Research on the advantages of the input data fusion of the Integrated Surveillance System

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Abstract

The Integrated Modular Avionics (IMA) architectures provide a shared computing, communications, and I/O resource pool that is partitioned by multiple avionics functions. Integrated Surveillance System is the core component of aircraft avionics system, which includes terrain awareness and warning system (TAWS), airborne collision avoidance system (TCAS), airborne weather radar (WXR) and mode S transponder. This paper prompts an integrated surveillance system simulator under IMA architecture. Compared with traditional surveillance system, this system has less equipment weight and consumes less power.

The IMA architectures share lots of system-level resources. This paper provides guidance for managing intersystem shared resources based on the IMA architectures, especially the input data of ISS. Each component of ISS has its input trajectory data individually, like longitude, latitude, height and ground speed. By fusing these data from different components, the system can reduce the false positive and false negative alert rate, thus eliminating unnecessary redundancy and increasing the degree of accuracy. The advantages of data fusion are displayed undoubtedly in this paper.

Key words: Integrated Modular Avionics (IMA), Integrated Surveillance System (ISS), Data Fusion, Data Accuracy

1 Introduction

Airborne Surveillance System is a part of Communication, Navigation and Surveillance (CNS). It can provide the terrain, air traffic and weather information to the aircraft, thus enhancing the pilot's perception of the surrounding environment and dangerous accidents, so that help the pilot to give warning correctly in order to ensure the safety of the flight.

Airborne surveillance system mainly includes Terrain Awareness Warning System (TAWS), Traffic Alert and Collision Avoidance System (TCAS), Airborne Weather Radar (WXR) and Mode S Transponder (XPDR). Because the traditional federated architecture could not meet the demand of civil aircraft market contemporarily in safety, economy and reliability, Integrated Surveillance System (ISS) which is a new generation of comprehensive monitoring system came into being.

The technology of Integrated Modular Avionics (IMA) grows rapidly. IMA shares a set of changes, reuse and inter-operability of the software and hardware resources, realizing the sharing of resources, and improving the performance. IMA promotes the development of civil aircraft avionics system, as well as enhancing the effectiveness and economy of civil aircraft avionics system.

Integrated surveillance system uses the concept of IMA to integrate the resource, function and task management of TAWS, TCAS and WXR. Compared with the traditional federated avionics architecture, this paper designed the integrated surveillance system simulator, and built the data generator, simulator and control system simulation platform, conducted the simulation of the basic functions of integrated surveillance system. In this paper, we fused different input data from different sensors to reduce the false positive, false negative rate. It will elevate the potential threat detection rate.

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2 Preprocessing of input data

Because the ISS input data of longitude, latitude and height is obtained by the geodetic coordinates. However, the motion equation is based on ECEF coordinate system, so the input data should transformed to ECEF coordinate system firstly. The longitude, latitude and height of geodetic coordinate system are defined as (L, B, H), which in the ECEF coordinate system are (X, Y, Z). The formula from the geodetic coordinate system to the ECEF coordinate system is shown as equation 1.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} (H+N)cosBcosL \\ (H+N)cosBsinL \\ (H+(1-e^2)N)sinB \end{bmatrix} \quad \text{(Eq.1)}$$

2.1 Target model and track fusion algorithm

The selection of model is very important to the tracking accuracy of maneuvering target. The model proposed by scholars at home and abroad can be applied to the maneuvering target: uniform acceleration model, Singer model, semi-Markov model and so on. The model adopted in this paper is the "current" statistical model proposed by Zhou Hongren. This model uses the current acceleration to estimate the acceleration of next moment. It is more close to the motion characteristics of the real flight of the aircraft.

