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Design of Hybrid Guidance Law for Homing Missile on a Stabilized Seeker Platform

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ABSTRACT: Major design challenge in missile guidance law is to maximize the Single Shot Kill Probability (SSKP) by minimizing the final miss distances and to enhance its manoeuvrability. However, such missile manoeuvres may cause the target to move out of seeker's Field of View (FOV). This can be overcome with inertial seeker servo stabilization system and Hybrid guidance law design which helps in maintaining a continuous look angle against manoeuvring targets (lock-on condition). The application of inertial stabilization system stabilizes the sensor's line of sight toward the target by isolating the sensor from disturbances induced by the operating environment based on the FUZZY PID type controller. And the hybrid guidance law design reduces the miss distance by combining the advantages of Proportional Navigation Guidance (PNG) and Sliding Mode Guidance (SMG) laws in an optimal way with effective switching logic to nullify its shortcomings. The former one helps to successfully achieve terminal homing phase, and the latter one bring back the look angle within the FOV during the complex manoeuvre phase. The results obtained in different test scenarios confirms that a further improved system performance can be achieved using the proposed guidance law scheme as compared to the conventional scheme.

KEYWORDS: Hybrid guidance law, Lock-on condition, Switching over logic, Field of View.

I. INTRODUCTION

The Proportional Navigation Guidance (PNG) law is the most widely used in guidance because it can be easily implemented and has good homing guidance performance. But it can frequently occur that the missile fails to chase high speed targets. Alternatively, this paper proposes the Hybrid Guidance law, which combines two guidance laws: the PNG law and the Sliding Mode Guidance (SMG) law. The two guidance laws are switched between each other at a certain value of the look angle called the switching boundary. In the first phase, where the look angle is within the switching boundary, the PNG law controls the missile. In the second phase, when the look angle is over the switching boundary, the SMG law is adopted to keep the look angle within the Field Of View (FOV).

While the missile is guided by the PNG law in the first phase, a maximum look angle is predicted on-line under the adoption of the SMG law based on the current look angle. When the predictive maximum look angle is equal to the FOV, the second phase is started and the current look angle is regarded as the switching boundary. In the second phase, the SMG law controls the missile while the look angle is larger than the switching boundary. When the look angle is less than the switching boundary, the first phase is adopted again. This logic is iterated until the missile intercepts the target.

Next, in order to reduce the miss distance and to increase the probability of kill we need to stabilize the seeker gimbal using advanced control algorithms. The stabilization loop plays an important role in searching and tracking a target. Generally, the two-axis gimballed platform must achieve rapid and precise response characteristics, and be stabilized during tracking a target. It is well known that tracking performance of air vehicles depend highly on stabilization performance, which is able to isolate a target tracker from various disturbances induced, by air vehicle body motion and vibration, even with satisfying the system stability margin and the desired high decoupling ratio between target tracker and air vehicle body. The several disturbance torques are included in the design model, and



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their physical parameters are used as identified experimentally. The most important disturbance sources are base's angular motion, gimbal cross-coupling and gimbal mass unbalance (both static and dynamic).

II. RELATED WORK

Chun-Liang Lin and Yi-Hsing Hsiao^[1] have presented the various sources of disturbance torque inputs for a missile seeker, which may severely degrade the seeker tracking accuracy of a guided missile. In their paper, they have presented a novel approach to treat the disturbance rejection problem for the missile seeker and improved the quality of seeker tracking accuracy by the addition of feedforward control. They proposed a multilayer feedforward neural network to realize the nonlinear adaptive feedforward controller. From their simulation results, the neural controller affords possibilities for improving the miss distance performance.

DaeKyu Sang, Chang-Kyung Ryoo, and Min-Jea Tahk^[3] worked on a guidance law with a switching logic that maintains seeker lock-on and proposed a simple guidance law that keeps the target look angle of the seeker constant. They have proposed the method for the terminal phase of a missile.

Ali Moharampour, Javad Poshtan, and Ali Khaki Sedigh^[4] have worked on target adaptive guidance (TAG) for passive homing missiles by using LOS coordinates with a particular definition. They proposed their method in modified spherical coordinate (MSC) combined with modified proportional navigation guidance (MPNG) law. The proposed guidance law is the traditional PPNG law with two additional terms, which has been calculated in 3-dimensional case. Their results indicate that MPNG properly provides terminal conditions for missile-target homing interception.

