A Ship Intelligent Anti-Collision Decision-Making Supporting System Based On Trial Manoeuvre

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Abstract

A novel intelligent anti-collision decision-making supporting system is addressed in this paper. To obtain precise anti-collision information capability, an innovative neurofuzzy network is proposed and applied. A fuzzy set interpretation is incorporated into the network design to handle imprecise information. A neural network architecture is used to train the parameters of the Fuzzy Inference System (FIS). The learning process is based on a hybrid learning algorithm and off-line training data. The training data are obtained by trial manoeuvre. This neurofuzzy network can be considered to be a self-learning system with the ability to learn new information adaptively without forgetting old knowledge. This supporting system can decrease ship operators' burden to deal with bridge data and help them to make a precise anti-collision decision.

1. Introduction

Navigation is becoming more and more complicated and dangerous. Because ship owners are constantly increasing the size and speed of new ships, this may reduce the manoeuvrability of the ship and make the waterways more congested. Ship operators are confronted with a wide-ranging variety of operational data and information. In most ships at present, the data and information must be correlated manually and mentally. This is a laborious and error-prone process. The human error in ship operation is one of the most important factors leading to accidents. The International Maritime Organization cites human error as the casual fact in 80% of ship accidents [O'Neil 1994].

Anti-collision remains the most important concern for ships travelling at sea. The collision avoidance regulations (COLREG 72) do not suggest precise or proper manoeuvres. Many of these rules are qualitative and can only be used after quantifying the situation. Finding a safe, anti-collision manoeuvre is traditionally executed by drawing radar plots based on the observed echoes of the moving objects. Newly built ships are equipped with specialized radar based anti-collision systems and automatic radar plotting aids (ARPA). With the rapid advances in computer technology, accurate positioning and navigation systems, there is a growing interest in applying intelligent methods to ship manoeuvring control. Automation is becoming more and more accepted in ship operations and ship to ship communication. e.g. Automatic Identification System (AIS). Such automation may be used in anti-collision measures. To make an intelligent model for collision avoidance action, it is useful to investigate the decision problems that must be addressed concerning the encountering of different ships.

2. Anti-Collision Decision-Making Scheme

Most of the information used for navigation is supplied independently. It is difficult for a human to sustain continuous monitoring and may be a source of mistakes. Most information is delivered to navigators by individual sensors in a raw form. It is impossible to analyze all information regarding all target ships, due to the limitation of a human's analyzing capability. Decision-making is mainly based on the information obtained through visual observation. Prediction relying on visual observation is often difficult. The execution of the anti-collision action is a very complicated task. Collision avoidance decision-making is the comprehensive utilization of raw data, regulations for preventing collisions, human experience and skills. Human ability is obviously influenced by environmental and psychological factors. When encountering a developing situation, ship operators will be confronted with data from a variety of sources and are required to make collision avoidance decisions in a tense situation. These conditions can cause information overload, which results from the operators' inability to interpret a large amount of data rapidly. In parallel with the development of world shipping, modern science and new technology, many researches have designed automatic collision avoidance systems. The core of the anti-collision process is the automatic decision making task. Several anti-collision models have been set up. Goodwin [1975] suggests a model based upon the theory of ship domain. A ship domain may be thought of as the sea around a ship that the navigator would like to keep free of other ships and fixed objects. Davis et al. [1980] further developed the model by adding the theory of 'arena'. A ship arena is a larger domain based upon the distance from another ship at which a mariner would start to take action in order to avoid a close quarters situation. Colley et al. [1983] proposed the Range to Domain and Range Rate model (RDRR). All of these models endeavour to address the navigator's concern with physical separation of ships and their perception with ship-ship encounters when regions (domain or arena et cetera) become populated with other ships. The concepts have little to do with the selection and timing of an avoidance action. Concerns regarding ship safety are partially addressed through improved availability of relevant information and through the provision of Automatic Radar Plotting Aids (ARPA), Electronic Chart Display and Information System (ECDIS) and Automatic Identification System (AIS). With the rapid advances in computer technology, accurate positioning and navigation systems, the intelligent method is receiving more attention in the context of anti-collision system development. Here intelligent approaches are applied to collision avoidance decision-making. To make a collision avoidance decision requires the own-ship to address three important points:

- Whether an anti-collision action is necessary.
- Pattern of the anti-collision behaviour.
- When own-ship should take action.

