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Synthesis of Line of Sight Angle Coordinate Filter with Three Different Target Models

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Abstract: *On the basis of the tracking multi-loop target angle coordinate system, the article has selected and proposed an interactive multi-model adaptive filter algorithm to improve the quality of the target phase coordinate filter. The interactive multi-model evaluation algorithm is capable of adapting to the maneuverability of the target as the evaluation process progresses to the most suitable model. In which, the 3 models selected to design the line of sight angle coordinate filter; Constant velocity (CV) model, Singer model and constant acceleration (CA) model, characterizing 3 different levels of maneuverability of the target. As a result, the evaluation quality of the target phase coordinates is improved because the evaluation process has redistribution of the probabilities of each model to suit the actual maneuvering of the target. The structure of the filters is simple, the evaluation error is small and the maneuvering detection delay is significantly reduced. The results are verified through simulation, ensuring that in all cases the target is maneuvering with different intensity and frequency, the line of sight angle coordinate filter always accurately determines the target angle coordinates.*

Keywords: Target model,Missile, Maneuvering, Angle of line of sight.

I. INTRODUCTION

In the tracking multi-loop optimal target angle coordinate system[1], [2], the maneuverability of the target is taken into account by the target normal acceleration model (j_t). This model is characterized by maneuvering frequency (α_{j_t}) and maneuvering intensity ($\sigma^2_{j_t}$). In this angular coordinate system, accuracy is enhanced by not using directly the signal equalization direction as the signal for evaluating the target coordinates, but using a separate line of sight angle coordinate evaluation filter[9]; at the same time the related states are evaluated by the Kalman filter algorithm in the tracking loop[10],[11]. However, since we cannot choose a target model suitable for all types of maneuverability, the optimal angular coordinate system with fixed parameters will appear large evaluation errors, when in reality, meneuver targets is different from the selected model.

The tracking multi-loop target angle coordinate determination system, in which the line-of-sight angle coordinate filter uses the interactive multi-model (IMM) filter algorithm will significantly reduce the tracking error when the target changes type maneuver, including both an uncertainty related to maneuvering moment and maneuvering intensity. Because, the interactive multi-model evaluation algorithm is capable of adapting to maneuverability of the target as the evaluation process progresses to the most suitable model[6].

On the basis of the tracking multi-loop target angle coordinate system, 3 models selected to design the line of sight angle coordinate filter are constant velocity (CV) model, Singer model and constant acceleration (CA) model.

II. SYNTHESIS OF LINE OF SIGHT ANGLE COORDINATE FILTER

The purpose of the line of sight angle coordinate filter is to evaluate the line of sight angle, line of sight angle speed and target normalization acceleration in order to provide the information required for the flying equipment guide law. With the optimal target angular coordinate system, this filter is designed with Singer model with fixed parameters. Then, the model's equation of state takes the form[3], [4], [5]:

$$\dot{\varepsilon}_d = \omega_d \quad (1)$$

$$\dot{\omega}_d = -\frac{2\dot{D}}{D}\omega_d + \frac{1}{D}(j_t - j_d) \quad (2)$$

$$\dot{j}_t = -\alpha_j j_t + \xi_{j_t} \quad (3)$$

Where: D - Relative distance between missile and target;

j_t - Normal acceleration of the target;

j_d - Normal acceleration of the missile;

ξ_{j_t} - Process noise of the model;

ε_d - Angle of the line of sight to target in the inertial coordinate system;

ω_d - Angular speed of line of sight.

On the basis of this idea, the article adds 2 other models, characteristic for the small and large degree of maneuverability of the target. Model with constant velocity (CV model) and almost constant acceleration model (CA model) to build the interactive multi-model (IMM) evaluation algorithm for the line of sight angle coordinate filter. This choice is derived from the point of view, these 3 models are suitable for 3 different levels of maneuverability of the target.

Thus, the line of sight angle coordinate filter includes 3 linear Kalman filters running in parallel using 3 models, respectively, CV model, Singer model and CA model. The final state evaluation is a combination of component filters with weighting on the exact probabilities of each model. As a result, the evaluation quality of the target phase coordinates is improved because the evaluation process has redistribution of the probabilities of each model to suit the actual maneuverability of the target. The specific kinetics model to build these 3 filters is as follows:

- The Kalman 1 filter uses a CV model for synthesis. This model considers the target normalized acceleration as white noise $j_t = \xi$ [5]. In this case, the velocity and angle of the target orbital inclination (θ_t) are almost constant due to $\dot{\theta}_t = \frac{j_t}{V_t}$ (assuming the target velocity is constant). This model characterizes the degree of maneuverability of the smallest targets.

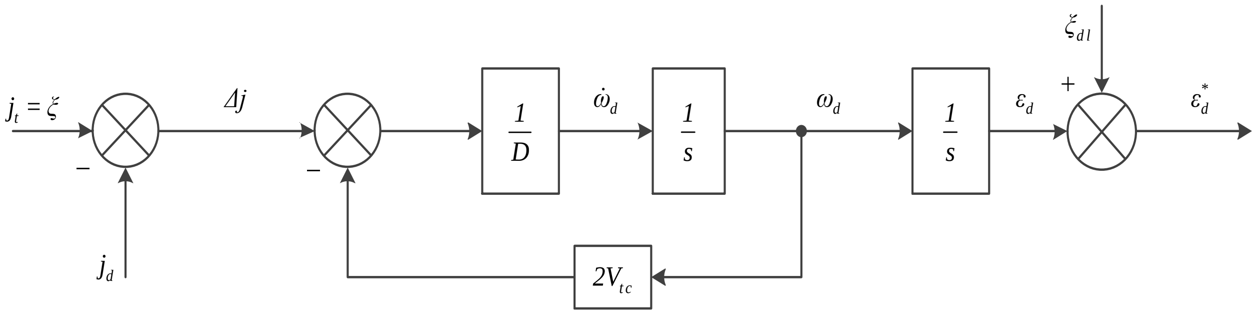

Fig 1. CV model to synthesize the Kalman filter 1

The model's equation of state takes the form:

$$\dot{\varepsilon}_d = \omega_d \tag{4}$$

$$\dot{\omega}_d = -\frac{2\dot{D}}{D}\omega_d - \frac{1}{D}j_d + \frac{1}{D}\xi = \frac{2V_{tc}}{D}\omega_d - \frac{1}{D}j_d + \frac{1}{D}\xi \tag{5}$$

Where: $\frac{\xi}{D}$ - Line of sight angular acceleration noise, due to the uncertainty in the model CV causes.

