Chapter 28
Formation Flight Control Scheme for Unmanned Aerial Vehicles

Zdzisław Gosiewski and Leszek Ambroziak

Abstract. Cooperative control of Unmanned Aerial Vehicles is currently being researched for a wide range of applications. Applicability of aerial unmanned systems might be increased by formation flight. In this paper, we present an application of a proportional-integral controller for formation flight of three Unmanned Aerial Vehicles (UAVs). A decentralized cooperative control scheme is used with information flow modeled by a leader-follower structure. Control laws, based on velocity and position errors between the vehicles, are defined and derived for each of the three flying objects in formation. The main goal of this work is a simulation study. Three-dimensional motion of the three-object formation was performed and analyzed using a six-degrees-of-freedom state space quadrotor model. The simulation studies presented allow verifying the adopted control structure. Convergence time is used as an indicator of the control system quality and the formation stability. The presented research and diagram of control algorithms tests were done before experimental tests and field trials of formation flight.

28.1 Introduction

Formation flight is defined as intended motion of two or more flying objects, connected by a common control law [1]. Formation flight is a special case of UAV group flight, which is focused on achieving and maintaining a particular structure (shape) of the entire formation, appropriate speed keeping at flight through individual objects in the formation, distance keeping by neighboring vehicles and collision avoidance. To meet all these criteria, the process of designing the control laws needs to be supported by numerous studies of simulation [2][3]. Formation flying, and problems associated with it are a relatively young field of science and a new theme...
inspired by biology. In 1977 Scholomitsky, Prilutsky, and Rodnin [5] worked on the concept of an infrared interferometer for a few flying objects. This date, according to the literature review related to this subject, is considered the beginning of work on formation flights. These studies were used and continued in the early eighties by Lyberie, Samarie, Schumacher, Stachnik, and Gezari [5], for formation flight of spacecrafts, their refueling and maintenance. In the mid-eighties and early nineties researchers began to focus on the use of formation flight for airplanes [8] and automatic refueling in the air. That was the beginning for research in the nineties and now on flights and flights within a group and formation of unmanned flying objects. There are many works which concern aircraft formation flight strategies such as fuzzy logic control [6], adaptive control [9], or robust control [7], but they are considered only theoretically. Practical formation flight tests are also taken [10, 11, 12], but they are always based on analytical and simulation research. In this paper we present an application of a proportional-integral controller to formation flight of three Unmanned Aerial Vehicles (UAVs). We adopted the leader-follower type pattern of communication between vehicles. Decentralized control laws were used and performed for each one of three UAVs. To check the adopted control system, simulations with six-degrees-of-freedom state space UAV model are presented.

28.2 Vehicle Model Description

In this paper we consider a formation of three identical flying objects which can communicate with one another to achieve the main goal – formation keeping. Every object in the formation has two main control loops. The first feedback control loop (internal) stabilizes the objects locally. The second feedback control loop (external) is a "formation-level" controller and is responsible for formation achieving. For this reason, we would like to present dynamics of the control objects and their local controllers first. We have chosen quadrotors as the control objects. They are vertical take-off and landing (VTOL) objects with very specific dynamics. Quadrotors are often used as a platform for formation flying control framework [4]. They can hover above the desired waypoint and can change the motion direction in place. It is simple to separate navigation from orientation in quadrotor motion. A simplified dynamics model of these objects is described in the next subsection.

28.2.1 Quadrotor Model Dynamics Used in Simulations

The dynamics of a single quadrotor is shown in equations (28.1)–(28.6). The quadrotor dynamical model is obtained from the Euler-Lagrange Equations with external force simplified based on [4]. For the first stage of simulations and to verify the control law quality this dynamics model is sufficient: