Computer Problem 1

TTK 4190 Guidance, Navigation and Control

Due Date: `Tuesday 30th March`

Problem 1 (DSRV)

The crew onboard a navy submarine can in an emergency situation be rescued by using an DSRV (*Deep Submergence Rescue Vehicle*). Consider the following model (from the lecture notes of Professor Anthony Healey, Naval Postgraduate School (NPS), Monterey, CA, 1992):

$$\begin{bmatrix} m - Z_{\dot{w}} & -Z_{\dot{q}} \\ -M_{\dot{w}} & I_y - M_{\dot{q}} \end{bmatrix} \begin{bmatrix} \dot{w} \\ \dot{q} \end{bmatrix} + \begin{bmatrix} -Z_w & -Z_q \\ -M_w & -M_q \end{bmatrix} \begin{bmatrix} w \\ q \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & -\frac{M_\theta}{U^2} \end{bmatrix} \begin{bmatrix} z \\ \theta \end{bmatrix} = \begin{bmatrix} Z_{\delta_S} \\ M_{\delta_S} \end{bmatrix} \delta_S$$

where the speed is:

$$U = \sqrt{u^2 + w^2} \tag{1}$$

This model describes the dynamics in heave and pitch. The model is linearized about a constant cruise speed $U_0 = 4.11$ m/s. A Matlab m-file function for computation of the DSRV dynamics can be downloaded from *http://www.itk.ntnu.no./fag/gnc/problems/index.htm.* The model is in the form:

```
xdot = DSRV(x,ui)
% xdot = DSRV(x,ui); returns the time derivative of the state vector
```

The DSRV kinematic equations of motion are:

$$\begin{aligned} \dot{x} &= u \cos\theta + w \sin\theta \\ \dot{z} &= -u \sin\theta + w \cos\theta \\ \dot{\theta} &= q \end{aligned} \tag{2}$$

1a) Consider the forward speed model:

$$(m - X_{\dot{u}})\dot{U} + \frac{1}{2}\rho C_d A (U - u_c)|U - u_c| = \tau \tag{3}$$

$$\dot{u}_c = \text{white noise} \tag{4}$$

where τ is the control input in N and:

$$m - X_{\dot{u}} = 1000.0 \text{ kg} \tag{5}$$

$$\frac{1}{2}\rho C_d A = 100.0 \text{ kg/s} \tag{6}$$

The desired cruise speed is:

$$u_d = 4.11 \text{ m/s} \tag{7}$$

Assume that the velocity U is measured and that the current velocity u_c is unknown. Design a speed controller (without using a state estimator) such that $U \rightarrow u_d$. The control system should try to maintain a constant speed for a slowly-varying currents u_c. Is this possible in the case when u_c is unknown (explain why or why not). It should also be possible to change the speed to 3 m/s or 5 m/s without overshoot. Explain why you use P, PI, PD or PID feedback controller.

1b) Is it possible to find two gains K_1 and K_2 such that the fixed gain nonlinear state estimator:

$$\begin{aligned}(m - X_{\dot{u}})\dot{\hat{U}} + \frac{1}{2}\rho C_d A(U - \hat{u}_c)|U - \hat{u}_c| &= \tau_1 + K_1(U - \hat{U}) &\quad (8)\\ \dot{\hat{u}}_c &= K_2(U - \hat{U}) &\quad (9)\end{aligned}$$

reconstructs the unmeasured current velocity u_c? (just try to simulate the system for different τ_1 and comment your results). No theoretical proof is required. Show plots of the estimation errors $U - \hat{U}$ and $u_c - \hat{u}_c$.

Problem 2 (DSRV Depth Controller)

Design a PID-based depth controller for the DSRV and simulate a depth changing maneuver from $z = 10$ m to $z = 100$ m for initial conditions $w(0) = q(0) = \theta(0) = 0$. Plot the trajectories $z(t)$ and $\theta(t)$ as a function of time. Also plot the depth profile (xz-plot). Check your design by plotting the stern rudder displacement $\delta_S(t)$ as function of time (the rudder should not saturate during the maneuver).

Problem 3 (Kalman Filter Design for the DSRV)

Assume that you only measure the states $x(t), z(t)$ and $\theta(t)$ while $q(t)$ is unknown. Estimate $q(t)$ in a Kalman filter and plot $q(t)$ (true value) and the estimate $\hat{q}(t)$ in the same plot as a function of time. Does $\hat{q}(t)$ converge to $q(t)$? Does the PID-controller in Problem 2 work satisfactory if the all states are replaced with the Kalman filter state estimates?