Advances in Computer, Signals and Systems (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/acss.2022.060602
ISSN 2371-8838 Vol. 6 Num. 6

Research on three-dimensional composite guidance law of switching between extended proportional guidance and conventional proportional guidance

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Keywords: Proportional guidance, Extended proportional guidance, Switching guidance, Composite Guidance, Miss distance

Abstract: According to the two-dimensional spatial relationship model of the relative motion between the missile and the target, on the basis of conventional proportional guidance and extended proportional guidance, a composite guidance method using conventional proportional guidance and extended proportional guidance to switch each other for three-dimensional guidance is proposed. The switching basis is based on the angle between the missile speed direction and the azimuth angle. When the included angle is large, the extended proportional guidance is used, and when the included angle is small, the conventional proportional guidance is used. Thus, the problem of rapid increase of miss distance at the end of conventional proportional navigation can be avoided. The simulation analysis also shows that this method is very effective.

1. Introduction

Conventional proportional navigation has been widely used in large mobile aircraft such as air-to-air missiles, but its disadvantage is that the overload at the end is often large, and the miss distance at the end will be extremely unstable[1-3]. Therefore, the extended proportional navigation method is proposed, and this problem has been greatly improved.

Manchester I.R. and Savkin A.V. designed a cyclic iterative proportional navigation [20], whose idea is to transform the nonlinear constraint problem in finite time into an equivalent linear programming problem in infinite time. Considering the limitation of the special angle when the missile meets the target, the relative movement of the missile and the target is described as a form of state equation including missile position, missile velocity and target velocity, and the guidance law is derived through theoretical analysis, Ensure the terminal miss distance. Due to the introduction of additional offset parameters, the guidance performance of offset proportional guidance is better than that of proportional guidance, and the stability is better. Byung soo Kim, Jango Gyu Lee and hyung Seok Han study the expansion of T-offset proportional guidance under angle constraints. Their method is to establish the linear equation of pursuit mode by using the two-dimensional relative motion relationship between the missile and the target. According to the basic assumptions of proportional guidance, the desired intersection angle is achieved through offset term compensation. The advantage of this method is that it does not need to estimate the remaining time[4-8].

However, when the missile velocity direction is consistent with the azimuth angle, the extended proportional navigation method is prone to divergence problems[9-12]. Based on the above reasons, this paper proposes a three-dimensional guidance method, which uniformly adopts extended proportional guidance in the initial stage and conventional proportional guidance in the final stage. Simulation experiments show that this method is very effective.

2. Two dimensional proportional navigation model

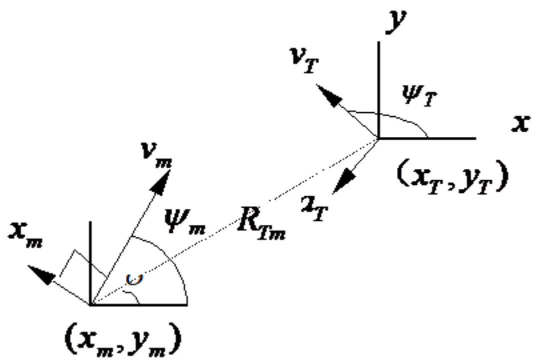

Figure 1: The location relationship between target and missile

According to reference [2], the model of conventional proportional guidance law can be built as follows. The motion of target and missile can be shown as figure 1. (x_m , y_m)are the location of missile and(x_T , y_T)are the location of target.(ψ_m , v_m)are the azimuth and speed of missile and (ψ_T , v_T)are the azimuth and speed of target.(a_m , a_T)are the acceleration of missile and target, and σ is the sight angle. And the model can be written as:

$$\ddot{x}_m = -a_m \sin\psi_m , \dot{x}_m(t_0) = v_{mx0} , x_m(t_0) = x_{m0} \tag{1}$$

$$\ddot{y}_m = a_m \cos\psi_m , \dot{y}_m(t_0) = v_{my0} , y_m(t_0) = y_{m0} \tag{2}$$

$$\ddot{x}_T = -a_T \sin\psi_T , \dot{x}_T(t_0) = v_{Tx0} , x_T(t_0) = x_{T0} \tag{3}$$

$$\ddot{y}_T = a_T \cos\psi_T , \dot{y}_T(t_0) = v_{Ty0} , y_T(t_0) = y_{T0} \tag{4}$$

$$\psi_m = \arctan(\dot{y}_m / \dot{x}_m), \psi_T = \arctan(\dot{y}_T / \dot{x}_T) \tag{5}$$

$$\Delta y = y_T - y_m , \Delta x = x_T - x_m , \sigma = \arctan(\Delta y / \Delta x) \tag{6}$$

According to the proportional law, it has

$$\dot{\psi}_m = k\dot{\sigma} \tag{7}$$

We assume that the velocity of the missile is approximately constant during its movement, and the control force is perpendicular to the velocity, so only the direction of the missile velocity is changed. Then there are:

$$a'_m = v_m \dot{\psi}_m ,\ v_m = \sqrt{{v_{mx0}}^2 + {v_{my0}}^2} \tag{8}$$

$$T\dot{a}'_m + a'_m = a_m \tag{9}$$

The above is a complete proportional navigation motion relationship model, where T represents the time constant of the control loop.

3. Design of extended proportional navigation law in three-dimensional space

According to the model of proportional navigation in the previous section, we extend it to three-dimensional space, where dtx_x、dty_x、dtz_x are the distance between missile and target on x、y、z axis direction. Then the azimuth of zox plane and yox plane can be solved as

$$\begin{aligned} q &= \arctan\left(dtz_x / dtx_x\right) \\ w &= \arctan\left(dty_x / dtx_x\right) \end{aligned} \tag{10}$$

And the initial value of q_0 and w_0 are set as 0, then its derivative can be solved as

$$\begin{aligned} dq &= \left(q - q_0\right)/dt \\ dw &= \left(w - w_0\right)/dt \end{aligned} \tag{11}$$

And the speed angle of missile of track angle and flight path angle θ_1 and θ_2 are used to solved error angle between speed angle and azimuth angle as

$$\begin{aligned} e_{\theta_1} &= q - \theta_1 \\ e_{\theta_2} &= w - \theta_2 \end{aligned} \tag{12}$$

If $\left|e_{\theta_1}\right| > 1rad$, we set

$$dd_1 = \frac{1}{\left(\sin e_{\theta_1}\right)^2} \tag{13}$$

and if $\left|e_{\theta_2}\right| < 1rad$ then set

$$dd_2 = 1 \tag{14}$$

Here, the extended proportional guidance coefficient is set as 2. According to the extended proportional guidance formula, the acceleration of the missile in the horizontal and vertical directions can be obtained:

$$\begin{aligned} a_1 &= 2 \cdot dq \cdot v_m \cdot dd_1 \\ a_2 &= 2 \cdot dw \cdot v_m \cdot dd_2 \end{aligned} \tag{15}$$

4. Simulation Example

We set the initial location of missile as (xm, ym, zm)=(0, 1000, 0), and set the initial coordinate of target as (xt, yt, zt)=(5000, 25, 30 0).Set the maximum value of missile movement time to tf=50.

In addition to the introduction of extended proportional navigation, the overload constraint is still 100. Therefore, only the simulation program of extended proportional navigation is given here:

```
q=atan(dtzx/dtxx);
dq=(q-q0)/dt;
q0=q;
w=atan(dtyx/dtxx);
dw=(w-w0)/dt;
w0=w;
vm=(vxm^2+vym^2+vzm^2)^0.5;
sita2=atan(vym/vxm);
sita1=atan(vzm/vxm);
esita1=q-sita1;esita2=w-sita2;
dd1=1;dd2=1;
if abs(esita1)>1/57.3 & endkz==0
dd1=1/(sin(esita1))^2;
endkz=1;
end
if abs(esita2)>1/57.3 & endkz==0
dd2=1/(sin(esita2))^2;
endkz=1;
end
ag=2*dq*vm*dd1;
ag2=2*dw*vm*dd2;
```

Figures 2 to 9 below show the three-dimensional motion curve of the missile and the target, the lateral motion curve of the missile and the target, and the vertical motion curve of the missile and the target respectively; Monocular range change curve, lateral velocity angle change curve of missile and target, vertical velocity angle change curve of missile and target, lateral acceleration change curve of missile and target, vertical acceleration change curve of missile and target.

