Optimal MLAT Tracking Based on Improved Simulation for Airport Surveillance

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Abstract: MLAT (Multilateration) is becoming one of the leading techniques in the airport surveillance. It locates the positions of aircrafts by the TDOAs (Time Difference of Arrivals) of signal from the aircraft to the different remote stations. In views of the influence from the geometric relation and the clock error among different stations, an improved simulation is proposed to estimate the measurement error for the optimal tracking. The model of simulation takes both the GDOP (Geometric Dilution of Precision) and TOA (Time of Arrival) error into consideration. Experiment results show that compared with the traditional simulation method, the improved simulation is more accurate and is able to be used in the practical application.

Introduction

The traditional radars including PSR (Primary Surveillance Radar) and SSR (Second Surveillance Radar) will be no longer the dominant technologies which are able to ensure the surveillance of air traffic. The extensive deployment of satellite system, ground stations and air-to-ground data links results in the emergence of complementary means and techniques on which a great deal of research and experiments have been carried out over the past ten years[1,2]. Among these new techniques, MLAT (Multilateration) is one of the most representative and typical. MLAT locates a target by accurately computing the TDOA (time difference of arrival) of a signal emitted from the target to three or more receivers, and it has attracted the world by its potential to achieve high accuracy and update rate. So in the A-SMGCS (Advanced - Surface Movement Guidance & Control System) architecture proposed by ICAO (International Civil Aviation Organization), MLAT is recommended as the necessary system for the airport traffic surveillance in the next 10 – 20 years.

A typical MLAT system includes at least no less than three remote stations, one center station and other auxiliary equipments. The remote stations are distributed to capture the signals from transponders mounted in the aircrafts and decode the TOAs (time of arrival). Then, the TOAs are delivered to the center station. Based on the TDOA (Time Difference of Arrival), the center station evaluates the position of the targets. The evaluation algorithm includes the iterative methods such as Taylor method [3], and the non-iterative methods such as CHAN method [4]. Theoretically, the computation error is mainly determined by GDOP (Geometric Dilution of Precision) that illustrates the position relation among the target and the stations. So many simulations focus on GDOP only [5]. MLAT require the revolution of clock be nanosecond, therefore, in practical applications, the clock error of MLAT networks exists. TOA error also has significant influence on the computation result. However, the clock error in different stations is different. It is difficult to present the influence through mathematic formula. It is the result based on statistical analysis. So this is implemented by an improved simulation. In the simulation, GDOP and TOA error are both taken into consideration. And further, the tracking parameter about the MLAT measurement error is optimally configured based on the simulation and the experimental results based on airport surveillance show this solution is accurate and effective.

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MLAT Theory

The MLAT system is described as figure 1. The data source as well as the aircraft sends a packet, and this packet is captured by the remote stations in the ground. Because the distances from the aircraft to each remote station are different, the TOAs to each remote station are also different.

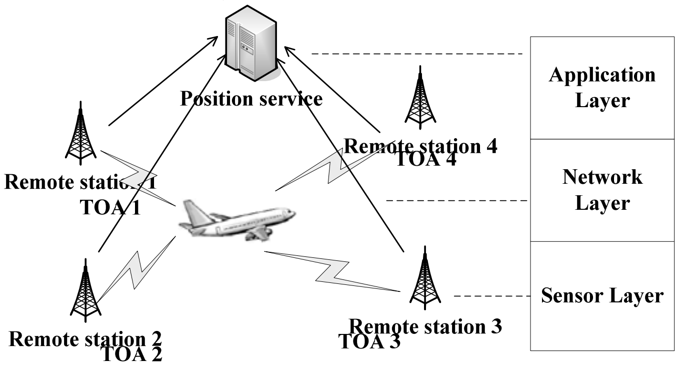


Figure 1 MLAT theory

Suppose M $(M \geq 3)$ remote stations receive the signal from the data source, (x, y) is the position of data source waiting for estimation, and (X_i, Y_i) is the position of remote station i which is know, so the distance from the source to remote station i is presented as

$$r_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2} \tag{1}$$

We denote $\boldsymbol{r} = [r_2, r_3, ..., r_M]^T$, $\boldsymbol{r_1} = [r_1, r_1, ..., r_1]^T$, and $\boldsymbol{n} = [n_{2,1}, n_{3,1}, ..., n_{M,1}]^T$, where $n_{i,1}$ is the error of clock synchronization between station i and station 1. So we have

$$\begin{aligned} \boldsymbol{\Delta r} = \boldsymbol{r} - \boldsymbol{r_1} + c\boldsymbol{n} &= [r_2 - r_1, r_3 - r_1, ..., r_M - r_1]^T + c\boldsymbol{n} \\ &= \begin{bmatrix} c\tau_{2,1} - cn_{2,1} \\ c\tau_{3,1} - cn_{3,1} \\ \cdots \\ c\tau_{M,1} - cn_{M,1} \end{bmatrix} + c\boldsymbol{n} \end{aligned} \tag{2}$$

Where $\tau_{i,1}$ is the TDOA measurement, and c is the velocity of light. So, computing the position of data source is converted to:

$$(\hat{x}, \hat{y}) = \arg\{\min[[\boldsymbol{\Delta r} - (\boldsymbol{r} - \boldsymbol{r_1})]^T [\boldsymbol{\Delta r} - (\boldsymbol{r} - \boldsymbol{r_1})]]\} \tag{3}$$

There are many ways to solve the minimum problem, including iterative algorithm such as Tailor method and non-iterative algorithm such as Chan, Si method. But whatever, it can be abstracted as:

$$\boldsymbol{P}_{TGR} = MLAT(\boldsymbol{P}_s, \boldsymbol{TDOA}_s) \tag{4}$$

Where,

$$\boldsymbol{P}_s = \begin{bmatrix} p_x^1 & p_y^1 & p_z^1 \\ p_x^2 & p_y^2 & p_z^2 \\ & \vdots & \\ p_x^M & p_y^M & p_z^M \end{bmatrix} \tag{5}$$

p_x^i, p_y^i and p_z^i are the position of remote station i in 3 dimension respectively. And

$$\boldsymbol{TDOA}_s = \begin{bmatrix} TDOA^2 \\ TDOA^3 \\ \vdots \\ TDOA^M \end{bmatrix} = \begin{bmatrix} TOA^2 - TOA^1 \\ TOA^3 - TOA^1 \\ \vdots \\ TOA^M - TOA^1 \end{bmatrix} \tag{6}$$

Where, $TDOA^i$ means the time difference of arrival between TOA^i and TOA^1.

Simulation Method

The simulation is extended from expression (4). It has two parameters: positions of stations and TDOA. Once the stations are fixed, GDOP is fixed. So the improved simulation puts emphasis on the influence on the computation error from TOA error when stations are fixed. The simulation method can be described as follows:

(1) Scenario configuration: An airport is simulated, which size is $3000\times3000m^2$, shown in figure 2(a). In the airport, there are M $(M\geq3)$ remote stations to receive the signal, shown as '*'. For station i, the position is denoted as (p_x^i,p_y^i,p_z^i) and the clock error obeys $N(\mu_i,\sigma_i^2)$. Particularly, p_z^i is assumed as a constant in the airport surface surveillance.

(2) Sample target configuration: There are N sample targets uniformly distributed in the airport, shown as '.'. Obviously, these targets are samples. The more the targets are, the more accurate the simulation is.

(3) Monte Carlo sampling: For each target j, suppose the position is (x_j,y_j,z_j), so TOA in station i can be simulated due to:

$$TOA_j^i=\sqrt{(p_x^i-x_j)^2+(p_y^i-y_j)^2+(p_z^i-z_j)^2}\Big/c+n \tag{7}$$

Where, n is a random number obeying $N(\mu_i,\sigma_i^2)$. So combined with expression (5), (6), and (7), the position of target j is estimated according to expression (4). Such process is repeated K times, the locating error can be obtain according to:

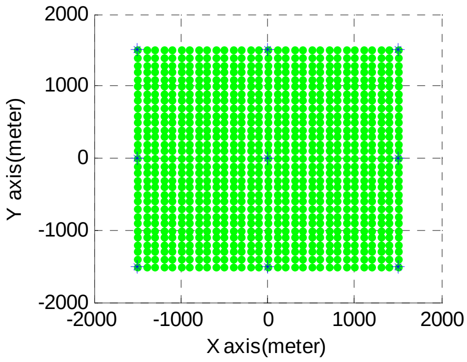
$$D_j=\sum_{k=1}^{K}D_j^k\Big/K \tag{8}$$

Where, D_j^k is the estimation error in sample k, expressed as:

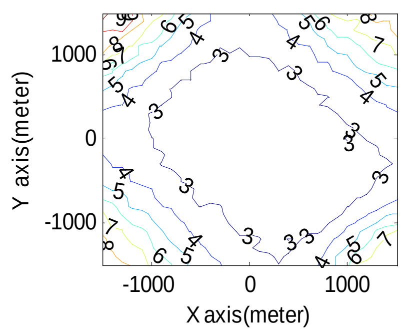
$$D_j^k=\sqrt{(p_{TGR}^x-x_j)^2+(p_{TGR}^y-y_j)^2+(p_{TGR}^y-z_j)^2} \tag{9}$$

Where, $(p_{TGR}^x,p_{TGR}^y,p_{TGR}^z)$ is the estimation of target based on expression (4). Similarly, the larger K is, the more accurate the simulation is.

(4) Contour line mapping: For each sample target, the estimation error of this position D_j is obtained. So the estimation error about the whole surveillance region is also obtained through the contour line map, shown in figure 2(b). The contour lines present the measurement error, and their unit is meter.



(a) Simulation scenario



(b) Measurement error distribution

Figure 2 Simulation result

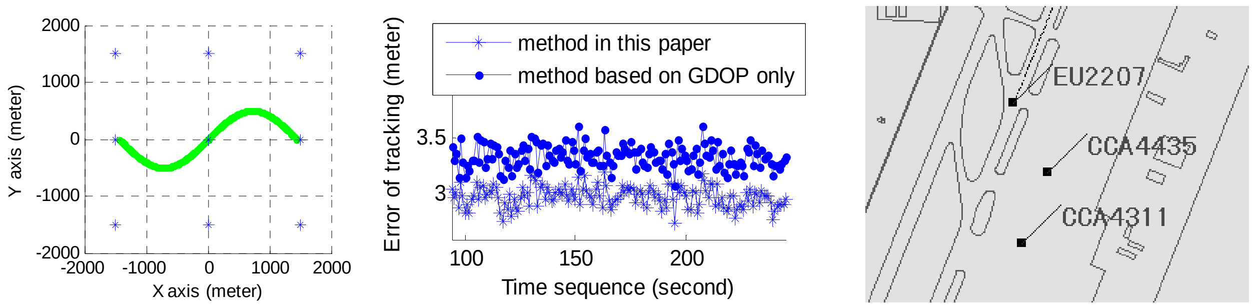
Application Experiments

On the basis of simulation result, a mapping table from target position to measurement error is established. And further, such error is used to configure the measurement parameter in the process of Kalman filter, which is important for surveillance and tracking. In the iterative steps of Kalman filter, the gain is set as:

$$K = PH^T(HPH^T + R)^{-1} \tag{10}$$

Where, K is the gain, P is the tracking error, and H is the measurement matrix. R is the estimation of measurement error and set according to simulation result.

Experiments show such the method is more accurate and effective. Figure 3(a) shows the movement of the target. The method in this paper is used to track the target. For better comparison, the tradition estimation result based on GDOP only is also used to track the target. Figure 3(b) shows the comparison based on precision and the method in this paper is better. Besides, the practical data is used to test our method. We mount over 5 remote stations near Chengdu Shuangliu international airport. The performance of tracking is shown in figure 3(c). The trajectory is smooth, which illustrates our simulation and its method is effective.



(a) Movement trajectory (b) Precision comparison (c) Out-door testing

Figure 3 Application performance

Summary

MLAT is becoming one of the leading techniques in the airport surveillance. Its model and simulation based on both GDOP and TOA error is analyzed in this paper. The application experiments in the airport show the method and its performance in this paper is accurate and effective.

Acknowledgement

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