AN APPROACH TO THE ADAPTIVE MODE TRANSITION CONTROL OF UNMANNED AERIAL VEHICLES

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Abstract

A new approach to the adaptive mode transition control of unmanned aerial vehicles is proposed. The proposed architecture consists of three levels: the highest level is occupied by mission planning routines where information about way points the vehicle must follow is processed. The mid-level controller uses a trajectory-planning component to coordinate the task execution and provides set points for low-level stabilizing controllers. The adaptive mode transitioning control algorithm resides at the lowest level of the hierarchy consisting of a mode transitioning controller and the accompanying adaptation mechanism. An actual flight demonstration is planned for the near future as part of a DARPA sponsored research program to validate the control algorithms.

1. Introduction

Control of Unmanned Aerial Vehicles (UAVs) presents unique challenges not only in the design of control algorithms, but also in the strategies used to integrate and implement them on the actual vehicle. In this paper a new approach to the adaptive mode transition control of UAVs is proposed. The main objective is to improve the degree of autonomy/intelligence of the UAV and its performance under uncertain conditions, for instance when external disturbances are present. The adaptive mode transition control scheme was first introduced in [1,2]. This paper suggests a new approach to the adaptive mode transition control problem and introduces a hierarchical architecture to implement it. The algorithms have been implemented and tested using the Open Control Platform (OCP) - a new open software infrastructure especially developed for the implementation of complex reconfigurable control systems such as UAVs [3].

2. Approach

The proposed architecture is depicted in Figure 1. At the lowest level of the hierarchy, an adaptive mode transition controller coordinates the execution of the local controllers or the active control models, which stabilize the vehicle and minimize the error between the set points generated by the middle level and the actual state of the vehicle. The adaptive mode transition control consists of the mode transition control component and the adaptation mechanism.

The mode transition control component consists of the local controllers (one for each local mode), the active control models (one for each transition), and the mode transition manager. The latter decides which controller to use at a given time (a local controller or an active control model) based on the actual state of the vehicle.

The local controllers are of the discrete time tracking variety running at a fixed sample rate. The control law is given by:

$$u(k) = K_i e(k) + u_{trim,i} \tag{1}$$

where k represents the discrete time, $u(k)$ is the actuator command vector, $e(k)$ is the error between the desired state (set point) generated by the trajectory planning component ($x_d(k)$) and the actual state of the vehicle obtained from on-board sensors ($x(k)$). The parameters for local controller i are the gain matrix K_i, and the trim value of the actuator command, $u_{trim,i}$.

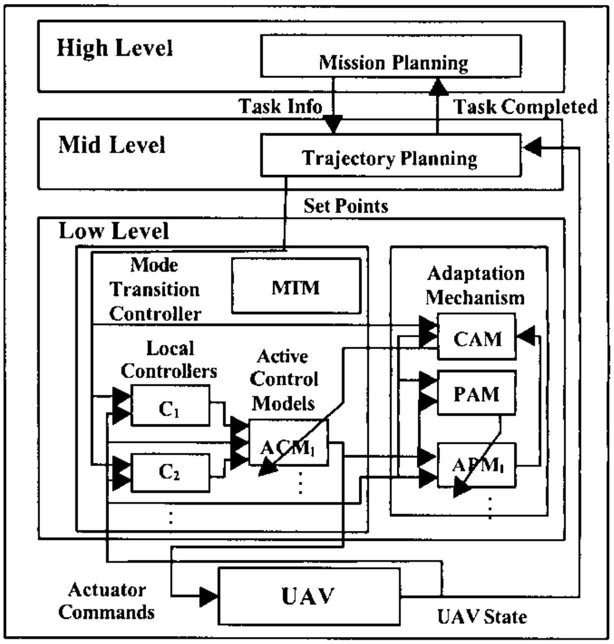

Figure 1. Adaptive Mode Transition Control Architecture

The state of the vehicle is given by

$$x(k) = [x, y, z, \phi, \theta, \psi, u, v, w, p, q, r]^T \tag{2}$$

where x, y, z represent the position, ϕ, θ, ψ the attitude, u, v, w the velocity, and p, q, r the angular rates.

Once the operating state of a mode is determined, an approximate model of the vehicle is linearized about that state, and then discretized. A linear quadratic regulator is computed for the gain matrix K_i and the same design procedure is used for each mode. When an approximate model of the vehicle is not available, the linearized model is obtained from a Fuzzy Neural Network (FNN) model trained with input-output data from the actual vehicle in the same way as with the active plant models to be discussed in the sequel.

The Mode Transition Manager (MTM) coordinates automatically the transitions based on the actual state of the vehicle. In order to accomplish this task, a Mode Membership Function is defined for each local mode and the MTM determines which local mode or transition should be activated relying upon these constructs.

