Research on Passive Radar Guidance Head/GFSINS Integrated Navigation against Target Radar Shutdown Based on AUKF

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Abstract. It's feasible to counter radar shutdown with passive radar guidance head/strapdown inertial navigation integrated system. Gyro inertial component has problems of high costs and gyro drift, so the paper discusses application of gyroscope free strapdown inertial navigation system (GFSINS). At first, a missile uses passive radar homing before an enemy radar shuts down, and sets up an inertial navigation axis pointed to the target based on prior information and adaptive unscented Kalman Filter(AUKF) algorithm to perform transferring alignment after the target shuts down, then switches to the inertial navigation system to guide the missile flight until hit. The simulation results show that the scheme is able to finish the task of countering radar shutdown for a long time while to guarantee the guidance precision.

Foreword

The anti-radiation missile (ARM) relies on the passive radar seeker head to capture the target. However, if a target radiation source is turned off, the target information of guidance head will be lost. So, the simplest and most effective method for radar against ARM is intermittently boot [1]. During the period of its shutdown, an ARM would lose the target information and couldn’t hit the radar because of lack of the emitter signals.

It has been one of the big problems many countries focus on in the study of an ARM how to improve guidance precision and ability against radar shutdown [2]. The paper focuses on passive radar guidance head/ GFSINS integrated navigation to counter radar shutdown, and applies AUKF algorithm to perform transferring alignment of GFSINS, in order to improve the capacity against radar shutdown and the kill probability of ARM.

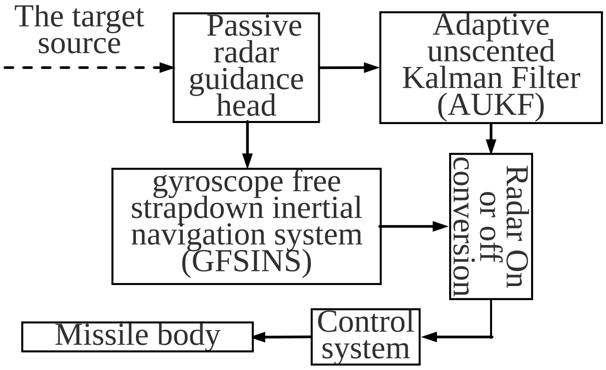

Fig.1 the scheme of passive radar guidance head/ GFSINS integrated navigation to counter radar shutdown

Design of the scheme against a target radar shutdown

The method of passive radar guidance head/GFSINS integrated navigation is employed to counter radar shutdown. The phrase of GFSINS is a kind of strapdown Inertial Navigation Systems, whose inertial components only use the accelerometer without the gyro. It applies AUKF algorithm to perform transferring alignment of inertial navigation system. The principle of the scheme is showed as Fig.1.The GFSINS has the prominent advantages of low cost, high reliability ,low power, long life ,rapid response and so on[3].

The phrase of transferring alignment means that after the target radar shuts down, an ARM swiftly figures out right navigation initial information and the coordinate system points of the missile inertial navigation system (the inertial sub-navigation) by dynamic base conditions. During the process of transferring alignment, ARM firstly needs to get navigational information of high accurate inertial navigation (the main inertial navigation).Then, based on it, ARM uses a certain filtering algorithm to estimate and compensate the alignment error between two sets of inertial navigation for specific maneuvering conditions, so as to let the navigation coordinate system set up by the inertial sub-navigation coincide with the one set up by the main inertial navigation.

The transferring alignment is divided into two sub-processes: coarse alignment and accurate alignment. The sub-process of coarse alignment binds the inertial sub-navigation with information of the attitude matrix, velocity and position gained from the airborne main inertial navigation, and the inertial sub-navigation uses these information as initial values to calculate attitude and navigation. Because distance, structure deformation and installation error etc. might result in the binding value inconsistent with the real attitude of the inertial sub-navigation. It induces a misalignment angle of the inertial sub-navigation, which changes according to the law determined by the error equation with one initial error angle. The task of the accurate process is to do real-time estimation on the misalignment angle with Kalman filter algorithm. When the estimated value reaches the required accuracy, it will make a one-time correction on the attitude of the real-time calculation.

Adaptive unscented Kalman filter algorithm (AUKF)

Unscented Kalman Filter (UKF)

The state equation and measurement equation of nonlinear discrete-time system are as follow:

$$X(k+1) = f(k, X(k)) + w(k) \tag{1}$$

$$z(k) = h(k, X(k)) + v(k) \tag{2}$$

$f(k)$ is nonlinear state transition ,and $h(k)$ is nonlinear measurement function.

