단거리 지대공 유도무기에서의 시선지령식 유도법칙과 비례항법 유도법칙의 성능비교

Performance Comparisons between Command to Line-of-Sight Guidance Law and Proportional Navigation Guidance Law in Short Range Surface-to-Air Missile

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Abstract : In this paper, a performance comparison between CLOS(Command to Line-of-Sight) guidance law and PN(Proportional Navigation) guidance law is made, based on a short range surface-to-air missile simulation program called KNUCLOS. This simulation program has a full nonlinear aerodynamic missile model, a tracker model for missile and target, and target model. According to the simulation results, the PN guidance law has a better performance than CLOS guidance law under various target speed.

Keywords : command to line-of-sight guidance, proportional navigation guidance, surface-to-air missile, performance

I. Introduction

From the day of the first missile invented, guidance law plays a crucial part of missile system. In Fig. 1. the general structure of a missile mission performance is consist of a ground part, a missile part and a target part. CLOS(Command to Line-of-Sight) guidance law, which is based on the three point concept, is the first generation method for guiding guided missiles[1,2]. The CLOS guidance law is easy to realized and do not need complex calculation. It is later found that another guidance law, called proportional navigation guidance (PNG) law, based on the method of maintaining the line-of-sight between missile and target, is also effective to make an interception [3-8]. There are two basic proportional navigation guidance laws in missile guidance-true proportional navigation(TPN) and pure proportional navigation(PPN). The missile command acceleration in TPN is defined to be perpendicular to the line-of-sight(LOS), and is proportional to the LOS rate and the closing velocity. While in PPN, the missile command acceleration is perpendicular to the missile speed vector, and is proportional to the LOS rate and the missile's velocity[7-13].

So in this paper, a model of short range surface-to-air missile called KNUCLOS is build to find the better guidance law between CLOS guidance law and PNG law. The traditional CLOS guidance law has its merits in its simple structure and low computational burden, and the PNG law has also lots of merits in various target conditions. According to the simulation result, the performance of PNG law is better than that of CLOS law, expecially under the condition of maneuvering target.

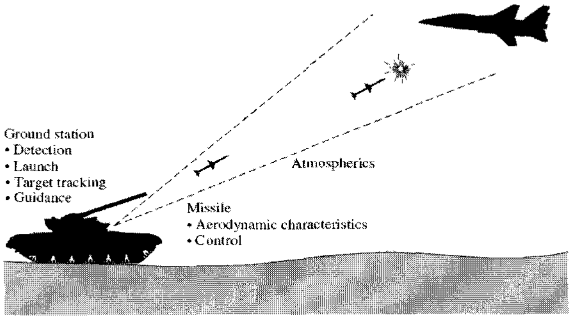

그림 1. 유도무기의 임무수행구조.
Fig. 1. The structure of a missile mission.

II. KNUCLOS system

KNUCLOS simulation program is a kind of short-range surface-to-air missile launch system with command to line-of sight guidance law. The launch site takes charge of detecting both target and missile, tracking the target, calculating a guidance command, and transmitting the guidance command to missile. The missile considers all the nonlinear aerodynamic characteristics, atmospherics and

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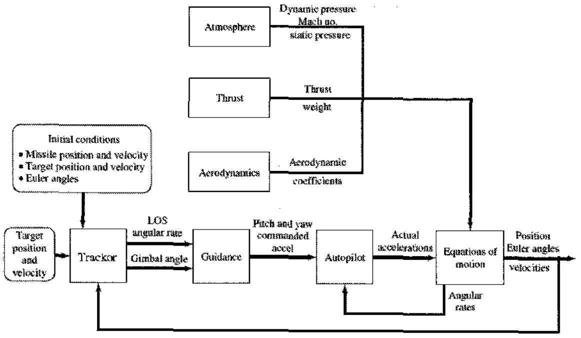


그림 2. KNUCLOS의 블록선도.

Fig. 2. Block diagram of KNUCLOS.

guidance command in order to make mission complete. Fig. 2. shows the block diagram of KNUCLOS structure.

The aerodynamic model for missile is denoted by Eq. 1. In the Eq. 1, v_m^M means the missile velocity in the missile body frame, F_A is the aerodynamic force, F_T is the thrust force. C_I^M is the coordinate transformation matrix from inertial frame to missile body frame, g^I is the gravity forcing to missile in the missile body frame. And the last term in the velocity derivation is the Coriolis effect. The range information after integration of the missile velocity is denoted in missile body frame, it should be transformed into inertial frame value. The missile angular velocity w^M is calculated from the aerodynamic moments of its rotational motion M_A and moments due to the missile thrust acting on the attitude of missile translational motion M_T. At each time, the angular velocity is converted into the Euler angle frame of the missile because the Euler angle frame may be changed by rotational motion of the missile. Converted Euler angle derivation is integrated to the former Euler angle. This Euler angle between inertial frame and missile body frame is used to calculate the coordinate transformation matrix.

$$\begin{aligned} \dot{v}_m^M &= \frac{F_A}{m} + \frac{F_T}{m} + C_I^M \cdot\ g^I - \ w^M \times v_m^M \\ \dot{r}^I &= C_M^I \cdot v_m^M \\ \dot{w}^M &= I_d^{-1}(\ M_A + \ M_T + \ w^M \cdot I_d \times \ w^M) \\ \dot{\nu}^M &= C_w^\nu \cdot\ w^M \end{aligned} \tag{1}$$

The tracker equipped on the launch site locks on the target and gets both of the target and missile data after missile gets its normal speed. Immediately after launching, the missile can not get enough speed for the aerodynamic force, which means that the guidance action is of no use. So, the tracker does not act for some delay time for missile to get enough speed making the aerodynamic force using control surface. In this simulation, the delay time is assumed as 0.5 second. After this delay time the speed of missile reaches up to meaningful speed, and the missile can follow the guidance command from the tracker. With guidance computer in the tracker, the guidance law is calculated and transmitted to the missile's autopilot system. The autopilot system measures the angular rate and acceleration through the onboard inertial measurement unit, and gives out the fin angle command in order to control the missile. The missile has to get the thrust and dynamics as well as atmospherics to calculate velocity and position of the missile.

III. CLOS guidance law

The CLOS guidance law is based on the concept that if a missile and a target are on the same line-of-sight from the launch site view any time during the interception, then an interception will occur.

In this program, the error compensation command (beam riding command) is provide by an error compensation system below, and its block diagram is in Fig. 3. The error compensation command consists of three part, LOS angle error compensation, gravity compensation, and feed forward command. Eq. 2 describes the LOS angle error compensation, and Fig. 4 denotes the block diagram for this error compensation procedure.

$$\begin{aligned} \varepsilon &= \theta_T - \theta_m \\ \dot{x}_1 &= W_1(\varepsilon R_m - x_1) \\ \dot{x}_2 &= W_1(\lambda\varepsilon R_m + (1-\lambda)x_1 - x_2) \\ \dot{x}_3 &= K_1(\lambda^2\varepsilon R_m + \lambda(1-\lambda)x_1 - (1-\lambda)x_2) \\ A_c &= K_G(\lambda^2\varepsilon R_m + \lambda(1-\lambda)x_1 - (1-\lambda)x_2 + x_3) \end{aligned} \tag{2}$$

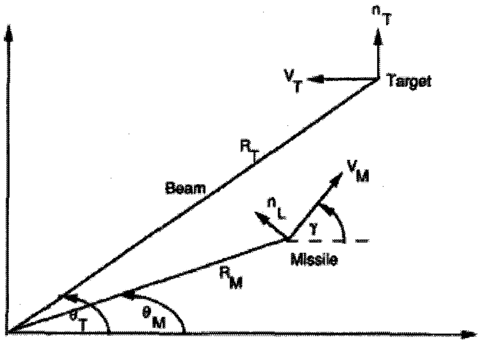


그림 3. 시선지령식 유도법칙의 개념도.

Fig. 3. CLOS guidance law geometry.

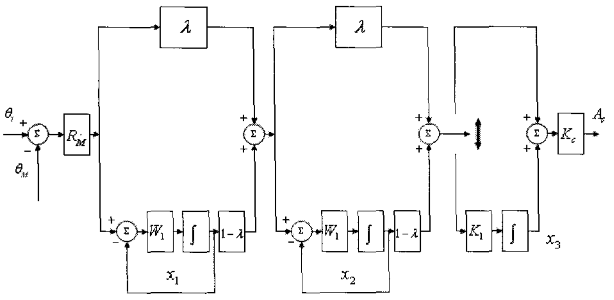


그림 4. 오차보상체계의 블록선도.

Fig. 4. Block diagram for error compensation system.

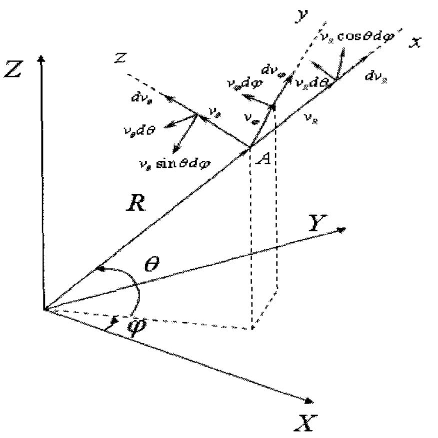


그림 5. 예측보상명령성분.

Fig. 5. Feed forward command component.

In this error compensation, error ε between target LOS angle and missile LOS angle is multiplied by missile range for the real deviation of missile from the target LOS. The error compensation command is produced by both proportional and integrating control factors cascaded in two stages. So the guidance law of CLOS is employed to maintain the missile is always on the line between the launch sight and the target. It is also easy to find that if the target has a large velocity or if the target makes evasive motions, the line-of-sight (LOS) between the tracker and the target will rotate quickly which makes this method lack of accuracy.

In order to improve the performance, the motion of the tracker LOS is taken in to account. The tracker always try to keep its LOS to coincide with the target LOS. But, the tracker has delayed response to keep the LOS with target LOS because of its dynamic property. If the prediction of target motion is possible, guidance command can lesson this tracker delay effect. This type of control shape is a type of feed forward compensation control. In order to locate the missile on target LOS according to target LOS prediction, target motion is scaled into missile range. Fig. 5 shows that the target is at the same range with missile, and the target has its three components accelerations in a spherical coordinate. Among these three acceleration components, the azimuth and elevation components can be used to prediction of target LOS. Accumulating all the acceleration components at each coordinate axis, the feed forward command is denoted as in Eq. 3.

$$\begin{pmatrix} A_y^L \\ A_z^L \end{pmatrix} = \begin{pmatrix} R_m \ddot{\psi}_T \cos\theta_T - 2R_m \dot{\psi}_T \dot{\theta}_T \sin\theta_T + 2\dot{R}_m \dot{\psi}_T \cos\theta_T \\ -2\dot{R}_m \dot{\theta}_T - R_m \ddot{\theta}_T - R_m \dot{\psi}^2 \cos\theta_T \sin\theta_T \end{pmatrix} \tag{3}$$

In the Eq. 3, A_y^L is the feed forward acceleration component of azimuth by prediction of LOS rate, and A_z^L is the elevation feed forward component. With these compensation, CLOS guidance law can be improved its performance for the evasive or maneuvering targets.

Actually the guidance command is produced by adding these two command, error compensation denoted by Eq. 2 and feed forward command denoted by Eq 3, with gravity compensation.

IV. PN guidance law

The most widely known and used guidance law for short-range or medium-range missiles is proportional navigation (PN) guidance law, because of its inherent simplicity and ease of implementation.

Simply stated as denoted in Fig. 6, classical proportional navigation guidance is based on recognition of the fact that if two bodies are closing on each other, they will eventually intercept if the line-of-sight between the two does not rotate relative to the inertial space. More specifically, the PN guidance law seeks to null the LOS rate against nonmaneuvering targets by making the interceptor missile heading proportional to the LOS rate. For instance, in flying a proportional navigation course, the missile attempts to null out any line-of-sight rate that may be developing.

