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PULSE TYPE SPACE INTERCEPT CONTROL PATTERN STUDIES

by

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ABSTRACT This article goes through linearization treatment, under certain conditions, of spacial intercept kinematics models and puts forward a kind of pulse type terminal control pattern. It not only satisfies target miss quantity indices but also makes maximum savings of track control engine fuel. Moreover, it is easy to realize as engineering. Simulation results clearly show that the performance of the control patterns in question are good.

KEY TERMS 1. Control Pattern 2. Space Intercept

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1 INTRODUCTION

At the present time, with regard to terminal control patterns supported by continuous thrust motors, people are already certainly not unfamiliar. However, with respect to track control motors, it is only possible to offer intercept devices associated with switch type thrust. With regard to its terminal control patterns, people have studied them but very little. Because of this, there is a need to design a kind of pulse type space intercept terminal control pattern supported by switch type thrust motors.

The foundation for designing pulse type control patterns is not only to make target miss quantities satisfy indices but also to make maximum fuel savings in track control motors. This is a control optimization problem. However, what is regrettable is that, no matter which type of typical control optimization theory is put to use, they all have no way to directly solve this problem. The reason is that, first of all, interception kinematics systems are a nonlinear system. Second, presuppositions associated with this problem are not only that controls are limited but also that required energy is minimal. As a result, this is a generalized optimized control problem with engineering significance.

In order to resolve this problem, it is possible to adopt the measures below. First, artificially take the whole terminal guidance process and divide it into two parts. As far as the first part is concerned, it opts for the use of maximum normal value thrust control. The model corresponding to it is nothing else than original nonlinear kinematics systems. With respect to the last part, option is made for the use of pulse type thrust control. The corresponding model is linearized forms associated with original nonlinear models. Second, during the process of pulse type thrust control associated with the last part, the width of each thrust pulse opts for the use of the smallest width which motors are capable of supplying. Third, during processes in the last part, make changes in line of sight angular velocities be limited to the interior of an envelope zone designated before the fact. The value of this envelope line at the instant when interception devices enter into blind zones is jointly determined by blind zone ranges as well as target miss quantity indices. In this way, it is then possible to make maximally large the intervals between each thrust pulse, that is, energies minimal. At the same time, target miss quantities are also made to satisfy requirements.

2 MATHEMATICAL MODELS AND THEIR LINEARIZATION TREATMENT

Taking longitudinal plane forms as an example, relative motion equation [1] is given for interception devices and targets.

$$\begin{cases} \dot{x}_1 = x_2 & \text{(2-1.a)} \\ \dot{x}_2 = x_1 x_3^2 & \text{(2-1.b)} \\ \dot{x}_3 = -\dfrac{2x_2x_3}{x_1} - \dfrac{u}{x_1} & \text{(2-1.c)} \end{cases}$$

In the equations, x1 stands for relative distances associated with interception devices and targets. x2 stands for relative velocities. x3 stands for longitudinal plane line of sight angular velocities. u stands for interception device maneuver acceleration perpendicular to longitudinal planes. Assuming that the initial instant of terminal guidance is to, the instant of entry into blind areas (that is, interception device control stop) is t_f .

During the process of space intercept terminal guidance, initial values of line of sight angular velocities are on the order of magnitude of 10-4 rad/sec. In the first phase of terminal guidance, due to opting for the use of maximum normal value thrust control, it causes, in this phase, angular velocity x3 to show a tendency toward monotonic (unreadable) changes (This article ignores lagging effects associated with motor thrust). Right up until after x3 values exceed zero, the first x3 sampling instant is the end. Only at this stage is completion declared./2 The instant in question is recorded as t1 . One then has

$$x_3(t_0)x_3(t_1) < 0 \qquad \text{(2-2.a)}$$

$$x_3(t_0)\dot{x}_3(t) < 0, t \in [t_0, t_1] \qquad \text{(2-2.b)}$$

When terminal guidance processes enter into a final stage, that is, t ∈ [t1,tf], if establishment of the form below is guaranteed,

$$|x_3(t)| \leqslant D, t \in [t_1, t_f] \qquad \text{(2-3)}$$

then, mathematical models can be linearized from (2-1) to be

$$\dot{x}_3 = a(t)x_3 + b(t)u, t \in [t_1, t_f] \qquad \text{(2-4)}$$

In this,

Moreover, in form (2-3), positive numbers D are determined before the fact in accordance with these types of principles. When x3, $t \in$ [t1,tf] satisfies form (2-3), it is possible to believe that $\dot{x}_3 \approx 0$. Moreover, it is possible to guarantee that line of sight angle q is bounded within a certain fixed range, that is, $|q| \leq Q$. Besides that, relative velocities x2 , in $t \in$ [t1,tf], are basically constants. Of course, in [to,t1], changes are also not large, that is, x2(t)=x2(t1)=const, $t \in$ [t1,tf].

