A New Guidance Law for Homing Missiles

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This paper presents a new type of guidance law for homing missiles. The design concept is based upon the minimization of time duration for homing. It is shown that to realize this guidance concept an algorithm to predict the collision course and a guidance command generator to turn the heading of the missile toward the direction of the predicted collision course are necessary. A prediction algorithm for the collision course is derived and the realized overall guidance law is shown to be easily implementable. Simulation results are given to demonstrate the minimum time behavior and the widened launching envelope.

Introduction

IN designing a homing guidance law for homing missiles, at least the following six items are to be considered: miss distance, launching envelope, control energy, missile structural constraints, noise immunity, and sensor requirements. In a brief look at these six items, it can be easily seen that the first two are design objectives and the rest are design constraints for a homing guidance law. However, miss distance and control energy have been used as major factors even in recent optimal guidance law design.[1-5]

In this paper, a new guidance law called prediction guidance (PRG) is developed to widen the launching envelope. This is achieved by predicting a straight-line collision course and by turning the heading of the missile toward the collision course as rapidly as possible. In comparison with conventional proportional navigation guidance law, this feature tends to minimize the time duration for homing and permits interception of more rapid and highly maneuvering targets. Simulation results demonstrate these facts. Also, it is shown that the proposed guidance law is easily implementable.

Concept of Prediction Guidance

If the dynamic lags of a missile system are assumed to be neglected, and if the trajectory of a target is assumed to be known a priori, the shortest trajectory of the missile for homing becomes a straight line called the collision course. It is clear that the shortest trajectory means the shortest time duration for homing. Thus, the minimum time strategy of guidance can be stated as follows: Determine the collision course; then turn the heading of the missile to coincide with the collision, and let it go straight until interception.

With this strategy of guidance, interception can be achieved in a minimum time, and any target of which the trajectory is interceptable geometrically can be intercepted. This feature implies that the above missile guidance strategy not only minimizes the homing time duration but also maximizes the launching envelope.

In realizing the proposed minimum time strategy of guidance, two problems occur: 1) the future trajectory of a target cannot be known a priori, and 2) the dynamic lags of the missile system should not be neglected. These problems cause inevitable modification of the minimum time strategy of guidance. One method of modification is to predict the direction of the collision course and to form a closed-looped system in order to compensate for tracking errors caused by the prediction, target maneuvering, etc. Figure 1 is the block diagram of a realization of the minimum time strategy of guidance. It consists of two parts: a predictor for the direction of the collision course and a guidance command generator to turn the heading of the missile toward the predicted direction. The term "prediction guidance" stems from this prediction feature.

Prediction of Collision Course

Without loss of generality, only one plane of motion will be considered. For a constant velocity target, the angle between the collision course and the current heading of the missile can be easily obtained as follows from the Fig. 2. Along the collision course,

$$V_m \sin(\psi-\phi) = -V_m \sin\phi - R\dot{\theta} \tag{1}$$

Therefore, ψ can be expressed as

$$\psi = \phi - \sin^{-1}(\sin\phi + R\dot{\theta}/V_m) \tag{2}$$

where ψ represents the angle between the collision course and the current heading of the missile, ϕ the angle between the line of sight and the current heading of the missile, R the range of the target, V_m the velocity of the missile, and $\dot{\theta}$ the angular velocity of the line of sight. Equation (2) shows that ϕ, R, and V_m are additionally necessary in comparison with the case of the proportional navigation guidance law.

For a maneuvering target, the situation is quite different. Equation (2) causes large numbers of errors in this case. To compensate for these prediction errors, information about the target acceleration is necessary. Let T be the time until interception and a_t be the acceleration of the target along the direction normal to the line of sight. Then, the straight-line collision course should satisfy

$$TV_m \sin(\psi-\phi) = T(-V_m \sin\phi - R\dot{\theta}) + \tfrac{1}{2}T^2 a_t \tag{3}$$

From Eq. (3) ψ can be expressed as

$$\psi = \phi - \sin^{-1}(\sin\phi + R\dot{\theta}/V_m - \tfrac{1}{2}Ta_t/V_m) \tag{4}$$

Here, the time until interception T can be approximated by

$$T = \beta\frac{R}{V_m} \tag{5}$$

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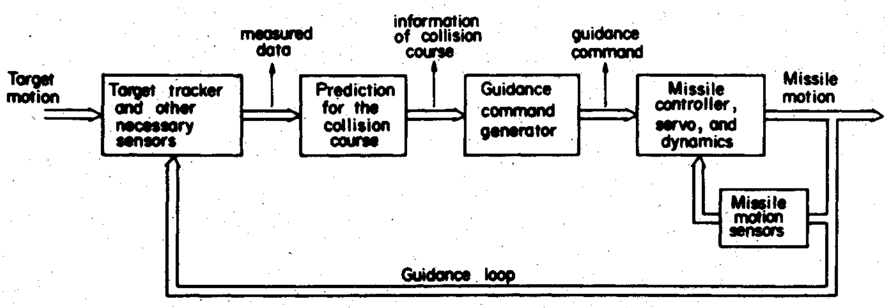

Fig. 1 A realization of minimum time strategy of guidance.

