Fuzzy logic intelligent decision support system for safety of maritime navigation based on COLREG.

José Ignacio Valles[1], José A. Olivas[2] [000-0003-4172-4729] and José A. González Prieto[3]

[1] University of Castilla-La Mancha, 13071 Ciudad Real, Spain
[2] Department of Information Technologies and Systems, University of Castilla-La Mancha, 13071 Ciudad Real, Spain
[2] Defense University Center - Spanish Naval Academy, 36920 Marin, Pontevedra, Spain

Abstract. The main objective of this work is the development of an intelligent decision support system based on soft computing and fuzzy logic that incorporates considerations from the Regulations for Preventing Collisions at Sea (COLREG) and navigation experts knowledge, able to face demanding and complex situations in an evolutive maritime environment, building a comprehensive understanding of the situation and providing explainable and interpretable recommendations to ships' watchkeeping officers or performing actions if integrated in autonomous ships navigation systems.

Keywords: Soft Computing, Fuzzy Logic, Computing with words, COLREG, Safety of Navigation.

1 Introduction

According to the Annual Overview of Marine Casualties and Incidents for the year 2023 prepared by the European Maritime Safety Agency [1], there have been an average of 2,646 casualties and incidents per year, mainly in areas close to the coast and having as one of the main causes the 'Collision' between ships, together with the 'Loss of control - Loss of propulsion power', highlighting the human factor as one of the main factors contributing to marine casualties and incidents.

The Convention of the International Regulations for Preventing Collisions at Sea held in London in 1972 (COLREGs) [2] and its subsequent amendments, set the rules to be applied by ships in order to prevent the risk of collisions at sea.

In this regard, an intelligent decision support system for ships' bridge officers in navigation could be a good tool to contribute to mitigate the human factor present in most maritime casualties and incidents or to be implemented in autonomous ship navigation systems.

Among the different approaches to the problem from the Artificial Intelligence (AI) point of view, we can highlight the use of Deep Learning techniques being applied on neural networks architectures and with the application of different types of algorithms and solutions [3][4], such us Reinforcement Learning [5] or intelligent systems based on rules generated from existing knowledge [6], such as Fuzzy Inference Systems [7][8][9].

2 The problem to navigate through.

Generally, a ship in navigation follows a planned trajectory that optimizes the ship's transit and ensures its safety in navigation with respect to static hazards present in the environment such as shallow areas, offshore structures, islands, the coastline, etc.

During its transit the vessel is subject to interaction with the other vessels navigating in the environment, with the physical characteristics of the environment and with the weather and environmental conditions.

Regarding interactions with other ships, it is vital to determine the risk of collision early enough to be able to take the required actions. Therefore, one of the first steps is the detection of the risk of collision with other ships based on input data gathered from the environment. This data can come from sensors and traditional navigation aid systems such as RADAR, Automatic Identification System (AIS), electronic chart systems, global positioning systems, depth and speed measurement devices, anemometers, etc., or from AI-enabled systems such as systems with artificial vision that can identify beacons, vessel types and their appearance, obstacles, etc.

Once the risk of collision has been determined, it is necessary to identify the situation in which the ships interact among those typified in the COLREG, both in conditions of good visibility and reduced visibility, in order to define the most appropriate actions that must be accomplished to avoid a dangerous situation.

Other key aspects to identify to be able to assess the situation, since they will determine which ship should be kept clear of another, are:

- The kind of vessel approaching the ship, such as mechanically propelled, sailboats, fishing vessels, vessels with restricted maneuverability, without steering capacity, anchored, aground, etc.
- The characteristics of the environment, i.e. whether the vessel navigates in open water, restricted water, narrow channels, traffic separation schemes, etc.
- Proximity to navigational hazards such as low sounding areas or obstacles.
- The evolutionary and acceleration/deceleration characteristics of the vessel, considering relative speeds and trajectories with the surrounding elements.
- The safe distance of passage to be kept with respect to other vessels depending on their characteristics and circumstances, such as size, appearance, etc.

To identify the risk of collision with other ships, the calculated distance of the Closest Point of approach (CPA) with each of them and the time in which it will occur (TCPA) will be considered.

In view of the situation identified, it will be necessary to define the actions to be taken by the vessel, such as varying speed, changing course, etc., while trying not to stray too far from the planned optimized and safe trajectory.

Due to the nature of the problem, in which an adequate expert knowledge base is available and considering the complexity and variability of the maritime environment, an intelligent decision support system based on fuzzy logic will be used to represent the complexity of the problem, to model the available knowledge and to deal with all different kinds of situations at sea, providing also an adequate level of explainability and interpretability.

3 The course to steer.

The first step is to model and develop a realistic 2D simulation environment that emulates the peculiarities of the maritime environment and allows testing the rule base and the inference system in complex and changing environments of multiple ships interactions.

The second step is to translate that simulated environment in the form of the data delivered by existing ship navigation aid systems that will serve as input data to the intelligent decision support system.

The third step is to define the linguistic term sets that will model the input data to the system, as well as the linguistic rule sets and the inference system for the determination of collision risk, excessive proximity to navigational hazards and general prioritization of threats to ship safety.

