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A Non-Switching Guidance Law with Terminal Constraints

Ashwini Ratnoo *

* *Assistant Professor, Department of Aerospace Engineering, Indian Institute of Science, Bangalore-560012 , India, (email:ratnoo@aero.iisc.ernet.in)*

Abstract: Impact angle controlled interception of stationary targets is considered in a surface-to-surface engagement. Existing Proportional Navigation based impact angle guidance methods require either a switching or a bias term to be added to the conventional guidance command. This paper presents a new guidance law with inherent terminal impact angle flexibility based on a lateral acceleration which is proportional to the product of the line-of-sight rate and the line-of-sight angle. Impact angle characteristics of the proposed guidance law are analyzed and sample simulations are carried out presenting the viability of the proposed method.

Keywords: Guidance systems, Impact angle control, Proportional Navigation.

1. INTRODUCTION

Impact angle constrained guidance laws have received significant interest in the context of terminal interceptor guidance. An impact along a specific direction provides a higher kill probability and a greater warhead effect. Prospective guidance laws are desired to have a simple structure, and preferably an inherent flexibility to achieve a specific impact angle.

Based on the line-of-sight rate information, Proportional Navigation Guidance (PNG) law[1, 2] is a widely used interceptor strategy owing to its simple structure, robustness and optimality. Lu et al. [3] addressed the problem of terminal guidance of a hypersonic vehicle against a stationary target using a switching logic for the PNG navigation gain. A PNG based two-stage guidance law was proposed by Ratnoo and Ghose for intercepting stationary[4] and moving[5] (non-maneuvering) targets with a desired impact angle. Therein, the first stage used a lower navigation gain to achieve a desired orientation for a switch to the second stage for achieving all impact angles in a surface-to-surface engagement. Note that switching in two-stage guidance methods leads to an abrupt change in lateral acceleration command which may be undesirable from a tracking point of view.

Adding a bias term to PNG command for shaping the trajectory is another approach that appears in the literature. A biased proportional navigation guidance (BPNG) law was proposed by Kim et al. [6] with an extra term for annulling the terminal impact angle together with the conventional line-of-sight rate term. Another two-phase impact angle constrained PNG law with a bias term was presented in [7]. The bias term was removed when a desired orientation is attained for the second phase.

Considering viability in terms of practical homing, field-of-view constrained impact angle guidance design has attracted recent attention. The methods use two-stage PNG approach[8, 9, 10] and bias shaping[11, 12, 13].

Based on the logic of a lateral acceleration proportional to the product of the line-of-sight rate and the line-of-sight angle, this paper proposes a new impact angle constrained guidance law. Closed-form expressions for the navigation gain are derived for achieving desired impact angles. Simulations are carried out supporting the analytic findings.

The organization of the rest of the paper is as follows: The guidance problem is defined in Section II followed by the proposed guidance law discussion in Section III . Section IV presents the simulations studies. Section V contains concluding remarks.

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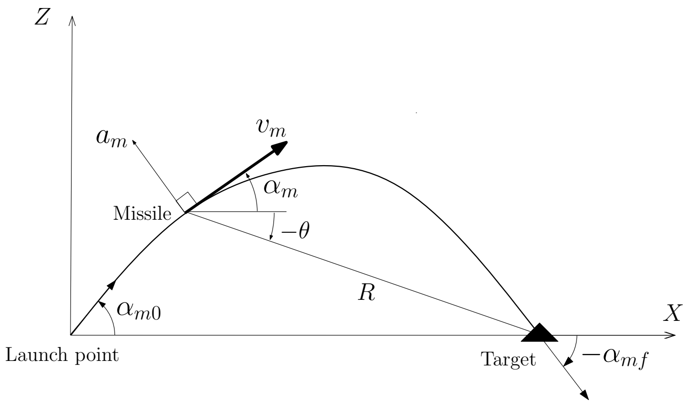

Fig. 1. Engagement geometry

2. PROBLEM STATEMENT

Consider a planar surface-to-surface engagement scenario against a stationary target as shown in Fig. 1. Here α_m, θ, and R denote missile heading, line-of-sight angle, and range-to-target, respectively. Lateral acceleration is denoted by a_m and is applied as a guidance command normal the velocity v_m. The engagement kinematics can be expressed in polar coordinates as

$$\dot{R} = -v_m \cos(\alpha_m - \theta) \quad (1)$$

$$\dot{\theta} = -\frac{v_m \sin(\alpha_m - \theta)}{R} \quad (2)$$

$$\dot{\alpha}_m = \frac{a_m}{v_m} \quad (3)$$

The guidance objective is to intercept the target satisfying a desired terminal impact angle $\alpha_{mf} \in (0, \ -\pi)$ from any initial launch angle $\alpha_{m0} \in (0, \ \pi)$.

3. PROPOSED GUIDANCE METHOD

The guidance law design is based on the line-of-sight rate and the line-of-sight angle information.

3.1 Guidance law

The new guidance law is proposed as

$$\dot{\alpha}_m = -k\theta\dot{\theta}, \quad k > 0 \quad (4)$$

where the lateral acceleration is proportional to the product of the line-of-sight rate and the line-of-sight angle.

3.2 Impact angle characteristics

Integrating (4),

$$\alpha_m = -\frac{k\theta^2}{2} + C \quad (5)$$

where the integral constant can be deduced using the initial conditions as,

$$C = \alpha_{m0} + \frac{k\theta_0^2}{2} \quad (6)$$

Considering, surface-to-surface engagements with $\theta_0 = 0$, the missile heading of (5) can be expressed as,

$$\alpha_m = -\frac{k\theta^2}{2} + \alpha_{m0} \quad (7)$$

Against stationary targets, the collision course corresponds to,

$$\alpha_{mf} = \theta_f \quad (8)$$

where, α_{mf} and θ_f are the terminal values of the missile heading and the line-of-sight angle, respectively. Using (8) in (7), at the final time,

$$k\alpha_{mf}^2 + 2\alpha_{mf} - 2\alpha_{m0} = 0 \quad (9)$$

$$\Rightarrow \alpha_{mf} = \frac{-1 \pm \sqrt{(1 + 2k\alpha_{m0})}}{k} \quad (10)$$

Again, for surface-to-surface engagements, $\alpha_{mf} < 0$, which leads to

$$\alpha_{mf} = \frac{-1 - \sqrt{(1 + 2k\alpha_{m0})}}{k} \quad (11)$$

as the relation between the choice of the gain and the resulting impact angle for a given initial heading. Alternatively, for a desired impact angle, the choice of gain k can be obtained as

$$k = \frac{2(\alpha_{m0} - \alpha_{mf})}{\alpha_{mf}^2} \quad (12)$$

4. SIMULATION RESULTS

Missile speed $v_m = 300$ m/sec together with the initial position $(x_{m0}, z_{m0}) = (0, 0)$ and is considered. A stationary target is considered at $(x_{t0}, z_{t0}) = (10000, 0)$ m. Simulations are terminated for a miss distance $R < 0.1$ m.

4.1 Vertical impact with a launch angle $\alpha_{m0} = 30$ deg.

With $\alpha_{m0} = 30°$ and $\alpha_{mf} = -90°$ the gain k can be computed using (12) as $k = 1.7$. The resulting missile trajectory is plotted in Fig. 2 (a) showing a successful interception with a less than 0.05° error in the impact angle. The lateral acceleration profile is shown in Fig. 2 (b)