Modeling of Target Tracking System for Homing Missiles and Air Defense Systems

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Abstract: *One reason of why the guidance and control systems are imperfect is due to the dynamics of both the tracker and the missile, which appears as an error in the alignment with the LOS and delay in the response of the missile to change its orientation. Other reasons are the bias and disturbances as well as the noise about and within the system such as the thermal noise. This paper deals with the tracking system used in the homing guidance and air defense systems. A realistic model for the tracking system model is developed including the receiver servo dynamics and the possible disturbance and noise that may affect the accuracy of the tracking signals measured by the seeker sensor. Modeling the parameters variability and uncertainty is also examined to determine the robustness margin of the tracking system.*

Key Words: *Tracking, Missile Seeker; Homing Guidance; Intercept; Engagement; Air Defense Systems (ADS); Line-Of-Sight (LOS)*

1. INTRODUCTION

As the most two guidance principles used today in the guided weapons are (a) the homing guidance, which relies on a target tracker "seeker" and an onboard processor "computer", and (b) the command guidance, which guides the missile according to commands transmitted from the ground station to the interceptor missile. These and other forms of guidance systems, attempt to remain the interceptor missile within certain determined trajectory that will eventually guarantee intercepting the given target [1-4].

The homing missiles latterly became a field of interest utilizing the assist of the accelerated technology. Considering advantages of the homing guidance the followings can be pointed out; (a) it does not depend on a separated tracking-commanding system that may be subjected to a counterattack, (b) possibility of launching multiple missiles at the same time in contrast with the command guidance, and (c) as the interceptor flight progresses toward the target, the accuracy of the measurement is improved continuously as a result of

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approaching the seeker from its target [5-8]. A better use of homing guidance required a great deal of technology to overcome the limitations for instance the missile diameter versus the size of seeker sensor as well as the built-in onboard computer. In addition to the extra power needed, the overload, the sensor accuracy and the computer processing speed, all of these and others should be carefully considered.

A precedent phase of the guidance loop that is including the guidance algorithm [9-13], is to establish and measure the target range and its motion. This can be accomplished by including a target tracker called homing eye or seeker since it is installed in the missile itself. Accurately determination and estimation the sight line angle, "the line joining the target and the missile", is an essential and critical stage so as to provide the guidance algorithm by uncontaminated and precise information about the target relative direction and motion. While the missile is flying along the intercept course, it is dealing with transmitted and received signals, which means that the missile should be able to accurately distinguish between both signals. For this purpose, many methods can be used for instance, highly directional antenna can be located in the missile nose or by utilizing the Doppler effect to differentiate the two signals echoes [14,15]. Since the missile approaches to the target the frequency of the reflected signal is greater than the guided signal.

In order to guarantee accurate intercept of the target, this paper will examine a realistic model for the homing tracking system. This realistic model will include the dynamics of the system and the possible disturbance and noise that may affect the accuracy of the tracking signal measure by the seeker sensor. Moreover, the system intrinsic nonlinearities and Model parameters variability and uncertainty will also be considered to ensure better accuracy of the missile performance and result in precise interceptions.

2. MODELING OF TRACKING SERVO AND ANGULAR ACCURACY

Mounting the seeker on a moving frame affects the accuracy of the measurement; this leads to exist some sort of gyroscope to give an inertial reference to help determine orientation. From another aspect, a sufficient high bandwidth of the homing head servos is required in order to keep the antenna beam width effectively pointing at the target.

As the seeker attempts to keep its boresight pointing at the target and aligned with the LOS and produce proportional signal to the misalignment, its accuracy will be limited by the noise as well as the base "mounting" motion. In practice there will also be a dynamic lag in the antenna following the LOS, which means that, the angular rate is not exact as the sight line rate. The basic requirement for the seeker sensor are:

- To be decoupled from the missile motion and kept stabilized in inertial space.
- To be accurately detect and track the target and fed precisely the guidance system with the required information.
- Some sort of noise filtration is necessary to work integrally with the tracking system.

The angular accuracy of the seeker influences by mechanical properties of the antenna, the quality and effectiveness of the seeker servo, the electronic circuit stability, atmospheric fluctuation, receiver noise level and the target reflected characteristics.

These factors reduce the tracking accuracy, produce a fluctuated reading of the target motion and cause error in the prediction of the future position of the target. The servo loop often consists of misalignment detector that produces signals proportional to the misalignment between the boresight and the LOS controller to amplify the error signal and the inner rate loop.

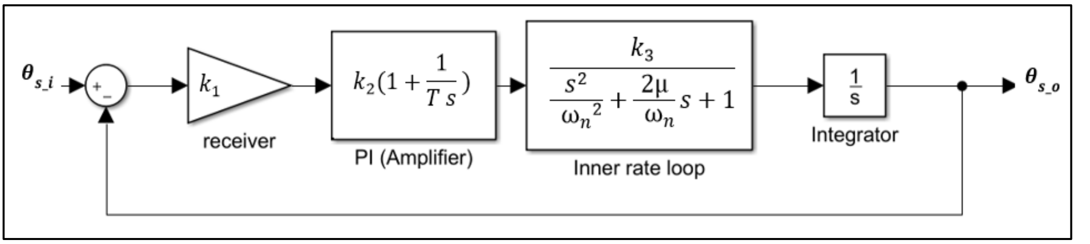

Figure 1: Realistic model of the tracking servo dynamics

There are many suggestions for the tracker model; in the present study we will consider the realistic model [16] or the fourth order servo model as depicted in figure (1) which consists of:

- A receiver modeled as gain k_1.
- PI controller with gain k_2 and time constant T.
- Second order inner rate loop with natural frequency ω_n, damping coefficient μ and gain k_3.
- Inherent Integrator.

Then the closed loop transfer function of the seeker is:

$$\frac{810080(s + 10)}{s^4 + 150.0225\, s^3 + 22502\, s^2 + 810080\, s + 8100800}$$

To see the time and frequency responses properties including the seeker dynamics only as a first stage, we will perform a unit step input to the seeker system. The time response is shown in figure (2) where the main properties are:

Rise Time= 0.02sec. Settling Time= 0.2 sec.

Overshoot =17%. Steady state accuracy (e_{ss})= zero%.

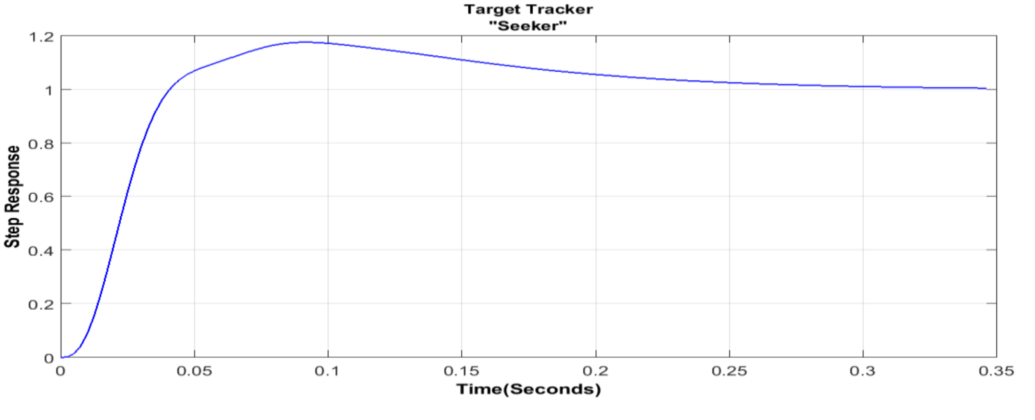

Figure 2: Time response of the seeker dynamics only

Figure (3) shows the frequency response characteristics, where the Phase Margin is 120 deg. at a phase crossover frequency = 38 rad/sec. The system gain Margin is 9.21 dB at a gain crossover frequency = 145 rad/sec.

At this stage, we only considered the tracking servo dynamics as shown in figure (1). To test the seeker dynamic response, we will enter random LOS angles to our configuration in the guidance program and observe the correspondence between the actual response outputs from the system and the ideal random LOS angles.

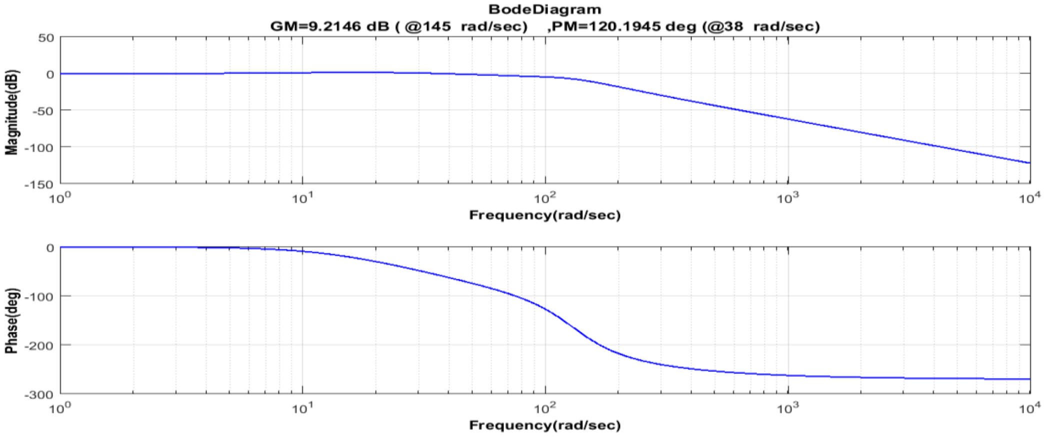

Figure 3: Frequency response of the seeker dynamics only

Let us suppose that an engagement scenario is continued for 30 sec. and the sight line angle changed randomly as depicted by the black "dashed" curve in figure (4).

The results depicted in figure (4) show that the actual LOS angles measured by the seeker system which is represented by the red "solid" curve are almost compatible with the ideal values.

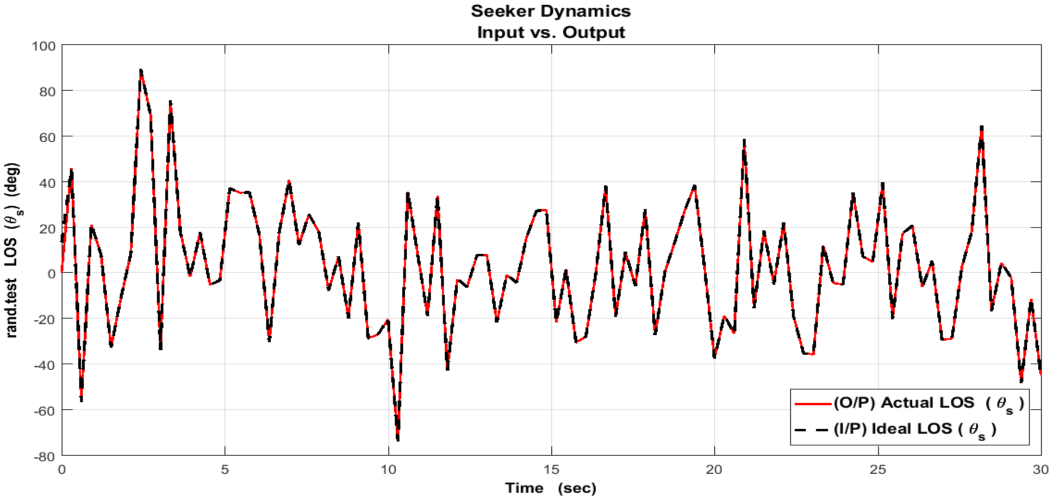

Figure 4: The time response of the actual versus the exact LOS angles

3. MODELING OF TARGET TRACKER IN UNCERTAIN AND NOISY ENVIRONMENT

In this stage, more realistic model of the seeker system will be considered which includes the possible noise as well as the disturbance that may affect the response of the tracking system. Moreover, the uncertainties that may exist for the system parameters due to any reason are also studied and included in the more realistic seeker model depicted in Figure (5). This figure shows a Simulink model of the interceptor seeker, which includes in addition to the seeker dynamics, the potential disturbance and noise, where the noise is modeled as a band limited white noise and the disturbance as a step input after half a second with amplitude of about -0.2.

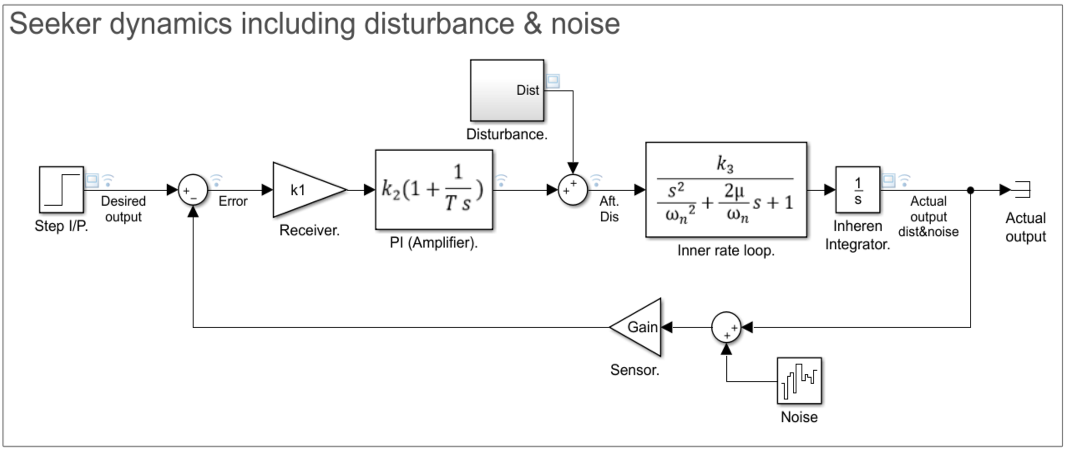

Figure 5: More realistic model of the tracking system for the LOS angle

Furthermore, to be more realistic, let us take into consideration the uncertainties regarding some parameters during the design process.

The estimation of system parameters sometimes needs to estimate the variability of these parameters that may results due to different disturbances or because of the system nature.

In this stage, the uncertainty model of the target tracker parameters is examined for the inner loop gain.

For simplicity and analysis purposes, we will take the uncertainty of k_3 as 30% of the nominal value i.e. there is 30 percent confident region “selecting this value subjected to design considerations”.

The time step response of the uncertain model is shown in figure (6); for more clarification, the worst case against the nominal case is depicted in figure (7), where {14} is the worst value of k_3 at the worst overshoot of {1.2794} as well as the largest rise time.

