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A Dynamic Forbidden Sector Skipping Strategy in Thrust Allocation for Marine Vessels

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Thrust allocation logic is one component of a dynamic positioning system, which allocates the thrust force generated by the control law among the available thrusters. Generally, forbidden sectors are set in thrust allocation to prevent thrusters from entering certain azimuth angles in order to avoid a large thrust loss for downstream thrusters. The reduction of the feasible azimuth thrust region must affect the ability of the whole thrust system. In this study, a novel forbidden sector skipping strategy is proposed. The strategy is based on the dynamic forbidden sector concept. We improved conventional thrust allocation logic by accounting for the dynamic forbidden sector and forbidden sector skipping strategy. The forbidden angle can be in real time and can be adjusted according to the propellers' speed ratio. When the forbidden angle becomes small enough, the corresponding thruster may skip the forbidden sector. A time-domain simulation for a barge was performed to demonstrate the performance of the skipping strategy. Thruster–current interaction was included in the simulation. The results demonstrated that the employment of the skipping strategy can give the azimuth thruster a more feasible zone and can guarantee the thrust allocation more reasonably. The strategy can also assist the dynamic positioning system in saving fuel and achieving higher safety.

INTRODUCTION

A dynamic positioning (DP) vessel is defined by the International Maritime Organization and certifying class societies as a vessel that automatically maintains its position and heading exclusively by means of active thrusters (Sørensen, 2011). Since the oil and gas offshore exploration and production (E&P) operations are going into deeper waters, a dynamic positioning system (DPS) has been widely used in offshore engineering over the last five decades. Brink and Chung (1981) carried out an extensive computer simulation and performance analysis and assessment for the dynamic positioning control of a 300,000-ton ship. A detailed description of DPSs, including their early history, can be found in Morgan (1978) and Fay (1990).

Thrust allocation logic, which is an essential part of a DPS, allocates the commanded thrust forces generated by the higher-level controller among all the available thrusters. The thrust allocation problem has been studied by many researchers. A survey of control allocation methods for ships and underwater vehicles can be found in Fossen and Johansen (2006). The thrust allocation problem has been formulated as a constrained optimization problem in which the objective is to minimize power consumption and the gap between commanded forces and achieved forces, subject to constraints such as thruster position limits; see Durham (1993), Enns (1998), and Bodson (2002). Furthermore, the solving of the constrained optimization problem in real time has been addressed by Harkegard (2002) and Johansen et al. (2004).

In thrust allocation, the hydrodynamic interaction between the azimuth thrusters should be considered since the performance of the downstream thruster can be significantly reduced when it is in a neighboring thruster's wake. The unexpected thrust reduction of the thrusters will crucially decrease the performance of the thrust system with respect to providing forces. Several reports, such as Lehn (1980) and Nienhuis (1992), are available to illuminate the phenomenon of thrust degradation due to the thruster–thruster interaction. To prevent the thruster–thruster interaction from reducing the performance of the DPS, forbidden sectors are generally included in thrust allocation algorithms as inequality constraints to forbid a thruster from entering a sector where a neighboring thruster can be affected by its wake.

Generally, forbidden sectors are considered to be static zones that will not be changed once they have been determined. However, the thruster–thruster interaction is essentially dependent on the ratio between the propellers' rotational speeds. A novel concept of dynamic forbidden sectors has been proposed by Li and Wang (2014), in which more flexible feasible sectors for azimuth thrusters can be established. As a result, the thrust allocation algorithm will give more reasonable results after dynamic forbidden sectors have been integrated into it.

Through the use of the method above, however, the thruster still cannot skip the forbidden sector. If one forbidden sector is set to $[-10°, 10°]$, the thruster must rotate more than 300° if it rotates from $-15°$ to 15°. If two or more forbidden sectors are set, the thrust region comprises two or more separated thrust zones, and the thruster cannot rotate to the other zone once its zone has been designated. Thus, the performance of the thrust system may be significantly harmed when the forbidden sector is considered. The harm is much more severe than excluding the forbidden sector from the original region itself unless the thruster can skip the forbidden sector.

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KEY WORDS: Thrust allocation, dynamic forbidden sector skipping, thrust reduction, propellers' speed ratio, feasible zone.