AutoNaut - Collision Avoidance

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This documents summarizes the results of collision avoidance first tests, happened on 12-13th December 2019 in Borsa.

1 First day - Virtual obstacles

This section shows the results of the first day (12th Dec.), where virtual obstacles were simulated on land. The algorithm ran on the AutoNaut and was invoked once every 5 seconds. It can be considered to call it more frequently when the obstacle(s) are very close. The following scenarios were tested:

- Head On (HO_ST) situation with static obstacle
- Head On (HO_DYN) situation with obstacle moving on straight line, not complying with COLREGS
- Obstacle Crossing from Port (CR_CP), not complying with COLREGS
- Obstacle Crossing from Starboard (CR_SB), not complying with COLREGS

d is the distance between the obstacle and the AutoNaut, d_{init} is the initial distance, d_{min}/d_{max} minimum and maximum distance between obstacle and AutoNaut, d_{safe} is the safety distance between obstacles and AutoNaut (all distances in meters), ψ_d is the AutoNaut desired course computed by LOS navigation, ψ_{off} is the course offset computed by sb_mpc, ψ_{new} is the new course reference to the course autopilot.

Head On, static obstacle

- $d_{init} = 1000$, $d_{safe} = 300$
- $\psi_d = -23°$
- from $d = 700$: $\psi_{off} = +30°$, $\psi_{new} = 5°$

- from $d = 380$: $\psi_{off} = +0°$, $\psi_{new} = \psi_d = -52°$
- $d_{min} = 351$

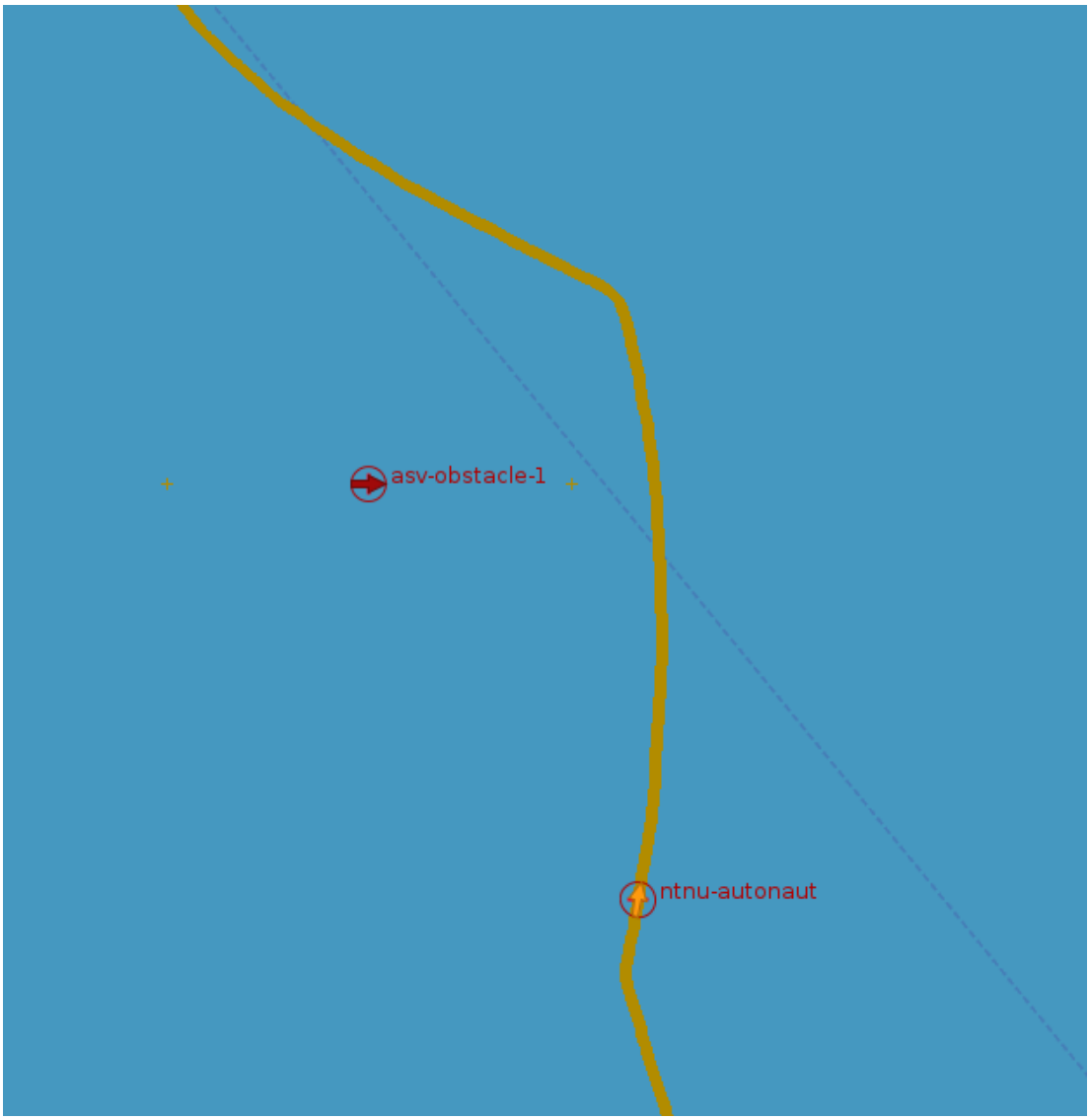

Figure 1: HO static scenario

The AutoNaut keeps a distance larger than the safety distance set to 300 meters. The minimum recorded distance during the trajectory is 351 meters.

