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FUZZY REASONING AS A BASE FOR COLLISION AVOIDANCE DECISION SUPPORT SYSTEM

ABSTRACT

Despite the generally high qualifications of seafarers, many maritime accidents are caused by human error; such accidents include capsizing, collision, and fire, and often result in pollution. Enough concern has been generated that researchers around the world have developed the study of the human factor into an independent scientific discipline. A great deal of progress has been made, particularly in the area of artificial intelligence. But since total autonomy is not yet expedient, the decision support systems based on soft computing are proposed to support human navigators and VTS operators in times of crisis as well as during the execution of everyday tasks as a means of reducing risk levels.

This paper considers a decision support system based on fuzzy logic integrated into an existing bridge collision avoidance system. The main goal is to determine the appropriate course of avoidance, using fuzzy reasoning.

KEY WORDS

maritime accidents, collision avoidance, radar plotting, fuzzy logic, decision support system

1. INTRODUCTION

Collision avoidance is one major task of every marine navigator. Each of them must obey the International Regulations for Preventing Collisions at Sea 1972 (COLREG) [1], which governs the rules for preventing collision at sea. Every seafarer must strictly consider COLREG rules in all situations, regardless of time, sea area and weather conditions. Since human error remains, proportionately, the most common cause of accidents at sea, knowing the COLREG rules is not enough to prevent collisions. Vessels also require experienced navigators who are capable of properly assessing a situation and making the correct decision at the right time to avoid other vessels at sea.

Many researchers around the world are engaged in the development of the autonomic Collision Avoidance System (CAS). Models of research may be divided into three categories: mathematical models and algorithms, soft computing (the evolutionary algorithms, neural networks, fuzzy logic and expert systems), and a combination of all - a hybrid navigation system [2].

Perera *et al.* [3] proposed a decision making system based on fuzzy logic in which the highlighted situations that occur at high seas when the “stand-on” vessel must make a manoeuvre to avoid collision. The stand-on vessel is the one with the right of way and should maintain her course and speed, while the “give-way” vessel is obligated to yield to the stand-on vessel.

The same authors soon presented an advancement by combining fuzzy logic and the Bayesian network, which works as an inference medium between collision avoidance decisions and collision avoidance actions [4]. Smierzchalski also tried to combine two computer techniques: evolutionary algorithms for the determination of the optimal path of passages and fuzzy logic to control the vessel after a set path of passage [5] (in this case fuzzy logic works as fuzzy control of the course and speed). Pietrzykowski *et al.* [6, 7] presented a collision avoidance trajectory with solutions determined by the method of multi-stage control in a fuzzy environment. In their paper they also presented a prototype of a navigational decision support system which utilizes knowledge of experienced navigators using artificial intelligence methods and tools including fuzzy logic. More complex hybrid systems for autonomous navigation were presented by Lee [8], where in addition to fuzzy logic, a Virtual Force Field from the field of mobile robotics was proposed.

Vessel’s trajectories in collision avoidance situations were the focus for the exploration of Szlapczynski who used a method called “Evolutionary sets of cooperating ship trajectories", which enable the navigator to predict the most probable behaviour of a target vessel and to plan their own vessel's manoeuvre in advance [9]. In a situation of heavy traffic this method also allows the VTS (Vessel Traffic Service) operator to coordinate the manoeuvres of all vessels. He used the evolutionary algorithms and the corresponding procedures for finding the fittest solution; in this case, the optimal trajectories of the vessel.

Expert systems are part of intelligent systems as well, which operate in accordance with the knowledge base. One way to present knowledge in the expert system is also the case-based reasoning (CBR), which was used for collision avoidance at sea by Liu [10]. A CBR system solves a new problem by retrieving a similar one from a case base. Liu *et al.* [11] also introduced the use of the computational information fusion method for the decision model. This consists of two types of virtual agents – vessel and VTS agents who monitor and process information of own and target vessels in the immediate surroundings, and on the basis of these data mutually decide which vessel has the right of way, when there is a change of the direction or speed, and the duration of these changes.

2. COLLISION RISK ASSESSMENT

Investigating the human factor error in maritime transport leads to Safety Management and, consequently, Risk Assessment. The latter has become the basis for a variety of studies assessing the level of risk of shipping for humans and the environment. An ongoing vessel represents high level of risk because it is constantly exposed to the unpredictable states of weather and sea, other conditions on the route (number of vessels and other floating objects in the vicinity, the state of waterways, pathways, etc.), the state of the vessel itself and the knowledge, skills, and health status of the navigator [12]. High levels of risk affect different people in different ways but often enough cause stress and consequently loss of control over the conduct of the vessel.

During the voyage the navigator controls the operation of navigational equipment, the steering and propulsion systems, and at the same time monitors the vessel's surroundings. Again, regarding collision avoidance the COLREG rules apply. COLREG includes 38 rules that are directly and indirectly related to the management of the vessel in relation to other vessels at sea, e.g. technical requirements for lights and day marks, acoustic signals, additional lights for fishing vessels and others. Interpretation of the rules and their use is explained by Cockcroft [13].

In addition to these rules the navigator must make proper use of navigation devices and the interpretation of data provided by them. For collision avoidance ARPA (Automatic Radar Plotting Aid) radar is one reliable piece of equipment useful for assessing the safety of navigation. Risk assessment and avoidance decisions are established depending on the information relayed by ARPA. However, studies have shown that more than 60% of accidents are caused by collision, of which 56% were due to failure to comply with COLREG rules [14]. In order to reduce the impact of human error, this paper proposes a decision support system based on fuzzy logic integrated into the ARPA radar collision avoidance system. With data calculated by the ARPA unit and knowledge of rules, the system would provide suggestions to navigators regarding the proper course deviation necessary to avoid an approaching target vessel.