3. EFFECTS OF LINERIZED MODELS ON SQUARE WAVE PULSES

Assuming that accelerations produced by maximum thrusts associated with interception device track control motors are um, minimum pulse width is Δ. When square waves such as those shown in Fig.1 act on system (2-4), its dynamic response can be described as follows:

(I) When $t1 \leq t \leq t'$

x3(t)=Φ(t,t1)x3(t1)

(II) When $t' \leq t \leq ti+1$

$$x_3(t)=\Phi(t,t')x_3(t') + \frac{u_m \operatorname{sgn} x_3(t_1)}{2x_2(t_1)}[\Phi(t,t')-1]$$

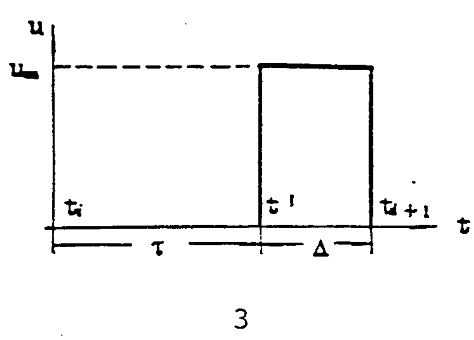
In this, the state transfer function is

$$\Phi(t,\tau)=\left[\frac{x_1(t_1)+x_2(t_1)(\tau-t_1)}{x_1(t_1)+x_2(t_1)(t-t_1)}\right]^2 = \frac{x_1^2(\tau)}{x_1^2(t)}$$

4 PULSE TYPE TERMINAL CONTROL PATTERN DESIGN

First of all, the envelope function for line of sight angular velocities associated with the last stage of terminal guidance, that is, when $t \in$ [t1,tf], is given

$$\bar{x}_3(t)=\bar{x}_{3m} e^{\frac{t-t_1}{t_f-t_1}\ln\frac{\bar{x}_{3f}}{\bar{x}_{3m}}}, \quad t\in[t_1,t_f] \qquad (4\text{-}1)$$



In this, $\bar{x}_{3f} > \bar{x}_{3m} > 0, \bar{x}_{3f}$ is set in accordance with the methods below. From the target miss quantity formula [2]

$$T_b = \frac{x_1^2(t_f)\,|x_3(t_f)|}{\sqrt{x_2^2(t_1) + x_1^2(t_f)x_3^2(t_f)}} \qquad (4\text{-}2)$$

It is possible to obtain:

$$|x_3(t_f)| = \frac{|x_2(t_1)| \cdot T_b}{|x_1(t_f)| \cdot \sqrt{x_1^2(t_f) - T_b^2}}$$

We adopt x3f to be

$$\bar{x}_{3f} = \min\left\{\frac{|x_2(t_1)| \cdot T_b}{B_i\sqrt{B_i^2 - T_b^2}}, D\right\} \qquad (4\text{-}3)$$

In this, Bi = |x1 (tf)| is the control head blind area range. Tb is the target miss quantity index. $\bar{x}_{3m}$ can be set at will. On the basis of the dynamic response associated with linear system (2-4) on square wave pulses, it is not difficult to deduce the conclusions:

$$\frac{d|x_3(t)|}{dt} > 0, t \in [t_i, t'] \qquad (4\text{-}4.a)$$

$$\frac{d|x_3(t)|}{dt} < 0, t \in [t', t_{i+1}] \qquad (4\text{-}4.b)$$

In view of the above, it is possible to design out the entire terminal guidance process, that is, pulse type control patterns associated with t ∈ [to,tf], as follows:

I. (Prior Stage)

$$u(t) = u_m \operatorname{sgn} x_3(t_0) \qquad (4\text{-}5)$$

As far as this stage is concerned, beginning from the instant to, it continues right on until the sampling instant t1 associated with the first line of sight angular velocity appearing with u(t)x3(t) < 0 and stops.

/3

II. (Final Stage)

This stage can be taken as being a "cyclical" pulse sequence. Within any arbitrary cycle [ti,ti+1] (i=1,2 ...),

$$u(t)=\begin{cases}0\\ u_m \operatorname{sgn} x_3(t)\end{cases} \tag{4-6}$$

When $|x_3(t)|<\bar{x}_3(t)$, time period Δ continues following close after.

