AUTOMATIC DEPENDENT SURVEILLANCE (ADS) SYSTEM RESEARCH AND DEVELOPMENT

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ABSTRACT

This paper presents the basic concept, construction principle and implementation work for the Automatic Dependent Surveillance (ADS) system. As a part of ADS system, the ADS message processing system based on PC computer was given more attention. Furthermore, the paper introduces the ADS trial status and points out that the ADS implementation will bring tremendous economical and social efficiency.

KEY WORDS

ADS, System Integration , Data Processing Algorithm , Real Time Operation.

INTRODUCTION

In order to overcome the defect of current air navigation system, and to improve this system essentially, the new Air Navigation System (FANS) has been developed by International Civil Aviation Organization (ICAO) in the recent years. The basic content of the FANS is using satellite technology to establish a new global Communication, Navigation and Surveillance (CNS) system and corresponding Air Traffic Management (ATM) system. The Automatic Dependent Surveillance system based on satellite is one of the most important parts of the FANS.

ADS is a function for use by air traffic services in which aircraft automatically transmit, via a datalink, data derived from on-board navigation systems. As a minimum, the data include aircraft identification and four-dimensional position information. Additional data may be provided as appropriate.

ADS is a new creative important idea in the Future Air Navigation System implementation. The introduction of air-ground datalink together with sufficiently accurate and reliable aircraft navigation systems present the opportunity to provide surveillance service in the oceanic areas and other desolate and uninhabited areas where the current systems were proved to be difficult, uneconomic, or even impossible to implement. In China, considering this aspect it is particular important. In the remote west part of China, there are a lot of mountains, desert and primeval forest where the conventional communication, navigation and surveillance ground facilities are difficult to build, or even impossible. Even though in the east part of China, the ground equipments are still not enough. Therefore, The ADS implementation is extremely urgent, so that to ensure aircraft flight safety.

ADS SYSTEM INTEGRATION

ADS system is a complex information system. It consists of message source, message channel and message processing system.

The message source may be on-board Inertial Navigation System (INS) or Global Positioning System (GPS). The message channel may be very high frequency (VHF) datalink, Modes S datalink or satellite datalink. The message processing system is a computer processor (PC computer or workstation).

The ADS system integration has been completed in China. The system consists of

1) Aircraft with INS, GPS, AES and ACARS;
2) VHF data link and satellite data link;
3) Ground Earth Station(GES), Remote Ground Station(RGS), SITA network and GPSTN network;
4) PC computer Data processing and Display system.

Fig 1. shows the ADS system integration scheme.

