TTK4190 Guidance and Control of Vehicles

Assignment 2, Pt. 4

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Problem 1 - LOS Guidance Law for Straight-Line Path Following

a)

Choose to use the proportional LOS guidance law since the solution should utilize the ship position and path information to calculate a reference course signal χ_d for the ship.

Using equation (12.78) from [1] means that the desired course angle can be calculated as:

$$\chi_d = \pi_p - tan^{-1}(K_p p_e^y) \tag{1}$$

where the proportional gain K_p is given as:

$$K_p = \frac{1}{\Delta} \tag{2}$$

The look-ahead distance Δ was experimentally found and set to ten times the ship length. The scalar cross-track error y_e^p is computed by using the coordinates of two waypoints $\boldsymbol{p}_i^n$ and $\boldsymbol{p}_{i+1}^n$ and a simplified equation (12.40) from [1]. The path-tangential angle π_p can be calculated from equation (12.54).

The implementation in Matlab is given as:

```
function chi_d = LOS_guidance(e_y,pi_p)
L        = 161;
Δ        = 10*L;
Kp       = 1/Δ;
chi_d    = pi_p - atan2(Kp*e_y,1);
end
```

b)

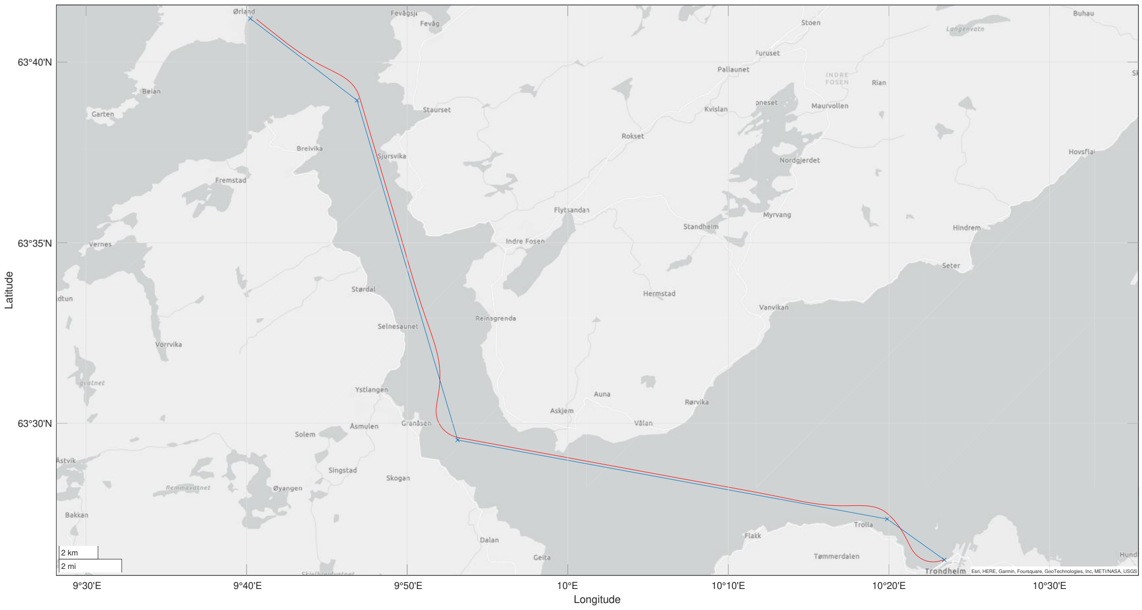
Using the modular approach suggested in the problem description with the output from the guidance law as a reference signal for the reference model, i.e. $\psi_{ref} = \chi_d$, the implementation in Matlab becomes:

```
function [xk1,yk1,xk,yk,last] = WP_selector(x,y,WP)
% [xk1,yk1,xk,yk,last] = WP_selector(x,y,WP) is a function that takes the
% current position of the ship in NED and a waypoint vector and calculates
% which waypoint to head towards.
%       x NED position
%       y NED position
%       WP vector of waypoints on the form [x1 x2 ... xk; y1 ... yk];
% If the ship is closer than R to the waypoint, the WP_selector chooses
% the next. If it is the last waypoint, the last flag is set high, and the
% simulation stops.

persistent k
if isempty(k)
    k = 1;
end

L                   = 161;          % length (m)
R                   = 2*L;          % radius

xk1                 = WP(1,k+1);
yk1                 = WP(2,k+1);

% If close enough to next waypoint, select next waypoint (12.52) in Fossen
if (xk1 - x)^2 + (yk1 -y)^2 ≤ R^2
    k               = k + 1;
end
```

