Design of Multi-Criteria PI Controller Using Particle Swarm Optimization for Multiple UAVs Close Formation

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ABSTRACT

Close formation flight is one of the most complicated problems on multiple Uninhabited Aerial Vehicles (UAVs) coordinated control. This paper proposes a new method to achieve close formation tracking control of multiple UAVs by applying Particle Swarm Optimization (PSO) based Proportional plus Integral (PI) controller. Due to its simple structure and effectiveness, multi-criteria PI control strategy is employed to design the controller for multiple UAVs formation, while PSO is used to optimize the controller parameters on-line. With the inclusion of overshoot, rise time, and system accumulated absolute error in the multi-criteria performance index, the overall performance of multi-criteria PI controller is optimized to be satisfactory. Simulation results show the feasibility and effectiveness of the proposed approach.

Keywords: Close Formation Flight, Particle Swarm Optimization (PSO), Proportional plus Integral (PI), Uninhabited Aerial Vehicle (UAV)

1. INTRODUCTION

Uninhabited Aerial Vehicle (UAV) is an aircraft that flies without a human crew on board the aircraft. Their largest uses are in military applications, especially to replace the human presence in repetitive or dangerous missions (Ambrosino et al., 2009). Multiple UAVs system is being used in a very diverse range of roles, from urban reconnaissance through to high altitude long endurance (HALE) operations (Constantinides et al., 2008). One of the problems particularly interesting to researchers is the automatic cooperative control of a group of UAVs flying in close formation (Duan et al., 2008). When multiple UAVs fly in formation, the formation’s initial geometry, including the longitudinal, lateral and vertical separation,
should be preserved during maneuvers with heading change, speed change and altitude change. A close formation, also called “tight formation”, is the one in which “the lateral separation between UAV is less than a wing-span” (Proud et al., 1999; Pachter et al., 2001). In this case, aerodynamic coupling is introduced into the formation’s dynamics. Multiple UAVs flying in a close formation can achieve a significant reduction in power demand, thereby improving cruise performances, such as range and speed, or to increase the payload (Zhang et al., 2010; Binetti et al., 2003). Various control strategies for multiple UAVs formation have been reported in the literatures. Among them, the Leader-Wingman approach has been well recognized and become the most popular approach (Liu et al., 2007): one or more UAVs of the flight formation are selected as leaders and are responsible for guiding the formation, with the rest of UAVs required to follow the leader.

The “Leader-Wingman” formation pattern can be shown with Figure 1.

If the wingman flies close to the leading UAV, the leader’s vortices will produce aerodynamic coupling effects, and a reduction in the formation’s drag can be achieved. According to the effects of aerodynamic interference, multiple UAVs close formation flight control is a complex problem with strongly nonlinear and coupling character. The development of a UAV is expensive, and a small error in automatic control can result in a crash (Chen & Chang, 2008). The design and implementation of control methods for multiple UAVs close formation is a hot issue recently. The problem of modeling and control of leader-follower close formation has been studied by many researchers. Many classic and modern control approaches have been applied to solving this problem, including PI controller (Proud et al., 1999; Pachter et al., 2001; Dargan et al., 1992; Buzogany et al., 1993), nonlinear adaptive control (Singh & Pachter, 2000), fuzzy logic (Li et al., 2005), robust control (Li et al., 2006), and receding horizon control (Zhang et al., 2010; Hu et al., 2007).

The conventional Proportional-Integral-Derivative (PID) controller is a widely used industrial controller that uses a combination of proportional, integral and derivative action to control error to form the output of the controller. Due to its simple structure and effectiveness, this control strategy has been the mainstay for decades among practicing engineers (Duan et al., 2009). After the three parameters have been tuned or set in some way, control parameters of the standard PID controller remain unchanged during the whole control process. Various parameters tuning methods have been presented, which can be classified as: (1) the Ziegler-Nichols (ZN) method and the Internal Model Control (IMC), these methods are treated as empirical methods; (2) analytical methods typified by root locus based techniques; (3) methods basing on optimization such as the iteration feedback tuning (IFT) (Hjalmarsson et al., 2005).
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