5 NUMERICAL VALUE SIMULATIONS

Postulating x1(to)=150km, x2(to)=-7.5km/sec, x3(to)=5x10-4 rad/sec, and, in conjunction with that, assuming that to=0, blind area range is Bi=300m, and target miss quantities are required to be smaller than 0.5m, that is, Tb=0.5m, line of sight angular velocity is limited to being D=5x10-4 rad/sec. Engine minimum pulse width Δ = 20msec. Acceleration produced by maximum motor thrust is um = 10m/sec2. Besides this, one adopts $\bar{x}_{3m}=10^{-6}$rad/sec.

In conjunction with this, it is possible to solve for $\bar{x}_{3f}=D=5\times10^{-4}$rad/sec. We make use of these above parameters to carry out numerical value simulations.

In order to measure the effects of changes in x1, x2, and x3 on target miss quantities, introduction is made of the function

$$D_b(t)=\frac{x_1^2(t)\cdot|x_3(t)|}{\sqrt{x_2^2(t)+x_1^2(t)x_3^2(t)}} \tag{5-1}$$

The final value of the function in question is nothing else than the actual value of target miss quantities, that is,

$$D_b(t_f)=\rho_m\leqslant T_b \tag{5-2}$$

In the equation, ρ_m stands for the actual value of target miss quantities.

Fig.'s 2-5 respectively display change patterns in relative distance x1, relative velocity x2, line of sight angular velocity x3, as well as interception device maneuver acceleration u in relation to time t. Fig.6 describes time change patterns associated with the function Db(t). From simulation results, it is possible to see that maneuver accelerations--that is to say, motor switch frequencies--are very low. Switching iteration numbers are very small. Overall motor operating times are also very short--only occupying slightly more than half the whole terminal guidance time. To summarize, this manifests the advantage of maximum conservation of motor energy. Besides this, the accuracy of changes in line of sight angular velocities is limited within an envelope region. Moreover, target miss quantities satisfy index requirements--even to within only a few centimeters--realizing accurate guidance.

6 CONCLUDING REMARKS

This article designed a kind of pulse type space intercept terminal guidance pattern. Speaking in regard to interception devices which are only capable of offering switch type thrust, this type of control pattern is on kind of optimum control pattern. It makes track control motor fuel consumption minimal. At the same time, it also makes target miss quantities satisfy design requirements. Moreover, it makes numerical values associated with line of sight angles as well as line of sight angular velocities be bounded within an artificially set range. Besides this, as far as the control patterns in question are concerned, except for requiring control heads to uninterruptedly supply line of sight angular velocity information, it is only necessary to search specialized computer memory on board missiles, and, in conjunction with that, calculate a simple envelope function as well as performing a number of numerical logic operations. There are no other requirements. Therefore, the control patterns in question are easy to realize as engineering.

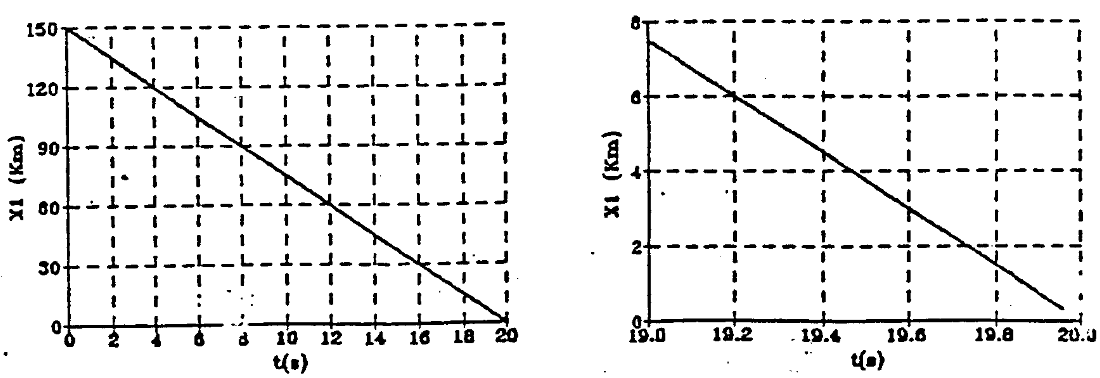


Fig.2 Relative Distance x1

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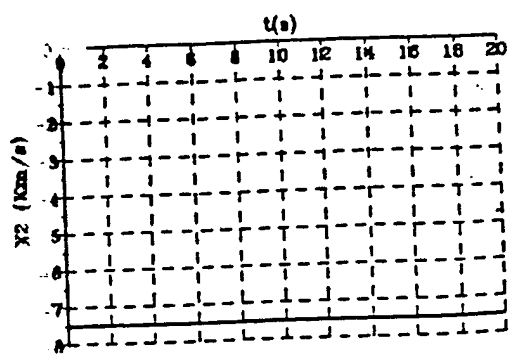

Fig.3 Relative Velocity x2

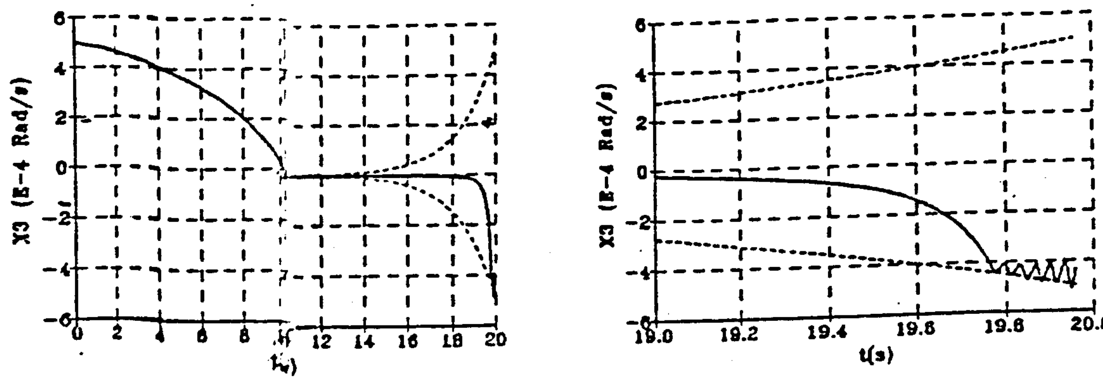

Fig.4 Line of Sight Angular Velocity x3

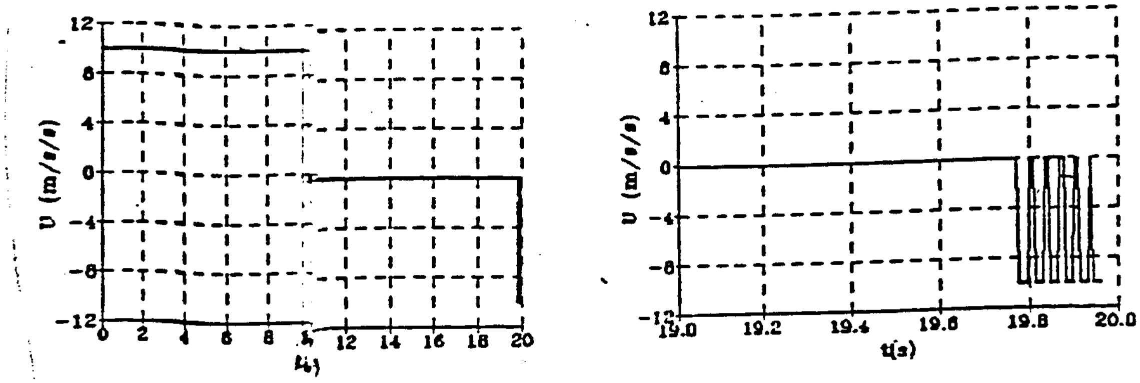

Fig.5 Maneuver Velocity u

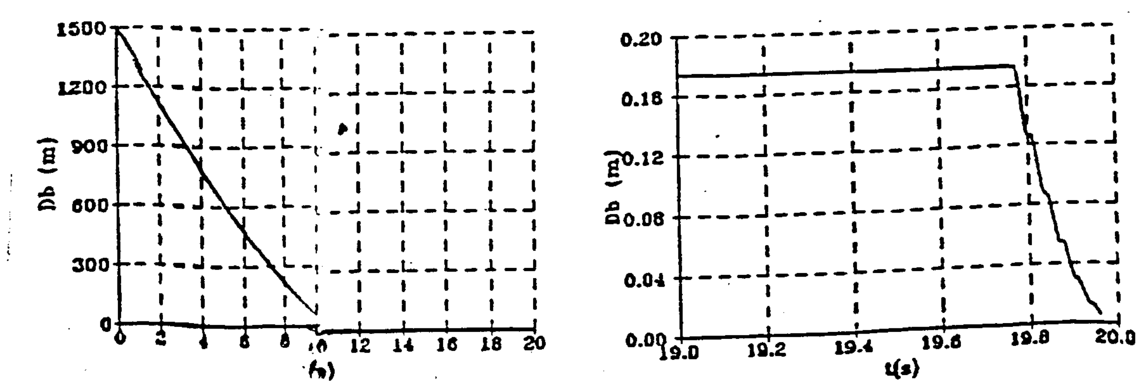

Fig.6 Time Change Patterns Associated with the Function Db(t)

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