By extending the processing of radar data and AIS data, a quantitative measure of risk of collision may be established for any traffic situation. If such a risk does exist then specific manoeuvre advice is generated. The proposed anti-collision scheme is demonstrated in Figure 1.

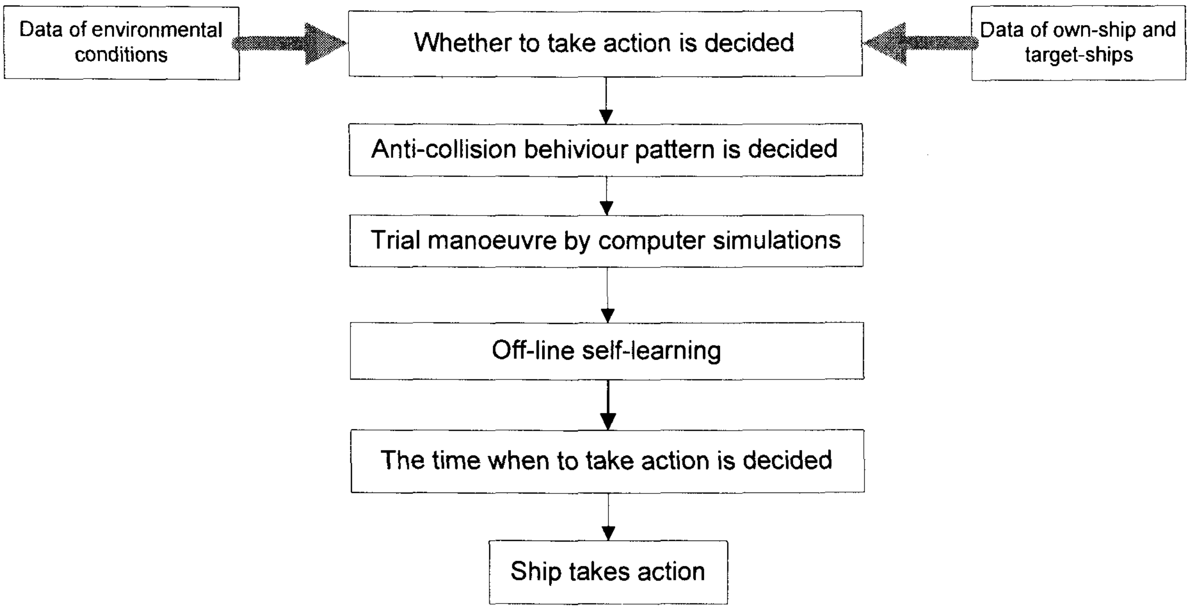

Figure 1 Demonstration of process to identify anti-collision action scheme

3. Whether to Take Action

Ship operators normally decide on the need for any actions through their appreciation of the collision regulation, the size of the ships involved and the value of DCPA. When DCPA is less than half the sum of the width of the two encountering ships, the two ships will collide in all encountering situations unless some action is taken. Let the universe U_d be the class that represents the changing field of DCPA, where $\tilde{A}_d$ is the fuzzy set in U_d such that $\mu_{\tilde{A}_d}$ indicates the membership function of $\tilde{A}_d$ and the authors assign it as follows:

$$\mu_{\tilde{A}_d}(DCPA) = \begin{cases} 1 & : DCPA \le (w_o + w_t)/2 \\ \exp[-(\frac{DCPA - (w_o + w_t)/2}{\mathrm{L_o} + \mathrm{L_t}})^2 & : DCPA > (w_o + w_t)/2 \end{cases} \quad (1)$$

$\mu_{\tilde{A}_d}$ as defined provides an assessment of the need (degree of urgency) to take some action to prevent a collision scenario. It is treated as a function of DCPA, w_o, the width of the own-ship, w_t, the width of the target-ship, L_o, the length of the own-ship and L_t, the length of the target-ship. The units of DCPA, ship width and ship length are nautical miles. That is, in restricted waters the ship dimensions influence the decision-making process. For the ships to keep well clear, after collision avoidance action, DCPA should be made as large as possible. On the other hand, optimal economic navigation requires the least deviation from the original selected course. $\mu_{\tilde{A}_d}(DCPA)$ as defined, provides a continuously varying function. However, in reality it is more likely that action will be taken or not depending on whether $\mu_{\tilde{A}_d}$ assumes a value above or below some threshold of concern. This situation is addressed by use of the so-called α -cut concept, that is, action is based on a binary value of $\mu_{\tilde{A}_d}$ defined as:

$$\mu_{\tilde{A}_{d\alpha}}(DCPA) = \begin{cases} 1 : \mu_{\tilde{A}_d}(DCPA) \ge \alpha \\ 0 : \mu_{\tilde{A}_d}(DCPA) < \alpha \end{cases} \quad (2)$$

When $\mu_{\tilde{A}_{d\alpha}}(DCPA) = 1$, the ship will take action to avoid collision. The selection of the threshold α will depend upon the nature of the restricted water, such as wind level and current speed. α will be assigned a value from the open interval (0,1).

4. Anti-collision Behaviour Pattern

To make a decision on when to take action depends on what kind of anti-collision behaviour pattern the own-ship will take. The decision must comply with COLREG 72 for them actual encounter situation. The encounter situation is also covered by COLREG 72 and is divided into three main types and each type has some subdivisions. Each main type of encounter situations is now considered in turn.

4.1 Head-on

The own-ship and target-ship are approaching each other on a reciprocal or near-reciprocal course. Both ships should alter their courses to starboard so that each shall pass on the port side of the other.

4.2 Crossing

The own-ship and target-ship are crossing each others intended path and so involve the risk of collision. The own-ship is the stand-on and keeps its course and speed when the target-ship is crossing from port to starboard of the own-ship. If the target-ship fails to take action, the own-ship alters course substantially to starboard and turns 360 degrees. The own-ship is the give-way ship when the target-ship is crossing from starboard to port of the own-ship. If there is sufficient sea room, the own-ship can alter course substantially to starboard and cross from the astern of the target. If the circumstance of the case does not admit course change, then own-ship must reduce speed.

4.3 Overtaking

A ship shall be deemed to be overtaking when another ship approaches from a direction more than 22.5 degrees abaft her beam.

4.3.1 Target-ship Overtaking Own-ship

The own-ship is the stand-on ship and keeps its course and speed.

4.3.2 Own-ship Overtaking Target-ship

The own-ship is the give-way ship. If own-ship is on the starboard quarter of target-ship, the own-ship alters course to starboard. If own-ship is on the port quarter of the target-ship, then own-ship alters course to port.

5. Assessing When to Take Action

For a target-ship, Part (a) of Rule 8 in COLREG 72 states that: "Any action taken to avoid collision shall, if the circumstance of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship." The last part of this statement implies an understanding of the correct response to the prevailing conditions. If a ship needs to take action as it approaches a target-ship, then the ship should act as soon as possible. However, the environmental conditions are continuously changing and hence there usually exists a reluctance to act too early. The actual time at which action is taken represents a compromise between these two conflicting influences. Before taking action each ship involved should identify itself as a give-way ship or a stand-on ship. Only when the give-way ship does not take action in good time, may the stand-on ship take action to avoid collision. The value of TCPA influences when the selected manoeuvre should be conducted. In order to determine when the first manoeuvre of anti-collision shall be taken, Davis et al. [1980,1982] used a large version of the domain as his arena. It was suggested that the action should be a function of the time taken to the CPA of the own-ship. Colley et al. [1983] developed the idea to be the time taken for the target-ship to reach the domain boundary according to the RDRR model. The arena and domain boundary have formerly been employed to define distance.

