

A Ship Manoeuvring Desktop Simulator for Developing and Validating Automatic Control Algorithms

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ABSTRACT: This paper presents a user-friendly simulator developed based on Windows Forms and deployed as a test bed for validating automatic control algorithms. The effectiveness of some of the integrated track controllers has been tested with free running experiments carried out in the Towing Tank for Manoeuvres in Shallow Water in Ostend, Belgium. The controllers enable a ship to follow predefined random paths with high accuracy. Ship-to-ship interaction is considered in some cases. Simulator environments provide useful tools for extending the number of validation scenarios, supplementing the work performed in the towing tank. The simulator is presented with a graphical user interface, aiming at providing a good user experience, numerous test scenarios and an extensively-validated library of automatic control algorithms. With the usage of the simulator, further evaluation of developed control algorithms by implementing extensive test runs with different ships and waterways could be made. Case studies are shown to illustrate the functionality of the simulator.

1 INTRODUCTION

Autonomous shipping refers to the concept of using advanced technology, such as cybernetics and robotics, to operate ships with less or even without human intervention. The research on autonomous shipping has been around for a long time, but it is gaining more and more attention recently as a result of the rapid advancements in technology, decreasing cost of required on-board sensors and the increasing demand for more efficient, more environmentally friendly and safer shipping practices.

Simulators are important tools for the development and validation of automatic control algorithms. They rely on mathematical manoeuvring models, which are often based on physical scale model tests especially in shallow and confined water, to simulate ship manoeuvring behaviours, providing

testing in a digital world [1]. They allow for the realistic testing of a wide range of scenarios and conditions in a safe and controlled environment. Different kinds of waterways can be implemented in the simulation environment to verify the practicability of track keeping autopilots. Weather conditions, such as waves, tides, and wind [2] can be modelled in a simulator and their intensity adjusted. Furthermore, the effect of shallow and confined water may also be taken into account by using corresponding models [3]. At the same time, simulators reduce the risks associated with physical tests on real ships, especially in challenging conditions. They allow developers to iterate on their designs and test different scenarios quickly and easily.

Testing in simulators is typically more cost-effective than physical testing on real ships. Physical testing can be carried out in two ways: at full scale or

at model scale. In a full-scale test, the experiment is applied on a real ship and conducted in a fairway or at sea. Testers have no control over hydro-meteorology and therefore should be lucky or patient. A significant amount of human resources is required to cooperate in the test. A model scale test is performed in an experimental environment (e.g. towing tank). Waves and wind can be made by a wave maker and a fan but also the water depth and bathymetry are under full control. The environment is controllable but the costs of installing and utilizing these facilities are high. By simulation, the costs of time and money are really low. A batch of simulation runs with different settings can be performed in a short time, which helps researchers test developed methods extensively before deployment. In this process, issues may be identified. In addition, bugs in the control algorithms can be identified in the debugging mode and parameter settings can be well-tuned before implementation. All of this help to speed up the development process and ensure that the final product is robust and effective.

This paper aims to elaborate on a ship manoeuvring desktop simulator applied to the development and validation of automatic control algorithms, which is developed recently by the Maritime Technology Division of Ghent University and Flanders Hydraulics. The layout of its user interface and the functions of each panel on the interface are shown in Section 2. The library of automatic control algorithms embedded in the simulator is introduced in Section 3. This library could be extended to test new methods in the simulator and could be exported to use in physical testing. Section 4 describes several legacy mathematical models of ship manoeuvring utilized to generate motion data. Section 5 gives five case studies with the application of this simulator. The cases are mainly distributed into three tasks: path following, trajectory tracking and collision avoidance.

2 GRAPHICAL USER INTERFACE

2.1 Layout

A dedicated graphical user interface (GUI) is created to facilitate performing simulations. It is a Windows Forms application developed on .NET Framework 4.7.2. The GUI of the simulator – of which a print screen is shown in Figure 1 – consists of several panels, e.g. a map panel (Map A + Map B), a gauge panel, a monitor panel and configuration panels.

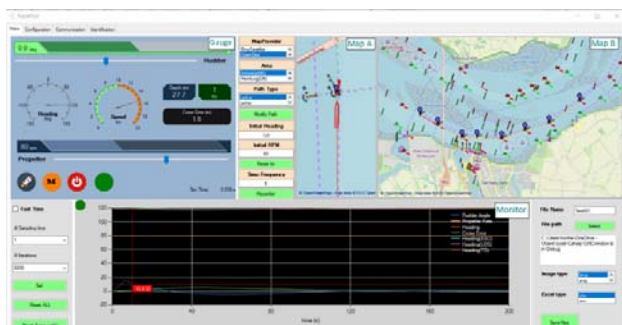


Figure 1. Graphical user interface of the ship manoeuvring simulator based on Windows Forms [4].