2.1 *ARPA system*

The ARPA unit is today the structural part of navigational radar that processes the received radar signals. Unlike regular radar, the navigator obtains the dynamic data of an observed vessel:

- distance (range) to target vessel (DTTV),
- bearing to target vessel,
- target vessel's course,
- target vessel's speed (true/ relative),
- closest point of approach (CPA),
- time to closest point of approach (TCPA).

With further connection to the Automatic Identification System (AIS) the navigator receives additional information such as the name of the vessel, Call Sign, MMSI (Maritime Mobile Service Identity) number, etc. All data are of great assistance to navigator, even if we consider the standard limitations and errors inherent to radar.

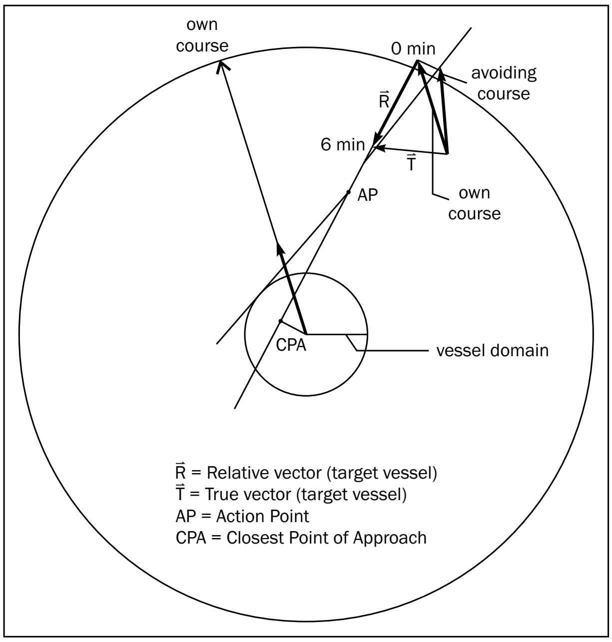


Figure 1 - Manual radar plotting

ARPA radar provides a function called "Trial Maneuver", which simulates a postponed navigational situation within a time interval [15]. With the input data (change of speed and course within the time delay) the navigator receives a picture of the target vessel's trajectory. This feature has replaced the manual graphic radar plotting (*Figure 1*) which was the navigator's job before the development of the ARPA unit. Using this method the navigator determined any alteration of his/her own vessel's course to avoid the target vessel.

2.2 Vessel domain

The vessel domain is an area around the vessel which must remain free from other vessels and fixed obstacles [16, 17]. In practice, this area is determined by the navigator, by the shipping company or other designated person/institution. If there is a risk of threat to the vessel domain by another vessel or an object, it is necessary to make an appropriate manoeuvre to avoid collision, and this manoeuvre must comply with COLREG rules. In everyday navigation the CPA is the most used indication of whether there is danger that the target vessel will enter one's own vessel domain. But the radar CPA does not take into consideration both vessels dimensions as well as manoeuvring specifications; consequently, this information is inadequate and probably the cause of many accidents. These accidents could be reduced by the implementation of a model of safe vessel domain.

Over the last 30 years objective determination of a vessel domain has become serious science and several authors have dealt with it, among the first being Goodwin, who suggests that the vessel domain is confined within three sectors that are similar to the horizontal angles of the side lights and stern light. The model was developed on the basis of statistical analysis of data from a wide range of registers and simulations [18, 17]. Most of the early developments of the vessel domain were created on the basis of statistical and analytical methods, but today's methods include the use of artificial intelligence: Pietrzykowski and Uriasz [19] with a fuzzy vessel domain (in combination with a self-learning neural network) as the safety criteria for navigation at high seas; a similar method is used by Wang [18], who said that for the navigator fuzzy domain limits are more practical than precise boundaries for the assessment of navigation safety. The use of artificial neural networks for subjective determination of the safe vessel domain has also been proposed [20].

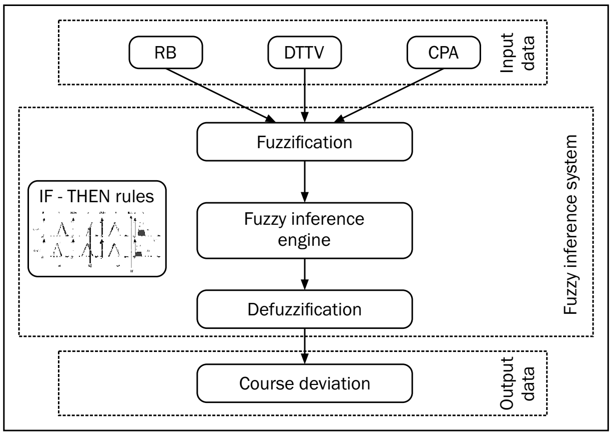


Figure 2 - Decision support system based on fuzzy logic, implemented in ARPA Radar

3. DECISION SUPPORT SYSTEM BASED ON FUZZY REASONING

To reduce human error in collision avoidance operations, subjective decisions should be limited and supported by computerized systems. One of the solutions is the decision support system (DSS) which could stand alone or be integrated into existent navigational equipment. The DSS proposed in this paper is based on fuzzy logic and composed of the following units (*Figure 2*):

- Input data – parameters received by ARPA unit. Experienced navigator makes decision based on the following information: CPA, relative bearing to target vessel (RB) and DTTV.
- Fuzzy inference system – system controlled by fuzzy logic.
- Output data – suggestion of appropriate course deviation of own vessel to prevent collision (change of speed is reserved for future research).