Maher Abdo, Ahmad Reza, Alireza Toloei, and Mohammed Reza Arvan^[5] have done a research on cross-coupling in a two axes gimbal system considering the dynamic unbalance. The aim of their work is to stabilize the sensor's line of sight towards a target by isolating the sensor from the disturbance induced by the operating environment, such as various disturbance torques and body motions on gimballed stabilization system with a two axes gimbal assembly. They have designed and simulated stabilization loops for the two axes gimbal system with a cross-coupling unit.

Maher Abdo, Ahmad Reza, and Alireza Toloei^{6†} have presented a model of control servo system for one axis gimbal mechanism using fuzzy PID type controller considering the base angular motion and dynamic unbalance. They have constructed a stabilization loop with their proposed fuzzy controller. The overall control system has beed simulated using MATLAB/Simulink, then they investigated the system performance in different cases for both conventional PI and fuzzy PID controller. From their simulation results, they have shown the proposed fuzzy controller provides improved system performance as compared to the conventional PI controller, and improves further the transient and the steady-state performance.

In-Joong Ha, Jong-Sung Hur, Myoung-Sam Ko, and Taek-Lwl Song^[11] analyzed the performance of the conventional proportional navigation guidance (PNG) law for a randomly maneuvering target. By means of the Lyapunov method, they proved that an ideal missile guided by the conventional PNG law can always intercept a target which maneuvers with time-varying normal acceleration provided that the navigation constant is sufficiently large. They also proposed a modified PNG (MPNG) law to improve the performance of the conventional PNG law at the final phase of pursuit. Their simulation results demonstrate that the MPNG law demands less missile acceleration at the final phase of pursuit than the conventional PNG law.

Chih-Min Lin, Chun-Fei Hsu, Shing-Kuo Chang, and Rong-Jong Wai^[12] investigated and compared the system behavior of guidance laws under different navigation constants. They presented the miss distance sensitivity analyses which consider the system noise, target step maneuver, initial heading error and system parameters for different guidance laws and navigation constants. Based on their analyses, they suggested a suitable guidance law and navigation constant for the design of missile guidance systems.

Se-Ah Jang, Chang-Kyung Ryoo, Keeyoung Choi, and Min-Jea Tahk^[15] worked on guidance algorithms design to overcome problems due to the parasite loop which severely degrades the guidance performance in the guidance system. They investigated the performance of the proposed algorithms via numerical simulations for short-range tactical missiles.



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III. INERTIAL STABILIZATION SYSTEM

One of the main functions of the missile seeker (also known as homing eye) subsystem is to provide the measurements of target motion required to mechanize the guidance law, and to track the target continuously after acquisition. These functions are to be met in an optimal way with the designed hybrid guidance law. The inertial stabilization system is achieved here with a stabilization loop controller design. Fuzzy PID type controller with several environmental and system disturbance model were included and tuned for stabilization loop. Our complete disturbance model includes seeker mass imbalance, seeker gimbal friction, seeker head restoring torque, gimbal cross-coupling. Other disturbances are missile body bending (flexing), gimbal scale factors, gyro drift. The various disturbances for a seeker were explained in [1]. The complete disturbance model is modelled in Simulink and is programmed in MATLAB Editor.

III.1 Stabilization Loop

The stabilization loop is shown in Fig. 1 and it constitutes controller, DC motor, gimbal platform, and rate gyro. The DC motor and the rate gyro are identified as follows:



Fig.1 LOS Stabilized Servo Control Loop

DC Motor

These motors speedily respond to a command signal by means of a suitable controller. In this kind of motors, the speed control is carried out by changing the supply voltage of the motor. In this paper, DC motor from NORTHROP GRUMMAN Company is utilized. The transfer function of the selected DC motor is given by:

$$G_m(s) = \frac{24637.68}{s^2 + 1500s + 20942} \tag{1}$$

Rate Gyro

In this paper, the 475T rate gyroscope from US DYNAMICS Company is considered. The rate gyro can be modelled in the second order system typically. It is assumed that the gyro's natural frequency $\omega_n = 50$ Hz, and that the damping ratio $\zeta = 0.7$. Thus, the gyro transfer function is

$$G_{gyro}(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} = \frac{2500}{s^2 + 70s + 2500}$$
(2)