2.2 Map Panel

The function of the map panel has been developed based on the open source library, GMap.net Windows Forms & Presentation [5]. It provides controls to select different map providers and define the centre and direction of the map. Currently, map providers, Google Satellite, Google Terrain, Bing Terrain, Bing Satellite and OpenSea, are available in the simulator. The OpenSea map is highly recommended as it provides nautical information. On this map panel, two map windows of different sizes and directions are included. Map A rotates with the ship because it directs to the ship heading, while Map B always points North. By default, the map centre is the position of the ship, so maps move with the ship.

Worldwide waterways, such as the Western Scheldt and Yangtze River as shown in Figure 2, can be chosen as the current navigation environment. This provides a number of realistic test scenarios, as a result the practicality of the automatic control algorithms can be validated.

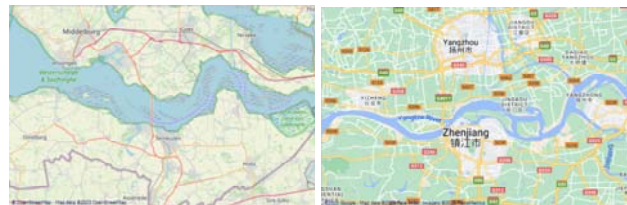


Figure 2. Western Scheldt, Netherlands (left) [4] and Zhenjiang section of Yangtze River, China (right) [6].

In addition, a custom navigation area, shown in Figure 3, has been created to represent a test basin environment. Simulation runs carried out within this area can then be referenced to free running tests performed in a towing tank, and the difference between a simulated and a real test can be compared to validate and improve mathematical models.



Figure 3. Custom navigation area representing the Towing Tank for Manoeuvres in Shallow Water.

Over the map layer, layers made up of markers and lines are added to illustrate waypoints, planned route, own ship contour, own ship's history trajectory and predictive trajectory, and encountered ship's contour and its trajectory, as shown in Figure 4.

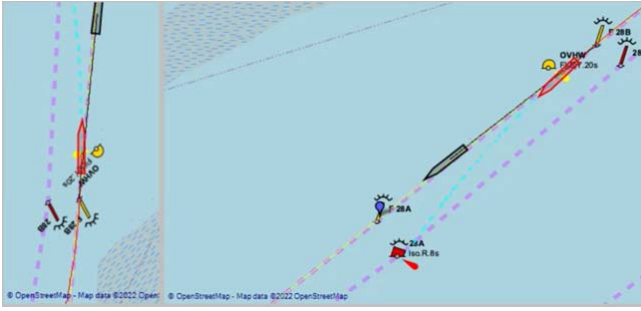


Figure 4 Waypoint (blue bullet), planned route (yellow line), own ship contour (red polygon), own ship's history trajectory (red line), own ship's predictive trajectory (blue line), encountered ship (black polygon) and encountered ship's trajectory (black line) displayed on the map [4].

Route planning is achieved by picking up waypoints on the map layer and generating a curved route through curve fitting and interpolation, as shown in Figure 5. A route can be modified by adding and deleting waypoints. Three methods are provided for generating a route: Piecewise Cubic Hermite Interpolating Polynomial (PCHIP), Cubic Spline Interpolation (SPLINE) or Akima Piecewise Cubic Hermite Interpolation (AKIMA). SPLINE leads to a smoother result, PCHIP produces less oscillation when data are not smooth, and AKIMA tries to combine the advantages of the previous two methods. In an oscillatory environment (on a track with more bends), PCHIP creates a flattened curve, while SPLINE and AKIMA both provide smooth curves (see Figure 6). As seen from Figure 7, in a flat region (on a track with fewer bends), SPLINE delivers a curve with sort of oscillation, while PCHIP and AKIMA could reduce it.



Figure 5. Planned route from waypoint selection in Yangtze River [7].

2.3 Gauge Panel

On the gauge panel (see Figure 1), which is developed based on a Windows Form package, WinForm Gauge [8], the ship's speed, heading, water depth, track error, rudder angle, propeller rate and sampling time

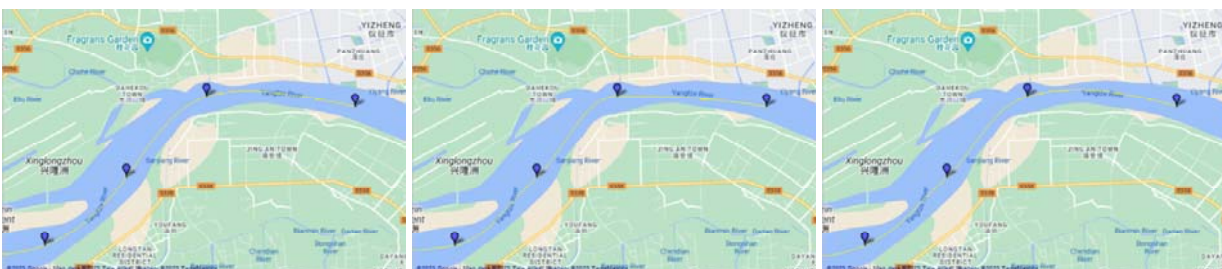


Figure 6 Path generation in an oscillatory environment (left to right: SPLINE, PCHIP, AKIMA) [7].

are displayed. Buttons to launch and suspend the simulation process as well as switch control modes between manual control and automatic control are present. When manual control is activated, the sliders can be moved to adjust the inputs of rudder angle and propeller rate.

2.4 Monitor Panel

The monitor panel plots the time history curves of the control actions (rudder angle and propeller rates) and some of the ship states (e.g. heading), and cross track error, as an example is shown in Figure 8. The window can be zoomed in and out and curves can be hidden to highlight the remaining ones. This information could help users to debug their programs, evaluate control performance and tune control parameters.

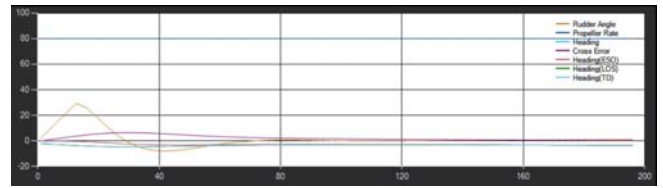


Figure 8 Monitor to show system's input and output

2.5 Configuration

Simulation frequency (the speed of the simulator that is asymptotically limited by calculation time) and sampling frequency (at which frequency a new math model evaluation is required) can be set independently to speed up or slow down the simulation process. According to the performance of the host computer and the complexity of the control algorithm chosen, there is a limitation to the maximum simulation frequency. The calculation time for each simulation step is displayed at the right-bottom corner of the gauge panel, and therefore the reciprocal of the simulation frequency should always be larger than this value.

Currently, three ship models, Tanker, Mariner and Container (see in Chapter 4), can be chosen as the control plant. Their main dimensions and initial states are displayed and can be modified. Two control schemes are available in the simulator. The essential parameters of each scheme are listed on the "Configuration" page and can be tuned before and during the simulation. Ship parameters and obstacle (encountered ships when considering ship-ship interaction) parameters are also adjusted on this page.

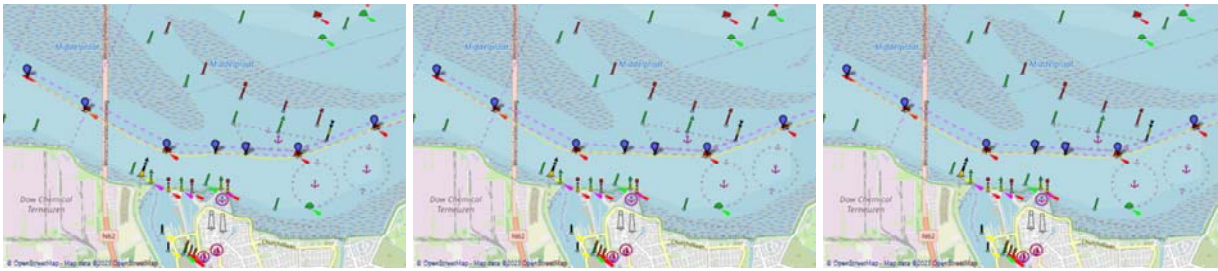


Figure 7 Path generation in a flat region (left to right: SPLINE, PCHIP, AKIMA) [4].

2.6 Other features

Fast-time simulation can also be performed to save time if the user is not interested to the simulation process. Only the final result will be shown on the monitor and map.

Simulation results can be saved, which provides a spreadsheet containing the values of the ship states and images visualizing the trajectory and time history of the heading, rudder angle, and propeller rate.



Figure 9. "Communication" page to configure the serial port

The simulator is able to communicate with other devices through serial port communication. This is achieved by the connecting the simulator and the ship (a virtual ship on another computer or a real ship) via a serial port line and talking to each other based on the predefined communication protocol. A "Communication" page is available to configure the serial port, as shown in Figure 9.

3 GUIDANCE, NAVIGATION AND CONTROL

3.1 Outline

Figure 10 illustrates the outline of the simulator, from which it can be seen that the simulator consists of three main parts, the GNC (guidance, navigation and control) library, the GUI and mathematical manoeuvring models.

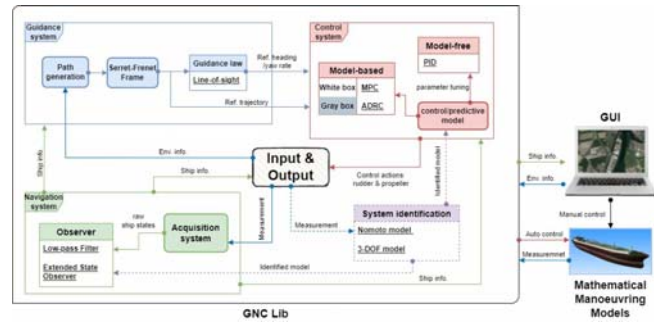


Figure 10 Framework of the simulator

The GNC library contains automatic control algorithms developed by Ghent University and Flanders Hydraulics, most of them are validated with free running tests in the Towing Tank for Manoeuvres in Shallow Water, Ostend, Belgium. The library is written in C# as in the framework of the GNC system proposed by Fossen [2].

3.2 Guidance system

The guidance system takes inputs from the navigation system (ship states) and the user interface (waypoints) and produces references to the control system. Based on the waypoints provided, a curved route for the ship to follow is then generated with fitting and interpolation (not only the waypoints but also the entire curve is taken into account in the track control).

A point selected on the map is presented in latitude and longitude. However, it is much more convenient to consider motion on a two-dimensional surface. Mercator projection is then implemented to map a point on the sphere surface to a two-dimensional surface [9]:

$$\begin{aligned} y_m &= R(\lambda - \lambda_0) \\ x_m &= \frac{R}{2} \ln \left(\frac{1 + \sin t}{1 - \sin t} \right) \end{aligned} \quad (1)$$

where (t, λ) represents a latitude-longitude point, (x_m, y_m) denotes a Web Mercator point, λ_0 is the longitude of an arbitrary central meridian that is usually that of Greenwich (i.e., zero), and R is the radius of earth, which is 6378137m. Latitude and longitude are in radians.

The inverse transformation of the above equation is

$$\lambda = \lambda_0 + \frac{x_m}{R} \quad (2)$$

$$\iota = 2 \tan^{-1} \left(\exp \left(\frac{y_m}{R} \right) \right) - \frac{\pi}{2}$$

Figure 11 shows the reference systems adopted in the simulator. A local ground-fixed frame system (LGF, north-east-down) whose origin locates at the beginning point of the planned route is used for simplifying calculation, as coordinates in the Mercator frame (MF) are usually huge numbers. The ship information relative to the route and path information, e.g. cross track error, along track error, relative heading/ course, desired positions on the route and curvature, is more difficult to obtain when following a curved route than following straight lines. Therefore, a moving path-tangential reference system, the Serret-Frenet frame (SF) [10], is then utilized to solve this. Based on the guidance law, line- of-sight [11], a reference heading is provided to reduce the cross track error in path following. However, some commercial autopilots require the reference yaw rate, which could be derived from the reference heading. In addition, in case of employing predictive control, the desired trajectory (including position, course and velocities) in a period should be given as the reference to the control system.

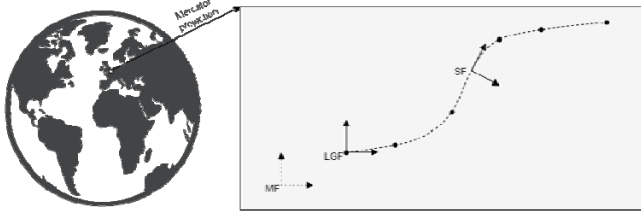


Figure 11 Reference systems adopted in the simulator

3.3 Navigation system

The navigation system plays a role in gathering sensor data about ship states and environmental perception, processing the raw data and delivering fused ship states and environmental information. For the processing, a low-pass filter is employed to filter the noise, while the extended state observer (ESO) is used for estimating ship states and disturbance.

Prediction can also be produced with the implementation of a predictive model based on the Nomoto model:

$$\begin{cases} \dot{\chi} = r + \beta \approx r \\ \dot{r} = -\frac{r}{T} + \frac{K}{T} \delta \\ \dot{x} = U \cos \chi \\ \dot{y} = U \sin \chi \end{cases} \quad (3)$$

where χ is the course, r is the yaw rate, β is the drift angle, K and T are the gain and time constant in the Nomoto model, δ is rudder angle, U is the speed, and (x, y) is the coordinate. Supposing the speed and drift angle remains constant in a prediction horizon, the ship's future trajectory with the current rudder angle

could be forecasted. In Figure 12, the blue dash lines represent the predictive trajectories in 150 seconds for a tanker class ship (length: 304.8 m, speed: 15 kn).

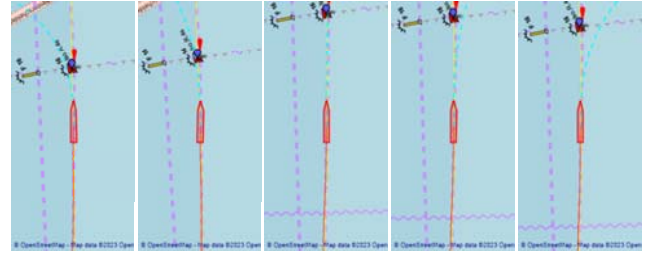


Figure 12. Predicted trajectories with rudder angles: -29 deg, -15 deg, 1.6 deg, 10.7 deg and 23 deg (left to right) [4].

3.4 Control system

The control system is the core of the decision-making process of the ship. Based on the reference states and real/predicted states, it proposes control actions for the ship to follow the reference. There are two main routes, model-free control and model-based control, to design a control scheme. The model-free control does not require an inherited model of the control plant, as the control laws are proposed according to the current error between the reference and measurement. Therefore, a correction appears after the existing deviation. However, ship models, which reflect the dynamic response to the control input of the ship, are utilized in model-based control. Dynamic behaviour is considered in the control law, leading to advanced control. A correction before deviation becomes possible if the prediction on model basis is considered in the algorithm.

In this simulator, two control methods are available.

- Active disturbance rejection control (ADRC), the framework of which is shown in Figure 13. It takes the reference heading (ψ_d) as input, employs an ESO to estimate the heading (z_1), yaw rate (z_2) and disturbance (z_3), uses a tracking differentiator (TD) to smoothen the reference (v_1) and gets its differential (v_2), and then produces feedback control (δ_0) (e.g. PD control). Another key in ADRC is dynamic compensation ($\delta\delta d$), which equips the controller ability to counteract the inner and outer disturbance ($b = T/K$).

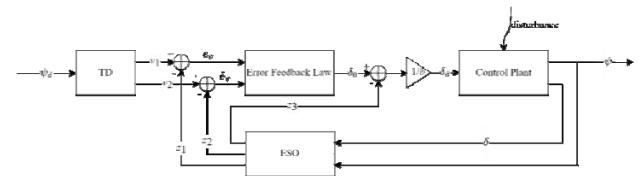


Figure 13. Framework of ADRC

- Model predictive control (MPC), the framework of which is shown in Figure 14 MPC is a state-of-the-art control method, which enables the system to take action in advance by looking ahead to the near future [12]. This requires a predictive model of the ship (e.g. a Nomoto model, or a simplified 3-DOF manoeuvring model). It optimizes the control action in a feasible region to minimize the

difference between the reference trajectory and the predicted trajectory. The feasible region is constrained by the maximum control input and collision-free condition. The optimization is performed at each time step, providing updated prediction and control action. This boosts the robustness of the control system, with the ability to tolerate the error from its predictive model and other uncertainties, and at the same time improves control accuracy.

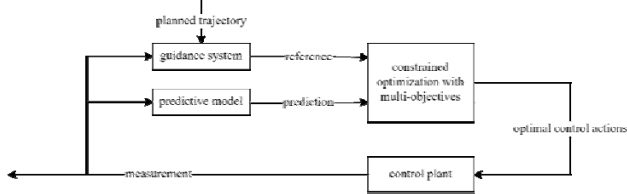


Figure 14. Framework of MPC

3.5 System identification

The GNC system is enhanced with system identification to make it more practical. Appropriate ship manoeuvring models are required in the navigation system to design observers and in the control system for the design of controllers. These models include principally the Nomoto model and the 3-DOF models, Abkowitz and MMG models. However, determining the coefficients in the models is quite difficult. The system identification technique can quickly estimate the coefficients based on systematic input-output data collected in manoeuvring tests or a navigation database. A number of parameter estimation methods can be found in literature, for instance, least square [13], Kalman filter [14] and support vector machine [15]. The simulator employs the least square method to identify the Nomoto model. During a simulation run, the user could pause the process and get the identified model on the "Identification" page.

4 SHIP MANOEUVRING MODEL

The computer numerical simulation necessitates accurate mathematical manoeuvring models of ships. To describe realistic manoeuvring behaviours, dedicated hydrodynamic manoeuvring models are utilized. They are critical to the simulator because they determine the simulation quality and the realism of the behaviour of the ships. The hydrodynamic models are derived through the theory of kinematics and dynamics and reflect ship motion response under the action of hydrodynamic forces and control forces. Models are typically divided into two types: modular models and integrated models. In an integrated model, such as the Abkowitz model [16] and Norrbinn model [17], the hydrodynamic forces on the hull, propeller and rudder are considered as a whole, which is then expanded to terms with respect to velocities and rudder angle by using Taylor series expansion. However, in a modular model, for instance the MMG model [18], the forces on hull, propeller and

rudder are modelled separately but with the consideration of interaction among them.

Several ship models are available in the simulator:

- Mariner
A Mariner class vessel (a fast cargo ship) operating at its design speed is presented in the form of the Abkowitz model. This model takes into account only the rudder angle as an input parameter, making it suitable for verifying a path-following (constant propeller rate) algorithm. The detailed model and its hydrodynamic coefficients can be found in [19], [20].
- Tanker
The Norrbinn model is preferable for simulating large ships. With the usage of the Norrbinn model, the manoeuvring motion of the ESSO Osaka 190000 dwt crude oil tanker is simulated. This model takes both rudder angle and propeller rate as inputs and is suitable in deep and shallow waters, with a concise form. Therefore, this ship model could be employed to test algorithms of trajectory tracking (the propeller needs to be controlled) and to investigate the shallow water effects on controllers. The formulas and parameters of the model are shown in [20], [21].
- Container
Son and Nomoto [22] presented a nonlinear rolling-coupled manoeuvring model of a container carrier that has a displacement of 21,222 m³. It is a type of the separated model with inputs for rudder angle and propeller rate, so it can be used for validating trajectory tracking. Coefficients of the model can be found in the above-mentioned literature and [20].

The main dimensions and the design speed of these ships are listed in Table 1.

Table 1. Principal parameters of ships utilized in the simulator

Ship [m]	Length between perpendiculars [m]	Breadth [m]	Design draft [m]	Design displacement [m] ³	Design speed [nm/h]
Tanker	304.80	47.17	18.46	220,000	16
Mariner	160.93	23.17	8.23	18,541	15
Container	175.00	25.40	8.50	21,222	-

5 APPLICATION

The simulator is implemented to model kinds of scenarios to validate and test the automatic control algorithms. In the following, five case studies applied to various ship models, navigation scenarios and controllers will be introduced to elaborate on the application of the simulator. This section is merely to show the applicability, because as depicted above, manoeuvring models that are a bit outdated and simplified are used as provided and have not been corrected for shallow or confined water. As discussed in Chapter 6, they will be updated with the models proposed by Flanders Hydraulics.

5.1 Case 1: ADRC path following

Figure 15 shows the result of Container's path following by implementing the ADRC controller in the Western Scheldt, The Netherlands. With the definition of 13 waypoints, a route was created and the Container could follow the predefined route with high accuracy (the red line agrees with the yellow line well). However, differences could still be seen at the corners of the route where the ship requires a (unachievable) large yaw rate to make a turn (for instance, as seen in Figure 15(b)). From Figure 15(c), it can be seen that the predicted trajectory of 150 seconds inputted with the current rudder command (for the ADRC algorithm, the predicted trajectory is just for indication to visualize the decision-making) was still directed to the outside of the planned route at the corner. This means that there is a late turning of the ship around the corner, which is due to that the ship could not make action in advance based on the information of the future path.

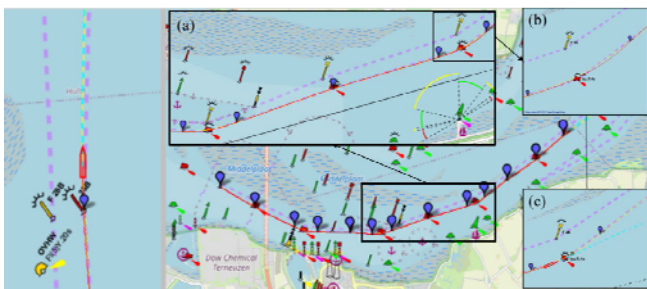


Figure 15. ADRC path following of the Container with a constant 80 rpm propeller rate in the Western Scheldt [4].

5.2 Case 2: MPC path following

Figure 16 illustrates Container's path following result by using the MPC controller in the Western Scheldt, Netherlands. The predefined route is the same as the one in Case 1. With the application of the MPC, the Container was able to follow the route with very high accuracy (see in Figure 16(a)) even around the corners of the route, where the tracking error was largely reduced compared with that when using the ADRC controller (see in Figure 15(b)) and Figure 16(b)). This is because of the action of the ship in advance with the implementation of a predictive model (a Nomoto model). As seen from Figure 16(c), the Container's predicted trajectory (only 30 seconds was shown as the prediction horizon used in the MPC was 30 seconds) was very close to the planned route. Therefore, the performance of the MPC controller is better than that of the ADRC controller.

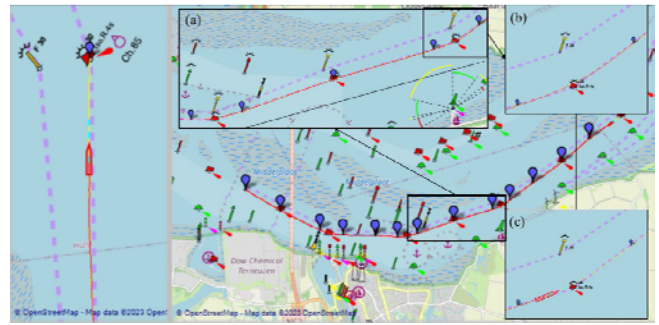


Figure 16. MPC path following of the Container with a constant 80 rpm propeller rate in the Western Scheldt [4].

The MPC algorithm was also validated with free running tests in the Towing Tank for Manoeuvres in Shallow Water in Ostend, Belgium. A KVLCC2 model ship a length of 4.267 meters, whose detailed main dimensions can be found in [23], was adopted as the control plant. Figure 17 shows the result of a free running test, where in can be seen that the MPC controller provides really high tracking accuracy.

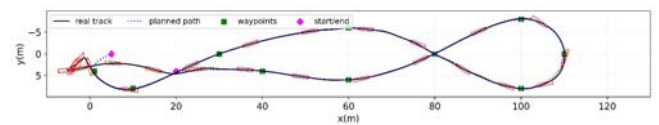


Figure 17. Validation of the MPC controller with a free running test of following a DNA-shaped path in the Towing Tank for Manoeuvres in Shallow Water (400 RPM, prediction horizon of 8 seconds)

5.3 Case 3: MPC trajectory tracking

Path following only set spatial constraints, while trajectory tracking has time limitations apart from the spatial constraints. In other words, the speed needs to be controlled in trajectory tracking. Figure 18 shows the result of trajectory tracking of the Tanker by using the MPC controller. The under keel clearance is set to 50% of the draft. The simulation is performed in the Nanjing section of the Yangtze River, China. A desired speed of 16 knots was required for the ship to keep. In this case, a simplified and identified 3-DOF predictive model was employed to couple the surge, sway and yaw motions, therefore rudder control and propeller control were then coupled. From the figure, it is easy to see that the real trajectory almost overlaps the planned route, indicating high accuracy in following the path. At the same time, the speed gauge presents a measured speed of nearly around 16 knots, meaning that the ship had reached the desired speed with the automatic control.

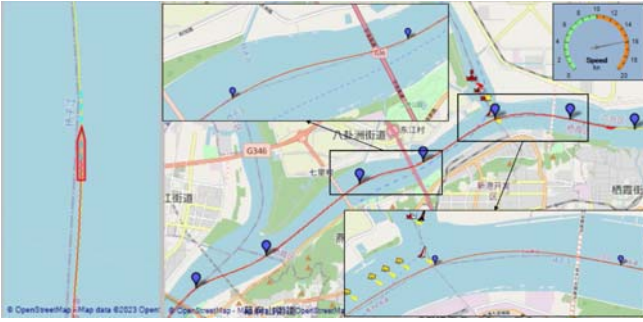


Figure 18. MPC trajectory tracking of the Tanker with a desire speed of 16kn in the Nanjing section of Yangtze River [24].

5.4 Case 4: half-automated collision avoidance by modifying the predefined route

Figure 19 shows the collision avoidance process of the Mariner ship in the Norderelbe, Germany by implementing MPC and modifying the predefined route manually. The propeller rate of the Mariner remained at 80 rpm, which results in her speed of around 15 knots. Figure 19(a) illustrates that the Mariner met a ship (length: 200 m, speed: 8 knots) around her predefined route in a head-on situation, and there is a high risk of collision. Based on the COLREGs [25], the Mariner needed to give her way to

her starboard side in this situation. As shown in Figure 19(b), the next waypoint was then moved to her starboard side with a distance manually by the user and the planned path was updated then. In Figure 19(c), (d) and (e), the Mariner went ahead to the new route and finally stayed on it and she avoid the conflict successfully.

5.5 Case 5: fully automated collision avoidance by setting constraints

In the MPC algorithm, distance constraints to the obstacles (encountered ships) can be set in its optimization function. In this way, while following the predefined route, a safety distance to the obstacle is also required. To be accordance with the COLREGs, constraints of the yaw rates should also be set to make the ship turn to its specific side (starboard or port). After that, three classic scenarios of collision, overtaking, meeting and crossing, were modelled. Figure 20 and Figure 21 shows the simulated overtaking and crossing process of the Tanker in the Western Scheldt by using the constrained MPC algorithm, while Figure 22 shows the meeting process in the Nieuwe Maas, Netherlands. The under keel clearance is set to 50% of the draft.



Figure 19. Half-automated collision avoidance of the Mariner by modifying the predefined route in the Norderelbe [26].

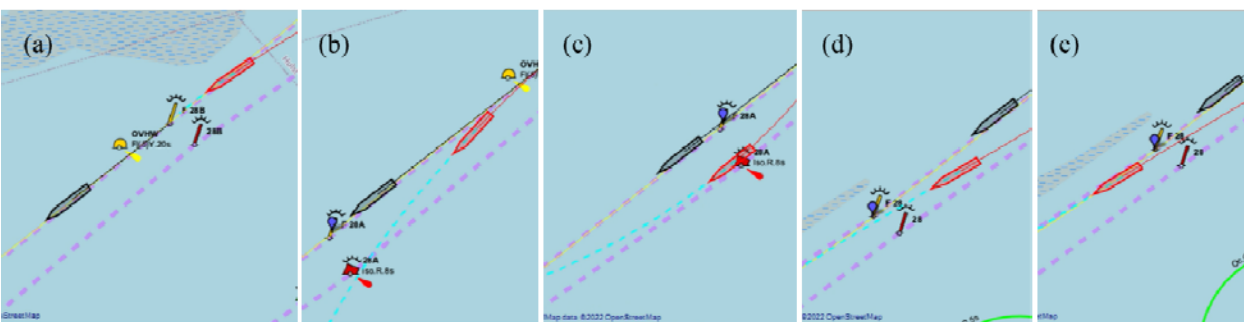


Figure 20. Automated overtaking process of the Tanker in the Western Scheldt by using constrained MPC [4].

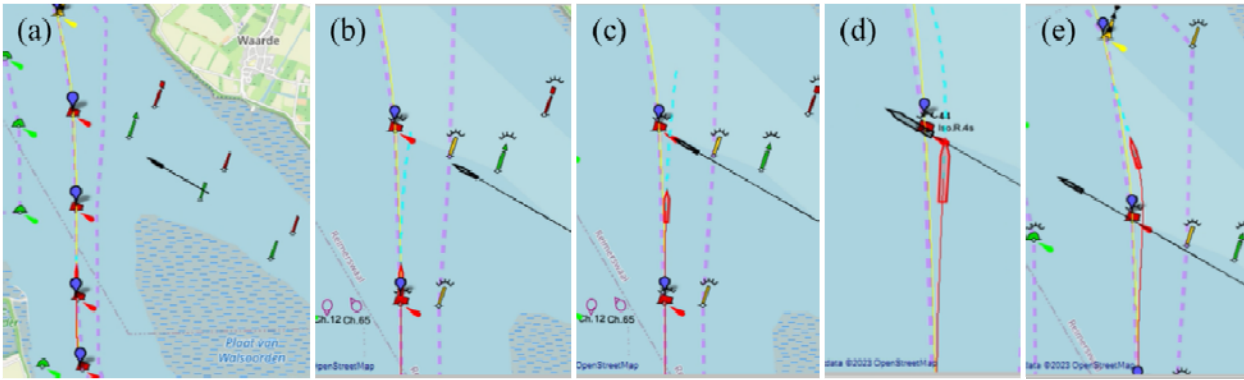


Figure 21. Automated crossing process of the Tanker in the Western Scheldt (at the crossing section of the main fairway and the secondary fairway between Bath and Hansweert) by using constrained MPC [4].

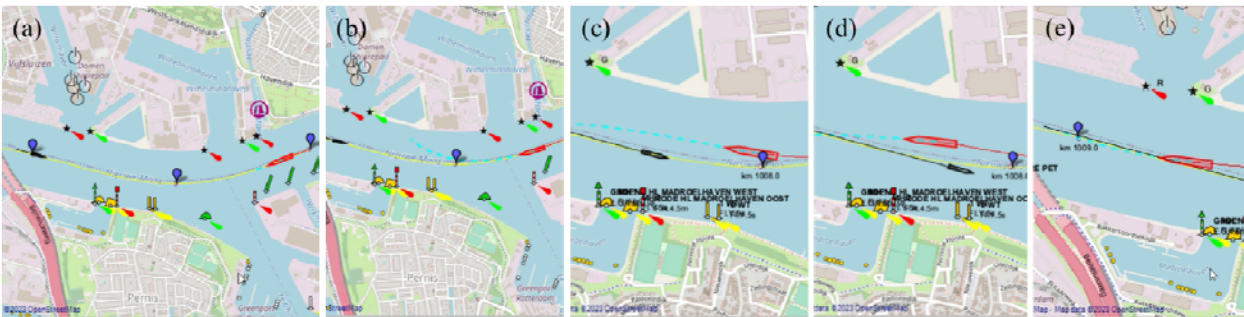


Figure 22. Automated meeting process of the Tanker in the Nieuwe Maas by using constrained MPC [27]

6 CONCLUSION

The proposed ship manoeuvring simulator provides a wide range of test scenarios for the validation of automatic control algorithms. Users can select different waterways, all around the world, to generate desired routes of different kinds as input of the algorithms and create custom collision scenarios (by generating dynamic obstacles) for ship-ship interaction. As a result, the developed control algorithms can be verified with well-rounded and extensive testing with this simulator.

The process of autonomous navigation is simulated and visualized via the user interface. During the process, the parameters of the controllers can be tuned based on the information displayed on the monitor panel and the map, which facilitates the investigation of the principles for parameter tuning. In the debugging mode, issues in the algorithms can be identified easily and then corrected.

The automatic control algorithms are wrapped in a module, increasing code reusability and extendibility. Extensively-tested algorithms can be extracted from the simulator and provided to clients to implement in physical testing. New algorithms can be verified with the simulator. One way is to establish communication with the simulator through a serial port connection. And another way is to incorporate them into the module of automatic control algorithms.

Although the presented simulator is a powerful tool to bring together manoeuvring models and control algorithms, rather simple and outdated manoeuvring models have been adopted to show the applicability in this paper. The environment provided in the simulator is limited to calm water and deep water (except for the Tanker model). This means that

presently the only possible environmental disturbance is shallow water. Flanders Hydraulics has more accurate shallow and confined manoeuvring models in calm water and recently disturbance from waves, current and wind is considered in some of the models. The coupling of the current simulator and the Flanders Hydraulics' ship model API will be done in the near future, bringing this tool and its output to a much higher level.

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