Model Based Design and Optimal Control of Crude Carrier in Narrow Waterways considering Sea-Induced Disturbances

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Abstract

This study focuses on the implementation of autonomous ships in the Istanbul Bosphorus, a crucial waterway connecting the Black Sea to the Sea of Marmara and the Mediterranean. The integration of autonomy to the ships in busy waterways can greatly improve efficiency and safety in inland shipping. To facilitate their successful implementation, the use of digital twin and model-based design technique including V-cycle approach is provided. Researchers can also anticipate possible challenges and devise solutions to address them by accurately portraying the external forces that affect ship behavior.

Digital twins, which simulate the behavior and performance of physical systems, can be utilized to develop robust autonomous control algorithms. These algorithms can optimize the maneuverability and safety of autonomous ships in narrow waterway environments. Furthermore, as legislation for autonomous ships is still being developed, the Istanbul Bosphorus case provides a valuable opportunity to test and refine the legal environment. The chosen model ship for this study is the KRISO Very Large Crude Carrier 2 (KVLCC2) [1]. The ship's geometric and hydrostatic properties, such as the ship's hydrodynamic coefficients, propeller parameters, and rudder parameters, are studied. Additionally, the ship's required trajectory is satisfied by means of rudder and propeller.

Considering wind and current disturbance models has prominent importance for the successful implementation and realistic validation of model-based autonomy for KVLCC2. To maintain dependable and safe operations, autonomous ships operating in real-world surroundings must account for external disturbances. Furthermore, by examining the response of the KVLCC2 full-scale model including wind and current disturbances, useful insights into the design and control of future autonomous ships can be gleaned. In this research, the optimization of PID control parameters for the control algorithm is performed using the Sequential Quadratic Programming (SQP) algorithm [2]. The SQP algorithm aims to minimize a nonlinear function subject to nonlinear equality and inequality constraints. To this end, the selected simulation environment is Matlab/Simulink, including toolsets implementing model-based design and control approaches. The optimized control parameters considering time-response transient and steady-state behaviour are supplied. The results of the simulation show satisfactory performance in terms of the ship trajectory tracking as illustrated in Fig. 1.

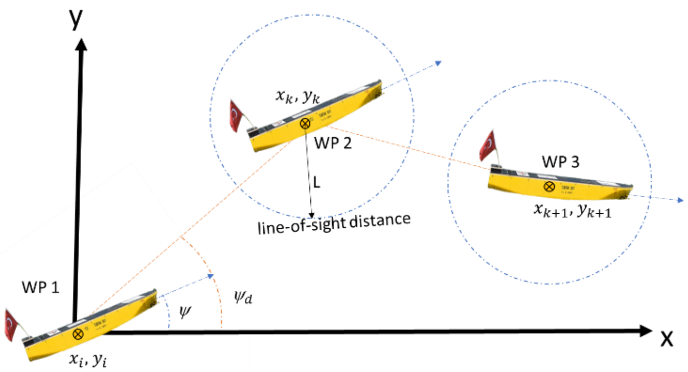

Fig. 1.KVLCC2 Model Ship's Path Plan [3]

However, certain issues are observed during the simulation, including slow dynamics in relation to the prescribed yaw angle reference, rudder saturation, and vibration in the rudder resulting in oscillatory response of the ship's yaw attitude angle. These aspects need further examination in terms of energy consumption and path planning aims. In conclusion, this study presents a promising step towards the development of fully autonomous ship control in ship navigation and maritime transportation. Additionally, further research is needed to validate the results in real-world scenarios, considering external factors, such as sea traffic congestion and weather conditions.

Keywords: Autonomous Navigation, PID Control, Sequential Quadratic Programming, KVLCC2

Literature

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