$V_{tc} = -\dot{D}$ - Target approach speed.

The vector form of the system of equations above:

$$\dot{\boldsymbol{x}}_1 = \boldsymbol{F}_{mh1}\boldsymbol{x}_1 + \boldsymbol{G}_{mh1}\boldsymbol{u}_1 + \boldsymbol{w}_1 \tag{6}$$

Where: $\boldsymbol{x}_1 = \begin{bmatrix} \varepsilon_d \\ \omega_d \end{bmatrix}$ - Ttarget phase coordinate state vector;

$\boldsymbol{u}_1 = j_d$ - Control signal;

$\boldsymbol{F}_{mh1} = \begin{bmatrix} 0 & 1 \\ 0 & \frac{2V_{tc}}{D} \end{bmatrix}$ - State transition matrix of filter 1;

$\boldsymbol{G}_{mh1} = \begin{bmatrix} 0 \\ -\frac{1}{D} \end{bmatrix}$ - Control matrix;

$$Q_{mh1} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{\sigma_{a_1}^2}{D^2} \end{bmatrix}$$ - Covariance matrix of process noise.

Discrete model above with cycle T, the base matrix is calculated as follows:

$$\Phi_{mh}(t) = L^{-1}\left\{(p\mathbf{I} - \mathbf{F}_{mh})^{-1}\right\}$$

Inside: L^{-1} - inverse Laplace transformations.

$\mathbf{I}$ - the unit matrix has dimensions consistent with $\mathbf{F}_{mh}$.

Replace the sampling cycle T to variable t of the base matrix to get the transition matrix $\Phi_{mh}^k = \Phi(T)$.

Discrete form control matrix, received by the formula:

$$\mathbf{G}_{mh}^k = \int_0^T \Phi_{mh}(t).\mathbf{G}_{mh} dt$$

The discrete form of the covariance matrix of the process noise:

$$\mathbf{Q}_{mh}^k = \int_0^T \Phi_{mh}(t).\mathbf{Q}_{mh}.\Phi_{mh}^T(t)dt$$

According to the above general formulas, the parameters of the CV model discrete form:

$$\Phi_{mh1} = \begin{bmatrix} 1 & \frac{D(\beta - 1)}{2V_{tc}} \\ 0 & \beta \end{bmatrix}$$ - State transition matrix;

$$\mathbf{G}_{mh1} = \begin{bmatrix} \frac{T}{2V_{tc}} - \frac{D(\beta - 1)}{4V_{tc}^2} \\ \frac{1-\beta}{2V_{tc}} \end{bmatrix}$$ - Control matrix.

Covariance matrix of the process noise discrete form as follows:

$$\mathbf{Q}_{mh_1}(1,1) = \left(\frac{\frac{D(\beta^2 - 1)}{4V_{tc}} - \frac{D(\beta - 1)}{V_{tc}} + T}{4V_{tc}^2} \right) \sigma_{a_1}^2$$

$$\mathbf{Q}_{mh_1}(1,2) = \mathbf{Q}_{mh_1}(2,1) = \left(\frac{\beta^2 - 1}{8V_{tc}^2} - \frac{\beta - 1}{4V_{tc}^2} \right) \sigma_{a_1}^2$$

$$\mathbf{Q}_{mh_1}(2,2) = \frac{\beta^2 - 1}{4V_{tc}D} \sigma_{a_1}^2$$

Inside: $\beta = e^{\frac{2V_{tc}T}{D}}$, T - Discrete cycle.

$\sigma_{a_1}^2$ - Process noise variance, which is characteristic of the maneuvering intensity.

- Filter Kalman 2 uses Singer model to describe target's movement[3], [4], [8]. This model characterizes the moderate maneuverability of the target, shown through the selection of two fixed parameters, maneuvering frequency α_j and maneuvering intensity $\sigma_{a_1}^2$. The kinetics of model 2 have the following form:

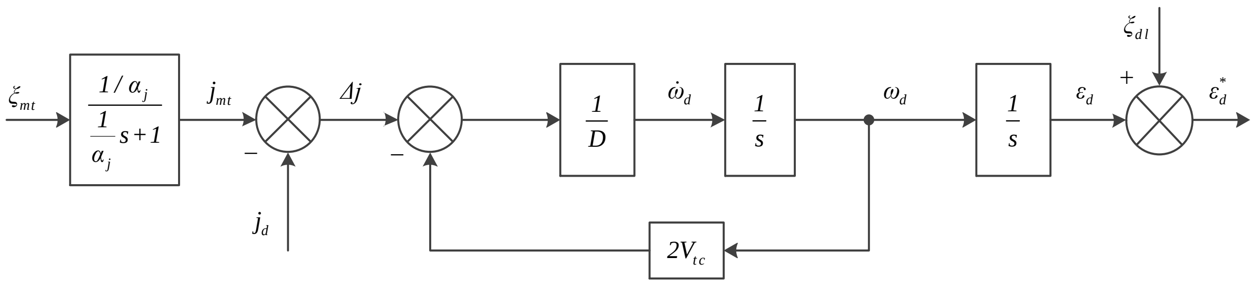

Fig. 2. Singer model to synthesize the Kalman filter 2

In the above model, the input inertia stage $(\frac{1/\alpha_j}{s/\alpha_j+1})$ is the shaping filter. To create the target maneuvering style with constant intensity and the moment of maneuverability evenly distributed during flight time, the spectral density function of process noise ξ_{j_t} has the form:

$$\sigma_{a_2}^2 = \frac{j_{max2}^2}{T_f}$$

Where: j_{max2} - Maximized target normal acceleration, maneuverable;

T_f - Flight time.