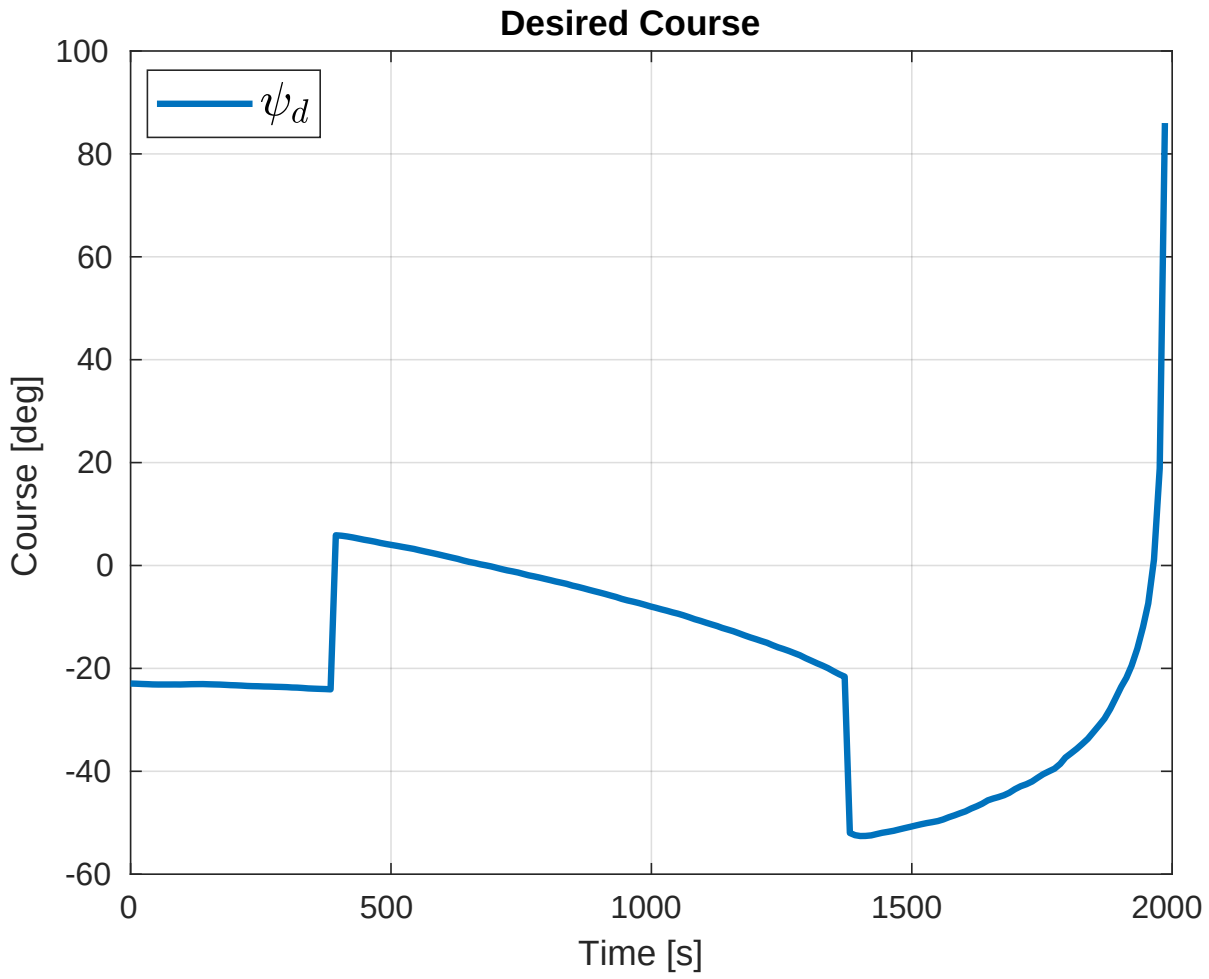

Figure 2: HO static AutoNaut Desired Course: initial desired course is modified by sb_mpc.

Head On, moving obstacle

v_o is the obstacle speed, ψ_o is the obstacle course.

- $d_{init} = 1500$, $d_{safe} = 150$
- $\psi_d = -60°$
- $v_o = 1.25$m/s, $\psi_o = 118°$
- from $d = 700$: $\psi_{off} = +60°$, $\psi_{new} = -1.3°$
- from $d = 530$: $\psi_{off} = +75°$, $\psi_{new} = 12.3°$
- from $d = 502$: $\psi_{off} = -60°$, $\psi_{new} = -123.3°$
- from $d = 431$: $\psi_{off} = -75°$, $\psi_{new} = -139.3°$

- from $d = 408$: $\psi_{off} = -60°$, $\psi_{new} = -124.5°$
- from $d = 384$: $\psi_{off} = +90°$, $\psi_{new} = 25.5°$
- from $d = 178$: $\psi_{off} = +15°$, $\psi_{new} = -55°$
- from $d = 196$: $\psi_{off} = +0°$, $\psi_{new} = -70°$
- $d_{min} = 161.5$

Figure 3: HO scenario with moving obstacle

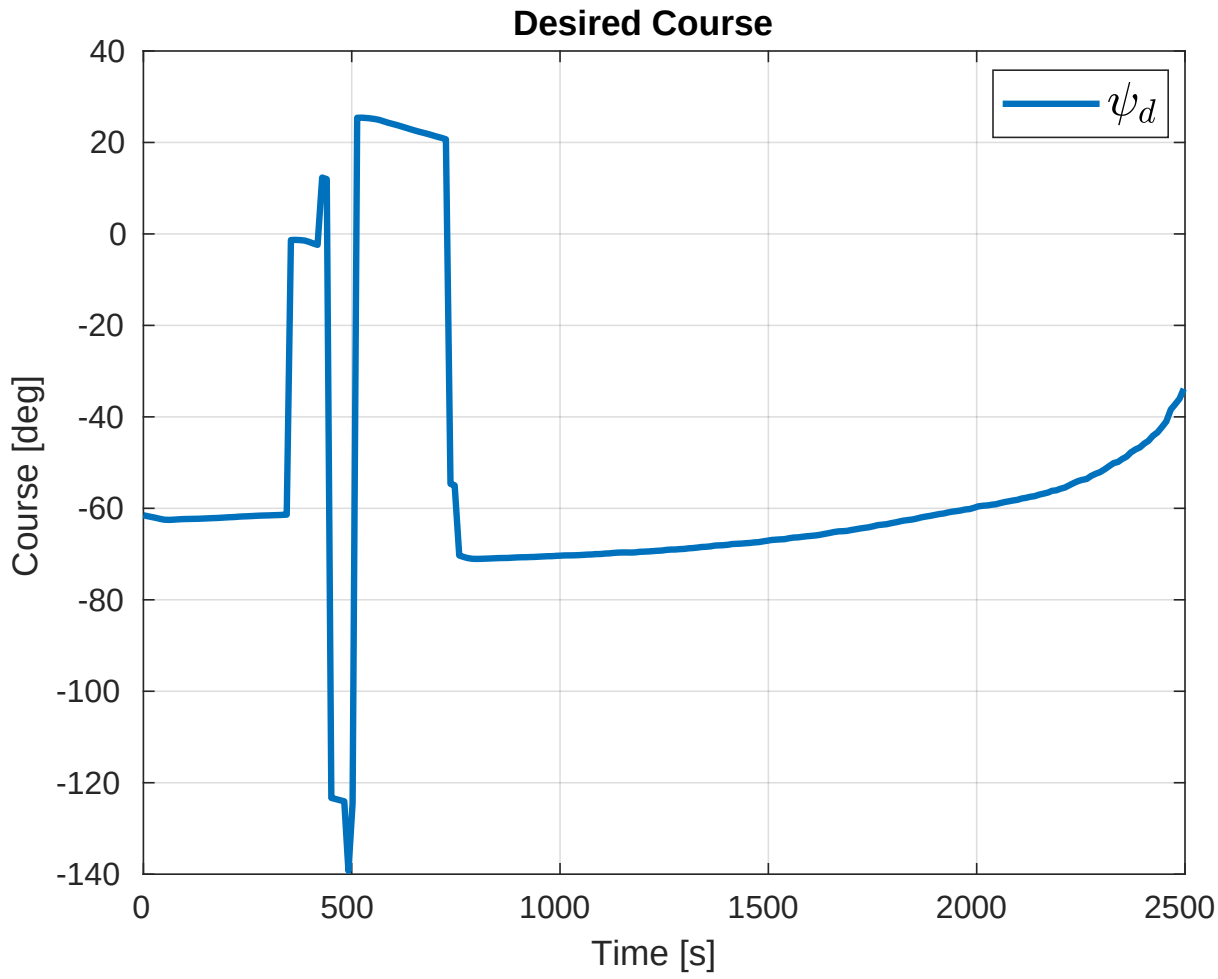

Figure 4: HO with moving obstacle - AutoNaut Desired Course: initial desired course is modified by sb_mpc.

Obstacle Crossing from Port

v_o is the obstacle speed, ψ_o is the obstacle course.