The equation of state for the target motion is

$$X_k = f(X_{k-1}) + W_{k-1} = \Phi_{k-1}X_{k-1} + G_{k-1}\bar{a} + W_{k-1} \quad \text{(Eq.2)}$$

in which

$$\Phi_{k-1} = \begin{bmatrix} 1 & T & \frac{1}{\alpha^2}(-1+\alpha T + e^{-\alpha T}) \\ 0 & 1 & \frac{1}{\alpha}(1-e^{-\alpha T}) \\ 0 & 0 & e^{-\alpha T} \end{bmatrix}$$

Character $\bar{a}$ represents the mean acceleration of $k-1$ moment. Character α represents the reciprocal value of maneuvering acceleration time constant. Character W_{k-1} represents the sequence of time discrete noise, the mean value of which is zero. Character Q_{k-1} represents variance. Character G_{k-1} represents input control matrix.

$$G_{k-1} = \begin{bmatrix} \frac{1}{\alpha}\left(-T + \frac{\alpha T^2}{2} + \frac{1-e^{-\alpha T}}{\alpha}\right) \\ T - \frac{1-e^{-\alpha T}}{\alpha} \\ 1 - e^{-\alpha T} \end{bmatrix} \quad \text{(Eq.3)}$$

$$Q_{k-1} = \frac{2\sigma_m^2}{\tau_m}\begin{bmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{bmatrix} \quad \text{(Eq.4)}$$

In which τ_m and σ_m represent target maneuvering time constant and standard deviation.

Accepting non-zero time target maneuvering model, it will be:

$$\ddot{X}_k = \bar{a}_k + a_k, \quad \text{(Eq.5)}$$

$$\dot{a}_k = -\alpha a_k + w_k, \quad \text{(Eq.6)}$$

In which w_k is system noise, we can take $w_k = a_k$. Introducing acceleration to system noise, putting Equation 5 into Equation 6, we will get the following equation

$$\dddot{X}_k = -\alpha\ddot{X}_k + \alpha\bar{a}_k + w_k. \quad \text{(Eq.7)}$$

Then, we can take $\hat{\ddot{X}}_{k/k-1}$ to the current acceleration in kT moment, which is also the mean value of random maneuvering acceleration.

$$\bar{a}_k = \hat{\ddot{X}}_{k/k-1}, \quad \text{(Eq.8)}$$

$$\sigma_a^2 = \begin{cases} \frac{4-\pi}{\pi}[a_{max} - \bar{a}_k]^2, & \bar{a}_k \geq 0, \\ \frac{4-\pi}{\pi}[\bar{a}_k - a_{min}], & \bar{a}_k < 0, \end{cases} \quad \text{(Eq.9)}$$

In which a_{max} and a_{min} are respectively the maximum and minimum maneuvering acceleration.

2.2 Track fusion algorithm

Scholars at home and broad have raised many typical track fusion algorithms, like Covariance Convex (CC), Information Matrix (IM), Covariance Intersection (CI), Best linear unbiased estimation (BLUE), etc.

In this paper, we use Bar-Shalom Campo (BC) algorithm which is proposed by Bar Shalom. The equation is shown as follow:

$$P_{k/k}^{ij} = P_{k/k}^{i}{P_{k/k-1}^{i}}^{-1}\left(\Phi_{k-1}P_{k-1/k-1}\Phi_{k-1}^{T} + \Gamma_{k-1}Q_{k-1}\Gamma_{k-1}^{T}\right){P_{k/k-1}^{j}}^{-1}P_{k/k}^{j} \quad \text{(Eq.10)}$$

Corresponding fusion algorithm and error covariance matrix are shown as follow:

$$\hat{X} = \hat{X}^i + \left(P^i - P^{ij}\right)\left(P^i + P^j - P^{ij} - P^{ji}\right)^{-1}\left(\hat{X}^j - \hat{X}^i\right) \quad \text{(Eq.11)}$$

$$P = P^i - \left(P^i - P^{ij}\right)\left(P^i + P^j - P^{ij} - P^{ji}\right)^{-1}\left(P^i - P^{ji}\right) \quad \text{(Eq.12)}$$

3 ISS Input Data Simulation

3.1 Software of simulation platform

ISS simulator software is consist of WXR simulator software, TCAS simulator software, TAWS simulator software, integrated management software, signal synthesis module and management module, signal conversion module software, AFDX interface software.

ISS prototype software is the core software of ISS, which is run in CPCI computers. We use Vxworks real time operating system. The core functions of WXR system, TAWS system, TCAS system are powered by the respective softwares. We use FSX powered by Microsoft as simulation platform to achieve a variety of models of the characteristics of the simulation.

