATA SYNCHRONIZATION OF THE INTEGRATED NAVIGATION SYSTEM

The integrated navigation system uses LINS as primary subsystem and GNSS, TAN, RA and ADS as aided subsystems. LINS is a self-contained navigation system with good anti-jamming performance, which can provide the attitude, position and velocity of the vehicle at high update rates without any external electromagnetic signals, but its measurement errors will accumulate over time. GNSS has the advantage of consistently high precision over time, but its

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signals may be interrupted or unusable in the large dynamic environments. In addition, the data update rate of a GNSS receiver is low normally at 1Hz, which cannot meet the requirement of real-time control on some occasions[3]. When the aircraft flies at low altitude, especially in foothill or valley area, the accuracy of GNSS will degrade due to the poor geometry, while the performance of TAN is on the best stage. TAN is independent of any external devices and anti-jamming, but it just works well at low altitude. So GNSS and TAN can complement each other. Therefore, the aim of the integrated navigation system is to fuse the data measured by various subsystems in optimal way and exploit their advantages as to provide more accurate, more reliable navigation information than any individual subsystem alone.

Figure. 1 shows a block diagram of the integrated navigation system. It can be seen that with the altitude-aid of ADS, LINS can output the position, velocity, attitude and orientation with short-term high precision, and then integrate with GNSS and TAN respectively. The federal filtering is employed in data fusion, in which LINS and GNSS form a local filter, LINS and TAN form another local filter, and then the main filter gives the optimal fusion information.

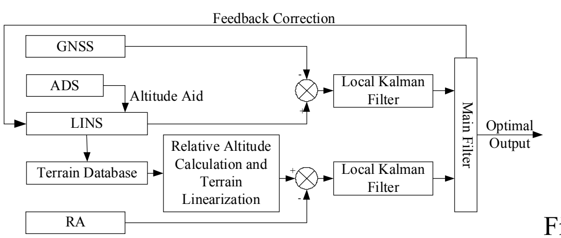

Figure. 1 Integrated navigation System Architecture

Before integration, the measurements of each subsystem should be at the same instant, that is to say, the LINS data and observations of other subsystems used for fusion should be at the same instant. The impact of synchronization error on the integrated system is significantly serious, especially in dynamic scenarios. What's more, the setting positions of the centre of LINS, the antennas of the GNSS receiver, the RA and ADS are not superposition, so they should transform to the same spatial reference point in data fusion. The problem that the data synchronization technique solves is to obtain the navigation data of various subsystems at the same instance from those with the different time standard and delays by the means of extrapolation, and transform these data into the same spatial reference point as to form the measurements of the data fusion algorithm at the same instant and spatial point.

III. TIME SYNCHRONIZATION OF THE INTEGRATED NAVIGATION SYSTEM

The update-rate of LINS is 50Hz, same to ADS, RA and TAN. But GNSS receivers have the different data update-rate, normally 1Hz. In theory, the update-rates of these subsystems are constant, but in practice, this is not necessarily the case. In addition, it should be noticed that the information updating instant is not the data output instant. In each subsystem, after navigation information updating finished, the computation and communication are needed before finally outputting the navigation data.

The PPS of GNSS is synchronized with the second of UTC, so is very accurate. The GNSS receivers measure the pseudorange, delta range and carrier phase observations and perform the GNSS standard timing, positioning, etc. at every edge of PPS, thus the data update-rate of GNSS can be considered as exactly 1Hz. Assume that the data update period of LINS is T_{LINS}, viz. 20ms. Therefore, choosing the PPS of GNSS as the standard instant of synchronization is the best option for the data fusion.

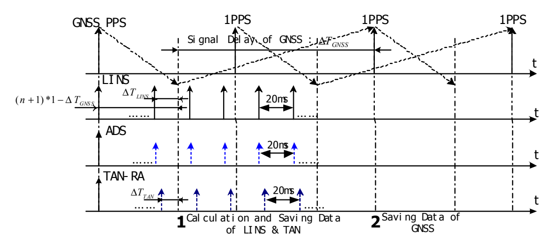

Figure. 2 Time Synchronization in Data Fusion

Figure. 2 shows the block diagram of data synchronization. The lag time of GNSS signals relative to LINS is ΔT_{GNSS} due to the delay of GNSS signals. The following method is used to synchronize GNSS and TAN data with LINS: to start the hardware timer 1 each time PPS of GNSS is arriving; to start the hardware timer 2 each time LINS updates the data; to start the hardware timer 3 each time TAN updates the data. When timer 1 reach $(n+1)*1-\Delta T_{GNSS}$ (where n is the integer part of the ΔT_{GNSS}), as the symbol 1 shown in Fig. 2, timer2 and 3 record the time ΔT_{LINS} and ΔT_{TAN} respectively. If LINS doesn't output the data at this moment, such measurements of the LINS as position, velocity and angle rate of the vehicle at this moment can be computed by extrapolation and saved, so do the data of TAN.

Then when the next PPS is coming, the observations of GNSS form the measurements of the Kalman filter along with the saved LINS data, and the saved LINS and TAN data will form the measurements of another Kalman filter, and then the date fusion is performed at this moment. As the altitude-aid of LINS, the ADS data are synchronized basically with LINS. Therefore, the synchronized measurements at the same instant are obtained.

The extrapolation uses a kind of digital signal holder algorithm[5]. At the instant of data fusion, the second order polynomial of the holder is given by:

$$X(nT+\Delta T) = a_0 + a_1\Delta T + a_2\Delta T^2 \qquad (1)$$

Where $X(nT+\Delta T)$ denotes the extrapolated data of LINS or TAN, ΔT denotes ΔT_{LINS} or ΔT_{TAN} , which is shown in Figure 2. T denotes the data updating period of LINS or TAN. The coefficients of polynomial are as follows:

$$a_0 = X(\text{nT})$$

$$a_1 = \frac{3X(nT) - 4X[(n-1)T] + X[(n-1)T]}{2T} \qquad (2)$$

$$a_2 = \frac{X(nT) - 2X[(n-1)T] + X[(n-2)T]}{2T^2}$$

IV. SPACE SYNCHRONIZATION OF INTEGRATED NAVIGATION SYSTEM

The center of LINS is not generally superposition with the antenna center of GNSS receiver. Considering the computation efforts, the antenna center of GNSS receiver should be transformed to the center of LINS since the data output frequency of GNSS is low. And the antenna of RA is also transformed to the center of LINS. In practice, ADS is used mainly to correct the height of LINS by its outputs, and its eccentricity is very small and can be ignored.

The transformation equations from the antenna centers of GNSS and RA into the center of LINS are as follows:

$$\begin{cases} r_{GI}^g = r_G^g + C_b^g L_G^b \\ V_{GI}^g = V_G^g + C_b^g \omega^b L_G^b \\ r_{RI}^g = r_R^g + C_b^g L_R^b \end{cases} \qquad (3)$$

Where L_G^b and L_R^b are the vectors from the antenna centers of GNSS and RA to the center of LINS in the body frame, respectively; r_G^g and V_G^g are the position and velocity of GNSS in the navigation frame respectively; r_R^g is the position of RA in the navigation frame; C_b^g is the transformation matrix from the body frame to the navigation frame; and ω^b is the angle rate of the body frame relative to the navigation frame in the body frame.

V. CONCLUSION

In the data fusion of integrated navigation system, the different data-updating rates of each subsystem will cause the loss of information and introduce the new error source. Therefore the data synchronization of all navigation subsystems should be carried out before effective data fusion. The synchronization algorithm based on analytical extrapolation and position transformation is proposed, which synchronize the various navigation information with the PPS signal of GNSS and transform the different settings of subsystems into the same reference point related to LINS. The data synchronization algorithm has been practically applied and satisfying results are achieved.

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