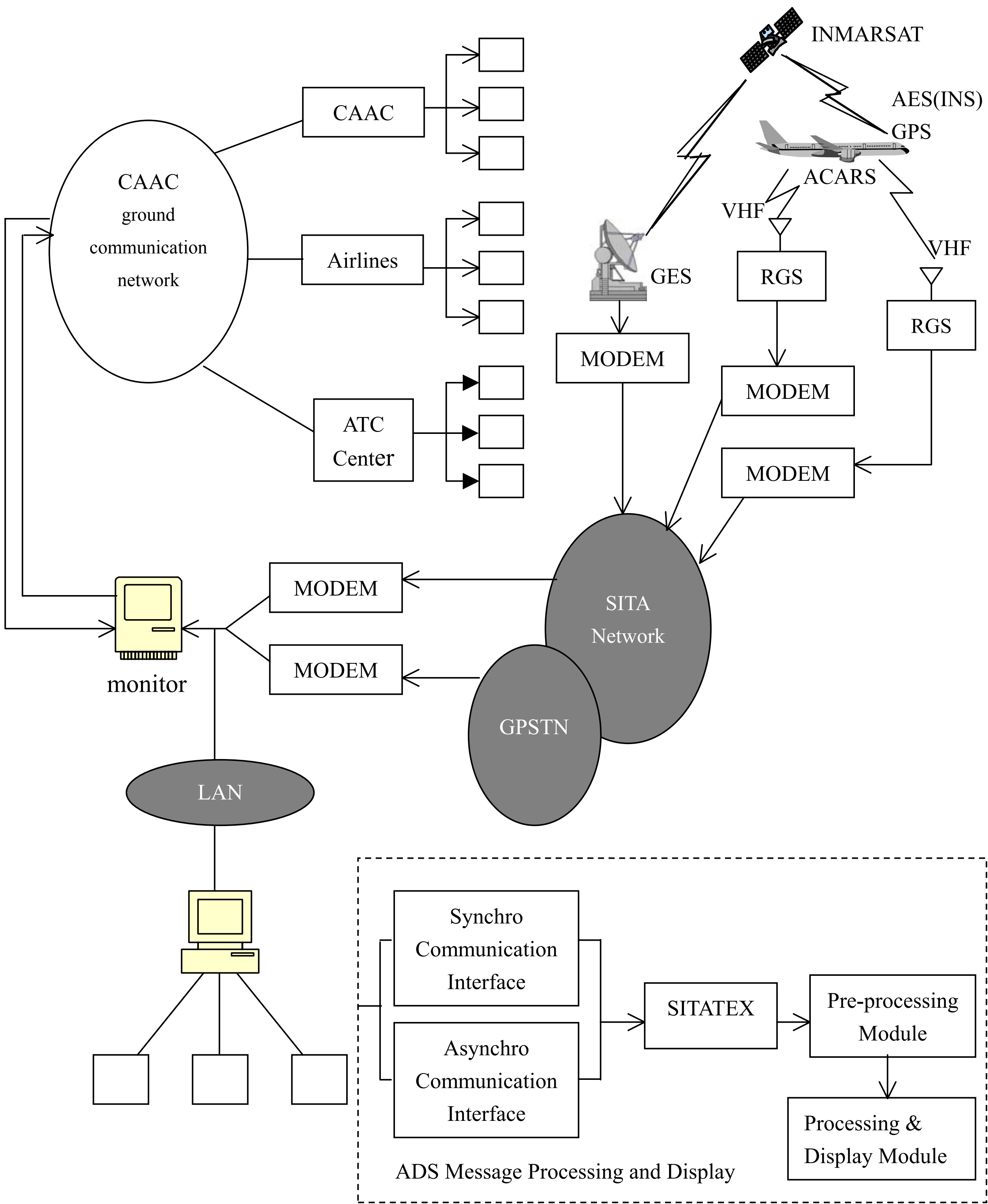

Fig.1 ADS system integration

THE ADS MESSAGE PROCESSING SYSTEM

The aircraft flight information through the satellite datalink enters the SITA network, then via the MODEM and the interface goes to the processing computer (processor).

a) module construction

The Computer Processing System adopts the module construction. The advantages of this construction are as follows: The modules are independent each other; The interfaces between modules are simple and clear; It is easy to improve and extend; It also has the good compatibility.

According to the ADS system function, the system can be divided into 7 modules:

1) deposition and initialization module
2) map background module
3) user interface module
4) text management module
5) object message processing module
6) help module
7) Kernel module

b) Display Window

The primary function of the ADS message processing system is to provide the user with a pictorial representation of aircraft position information supplied via satellite datalink and the SITA ground based communications network. In addition, the user has the ability to compile and transmit messages via the SITA network to any other SITA addresses. To this end the system will provide the user with three distinct display areas:

1) Situation Display: This display area provides the user with a pseudo radar picture of aircraft current within the system at a user definable scale and center.
2) Parameter Display: This display area provides the user with textual data associated with the aircraft current within the system.
3) Text Display: This display area provides the user with an interface to textual messages within the system, either those received from external sources via the SITA network or those being compiled by the user for onward transmission.

FLIGHT PATH PROCESSING ALGORITHM

1.Singer Model

During the period of signal propagation, various noises and errors are brought about by observing equipments, the Kalman Filtering is used to improve the precision in flight path calculation, also when the dynamic model is uncertain.

Suppose (X, Y, Z) is Cartesian coordinate values in accordance with aircraft's position(longitude, latitude and altitude). The system state vector is $(X \quad \dot{X} \quad \ddot{X} \quad Y \quad \dot{Y} \quad \ddot{Y} \quad Z \quad \dot{Z} \quad \ddot{Z})^T$.

The noise of maneuvering is embodied in the disturbance of acceleration. One dimension acceleration correlated function is $R_a(\tau) = E[a(t)a(t+\tau)] = \sigma_a^2 e^{-\alpha|\tau|}$.

When σ_a^2 is the aircraft location acceleration variance, a is the maneuvering acceleration, α is the reciprocal of the maneuvering time constant.

The extended state equation of continuous moving aircraft is $\dot{X} = AX(t) + Bw(t)$, $w(t)$ is a white noise with a variance of $2\alpha\sigma_a^2$.

Using Wiener-Kolmogorov whitening process, the maneuvering acceleration can be represented by $\dot{a}(t) = -\alpha a(t) + w(t)$,then the maneuvering aircraft's model is becoming

$$\begin{bmatrix} \dot{X}(t) \\ \ddot{X}(t) \\ \dddot{X}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & -\alpha \end{bmatrix} \begin{bmatrix} X(t) \\ \dot{X}(t) \\ \ddot{X}(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} w(t)$$

Obviously, When $\alpha = 0$,

$$\begin{bmatrix} \dot{X}(t) \\ \ddot{X}(t) \\ \dddot{X}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} X(t) \\ \dot{X}(t) \\ \ddot{X}(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} w(t)$$, this is a linear acceleration movement.

When $\alpha \to \infty$, then $a(t) = 0$, this is a uniform rectilinear movement. This is a global stochastic model. It has extensive adaptability with various maneuvers.

2. "Present" Stochastic Model

In this situation, the acceleration has the following relationship:

$$\ddot{X}(t) = \bar{a}(t) + a(t), \quad \dot{a}(t) = -\alpha a(t) + w(t)$$

where $\overline{a}(t)$ is a "present" mean value of maneuver acceleration, $w(t)$ is a white noise with zero-mean and a variance of $\sigma_w^2 = 2\alpha\sigma_a^2$. Maneuver aircraft's "present" stochastic model is

$$\begin{bmatrix} \dot{X}(t) \\ \ddot{X}(t) \\ \dddot{X}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & -\alpha \end{bmatrix} \begin{bmatrix} X(t) \\ \dot{X}(t) \\ \ddot{X}(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \alpha \end{bmatrix} \overline{a}(t) + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} w(t)$$

3. Adaptive Filtering Algorithms

a) Adaptive filtering algorithm of acceleration mean.

For above state equation, the discrete state equation is

$X(k+1) = \Phi(k+1,k)X(k) + U(k)\overline{a} + W(k)$ where $X(k) = [X(k) \quad \dot{X}(k) \quad \ddot{X}(k)]^T$

$$\Phi(k+1,k) = \begin{bmatrix} 1 & T & \frac{1}{\alpha^2}\left(-1+\alpha T + e^{-\alpha T}\right) \\ 0 & 1 & \frac{1}{\alpha}\left(1 - e^{-\alpha T}\right) \\ 0 & 0 & e^{-\alpha T} \end{bmatrix} \quad U(k) = \begin{bmatrix} \frac{1}{\alpha}\left(-T + \frac{\alpha T}{2} + \frac{1-e^{-\alpha T}}{\alpha}\right) \\ T - \frac{1-e^{-\alpha T}}{\alpha} \\ 1 - e^{-\alpha T} \end{bmatrix}$$

We consider $\overline{a}(k) = \hat{\ddot{X}}(k/k-1)$. It means, when we estimate the aircraft's state, we can get the maneuver acceleration mean simultaneously. Therefore we can correct the acceleration in time.

b) Adaptive filtering algorithm of noise variance.

The standard kalman filtering equation becomes

$$\hat{X}(k/k) = \hat{X}(k/k-1) + K(k)\left[Y(k) - H(k)\hat{X}(k/k-1)\right]$$

$$\hat{X}(k/k-1) = \Phi(k,k-1)\hat{X}(k-1/k-1) + U(k)\overline{a}(k)$$

$$K(k) = P(k/k-1)H^T(k)\left[H(k)P(k/k-1)H^T(k) + R(k)\right]^{-1}$$

$$P(k/k-1) = \Phi(k,k-1)P(k-1/k-1)\Phi^T(k,k-1) + Q(k-1)$$

$$P(k/k) = [I - K(k)H(k)]P(k/k-1)$$

Substitute $\overline{a}(k) = \hat{\ddot{X}}(k+1/k)$ into above second equation, we get

$$\hat{X}(k+1/k) = \Phi 1(T)\hat{X}(k/k), \text{ where } \Phi 1(T) = \begin{bmatrix} 1 & T & T^2/2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}.$$

Using the following relationship: $\sigma_w^2 = 2\alpha\sigma_a^2 = 2\alpha_{\frac{4-\pi}{2}}\left(\hat{X}(k/k) - A_{\max}\right)^2$, where $A_{\max}$ is the maximum maneuver acceleration, we can get the adaptive filtering algorithm of noise variance.

4. U-D factorization algorithm

Computer round-off errors may lead the covariance matrix P to become non-positive definite or non-symmetry in realizing the algorithms mentioned above. It causes the filtering gain and estimation to depart from the theoretical values more and more, even causes the filter to diverge. In order to overcome this problem, we adopted the U-D factorization algorithm. Here the covariance matrix P can be decomposed into the upper triangular matrix U times the diagonal matrix D:

$$P(k+1/k) = U(k+1/k)D(k+1/k)U^T(k+1/k)$$

$$P(k/k) = U(k/k)D(k/k)U^T(k/k)$$

Therefore, we can get the "present" stochastic model (Kalman Filter) based on U-D factorization algorithm.

THE ADS SYSTEM REAL TIME OPERATION

The ADS system currently supports the ADS messages received from the AIR China(CA), China Eastern Airlines(MU), China Southern Airlines (CZ), Cathay Pacific(CX), Quatntas(QF), Scandinavia(SK), Lawda(NG) and so on. In order to verify the feasibility of the ADS system, we carry out a lot of trials with the system. The trial results showed that this system is successful. The display window provides clear aircraft position, important parameters and necessary text. The trial results were showed in Fig.2, Fig.3 and Fig.4.

The important parameters showed in parameter area include:

Airline code
Aircraft flight number
Flight altitude
Time
Longitude

Latitude

These parameters are just the necessary aircraft identification messages and four dimensional position messages.

