Embedded Real-Time Systems (AME 3623)
Homework 5 Solutions

May 2, 2006

Question 1

Helicopter dynamics in general are quite complicated (and hence, so is control). However, in certain regions of the helicopter state space (as described by variables including Cartesian and rotational position/velocity, and position and velocity of the main rotor), the helicopter behaves in a linear fashion. Three such regions are hovering, fast forward flight, and hovering upside down. This linear property makes it easy to design a feedback controller that maintains the helicopter within the corresponding region (we have one such controller for each region). But – to move between these regions requires the helicopter to pass through very non-linear (and unstable) regions of space. One strategy is to command the helicopter in a ballistic manner (without the use of feedback) so as to move as quickly through the non-linear region and arrive at a linear one (for example, hard pitch forward to quickly transition from hover to fast forward flight, where the "fast forward flight" controller can take over).

Assume that your controller has access to sensory data that includes pitch angle and forward velocity. In addition, assume that a significant change in pitch angle (e.g., by 180 degrees) requires the helicopter to be moving laterally by $.5m/s$). Design a FSM that, on command from a ground station, will bring your helicopter from hover to hovering upside down. Once in this state, on a second command, the FSM will bring the helicopter back to the hover state.

Given the specification, there are several appropriate answers to this question.

1. (5 pts) What are the states?

   The states correspond to the stable configurations of the craft. Using our linear feedback controllers, we can easily maintain the craft within these states for an arbitrary amount of time.

   The states are:

   - *Hover right-side-up (H)*
   - *Fast forward flight: right-side-up (FF)*

- *Hover up-side-down (Husd)*
- *Fast forward flight: up-side-down (FFusd)*

It is technically not correct to combine FF with FFusd because they fundamentally involve the use of different linear controllers to maintain their state. (however, we were quite liberal in our grading of this)

2. (5 pts) What are the events?

   There are two classes of events: the signals from the ground (S1 and S2), and the transition to a lateral velocity exceeding 0.5 m/s (V).

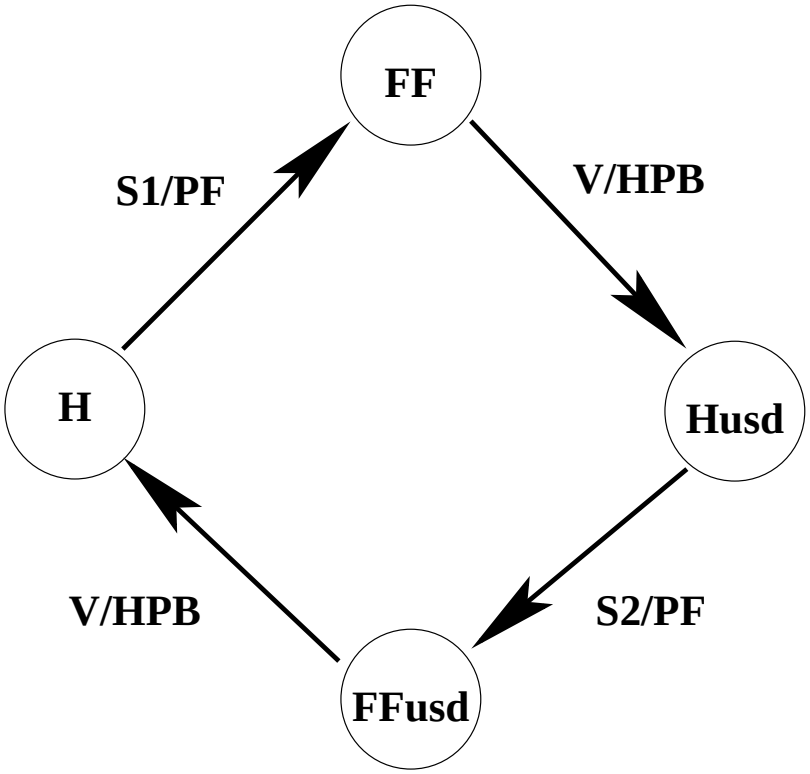
3. (10 pts) What are the outputs?

   We technically have two classes of outputs: one class that is used in response to an event; the other class of actions corresponds to what one does while one is in a state. The former are the actions that we will use to take us through the regions corresponding to the nonlinear dynamic regions (and hence between the stable regions):

   - *Pitch forward (PF)*
   - *Hard pitch backward (HPB)*

   The latter actions are the linear controllers that keep us within the state (H, FF, Husd, FFusd).

4. (10 pts) Show the state transition diagram.



If one were to combine states FF and FFusd, we would then have the situation in which there are two arrows from this state labeled with the same event, but that terminate at different states. This is technically not allowed in a finite state machine (although it does occur in generalizations of FSMs).