Samenvatting proefschrift

Supporting Human-Machine Interaction in Ship Collision Avoidance Systems

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Ship collision is a classical problem for maritime practitioners and researchers. Human error is a major cause of collision accidents, which motivates researchers to develop automation systems replacing navigators on board. In particular, the developments of self-driving cars, robotics, and unmanned drones boost the confidence of having Maritime Autonomous Surface Ships (MASS). However, before autonomous ships fully replace all conventional ships, supporting the situational awareness of human operators is still a rigid demand, where the design of human-machine interactions (HMIs) become crucial.

This dissertation pays special attention to HMIs during collision avoidance. Specifically, a Human-Machine Interaction oriented Collision Avoidance System (HMI-CAS) is proposed, which allows the human operators and automation to share their intelligence. During collision avoidance, the HMI-CAS can not only offer one (optimal) solution to human users but also indicate the dangerous solutions. So, the decision process of the machine becomes transparent for the human users. The human operators can not only read and understand the solutions found by the machine but also validate and modify the solutions via an interface in the HMI-CAS. Without human interventions, the HMI-CAS works as an autonomous collision avoidance system. Moreover, to support the operators decide in time, a novel measure of collision risk using a concept called “room-for-maneuver” is proposed. Therefore, the measured risk reflects the dangerous level of the approaching ships and the difficulty to handle the encounter.

Human-machine interaction in the developments of MASS

This research found that the focuses of studies for manned and unmanned ships are different and complementary: the research for manned ships concentrates more on conflict detection; the research for unmanned ships concentrates more on conflict resolution. Thus, it is beneficial to learn from each other. However, developing various levels of unmanned ships requires not only better conflict detection and conflict resolution but also a user-friendly design that supports various HMIs, which is less discussed in the literature.
The benefits of developing HMIs are:

1) Supporting MASS I-III;
2) Building trust to ASVs and promoting ASVs;
3) Borrow knowledge from human operators to develop rule-compliant ASVs.
4) Improving existing collision alert system with more functions

Functions and framework of the HMI-CAS

The demands on HMIs in collision avoidance contain seven aspects, i.e., “early warning”, “solution advice”, “automated solution execution”, “cooperation support”, “trajectory prediction”, “data collection”, and “turning off/on the system”. “Solution advice” and “cooperation support” are less discussed, but they are crucial for supporting collision avoidance and are required in Type I-III MASS and Control Mode 1-4. Accordingly, five possible solution forms supporting HMIs are identified, i.e., one solution, an optimal solution, finite feasible solutions, a set of feasible solutions, all sets of unsafe solutions.

To support autonomous functions, the framework of the HMI-CAS remains the same as the Guidance, Navigation, and Control (GNC) system. Nevertheless, for exchanging information between human operators and the systems, an interface is designed.

A family of algorithms supports various HMIs during collision avoidance

With a comprehensive literature review on the state-of-the-art methods and the analysis on the requirements of HMIs, a family of Velocity Obstacle (VO) algorithms are chosen to be applied in the HMI-CAS. Specifically, these algorithms visualize the solution space of the own-ship (OS), collect the dangerous solutions in VO sets, and then find collision-free solutions out of the VO sets. Thus, the users can easily understand how the system make decisions. Three VO algorithms are employed, which are linear velocity obstacle (LVO) algorithm, non-linear velocity obstacle (NLVO) algorithm, and probabilistic velocity obstacle (PVO) algorithm in this research. Different from traditional methods, the VO algorithms do not require the target ship (TS) to keep constant speed and course. Therefore, these algorithms can incorporate the (non-linear, probabilistically predictable, etc.) predicted trajectories of the obstacles and TSs in collision avoidance.

Improved conflict resolution in the HMI-CAS considering ship dynamics and navigational regulations

The VO algorithms are convenient for human operators to join the conflict resolution in the HMI-CAS. However, the dynamics of ships are ignored when identifying the closed regions of dangerous solutions. Ships usually have

[1] *Promotie instituut: TU Delft; promotiedatum: 18 november 2019*

poor maneuverability, and therefore more time and space are needed to achieve the desired velocity. That means the collision might happen before the ship achieves the desired velocity in the extreme case. To handle this issue, the generalized velocity obstacle (GVO), which considers the ship's dynamics and controllers, is integrated into the HMI-CAS. Moreover, the interface of the HMI-CAS is modified to be user-friendly. Comparing with the HMI-CAS using VO algorithms, using the GVO in the HMI-CAS has two advantages: (1) supporting collision avoidance in a close distance where the VO algorithms might lead to a collision; (2) avoiding collisions using less evasive actions, which is advocated by navigational regulations, i.e., COLREGs.

Improved conflict detection in the HMI-CAS for supporting evasive actions in time.

The core of conflict detection is a measurement of collision risk that indicates the safety/danger level of the ship. When the risk is high, the collision alarm is triggered for taking evasive actions in the HMI-CAS. There are numerous risk measures which can assess collision risk, but most of them are independent of conflict resolution. As a result, the measured risk is independent of whether the collision is avoidable, which is not suitable for the proposed HMI-CAS.

A Time-varying Collision Risk (TCR) measure is proposed, which defined the collision risk as to the chance of avoiding dangers, i.e., the percentage of controls leading to collisions. High TCR level reflects a condition where the collision event is difficult to solve, and the collision is highly possible to happen. This measure is also compliant with common sense that the risk would not decrease when the ship encounters with more ships or the ship has poor maneuverability. TCR indicator, therefore, is proposed to be an auxiliary tool in the conflict detection module of HMI-CAS. Specifically, human operators can safely postpone evasive actions until the TCR reaches 1.

In summary, this dissertation proposes a prototype of a collision avoidance system that supports human-machine interactions, call HMI-CAS. Instead of replacing humans on board, the proposed system aims at bridging the intelligence of humans and machines, which enables cooperation between humans and machines and enriches the choice of collision avoidance systems for supporting human operators and for developing autonomous ships. It is expected to reduce the collision risk, to facilitate human operators, and to promote the development of Maritime Autonomous Surface Ships.

Reference

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