3.1 Fuzzy inference system

Fuzzy logic belongs in the area of artificial intelligence, which was first introduced by Zadeh [21], who wrote that human decisions are based on imprecise information. The advantage of fuzzy logic is in its processing of inaccurate data to create precise solutions. As an example (*Figure 3*), let us take the watch keeping navigator, who visually observes the surrounding area of the vessel. He/she uses linguistic terms to describe the distance to other vessels, such as: the vessel is far away, the vessel is at medium distance or the vessel is at a short distance. At the same time the navigator assesses the risk of collision. In short, the navigator describes the situations inaccurately (instead of 10.5 nautical miles they say that the vessel is far away and the risk of collision is minor or does not exist), and so develop the so-called fuzzy sets, which do not have clear boundaries. We say the statement belongs to a set of statements with a certain grade of membership. Statements about the distance of the vessel can be illustrated graphically, with a fuzzy membership function, where "N" means that the observed vessel is near, "M" means middle distance and "F" means far away (*Figure 3*).

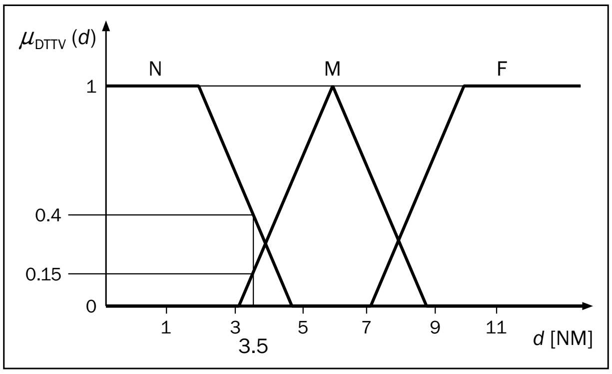


Figure 3 - Example of fuzzy membership function

The horizontal axis of a two-dimensional Cartesian coordinate system presents the distance in nautical miles (NM); the vertical axis shows the grade of membership of elements to a fuzzy set. The theory of classical logic assumes only the correct and incorrect statements, so that the statement belongs to a set (true or 1), or does not belongs to a set (false or 0). In the case of fuzzy logic, however, the element belongs to a set with a certain grade of membership depending on the truth of the statement. For example, if the distance to a target vessel is d = 3.5 NM, it means that it belongs to both sets N and M, but with varying grades of membership: $\mu_N(d) = 0.15$ and $\mu_M(d) = 0.4$ (*Figure 3*). The shape of a fuzzy set can also be defined mathematically. As an example, let us look at the definition of fuzzy set M:

$$\mu_M(d) = \begin{cases} 0, & d < 3\,\text{NM} \\ \left(\frac{d-3}{3}\right), & 3 \leq d \leq 6\,\text{NM} \\ \left(\frac{9-d}{3}\right), & 6 \leq d \leq 9\,\text{NM} \\ 0, & d > 9\,\text{NM} \end{cases}, \tag{1}$$

Limits of the fuzzy set M (3, 6, and 9) in an example were chosen randomly. The form of the set is determined by an expert, thus we know the sets in the form of a triangle (the most commonly used form of the sets in the literature), a trapezoid, a Gaussian curve, etc. The procedure by which a certain number or parameter (input) is appointed to an appropriate set and by which a grade of membership is determined (a subjective determination by an expert), is called fuzzification. The fuzzy inference system (FIS), also known as the fuzzy rule-based system, is the process of formulating the mapping from a given input to an output, using fuzzy logic. It is one of the main elements of the fuzzy logic system. The fuzzy rules are drawn by an expert, taking into account all relevant COLREG rules. The FIS type in this paper is “Mamdani”, which is the most commonly used fuzzy methodology. The use of the IF-THEN rules (*Figure 4*) is organized with the “AND (min)” and “OR (max)” operators. Defuzzification is the last step in FIS and it is a conversion of fuzzy output quantities into a crisp output quantity (*Figure 4*).

Membership function of output D takes the form:

$$\mu_D(x) = \max_n\{\min[\mu_{An}(ai), \mu_{Bn}(aj), \mu_{Cn}(ak)]\},$$
$$n = 1, 2, 3 \ldots \text{N} \tag{2}$$

4. SIMULATION

Simulations were performed with the Matlab Fuzzy Logic Toolbox Graphical User Interface. Input data are RB (*Figure* 5a), DTTV (*Figure* 5b) and CPA (*Figure* 5c). Output data (decision) is course deviation (*Figure* 5d). Altogether, 84 rules govern fuzzy reasoning based on parameters the navigator receives from the ARPA radar. Fuzzy sets and rules were modelled regarding the

