Computers and Electrical Engineering 000 (2016) 1–10

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Using proportional navigation and a particle swarm optimization algorithm to design a dual mode guidance☆

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ARTICLE INFO

Article history:
Received 30 June 2015
Revised 27 January 2016
Accepted 27 January 2016
Available online xxx

Keywords:
Proportional navigation (PN)
Particle swarm optimization (PSO)
Improved PSO guidance (IPSOG)
Line-of-sight (LOS)
Guidance law
Missile

ABSTRACT

This paper proposes a dual mode guidance, which is called the proportional navigation-improved particle swarm optimization guidance (PN-IPSOG), in order to optimize the guidance performance of a missile. The improved particle swarm optimization guidance (IPSOG) has the advantages of a robustness and fast reaction, but the attitude of the missile is unstable in the initial phase. Therefore, proportional navigation (PN) guidance is used to adjust the attitude of the missile in the initial phase. Meanwhile, the angle μ that is between the tangent of the current line-of-sight (LOS) rate and the horizontal reference line is calculated. When a set of μ is close to zero, the PN-IPSOG switches from the PN guidance to the IPSOG. Numerical simulation results show that the performance of the PN-IPSOG is better than the PN guidance at miss distance and lateral accelerations.

1. Introduction

Missiles have become important in combat and during the writing of this paper many missile guidance laws were researched. These included proportional navigation (PN) guidance [1], ideal proportional navigation (IPN) guidance [2], and pure proportional navigation (PPN) guidance [3]. With the spread of artificial intelligence (AI) and machine learning, intelligent missile guidance is becoming more widespread. For example, Dalton et al. [4] designed a neural network controller which used the notion of an adaptive critic to solve the pursuit-evasion problem. Lin [5] proposed a fuzzy logic based missile terminal guidance in which the fuzzy rule was based on the line-of-sight (LOS) rate, LOS angular acceleration and relative distance. Li et al. [6] developed a fuzzy logic guidance based on PN guidance, and utilized a genetic algorithm to optimize the fuzzy rule base.

In 2013, particle swarm optimization guidance (PSOG) was proposed by Kung et al. [7], and made its debut in the missile guidance field. The PSOG was based on a particle swarm optimization (PSO) algorithm, and optimized the lateral acceleration at each time-step. Afterward, the performance was improved by Chen et al. [8], which is called the improved PSOG (IPSOG). The concept was that the LOS rate is close to zero at each time-step. In other words, the IPSOG was similar to parallel navigation. The IPSOG has the advantages of a robustness and fast reaction; however, the lateral acceleration has severe variations in the initial phase. The attitude of a missile does not only become unstable, but also affects the structure. As for PN guidance, the lateral acceleration had a slight variation in the initial phase. In the terminal phase, it usually varied with

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http://dx.doi.org/10.1016/j.compeleceng.2016.01.025

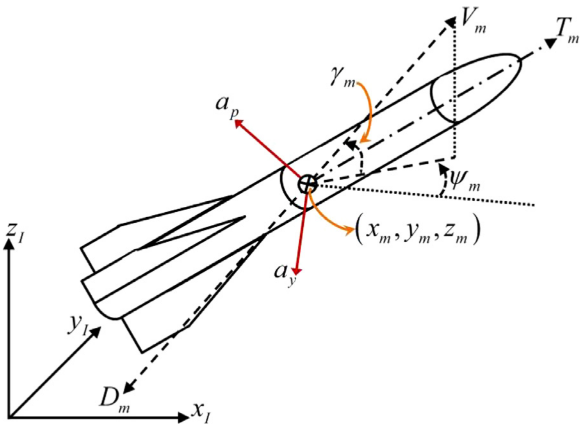

Fig. 1. Definition of a missile's aerodynamic vectors.

a target's maneuvering. Thus, miss distance (MD) might not only be greater, but the final lateral acceleration also might fall in saturation.

In this paper, we propose a dual mode guidance, which is called the PN-IPSOG. The concept is derived from the guidance method of a medium-range missile. In the initial phase, the lateral acceleration is given by the PN guidance. Meanwhile, the switch law (SL) is used to detect the switch timing. When the switch timing arrives, the PN-IPSOG would switch from the PN guidance to the IPSOG. We expect that the PN-IPSOG will not only maintain the advantages of the IPSOG, but will also take the advantages of the PN guidance to replace the disadvantages of the IPSOG.

This paper is organized as follows: Section 2 gives mathematical models; Section 3 describes the PN guidance, the IPSOG, and the details of the SL; simulation experiments are shown in Section 4; Finally, Section 5 is the conclusion.

2. Mathematical models

2.1. Missile dynamic

Fig. 1 shows the aerodynamic vectors of a missile. The equations of a missile dynamic [9] are as follows:

$$\dot{x}_m = V_m \cos\gamma_m \cos\psi_m \tag{1}$$

$$\dot{y}_m = V_m \cos\gamma_m \sin\psi_m \tag{2}$$

$$\dot{z}_m = V_m \sin\gamma_m \tag{3}$$

$$\dot{V}_m = \frac{T_m - D_m}{m_m} - g\sin\gamma_m \tag{4}$$

$$\dot{\gamma}_m = \frac{a_p - g\cos\gamma_m}{V_m} \tag{5}$$

$$\dot{\psi}_m = \frac{a_y}{V_m\cos\gamma_m} \tag{6}$$

$$\dot{a}_p = \frac{a_{pc} - a_p}{\tau_m} \tag{7}$$

$$\dot{a}_y = \frac{a_{yc} - a_y}{\tau_m} \tag{8}$$

$$D_m = k_1 V_m^2 + k_2 \frac{a_{pc}^2 + a_{yc}^2}{V_m^2} \tag{9}$$

where x_m, y_m, z_m are x-, y-, z-coordinates, respectively; γ_m and ψ_m are the flight path angle and the azimuth angle, respectively; V_m, T_m, D_m, and m_m are the velocity, the thrust, the drag, and the mass, respectively; τ_m is a time constant; Both k_1 and k_2 are the drag coefficients; a_{pc} and a_{yc} are the lateral accelerations of the y- and z-axis, respectively; g is the gravity force.

Please cite this article as: Y.-L. Lee et al., Using proportional navigation and a particle swarm optimization algorithm to design a dual mode guidance, Computers and Electrical Engineering (2016), http://dx.doi.org/10.1016/j.compeleceng.2016.01.025