TTK4190 Guidance and Control of Vehicles

Assignment 3

Written Fall 2019 By Group 6

1 Autopilot Design

1.1 Heading Autopilot

Task 1.1

The model used in this task is Nomoto 1st-order model [1], since it is less computational demanding, and only two parameters need to be found. The model is defined as

$$\begin{aligned} T\dot{r} + r =& K\delta \\ \dot{\psi} =& r \end{aligned} \tag{1}$$

The corresponding transfer function of this model is

$$\frac{\psi}{\delta} = \frac{K}{s(1+Ts)} \tag{2}$$

Task 1.2

The realization of Nomoto 1st-order model is given as

$$r(t) = e^{-\frac{t}{T}} r(0) + (1 - e^{-\frac{t}{T}}) K\delta \tag{3}$$

where $r(0) = 0$.

Using `lsqcurvefit` in MATLAB we obtain

$$\begin{aligned} T =& 111.5713 \\ K =& -0.0052 \end{aligned} \tag{4}$$

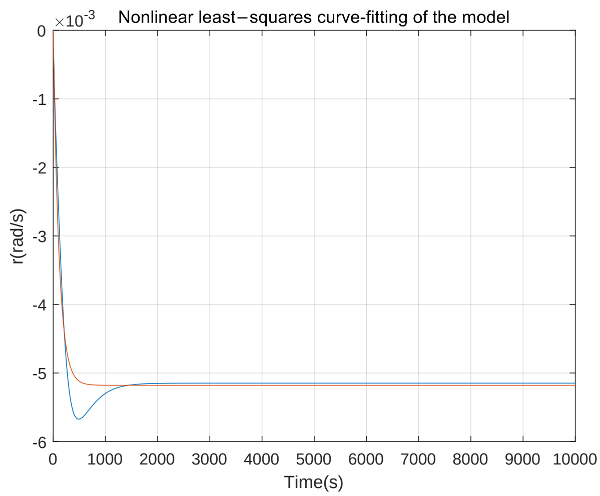


Figure 1: Curve-fitting of the response with $\delta_c = 5°$

Task 1.3

We define $\tilde{\psi} = \psi - \psi_d$ and $\tilde{r} = r - r_d$ where ψ_d and r_d are desired, time-varying yaw angle and yaw rate reference signals, respectively. We use control law

$$\tau_N = -K_p\tilde{\psi} - K_i\int_0^t \tilde{\psi}(\tau)d\tau - K_d\tilde{r} \tag{5}$$

where

$$\begin{aligned} \omega_n &= \frac{1}{\sqrt{1 - 2\zeta^2 + \sqrt{4\zeta^4 - 4\zeta^2 + 2}}}\omega_b \\ K_p &= \frac{\omega_n^2 T}{K} \\ K_i &= \frac{\omega_n^3 T}{10K} \\ K_d &= \frac{2\zeta\omega_n T - 1}{K} \end{aligned} \tag{6}$$

The ocean currents give drift force to the vessel, and the integral action in the control law will address this effect. The controller is model-based, which means it needs accurate model parameter (T and K in this case), and it is not valid for different vessels.

Task 1.4

The control parameters used are $K_p = -2.2816, K_i = -0.0023$ and $K_d = -161.6429$. The result given below shows that the controller is able to follow the reference signals in the present of current.

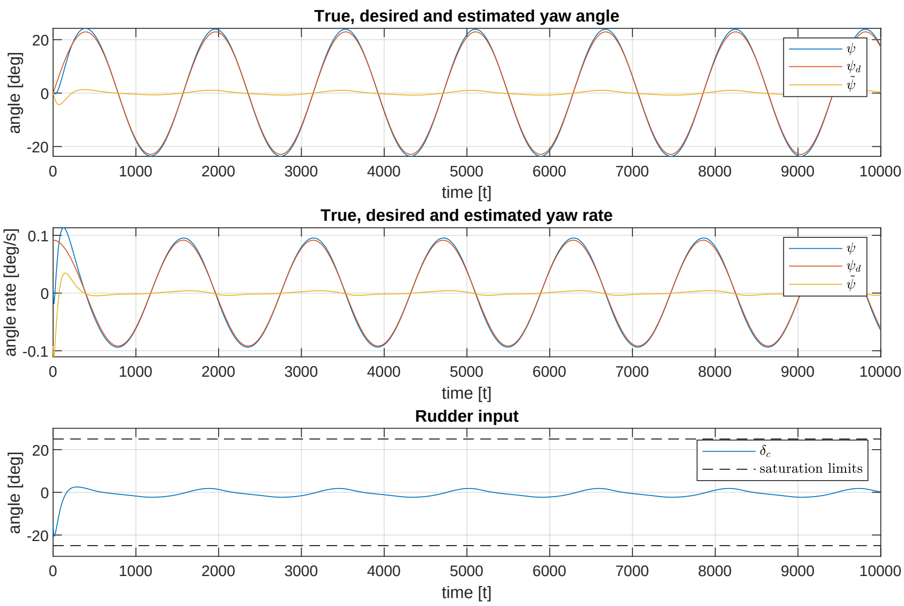


Figure 2: Task 1.4 results

1.2 Speed Autopilot

Task 1.5

In this task, forward speed model in [1] is used, given below

$$(m - X_{\dot{u}})\dot{u} - X_u u_r - X_{|u_r|u_r}|u_r|u_r = \tau_1 = K|n_c|n_c \tag{7}$$

where K is constant and chosen as $K = 1$.

The model can be rewritten as

$$a_1\dot{u} + a_2u_r + a_3|u_r|u_r = |n_c|n_c \tag{8}$$

where a_1, a_2 and a_3 are unknown parameters need to be found.

Task 1.6

To find the parameters, we first set $\psi_d = 0$ and turn off the current. Then we choose a series of n_c and record the steady state surge speed. In this case, the term related to $\dot{u}$ disappear and $u_r = u$. By curve-fitting we find $a_2 = -0.0075$ and $a_3 = 1.0384$. To find a_1, we use constant n_c and record u and $\dot{u}$. Using curve-fitting again we obtain $a_1 = 6145$.

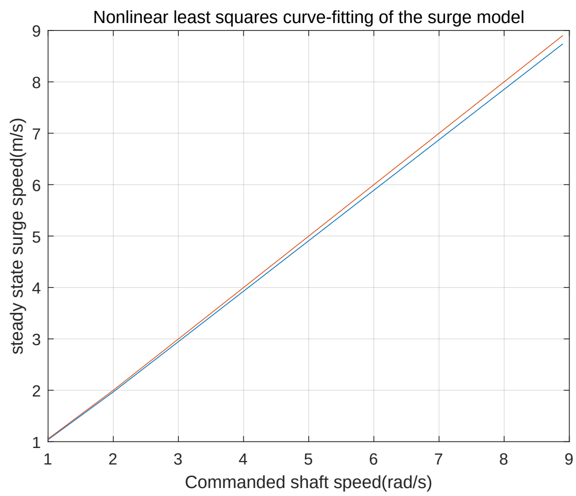


Figure 3: Steady state condition to find a_2 and a_3

Task 1.7

The control law is given as

$$\tau = a_1(\dot{u}_d - K_p\tilde{u} - K_i\int_0^t \tilde{u}(\tau)d\tau) + a_2u_r + a_3|u_r|u_r \tag{9}$$

which is a PI controller with acceleration feedforward. K_p and K_i are controller gains, which are found as $K_p = 0.2$ and $K_i = 10^{-6}$ by tuning.

Task 1.8

The speed autopilot works as expected. It regulates the ship to desired speed with constant shaft speed. At the same time, the yaw angel and yaw rate become zero.

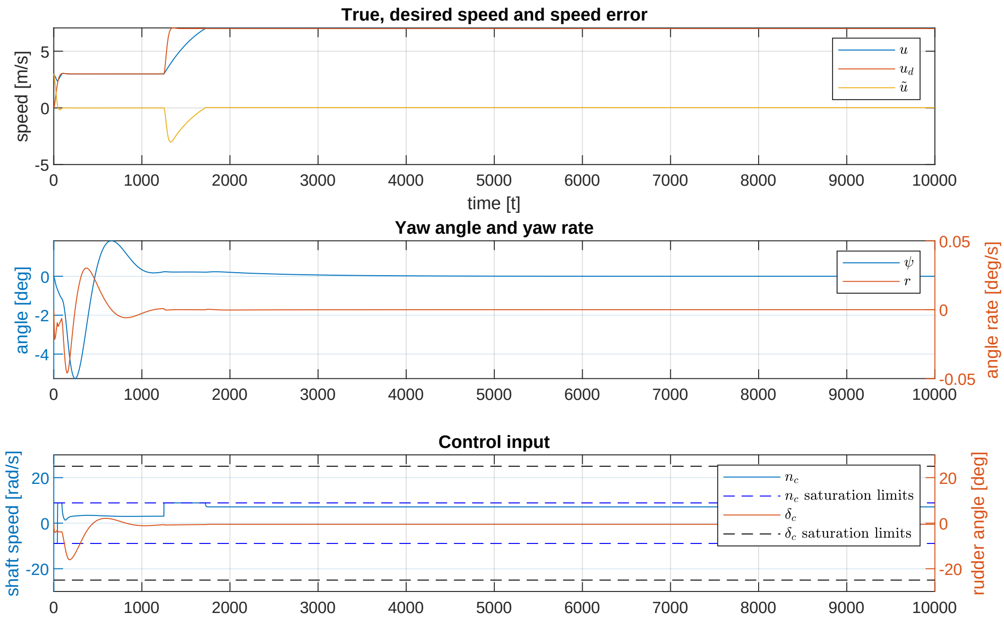


Figure 4: Task 1.8 results

2 Path Following and Target Tracking

2.1 Path Following

Task 2.1

In this task, the guidance law we choose is loodahead-based steering. The method is less computationally heavy than enclosure-based steering, and is valid for all cross-track errors.

The desired course angle is given as

$$\chi_d(e) = \chi_p + \chi_r(e) \tag{10}$$

where

$$\begin{aligned} \chi_p = \alpha_k = arctan(\frac{y_{k+1} - y_k}{x_{k+1} - x_k}) \\ \chi_r(e) = arctan(\frac{-e}{\Delta}) \\ e = -[x(t) - x_k]sin(\alpha_k) + [y(t) - y_k]cos(\alpha_k) \end{aligned} \tag{11}$$

where Δ is lookahead distance and chosen to be 500, e is cross-track error, $p_k = [x_k, y_k]$ is waypoint, and $p(t) = [x(t), y(t)]$ is position of ship.

When the ship is within certain distance R of the target waypoint, the next waypoint should be selected so that the ship will move towards it. The distance R is chosen to be 500m. The desired speed U_d is set to be 5 m/s.

Task 2.2

The results are shown below.

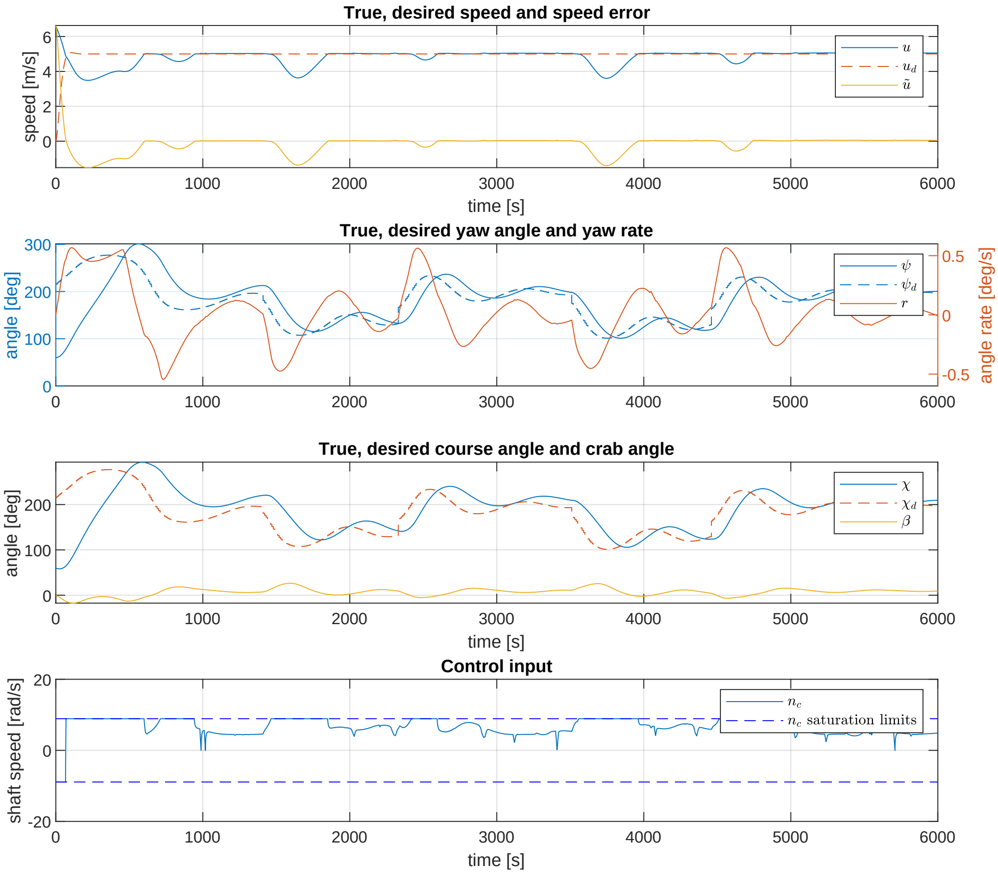
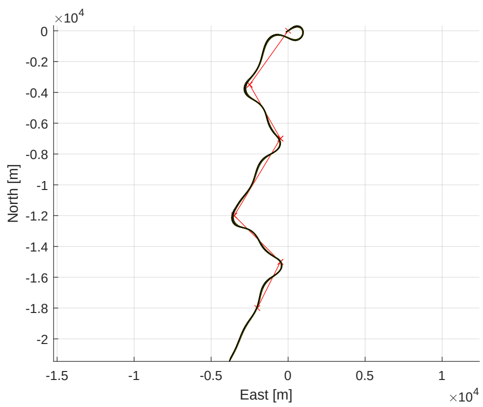
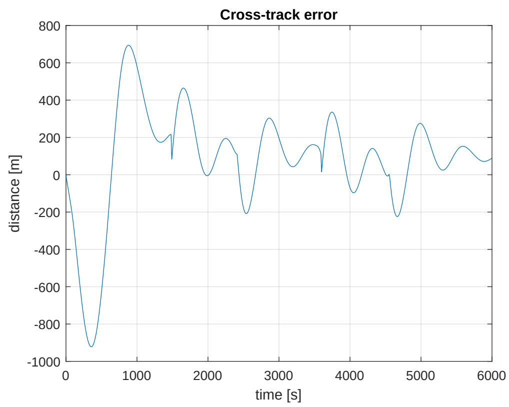


Figure 5: Task 2.2 results



(a) Path plot



(b) Cross-track error

Figure 6: Task 2.2 pathplotter

Task 2.3

From the result, the ship is able to follow the path and reach waypoints. While because crab angle is not compensated, the ship has cross track error from the path.

2.2 Path Following with Crab angle Compensation

Task 2.4

In the last section, we neglect crab angle and directly assign $\psi_d = \chi_d$. The course χ, desired course χ_d, heading ψ and crab angle β in Task 2.2 are shown in Figure 6. We can found that the heading follows the desired course angle. Besides, the heading and true course angle are not the same because the actual crab angle is not zero due to the current acting on the vessel.

Task 2.5

The transformations converts χ_d to ψ_d and U_d to u_d is given as

$$\begin{aligned} \psi_d &= \chi_d - \beta \\ u_d &= \sqrt{U_d - v} \end{aligned} \tag{12}$$

where

$$\beta = \sin^{-1}(\frac{v}{U}) \tag{13}$$

Task 2.6

With crab angle compensation, the performance of ship is better. We can see from the cross track error, which has less oscillation compared to the result without crab angle compensation. This means the ship stays closer to the path.

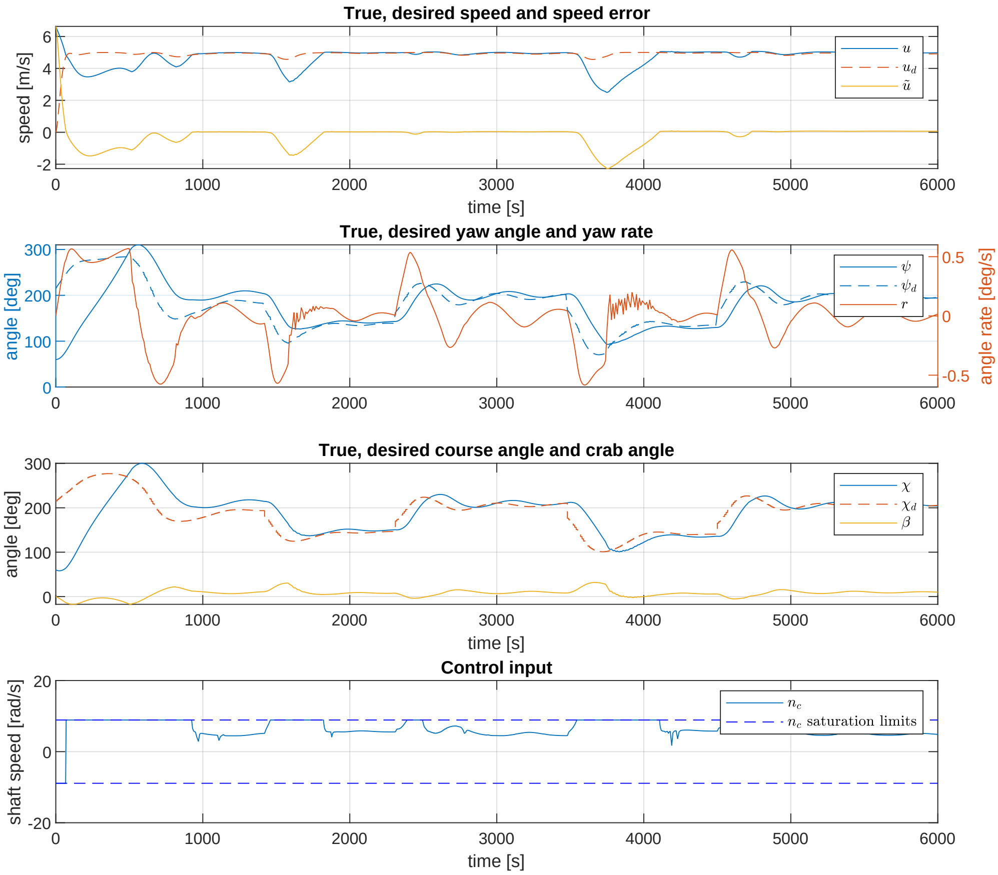
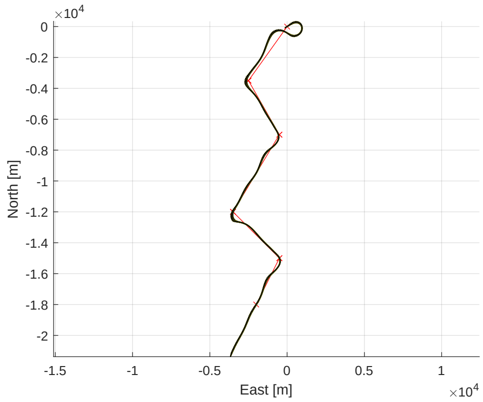


Figure 7: Task 2.6 results



(a) Path plot

(b) Cross-track error

Figure 8: Task 2.6 pathplotter

2.3 Target Tracking

Task 2.7

In this task, we want to track a target moving with constant speed $U_t = 3$ m/s. The positions vector between the vessel and the target is

$$\tilde{\mathbf{p}}^n = \mathbf{p}^n - \mathbf{p}_t^n \tag{14}$$

The desired velocity is given by

$$v_d^n = v_t^n + v_a^n \tag{15}$$

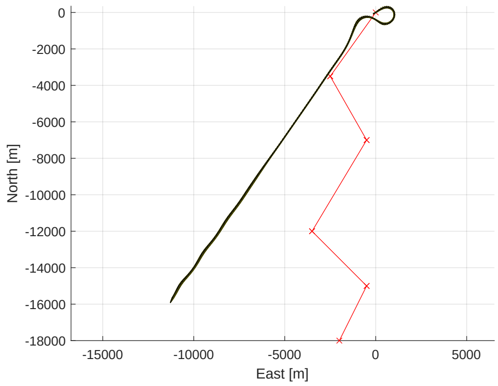
$$v_a^n = -\kappa \frac{\tilde{\mathbf{p}}^n}{||\mathbf{p}^n||} \tag{16}$$

where

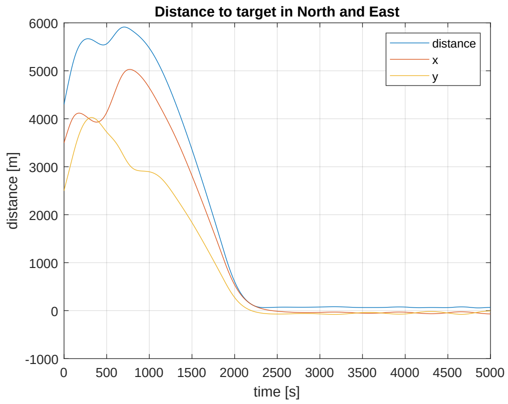
$$\kappa = U_{a,max} \frac{||\mathbf{p}^n||}{\sqrt{(\mathbf{p}^n)^T \mathbf{p}^n + \Delta_{\tilde{p}}^2}} \tag{17}$$

$U_{a,max}$ is the maximum approach speed toward the target and $\Delta_{\tilde{p}}$ affects the transient interceptor-target rendezvous behavior. They are chosen as $U_{a,max} = 8$m/s and $\Delta_{\tilde{p}} = 1500$.

The result shows that the ship is able to track the moving target, as the distance between the ship and target decreases to about zero.



(a) Path plot



(b) Target tracking distance in North and East

Figure 9: Task 2.7 results

References

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