The Improvement of Aircraft Position Information with the Unscented Kalman Filter

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Abstract

Rapidly increasing growth and demand in CNS/ATM, the advanced scheme for air traffic management, ADS-B system which is based on digital communication is being implemented in the field of surveillance. ADS-B concept appears to be an economically viable solution to obtain accurate aircraft position information. ADS-B system has better performance than the traditional radar and ADS-B system replace the radar in the near future. However, as the position information of the ADS-B is obtained from the GPS, the accuracy of the ADS-B lies on GPS. Therefore, the ADS-B information includes GPS errors. In this paper, we applied the unscented kalman filter to the ADS-B information to improve the accuracy of the ADS-B information. Comparisons with the original ADS-B information and the ADS-B information with the unscented kalman filter show that the ADS-B information with the unscented kalman filter provides the better.

Keywords: CNS/ATM, aircraft position information, unscented kalman filter, GPS, GPS errors

1. Introduction

Aviation leaders, such as United States, are trying to achieve significant advances in aviation safety all the while experiencing rapid increases in air traffic levels. To accommodate the increasing air traffic and increase safety and efficiency of aviation operation, International Civil Aviation Organization (ICAO) recommended the development and implement of a new CNS/ATM system. The system is composed of Communication, Navigation, Surveillance and Air Traffic Management. ICAO set up the Future Air Navigation System (FANS) and has studied the Communication Navigation Surveillance / Air Traffic Management (CNS/ATM) system, the new scheme for air traffic management. The CNS/ATM system incorporates communications, navigation, and surveillance systems, employing digital technologies, including satellite systems together with various levels of automation applied in support of a seamless global air traffic management system.

At the center of the CNS/ATM system, the Automatic Dependent Surveillance – Broadcast (ADS-B) system, which is based on digital communication, is being implemented [1]. Traditional surveillance methods include voice reporting, visual checks, and primary and secondary surveillance radars, but in the CNS/ATM system, these methods will be replaced by ADS-B. ADS-B is radically new technology that is redefining the paradigm of communications, navigation and surveillance in Air Traffic Management today. Already proven and certified as a viable low cost replacement for conventional radar, ADS-B allows pilots and air traffic controllers to see and control aircraft with more precision, and over a far larger percentage of the earth's surface, than has ever been possible before. ADS-B is the next generation air surveillance system

which supplants and complements the limitations of conventional radar, since conventional air traffic management radar systems will reach their limits soon due to the increases in air traffic. According to recent studies, the position accuracy of conventional radar is 200m, however the ADS-B position accuracy is much better at 33m [2]. Although ADS-B has a better position accuracy than the radar, it includes errors from the Global Positioning System (GPS) since the position information of the aircraft completely relies on GPS.

Therefore, in this paper, we propose a novel method that obtains more accurate position information for the aircraft using the unscented kalman filter, which is used in radar tracking. With the unscented kalman filter, the position accuracy of the aircraft obtained from the ADS-B can be improved greatly, which has been verified through simulations

2. Related Work

2.1. ADS-B Errors

The reliability of the ADS-B information relies on GPS, and therefore the ADS-B information includes GPS errors. Although the GPS system has been designed to be quite accurate errors still occur. Added together, these errors can cause a deviation comprised of tens of meters. There are several sources for these errors. They are: ionosphere and troposphere disturbances, signal reflection, clock errors, the visibility of satellites, and satellite Shading [3].

Ionosphere and troposphere disturbances cause the satellite signal to slow down as it passes through the atmosphere. However the GPS system has a built in model that accounts for an average amount of these disturbances. Signal reflection is reflected off objects like tall buildings, rocks and mountains. This causes the signal to be delayed before it reaches the receiver. Ephemeris errors are also called as orbital errors. These are errors in the satellite position against its true position. Clock errors mean that the built in clock of the GPS receiver is not as accurate as the atomic clocks of the satellites. Visibility of Satellites means that the more the number of satellites a GPS receiver can lock with, the better its accuracy. GPS receivers do not work indoors and underground. Satellite shading does not help in GPS. For the signals to work properly the satellites have to be placed at wide angles from each other. Poor geometry resulting from tight grouping can result in signal interference.

Among these errors, the ionosphere and troposphere disturbances are the largest errors in the GPS system. Therefore, the reliability of the ADS-B information is strongly affected by the ionosphere and troposphere disturbances.

2.2. An Overview of the Unscented Kalman Filter

Nonlinear state estimation is a challenge problem. The well-known kalman filter is only suitable for linear systems [4]. The extended kalman filter has become a standarded formulation for nonlinear state estimation [5]. However, it may cause significant error for highly nonlinear systems because of the propagation of uncertainty through the nonlinear system.

The unscented kalman filter is a novel development in the field [6]. The idea is to produce several sampling points, we called Sigma points, around the current state estimate based on its covariance. In other words, Instead of linearizing using Jacobian matrices, the unscented kalman filter uses a deterministic sampling approach to capture

the mean and covariance estimates with a minimal set of sample points. Then, the unscented kalman filter propagates these points through the nonlinear map to get more accurate estimation of the mean and covariance of the mapping results. In this way, it avoids the need to calculate the Jacobian, hence incurs only the similar computation load as the extended kalman filter [7]. That is, the unscented kalman filter provides superior performance at and equivalent computational complexity.

3. The ADS-B Information with the Unscented Kalman Filter

In this paper, the aircraft system model is modeled as the Constant Acceleration (CA) models; it frequently occurs in aircraft flights.

The system model is that moves with constant acceleration, and is expressed as:

$$x(k) = \begin{bmatrix} 1 & 0 & T & 0 & \frac{1}{2}T^2 & 0 \\ 0 & 1 & 0 & T & 0 & \frac{1}{2}T^2 \\ 0 & 0 & 1 & 0 & T & 0 \\ 0 & 0 & 0 & 1 & 0 & T \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} x(k-1) + \begin{bmatrix} \frac{1}{2}T^2 & 0 \\ 0 & \frac{1}{2}T^2 \\ T & 0 \\ 0 & T \\ 1 & 0 \\ 0 & 1 \end{bmatrix} v(k-1) \qquad (1)$$

The state vector x(k) is same as that found in

$$x(k) = \begin{bmatrix} x & y & \dot{x} & \dot{y} & \ddot{x} & \ddot{y} \end{bmatrix}' \qquad (2)$$

The position of the aircraft comes from the ADS-B; measurement model is:

$$z(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} x(k) + w(k) \qquad (3)$$

where, w(k) is a measurement noise at time k.

Through this modeling, the unscented kalman filter can be applied to the ADS-B information. Figure 1 shows the procedural flowchart for the ADS-B information using the unscented kalman filter. The ADS-B information comes from the GPS. After applying the unscented kalman filter, The ADS-B information using the unscented kalman filter is generated. The ADS-B information using the unscented kalman filter is sent to aircrafts and ground stations.
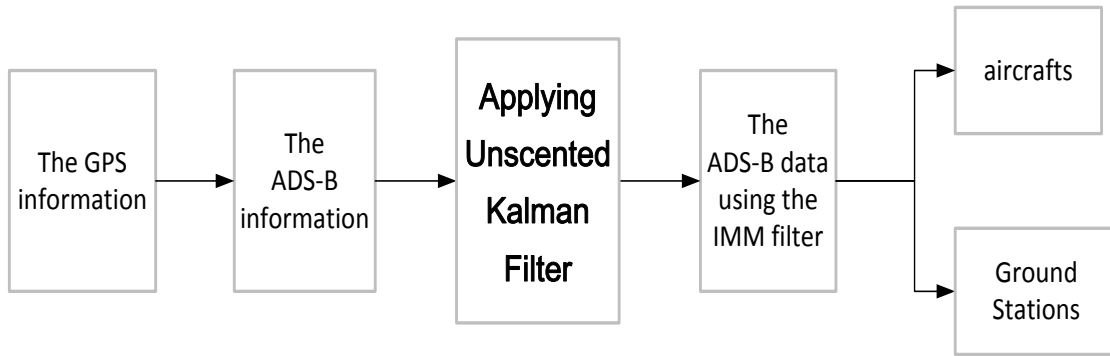
Figure 1. The Flowchart for the ADS-B Information with the Unscented Kalman Filter Procedures

4. The Performance Evaluation

Simulations have been carried out to compare the ADS-B information and the ADS-B information using the unscented kalman filter. Figure 2 and Figure 3 show the simulation results. The trajectories of Figure 2 consist of 5 segments: acceleration motion with constant acceleration → deceleration motion with constant acceleration → left turn → acceleration motion with constant acceleration → deceleration motion with constant acceleration. Each segment lasts 10 seconds and it is possible to get the position information from the aircraft every 1 second from the ADS-B. We used MatLAB software for the simulations.
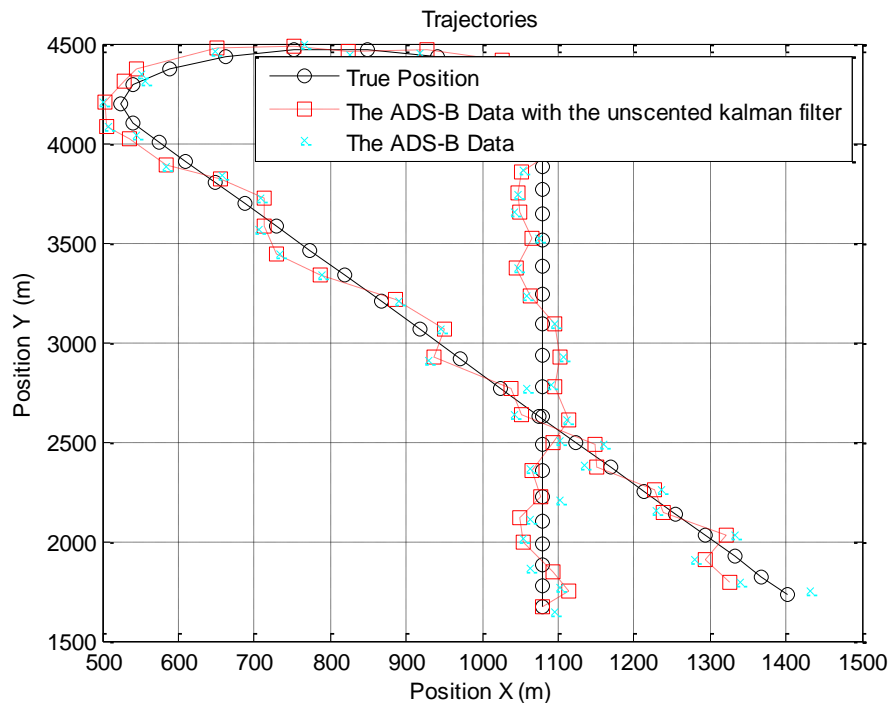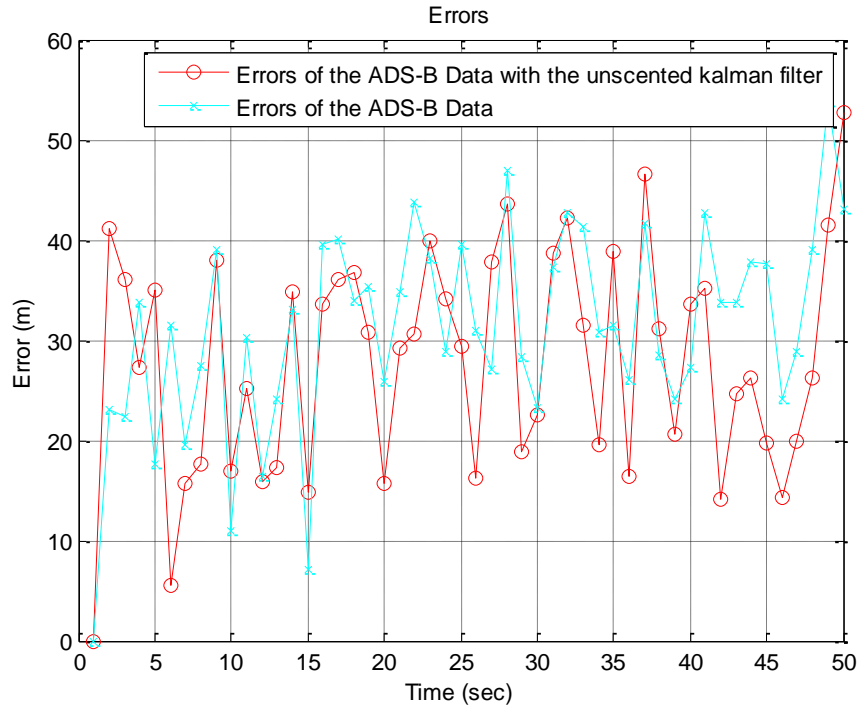

Figure 2. The Aircraft Trajectories

Figure 3. The ADS-B Information and ADS-B Information with the Unscented Kalman Filter Errors

Figure 3 shows the errors found in the ADS-B information and the ADS-B information with the unscented kalman filter. As shown in the figure, the errors found in the ADS-B information with the unscented kalman filter are less than the ones found in the ADS-B information without the filter. On average, the errors in the ADS-B information are 33.1m, whereas the errors in the ADS-B information with the unscented kalman filter are 29.3m. Therefore, the results of the simulations show that the aircraft position using the ADS-B information with the unscented kalman filter is 11.5% better than that of the ADS-B.

5. Conclusion

In this paper, we present a novel method used to obtain more accurate position information for an aircraft by employing an unscented kalman filter. The system model is modeled the Constant Acceleration model. We applied the unscented kalman filter to ADS-B. When using the unscented kalman filter, the position accuracy of the aircraft obtained from the ADS-B data was improved by 11.5%.

Acknowledgements

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