TTK4190 Guidance and Control of Boats

Assignment 2, Pt. 3

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Problem 1 - Propeller Revolution and Speed Control

a)

The propeller thrust and torque coefficients K_T and K_Q can be computed by using the wageningen function found in the MSS toolbox.

```
Ja                    = 0;    % advance number
PD                    = 1.5;  % pitch/diameter ratio
AEAO                  = 0.65; % blade area ratio
z                     = 4;    % number of propeller blades
[KT,KQ]               = wageningen(Ja,PD,AEAO,z);
```

b)/c)

$\tau = 0$ and looking at the figure $Y = \frac{Q_d}{K_m}$ Converting equation to time domain

$$\begin{aligned}
\frac{Q_m}{Y} &= \frac{K_m}{T_m s + 1} e^{-\tau s} \\
\mathcal{L}^{-1}(Q_m T_m s + Q_m &= Q_d) \\
\dot{Q}_m T_m + Q_m &= Q_d \\
\dot{Q}_m &= -\frac{Q_m}{T_m} + \frac{Q_d}{T_m} \\
&= -\frac{1}{T_m} * Q_m + \frac{K_m}{T_m} * Y
\end{aligned}$$

which is implemented in *ship.m* as follows

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Part 3, 1b,1c) compute torque-based shaft dynamics here
Im      = 10^5;                                 % (kg m^2)
Km      = 0.6;                                  % (s^-1)
Tm      = 10;                                   % (s)
tau     = 0;                                    % time delay (s)

thr = rho * Dia^4 * KT * abs(n) * n;     % thrust command (N)
Q = rho * Dia^5 * KQ * abs(n) * n;       % torque command

persistent Qm
    if isempty(Qm)
        Qm = 0;
    end

Qd = rho*Dia^5*KQ*abs(n_c)*n_c;
Qm_dot   = (Qd - Qm)/Tm;

Y = Qd/Km;                                % control input

A = -1/Tm;                                % transfer function to state space
B = Km/Tm;

Qm_dot = A * Qm + B * Y;

Qm = euler2(Qm_dot,Qm,h);

n_dot    = (1/Im) * (Qm - Q);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Thus, the formula for the shaft speed dynamics $\dot{n}$ is found.

d)

The linear surge equation for the surge subsystem from [1] can be expressed as

$$U = \frac{(t-1)T}{X_u}$$

through this derivation:

$$\begin{gathered}
(m - X_{\dot{u}})\dot{u}_r - X_u u_r = -X_{\delta\delta}\delta^2 + (1-t)T \\
\dot{u}_r = \delta = 0 \\
\downarrow \\
-X_u u_r = (1-t)T \\
u_r = U \\
\downarrow \\
U = \frac{(t-1)T}{X_u}
\end{gathered}$$

The assumptions are that the Boat must not accelerate and the rudder angle must be zero ($\dot{u}_r = 0$, $\delta = 0$).

e)

The desired thrust T_d can be computed from d) as

$$T_d = \frac{U_{ref} X_u}{(t-1)} \tag{1}$$

and propeller revolution n_d as

$$n_d = sgn(T_d)\sqrt{\frac{|T_d|}{\rho D^4 K_T(0)}} \tag{2}$$

```
function n_c = open_loop_speed_control(U_ref)
% Ship variables
m                      = 17.0677e6;          % mass (kg)
Xudot                  = -8.9830e5;          % added mass in surge
T1                     = 20;                 % linear damping time constant
Xu                     = -(m-Xudot)/T1;      % linear damping in surge

% Propeller variables
Dia                    = 3.3;                % propeller diameter (m)
rho                    = 1025;               % density of water (m/s^3)
Ja                     = 0;                  % advance number
PD                     = 1.5;                % pitch/diameter ratio
AEAO                   = 0.65;               % blade area ratio
z                      = 4;                  % number of propeller blades
[KT,¬]                 = wageningen(Ja,PD,AEAO,z);

t                      = 0.05;               % thrust deduction number p. 164 in Fossen

% Combining the equation in task d) and inserting T (eq. 9.7 in Fossen)
n_c_squared            = U_ref * Xu / ((t-1) *rho * Dia^4 * KT);
n_c                    = sign(n_c_squared) * sqrt(abs(n_c_squared));
end
```

The Boat does not reach the desired velocity when maintaining a constant heading angle, as we are not utilizing closed-loop control to regulate speed.

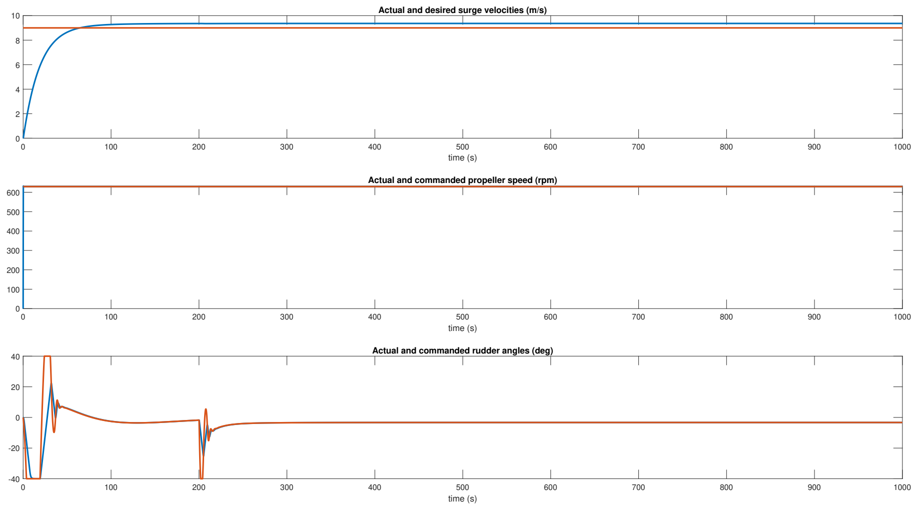

Figure 1: The result of open-loop speed control

References

[1] T. Fossen, *Handbook of Marine Craft Hydrodynamics and Motion Control.* John Wiley & Sons, 2011.