The missile tries to do this by commanding fin deflections to the control surfaces. Consequently, these deflections cause the missile to execute accelerations perpendicular to its instantaneous velocity vector. In the Fig. 7, proportional navigation guidance law geometry is shown. Thus, the missile commands try to null out measured LOS rate. Consider a two-dimensional figure in order to make a simple discussion, the target velocity V_T has two

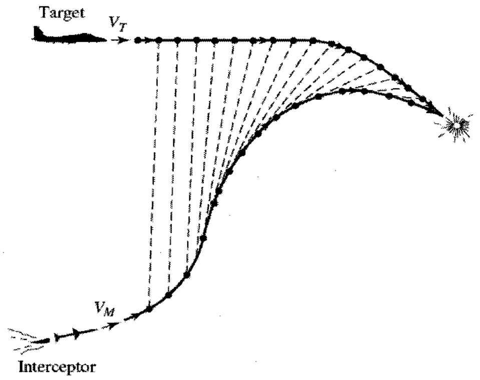


그림 6. 비례항법 유도법칙의 개념도.

Fig. 6. Proportional navigation PN guidance law geometry.

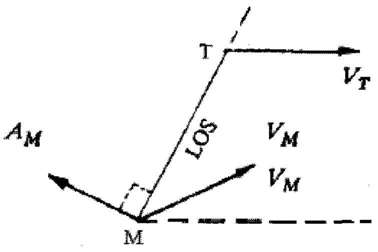


그림 7. 비례항법 유도법칙의 명령방향.

Fig. 7. PN guidance law geometry.

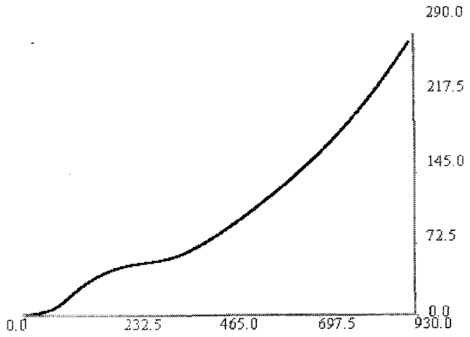
components, one is parallel component with LOS between target and missile, and the other is perpendicular component to the LOS. The former component is closing velocity to the missile. Similarly on the missile side, the missile velocity V_M has two components, one is parallel component with LOS between missile and target, and the other is perpendicular component to the LOS. Both of the parallel components makes the closing velocity along the LOS if the LOS keeps the same direction during the mission. The guidance command A_M is perpendicular to the LOS in order to have positive closing velocity, and describes in Eq. (4).

$$A_M = NV_c\left(\frac{d\lambda}{dt}\right) \tag{4}$$

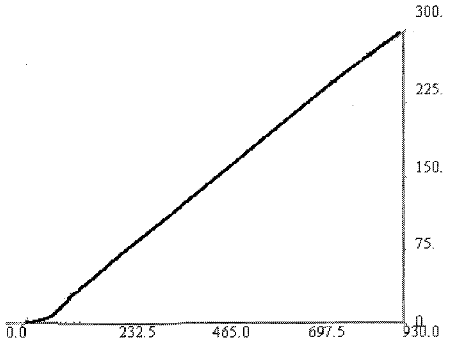
In Eq. 4, N is the navigation constant (also known as navigation ratio, effective navigation ratio, and navigation gain), and V_c is the closing velocity to the target. λ is LOS angle between missile and target, the commanded normal acceleration A_M is proportional to this differentiation of the LOS angle.

V. Simulation Results

The simulation program is implemented in FORTRAN language, with the compiler of Visual FORTRAN 6.6 in windows environment.



(a) CLOS guidance law case



(b) PN guidance law case

그림 8. 유도무기의 궤적들.

Fig. 8. Missile trajectories.

표 1. (2000,100,100)의 표적에 관한 거리오차와 시간.

Table 1. Miss distance and hit time for (2000,100,100).

Velocity of missile	CLOS		PNG	
	MD(m)	HT(sec)	MD	HT
-346 m/s	4.3	2.705	2.4	2.509
-396 m/s	5.3	2.603	3.6	2.407
-446 m/s	6.6	2.483	4.3	2.281
-496 m/s	8.0	2.387	5.3	2.182
-546 m/s	9.4	2.263	5.6	2.060

In the program nonlinear differential equations for missile dynamics are integrated by Runge-Kutta 4-th order method at every 1 msec. And the guidance command is up-linked to the missile at every 20msec. When the target initial position is (2000, 0, 300), the trajectory of the missile shows in Fig. 8. In the figure, the PN guidance law makes more smooth trajectory of (b) than the CLOS guidance law case of (a). That means PN guidance law has less fluctuations of control surface than CLOS guidance law. Less fluctuation tells that the missile follows more accurately the target.

When the target initial position is (2000, 100, 100), the miss distance and hit time is given in Table 1. In this initial condition, the LOS from tracker to target has small angles in inertial frame. When the target speed is -346 m/s towards to the tracker, the miss distance is 4.3m in the case of CLOS guidance law and 2.4m in the case of PN guidance law. In the same condition of the target, the ending time is 2.705sec in the case of CLOS guidance law and 2.509sec in the case of PN guidance law. Those results tell that less fluctuation in trajectory makes better performance and needs less time for mission. As the target speed grows, the miss distance increases as well in the other results on Table 1. In the PN guidance law case, the same thing happens, however the results is obviously better than that in CLOS, especially when the target speed is high.

When the target initial position is (2000, 200, 200), the miss distance and hit time is given in Table 2. In this initial condition, the angles of LOS is lager than the former case. The performance of CLOS becomes worse quickly, while for the PN guidance law, just a little bit worse than before. In the case of CLOS guidance law, the miss distance is quickly increases as the target speed increases. However, in the case of PN guidance law, the miss distance is under half of the CLOS case.

When the target initial position is (2000, 300, 300), the miss distance and hit time is given in Table 3. In this condition, the LOS angles become even larger, when the target speed becomes -446m/s the miss distance of CLOS becomes as large as 22 meter, while the PNG only has 8 meter of miss distance.

표 2. (2000,200,200)의 표적에 관한 거리오차와 시간.
Table2. Miss distance and hit time for (2000,200,200).

Velocity of missile	CLOS		PNG	
	MD	HT	MD	HT
-346 m/s	9.4	2.748	1.3	2.542
-396 m/s	11.9	2.628	5.0	2.425
-446 m/s	14.7	2.524	5.9	2.328
-496 m/s	17.7	2.406	6.6	2.207
-546 m/s	20.9	2.323	7.7	2.123

표 3. (2000,300,300)의 표적에 관한 거리오차와 시간.
Table3. Miss distance and hit time for (2000,300,300).

Velocity of missile	CLOS		PNG	
	MD	HT	MD	HT
-346 m/s	14.8	2.782	4.2	2.587
-396 m/s	18.6	2.601	6.4	2.402
-446 m/s	22.8	2.569	8.1	2.360

When the target initial position is (3000, 50, 200), and initial velocity is -346m/s, CLOS law has its minimum miss distance 1.2 meter, while the hit time is 3.801 second. On the other hand, when the target initial position is (3000, 100, 300), and initial velocity is -450m/s, PN guidance law has its minimum miss distance 0.9 meter, while the hit time is 3.521 second. These results describe that the PN guidance law has better performance under the large LOS angle variations than the CLOS guidance law.

VI. Conclusions

In this paper, the CLOS guidance law and PN guidance law are compared. Because of the highly nonlinear behavior of the missile dynamics the simulation is necessary. From the results acquired by the simulation, it can be found that the CLOS guidance law performs well when the target speed is low and angles of the LOS between tracker and target are small, while in the same condition, the PNG law performs better than the CLOS law especially when the target velocity is high and with large LOS angles.

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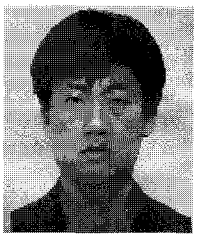

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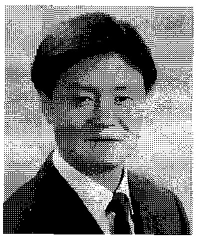

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