Equation of state of model 2 (Singer model):

The above equation is in vector form:

$$\dot{\varepsilon}_d = \omega_d \tag{7}$$

$$\dot{\omega}_d = \frac{2V_{tc}}{D}\omega_d + \frac{1}{D}j_t - \frac{1}{D}j_d \tag{8}$$

$$\dot{j}_t = -\alpha_j j_t + \xi_{j_t} \tag{9}$$

The above equation is in vector form:

$$\dot{\boldsymbol{x}}_2 = \boldsymbol{F}_{mh2}\boldsymbol{x}_2 + \boldsymbol{G}_{mh2}\boldsymbol{u}_2 + \boldsymbol{w}_2$$

Inside: $\boldsymbol{x}_2 = \begin{bmatrix} \varepsilon_d \\ \omega_d \\ j_{td} \end{bmatrix}$ - Target phase coordinate state vector;

$\boldsymbol{F}_{mh_2} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & \frac{2V_{tc}}{D} & \frac{1}{D} \\ 0 & 0 & -\alpha_j \end{bmatrix}$ - State transition matrix of filters 2;

$\boldsymbol{G}_{mh_2} = \begin{bmatrix} 0 \\ -\frac{1}{D} \\ 0 \end{bmatrix}$ - Control matrix;

$\boldsymbol{Q}_{mh2} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}\sigma_{a_2}^2$ -Covariance matrix of process noise.

Similarly, we have the parameters of model 2 in discrete form:

$$\boldsymbol{\Phi}_{mh2} = \begin{bmatrix} 1 & \frac{D}{2V_{tc}}(\beta-1) & \frac{e^{-\alpha T}}{\alpha(2V_{tc}+D\alpha)} - \frac{1}{2V_{tc}\alpha} + \frac{D\beta}{2V_{tc}(2V_{tc}+D\alpha)} \\ 0 & \beta & \frac{\beta - e^{-\alpha T}}{2V_{tc}+D\alpha} \\ 0 & 0 & e^{-\alpha T} \end{bmatrix}$$

$\boldsymbol{G}_{mh2} = \begin{bmatrix} \frac{T}{2V_{tc}} + \frac{D(1-\beta)}{4V_{tc}^2} \\ \frac{1-\beta}{2V_{tc}} \\ 0 \end{bmatrix}$ - Control matrix.

Covariance matrix of the process noise discrete form as follows:

$$Q_{mh_2}(1,1)=\frac{(e^{-\alpha T}-1)(\frac{8V_{tc}^2}{\alpha}+4DV_{tc})+T(D^2\alpha^2+4DV_{tc}\alpha+4V_{tc}^2)-(\beta-1)(\frac{D^3\alpha^2}{V_{tc}}+2D^2\alpha)}{4D^2V_{tc}^2\alpha^4+16DV_{tc}^3\alpha^3+16V_{tc}^4\alpha^2}$$

$$\frac{-\frac{2V_{tc}^2}{\alpha}(e^{-2\alpha T}-1)+\frac{D^3\alpha^2(\beta^2-1)}{4V_{tc}}+\frac{4D^2V_{tc}\alpha}{2V_{tc}-D\alpha}(e^{\frac{2V_{tc}T}{D}-\alpha T}-1)}{4D^2V_{tc}^2\alpha^4+16DV_{tc}^3\alpha^3+16V_{tc}^4\alpha^2}.\sigma_{a_2}^2$$

$$Q_{mh_2}(1,2)=Q_{mh_2}(2,1)=\frac{D(e^{\frac{2V_{tc}T}{D}-\alpha T}-1)-(\beta-1)(\frac{D^2\alpha}{2V_{tc}}+D)-(e^{-\alpha T}-1)(D+\frac{2V_{tc}}{\alpha})}{2D^2V_{tc}\alpha^3+8DV_{tc}^2\alpha^2+8V_{tc}^3\alpha}$$

$$\frac{+\frac{V_{tc}(e^{-2\alpha T}-1)}{\alpha}+\frac{D^2\alpha(\beta^2-1)}{4V_{tc}}}{2D^2V_{tc}\alpha^3+8DV_{tc}^2\alpha^2+8V_{tc}^3\alpha}.\sigma_{a2}^2$$

$$Q_{mh_2}(1,3)=Q_{mh_2}(3,1)=\frac{(e^{-\alpha T}-1)(D+\frac{2V_{tc}}{\alpha})-\frac{V_{tc}(e^{-2\alpha T}-1)}{\alpha}+\frac{D^2\alpha(e^{\frac{2V_{tc}T}{D}-\alpha T}-1)}{2V_{tc}-D\alpha}}{4V_{tc}^2\alpha+2DV_{tc}\alpha^2}.\sigma_{a2}^2$$

$$Q_{mh_2}(2,2)=\frac{\frac{1-e^{-2\alpha T}}{2\alpha}+\frac{D(\beta^2-1)}{4V_{tc}}-\frac{2D(e^{\frac{2V_{tc}T}{D}-\alpha T}-1)}{2V_{tc}-D\alpha}}{D^2\alpha^2+4DV_{tc}\alpha+4V_{tc}^2}.\sigma_{a2}^2$$

$$Q_{mh_2}(2,3)=Q_{mh_2}(3,2)=\left(\frac{e^{-2\alpha T}-1}{2(D\alpha^2+2V_{tc}\alpha)}+\frac{D(\beta e^{-\alpha T}-1)}{4V_{tc}^2-D^2\alpha^2}\right)\sigma_{a_2}^2$$

$$Q_{mh_2}(3,3)=\frac{1-e^{-2\alpha T}}{2\alpha}\sigma_{a_2}^2$$

- Filter 3 is synthesized based on the CA model. This model considers the target normal acceleration is almost constant (also known as Jerk acceleration model is approximately equal to 0)[3], [4], [8]. This model characterizes a high degree of maneuverability, when the target is to maneuver continuously at nearly constant acceleration.

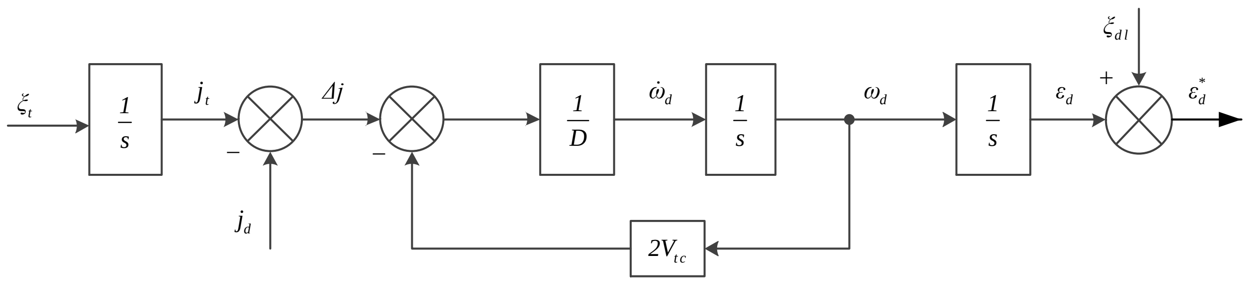

Fig3. CA model for synthesis of Kalman filter 3

Then, the model's equation of state takes the form:

$$\dot{\varepsilon}_d=\omega_d \tag{10}$$

$$\dot{\omega}_d=\frac{2V_{tc}}{D}\omega_d+\frac{1}{D}j_t-\frac{1}{D}j_d \tag{11}$$

$$\dot{j}_t=\xi_{j_t} \tag{12}$$

In which, the input integral stages is the shaping filter. Similarly, to create the target maneuvering style with constant intensity and the moment of maneuverability evenly distributed during flight time, the spectral density function of process noise ξ_{j_t} has the form:

$$\sigma_{a_3}^2=\frac{j_{max3}^2}{T_f}$$

Where: j_{max3} - Maximized target normal acceleration, maneuverable.

T_f - Flight time.

Note, when designing each filter, the spectral density of the process noise in the Singer and CA models is different, due to the different maneuvering intensity.

Equation of state in vector form:

$$\dot{\boldsymbol{x}}_3 = \boldsymbol{F}_{mh3}\boldsymbol{x}_3 + \boldsymbol{G}_{mh3}\boldsymbol{u}_3 + \boldsymbol{w}_3 \tag{13}$$

Inside: $\boldsymbol{x}_3 = \begin{bmatrix} \varepsilon_d \\ \omega_d \\ j_{td} \end{bmatrix}$ - Target phase coordinate state vector.

$\boldsymbol{F}_{mh_3} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & \frac{2V_{tc}}{D} & \frac{1}{D} \\ 0 & 0 & 0 \end{bmatrix}$ - State transition matrix of filters 3.

$\boldsymbol{G}_{mh3} = \begin{bmatrix} 0 \\ -\frac{1}{D} \\ 0 \end{bmatrix}$ - Control matrix.

$\boldsymbol{Q}_{mh3} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}\sigma^2_{a_3}$ - Covariance matrix of process noise.

Switch to the discrete model, we have:

$\boldsymbol{\Phi}_{mh3} = \begin{bmatrix} 1 & \frac{D(\beta-1)}{2V_{tc}} & \frac{D(\beta-1)}{4V_{tc}^2} - \frac{T}{2V_{tc}} \\ 0 & \beta & \frac{\beta-1}{2V_{tc}} \\ 0 & 0 & 1 \end{bmatrix}$ - State transition matrix.

$\boldsymbol{G}_{mh3} = \begin{bmatrix} \frac{T}{2V_{tc}} + \frac{D}{4V_{tc}^2}(1-\beta) \\ \frac{1-\beta}{2V_{tc}} \\ 0 \end{bmatrix}$ - Control matrix.

Covariance matrix of the process noise discrete form as follows:

$$Q_{mh_3}(1,1) = \left(\frac{D^3(\beta^2-1)}{64V_{tc}^5} + \frac{D^2T}{16V_{tc}^4} - \frac{D^2T\beta}{8V_{tc}^4} + \frac{DT^2}{8V_{tc}^3} + \frac{T^3}{12V_{tc}^2} \right)\sigma^2_{a_3}$$

$$Q_{mh_3}(1,2) = Q_{mh_3}(2,1) = \left(\frac{D^2(\beta^2-1)}{32V_{tc}^4} + \frac{DT}{8V_{tc}^3} - \frac{DT\beta}{8V_{tc}^3} - \frac{D^2(\beta-1)}{16V_{tc}^4} + \frac{T^2}{8V_{tc}^2} \right)\sigma^2_{a_3}$$

$$Q_{mh_3}(1,3) = Q_{mh_3}(3,1) = \left(\frac{D^2(\beta-1)}{8V_{tc}^3} - \frac{DT}{4V_{tc}^2} - \frac{T^2}{4V_{tc}} \right)\sigma^2_{a_3}$$

$$Q_{mh_3}(2,2) = \left(\frac{D(\beta^2-1)}{16V_{tc}^3} - \frac{D(\beta-1)}{4V_{tc}^3} + \frac{T}{4V_{tc}^2} \right)\sigma^2_{a_3}$$

$$Q_{mh_3}(2,3) = Q_{mh_3}(3,2) = \left(\frac{D(\beta-1)}{4V_{tc}^2} - \frac{T}{2V_{tc}} \right)\sigma^2_{a_3}$$

$$Q_{mh_3}(3,3) = T\sigma^2_{a_3}$$

Where; $\beta = e^{\frac{2V_{tc}T}{D}}$, T - Discrete cycle.

III. SIMULATION RESULTS AND ANALYSIS

To survey the quality of the tracking multi-loop target angle coordinate system using the interactive multi-model filtering algorithm, we will simulate the angular coordinate system with different maneuvering style of the target in the horizontal plane. Then, compare with the quality of the optimal angular coordinate system (with fixed parameters based on Singer model) according to the criteria of mean square error (MSE).