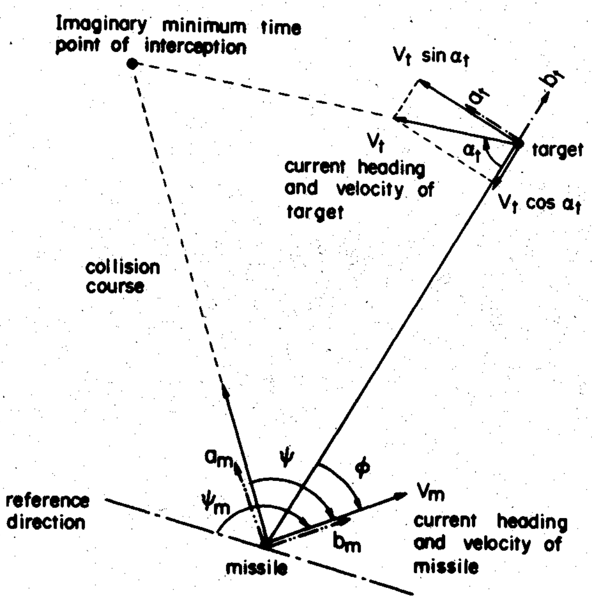

Fig. 2 A homing geometry.

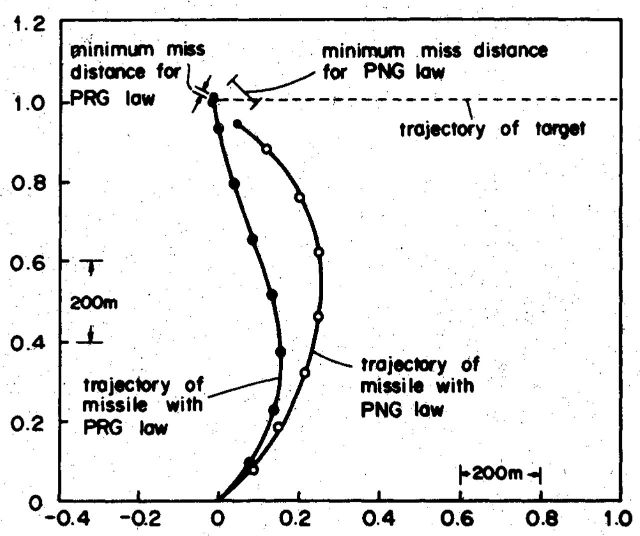

Fig. 3 Trajectories for PRG and PNG laws.

where β is a constant depending on the geometry of the target and the missile trajectory. Using the kinematic relation in Eq. (6), a_t can also be obtained.

$$a_t = -b_m \sin\phi + a_m \cos\phi - R\ddot{\theta} - 2\dot{\theta}\dot{R} \tag{6}$$

where b_m is the left lateral acceleration of the missile, a_m the forward acceleration of the missile, $\ddot{\theta}$ the rate of change of the line of sight rotation rate, and $\dot{R}$ the rate of change of the range. Now, the final result is obtained as follows from the Eq. (4), (5), and (6).

$$\psi = \phi - \sin^{-1}\{\sin\phi + \frac{R}{V_m}\dot{\theta} + \frac{1}{2}\frac{R}{V_m^2}\beta \times (b_m \sin\phi - a_m \cos\phi + R\ddot{\theta} + 2\dot{\theta}\dot{R})\} \tag{7}$$

Note that for a maneuvering target ϕ, R, $\dot{R}$, $\ddot{\theta}$, b_m and a_m are additionally required in comparison with the case of the proportional navigation guidance law. However, these quantities can be easily measured with conventional sensors.

Guidance Command Generator

To realize the prediction guidance concept on a homing missile system, it is now sufficient to construct a guidance command generator which can turn the heading of the missile immediately toward the predicted collision course. In other words, if the guidance command generator is installed to make ψ decrease to zero, and if a feedback loop is given to update the inaccurate prediction of ψ, a realization of the prediction guidance law can be obtained.

There may be many kinds of controllers for such functional requirements, for example, bang-bang, PID and optimal controller. Here a proportional controller is chosen for simplicity. Then the ultimate guidance command has the form

$$A = K_R \psi \tag{8}$$

where A is the lateral acceleration command to the missile autopilot and K_R is the prediction guidance gain.

It is known that the proportional navigation guidance is that of energy optimal when the navigation constant is chosen as 3.[6] Here the prediction guidance gain K_R is chosen to give the same control energy as in the case of proportional navigation guidance with navigation constant 3. Through some calculations it is given by[7]

$$K_R = 6V_{m0}/R_0 \tag{9}$$

where V_{m0} and R_0 are the velocity of the missile and the range of the target at the time of guidance engagement, respectively.

Simulation Results

Both the prediction guidance law and the conventional proportional navigation guidance law were simulated on a digital computer for comparison purposes. The missile dynamics were modeled as a second-order system. Also the target tracker was assumed to have the second-order dynamic lags. Table 1 lists the numerical data used for the simulations.

Simulations were made for many engagement scenarios. Since the acceleration of the target along the direction normal to the line of sight is very slowly varying for most maneuvering targets, the prediction of the collision course with Eq. (7) shows good accuracy. Thus the proposed prediction guidance law shows reasonably better performances even for the maneuvering targets.

Table 1 Summary of the missile and target data

	Missile	Target
Initial x-position	0 m	1000 m
Initial y-position	0 m	1000 m
Initial velocity	500 m/s	250 m/s
Initial orientation	45 deg	−90 deg
Forward acceleration	0 m/s^2	200 m/s^2
Lateral acceleration	to be controlled	0 m/s^2
Lateral acceleration limit	500 m/s^2	-
Damping ratio of target tracker	0.8	-
Natural frequency of target tracker	10 rad/s	-
Damping ratio of missile dynamics	0.6	-
Natural frequency of missile	50 rad/s	-
β in Eq. (5)	1	-

Table 2 Performance of guidance laws

	PRG	PNG
Miss distance	7 m	80 m
Homing time duration[a]	2.13 s	2.15 s

[a]The homing time duration indicates the time interval between initial time and the time of minimum miss distance.

A most significantly improved performance is obtained for the case listed in Table 1. With the data given in Table 1 the trajectories for each guidance law are depicted in Fig. 3, and such guidance performances as miss distance and homing time duration are summarized for the two guidance laws in Table 2. From the trajectories shown in Fig. 3, it can be seen that the prediction guidance causes relatively large amount of control force only in the initial phase of homing. However, the proportional navigation guidance requires relatively little control force in the initial phase of homing, and it leads extremely large amounts of control force thereafter. Hence, large miss distance is induced. Eventually the prediction guidance shows much better performance in the miss distance and also in the time duration for homing, as can be seen from Table 2.

Concluding Remarks

Starting from minimizing the time duration for the target homing, a new guidance law has been proposed. Simulation result shows that even an accelerating target can be intercepted with shorter miss distance and less time duration for homing in spite of the dynamic lags in the target tracker and the missile dynamics. Extensive further study of the guidance command generator including bang-bang, PID, and optimal controllers, is expected to give better performance of the prediction guidance law than the one used in this paper.

References

[1]Garber, V., "Optimal Intercept Laws for Accelerating Targets," *AIAA Journal,* Vol. 6, Nov. 1968, pp. 2196-2198.

[2]Nazaroff, G.J., "An Optimal Terminal Guidance Law," *IEEE Transactions on Automatic Control,* Vol. AC-21, June 1976, pp. 407-408.

[3]Gutman, S., "An Optimal Guidance for Homing Missiles," *Journal of Guidance and Control,* Vol. 2, 1979, pp. 296-300.

[4]Shrider, B. and Gupta, N.K., "Missile Guidance Laws Based on Singular Perturbation Methodology," *Journal of Guidance and Control,* Vol. 3, 1980, pp. 158-165.

[5]Axelband, E.I. and Hardy, F.W., "Quasi-optimum Proportional Navigation," *IEEE Transactions on Automatic Control,* Vol. AC-15, Dec. 1970, pp. 620-626.

[6]Garnell, P. and East, D.J., *Guided Weapon Control Systems,* Pergamon Press, Oxford, 1977.

[7]Kim, Y.S., "A New Guidance Law for Homing Missiles," M.S. Thesis, The Korea Advanced Institute of Science and Technology, Department of Mechanical Science, Feb. 1983.