Mechatronics 21 (2011) 844–860

Contents lists available at ScienceDirect

Mechatronics

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

Autonomous terrain-following for unmanned air vehicles

Raza Samar *, Abdur Rehman

Centre for Control & Instrumentation, Engineering & Scientific Commission, Islamabad, Pakistan

ARTICLE INFO

Article history:
Available online 25 October 2010

Keywords:
Terrain-following
Decision making and autonomy
Altitude control
Mission planning
Guidance and control of UAVs
Trajectory tracking and path following
robust control applications
Ectromechanical actuators

ABSTRACT

This paper presents an integrated guidance and control design scheme for an unmanned air vehicle (UAV), and its flight test results. The paper focuses on the longitudinal control and guidance aspects, with particular emphasis on the terrain-following problem. An introduction to the mission, and the terrain-following problem is given first. Waypoints for climb and descent are defined. Computation of the reference trajectory in the vertical plane is discussed, including a terrain-following (TF) algorithm for real-time calculation of climb/descent points and altitudes. The algorithm is particularly suited for online computation and is therefore useful for autonomous flight. The algorithm computes the height at which the vehicle should fly so that a specified clearance from the underlying terrain is always maintained, while ensuring that the vehicle's rate of climb and rate of descent constraints are not violated. The output of the terrain-following algorithm is used to construct a smooth reference trajectory for the vehicle to track. The design of a robust controller for altitude tracking and stability augmentation of the vehicle is then presented. The controller uses elevators for pitch control in the inner loop, while the reference pitch commands are generated by the outer altitude control loop. The controller tracks the reference trajectory computed by the terrain-following algorithm. The design of an electromechanical actuator for actuating the control surfaces of the vehicle during flight is also discussed. The entire guidance and control scheme is implemented on an actual experimental vehicle and flight test results are presented and discussed.

1. Introduction

The notion of unmanned vehicles capable of autonomous flight is fast becoming a reality, with the level of autonomy continuously on the increase. The availability of high performance embedded computing platforms combined with the development of sophisticated algorithms has transformed the realm of unmanned vehicles within a span of a few years. In this paper we present an integrated approach to the design of a practical and autonomous terrain-following guidance and control system for an experimental aircraft, and discuss its in-flight performance.

The UAV under consideration is a high performance vehicle, shown in Fig. 1. It is propeller driven in a push-configuration. Pitch control is provided by a set of canards located forward of the main wing, roll control is provided by ailerons on the main wing, and the two vertical tails have rudders. The cruising speed is about 50 m/s. The main tasks of the planning, guidance and control system are to:

- given a mission in terms of geographical waypoints (latitude and longitude information), generate a series of altitude change (or climb/descent) points while satisfying vehicle constraints and providing a minimum clearance above the terrain,
- use the altitude change points to generate a feasible terrain-following reference trajectory for the vehicle,
- fly the vehicle on the reference path with minimum altitude error, and
- provide robust stabilization and control during flight.

Various approaches for terrain-following and avoidance have been discussed in the literature, see for example [1–4]. In [1] an optimization problem is set up in which cubic splines are optimized to lie close to the underlying terrain. Constraints are satisfied at node points which are also the optimization parameters. The larger the number of node points, the more the number of optimization parameters and hence the greater the computational cost. In [5] the vertical path is generated by using a large number of parabolic segments called the *pullup* and *pushover* parabolas. The parabolas are designed to satisfy the acceleration limits of the vehicle; terrain peaks are crossed horizontally, with a given clearance. Lu and Peirson [2] formulate the terrain-following problem as an optimal control problem and suggest a numerical method for its solution based on an inverse dynamics approach. The time of flight is included in the objective function and the dynamics of the aircraft are considered. The analysis however focuses on *offline* trajectory planning only and the results are not readily applicable to real-time onboard implementation. A nonlinear flight control law for terrain-following is discussed in [3] based on the predictive

* Corresponding author.
E-mail addresses: raza.samar@gmail.com, raza@mail.comsats.net.pk (R. Samar).

0957-4158/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechatronics.2010.09.010