Adaptive Unscented Kalman Filter (AUKF)

The traditional UKF algorithm is more sensitive to initial value, so the uncertainty of the related system noise information and the disturbance of the state equation will both affect accuracy of the UKF filter solution [4]. The paper uses the principle of variance inflation to make adaptive expansion on the relevant covariance matrixes of $x_{k,k-1}$ and $\hat{z}_k$, which both have deviation, so as to adjust their roles in the filtering solution. Here ,we introduce the adaptive factor α_k , $0 < \alpha_k \le 1$, and α_k is constructed as:

$$\alpha_k = \begin{cases} 1 & tr(V_k V_k^T) \le tr(P_{x_k z_k} P_{x_k z_k}^T) \\ \dfrac{tr(P_{x_k z_k} P_{x_k z_k}^T)}{tr(V_k V_k^T)} & tr(V_k V_k^T) > tr(P_{x_k z_k} P_{x_k z_k}^T) \end{cases} \tag{3}$$

The prediction error is:

$$V_k = z_k - \sum_{i=0}^{2n} W_i^n z_{i,k-1} \tag{4}$$

Thus, the observation covariance matrix, the state and observation mutual covariance matrix and the updated state variance of the system are as follow:

$$P_{z_k} = \frac{1}{\alpha_k} \cdot \sum_{i=0}^{2n} W_i^c (z_{i,k} - \hat{z}_k)(z_{i,k} - \hat{z}_k)^T + R_k \tag{5}$$

$$P_{x_k z_k} = \frac{1}{\alpha_k} \sum_{i=0}^{2n} W_i^c (\chi_{i,k} - \hat{x}_{k,k-1})(z_{i,k} - \hat{z}_k)^T \tag{6}$$

$$P_k = \frac{1}{\alpha_k} P_{k,k-1} - K_k P_{z_k} K_k^T \tag{7}$$

If there is deviation in the selection of UFK initial value or abnormal disturbance in the state model, α_k will be less than 1, which means the contribution of the state model prediction information to the final filtering solution will be as small as possible. If there is great error in the state model prediction information, α_k will be close to 0, which means that the dynamic model information will be completely abandoned and the filter will tend to diverge. It is said that the introduction of α_k is able to adaptively adjust the contribution of $\hat{x}_{k,k-1}$ to the state updating according to the prediction residual V_k and the observation information z_k .Thereby it reduces the effect of the state model error on the filtering solution.

The research on the GFSINS transferring alignment

The technology of the GFSINS transferring alignment is to figure out the right navigation initial information and the coordinate system points of ARM inertial navigation system (the inertial sub-navigation) rapidly by dynamic base conditions. During the process of transferring alignment, ARM firstly needs to get navigational information of high accurate inertial navigation (the main inertial navigation).Then, based on it, ARM uses a certain filtering algorithm to estimate and compensate the alignment error between two sets of inertial navigation for specific maneuvering conditions, so as to let the navigation coordinate system set up by the inertial sub-navigation coincide with the one set up by the main inertial navigation.

The matched value of the transferring alignment

The speed matched value. The paper assumes that the speed outputs of the main inertial navigation and the inertial sub-navigation are represented as V_{mE}^C、V_{mN}^C、V_{mU}^C and V_E^C、V_N^C、V_U^C. Thus, the speed matched values are as follows:

$$Z_1 = V_E^C - V_{mE}^C = \delta V_E - \delta V_{mE} + V_E \tag{8}$$

$$Z_2 = V_N^C - V_{mN}^C = \delta V_N - \delta V_{mN} + V_N \tag{9}$$

$$Z_3 = V_U^C - V_{mU}^C = \delta V_U - \delta V_{mU} + V_U \tag{10}$$

The attitude angle matched value. The paper assumes the attitude matrixes determined by the inertial sub-navigation and the main inertial navigation are represented as $C_{b'}^{n'}, C_b^n$, and

$$C_{b'}^{n'} = \begin{bmatrix} T_{11}' & T_{12}' & T_{13}' \\ T_{21}' & T'_{22} & T_{23}' \\ T_{31}' & T_{32}' & T_{33}' \end{bmatrix} \tag{11}$$

Because the course angle, the pitch angle and the roll angle determined by the attitude matrix of inertial navigation are as follows:

$$\psi_s = \psi + \delta\psi \tag{12}$$

$$\vartheta_s = \vartheta + \delta\vartheta \tag{13}$$

$$\gamma_s = \gamma + \delta\gamma \tag{14}$$

$\delta\psi, \delta\vartheta, \delta\gamma$ represent corresponding error.

The state equation and observation equation of the transferring alignment

The construction of the state equation

During the process of transferring alignment, the accuracy of the main inertial navigation is several orders of magnitude higher than the inertial sub-navigation. The platform coordinate system of the main inertial navigation could be regarded as the true geographic coordinate system.

Therefore, it is to forecast the misalignment angle of the inertial sub-navigation and the geographic coordinate system, instead of forecast on the misalignment angle of the navigation coordinate system between the main inertial navigation and the sub-navigation inertial navigation, which means that the transferring alignment problem is transformed into a navigational problem. However, the speed of transferring alignment should be taken account; the paper ignores the ellipticity of the Earth, the latitude and height error, so the state equation of the simplified error model of the inertial navigation system is as follows:

$$\begin{aligned}\delta\dot{V}^n &= \phi^n \times L^n \times [\omega_{nb}^n \times (\omega_{nb}^n \times 2\omega_{ie}^n \times \omega_{en}^n) - \dot{\omega}_{nb}^n] \\ &\quad - \phi^n \times f^n + \delta V^n \times (2\omega_{ie}^n \times \omega_{en}^n) + \nabla^n\end{aligned} \tag{15}$$

$$\dot{\phi} = \phi \times \omega_{in}^n + \delta\omega_{in}^n \tag{16}$$

$\omega_{nb}^n, \omega_{ie}^n, \omega_{en}^n$ are the binding values of the inertial sub-navigation in the process of the coarse alignment and, ϕ is the misalignment angle vector of the two navigation coordinate systems. Here, $\dot{\nabla}^n = 0$ and $\nabla_a, \nabla_b, \nabla_c, \nabla_d, \nabla_e, \nabla_f$ are expanded to be state variables. Then the paper assumes symbol X ($X = [\phi_E\ \phi_N\ \phi_U\ \delta V_E\ \delta V_N\ \delta V_U\ \nabla_a\ \nabla_b\ \nabla_c\ \nabla_d\ \nabla_e\ \nabla_f]^T$) and establishes the corresponding state equation of the Kalman filter.

$$\dot{X} = AX + BW \tag{17}$$

A is a 12×12 time-varying state matrix and B is a 12×6 system noise matrix, which are determined by the velocity error equation and the misalignment angle equation of GFSINS.

The construction of the observation equation

The paper introduces Z ($Z = [\delta V_x\ \delta V_y\ \delta V_z\ \delta\psi\ \delta\gamma\ \delta\vartheta]^T$) as the observation value and establishes the corresponding observation equation of the Kalman filter:

$$Z = CX + \upsilon \tag{18}$$

C is a 6×12 output matrix determined by the matched value of the velocity and the attitude angle, and v is measurement noise.

The simulation analysis of the GFSINS transferring alignment

The paper makes the following assumption: the main inertial navigation works in pure inertial navigation state.

The carrier state:

$L = 45°,\ \lambda = 0°,\ h = 5000m$

$V_x^b = 200m/s, V_y^b = 0, V_z^b = 0$

The constant component of gyro drift: $0.001^0/h$.

The random component of gyro drift: $0.001^0/h$.

The constant error of the accelerometer: 5×10-5g（m/s^2）;

The random error of the accelerometer: 5×10-5g（m/s^2）;

The initial velocity error of GFSINS: 0(m/s): the horizontal error: 2 arc minute; the azimuth error: -1 arc minute; the position error: -55 arc minute.

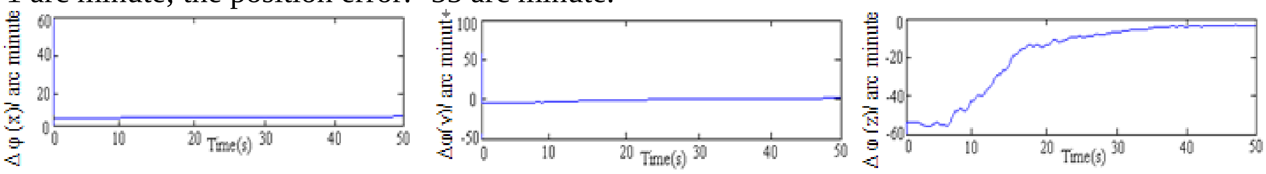

Fig.2 The curve of error for misalignment angle

The simulation time is set to be 50 seconds and, the velocity of the carrier aircraft is 200m/s along the x axis. In the alignment process, the carrier aircraft makes the appropriate maneuvers to improve the observability of the inertial navigation alignment vector. The filtered misalignment angle error result is shown in Fig.2.

