Altitude hold autopilot design for Foxtrot fighter aircraft

Zewail city of science & technology, Aerospace engineering department

Abdelrahman Mahmoud, Ahmed Adham, Waleed Hamdy, Ahmed Samir

I. Aircrafts operating conditions and linearized dynamics:

The following Operating conditions are chosen for linearization of the aircraft's dynamics:
Uo=265 m/s, αo=2.6 deg, ϒo=0 deg, g=9.801

The following are the aircraft's longitudinal stability derivatives:
Xu=-0.009, Xw=0.016, Xde=0.69, XdT=0.00006
Zu=-0.088, Zw=-0.547, Zwd=0, Zq=-0.88, Zde=-15.12, ZdT=-0.00005
Mu=-0.008, Mw=-0.03, Mwd=-0.001, Mq=-0.487, Mde=-11.4, MdT=-0.000003
Yv=-80.6/Uo, Yp=0, Yr=0, Lbetad=-18.3, Lpd=-1.24, Lrd=0.395, Nbetad=4.97, Npd=-0.0504, Nrd=-0.238
Ydast=-0.0007, Ydrst=0.0043, Ldad=9, Ldrd=1.95, Ndad=0.2, Ndrd=2.6

The altitude equation is: $h^{\cdot} = Uo\ sin\Upsilon = Uo\ (\theta - \alpha) = Uo\ \theta - w$

Substituting by the stability derivatives and adding the altitude state equation, the aircrafts longitudinal dynamics can be represented in state space form as follows: $x^{\cdot} = Ax + Bu, y = Cx$
A is a 5x5 matrix, B is a 5x1 column vector, u is the elevator angle and C is a 1x5 row vector.

II. LQR controller design:

The LQR control technique is used instead of the pole placement using state feedback technique for one reason: it does not need to determine the desire poles of the system. We had a problem determining what our desired poles are. We wanted to make the aircraft's rate of level1 flight quality, thus we have a numerical range for both the damping ratios of the short period and phugoid dynamics, we did not know if there is a way for computing the desired poles of the full dynamics given the desired damping ratios and natural frequencies of the short-period & long period approximations. LQR solves this as it does not require the desired poles as input. It gives the optimum solution as long as the system is fully-state controllable, which is the case here.

We started by setting the Q matrix of LQR algorithm to be a 5x5 identity matrix and setting R to 1. This resulted in a very high pitch-angle gain (535). We set the weights of all of the states to 0 except for the weight of the altitude state is was set to 0.5, this is to reduce pitch-angle gain. This reduced this gain significantly (~ 91), but still it needs to be reduced further more. The R value is increased to get lower gains, it is finally set to 50 and the gain became 19.4 which is acceptable. The resulted state feedback gains show that the short-period and phugoid damping ratios are within the ranges of level1, cat C, class IV aircrafts. The resulted gains are:
[-0.0012 0.0638 -0.6903 -19.4472 -0.1]