The fourth step is to model the knowledge contained in COLREG for the creation of the set of linguistic rules necessary for the inference of the recommendation, adding as many input linguistic sets as necessary to cover all the possibilities contemplated in COLREG and those existing in a real maritime environment. In addition, and because COLREG does not detail all possible situations, such as situations of interaction with multiple vessels simultaneously, it will be necessary to model the necessary rules to cover complex situations (see Fig. 1), taking as a starting point the general information contained in COLREG and prioritizing actions according to the risk of collision with other vessels and the elements of the environment. During this process it is necessary to add considerations such as the size and physical and evolutionary characteristics of the ships, incorporate them into the fuzzy inference system and take them into account when recommending actions (see example in Fig. 2).

In addition, it is necessary to define and model a set of actions and their characteristics that will represent the output of the intelligent decision support system. These proposed actions must be presented in a natural and interpretable form by the ships' watchkeeping officers and accompanied by an explanation and motivation. On the other hand, in case of being integrated in autonomous ships navigation systems, the autonomous actions taken based on the intelligent system outputs, could be logged along with their explanation and motivation.

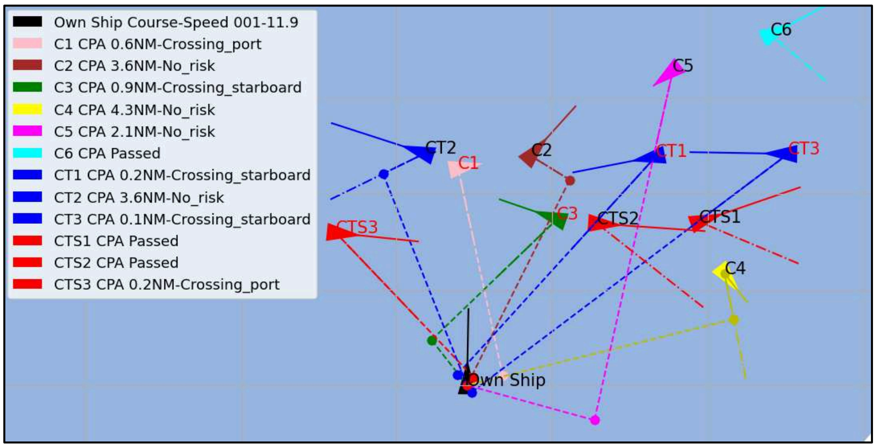

Fig. 1. Complex maritime environment with ship´s relative trajectories (12 Ships).

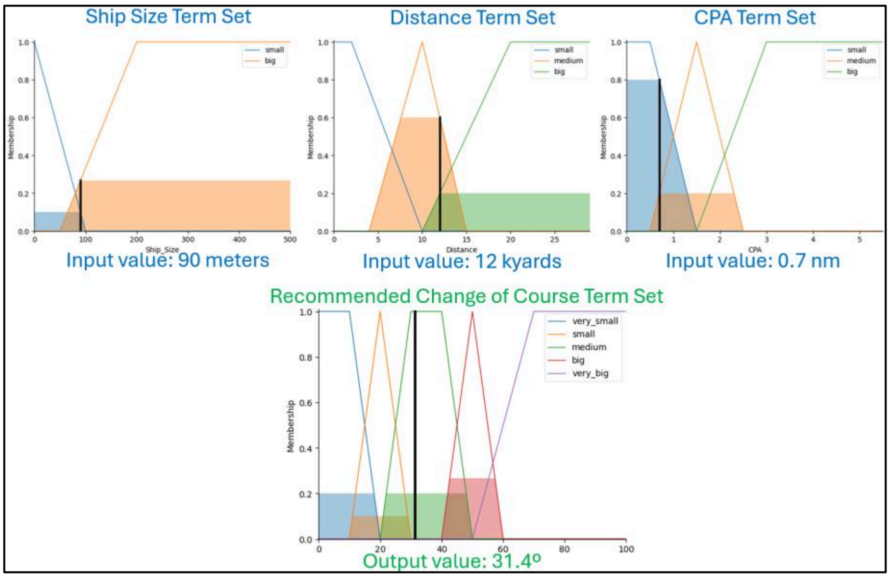

Fig. 2. Example of term sets and inference process used to determine the required change of course in an overtaking situation.

4 Conclusions.

The outcome of this thesis is the development of an intelligent decision support system based on fuzzy logic and approximate reasoning capable of receiving the processed input data coming from the ship's sensors and navigation aid systems, obtaining a comprehensive knowledge of the environment, assessing the situation, determining the risk of collision and excessive approach to navigational hazards and recommending a suitably motivated action to maintain the safety of the ship while navigating along a predefined trajectory.

The main effort will consist of the proper modeling of the simulation environment, as well as the fuzzy sets and linguistic rules needed to capture the complexity of the environment and the available expert knowledge and the design of an inference system that will yield appropriate and interpretable recommendations by the officers on watch on the ship's bridges or autonomously perform actions if integrated in autonomous ships navigation systems.

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