When a local mode is active, the corresponding local controller is used to compute the control output whereas when a transition is active, the corresponding Active Control Model (ACM) is used to compute the control output.

The Active Control Models are in charge of the transitions between local modes. The function of the ACM is to blend the outputs of the local controllers corresponding to a certain

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transition in a smooth and stable way, that is, the blending of the local controllers should not deteriorate the overall performance of the closed loop system. Every ACM includes a FNN that generates the blending gains to compute the control output. At run time, the FNN of each ACM is adapted on-line by the control adaptation mechanism.

The adaptation mechanism consists of the plant adaptation and component adaptation mechanisms and also includes the active plant models (one for each transition), which serve as partial models of the plant in the transitions.

The APMs provide the sensitivity matrices required to adapt the ACMs and include a FNN that is trained to represent the dynamics of the vehicle in the transition.

When the vehicle is in a transition, input/output information from its sensors is used by the plant adaptation mechanism to train the APM by calling upon a recursive least squares training routine from the FNN.

The control adaptation mechanism provides the adaptation function to the ACMs. When an ACM is active and the control adaptation mechanism is enabled, a dynamic optimization routine is used to find the optimal control value at each time step; the optimal blending gains that minimize the error between the optimal control and the control produced by the ACM are also computed. These optimal blending gains constitute the desired outputs for the recursive least squares training algorithm in the FNN, corresponding to that ACM, which is in turn called by the control adaptation mechanism.

3. Implementation And Simulation Results

The architecture has been implemented using an Open Control Platform developed jointly by Boeing and Georgia Tech to enable the implementation of advanced control algorithms for UAVs [3]. Figure 2 shows how the OCP is used to implement this hierarchical control architecture in a software-in-the-loop simulation of the UAV. A hardware-in-the-loop simulation and a flight test will be performed in the near future.

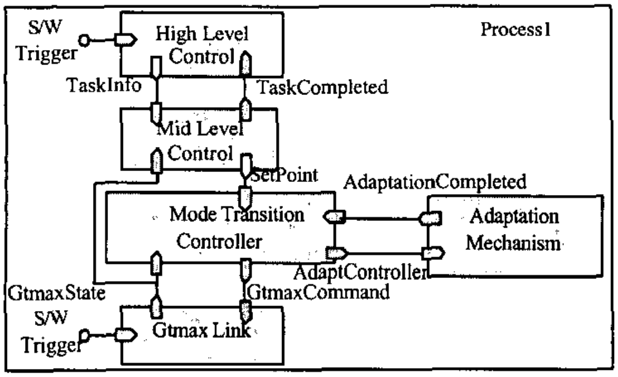

Figure 2. Adaptive Mode Transition Control Implementation On The OCP

The hierarchical/intelligent control architecture was tested in a software-in-the-loop simulation of a Yamaha Rmax helicopter. The adaptive mode transition controller includes three modes (hover, forward flight at 20ft/sec, and forward flight at 50ft/sec) and two transitions (hover - forward flight at 20ft/sec, and forward flight at 20ft/sec - forward flight at 50ft/sec). Simulation results are presented in Figure 3. It is observed how the vehicle remains stable and transitions are carried out smoothly among local controllers while keeping a small error with respect to the desired trajectory.

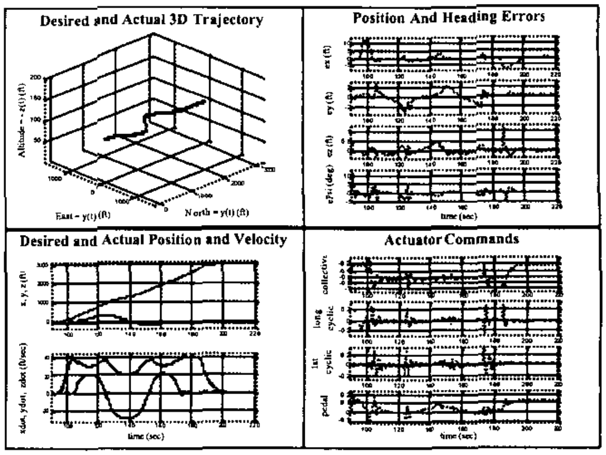

Figure 3. Simulation Results

4. Conclusions

A new approach to the adaptive mode transition control of unmanned aerial vehicles is proposed. Its architecture entails new components in the middle level and high level of the hierarchy to establish a mission and generate the set points for the corresponding trajectory. Simulation results are presented for the application of this architecture to the control of a rotary wing UAV. Results from a software-in-the-loop simulation of the vehicle illustrate the effectiveness of the scheme.

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