III.2 Controller Design

Although, the researchers tried to utilize and apply many different modern techniques to control inertial stabilization systems, the conventional PID is still the most used approach due to their simple structure, cheap costs, simple design and high performance. The drawback of the conventional PID appears when the control system work under variable conditions. Therefore, in systems such as gimbal system proposed, PID controller cannot maintain the good performance unless the controller parameters are retuned. Thus the PI controller has been the right choice. If gimbal design is not proper, the control algorithms may become complex and it may not be possible to meet the performance criteria. While the well-designed gimbal assembly reduces the jitter of sensor's line of sight and hence needs a simpler control system that simplifies the implementation of control laws in real time. Many reports pointed out



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that the adaptive control technique is the future development direction of LOS inertial stabilization systems. Recent years, fuzzy logic control has been increasingly developed.

Here, we propose fuzzy PID controller for gimbal LOS stabilization. In order to evaluate the efficiency of proposed fuzzy PID controller, PI controller has been utilized to compare with the performance of the proposed fuzzy controller.

PI Controller

Conventional PI controller is tuned for elevation and azimuth axes individually without considering the cross coupling effects. The selected PI controller transfer function is given by:

$$K(s) = 0.09 + \frac{12.5}{s} \tag{3}$$

With the selected PI controller, the two-axis stabilization loop for the gimbal system with cross coupling is shown in Fig. 2.



Fig. 2 Two-axis stabilization loop using PI Controller with cross coupling effect

Fuzzy PID Controller

The proposed Fuzzy controller comprises of four main components: Fuzzification interface, Knowledge base, Inference mechanism and Defuzzification interface. Fig. 3 shows the components of fuzzy logic controller.



Fig. 3 Components of fuzzy controller

Fuzzification converts input data into suitable linguistic values, while defuzzification yields a non-fuzzy control action from inferred fuzzy control action. The rule base is a decision-making logic, which is, simulating a human decision process, inters fuzzy control action from the knowledge of the control rules and linguistic variable definitions. The fuzzified input variables are used by the inference mechanism to evaluate control rules stored in the fuzzy rule-base which are given in Table 1. The result of this evaluation is a single fuzzy set or several fuzzy sets. Seven triangular membership functions indicated in Fig. 4 are used for the fuzzification of the input $\{e_i, \dot{e}_i\}$ and output $\{U\}$ variables.



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Table 1: Fuzzy Rule Base

eė	NL	NM	NS	ZR	PS	PM	PL
NL	LN	LN	LN	LN	MN	SN	ZE
NM	LN	LN	LN	MN	SN	ZE	SP
NS	LN	LN	MN	SN	ZE	SP	MP
ZR	LN	MN	SN	ZE	SP	MP	LP
PS	MN	SN	ZE	SP	MP	LP	LP
PM	SN	ZE	SP	MP	LP	LP	LP
PL	ZE	SP	MP	LP	LP	LP	LP



Fig. 4 Input and Output Membership functions

For the membership functions used, NL, NM, NS, ZR, PS, PM, PL denotes negative large, negative medium, negative small, zero, positive small, positive medium, and positive large, respectively. All membership functions are defined on the [-1,1] closed interval. All the scaling factors are used to map the related crisp values to their fuzzy universe of discourse. The control output U can be determined from the method of the centre of the gravity. The block schematic Simulink model of stabilization loop using Fuzzy PID controller considering cross coupling effect is shown in Fig. 5.



Fig. 5 Two axis stabilization loop using Fuzzy Controller

The rules of the proposed controller are expressed as follows:

If {e is ZR and e is ZR}, then {U is ZR}. The rule base is constructed based on the following approach: when the system output is far from the desired output, i.e. e is PL and is e is ZR then U is selected to be PL in order to decrease the error value and bring the system state to the desired value rapidly. If the error e is ZR and it tends to increase due to the nonzero ee thus, U should not be zero (for example, if e is ZR and is ee is NM then U is NM). When both e and e



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are zero which is the desired case and the system does not need any control input therefore, U is selected to be ZR. The values of fuzzy subsets *ee* are

$$\{e_i\} = \{e_{-3}, e_{-2}, e_{-1}, 0, e_1, e_2, e_3\} = \{-1, -0.66, -0.33, 0, 0.33, 0.66, 1\}$$

$$\{\dot{e}_j\} = \{\dot{e}_{-3}, \dot{e}_{-2}, \dot{e}_{-1}, 0, \dot{e}_1, \dot{e}_2, \dot{e}_3\} = \{-1, -0.66, -0.33, 0, 0.33, 0.66, 1\}$$

