ELEC 3224 — Homing Guidance

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Introduction

- Many guided missiles employ some version of PN as the guidance law during the terminal homing phase.
- Surface-to-air, air-to-air, and air-to-surface missile engagements, as well as space applications (including rendezvous), use PN in one form or another as a guidance law.
- A major advantage of PN, contributing to its longevity as a favored guidance scheme over the last five decades, is its relative simplicity of implementation.

Introduction

- The most basic PN implementations require low levels of information regarding target motion compared with other more elaborate schemes.
- This, in turn, simplify's onboard sensor requirements.
- Moreover, it has proven to be relatively reliable and robust.
- Under certain conditions and (simplifying) assumptions about target and missile characteristics, the PN law is an optimal guidance strategy in the sense of minimising the terminal miss distance.

Mechanisation

- Central issue is the type of sensor that is used to detect and track the target: whether it is a passive (e.g., IR), semi-active, or active (e.g., RF or laser) sensor and, as important, how it is mounted to the missile.
- Conventional implementation: requires the closing velocity and LOS rate information to produce the guidance (acceleration) commands.
- Restrict attention to planar engagements, then

$$a_{M_c} = N V_c \dot{\lambda} \tag{1}$$

- To implement PN guidance law in three dimensions it is necessary to measure the LOS rate in two sensor instrument axes that are mutually perpendicular to the sensor boresight (near-coincident with the measured LOS to the target).

Mechanisation

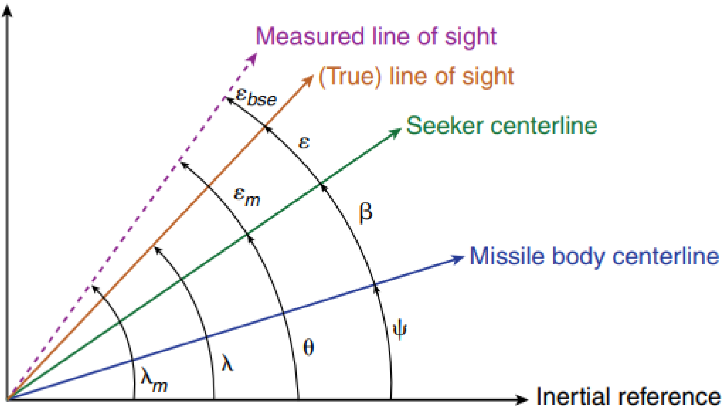
- Mechanising (1) in terms of the closing velocity V_c and the LOS rate $\dot{\lambda}$ is a function of the type of target sensor that is used and how it is mounted to the missile body.
- Acquiring closing velocity information depends primarily on the target sensor type.
- Given an (onboard) active or semi-active RF system, for example, the observed Doppler frequency of the target return can be used to develop a good estimate of closing velocity V_c.
- Other options include periodic uplinking.

Mechanisation

- The way in which LOS rate $\dot{\lambda}$ information is derived depends on the type of target sensor that is used and how it is mounted to the missile.
- For example, a space-stabilized sensor (various options) is mounted on a gimbaled platform to increase the field of regard of the sensor and to isolate it from missile body motion.
- Conversely, tracking systems that do not require a large field of regard or that employ an IR focal plane array, for example, are fixed to the body (strapdown systems).

Mechanisation

- Figure below is used in the derivation of LOS rate for guidance



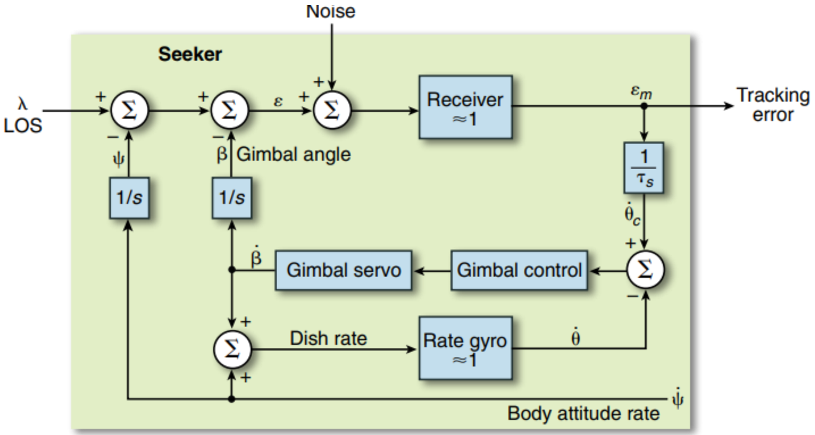
Mechanisation

- In this figure: ψ is the inertial angle to the missile body centerline; θ is the inertial angle to the seeker centerline (inertial dish angle); β is the gimbal angle (angle between seeker boresight and missile centerline)
- ϵ is the true tracking error between the LOS and seeker centerline; ϵ_{bse} is a perturbation to the true ϵ caused by radome refraction of the RF energy or irdome distortion of IR energy as it passes through the material
- ϵ_m is the measured ϵ.

Mechanisation

- λ is the true inertial LOS angle; λ_m is the measured or reconstructed inertial LOS angle.
- Tracking of a target requires the continuous pointing of the sensor beam at the target.
- Next figure: Simplified planar model of a gimbaled seeker track loop (without radome effects). In this configuration, the commanded dish rate is proportional to the tracking error.

Mechanisation



Mechanisation

- Tracking of a target requires the continuous pointing of the sensor beam at the target.
- The receiver measures the tracking error (ϵ_m) with respect to seeker coordinates.
- The measured tracking error, in turn, is used by the tracking system (the seeker track loop) to drive the seeker dish angle θ (via servomotor torquing of the gimbals) such as to minimize the tracking error, thereby keeping the target in the field of view.

Mechanisation

- Consequently, the seeker dish rate, $\dot{\theta}$ is approximately equal to the inertial LOS rate. The transfer function of LOS rate to seeker dish rate can be approximated by the following first-order transfer function:

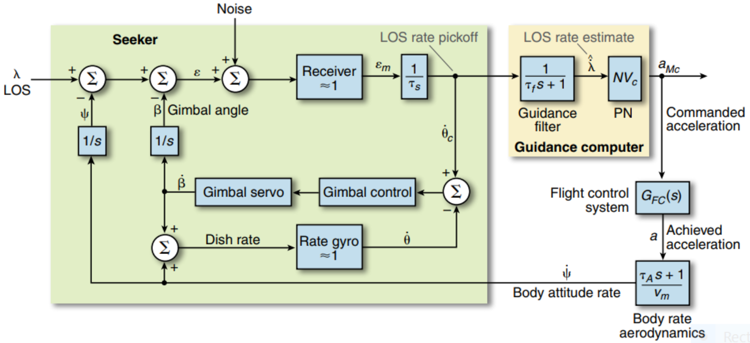
$$\frac{\dot{\theta}}{\dot{\lambda}} = \frac{1}{\tau_s s + 1} \tag{2}$$

- τ_s – seeker track-loop time constant.
- Thus, the seeker dish rate will lag the LOS rate. The accuracy to which the seeker is stabilized places fundamental limitations on the homing precision of the missile.

Mechanisation

- Next Figure: simplified planar model of a traditional LOS rate reconstruction approach that directly supplies an LOS rate measurement to the guidance computer.
- The LOS rate pickoff is assumed to be proportional to the boresight error measurement.
- The measured LOS rate is subsequently filtered to mitigate measurement noise and then applied to the PN homing guidance law.

Mechanisation



Mechanisation

- This last figure is a simplified block diagram comprising the seeker, guidance computer, flight control system, and body rate aerodynamic transfer function.
- For simplicity, the flight control system (i.e., the combined representation of the control surface actuators, aerodynamics, and autopilot) is expressed as the transfer function represented by $G_{FC}(s)$.
- The guidance system is represented as a simplified LOS rate guidance filter followed by a PN guidance law. The combined guidance system transfer function is

$$\frac{a_c}{\dot{\lambda}_m} = \frac{NV_c}{\tau_f s + 1} \tag{3}$$

- τ_f is the guidance filter time constant.

Mechanisation

- The transfer function from commanded acceleration (from the guidance law) to missile body rate ($\dot{\psi}_c$) is approximated by the following aerodynamic transfer function

$$\frac{\dot{\psi}}{a_c} = \frac{\tau_A s + 1}{v_m} \tag{4}$$

- τ_A – turning rate time constant.
- v_m missile velocity.

Mechanisation

- In this approach, the fact that the LOS rate is embedded in the tracking error (ϵ_m) is exploited.
- A LOS rate estimate is derived by appropriately filtering the receiver tracking error scaled by the seeker tracking loop time constant.
- Other methods exist for obtaining the LOS rate — not considered here.
- In endoatmospheric engagements, a radome (or irdome) is required in order to protect the onboard seeker from the elements.
- For exoatmospheric vehicles, a radome/irdome is not necessarily required. (Not considered further here.)

Guidance System Design Challenges

- There are a significant number of challenges to designing guidance systems: the design must provide the desired performance while remaining robust to a multitude of error sources, limited control system bandwidth, and inherent system nonlinearities.
- The root-mean-square final miss distance from all noise sources must be minimized.
- Guidance system stability must be maintained in the parasitic feedback loop (this is caused by angular distortion of the radome/irdome). Radome angular distortion, in particular, is a key contributor to final miss distance but is considered separately from other noise sources as its impact on guidance system stability is substantial.