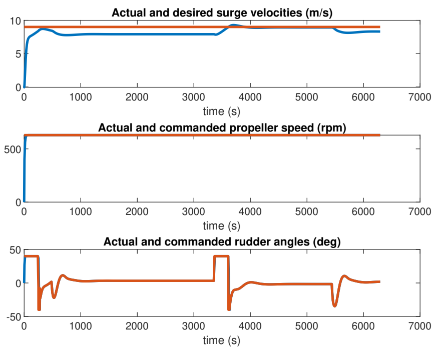
```

if k ≥ length(WP)
    xk              = 0;
    yk              = 0;
    xk1             = 0;
    yk1             = 0;
    last            = 1;
else
    xk              = WP(1,k);
    yk              = WP(2,k);
    xk1             = WP(1,k+1);
    yk1             = WP(2,k+1);
    last            = 0;
end
```

```
function [e_y,pi_p] = crossTrackError(xk1,yk1,xk,yk,x,y)
% [e_y,pi_p] = crossTrackError(xk1,yk1,xk,yk,x,y) calculates the
% cross-track error using the current x,y position in NED, the current and
% next waypoint from the WP_selector.m using equation 12.54 and 12.55 in
% Fossen

pi_p = atan2(yk1 - yk,xk1 - xk);

e     = R(pi_p).' * [x - xk; y - yk];
e_y   = e(2);
end

function R = R(phi)
    R = [cos(phi) -sin(phi); sin(phi) cos(phi)];
end
```

c)



(a) Straight line path between waypoints (blue) and the ship's traveled path (red)

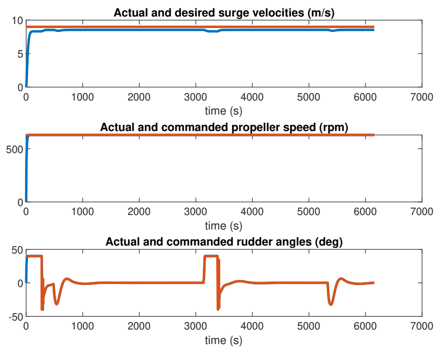


(b) The control system's desired an actual surge velocity, actual and commanded propeller speed and actual and commanded rudder angles

Figure 1: The ship's traveled path and it's commands when enviromental disturbances affects the ship

When there are enviromental disturbances that affects the ship, having a course proportional LOS guidance law and a PID heading autopilot with integrator anti-windup, the ship does not follow the straight lines perfectly. A small deviation from the straight lines is noteable in the plot.

(a) Straight line path between waypoints (blue) and the ship's traveled path (red)



(b) The control system's desired an actual surge velocity, actual and commanded propeller speed and actual and commanded rudder angles

Figure 2: The ship's traveled path and it's commands when there are no enviromental disturbances that affects the ship

When the ship is not affected by environmental disturbances, the cross-track error is almost completely eliminated and the ship's path follows the straight-line path with marginal deviations. The exceptions are when changing from one waypoint to the next.

The two simulations in Figure 1 and Figure 2 are similar to what one would expect for an proportional LOS course guidance law. Since there is only a proportional gain in this guidance law, no action is taken to correct the deviations we can see in the plots between the straight-lines and the ship's path.

The PID heading autopilot has a bandwidth of $\omega_b = 0.06$ rad/s. ω_{ref} in the simulations was set to $\omega_{ref} = 0.03$ rad/s to obtain satisfactory tracking performance and stability. The autopilot reference model computes smooth trajectories for ψ_d, r_d and $\dot{r}_d$ needed for course-changing maneuvers. The cutoff frequency of the reference model must never exceed the closed-loop bandwidth of the system in order to guarantee that the craft is able to track the desired states. Since the ship's path seemed satisfactory with it's known limitations, ω_{ref} was left unchanged.