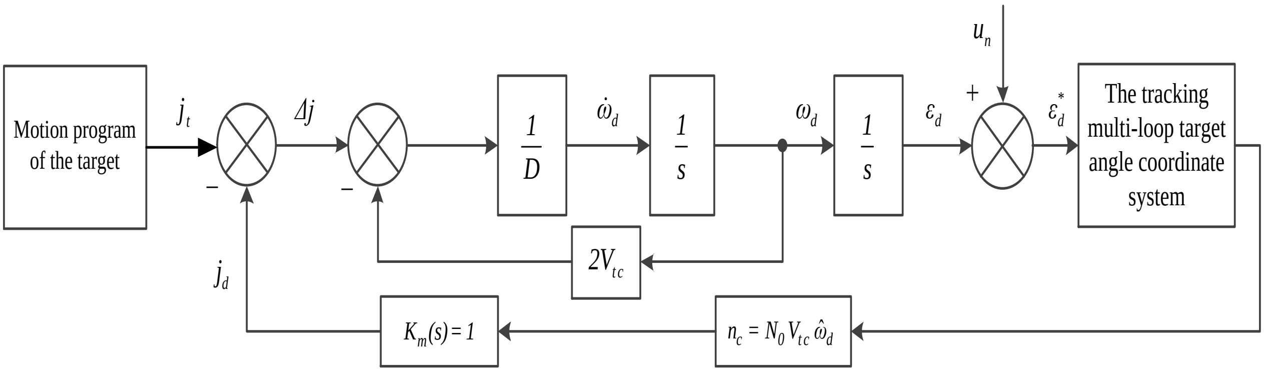

Fig 4. Diagrams simulation of the target angle coordinates system in the ideal missile control loop

- The target's initial position: $x_t(0) = 40\ (km)$; $y_t(0) = 0(km)$.
- The missile initial position: $x(0) = 0(km), y(0) = 0(km)$.
- The target flies in at velocity: $350\ (m/s)$.
- Missile velocity: $1000(m/s)$.
- The target's initial trajectory tilt angle: $\theta_t = 0^o$.
- Normal acceleration of the target:

$$j_t = \begin{cases} 0 & when \quad t < 20\,s \\ 30\ (m/s^2) & when \quad t \geq 20\,s \end{cases} \qquad (14)$$

With this model, initially, the target evenly straight movement. After 20 seconds, the target suddenly maneuvers continuously with constant normal acceleration $30(m/s^2)$. Thus, the target has a change from non-maneuverable model to maneuverability with constant normal acceleration. This motion model has uncertainty in maneuvering moment and maneuvering intensity.

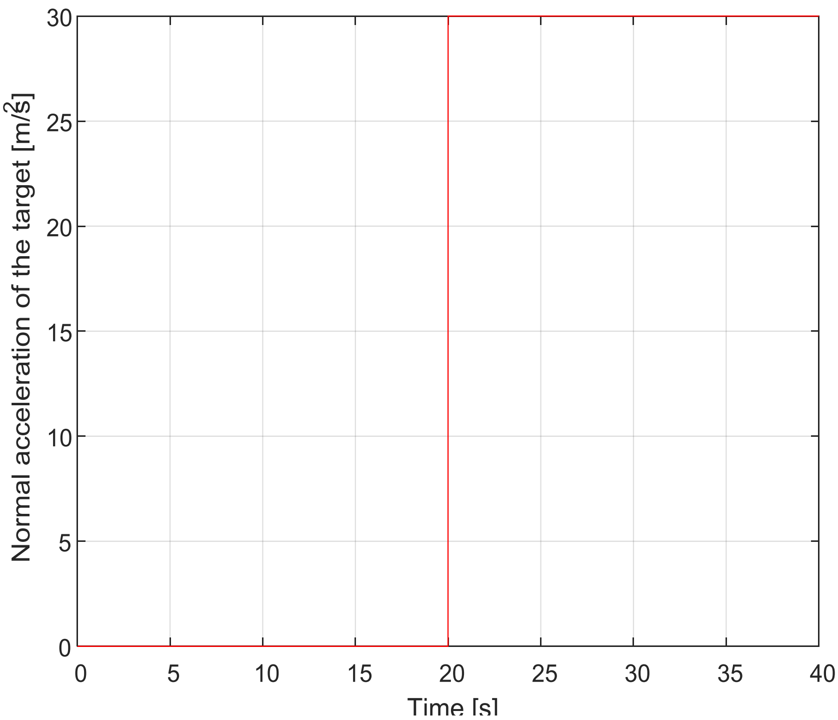

Fig 5. Normal acceleration of the target

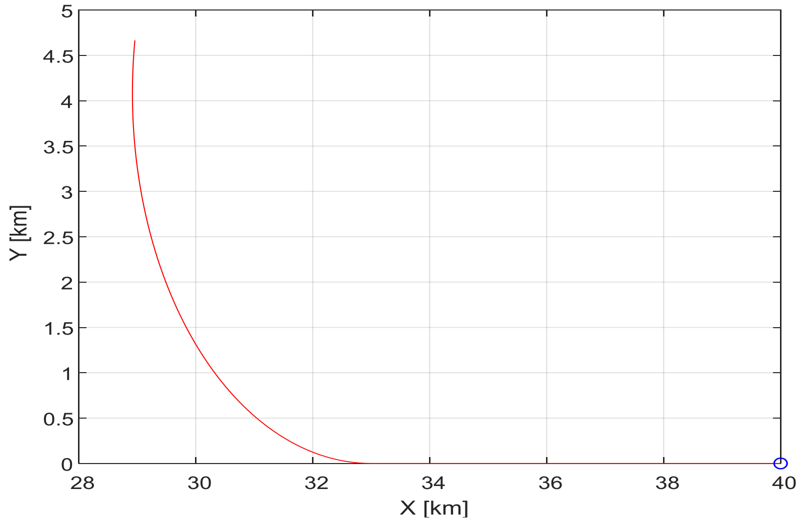

Fig 6. Ladder type maneuvering target trajectory

The simulation results of the target angle coordinate system for the case of ladder type maneuvering targets are as follows:

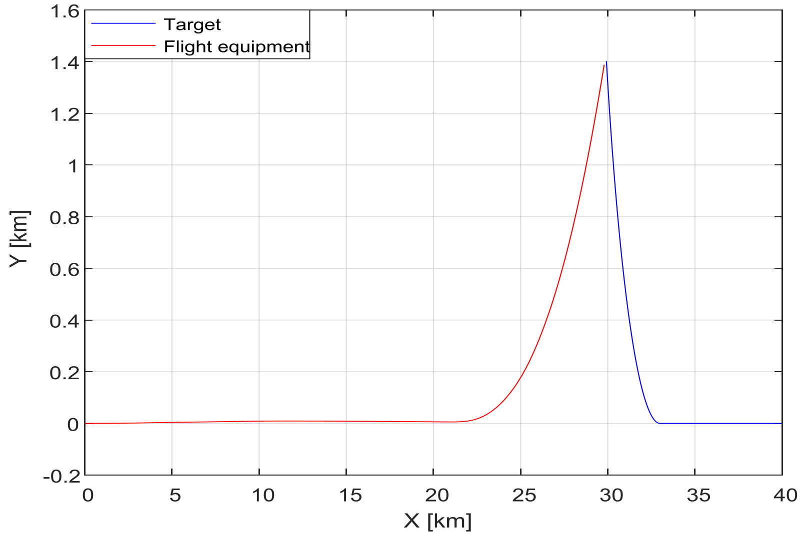

Fig 7. Missile - target trajectory

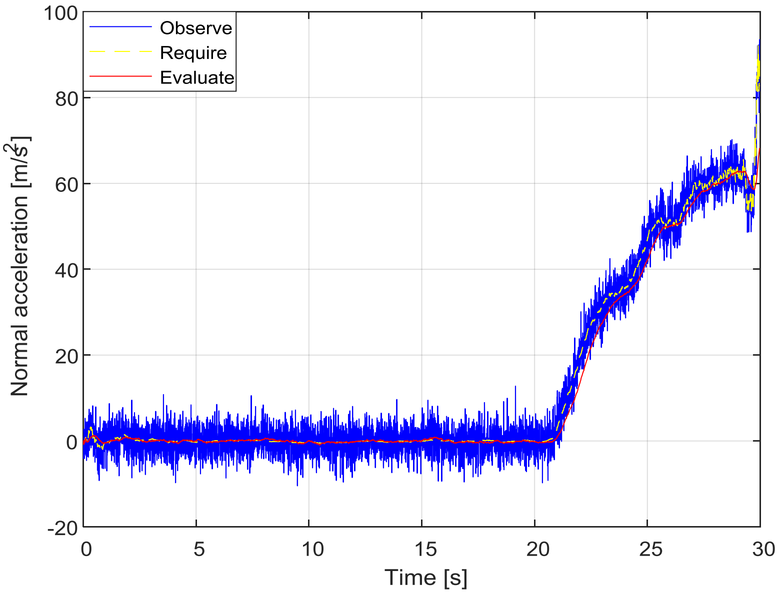

Fig 8. Normal acceleration of the missile

After 20 seconds of steady straight movement, the maneuvering target with constant normal acceleration. This causes the required normal acceleration of the small missile at an early stage (before 20 seconds), then increases continuously until the meeting point. However, the missile normal acceleration filter still gives a good evaluation.

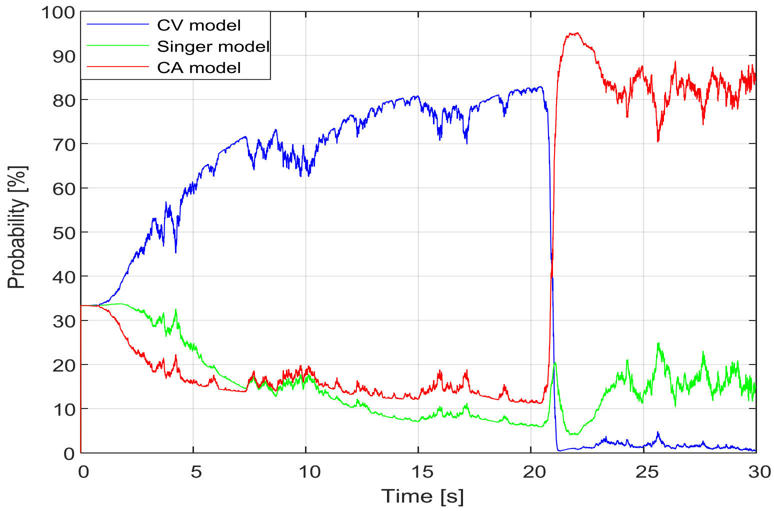

Fig 9. The graph shows the correct probabilities of the model

Figure 9 shows that from 0 to 20 seconds, the CV model dominates, but after about 22 seconds (the transition time of the IMM algorithm is about 2 seconds), the probability of the CA model is clearly dominant compared to the other 2 models. This trend continue to maintain in the remaining maneuverable time of the target. This evaluation result of the algorithm reflects quite correctly with the actual maneuvering of the target.

The results of evaluating the target phase coordinate for the case of ladder type maneuvering target are as follows:

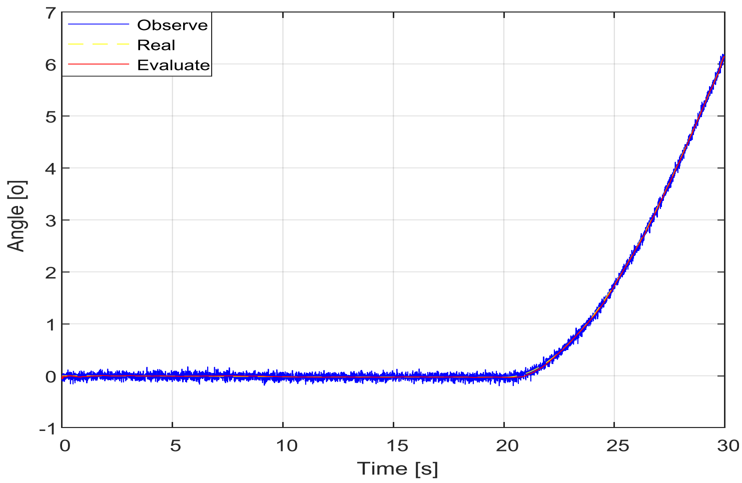

Fig 10. Evaluate the angle of the line of sight

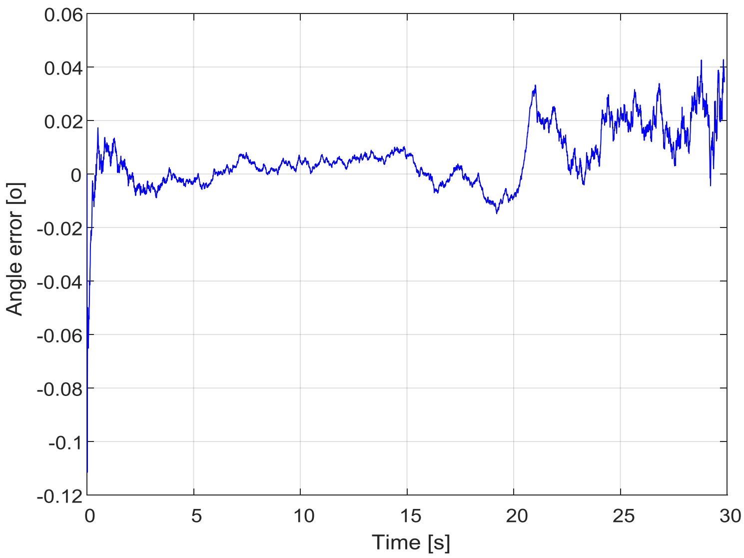

Fig 11. Evaluation error of the line of sight angle

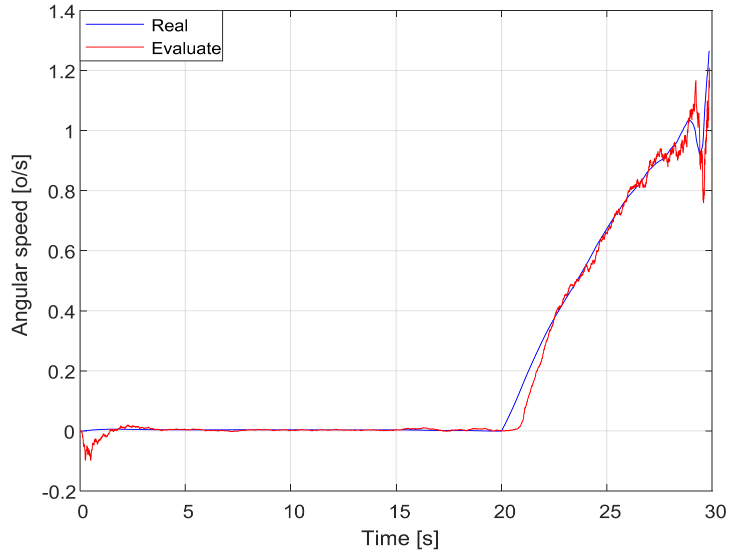

Fig 12. Speed evaluation the angle of the line of sight

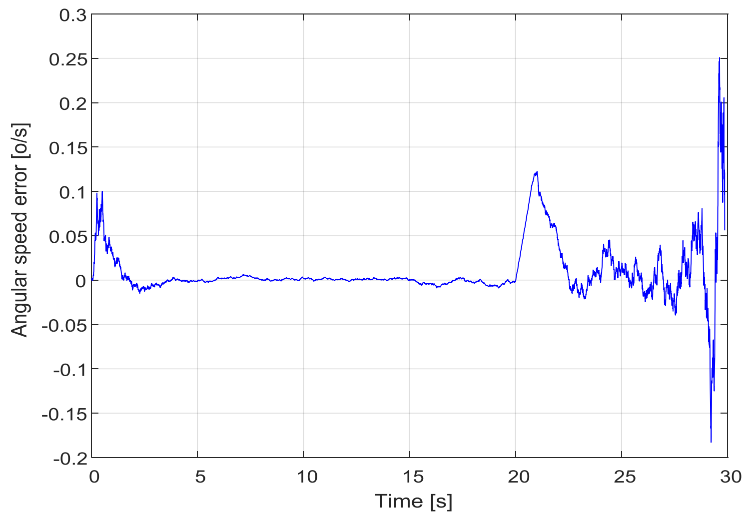

Fig 13. Evaluation error of the line of sight angle speed

The simulation results show that, in all 3 states: The line of sight angle, the line of sight angle speed and the normal acceleration of the target, the IMM evaluation algorithm gives a greater error at the time the target starts to maneuver (model change time). But right after that, the clinging error is smaller. Compare the quality of the IMM filter algorithm with the optimal filter algorithm after 100 Monte-Carlo runs:

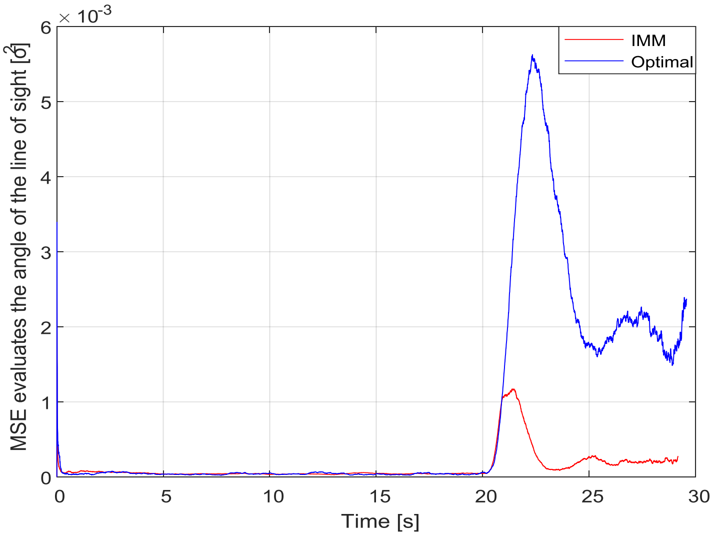

Fig 14. Compare the MSE to evaluate the angle of the line of sight

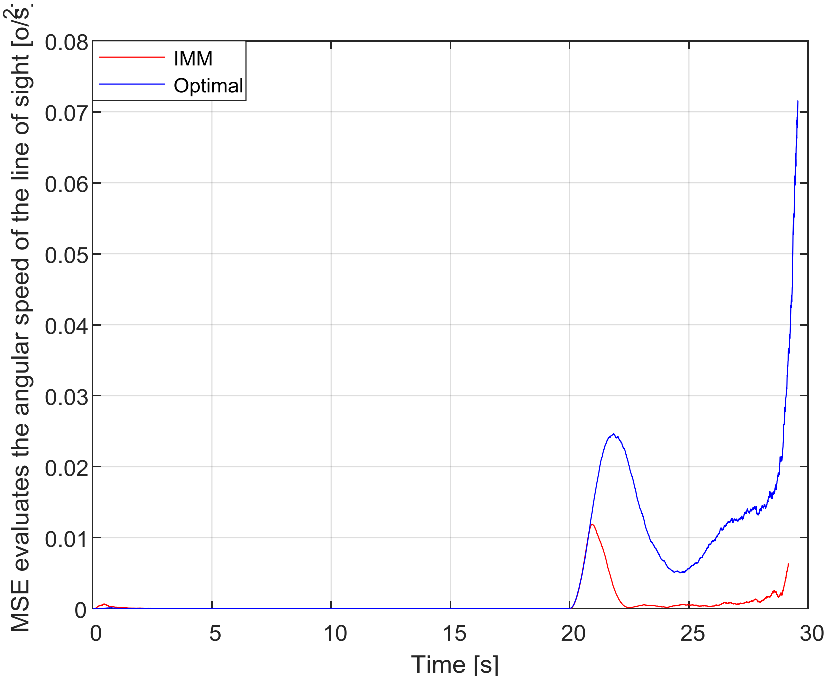

Fig 15. Compare the MSE to evaluate the angular speed of the line of sight

Before the maneuvering target time (20s), the evaluation quality of the two algorithms was equivalent (the evaluation error of the optimal filtering algorithm was trivial smaller). But after 20 seconds, there is a difference in evaluation quality. Detail:

- With line of sight angle, the evaluation error of the IMM algorithm at the time of maneuvering model transfer (change) is $MSE(\varepsilon_d) \approx 1{,}2.10^{-3}\,[(o)^2]$, also the optimal filtering is $MSE(\varepsilon_d) \approx 2{,}5.10^{-3}\,[(o)^2]$. Then, at the stable tracking stage, the optimal filter algorithm for error is $MSE(\varepsilon_d) \approx 0{,}85.10^{-3}\,[(o)^2]$, the IMM algorithm is $MSE(\varepsilon_d) \approx 0{,}25.10^{-3}\,[(o)^2]$.

- With the angular speed of the line of sight, the evaluation error of the IMM algorithm at the time of maneuvering model transfer is $MSE(\omega_d) \approx 0{,}012\ [(o/s)^2]$, also the optimal filtering is $MSE(\omega_d) \approx 0{,}015\ [(o/s)^2]$. At the stable tracking stage, the optimal filter algorithm for error is $MSE(\omega_d) \approx 0{,}004\ [(o/s)^2]$, the IMM algorithm is $MSE(\omega_d) \approx 0{,}001\ [(o/s)^2]$.

- With the target normal acceleration, at the time of maneuvering model transfer, both algorithms give large evaluation errors $MSE(j_t) \approx 900\ [(m/s^2)^2]$. At the stable tracking stage, the optimal filter algorithm for error is $MSE(j_t) \approx 220\ [(m/s^2)^2]$, while the IMM filter gives a significantly smaller error with $MSE(j_t) \approx 10\ [(m/s^2)^2]$.

Obviously, when the maneuvering target with constant acceleration, the evaluation quality of the target angular coordinate system using IMM filter algorithm improved when compared to the optimal filter algorithm.

IV. CONCLUSION

The maneuver of the target directly affect to the line of sight angle coordinate evaluation filter. So, to synthesize the target angle coordinate determination system with high accuracy in the maneuver and super maneuverable target conditions, just improve and advance the line of sight angle coordinates evaluation filter, the other filters are kept intact.

The simulation results of the tracking multi-loop target angle coordinate system show that, when comparing the quality of the line of sight angle coordinate filter using the IMM filter algorithm based on the MSE criteria, the evaluation error is smaller than the optimal filtering algorithm under different maneuvering target conditions. Here, the change of the target maneuvering styles while in the process of the missile approaches the target, highlighting the advantages and reliability of the interactive multi-model evaluation algorithm.

REFERENCES

[1] Xiu L. H., Jing S. Y, Curve Model of Adaptive Interaction Model Algorithm Tracking Method,*Applied Mechanics and Materials*, Vol 738, March 2018, pp. 344-349.

[2] Sambasiva R., Raj K, Implementation of Adaptive Filter Algorithm for Underwater Acoustic System,*International Journal of Recent Trends in Engineering*, Vol 2, No.2, 2019, pp. 13-22.

[3] Le X.R., Kilkov V.P, A survey of maneuvering target tracking: Approximation techniques for nonlinear filtering,*Proceedings of SPIE conference on signal and data processing of small targets,* 2014, pp. 537-550.

[4] Li X.R., Jilkov V.P, Survey of maneuvering target tracking-part V, *IEEE transaction on aerospace and electronic systems*, 41 (4). 2015, pp. 1255-1321.

[5] Xu B, An adaptive tracking algorithm for bearings-only maneuvering target,*International journal of computer science and network security*,Vol7(1). 2017, pp.34-36

[6] Kim H. S., Chun Seung Yong, Design of fuzzy IMM algorithm based on Basic Sub-models and Time-varying mode transition probabilities,*International journal of control automation and systems*, Vol4 (5).2016, pp. 559-566.

[7] Lee J. B., Joo Y. H., Park J. B, IMM method using intelligent input estimation for maneuvering target tracking, *ICCAS* 2013, pp. 1278-1282.

[8] Jiadong R., Xiaotong Z, Interactive multi-model target Maneuver tracking method based on the adaptive probability correction, *International Conference on Swarm Intelligence*, *ICSI* 2018, pp. 235-245.

[9] Nguyen Van Bang, Synthesis of evaluation filter of line of sight angle coordinates with maneuvering detection on the basis of correction of amplification factor according to the tracking error signal, *International Journal of Software & Hardware Research in Engineering*, Volume 9, Issue 8, August 2021, pp.69-77.

[10] Nguyen Van Bang, Algorithm to determine target angle coordinates with maneuvering detection of self-guided head on the basis of state model parameter recognition, *International Journal of Scientific Engineering and Science*, Volume 5, Issue 8, August 2021, pp. 65-71.

[11] Nguyen Van Bang, Synthesis of target angle tracking system combining kalman filter algorithm with fuzzy logic controller, *International Research Journal of Advanced Engineering and Science*, Volume 6, Issue 3, September 2021, pp. 302-310.