- $d_{init} = 1000$, $d_{safe} = 200$
- $\psi_d = -17°$
- $v_o = 1.25\text{m/s}$, $\psi_o = 76°$
- from $d = 700$: $\psi_{off} = +45°$, $\psi_{new} = 28.3°$
- from $d = 294$: $\psi_{off} = +0°$, $\psi_{new} = -38.2°$
- $d_{min} = 245.5$

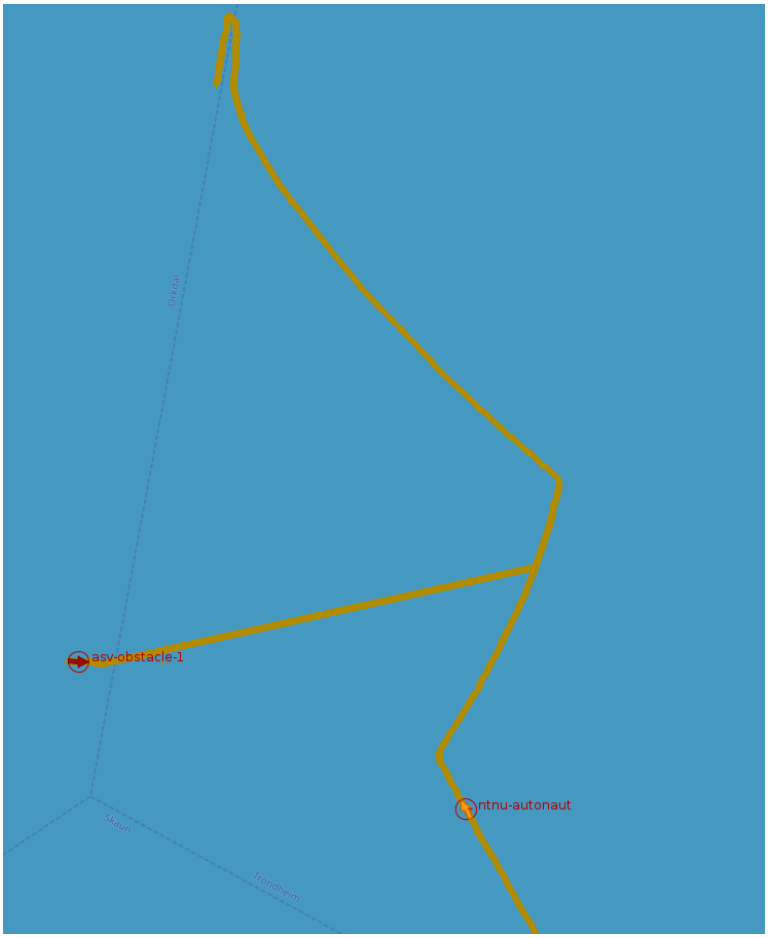

Figure 5: Obstacle crossing from Port scenario.