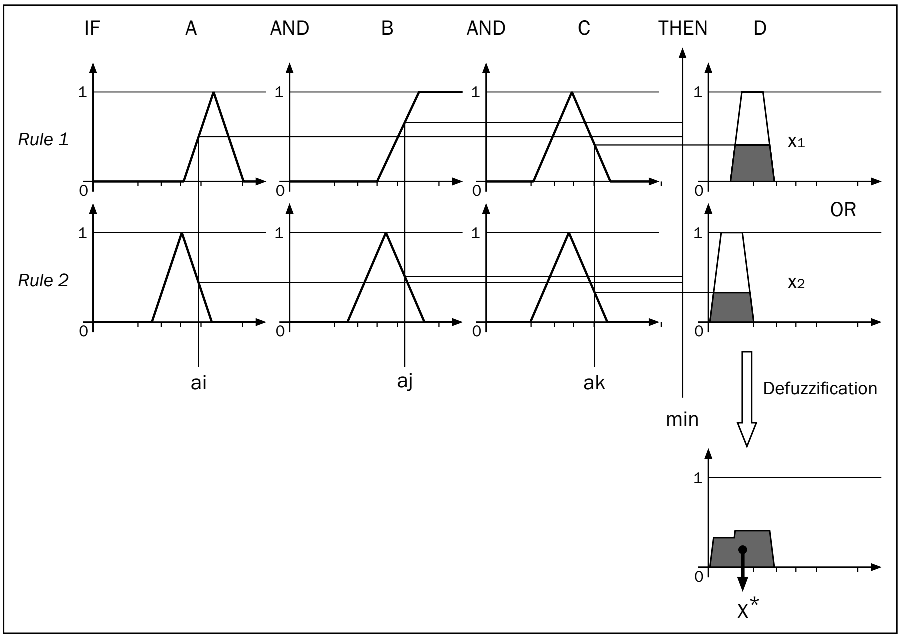


Figure 4 - Graphical interpretation of fuzzy inference with MIN and Max operators

analysis of 144 results obtained by the manual radar plotting method:

- Input variable "RB" - 7 fuzzy sets with corresponding membership functions (*Figure 5* (a)):

$$\mu_1(x)=\begin{cases} 0 & x<0 \\ \frac{x-0}{0-0} & 0\le x\le 0 \\ 1 & 0\le x\le 20 \\ \frac{30-x}{30-20} & 20\le x\le 30 \\ 0 & x>30 \end{cases},\tag{3}$$

$$\mu_2(x)=\begin{cases} 0 & x<15 \\ \frac{x-15}{25-15} & 15\le x\le 25 \\ 1 & 25\le x\le 35, \\ \frac{45-x}{45-35} & 35\le x\le 45 \\ 0 & x>45 \end{cases}\tag{4}$$

$$\mu_3(x)=\begin{cases} 0 & x<30 \\ \frac{x-30}{40-30} & 30\le x\le 40 \\ 1 & 40\le x\le 50, \\ \frac{60-x}{60-50} & 50\le x\le 60 \\ 0 & x>60 \end{cases}\tag{5}$$

$$\mu_4(x)=\begin{cases} 0 & x<45 \\ \frac{x-45}{55-45} & 45\le x\le 55 \\ 1 & 55\le x\le 65, \\ \frac{75-x}{75-65} & 65\le x\le 75 \\ 0 & x>75 \end{cases}\tag{6}$$

$$\mu_5(x)=\begin{cases} 0 & x<60 \\ \frac{x-60}{70-60} & 60\le x\le 70 \\ 1 & 70\le x\le 80, \\ \frac{90-x}{90-80} & 80\le x\le 90 \\ 0 & x>90 \end{cases}\tag{7}$$

$$\mu_6(x)=\begin{cases} 0 & x<75 \\ \frac{x-75}{85-75} & 75\le x\le 85 \\ 1 & 85\le x\le 95 \\ \frac{105-x}{105-95} & 95\le x\le 105 \\ 0 & x>105 \end{cases},\tag{8}$$

$$\mu_7(x)=\begin{cases} 0 & x<90 \\ \frac{x-90}{100-90} & 90\le x\le 100 \\ 1 & 100\le x\le 110, \\ \frac{110-x}{110-110} & 110\le x\le 110 \\ 0 & x>110 \end{cases}\tag{9}$$

- Input variable "DTTV" - 4 fuzzy sets with corresponding membership functions (*Figure 5* (b)):

$$\mu_{VN}(x)=\begin{cases} 0 & x<1 \\ \frac{x-1}{2-1} & 1\le x\le 2 \\ 1 & 2\le x\le 4, \\ \frac{5-x}{5-4} & 4\le x\le 5 \\ 0 & x>5 \end{cases}\tag{10}$$

$$\mu_{N}(x)=\begin{cases} 0 & x<3 \\ \frac{x-3}{4-3} & 3\le x\le 4 \\ 1 & 4\le x\le 6, \\ \frac{7-x}{7-6} & 6\le x\le 7 \\ 0 & x>7 \end{cases}\tag{11}$$

$$\mu_{M}(x)=\begin{cases} 0 & x<5 \\ \frac{x-5}{6-5} & 5\le x\le 6 \\ 1 & 6\le x\le 8, \\ \frac{9-x}{9-8} & 8\le x\le 9 \\ 0 & x>9 \end{cases}\tag{12}$$

$$\mu_{F}(x)=\begin{cases} 0 & x<7 \\ \frac{x-7}{8-7} & 7\le x\le 8 \\ 1 & 8\le x\le 10 \\ \frac{11-x}{11-10} & 10\le x\le 11 \\ 0 & x>11 \end{cases},\tag{13}$$

where:

VN *means* "Very near" distance to target vessel
N *means* "Near" distance to target vessel
M *means* "Middle" distance to target vessel
F *means* "Far" distance to target vessel

- Input variable "CPA"- 3 fuzzy sets with corresponding membership functions (*Figure 5* (c)):

$$\mu_{P}(x)=\begin{cases} 0 & x<-1 \\ \frac{x+1}{-0.8+1} & -1\le x\le -0.8 \\ 1 & -0.8\le x\le -0.5, \\ \frac{-0.3-x}{-0.3+0.5} & -0.5\le x\le -0.3 \\ 0 & x>-0.3 \end{cases}\tag{14}$$

$$\mu_{C}(x)=\begin{cases} 0 & x<-0.45 \\ \frac{x+0.45}{-0.3+0.45} & -0.45\le x\le -0.3 \\ 1 & -0.3\le x\le 0.3 \\ \frac{0.45-x}{0.45-0.3} & 0.3\le x\le 0.45 \\ 0 & x>0.45 \end{cases},\tag{15}$$

$$\mu_{S}(x)=\begin{cases} 0 & x<0.3 \\ \frac{x-0.3}{0.5-0.3} & 0.3\le x\le 0.5 \\ 1 & 0.5\le x\le 0.8, \\ \frac{1-x}{1-0.8} & 0.8\le x\le 1 \\ 0 & x>1 \end{cases}\tag{16}$$

where:

P *means* CPA in the area "Port Out"
C *means* CPA in the area "Center"
S *means* CPA in the area "Stbd Out"

– Output variable "Course - deviation" - 13 fuzzy sets (*Figure 5* (d)):

10 = (0, 0, 10)
20 = (0, 10, 20)
30 = (10, 20, 30)
40 = (20, 30, 40)
50 = (30, 40, 50)
60 = (40, 50, 60)
70 = (50, 60, 70)
80 = (60, 70, 80)
90 = (70, 80, 90)
100 = (80, 90, 100)
110 = (90, 100, 110)
120 = (100, 110, 120)
130 = (110, 120, 130, 130)

In the process of fuzzification, input data are assigned to an appropriate fuzzy set via membership functions. Determination of fuzzy membership function for each parameter (RB, DTTV and CPA) could be made subjectively or, as proposed in this paper, based on the verified 144 results obtained by the graphical manual radar plotting method. Through this method a database of relevant solutions (course deviations) was first drawn using different values of parameters: distance to target vessel (2 NM, 4 NM, 6 NM, 8 NM), relative bearing (0° ~ 110°, for each 10°) and CPA (0 NM, + 0.5 NM, – 0.5 NM). In the latter case (+) means the observed vessel ap-

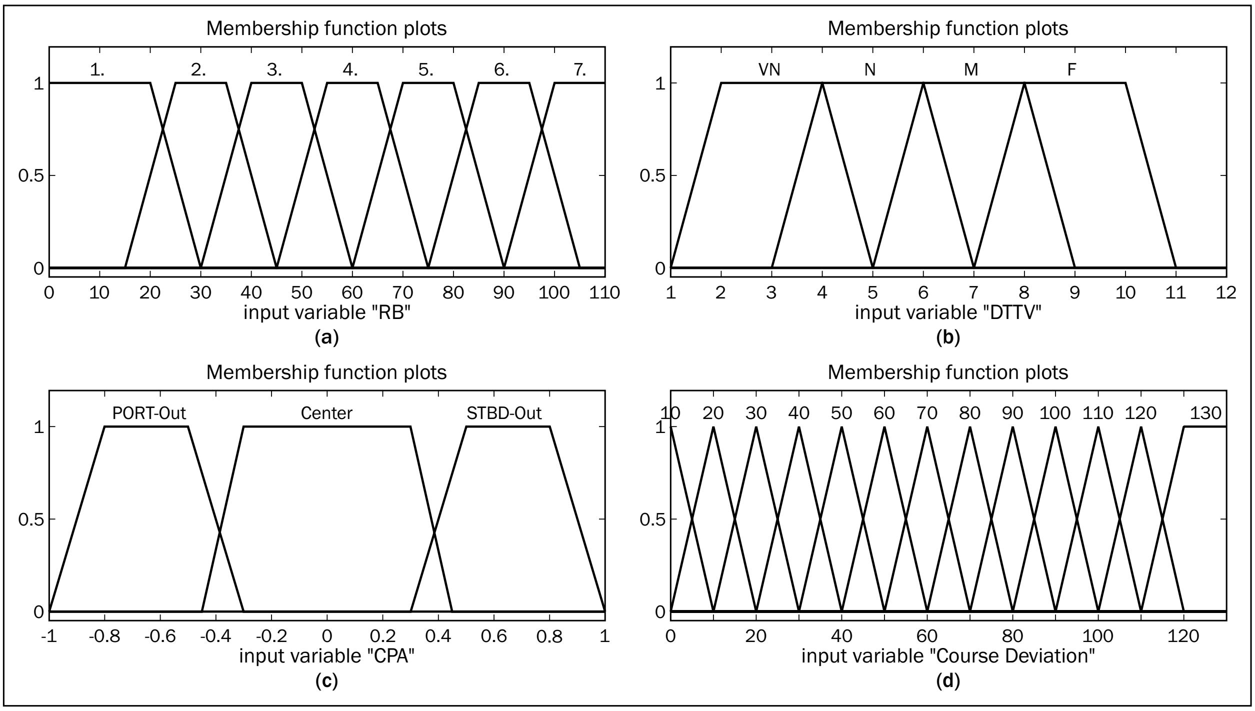


Figure 5 - Fuzzy membership functions; (a) RB, (b) DTTV, (c) CPA and (d) course deviation

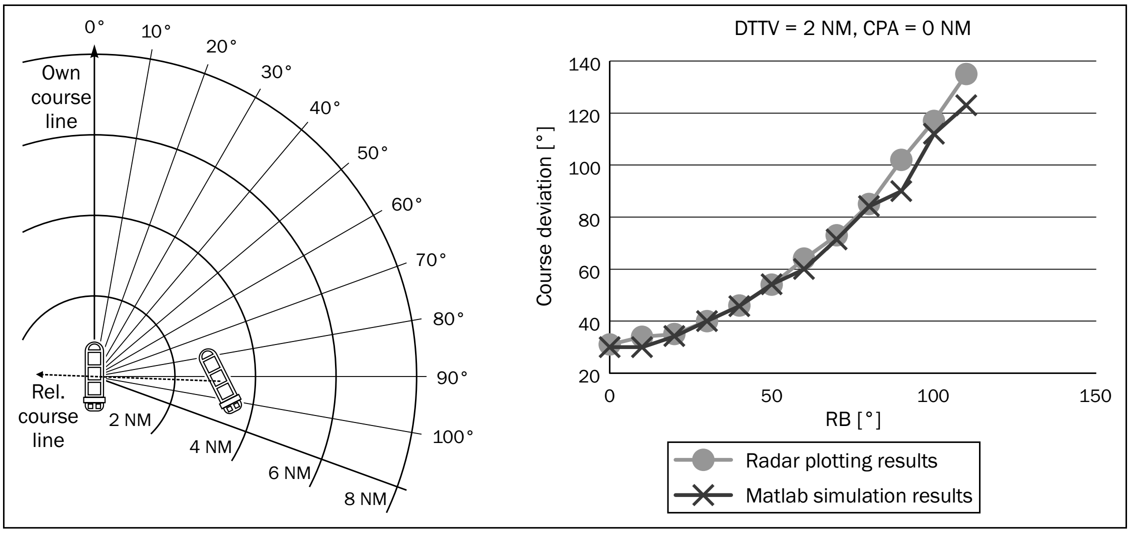
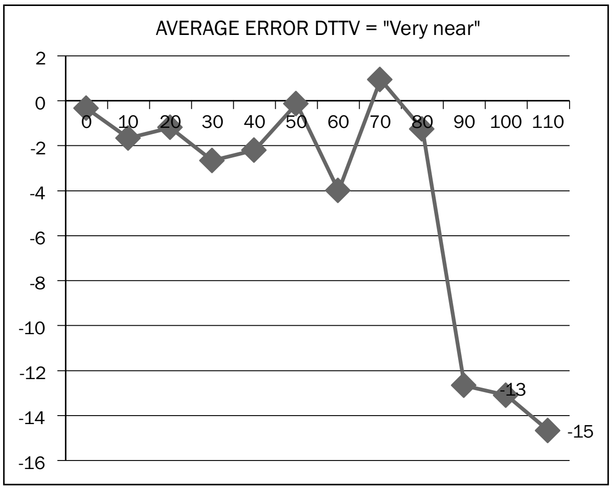


Figure 6/ Graph 1 - Crossing situation, own vessel is avoiding target vessel at a distance of 2 nautical miles, at different relative bearing, CPA is 0 NM proached the starboard side or the stern of the own vessel, the negative (–) means she approached the port side or the bow. The vessels dimensions were neglected, velocity of own vessel was 20 knots (NM per hour) and the relative approximation velocity was also 20 knots. Own vessel's safety domain was determined subjectively by the authors and was 1 NM. The simulation and radar plotting highlighted a crossing situation between two power-driven vessels that meet on the open sea. The give-way vessel (in this paper the own vessel) is obliged to avoid (by turning the own vessel's course to the starboard side) a vessel that comes from her right side (the right RB from 0° to 112.5°), referring to the COLREG rule 15 [13].

Comparison of the results obtained by graphical plotting and Matlab fuzzy simulation displayed the similarity between the methods as seen in Graphs 1, 3, 5 and 7:



Graph 2 - Average error for scenarios "very near"

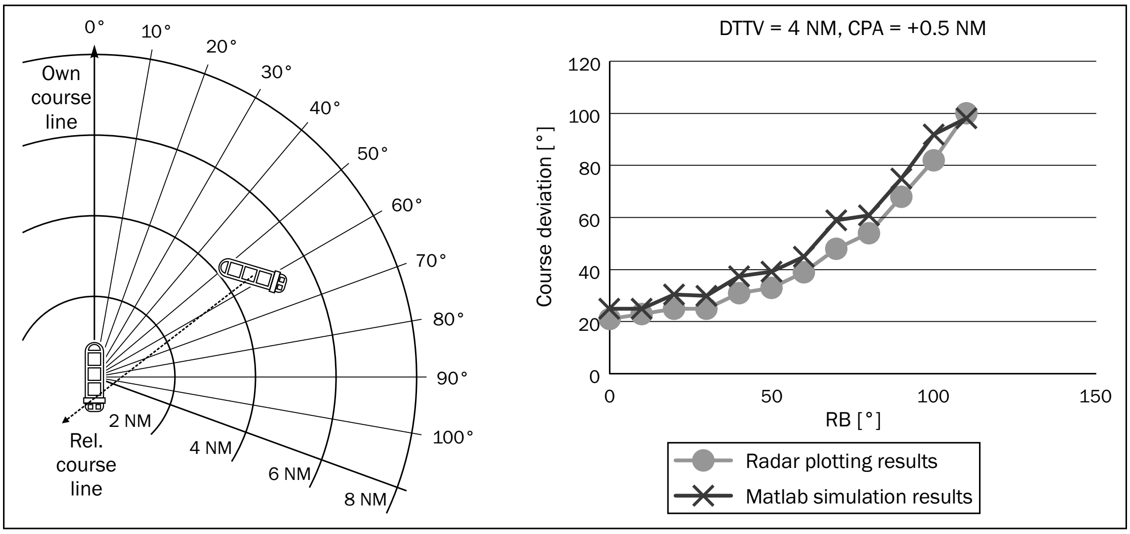


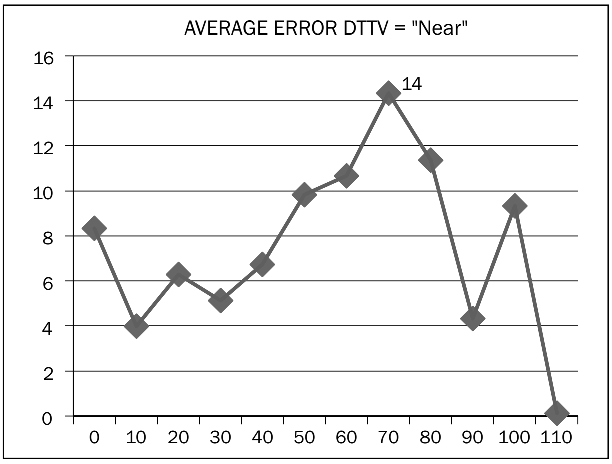
Figure 7/ Graph 3 - Crossing situation, own vessel is avoiding target vessel at a distance of 4 nautical miles, at different relative bearing, CPA is 0.5 NM (starboard side)

a) Simulation (1):