IV. DESIGN OF HYBRID GUIDANCE (HG) LAW

Proportional navigation guidance law has been widely used for tactical applications. The PNG law can be derived to nullify the LOS rate. PNG generates the acceleration command perpendicular to the velocity vector of missiles. But it can frequently occur that the missile fails to chase high speed targets when a strapdown seeker is used. Alternatively, this paper proposes the HG law, which combines two guidance laws: the PNG law and the SMG law. The two guidance laws are switched between each other at a certain value of the look angle \mathcal{E} called the switching boundary, $\mathcal{E}_{boundary}$. In

the first phase, where the look angle is within the switching boundary, the PNG law controls the missile. In the second phase, when the look angle is over the switching boundary, the SMG law is adopted to keep the look angle within the FOV. The hybrid guidance scheme is presented in Fig. 6.



Fig. 6 Hybrid guidance law scheme

IV.1 Missile Kinematics and Dynamics

The general three-dimensional guidance can be dealt with by resolving the LOS rate vector into two lateral planes of the missile by neglecting cross-coupling between the two orthogonal components such as pitch and yaw plane. We have considered only two-dimensional planar guidance in this paper. To facilitate the performance analysis of the proposed guidance law, we assume the following.

- a) The antenna centreline is aligned with the missile centreline.
- b) The seeker dynamics are fast enough to be neglected.
- c) The missile and the target are considered as geometric points moving in the pitch plane.
- d) The missile angle-of-attack is ignored.
- e) The missile velocity V_m and target velocity V_t are constant.
- f) The autopilot and airframe have first order dynamics.

Under the above assumptions, the engagement geometry of the missile and the target is depicted in Fig. 7. The target moves with the velocity V_t and the normal acceleration a_t . The missile chases the target with the velocity V_m and the normal acceleration a_m . The normal acceleration is obtained by an acceleration command a_{mc} through first order dynamics with time constant τ . The seeker measures the look angle ε , which depends on the attitude of the missile and the LOS angle σ . The LOS angle σ , which is used in PNG law, is obtained by combining the look angle and the attitude of the missile. From assumptions c) and e), the missile flight path angle γ_m replaces the attitude of the missile.



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Fig. 7 Missile-Target engagement geometry

Based on the above engagement geometry, the kinematics and the dynamics are obtained as follows:

$$\dot{\gamma}_t = \frac{a_t}{V_t} \tag{4}$$

$$\dot{\gamma}_m = \frac{a_m}{V_m} \tag{5}$$

$$\dot{r} = V_t \cos \theta_t - V_m \cos \varepsilon \tag{6}$$

$$r\dot{\sigma} = V_t \sin\theta_t - V_m \sin\varepsilon \tag{7}$$

where θ_t , \mathcal{E} and a_{mc} are defined by

$$\theta_t = \gamma_t - \sigma \tag{8}$$

$$\varepsilon = \gamma_m - \sigma \tag{9}$$

$$a_m = \frac{1}{\tau_S + 1} a_{mc} \tag{10}$$

where τ and γ_t are time constant and target flight angle, respectively.

IV.2 Guidance System Model

The guidance law implementation is shown in Fig. 8.



Fig. 8 Guidance law implementation



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The complete Homing Guidance loop consists of a Seeker/Tracker subsystem which returns measurements of the relative motion between the missile and target, and the Guidance subsystem which generates normal acceleration demands which are passed to the autopilot. The autopilot is now part of an inner loop within the overall homing guidance system. The function of the Guidance subsystem is to not only generate demands during closed loop tracking, but also perform an initial search to locate the target position.

IV.3 Seeker Model and Target Model

The seeker model with tracking loop and stabilization loop is shown in Fig. 9. The aim of the Seeker/Tracker subsystem is both to drive the seeker gimbals to keep the seeker dish aligned with the target, and to provide the guidance law with an estimate of the sightline rate.



Fig. 9 Stabilization and Tracking loop

The tracker loop time constant is set to 0.05 seconds, and is chosen as a compromise between maximizing speed of response, and keeping the noise transmission to within acceptable levels. The stabilization loop aims to compensate for body rotation rates, and the gain K_s , which is the loop cross-over frequency, is set as high as possible subject to the limitations of the bandwidth of the stabilizing rate gyro. The sightline rate estimate is a filtered value of the sum of the rate of change of the dish angle measured by the stabilizing rate gyro, and an estimated value for the rate of change of the angular tracking error (e) measured by the receiver. Here, the bandwidth of the estimator filter is set to half that of the bandwidth of the autopilot.