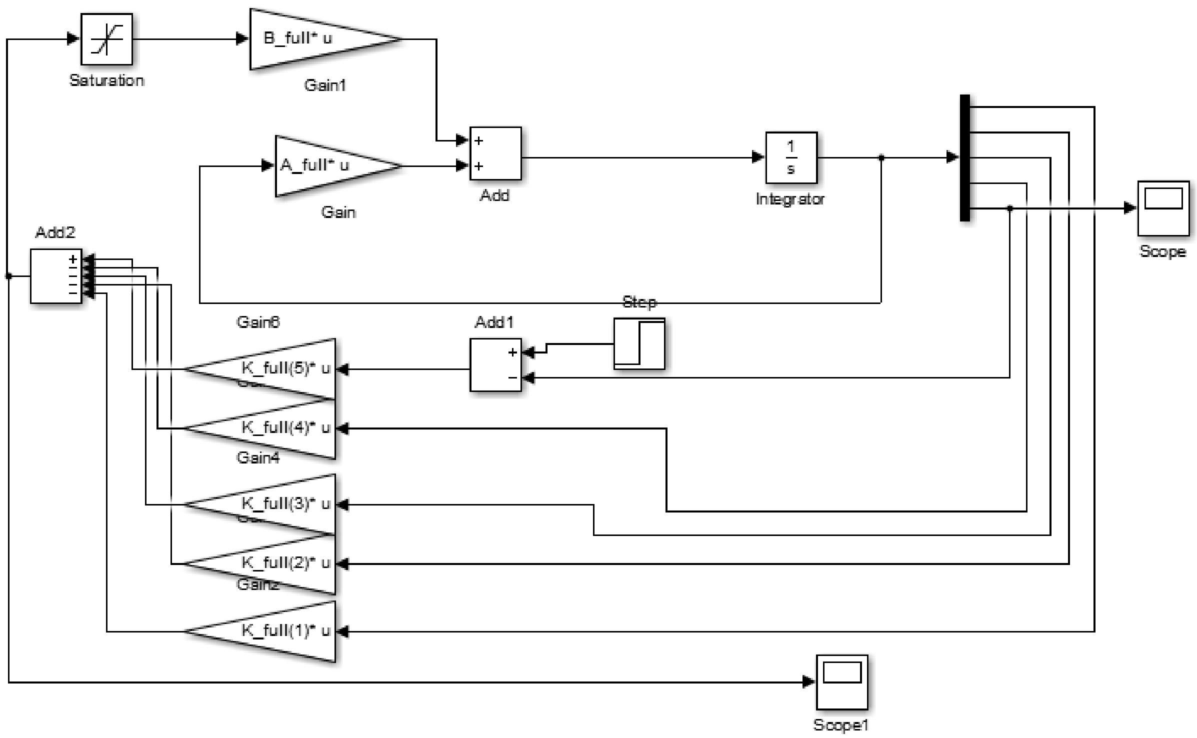
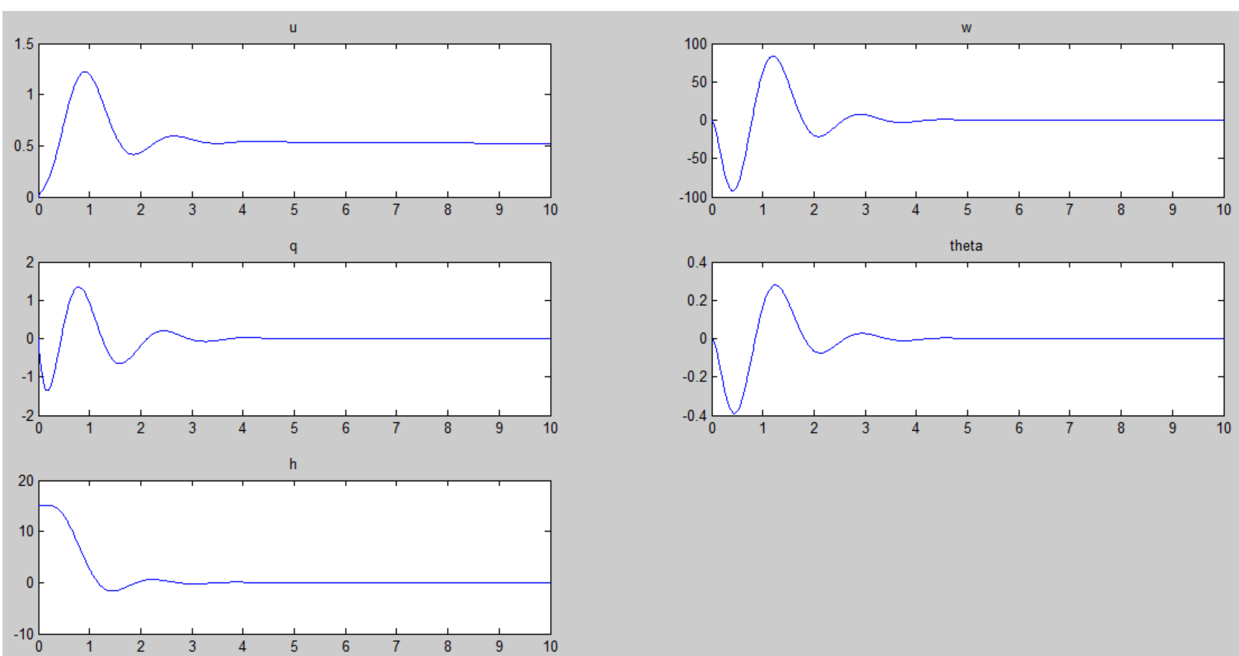