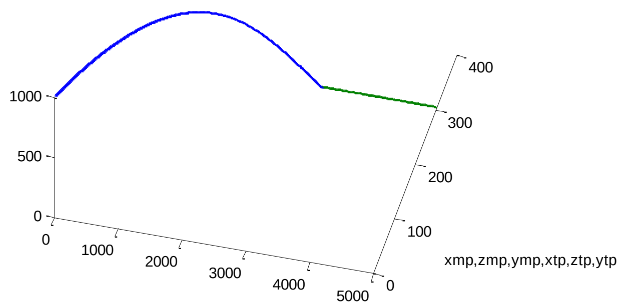

Figure 2: Three dimensional image of missile and target trajectory

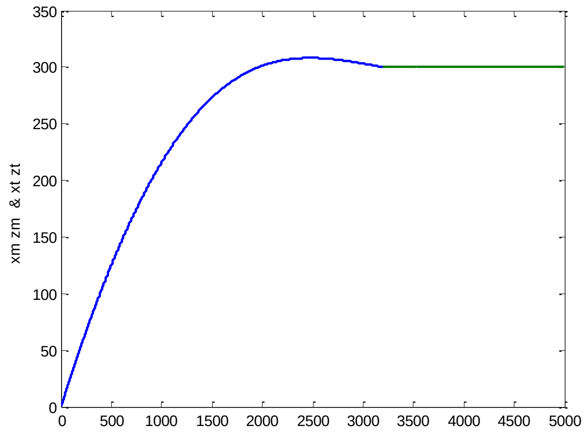

Figure 3: Lateral motion diagram of missile target

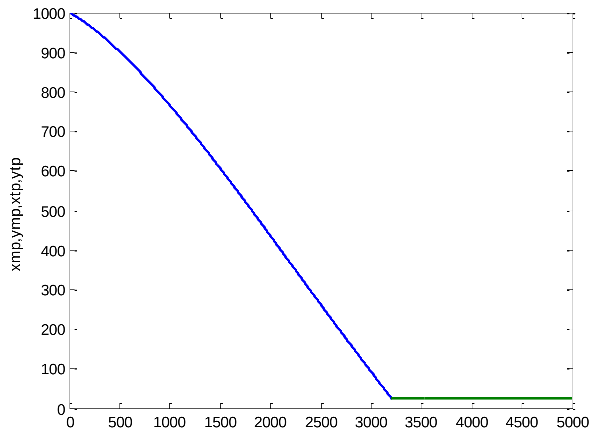

Figure 4: Vertical motion diagram of missile target

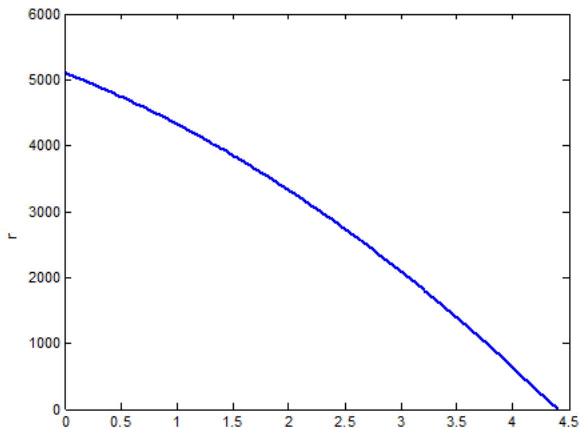

Figure 5: Missile target distance map and miss distance

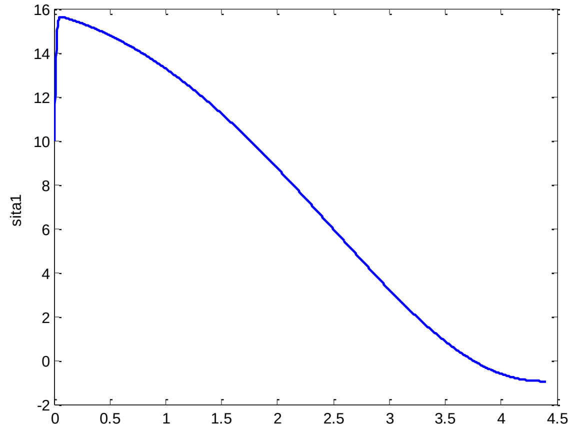

Figure 6: Lateral speed angle

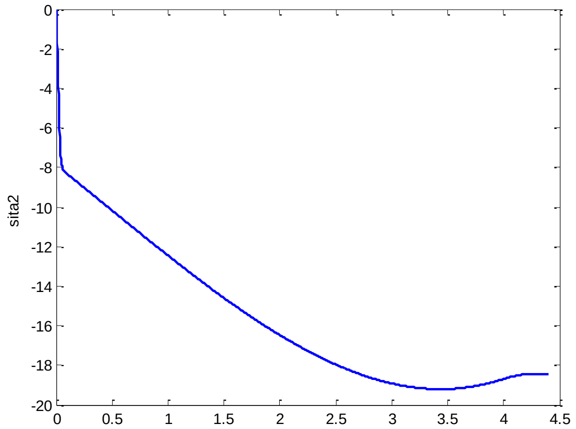

Figure 7: Vertical speed angle

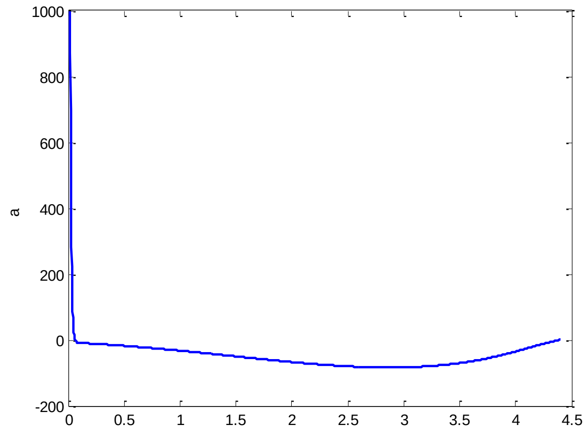

Figure 8: Lateral acceleration

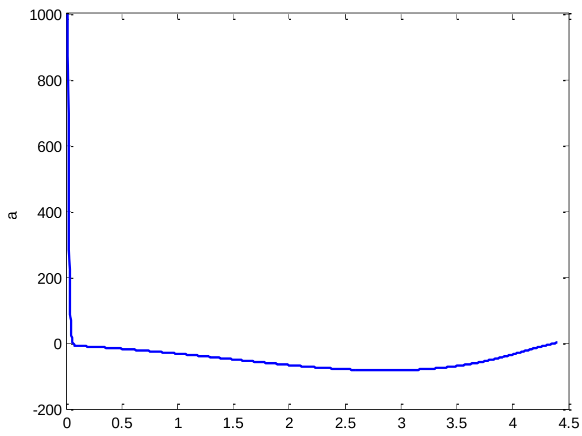

Figure 9: Vertical acceleration

It can be seen from the simulation curve that the final miss distance between the missile and the target according to the guidance law is less than 0.5m. It shows that the guidance law is correct and effective. At the same time, it can be seen that the acceleration curve changes smoothly and the angle curve has no sudden change, which shows that the guidance law is very easy to be adopted by engineering applications and has high engineering practical value.

5. Conclusions

In this paper, firstly, according to the proportional guidance model of two-dimensional plane, it is extended to three-dimensional space, and the extended proportional guidance model is established. At the same time, the overload limit in the two planes is considered, and a termination standard is introduced. When the deviation between the velocity direction and the azimuth direction of the missile is large, the extended proportional guidance is adopted, otherwise the conventional proportional guidance is adopted, thus forming a guidance method based on the mutual switching between the extended proportional guidance and the conventional proportional guidance, The final simulation results show that the proposed switching guidance method has a good guidance effect.

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