Change of course obtained by Matlab simulation, for situations when the target vessel is "very near" and with CPA being "Center" (which means the risk of collision is high), shows minor deviation from manual radar plotting results. There is a bit greater difference when the target vessel is in the area of relative bearing 90° - 110°. Acceptable error is - 10°, where (-) means the Matlab simulation shows lesser change of course. If the error is positive (+), fuzzy simulation results are estimated as very good. The average error for scenarios "Very near" is - 4.4°.

b) Simulation (2):

Fuzzy simulation displayed in *Graph 3* shows higher course deviation. The results are estimated as very good and are in compliance with basic demand – the safety vessel domain. The average error for scenarios "Near" is +7.5°.



Graph 4 - Average error for scenarios "Near"

c) Simulation (3):

In situations when a target vessel is at the "Middle" distance from the own vessel, the Matlab simulation

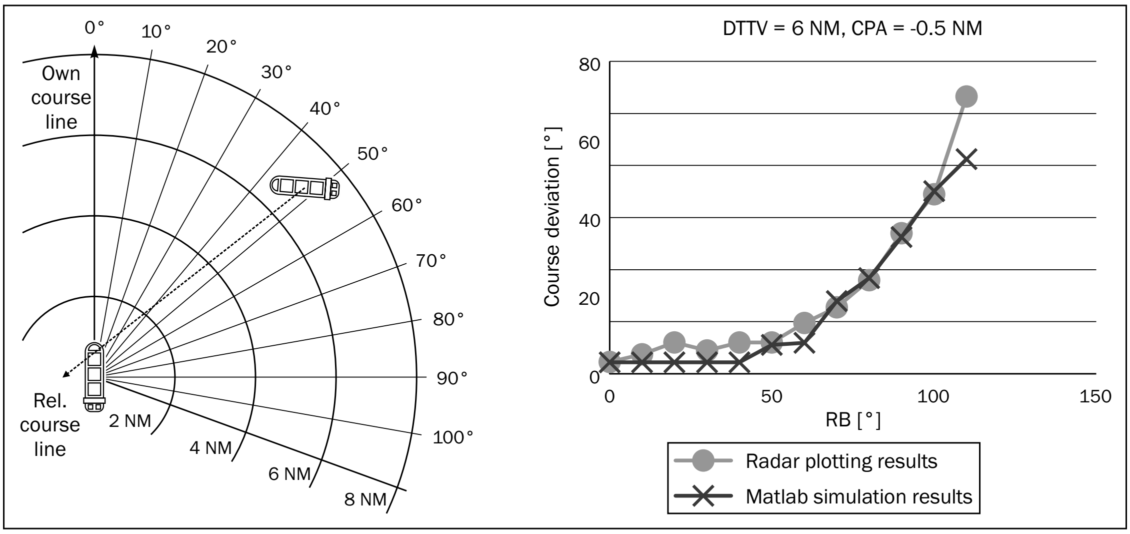
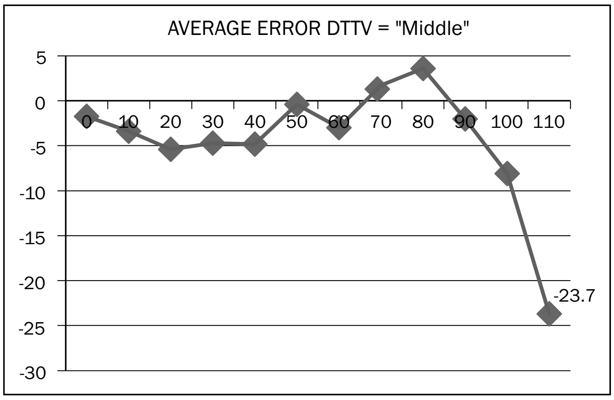


Figure 8/Graph 5 - Crossing situation, own vessel is avoiding target vessel at a distance of 6 nautical miles, at different relative bearing, CPA is – 0.5 NM (port/ bow side)



Graph 6 - Average error for scenarios "Middle"

results show lesser deviation from the desired course change, but the error in the RB area 0° - 50° is negligible. In the case of RB 110°, the error is greater than 10° and therefore unacceptable. The average error is -4.3°, with an extreme error (RB 110°) of -23.7°.

d) Simulation (4):

Graph 7 shows the comparison between two methods for situations when the target vessel is far away (approx. 8 NM). The average error of the Matlab simulation results is -1.4°. The negative error is at RB 110°. Thus the Matlab simulation satisfies the COLREG requirements.