In this work, the collision avoidance model will be defined in terms of time. Firstly ship operator should decide the SDA (Safety Distance to Approach) according to the environmental situation. Then trial manoeuvre by computer simulations will be implemented to collect data. At last, TTA (Time to Take Action) will be obtained by off-line self-learning intelligent approach. TTA means the value of TCPA at the moment the own-ship should take action.

6. Trial Manoeuvre by Computer Simulations

The Automatic Radar Plotting Aids (ARPA) provides efficient navigational support with regard to speed and accuracy of calculation. ARPA facilitates the navigator's work considerably with its ability to process data and display the navigational situation on the radar screen, thus allowing the navigator to make reasonable decisions about which manoeuvre to adopt. However, on the basis of this information, the final decision on how to act to avoid the collision must still be made by individual navigator. The most significant feature of ARPA is the so-called trial manoeuvre facility in which the vector representing the own-ship motion may be modified continuously, with all target-ship vectors being adjusted and displayed accordingly. Thus a proposed manoeuvre by own-ship may be rapidly assessed in terms of its effectiveness relative to all nearby target-ships. To identify the efficient action one may simulate all possible anti-collision actions by trial manoeuvres using ARPA. However this is a large task and may take more time than the time available before the own-ship should take action.

In this paper, AIS is supposed to be installed on board. To collect the training data set, trial manoeuvre is applied by live off-line comuter simulations in non- real-time style. This means the simulation is applied at the time when own-ship encounters a target-ship. The heading, speed and bearing of target-ship and hence the relative speed, DCPA and own-ship manoeuvrability are fixed at that moment. After a new course is set, PD (Passing Distance) is determined for different randomly assigned TTA values.

The MMG model is used as the ship manoeuvring mathematical model for trial manoeuvre. The nonlinear ship mathematical model was built by the ship manoeuvring mathematical model group in Japan. For the anti-collision problems only the horizontal ship motion is used. So the general 6 Degrees Of Freedom (DOF) model is reduced by neglecting pitch, roll and heave motions and take under consideration the ship motion in three degrees of freedom relating the surge, sway and yaw response to the rudder at a constant cruising speed. The detail of the model is described in the work of Yang (1996).

7. Off-line Self-learning Scheme

Here self-learning means the construction of a Fuzzy Inference System (FIS) for achieving a desired nonlinear mapping that is regulated by a large representative data set consisting of a number of relevant input-output pairs related to the target-ship. Once the FIS parameters have been adjusted to improve performance, the system can perform a prescribed task without resorting to human experts. Hence the only input factor is SDA. The data that is generated to train the network is obtained through the trial manoeuvre of a virtual own-ship using computer simulations. Through each manoeuvre, a set of data (SDA, TTA) is collected. After 100 such simulations there are 100 inputs of the SDA with 100 corresponding values of TTA, determined on the basis that SDA has been equated PD. The self-learning off-line training scheme is shown in Figure 2.