3.2 Input data fusion

To measure the same parameters, different sensors have different values because of various reasons like delay, sampling precision. These errors will bring fault in decision stage. To solve the problem, we planned to fuse data to promote the precision and get high precision numerical input data.

We use C++ language to realize each alarm module under the VxWorks real-time operating system. In order to obtain the real trajectory data, we use Flight Simulator X software powered by Microsoft to complete ISS simulator, also use QT and OpenGL library to complete navigation display simulation software. In order to trigger warnings as many as possible in a short period of time, the flight route we selected should have high change rate of terrain. Thus, we choose to depart from Chengdu Shuangliu Airport and land Xichang Qingshan Airport.

We added white Gaussian noise with different variance of the data into the original data from SimConnect SDK to simulate input data from different sensors.

3.3 Fusion profit analysis

In flight process, we applied Local Calman filter to the longitude, latitude and height data from TAWS system based on the current statistical model. After adding white Gaussian noise with different variance, we can get the simulating data, which are supposed from sensor 1 and sensor 2. Through the track fusion algorithm, the two kinds of data are further fused and processed, and the longitude, latitude and altitude data after fusion are obtained. Fig 1, 2 and 3 represent the longitude, latitude and height data from the true value, sensor 1, sensor 2 and the fused one respectively.

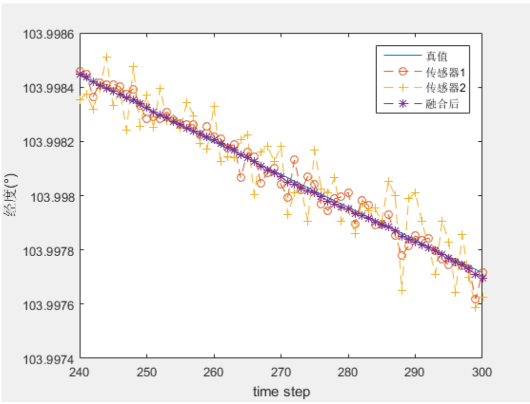

Fig. 1 Longitude of track fusion from one flight simulation

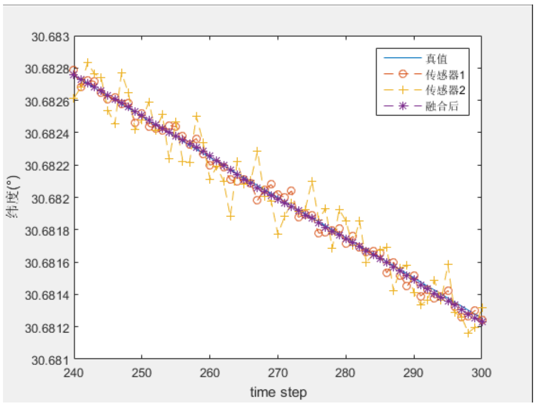

Fig. 2 Latitude of track fusion from one flight simulation

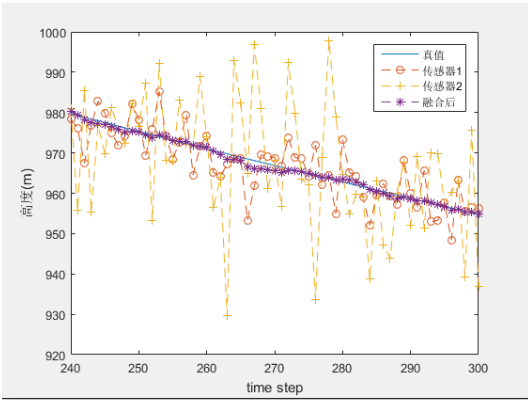

Fig. 3 Height of track fusion from one flight simulation

Subtracting the true value, the errors of longitude, latitude and height are shown as followed.

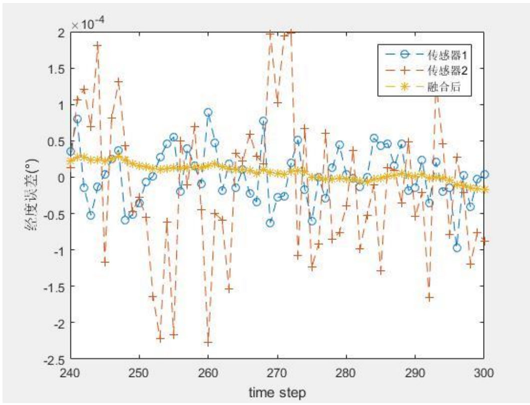

Fig. 4 Error of longitude from one flight simulation

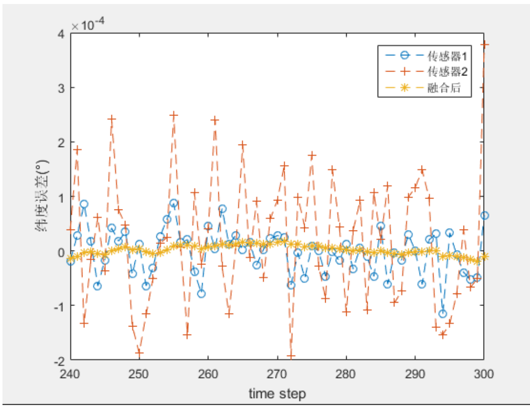

Fig. 5 Error of latitude from one flight simulation

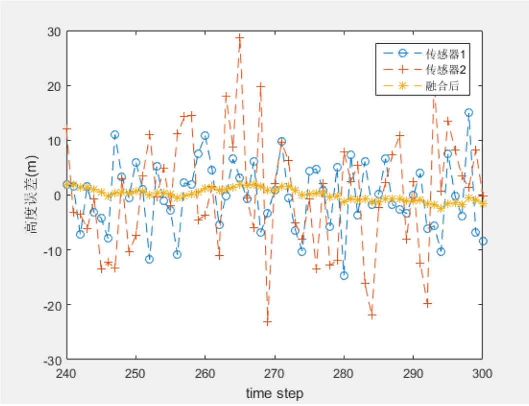

Fig. 6 Error of height from one flight simulation

Applying true track data incentive to ISS simulator, TAWS alarm mode distribution can be achieved. As shown in Figure 7, horizontal axis represents simulation time (in seconds), while vertical axis represents all TAWS alert types. Red fragment means that the input data triggers alert in the time period. The alarm distribution will be used as a benchmark for the subsequent comparison, denoted as the benchmark alarm distribution P_{ture}, in order to calculate the False positive alert and False negative alert because of the error from input data.

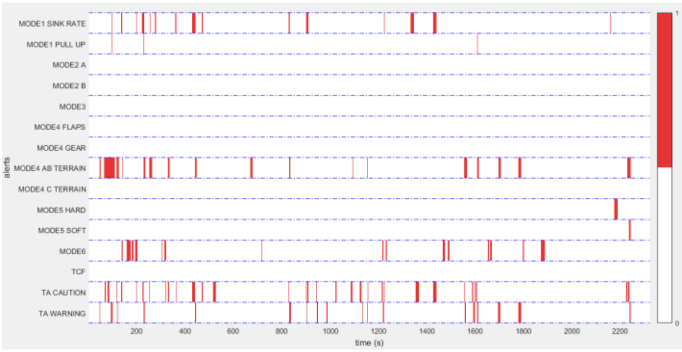

Fig. 7 Alerts with true trajectory in a single flight simulation

Then, we applied data with error and fused data to ISS simulator, figure 8 and figure 9 represent alarm mode distribution, which are defined as P_{normal} and P_{fusion}.

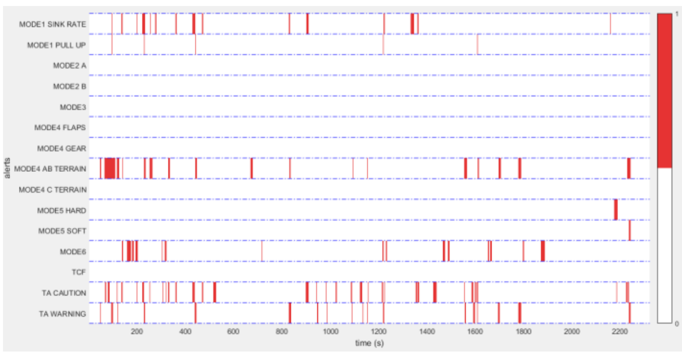

Fig. 8 Alerts with fused trajectory in a single flight simulation

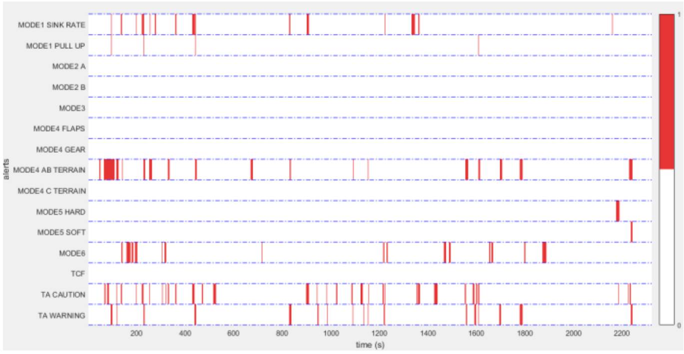

Fig. 9 Alerts with single sensor trajectory in one flight simulation

Comparing P_{normal} and P_{fusion} with P_{ture}, we can get the distribution of false positive alert and false negative alert. Green fragment represents false positive alert, which means true input data does not trigger alert while the normal data or fused data trigger alert. Red fragment represents false negative alert, which means true input data trigger alert while the normal data or fused data does not trigger alert.

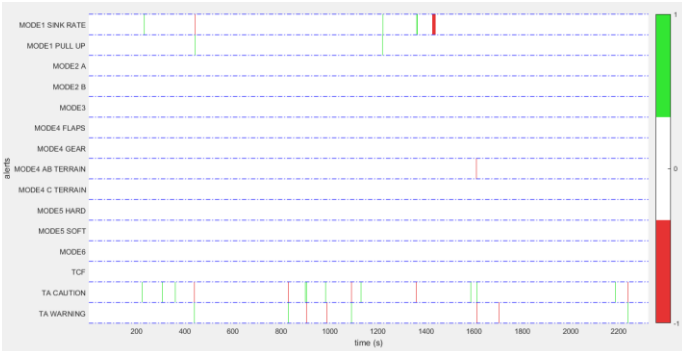

Fig. 10 Alerts differences with fused trajectory

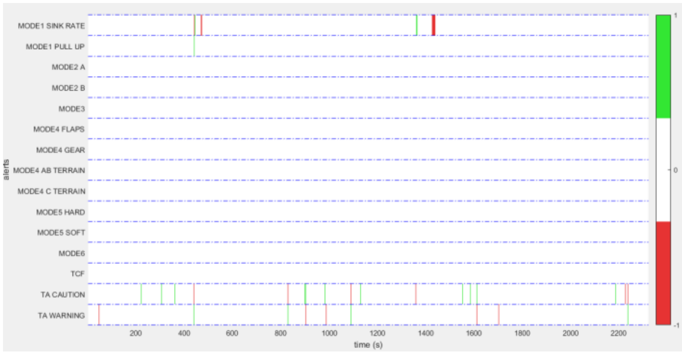

Fig. 11 Alerts differences with single sensor trajectory

Through multiple flight simulation, we can count the number of false positive alert and false negative alert caused by fused and non-fused input data. The statistical results as shown in the following table:

Table 1 Effects of input data fusion to ISS simulator

Type	Simulation Time (time step)	Alert Time (time step)	False Positive Alert (time step)	False Negative Alert (time step)
Fusion	**285817**	**54637**	**3972**	**3176**
Non-fusion		**54487**	**4228**	**3582**

It can be clearly noticed that input data with high precision can help ISS to understand the flight condition precisely, thus helping ISS to make correct decision and reducing the false positive alert and false negative alert rate.

4 Conclusions

In this paper, the ISS input data fusion is simulated and verified, and it is proved that the ISS input track fusion is helpful to reduce the false positive, false negative rate, thus guaranteeing the flight safety. In this paper, we use the current statistical model and the BC fusion algorithm to fuse the fuse data from different sensors. But we only processed data from the aircraft position (longitude, latitude and height), other important data like speed and acceleration have not been covered. In further research, we hope to fuse speed, acceleration and other physical quantity of input data to promote data precision.

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