Estimating Seeker Measurement Signals for Homing Missile Guidance System

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Abstract - Most of missile guidance systems use different electromagnetic spectrum ranges to perform the guidance functions. Based on long range operations and less susceptibility for weather conditions, RF seekers are usually employed in homing missiles and due to measurement signal errors of these seekers, missile guidance system performance cannot be accurate. So to achieve the required accuracy, modern guidance systems utilizes modern filtering and estimation techniques as well as closed-loop control methods by continuously computing errors occurred in the missile-to-target intercept geometry and converting them into corrective missile control commands to reduce miss distance to zero. Here; noisy RF seeker data is characterized by correlated non-Gaussian target glint, normally distributed random thermal noise, clutter and range independent noises. In this study, the gimballed type missile seeker, seeker measurement noises, Kalman filter and digital fading memory are simulated in Matlab Simulink and the guidance system performance analysis and evaluation also done based on the value of miss distance and time of interception obtained from simulation results.

Keywords: *Estimates, Homing missiles, Measurement noise, Proportional navigation, Seeker measurement signals.*

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1. INTRODUCTION

Guided missile systems have tactical duties similar to those of conventional weapons (guns, rockets, and bombs). However, in conventional weapon systems, information concerning the target is gathered by observation. In contrast to the conventional weapons, guided missiles in flight are constantly re-aimed based on the target information obtained by on board sensors called seekers [6].

In its simplest form a radar seeker sends out radio pulses and listens for echoes, whereby an echo indicates an object in the surroundings. From returning echoes it is possible to derive information about how far away an object is, how fast it is approaching as well as a relative angular position [2]. The angular location of the target is found with a directive antenna (with a narrow beam width) to sense the angle of arrival of the echo signal. If the target is moving, a radar can derive its track, or trajectory, and predict the future location. The shift in frequency of the received echo signal due to the doppler effect caused by a moving target allows a radar to separate desired moving targets (such as aircraft) from undesired stationary targets (such as land and sea clutter) even though the stationary echo signal may be many orders of magnitude greater than the moving target [8]. The kind of sensor that is used for a specific tactical missile design is determined by such factors as maximum operating range, operating conditions, band width, the kind of target information needed, the accuracy required, viewing (field-of-view) and gimbal angles, weight/size of the sensor, and the type/speed of the target [7]. Homing guidance technology has made a great deal of progress over the past seven decades and today's tactical guided missile designs involve much more complex engineering work in terms of inertial and targeting sensors together with guidance and autopilot control systems. The main idea beyond the development of homing guidance technique is to guide the missile in order to intercept non-stationary targets that can handle evasive manoeuvres in an unpredictable manner. In all types of homing guidance, an on board sensor, namely a seeker, is utilized to provide target data so as to ensure target acquisition and tracking by the missile [11]. The process of intercepting a highly manoeuvrable target requires continuous estimation regarding the target's location in space relative to the missile and a responsive attitude by the missile to any changes.

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In most cases, a target estimator plays a crucial role in post-processing of the sensed data to make reasonable predictions about the target's states. By the nature of homing guidance, as the missile gets closer to the target, the quality of the real time information obtained from the seeker related to the target states generally improves and, as a result, a superior intercept accuracy is likely to be achieved compared to any other form of missile guidance [3].

Early missile systems used a variety of guidance laws including beam riders and pursuit guidance. However, proportional navigation proved to be the most versatile and, with suitable modification or augmentation, still remains in use in most contemporary guided missile systems as mentioned in [4], [10]. As discussed in [5], for a small navigation constant N, the missile corrections are small early on in the flight, yet may become quite pronounced as the missile nears intercept. The situation is reversed for larger values of N, where the collision course errors are corrected early on in flight, and manoeuvres consequently are kept at reasonable levels in the terminal phase.