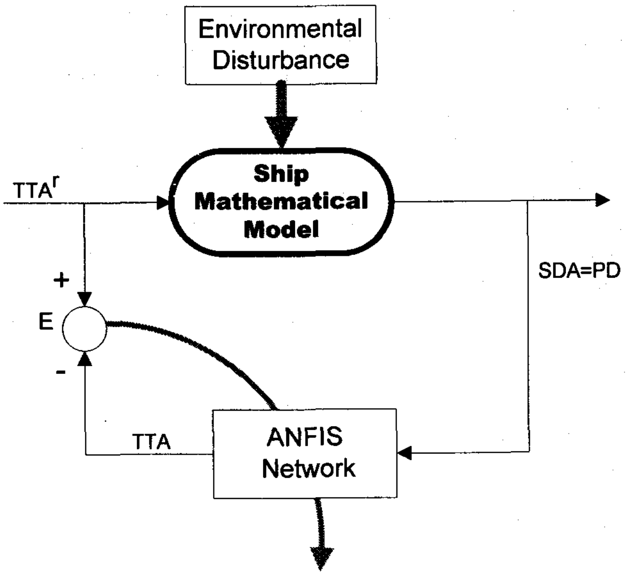

Figure 2 Self-learning off-line training scheme

Fuzzy logic provides a feasible control method as it can readily capture the approximate, qualitative aspects of human knowledge and reasoning. However, the performance of fuzzy logic relies on two important factors: the quality of the knowledge acquisition techniques used and the availability of domain experts. These two factors substantially restrict the application domains of fuzzy logic. Here this means that whilst the FIS consists of interpretable linguistic rules, the FIS cannot learn and therefore learning algorithms based on neural networks are used to create the FIS from the available generated data. The learning algorithms can identify the parameters of fuzzy sets and fuzzy rules as well as exploit any prior knowledge made available.

The intelligent method used is known as an Adaptive Neuro-Fuzzy Inference System or ANFIS for short. Fundamentally, ANFIS is about taking a fuzzy inference system (FIS) and tuning it with a back-propagation algorithm using the available input-output data. This allows the fuzzy systems to learn. The ANFIS can construct an input-output mapping based on both human knowledge and stipulated input-output data pairs. The ANFIS network used here to identify the parameters of the Sugeno-type FIS is demonstrated in Figure 3.

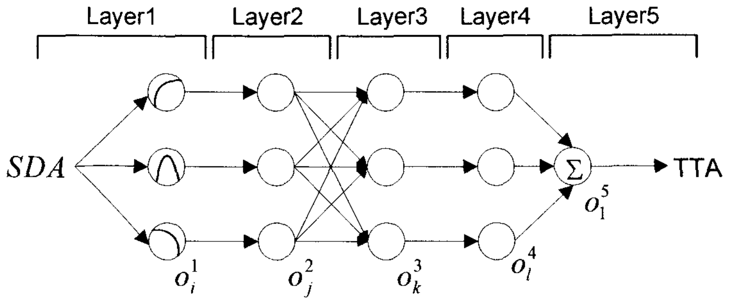

Figure 3 The proposed ANFIS network

Here the ANFIS uses a hybrid learning algorithm to identify the parameters of Sugenotype fuzzy inference systems [Sugeno 1985]. It applies a combination of the least-squares method and back-propagation gradient descent method for training the parameters of the fuzzy inference system membership function to emulate a given training data set [Jang 1993]. Here the selected training data set consists of a finite number of pairs consisting of SDA and TTA values.

8. Application of Anti-collision Supporting System

To demonstrate the intelligent anti-collision decision-making supporting system, a general cargo ship with a length of 126.0 m and a width of 20.8 m is used as the own-ship. The speed of the own-ship is 11.8 knots. Here it is assumed that a target-ship has a length of 196m and width of 30m and is traveling at a speed of 7.7 knots on a course setting of 250° with bearing 028° with respect to the own-ship, see Figure 4. In this environment α is defined as 0.5. The development of the situation and the calculation procedure associated with the own-ship taking action are as follows:

1. According to COLREG 72 the own-ship is the give-way ship and the target ship is the stand-on ship. Hence in this case the own-ship is required to take collision avoidance action when necessary. Assume the data about the target-ship is available to the own-ship through implementation of AIS.
2. In accordance with the positions, speeds and courses of the own-ship and the target-ship, DCPA is calculated as 0.1 nm. In accordance with Equation (1) & (2), $\mu_{\tilde{A}_{d\alpha}}(DCPA) = 1$, so action must be taken in accordance with the model.
3. Generate a random set of TTA^r values. Values of PD are obtained by trial manoeuvre. Assign SDA equal to PD. After 100 simulations for different TTA^r, Table 1 shows the TTA calculated by ANFIS approach for different angle between original course and new course.

Table 1 The relationship between TTA and course changing angle.

Angle between original course and new course	20°	30°	40°	50°	60°
TTA (minute)	15.42	12.18	9.47	8.85	8.58

To assess whether such a TTA value is reasonable, simulate the own-ship approaching target-ship with the action of altering course to starboard 30° at this TTA (12.18 minutes). The ship track and the result of the described action are shown in Figure 4. It should be noted that this TTA almost satisfy SDA = PD.

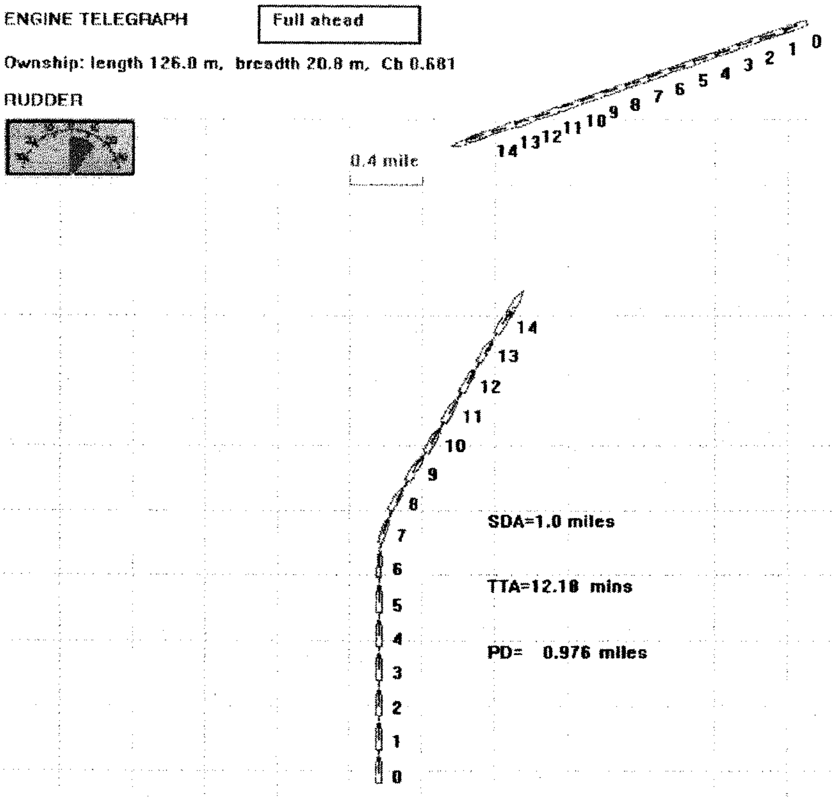

Figure 4 The test of TTA

9. Conclusions

This paper has introduced a self-learning off-line training scheme to obtain TTA, which is an important parameter in the developed intelligent anti-collision supporting system. The system has used the ANFIS learning algorithm and the model is based on a three-stage calculation to facilitate automatic collision avoidance using fuzzy theory and expert navigation experience. Ships are assumed to have installed AIS, ECDIS so as to obtain data and information on target-ships. Fuzzy logic is applied to deal with whether the ship should take action to avoid collision. Recognizing that ship anti-collision is a complicated situation, ship manoeuvreability and ship sizes are considered in the model.

From the simulation results, a rather precise TTA is obtained by the ANFIS algorithm with the self-learning training. The model appears to be suitable for ship encounters. Need to mention that in this paper one has only considered the immediate action to take to avoid potential collision. One has not considered the full sequence of anti-collision action.

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