Problem 2 - Crab Angle Compensation and Integral LOS

a)

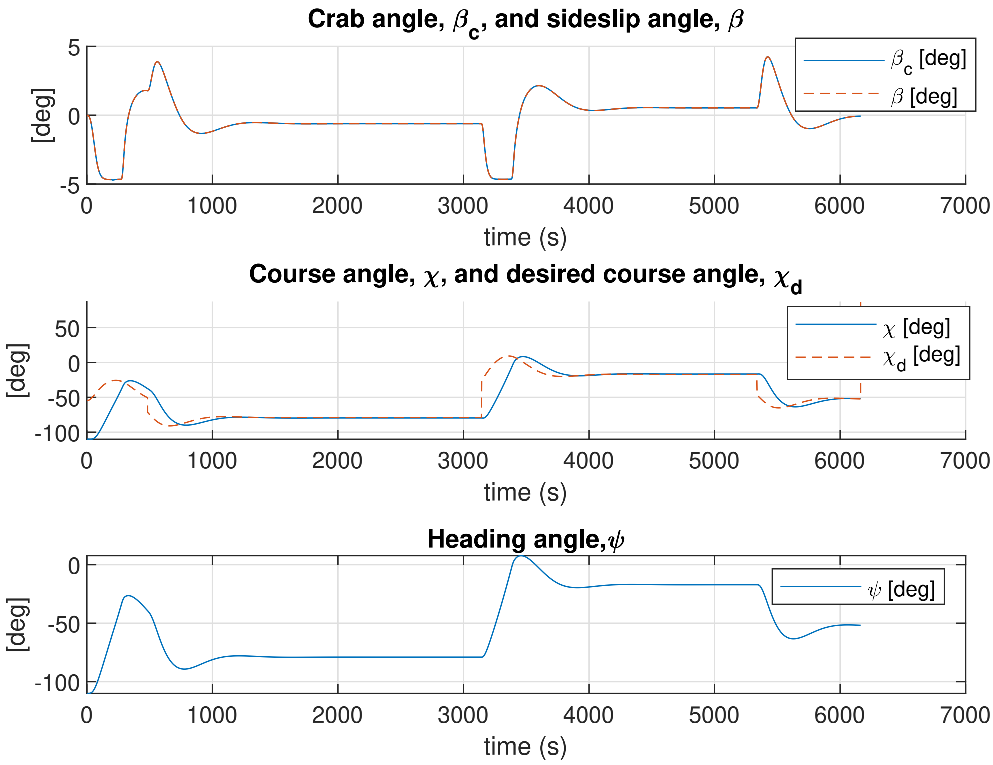


Figure 3: Crab-angle, sideslip, course, desired course and heading angle with no current

With only wind as an external disturbance, there is no relative speeds, hence $\beta = \beta_c$. The wind makes the ship crab when traveling straight ($\dot{\psi} = 0$) with $\beta \approx \pm 0.5°$. It also crabs when turning, but this is expected. Since the crab angle is so small, we don't think it is necessary to add crab-angle compensation.

b)

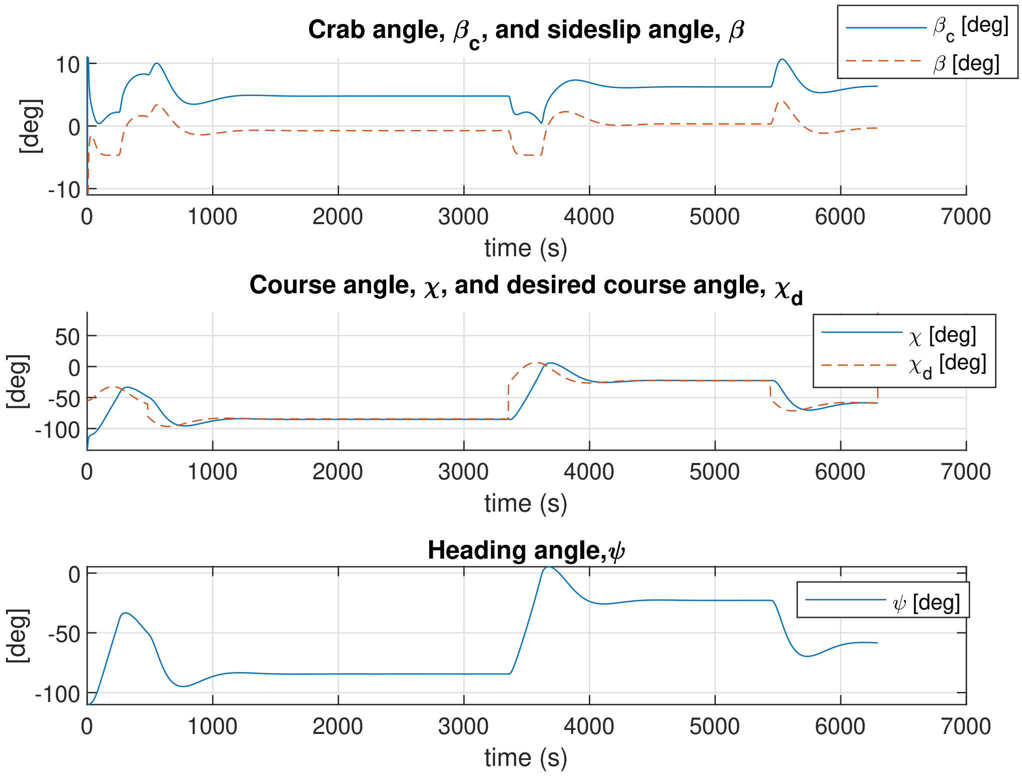


Figure 4: Crab-angle, sideslip, course, desired course and heading angle with current

Figure 4 shows that when current is affecting the ship, the crab angle increases. Since the crab angle is much larger than in Figure 3, we think that it is necessary to compensate for the crab angle when environmental disturbances are present.

c)

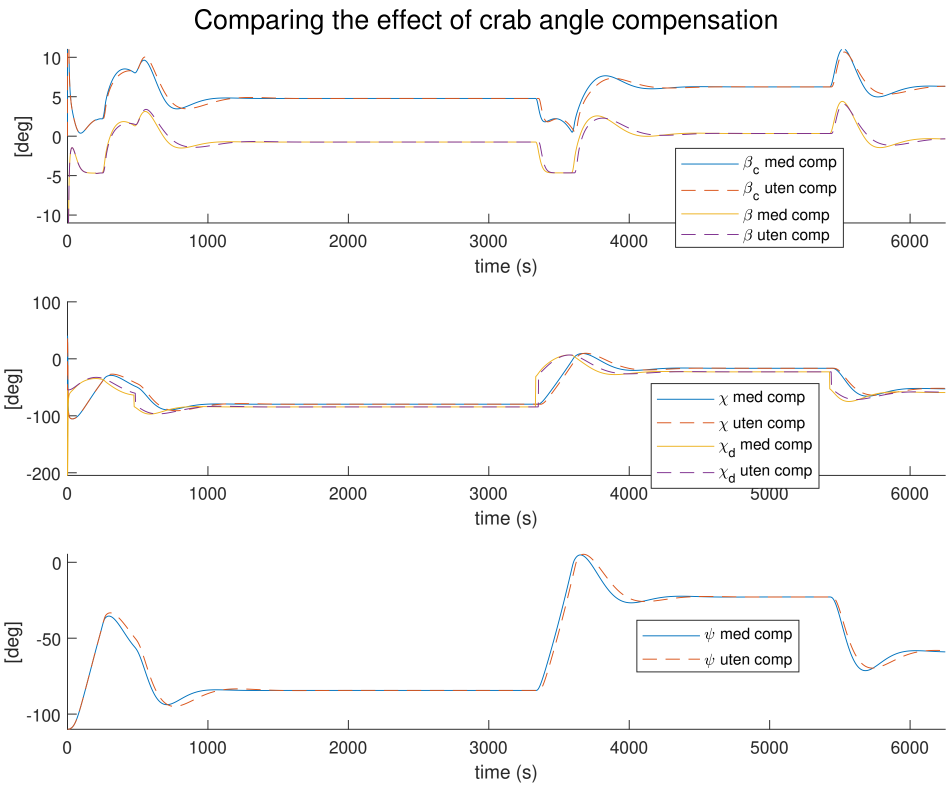
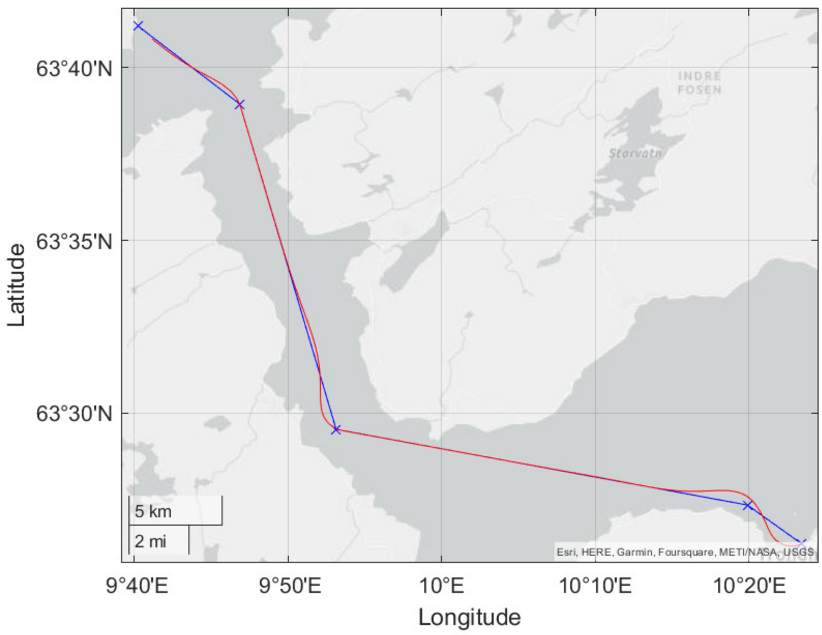


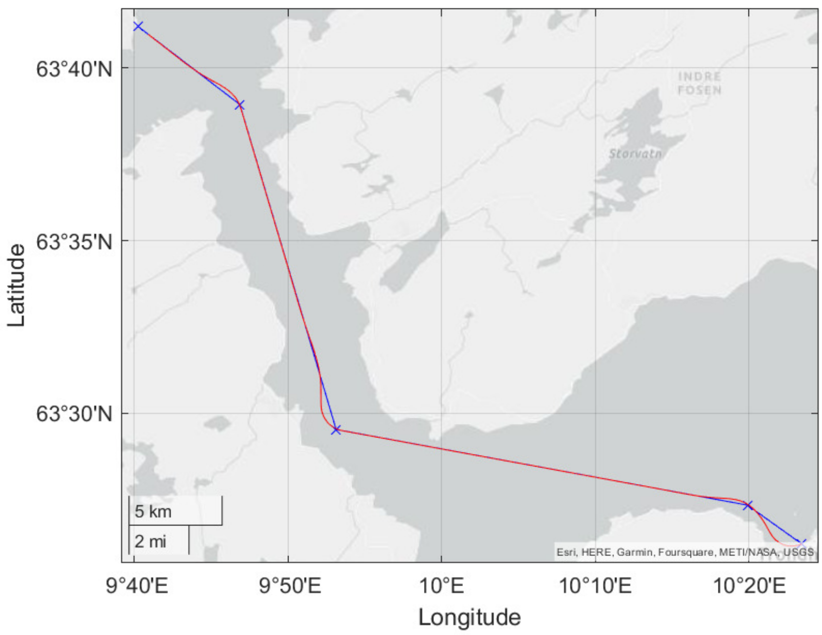
Figure 5: Comparing with and without crab angle compensation

From Figure 5, it appears that the crab-angle compensation slightly enhances the rate at which the vessel tracks χ_d, indicating that the crab angle compensation is effective.

d)



(a) Using ILOS guidance law with no crab angle compensation



(b) Using crab angle compensation and proportional LOS guidance law

Figure 6: The ship's traveled path when there are enviromental disturbances that affects the ship

From Figure 6 the crab angle compensation using proportional LOS surprisingly performs better than the ILOS solution without crab angle compensation. This could be due to poor tuning of the ILOS.

According to [1], when there are no velocity measurements to approximate β_c, integral action on the cross-track error can be used to compensate for the unknown drift term β_c. A con is that there are no global stability results for ILOS.

References

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