2. SYSTEM MODELS

2.1. Seeker Model

Usually, seekers are mounted on two mutually perpendicular yaw and pitch gimbals and hence, seekers are always stabilized, that is, their axes remain fixed in space. In order to track manoeuvrable targets and derive the rates of range and LOS angles in azimuth and elevation planes, we can use the basic equations shown below.

$$\text{Range rate} = \frac{X_{TM}.V_{xTM} + Y_{TM}.V_{yTM} + Z_{TM}.V_{zTM}}{\sqrt{(X_{TM}^2+Y_{TM}^2+Z_{TM}^2)}}, \quad (1)$$

Elevation angle rate =

$$\frac{(X_{TM}^2 + Y_{TM}^2).V_{zTM} - \left(X_{TM}.V_{xTM} + Y_{TM}.V_{yTM}\right).Z_{TM}}{\sqrt{(X_{TM}^2+Y_{TM}^2}\;.\;(X_{TM}^2+Y_{TM}^2+Z_{TM}^2)}, \quad (2)$$

$$\text{Azimuth angle rate} = \frac{X_{TM}.V_{yTM} - Y_{TM}.V_{xTM}}{\sqrt{(X_{TM}^2+Y_{TM}^2)}}, \quad (3)$$

Where, X_{TM}, Y_{TM}, Z_{TM} are relative position vectors.

2.2. Target Model

The kinematic equations for the three degree of freedom, point mass target model can be easily described and implemented for simulating the target trajectories.

$$\dot{\gamma}_t = \eta_{vt} * \frac{g}{V_t}, \quad (4)$$

$$\dot{\phi}_t = \frac{\eta_{ht} g}{V_t \cos(\gamma_t)}, \quad (5)$$

$$\dot{h}_t = V_t \sin(\gamma_t), \quad (6)$$

$$\dot{y}_t = V_t \cos(\gamma_t)\sin(\phi_t), \quad (7)$$

$$\dot{x}_t = V_t \cos(\gamma_t)\cos(\phi_t), \quad (8)$$

Where, V_t is a constant speed of target, η_{vt} and η_{ht} are the load factors in pitch and yaw planes respectively, (g = 9.8 m/s^2) is the gravitational constant, $\phi_t$and $\gamma_t$are azimuth and elevation of target and x_t , y_t, h_t are the target positions along inertial x, y, and z axis respectively [9].

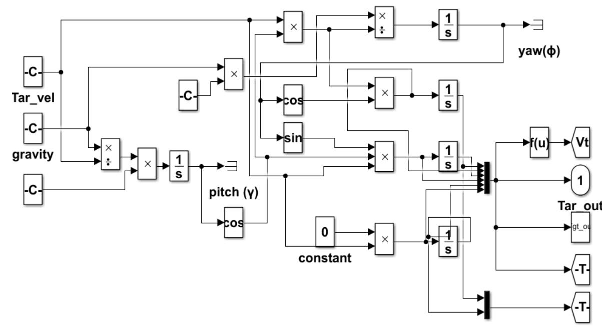

Figure 1: Target Simulink model

2.3. Noise Model

Glint noise:

Since glint is happened due to change of the apparent angle of arrival of the wave front, it is mainly determined by the parameters shown in the table 1 below.

Table1: Parameters used in glint noise model

Parameter	Value
Sampling time	0.125s
Target characteristic length	3 m
Wave length	0.3m
Target rotation rate	0.2deg/s
Mean value	0.0

The simulation result of the glint noise with respect to flight time is shown in the figure 2 below.

Since glint is a distance error along the target length, the equivalent angular error varies as inversely proportional to range to go through the flight time. As shown in the figure 2, the glint noise increases as range to go decreases and we can observe that it has greater effect on the guidance system performance during terminal phase compared to midcourse phase.

Range Independent Noise:

Range independent noise can be modelled as a normally distributed random noise having zero mean, and the standard deviation of 0.25 for this study.

Due to the random nature of background noise, range independent noise shown in the figure 2, affects the system equally through the flight time.

Thermal Noise:

Thermal Noise is the noise produced by the random motion of charged particles (usually electrons) in receiver. With a given resistance R value in ohms and at temperature T in degree Kelvins, the noise voltage v(t) due to random electron process is a Gaussian distributed random variable with zero mean, and variance of:

$$\sigma_T{}^2 = \frac{(2\pi KT)^2 R}{3h}, \qquad (9)$$

Where, K is the Boltzmann constant ($1.38 * 10^{-23}$ Joules/Kelvin), and h is the Planck's constant ($6.62 * 10^{-34}$ Joules second).

Table 2: Parameters used in thermal noise model

Parameter	Symbol	Value
Boltzmann constant	k	1.38e-23 Joules/Kelvin
Planck's constant	h	6.62e-34 Joules second
Temperature in Kelvin	T	600 k
Receiver Impedance in Ohm	R	50 ohm
Mean value	Mean	0.0

The thermal noise shown in the figure below, has less magnitudes compared to other noises, this is because of less amount of change in temperature inside the receiver, of Corse in this case due to maximum exhaust temperature and maximum heat transfers to receiver 600 degree kelvin is assumed.

Clutter Noise:

Likewise clutter noise can be modelled as a normally distributed random noise having zero mean, and standard deviation of $1.25 * 10^{-4}$. Similar to that of the range independent noise, clutter noise also affects the system equally throughout the flight time, and its magnitude depends on the value of the variance used in the model.

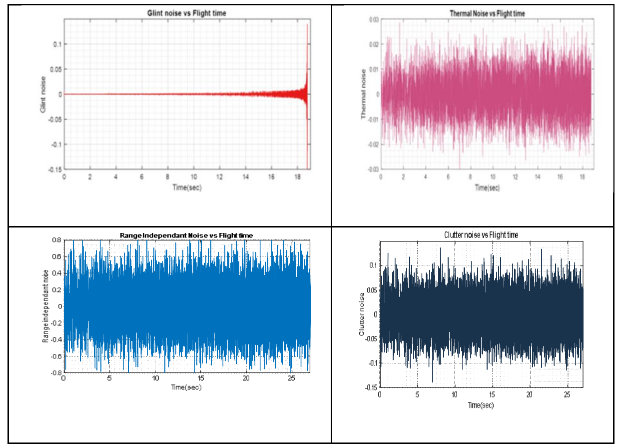

Figure 2: Simulation results of noises

2.4. Seeker measurement filtering

Information required by guidance laws is obtained based on measurements provided by a seeker. Noise and error sources accompanied by target manoeuvres are likely to play a crucial role in engagement scenarios and they can yield large miss distances by directly influencing the measured seeker data. It is known that the command acceleration obtained from noisy seeker measurements can affect the guidance system performance to a certain degree. So to compensate this degradation modern filtering techniques are implemented. There are different estimation techniques but Kalman filter is considered as a more sophisticated filtering and estimation tool practically as discussed by [12].

Missile seekers provide measurement information about the target relative to the missile. Mostly these measurements are elevation and azimuth angle rates of line of sight and range rate as described by the (1), (2) and (3).

As is easily seen the measurement equations defined by (1), (2), and (3) is a highly nonlinear function of the target states. For this reason, the basic Kalman filter is not applicable, and either a higher order filter or an approximate Kalman filter, such as the extended Kalman filter, must be used as in [1].

2.4.1. Seeker Measurement estimation via EKF

State vector:

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix} = \begin{bmatrix} X_{TM} \\ V_{x_{TM}} \\ Y_{TM} \\ V_{y_{TM}} \\ Z_{TM} \\ V_{z_{TM}} \end{bmatrix}, \quad (10)$$

The linear version of the state equation can be written in the form of: $\dot{x}(t) = A(t).x(t) + w(t)$,

$$\frac{d}{dt}\begin{bmatrix} X_{TM} \\ V_{x_{TM}} \\ Y_{TM} \\ V_{y_{TM}} \\ Z_{TM} \\ V_{z_{TM}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} X_{TM} \\ V_{x_{TM}} \\ Y_{TM} \\ V_{y_{TM}} \\ Z_{TM} \\ V_{z_{TM}} \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}, \quad (11)$$

The measurement model, given that the radar measures elevation line of sight rate, azimuth line of sight rate and range rate, can be represented by the equation:

$$z(t) = \begin{bmatrix} \frac{(X_{TM}2+Y_{TM}2).V_{z_{TM}} - \left(X_{TM}.V_{x_{TM}} + Y_{TM}.V_{y_{TM}}\right).Z_{TM}}{\sqrt{(X_{TM}2+Y_{TM}2} \, . \, (X_{TM}2+Y_{TM}2+Z_{TM}2)} \\ \frac{X_{TM}.V_{y_{TM}} - Y_{TM}.V_{x_{TM}}}{(X_{TM}2+Y_{TM}2)} \\ \frac{X_{TM}.V_{x_{TM}} + Y_{TM}.V_{y_{TM}} + Z_{TM}.V_{z_{TM}}}{\sqrt{(X_{TM}2+Y_{TM}2+Z_{TM}2)}} \end{bmatrix} + \begin{bmatrix} v_{ele}(t) \\ v_{azi}(t) \\ v_R(t) \end{bmatrix}, \quad (12)$$

Where, X_{TM}, Y_{TM}, Z_{TM} are target positions relative to missile and $V_{x_{TM}}, V_{y_{TM}}$ and $V_{z_{TM}}$ are relative velocities. And the measurement noise $v(t)$ is combination of noises described in noise modes above.

For a given assumptions, initial conditions, missile and target parameters, the Kalman filter suppresses elevation angle rate, azimuth angle rate and range rate measurement errors as shown in the figure 3 below.

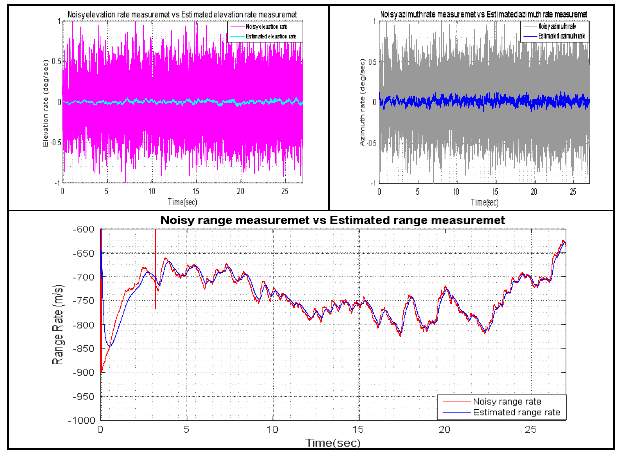

Figure 3: Simulation results of noisy and estimated measurement signals

As shown clearly in the figure above, elevation angle rate measurement errors are suppressed from 1 to 0.03 degree per seconds and this shows that the filter attenuates the noise by the value 15.2 db. Similarly, azimuth angle rate measurement errors are also suppressed from 1 to 0.1 degree per seconds as shown in the figure 3. This shows that the filter attenuates the noise by the value 10.0 db. Range rate measurement errors are also improved by a magnitude of the attenuation around 2.5 db.

3. RESULTS AND DISCUSSION

3.1. Assumptions and Initial conditions

On this work, two launching platforms are considered. The first one is from the aircraft on the air which is air to surface (ASM) and the second is from the ground on fixed location which is surface to surface (SSM) and surface to air (SAM) scenarios are assumed. It is known that guidance system activity is started after booster separation time (assuming 4 seconds), and guidance system function is switched on after 4 seconds to provide acceleration commands, and for the ease of complicity in this study the missile is assumed single stage.

Here two types of targets are assumed and the first one is a ground target moving with constant speed at a maximum separation distance of 20 kilometre from the launching platform and the second target type is manoeuvring air target.

Scenario 1: (Surface to surface)

Assuming the launcher is located and fixed on the ground somewhere on pre allocated position, and a target is assigned as aground target moving with a constant velocity. Taking five different groups of target parameters for comparison purpose, and naming TP1, TP2, TP3, TP4 and TP5 assigning different position, velocity and heading angle parameters for each, the corresponding simulation result for the three dimensional engagement are shown in the figure 4 below.

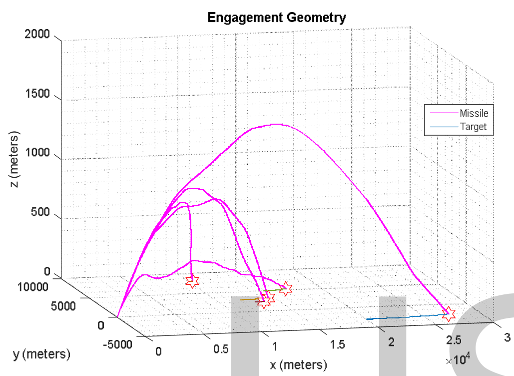

Figure 4: Simulation result for scenario 1

As a performance metrics, simulation results of the miss distance and engagement time are recorded and shown in the table 3 below.

Table 3: Recorded data for scenario 1

Parameters	Miss distance in (meters)	Engagement time in (seconds)
TP1	1.513	29.16
TP2	1.244	16.50
TP3	0.907	20. 29
TP4	0.923	16.16
TP5	1.715	17.32

Scenario 2: (Air to surface)

In this scenario the initial velocity of the missile will be the sum of the aircraft and the initial launching speed, so comparatively this should be greater than the speed defined in scenario 1, whereas the target parameters are similar to that of the previous scenario.

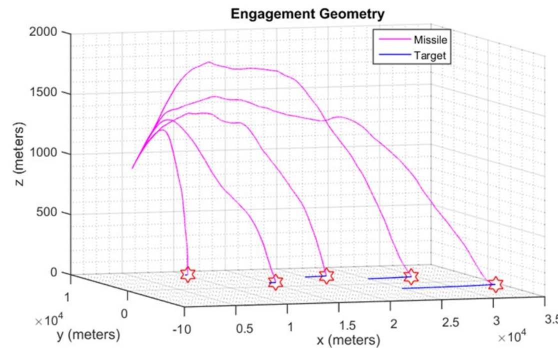

Figure 5: Simulation result for scenario 2

Table 4: Recorded data for scenario 2

Parameters	Miss distance in (meters)	Engagement time in (seconds)
TP1	1.950	38. 14
TP2	1.800	30.26
TP3	1.466	22. 35
TP4	1.079	15.13
TP5	1.951	13.23

Scenario 3: (Surface to Air)

Since PN guidance is effective for both stationary or moving ground targets as well as fast manoeuvring air targets, it is also necessary to account flying air targets in the simulation model to evaluate guidance system performance effectiveness. In this case, the previous target model is modified and implemented by considering real situations that flying air targets can possess. Here a manoeuvring fighter jet aircraft target is assumed, and it is modelled to manoeuvre with the acceleration of 9g, and maximum velocity of 300 meters per second.

In this scenario, the missile is launched from the surface of the earth, which is within the acceptable range of the target. Changing the value of initial height of target ZT_1 = ZT_2 = ZT_3 = ZT_4 = ZT_5 = 3000 meters, and simulating the system for TP1 up to TP5 initial target positions, we can clearly observe that the guidance system is effective for manoeuvring targets too. The simulation results for five different target initial positions are shown below.

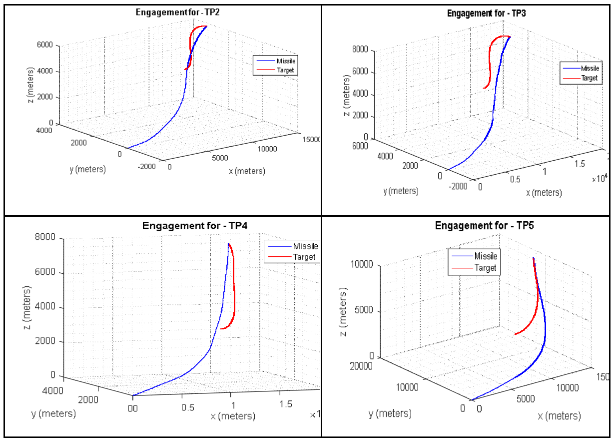

Figure 6: Simulation result for scenario 3

Table 5: Recorded data for scenario 3

Parameters	Miss distance in (meters)	Engagement time in (seconds)
TP1	1.60	22.7
TP2	1.73	18.39
TP3	1.99	22.69
TP4	1.71	19.02
TP5	1.67	23.91