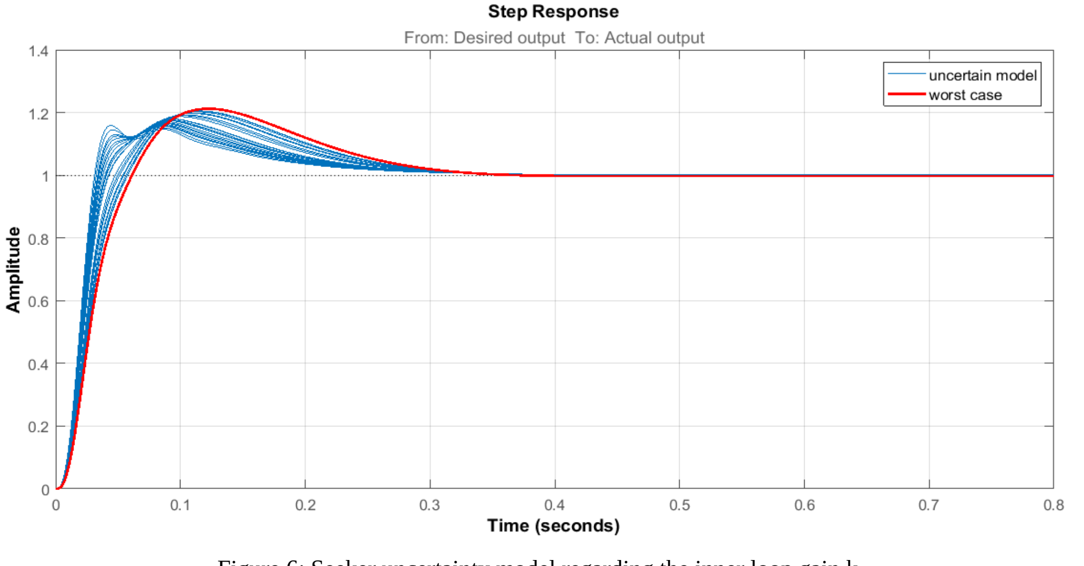

Figure 6: Seeker uncertainty model regarding the inner loop gain k_3

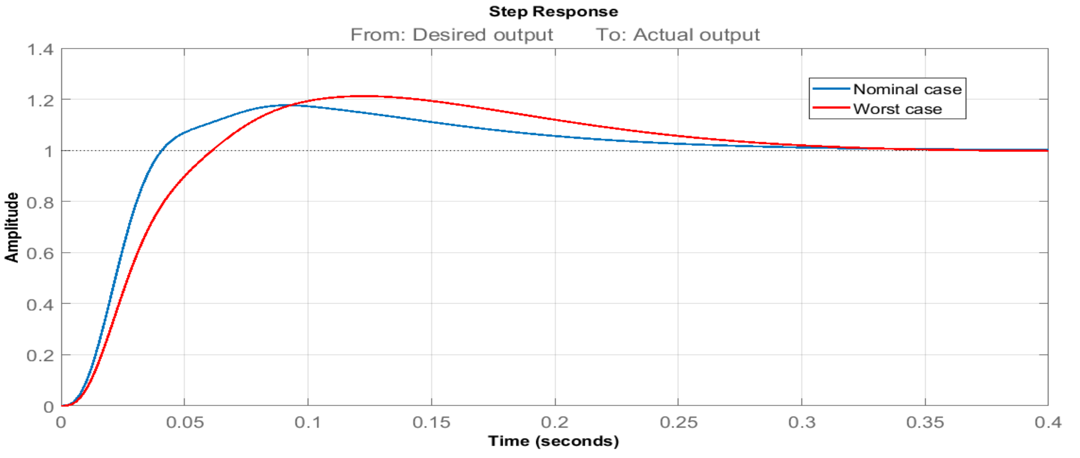

Figure 7: Time response of the different versions of the seeker realistic models and the controller output for each case.

We collect the outputs of the different versions of the target tracker models in figure (8) to see the actual output from our seeker model in case of including the system (1) Dynamics only, (2) Dynamics and disturbance, and (3) Dynamics, disturbance and noise.

Figure (8) also depicts the output form the controller "PI/Amplifier" and the history of the error signal in the three cases mentioned above.

Moreover, to check the robustness margin of our model, we will apply Argoun method [17] for robustness by subjecting the seeker model to an identical perturbation Δa_i as follows:

$$\Delta a_i = p\, a_i$$

where a_i the coefficients of the nominal Hurwitz polynomial.

The estimated robustness margin p of the seeker model is: $p = \pm 0.327$.

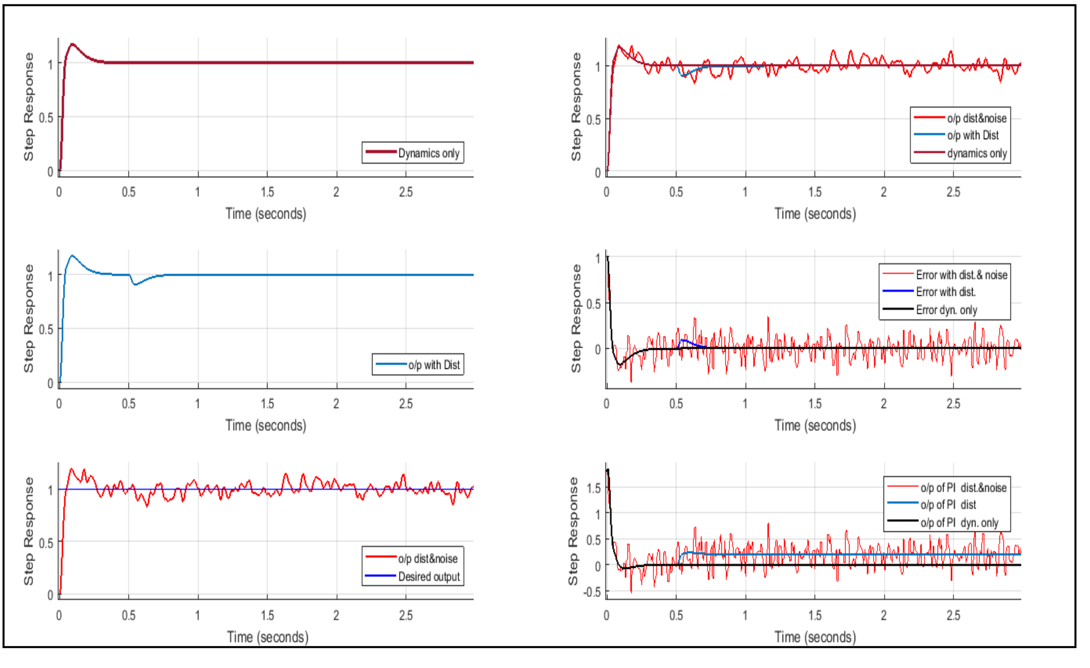

Figure 8: Time response of the nominal vs. the worst case in an uncertainty of k_3

4. CONCLUSIONS

The development of guided weapon is forced to produce more precise homing guidance systems by improving their tracking, guidance and control capability. This paper deals with the seeker system in the tactical homing missiles and air defense systems. Modeling, design and analysis of the tracking system is considered from different aspects, whereas the response of the interceptor seeker is examined for the seeker dynamics including the possible disturbance and noise. The paper also deals with the uncertainty and parameters variability as well as the robustness measurement to show the essential properties and characteristics that will improve the scanning and tracking ability of the missile seeker and homing tracking systems.

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