Fig. 10 Target model



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For the simulation, the target dynamics were modelled as a point mass model and implemented. The target model is shown in Fig. 10. In this target dynamic model, the target is modelled with lateral accelerations that are given as turn rate, ω . The vertical acceleration is given as a direct input, a_z , to the subsystem, which is equal to the gravitational acceleration.

IV.4 Proportional Navigation Guidance Law

The proportional navigation guidance (PNG) law can be derived to null the LOS rate. Among various PNG laws, we use the pure PNG (PPNG) law, which generates the acceleration command perpendicular to the velocity vector of the missile:

$$a_{mc} = N_1 V_m \,\dot{\sigma} \tag{11}$$

where N_1 is a unit-less designer-chosen gain that is usually in the rage of $3 \sim 5$. Here, we use $N_1 = 3.5$.

IV.5 Sliding Mode Guidance Law

The sliding mode control methodology is used in the second phase of guidance law derivation. In order to apply the sliding mode control, we need to set a switching surface. The guidance goal in this phase is to reduce the look angle against the high speed target. Hence, the switching surface should be chosen such that:

$$s(t) = \varepsilon(t) \tag{12}$$

The basic idea for the selection of the above switching surface is to decrease the look angle. The next step is to design a control law that satisfies the sliding condition. To achieve this, we consider the time derivative of a Lyapunov function, $V = s^2(t)/2$.

Thus

$$\dot{V} = s(t)\dot{s}(t) = \varepsilon(t)\dot{\varepsilon}(t) = \varepsilon(t)(\dot{\gamma}_{m}(t) - \dot{\sigma}(t))$$

$$= \varepsilon(t)\left(\frac{a_{m}(t)}{V_{m}} - \dot{\sigma}(t)\right)$$
(13)

It is regarded that a delay between the normal acceleration a_m and the acceleration command a_{mc} is neglected herein. That is, $a_m = a_{mc}$. The control a_{mc} that will ensure that the above equation is less than zero is:

$$a_{mc}(t) = V_m \dot{\sigma}(t) - N_2 sign(\varepsilon)$$
⁽¹⁴⁾

where $N_2 > 0$ is constant, and $sign(\mathcal{E})$ is a sign function as follows:

$$sign(x) = \begin{cases} 1 & if \ x > 0 \\ 0 & if \ x = 0 \\ -1 & if \ x < 0 \end{cases}$$
(15)

The first term of the SMG law of equation (14) is an acceleration value to keep the look angle steady. The second term influences the degree to lead the look angle to zero.

IV.6 Switching Logic and Estimation of Switching Boundary

As can be seen in Fig. 6, while the missile is guided by the PNG law in the first phase, a maximum look angle is predicted on-line under the adoption of the SMG law based on the current look angle. When the predictive maximum look angle is equal to the FOV, the second phase is started and the current look angle is regarded as the switching boundary. In the second phase, the SMG law controls the missile while the look angle is larger than the switching boundary. When the look angle is less than the switching boundary, the first phase is adopted again. This logic is iterated until the missile intercepts the target.

If the missile is guided by only the SMG law, it is steered so that the velocity vector of the missile points at the target at every instant in time. Then, the closer the missile approaches the target, the more it needs the normal acceleration command to turn towards the target. Finally, the normal acceleration command exceeds the missile hardware limit and the missile fails to intercept the high speed target. On the other hand, because the PNG law orients the missile to an estimated interception point, it does not have this problem. The PNG law has better intercept



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performance against the high speed target than the SMG law. Therefore it is important that we decide the switching boundary $\mathcal{E}_{boundary}$ to use the PNG law as much as possible during the overall homing phase.