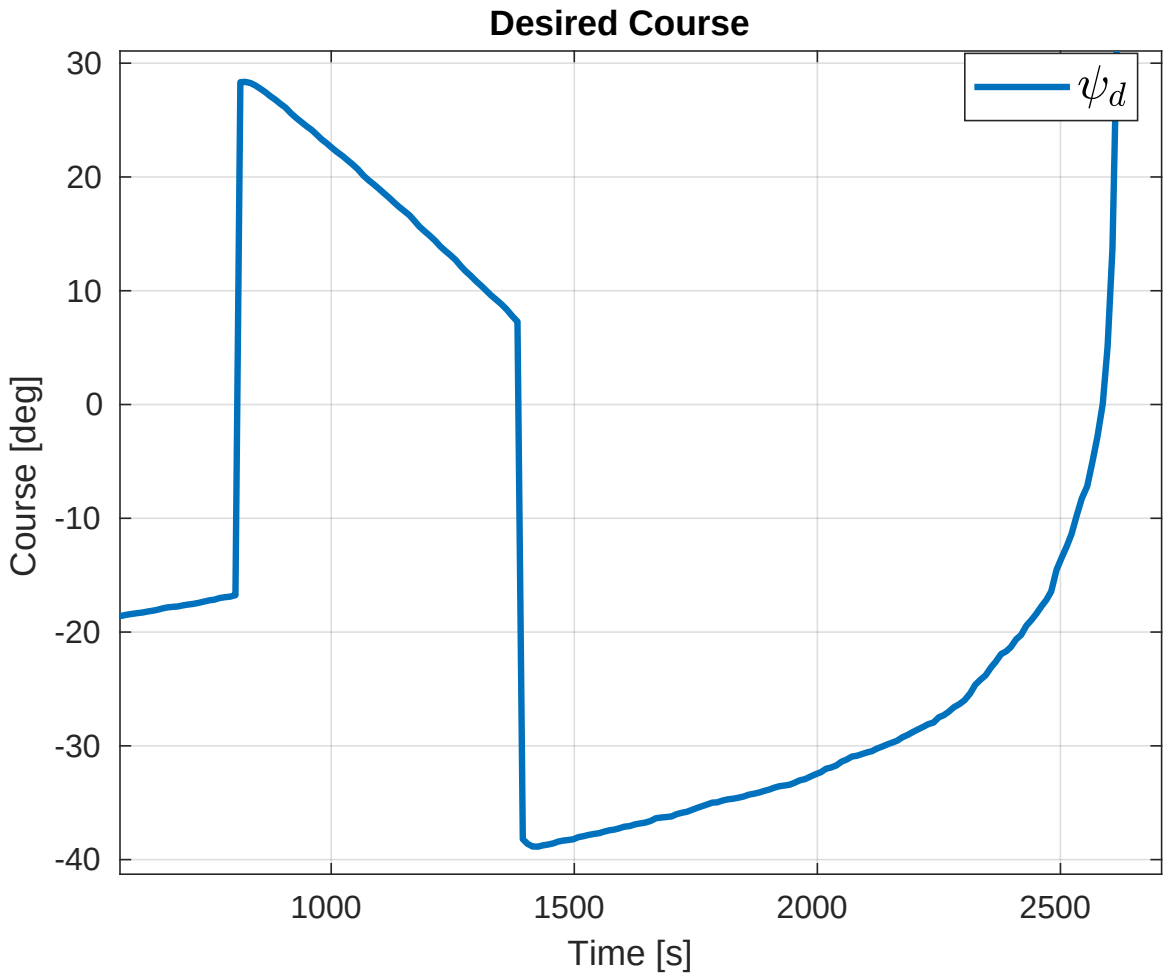

Figure 6: Obstacle crossing from Port - AutoNaut Desired Course: initial desired course is modified by sb_mpc.

Obstacle Crossing from Starboard

v_o is the obstacle speed, ψ_o is the obstacle course.

- $d_{init} = 1030$, $d_{safe} = 200$
- $\psi_d = -170°$
- $v_o = 1.25\text{m/s}$, $\psi_o = 90°$
- from $d = 700$: $\psi_{off} = +15°$, $\psi_{new} = -156°$
- from $d = 550$: $\psi_{off} = +30°$, $\psi_{new} = -141.2°$
- from $d = 527$: $\psi_{off} = +45°$, $\psi_{new} = -126°$
- from $d = 360$: $\psi_{off} = +0°$, $\psi_{new} = -172.8°$
- $d_{min} = 360$

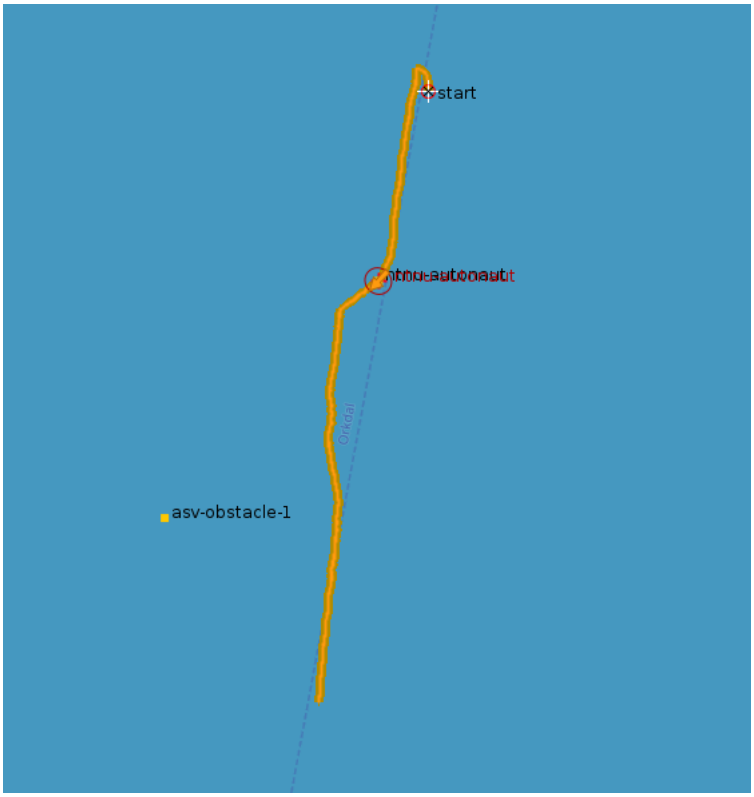

Figure 7: Obstacle crossing from Starboard scenario: obstacle is the yellow dot, with course 90deg.

Figure 8: Obstacle crossing from Starboard - AutoNaut Desired Course: initial desired course is modified by sb_mpc.

Obstacle overtaking situation

This maneuver was executed right after crossing from starboard.
In this scenario the obstacle overtakes the AutoNaut. v_o is the obstacle speed, ψ_o is the obstacle course.