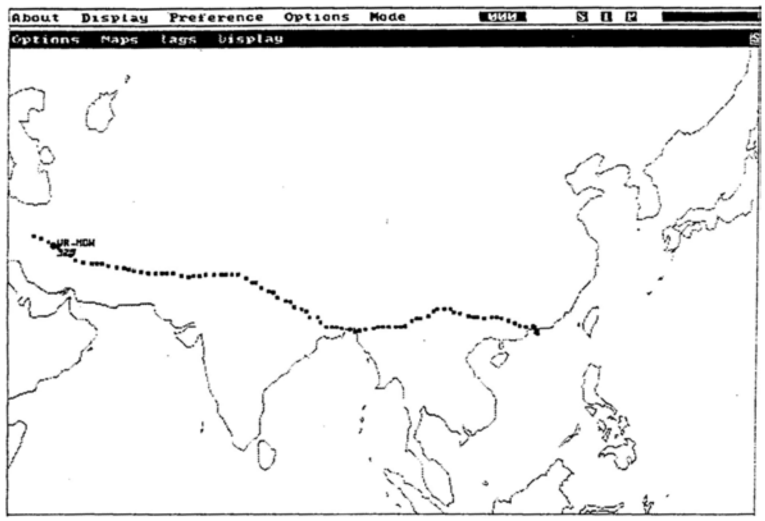

Fig.2 Position display

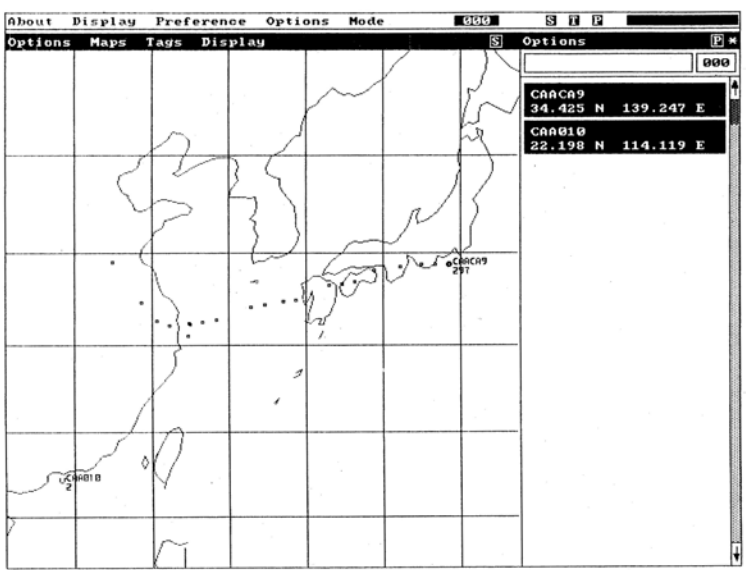

Fig.3 Position and Parameter display

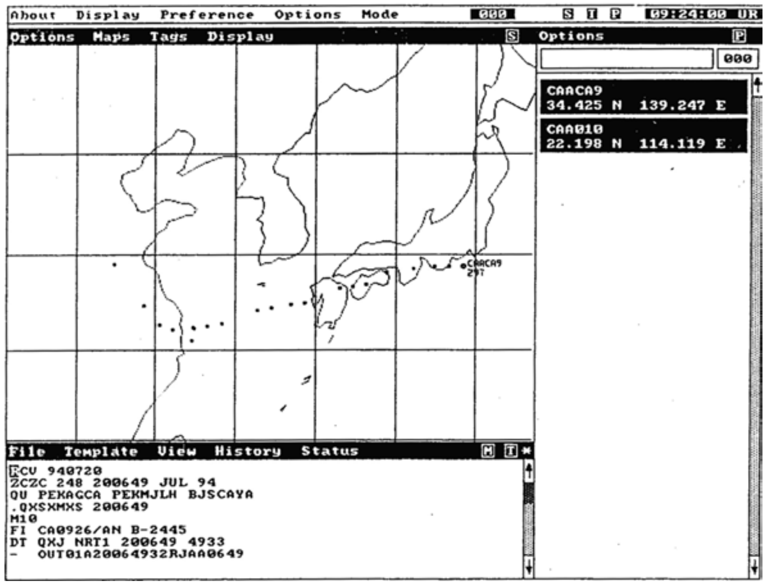

Fig.4 Position, Parameter and Text display

CONCLUSION

ADS system is a very important subsystem in the Future Air Navigation System (FANS). Research work showed that the implementation of ADS system will bring tremendous economical and social efficiency. ADS based Air Traffic Control (ATC) system will provide increased safety through improvements in surveillance and communication capabilities. The improved surveillance capability enables the ATC facility to identify potential deviations from the cleared flight path profile caused by way-point insertion errors. Furthermore, the ATC facility will be able to continually monitor the flight progresses to ensure conformance with a cleared flight plan. The ADS system will enable controllers to provide more efficient flight path and hence lower costs to the airlines.

In addition, it should be possible at some future time to reduce oceanic separation minima, thereby further increasing airspace capacity.

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