Meanwhile, because there are some delays between a_m and a_{mc} in an actual situation, the look angle is increased gradually during a certain time although the SMG law is adopted. The pattern of the look angle in the second phase is influenced by the characteristics of guidance system, such as system delay, and the engagement, such as missile velocity and look angle rate and so on. In order to keep the pattern of the look angle in second phase as similar as possible in various engagements, the gain N_2 of the SMG law is determined by considering the time constant of the guidance system, the look angle rate and the missile velocity. To consider these factors, let us choose the gain N_2 feasibly such that:

$$N_2 = \rho \, \tau V_m \, \dot{\varepsilon} \left(t_b \right) \tag{16}$$

where τ , V_m , $\rho > 0$ and t_b are the time constant, the missile velocity, a proportional gain and the time to switch from the first phase to the second phase, respectively. $\dot{\varepsilon}(t_b)$ is the look angle rate at the time t_b . We assume that the guidance law is changed from the first phase to the second phase at certain time t_0 . The look angle reaches its peak at the time $t_0 + \hat{T}_o$, the maximum value of the look angle $\hat{\varepsilon}_{m,\max}\Big|_{t=t_0}$ and \hat{T}_0 can be predicted by using parameters of the time t_0 . To predict these values, we assume as follows:

 $_0$. To predict mese values, we assume as follows.

$$\hat{\sigma}(t) = \dot{\sigma}(t_0), \quad t \in \left[t_0, t_0 + \hat{T}_0\right]$$
(17)

Then the predicted acceleration command is:

$$\hat{a}_{mc}(t) = V_m \,\hat{\sigma}(t) - \rho \,\tau V_m \,\dot{\varepsilon}(t_0) = V_m \,\hat{\sigma}(t_0) - \rho \,\tau V_m \,\dot{\varepsilon}(t_0), \quad t \in \left[t_0, \, t_0 + \hat{T}_0\right] = \hat{a}_{mc}(const)$$
(18)

If the predicted acceleration command is a constant, the estimate of the normal acceleration is related to the predicted acceleration command.

$$\hat{a}_m(t) = e^{-(t-t_0)/\tau} a_m(t_0) + \left(1 - e^{-(t-t_0)/\tau}\right) \hat{a}_{mc}$$
(19)

Differentiating equation (9) and using equations (5), (12) and (16), we can derive the following equation for the estimation of the look angle rate:

$$\hat{\varepsilon}(t) = \left\{ e^{-(t-t_0)/\tau} \left(1 + \rho \tau \right) - \rho \tau \right\} \dot{\varepsilon}(t_0)$$
⁽²⁰⁾

When the estimated look angle rate is zero, the estimated look angle reaches its peak. That is,

$$\hat{\hat{\varepsilon}}_{m}\left(t_{0}+\hat{T}_{0}\right) = \left\{e^{-\hat{T}_{0}/\tau}\left(1+\rho\tau\right)-\rho\tau\right\}\hat{\varepsilon}\left(t_{0}\right) = 0$$
(21)

Thus, \hat{T}_0 satisfying equation (19) is the estimated time that elapses from the start time of the second phase up to the time when the estimated look angle is maximum.

$$\hat{T}_0 = -\tau \ln\left(\frac{\rho\tau}{1+\rho\tau}\right) \tag{22}$$

Therefore the varied quantity of the estimated look angle during t_0 and $t_0 + T_0$ is:

$$\int_{t_0}^{t_0+T} \hat{\hat{\varepsilon}}_m(t) dt = \left\{ \tau \left(1 + \rho \tau\right) \left(1 - e^{-T/\tau}\right) - \rho \tau T \right\} \dot{\varepsilon}(t_0)$$
(23)

Now the maximum look angle which is estimated at the time t_0 is obtained as:

$$\hat{\varepsilon}_{m,\max}\Big|_{t=t_0} = \varepsilon(t_0) + \int_{t_0}^{t_0+\hat{t}_0} \hat{\varepsilon}_m(t) dt$$



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$$= \varepsilon \left(t_0 \right) + \left\{ \tau \left(1 + \rho \tau \right) \left(1 - e^{-\hat{T}_0/\tau} \right) - \rho \tau \hat{T}_0 \right\} \dot{\varepsilon} \left(t_0 \right)$$
(24)

As discussed earlier, $\hat{\mathcal{E}}_{m,\max}\Big|_{t=t_0}$ is smaller than the FOV of the strapdown seeker. Thus the missile chases the target using the first guidance law. We iterate this process until the updated maximum of the estimated look angle equals the FOV of the strapdown seeker. t_1 is the time satisfying:

$$\hat{\varepsilon}_{m,\max}\Big|_{t=t_1} = FOV \tag{25}$$

where *FOV* is the field of view of the strapdown seeker. $\varepsilon(t_1)$ is determined as the switching boundary. And the missile is guided by the second guidance law from this time t_1 until $\varepsilon(t)$ is smaller than the switching boundary.

