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Finite time convergence cooperative guidance law based on graph theory

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ABSTRACT

A new cooperative guidance law with impact time and impact angle constraints is presented for multiple flight vehicles to against the stationary target. The proposed guidance law has two projection components: the one that along the line-of-sight (LOS) ensures that all flight vehicles reach the target simultaneously with impact time constraints, another one that normal the LOS guarantees the convergence of the LOS angular rate with terminal impact angle constraints. Using the second Lyapunov stability method, we prove that the time-to-go of all flight vehicles reach at agreement in finite time if the connecting time of the communication topology is larger than the required convergent time. Nonlinear simulations demonstrate the effectiveness of the proposed law.

1. Introduction

In modern warfare, some strategic and tactical targets such as airports and ships have a number of self-defense measures against missiles, such as surface-to-air missile system, ECM(Electronic countermeasures) and CIWS(close-in weapon system) [1]. These systems have been great obstacles of flight vehicles to complete their missions. As an effective countermeasure for these defense systems, the salvo attack, which means that many flight vehicles are required to reach the target simultaneously, attracts more and more attentions from researchers. Obviously, even if some flight vehicles are intercepted by the self-defense system, the target can still be destroyed by the remaining flight vehicles.

Previous guidance law is to control the flight vehicle to intercept a designated target with minimum miss distance and less energy consumption [2]. Guidance problems with impact time constraints have been researched in recent years as the result of development of cooperative control of multi-vehicle systems. An impact-time-control guidance (ITCG) based on traditional proportional navigation guidance (PNG) for accomplishing the salvo attack mission is proposed in [3]. As an extension of this study, the authors in [4] derived a new guidance law called impact-time-and-angle-control guidance (ITACG) to satisfy both impact time and impact angle constraints. Zhao S. Y proposed a novel leader-follower method by introducing a virtual leader for each flight vehicles, with which a time-constrained cooperative guidance scheme was designed [5,6]. A new concept, the variance of the time-to-go, is introduced and a cooperative proportional navigation guidance law, which can achieve a simultaneous attack by decreasing the variance of time-to-go cooperatively till the intercept is presented in [7]. In [8], the authors first provided a novel sliding mode control by backstepping approach and then used it to derive an impact time and impact angle constrained guidance law through the line-of-sight rate shaping. Recently, the consensus problem of multiple agent system with finite time convergence attracts more and more attention from researchers [9–12]. The authors

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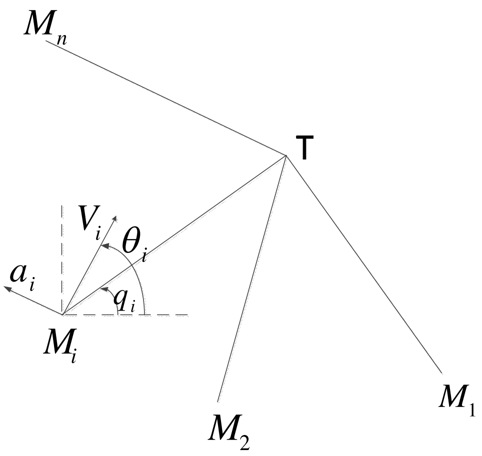

Fig. 1. Two-dimensional engagement geometry.

in [13] designed a novel finite time convergence cooperative guidance law for multi-vehicle considering actuator failures with impact time constraints.

Motivated by these studies, a new cooperative guidance law for multi-vehicle with impact time and impact angle constraints is provided in this paper based on graph theory. The proposed guidance law has two projection components, the one that along the line-of-sight (LOS) is used to ensure that all flight vehicles reach the target simultaneously with impact time constraints, another one that normal the LOS is designed to guarantee the convergence of the LOS angular rate with terminal impact angle constraints.

This paper is organized as follows: In Section 2, the problem statement is provided. Preliminaries of graph and some Lemmas are given in Section 3. In Section 4, a new cooperative guidance law for multi-vehicle with arrival time constraint based on graph theory and impact angle constraints is provided. Simulation results and analysis are shown in Section 5. Finally, the concluding remarks are offered in the last Section.

2. Problem statement

The engagement geometry for a planar attack between multiple flight vehicles and the stationary target is shown in Fig. 1. Here, M denotes the flight vehicle and T denotes the target in the coordinate; q and θ denotes the LOS angle and the flight vehicle flight path angle, respectively; where r denotes the relative distance between the flight vehicle and the target. V denotes the flight vehicle velocity. The parameter with a subscript $i(i = 1, 2, \cdots n)$ denotes the state variable of the ith flight vehicle. Both the flight vehicle and target are assumed to be point-mass and system lag, such as autopilot lag, is negligible.

Since most information related to flight vehicle and target is convenient to be described in the LOS frame. The differential equation describing the relative kinematics of the ith flight vehicle and the target can be formulated as

$$\dot{r}_i = -V_i \cos(\theta_i - q_i) \tag{1}$$

$$r_i \dot{q}_i = -V_i \sin(\theta_i - q_i) \tag{2}$$

Differentiating Eqs. (1) and (2) with respect to time yields,

$$\ddot{r}_i = r_i \dot{q}_i^2 - u_{r,i} \tag{3}$$

$$r_i \ddot{q}_i = -2\dot{r}_i \dot{q}_i - u_{q,i} \tag{4}$$

Where, $u_{r,i}$,$u_{q,i}$are the acceleration components along the LOS and normal the LOS of the ith flight vehicle. Let $V_{r,i} = \dot{r}_i$ and $V_{q,i} = r_i \dot{q}_i$ be the flight vehicle velocity components along the LOS and normal to the LOS of the $i$thflight vehicle, respectively.

The kinematics between flight vehicle i and the target in the LOS frame can be rewritten as

$$\begin{bmatrix} \dot{r}_i \\ \dot{V}_{r,i} \\ \dot{V}_{q,i} \end{bmatrix} = \begin{bmatrix} V_{r,i} \\ \dfrac{V_{q,i}^2}{r_i} - u_{r,i} \\ -\dfrac{V_{r,i} V_{q,i}}{r_i} - u_{q,i} \end{bmatrix} \tag{5}$$