Looking deep to the guidance system outputs, the generated commanded acceleration components are bounded in the range between [-220 380] m/s^2 values and still it needs to be more smoothened for better terminal engagement performance. In this study a first order digital fading memory filter is incorporated to smooth the generated command acceleration. After digital fading memory filter, the commanded acceleration value fluctuates between ± 200 m/s^2 that shows the magnitude is reduced by 1.8 percent. And due to the fact that excessive large amount of acceleration command can increase the total drag which minimizes the controllability of the missile. So we can conclude that in addition to estimating seeker measurement signals, incorporating fading memory filters and smoothing the acceleration command improves the miss distance better.

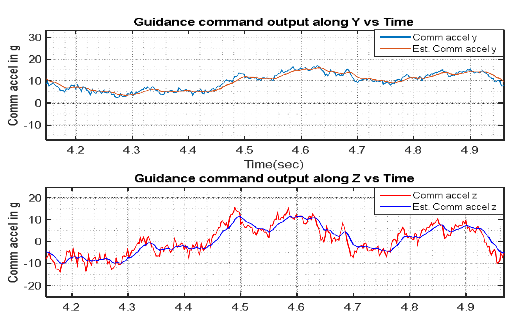

Figure 7: Command acceleration smoothed by fading memory filer

4. CONCLUSIONS

Seeker measurement signals are normally corrupted by the disturbance in the apparent angle of arrival of the received signal and additive noises generated by the background radiation from environmental and receiver effects. For simulation purpose, these noises are modelled using Matlab Simulink and added with seeker measurement signals. EKF is applied to estimate noisy seeker measurement signals and a constant gain filter is implemented to smooth the guidance command acceleration for better guidance system performance.

Here in this work different test scenarios are established and simulation results are compared by varying the parameters of the missile and target, and system performance is also analysed, with selected performance metrics of terminal miss distance and the engagement time.

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REFERENCES

[1] C. Andrew, "*Dual-seeker measurement processing for tactical missile guidance"* Air Force Institute of Technology, December 1982, (Master's thesis)

[2] M. Benjamin,. "*Statistical Methods for Launch Vehicle Guidance, Navigation and Control (GN&C) System Design and Analysis",* Utah State University, 2012, (Masters' thesis)

[3] J. Daniel, "*Missile design pc TRAP: an improved pc trap for tactical missile design",* Naval Postgraduate School, 1993, (Masters' thesis)

[4] P. Darren, & E. Naomi, "*Pursuit and Evasion: Evolutionary Dynamics and Collective Motion"*, AIAA Guidance, Navigation, and Control Conference, 2010, Toronto, Ontario, Canada

[5] Z. Joseph, & B. Asher, "*Optimal Control Theory with Aerospace Applications"*, 2010, AIAA

[6] A. Kapoor, & T. Karthikeyan, *Guided missiles*. Hyderabad, Defense Research and Development laboratory, 1990

[7] G. Kouemou, "*Radar Target Classification Technologies",* December, 2009, EADS Deutschland GmbH Germany.

[8] W. Robert, & L. Robert, Mc Donald, Number 4, *Standard missile: guidance system development* (Vol. 2) 1981, Johns Hopkins APL Technical Digest.

[9] K. SudeshK., N. Shanthakumar, & G. Girija, "*IMM based Augmented EKF for RF Seeker Filter"*, Multi Sensor Data Fusion Lab: Flight Mechanics and Control Division National Aerospace Laboratories, Bangalore-560 017.

[10] R. Toribio, & J. Saillard, "*Identification of radar targets in resonance zone: e-pulse techniques"*, Progress report In Electromagnetics Research, 2003, PIER, France.

[11] R. Walter, "*Modern Missile: Analysis, Guidance, Control, Seeker and Technology"*, 2004, Applied technology Institute, Riva, Maryland 21140.

[12] R. Yanushevsky, *Modern Missile Guidance*. CRC Press, Boca Raton, London New York, 2008