There are some errors between the peaks of actual and estimated look angle, because the estimated LOS angle rate has some errors. The problem occurs when the actual look angle exceeds the FOV of the strapdown seeker. Then the seeker lock-on condition is broken. The missile keeps the acceleration command at the time when it misses the target. The errors between the two peaks of actual and estimated look angle are small and the acceleration command is large enough to decrease the look angle. Thus, even if this situation occurs, the actual look angle eventually enters the FOV of the strapdown seeker quickly.

V. SIMULATION AND RESULTS

Of the proposed controller designs namely, PI and Fuzzy PID, Fuzzy PID is of self-organizing cum adaptive in nature than the conventional controller. Henceforth analysis is made on Conventional PI vs. Fuzzy PID with several scenarios. Each scenario is made and used in Conventional PI and Fuzzy PID. From the scope output, peak overshoot (OV) and settling time (t_s) is noted for each case. The results for the overall scenario are presented in Table 2.

]	Fuzzy PID					
q (deg/sec)	Elevation		Azimuth		Elevation		Azimuth	
	OV %	$t_{\rm s}$ sec	OV %	$t_{\rm s}$ sec	OV %	$t_{\rm s}$ sec	OV %	$t_{\rm s} \sec$
2	1.3	0.2	1.5	0.1	0	0.15	0	0.13
4	7.76	0.225	9.7	0.19	0	0.1	0	0.1
6	8.78	0.33	15.1	0.17	0.5	0.1	0	0.07
8	18.76	0.35	24.3	0.16	1.4	0.09	2	0.05
10	50.57	0.3	36.2	0.16	2	0.06	2.3	0.03
12	77.25	0.3	50	0.15	14	0.03	16	0.02
14	88.5	0.45	64.6	0.16	20	0.02	18.6	0.02

Table 2: Comparative results for seeker system stabilization

In the Hybrid Guidance Law simulation, the guidance loop is regarded as a first-order system which has a time constant of 1 sec. The target initially flies 4.5 km away from the missile. The initial target flight path angle, the initial missile flight path angle and the initial LOS angle are 50 deg, -10 deg and 0 deg, respectively. Also, the velocity of the missile and target are 340 m/s and 250 m/s, respectively. The FOV of the seeker is 30 deg (-15 to +15). For the purpose of comparison, the conventional PNG law is employed in this simulation. The missile guided by the PPNG law goes beyond the FOV of the seeker after 2.4 sec and fails to intercept the target. On the other hand, the missile guided by the proposed HG law maintains the seeker lock-on condition until it is near the target. The look angle comparison is shown in Fig. 11.



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Fig. 11 Look angle Comparison for Hybrid Guidance with Stabilized platform

The various engagements have been made and the miss distances for several cases of engagements obtained were tabulated in Table 3. These results also demonstrate that the proposed guidance law increases the success probability to intercept the target in various engagements.

Scenarios	Target flight	Missile flight path angle (degrees)	Miss Distance (meters)			
	path angle (degrees)		PNG	HG	HG with Stabilized Seeker Platform	
1	45	10	76.024 m	1.9656 m	1.3586 m	
2	45	-10	69.056 m	3.5562 m	2.9894 m	
3	90	10	35.265 m	11.2352 m	9.5869 m	
4	135	-10	75.056 m	21.6268 m	18.2562 m	

Table 3: Test cases and miss distance comparison for Hybrid Guidance Law simulation

VI. CONCLUSION AND FUTURE WORK

The results obtained have shown that the proposed fuzzy controller can meet the variation of operation conditions and realize fast response with lower overshoot compared to conventional PI controller. We have proposed a missile guidance scheme with seeker gimbal platform stabilization against high speed targets. With these schemes a considerable amount of miss distance has been reduced and continuous missile target lock-on condition is maintained with inertial stabilization system. The results obtained in different conditions confirms that a further improved system performance can be achieved using the proposed guidance scheme as compared to the conventional scheme.

In future, still a better stabilization controller can be designed for a modified PNG law, which includes time to go (t_{go}) i.e., time required for the missile to reach target and filtering techniques can be implemented to predict both LOS range and LOS rate measurements using a single filter.

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