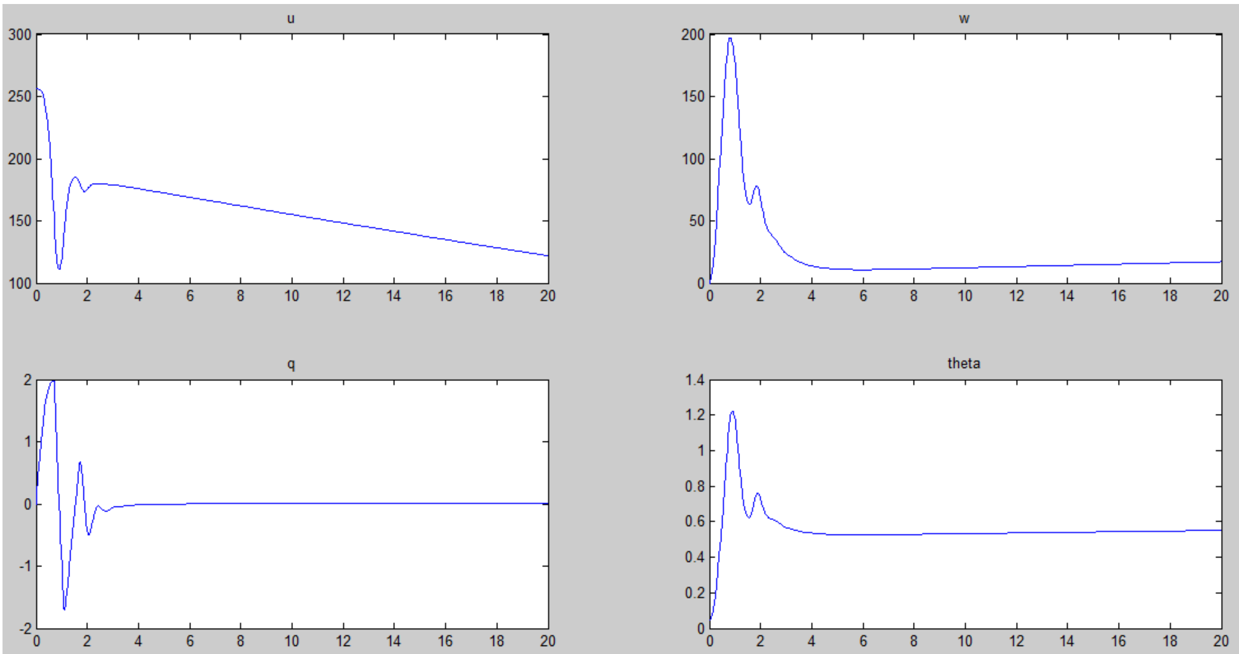
Figure 1: Control & simulation of the aircraft on Simulink

The following is the system response for a disturbance of 15m:



III. Testing the controller on the nonlinear dynamics of the aircraft & implementation:

The controller is tested on the nonlinear model of the aircraft. The aircraft is commanded to 0.5 rad pitch angle, following is the response:



Following is the controller deployment on Arduino Mega-25060: