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Two Levels Data Fusion Filtering Algorithms of Multimode Compound Seeker

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Abstract

The multimode compound guidance is an important guidance system, which can assurance missile impact accuracy in the complicated electromagnetic environment. Aiming at the data fusion filtering problem of multimode compound seeker, this paper presents a two-stage data fusion algorithm. First of all, each sensor data is send into first-stage fusion structure for centralized fusion processing after time registration, and then the processing results are sent into second-stage fusion structure for distributed fusion processing with radar and infrared information processing results. Meanwhile, in order to solve the problems that the different observation information in distributed fusion structure has different dimensions, the observation data is extended to the same dimension. Simulation results show that the proposed algorithm can effectively improve the data fusion efficiency, and improve the efficiency of the filter convergence accuracy and convergence speed, which has a certain guiding significance to engineering practice.

Keywords: multimode compound guidance, two-stage data fusion, sub-filter, extended dimension matrix

1. Introduction

The improvement of the guidance ability and anti-interference ability has been the focus of research on the accuracy guided weapon, so the multimode compound guidance has become an important direction that the accuracy guided weapon develops to intelligent weapon. At present, used or developing multimode compound seeker mainly adopts dual mode composite form. Radar and infrared sensor compound seeker are the most common form among them. The infrared sensor can measure the angle information of target, which has some advantages such as high angle measuring accuracy and continuous measurement, but it cannot get the range information, on the opposite, radar can all-weather measure the target's angle and distance information, but its angle measuring accuracy is low, and it will produce missing detective phenomenon in some measure period. Therefore, an effective fusion of their information can improve the guidance's target tracking accuracy and enhance its target tracking robustness and anti-interference ability.

Multi-sensor information fusion is the key technology in radar and infrared dual mode guidance system. Reference [1] put forward a radar and infrared collaborative tracking methods, and improved the target tracking accuracy by using Unscented Kalman Filter (UKF), reference [2] put forward an estimate method using fusion measurement to estimate the target state and reduced the estimation error, reference [3] put forward a method that measurement directly involved in track fusion, which used the public dynamic equation as foundation and got fusion formula, reference [4, 5] discussed sensors' track fusion problem which had different measuring accuracy, but the sensors data had the same dimension, state matrix, measurement matrix and state transition matrix, reference [6] discussed the data fusion problem about 2d/3d radar and different 2d passive sensor, reference [7] discussed asynchronous data fusion problem about multitasking radar and optical sensor.

The data fusion methods mentioned above can be divided into centralized fusion and distributed fusion. Centralized fusion is a method that all sensor measurement data are transmitted to a central processor for processing and fusion, and distributed fusion is a method that each sensor data processing intermediate result is transmitted to the center node for processing and fusion. In order to make full use of high accuracy angle information of infrared

seeker, based on the two kinds of fusion, this paper proposes a two-stage data fusion algorithm: first, each sensor data after time registration is send into first-stage fusion structure for centralized fusion processing, and then the processing results are send into second-stage fusion structure for distributed fusion processing with radar and infrared sensor independent processing results. Meanwhile, in order to solve the problems that different observation information in distributed fusion structure has different dimensions, the observation data is extended to the same dimension. In this way, the data processing module can provide high accuracy guidance information to seeker and improve the seeker electronic interference resistance ability.

2. The Proposed Method

Aiming at the double sensor system in a same platform, in order to make effectively use of the measurement data in fusion processing, the measurement data needs time and space registration before data fusion. The purpose of time registration is to ensure that the data input to the fusion filter is measured at the same time, so that the filter can estimate the accurate target motion state. Because infrared sensor sampling rate is higher than radar sampling rate, so we assume the ratio of radar sampling period T_R and infrared sensor sampling period T_I is a positive integer n. If the last track update time is t_{k-1}, then the next track update time is $t_k = t_{k-1} + nT_I$, so the infrared sensor has n measured values in the interval $[t_{k-1}, t_k]$. Using the least square method to fusion the n measured values into a virtual measured value as infrared sensor measurement at the moment t_k, which can realize time registration of two sensor measurements.

The radar and infrared sensor is distributed in the same seeker platform, so before the data fusion we need to get space registration of data comes from two sensors. The purpose of space registration is to translate the different sensor measurement data into the same coordinate system, and then carry on fusion filtering.

Assuming the platform coordinate system $o-xyz$'s origin o is in missile center of mass, axis $o-x$ is reclosing with the projectile longitudinal axis and its positive direction is the direction of projectile head, axis $o-y$ is in projectile longitudinal symmetry plane, perpendicular to the $o-x$ axis, which points to the upside is positive, axis $o-z$ is perpendicular to the plane $x-o-y$, and its direction is determined according to the right-hand rule. The pitch angle and azimuth angle directed by radar optic axis are θ_R and φ_R, the pitch angle and azimuth angle directed by infrared sensor optic axis are θ_I and φ_I, radar installation rolling angle is γ_R, infrared sensor installation rolling angle is γ_I. Set the declinate between radar and infrared sensor measurement is $\Delta\gamma = \gamma_R - \gamma_I$, and the rectangular coordinate system origin of radar in the infrared sensor rectangular coordinate system is $\Delta E = [\Delta x_e, \Delta y_e, \Delta z_e]^T$. $R_{TI}, \theta_{TI}, \varphi_{TI}$ are range, pitch angle and azimuth angle of target when they are transformed from radar coordinate system to infrared coordinate system respectively. The coordinate transformation process can be completed through the coordinate rotation transformation and coordinates translation transformation:

$$\begin{bmatrix} x_{TI} \\ y_{TI} \\ z_{TI} \end{bmatrix} = R_x(\theta_I - \theta_R) \cdot R_y(\varphi_I - \varphi_R) \cdot R_z(\gamma_I - \gamma_R) \begin{bmatrix} x_{TR} \\ y_{TR} \\ z_{TR} \end{bmatrix} + \Delta E \tag{1}$$

Where:

$$\begin{cases} x_{TR} = R_{TR} \cdot \cos\theta_{TR} \cdot \sin\varphi_{TR} \\ y_{TR} = -R_{TR} \cdot \sin\theta_{TR} \\ z_{TR} = R_{TR} \cdot \cos\theta_{TR} \cdot \cos\varphi_{TR} \end{cases} \tag{2}$$

$$R_x(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix} \tag{3}$$

$$R_y(\alpha) = \begin{bmatrix} \cos\alpha & 0 & -\sin\alpha \\ 0 & 1 & 0 \\ \sin\alpha & 0 & \cos\alpha \end{bmatrix} \tag{4}$$

$$R_z(\alpha) = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$[x_{TR}, y_{TR}, z_{TR}]^T$ is the coordinates of target in radar rectangular coordinate system, $[x_{TI}, y_{TI}, z_{TI}]^T$ is the coordinates of target in infrared sensor rectangular coordinate system, $R_k(\alpha)$ is rotation matrix when the coordinate system rotates α degrees around the axis k.

Therefore, radar measurement in infrared sensor coordinate system can be expressed as:

$$\begin{cases} R_{TI} = \sqrt{x_{TI}^2 + y_{TI}^2 + z_{TI}^2} \\ \theta_{TI} = -\arcsin\dfrac{y_{TI}}{R_{TI}} \\ \varphi_{TI} = \arcsin\dfrac{x_{TI}}{R_{TI}} \end{cases} \tag{6}$$

In order to narrative conveniently, the coordinate transformation of radar measurement $R_{TI}, \theta_{TI}, \varphi_{TI}$ are recorded as $\breve{R}_R, \breve{\theta}_R, \breve{\varphi}_R$.

3. Research Method

When radar measurement data and infrared sensor measurement data are got time and space registration, they will carry on data fusion. Because infrared sensor can only measure the angle of target information, so in this paper, only the two kinds of sensor angle information are got fusion. There are many methods for measurement data fusion, and this paper uses the weighted average method for data fusion. According to the principle that fusion measurement information has the minimum root mean square error, we can get the fusion target measurement value. Recording θ_{RI} as fusion target pitch angle, φ_{RI} as fusion target azimuth angle, $\sigma_{\theta RI}^2$ as fusion pitch angle measurement variance, $\sigma_{\varphi RI}^2$ as fusion azimuth angle measurement variance, $\sigma_{\theta I}^2$ as infrared sensor pitch angle measurement variance, $\sigma_{\varphi I}^2$ as infrared sensor azimuth angle measurement variance, $\breve{\sigma}_{\theta R}^2$ as radar pitch angle measurement variance after coordinate conversion, $\breve{\sigma}_{\varphi R}^2$ as radar azimuth angle measurement variance after coordinate conversion, then:

$$\theta_{RI}(k) = \sigma_{\theta RI}^2 \left(\frac{\breve{\theta}_R}{\breve{\sigma}_{\theta R}^2} + \frac{\theta_I}{\sigma_{\theta I}^2} \right) \tag{7}$$

$$\sigma_{\theta RI}^2 = \frac{\breve{\sigma}_{\theta R}^2 \sigma_{\theta I}^2}{\breve{\sigma}_{\theta R}^2 + \sigma_{\theta I}^2} \tag{8}$$

$$\varphi_{RI}(k) = \sigma_{\varphi RI}^2 (\frac{\breve{\varphi}_R}{\breve{\sigma}_{\varphi R}^2} + \frac{\varphi_I}{\sigma_{\varphi I}^2}) \tag{9}$$

$$\sigma_{\varphi RI}^2 = \frac{\breve{\sigma}_{\varphi R}^2 \sigma_{\varphi I}^2}{\breve{\sigma}_{\varphi R}^2 + \sigma_{\varphi I}^2} \tag{10}$$

In order to improve the utilization rate of infrared data, and get more accurate estimation of first-stage data fusion filtering results, this paper uses distributed filtering thoughts to design three sub-filter. They carry on filtering processing for radar measurement data, infrared sensor measurement data and first-stage fusion measurement data respectively, then the processing results will be sent to the second-stage fusion filter for state estimation fusion, and the fusion result is used to correct the sub-filter results, which in order to make results have higher accuracy than centralized fusion or distributed fusion.

Radar measurement data are obtained in the polar coordinates system, in order to apply it to the standard KF, the measurement data and its mean and variance need to get coordinate conversion. Measurement data in the form of coordinate conversion is such as type (3). Recording the state vector as $X_R = \begin{bmatrix} x & y & z & \dot{x} & \dot{y} & \dot{z} \end{bmatrix}$, the form of converted measurement data mean is as follows:

$$\mu_\alpha \overset{\Delta}{=} \begin{bmatrix} R_{TR} \cos\theta_{RI} \cos\varphi_{RI} (e^{-\sigma_{\theta RI}^2 - \sigma_{\varphi RI}^2} - e^{(-\sigma_{\theta RI}^2/2 - \sigma_{\varphi RI}^2/2)}) \\ R_{TR} \cos\theta_{RI} \sin\varphi_{RI} (e^{-\sigma_{\theta RI}^2 - \sigma_{\varphi RI}^2} - e^{(-\sigma_{\theta RI}^2/2 - \sigma_{\varphi RI}^2/2)}) \\ R_{TR} \sin\theta_{RI} (e^{-\sigma_{\theta RI}^2} - e^{(-\sigma_{\theta RI}^2/2)}) \end{bmatrix} \tag{11}$$

The debased measurement value is:

$$\begin{bmatrix} x_{TR} \\ y_{TR} \\ z_{TR} \end{bmatrix} = \begin{bmatrix} x_{TR} \\ y_{TR} \\ z_{TR} \end{bmatrix} - \mu_\alpha \tag{12}$$

So far we can use the standard KF to filter the measurement.

Because infrared sensor can only observed the target angle data, in order to make it can be applied to kalman filter, we need to use pseudo linear estimation method. In reference [8-10], the pseudo linear estimator is applied in the extended kalman filter to carry on the angle measurement passive tracking. Although this method is a biased estimation, it can overcome the filter divergence phenomenon because it uses the pseudo linear estimator's valuation as kalman filter's initial value. The pseudo linear filter system parameters can be expressed as follows:

The state vector:

$$X_I = \begin{bmatrix} x & y & z & \dot{x} & \dot{y} & \dot{z} \end{bmatrix} \tag{13}$$

The measurement matrix:

$$Z_I = \begin{bmatrix} x\sin\theta_I \cos\varphi_I + y\sin\theta_I \sin\varphi_I - z\cos\theta_I \\ x\sin\varphi_I - y\cos\varphi_I \end{bmatrix} \tag{14}$$

The transfer matrix:

$$H_I = \begin{bmatrix} \cos\varphi_I \sin\theta_I & \sin\varphi_I \sin\theta_I & \cos\theta_I & 0 & 0 & 0 \\ \sin\varphi_I & -\cos\varphi_I & 0 & 0 & 0 & 0 \end{bmatrix} \tag{15}$$

The measurement data variance:

$$R_I = \begin{bmatrix} \left(\sqrt{x^2 + y^2 + z^2}\right)\cdot\sigma_{\theta I}^2 & 0 \\ 0 & \left(\sqrt{x^2 + z^2}\right)\cdot\sigma_{\varphi I}^2 \end{bmatrix} \tag{16}$$

So far we can use the standard KF to filtering the measurement.

Due to the measurement matrix of each filter has different dimension, in order to make sure that three sub-filter's filtering results can be reprocessing in the same KF filter, dimension of parameters in each sub-filter's measurement equation needs to be extended. Three sub-filter's extended measurement matrix is as follows:

$$Z = \begin{bmatrix} R_{TR}\cos\theta_{RI}\cos\varphi_{RI} \\ R_{TR}\cos\theta_{RI}\sin\varphi_{RI} \\ R_{TR}\sin\theta_{RI} \\ x\sin\theta_{RI}\cos\varphi_{RI} + y\sin\theta_{RI}\sin\varphi_{RI} - z\cos\theta_{RI} \\ x\sin\varphi_{RI} - y\cos\varphi_{RI} \end{bmatrix} \tag{17}$$

The transfer matrix is:

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ \cos\varphi_{RI}\sin\theta_{RI} & \sin\varphi_{RI}\sin\theta_{RI} & \cos\theta_{RI} & 0 & 0 & 0 \\ \sin\varphi_{RI} & -\cos\varphi_{RI} & 0 & 0 & 0 & 0 \end{bmatrix} \tag{18}$$

So far we can use KF for second-stage fusion, the two-stage data fusion algorithm process is as follows:
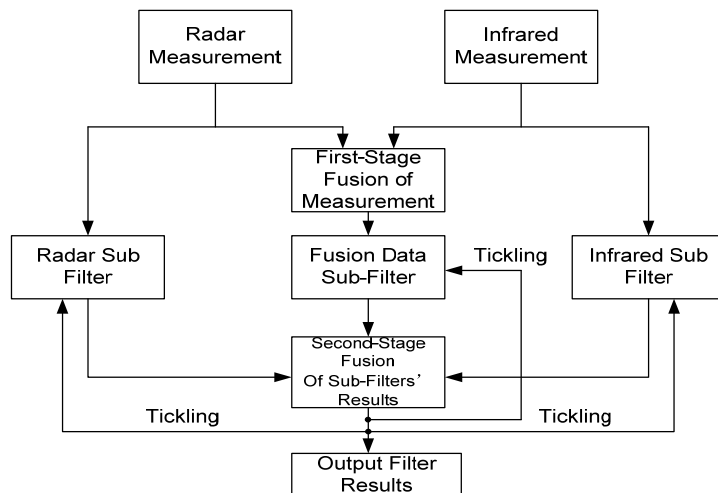

Figure 1. Data Processing Flow Chart of Two Level Fusion Algorithm

4. Results and Discussion

Suppose an anti-ship missile with radar-infrared dual mode seeker uniform flight in a straight line close to sea level at the speed of 1Ma, and its initial position in the geography rectangular coordinates system is $(0m, 0m, 20m)$. It's cruise angle is 0°, radar filter's sampling rate is $10Hz$, infrared filter's sampling rate is $50Hz$. Our ship is static and the initial position is $(10000m, 0m, 0m)$. The fusion detection data is shown in Figure 2, three sub-filter's position filtering error is shown in Figure 3, and the contrast diagram of two-stage fusion filter's position filtering results and one-stage fusion filter's position filtering results is shown in Figure 4 and Table 1.
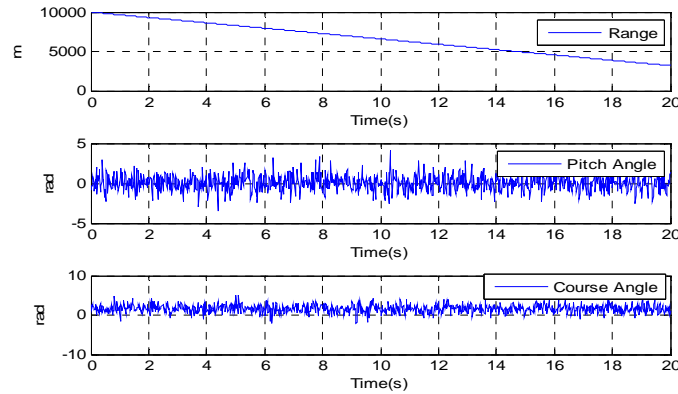

Figure 2. Measurement Data Simulation Diagram

As can be seen in Figure 3, three sub-filter's prediction accuracy on the measurement data is: fusion sub-filter accuracy > infrared sensor sub-filter accuracy > radar sub-filter accuracy. This phenomenon is determined by the measurement information quality which input to filter: infrared sensor has high data sampling rate, if it combined with higher accuracy initial value, then it can get high accuracy filtering results; radar has low data sampling rate, but it is a three coordinates radar, which can provide target range information, so it also can get good filtering results; fusion filter due to combined with both effective measurement information from infrared sensor and radar, so it get the highest accuracy filtering results. The filtering result in Figure 4 and Table 1 shows that the two-stage fusion filter has a better performance than one-stage fusion filter in convergence accuracy and convergence time. The reason is that the two-stage fusion filter makes full use of every sensor's measurement data and the filtering results.
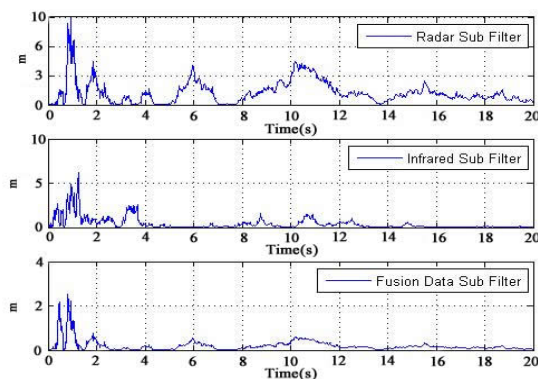

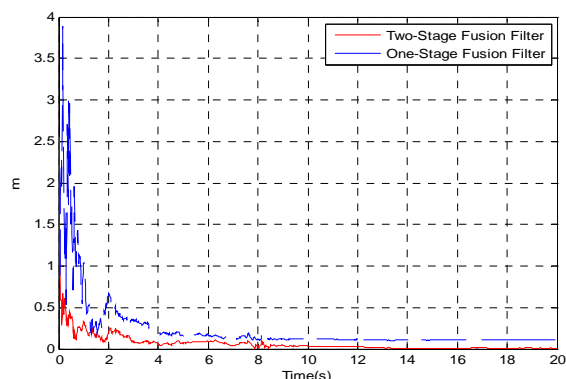Figure 3. Sub-filter's Position Filtering Error Schematic Diagram

Figure 4. Contrast Diagram of Fusion Filters' Position Filtering Error

Table 1. The Convergence Accuracy Comparison of One Stage Fusion Sub-filter and Two Stage Fusion Filter Results

		x axis	y axis	z axis
one stage fusion sub-filter	position convergence precision (m)	0.2371	0.2106	0.1396
	velocity convergence precision (m/s)	0.4500	0.3756	0.4711
two stage fusion filter results	position convergence precision (m)	0.1597	0.1560	0.0652
	velocity convergence precision (m/s)	0.6769	0.2361	0.1249

5. Conclusion

Multimode compound guidance is one of the accuracy guidance weapon's important development directions, and how to make reasonable and effective use of data information from multisensor is a very remarkable research direction. In order to improve the multimode compound seeker's target tracking accuracy, this paper puts forward a kind of two-stage fusion filter. This filter has a complex structure, and this feature makes it has a higher accuracy data processing result. The simulation results indicate that the method can effectively improve the filtering convergence accuracy and convergence time, which has certain engineering guiding significance in improving the multimode compound seeker guidance accuracy.

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