- $d_{init} = 750$, $d_{safe} = 200$
- $\psi_d = -170.5°$
- $v_o = 1.25$m/s, $\psi_o = -165°$
- from $d = 400$: $\psi_{off} = -15°$, $\psi_{new} = 172.4°$
- from $d = 342$: $\psi_{off} = +0°$, $\psi_{new} = -172.4°$
- from $d = 335$: $\psi_{off} = -15°$, $\psi_{new} = 172.6°$
- from $d = 245.2$: $\psi_{off} = +0°$, $\psi_{new} = -171.7°$
- from $d = 242$: $\psi_{off} = -15°$, $\psi_{new} = 173.4°$
- from $d = 232.4$: $\psi_{off} = +0°$, $\psi_{new} = -171.5°$
- from $d = 217.2$: $\psi_{off} = -15°$, $\psi_{new} = 173.5°$
- from $d = 216.8$: $\psi_{off} = +0°$, $\psi_{new} = -171.5°$
- from $d = 242$: $\psi_{off} = -15°$, $\psi_{new} = 173.4°$
- $d_{min} = 216.7$

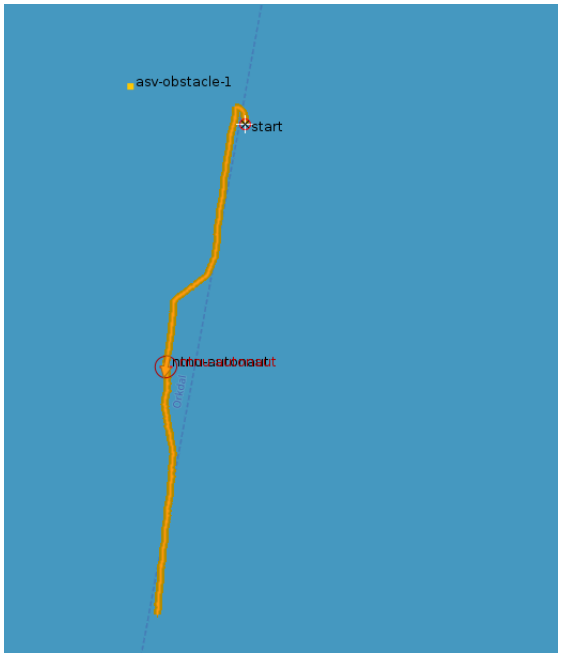

Figure 9: Obstacle overtaking scenario: obstacle is the yellow dot, with course -170deg.

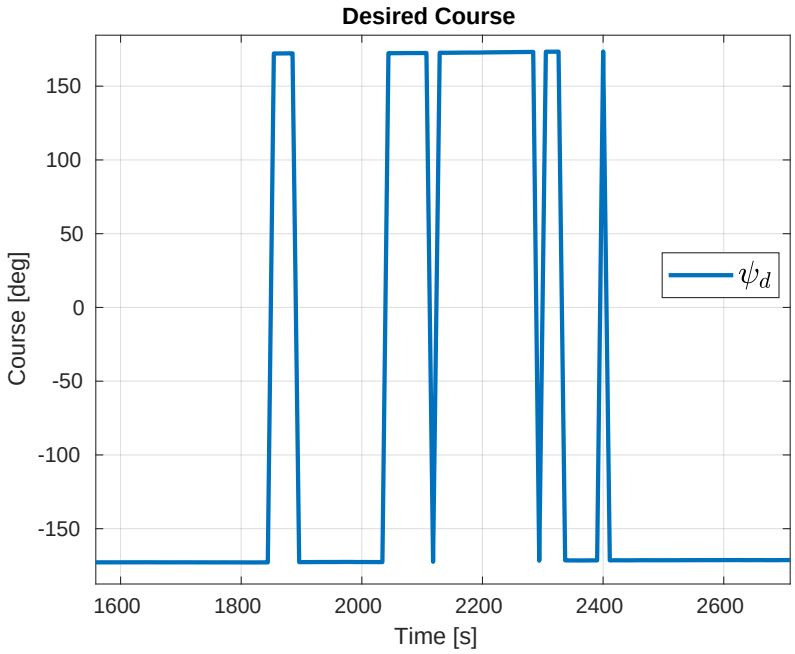

Figure 10: Obstacle overtaking the AutoNaut - AutoNaut Desired Course: initial desired course is modified by sb_mpc.

Consecutive Head On situations

The Head On with moving obstacle scenario was repeated two times. v_o is the obstacle speed, ψ_o is the obstacle course. First head on:

- $d_{init} = 3000$, $d_{safe} = 200$
- $\psi_d = 125°$
- $v_o = 1.25\text{m/s}$, $\psi_o = -53°$
- from $d = 700$: $\psi_{off} = +45°$, $\psi_{new} = 173°$
- from $d = 670$: $\psi_{off} = +75°$, $\psi_{new} = -156.7°$
- from $d = 600$: $\psi_{off} = +90°$, $\psi_{new} = -142°$
- from $d = 156$: $\psi_{off} = +0°$, $\psi_{new} = 125.5°$
- $d_{min} = 155.3$

Second head on:

- $d_{init} = 1920$, $d_{safe} = 200$
- $\psi_d = 125.8°$
- $v_o = 1.25\text{m/s}$, $\psi_o = -50°$
- from $d = 700$: $\psi_{off} = +30°$, $\psi_{new} = 156.3°$
- from $d = 686$: $\psi_{off} = +45°$, $\psi_{new} = 171.3°$
- from $d = 231$: $\psi_{off} = +0°$, $\psi_{new} = 123°$
- $d_{min} = 231.2$

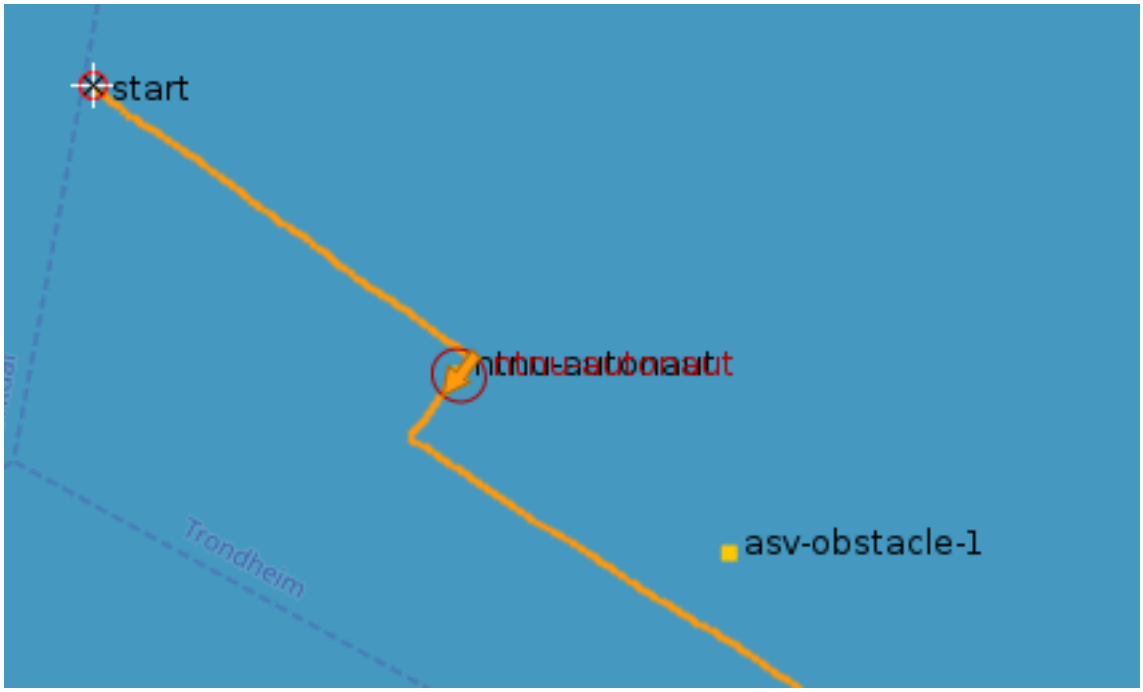

Figure 11: First leg of HO scenario: obstacle is the yellow dot, with course -53deg.

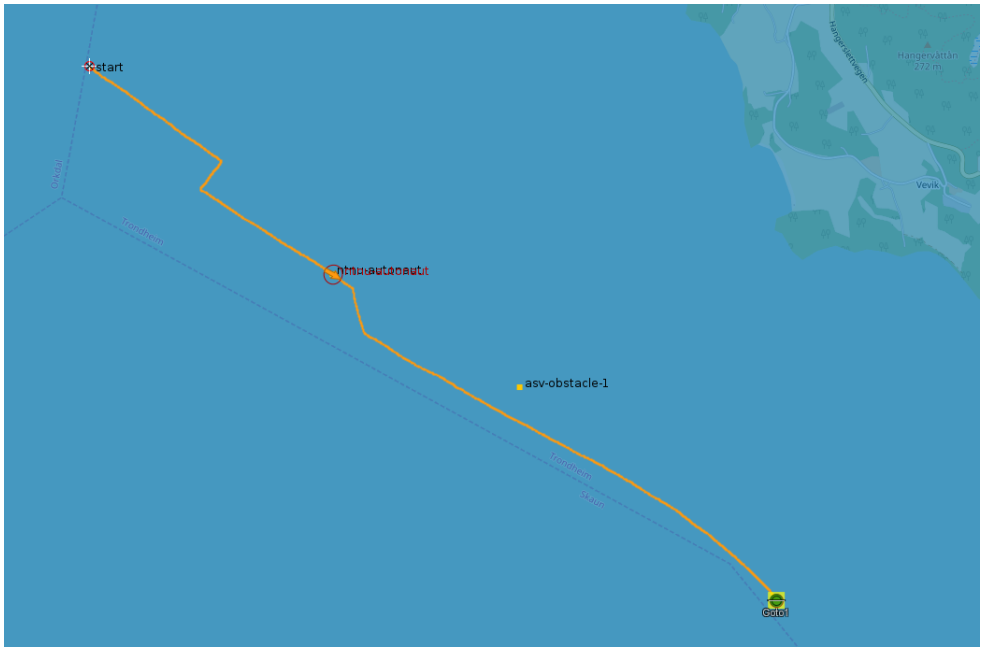

Figure 12: Second leg of HO scenario: obstacle is the yellow dot, with course -50deg.

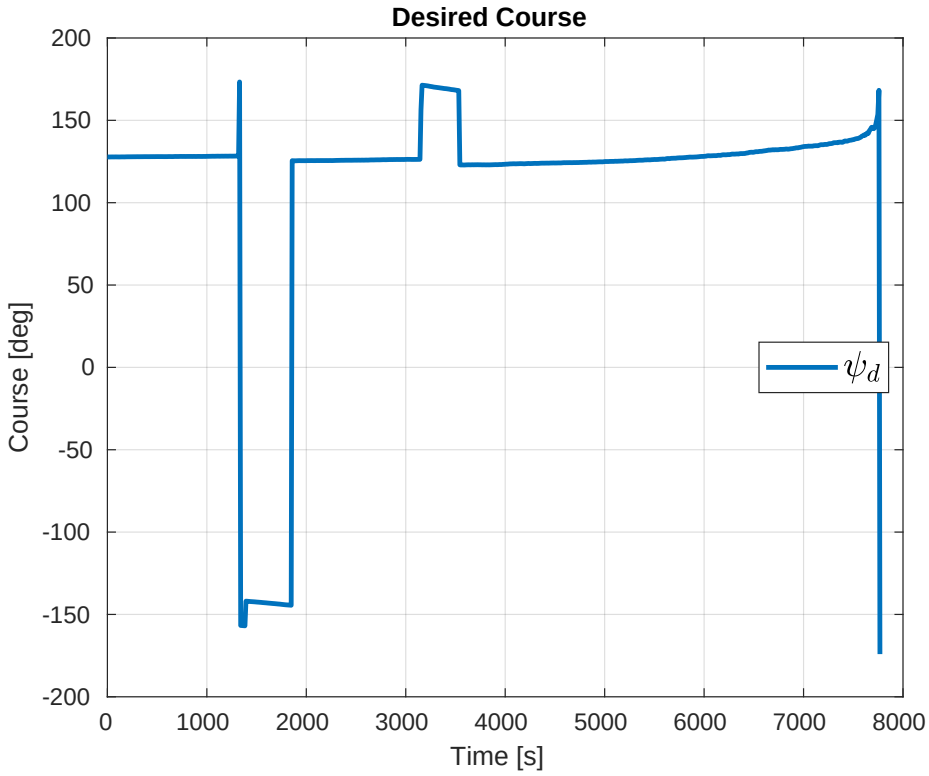

Figure 13: Two consecutive head on situations - AutoNaut Desired Course: initial desired course is modified by sb_mpc.

2 Second day - Almost real obstacles

In this section the obstacle is a manned boat (Buster) with variable speed and course. The intention was to test more realistic situations, where vessels can both either comply or not to COLREGS rules but also trigger some dangerous situation.
Instead of plots, watch attached video. Here below some comments.

Head On - video name: real_aut_ho

Two head on situations were tested. Depending on the 2D geometry and the angles that result based on the position of the obstacle wrt the AutoNaut, the AutoNaut turns port the first time and starboard the second.

Overtaking - video name: real_aut_ot, real_aut_chasing

Then we overtake the AutoNaut coming from south. As the distance between the vessels becomes 700 meters the AutoNaut takes a turn to SB with a course offset up to +90 degrees. Once the AutoNaut is overtaken and the distance becomes 250 meters, the offset goes back to 0.

The same situation is then repeated, this time with both vehicle moving south. This time the obstacle takes a turn starboard instead of keeping the same course. So the AutoNaut, after a turn SB, comes back to the original course in order to avoid collision with the "irresponsible" (crazy?) obstacle.
After a short break, the obstacle tries to chase again the AutoNaut, that again turns SB to let the obstacle pass. However, for the second time, the obstacle turns SB and overtakes the vehicle from its SB side. Again the AutoNaut corrects the course to port (original course) in order to avoid the collision.

Crazy Head On - video name: real_aut_ho_crazy

The very last maneuver we performed is a head on situation with AutoNaut moving south and Buster moving north. This time, instead of keeping the course or turning SB, the obstacle turns Port trying to collide with the AutoNaut. It can be seen that the AutoNaut turns SB, as the vehicle seems to be keeping its course. However, when the obstacle turns Port, sb_mpc computes a quick Port turn for the AutoNaut (-90deg offset) in order to avoid the collision. Once the collision is avoided, the offset goes back to 0.