According to the simulation result, the steady-state errors of the transferring alignment system are less than 20 arc minute. Thus, we could conclude that the transferring alignment system with the GFSINS as the inertial sub-navigation has high precision.

The simulation of passive radar guidance head/GFSINS integrated system to counter radar shutdown

The initial simulation conditions are as follows: one ARM (with a maximum speed of 4 mach and a range of 80 km) directly attacks the target radar, which is horizontally launched at the speed of 3.5 mach. The coordinates of the target radar and the missile in the projectile coordinate system are (59000m,-2000m,4500m) and (0,0,0). The angle measurement noise variance of the passive radar seeker is 0.5° and its measurement noise obeys the $N(0,(0.1^0)^2)$ Gaussian distribution. (Its constant deviation $\varphi_{sbo},\theta_{sbo} \sim N(0.0.2^0)$ and its random error $\Delta\varphi_{sb},\Delta\theta_{sb} \sim N(0.0.2^0)$). The parameters of the AUKF filter are $\alpha = 0.6, \beta = 1.5, \gamma = -0.5$. The sampled time is 0.01s and the simulation time is about 50s.

The target radar shuts down in 20 seconds. The simulation results of the AUKF filtering experiment and passive radar guidance head/GFSINS integrated system are shown in Fig. 3 and Fig.4.

From the simulation curve, the main and sub- navigation misalignment angle of the filtering steady-state estimation value is small enough to meet the accurate attack conditions. In the case of the target radar shuts down for a long time, the scheme of passive radar guidance head/GFSINS integrated system has a better tracking performance and a smaller steady-state position error.

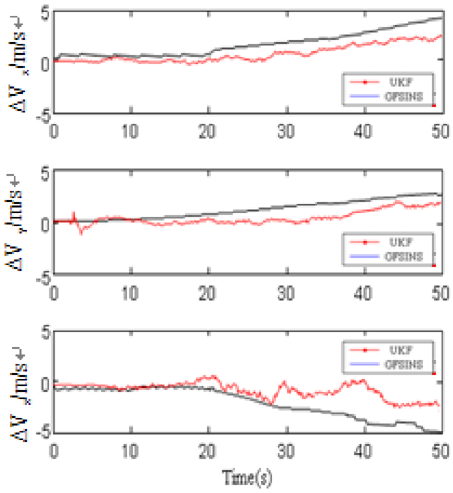

Fig.3 The comparison of error of speed

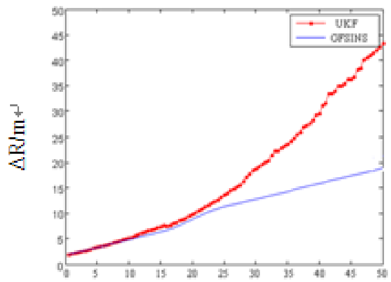

Fig.4 The compare of error of missile's actual position

According to the simulation results, employed AUKF to perform transferring alignment on the main inertial navigation and sub-navigation, an ARM with passive radar guidance head/GFSINS integrated system improves literally the ability to counter a radar shutdown greatly based on a small cost. Therefore, the scheme above has been proved feasible.

References

[1] Yang Linchong. Research on the Relationship Between the Inertial Navigation Accuracy and the Ability Against the Shutdown Radar of ARM[J]. Tactical Missile Technology, 2011，1：85-86.

[2] Tang Hua, Qu Changwen. Method and Ability Analysis of Anti-radiation Missile Against Target Radar Switching Off [J]. Journal of Projectiles Rockets Missiles and Guidance, 2009，1：260-261.

[3] Wang Xiaona, Wang Shuzong, Zhu Huabing, Gyroscope-free Strapdown Inertial Measurement Techniques[J]. Journal of Chinese Inertial Technology, 2010，10：539-540.

[4] Gao Weiguang, He Haibo, Cheng Jinping. An Adaptive UKF Algorithm and Its Application for GPS/INS Integrated Navigation System[J]. Journal of Beijing Institute of Technology(Natural Science Edition), 2008，28：505-509.