5. CONCLUSION

The fuzzy inference system, which would provide solutions or decisions similar to those obtained by the graphic plotting method, has proven to be promising. The authors have estimated that the simulation responds worse at higher relative bearings, except in

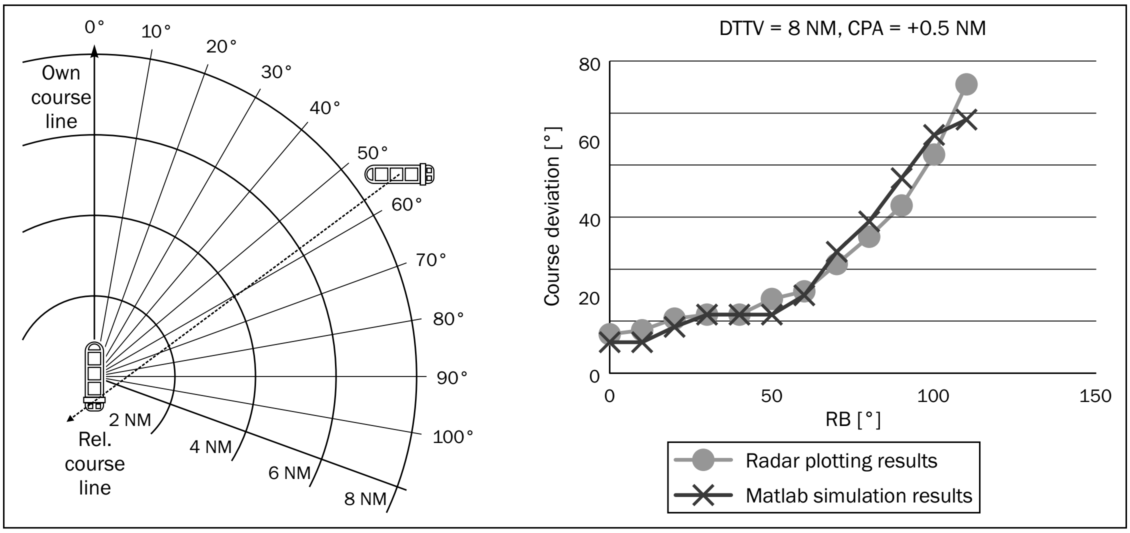
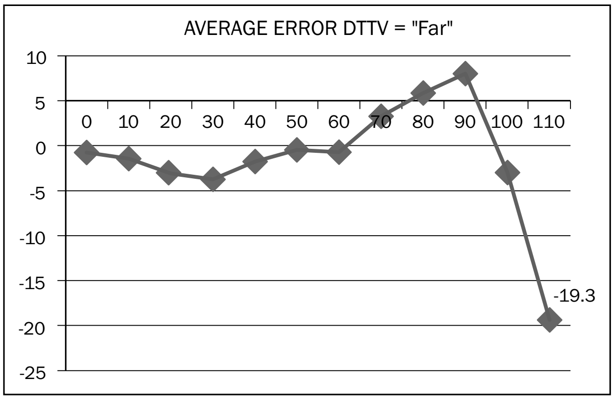


Figure 9/Graph 7 - Crossing situation, own vessel is avoiding target vessel at a distance of 8 nautical miles, at different relative bearing, CPA is 0.5 NM (starboard side)



Graph 8 - Average error for scenarios "Far"

cases when the own vessel avoids a target vessel at the distance “Near”, when the simulation in fuzzy logic offers a higher value of course deviation and satisfies the vessel safety domain requirements (1 NM). In cases when error exceeds -10°, a circle (360°) turn is proposed as an acceptable manoeuvre. And although the change of course in the area of relative bearing 90° - 110° mostly does not satisfy the minimum requirements for safety vessel domain, it is in accordance with COLREG Rule 15 and Rule 8, which stresses that the navigator on a “Give-way” vessel should perform a change of course noticeable to other vessels in the vicinity. In his interpretation of the rules, Cockcroft [13] suggests that alterations of course and speed should be substantial so that they may be readily apparent to another vessel observing by radar.

Time to the closest point of approach (TCPA) is very important when deciding about avoidance manoeuvres. Future research will be based on consideration of the time, resulting in a consideration of the true speed of the observed vessel. It is also necessary to solve the problem of avoidance in terms of multi-vessel situations in a restricted environment.

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POVZETEK

MEHKO SKLEPANJE KOT OSNOVA NAVIGACIJSKEGA ODLOČITVENEGA SISTEMA ZA POMOČ PRI IZOGIBANJU PLOVIL NA MORJU

Kljub visoki kvalifikaciji pomorščakov se na področju pomorskega prometa še vedno dogajajo nesreče, katerim v veliki meri botruje človeški faktor. Tako imenovana človeška napaka je prisotna pri nasedanju, trčenju, požaru ali onesnaženju z ladje, zato je že več desetletij preučevanje človeškega vpliva na izvajanje nalog samostojna znanstvena disciplina. Da bi to napako kar se da omejili oziroma jo izničili, je razvoj usmerjen predvsem v avtomatizacijo ali bolje rečeno, avtonomnost plovil, tako da bi človeka nadomestil računalniški sistem, pri čemer se v zadnjih dveh dekadah močno razvijajo sistemi, ki delujejo na osnovi umetne inteligence. Ker pa popolna avtonomnost trenutno še ni smiselna, je smotrno razmišljati o sistemih za pomoč pri odločitvah, ki bi delovali na podlagi umetne inteligence in svetovali navigatorjem ter VTS operaterjem, kako postopati v kriznih ali pa čisto vsakdanjih nalogah in s tem zmanjšali nivo tveganja, ki je v pomorstvu še kako prisoten.

Ta članek predstavlja sistem za pomoč pri odločanju, ki temelji na uporabi mehke logike, integrirane v obstoječi ladijski sistem za izogibanje plovil na morju. Cilj raziskovanja je določitev ustrezne spremembe gibanja lastnega plovila, v funkciji izogibanja, z uporabo mehkega sklepanja.

KLJUČNE BESEDE

pomorske nesreče, izogibanje trčenju na morju, radarsko vrisovanje, mehka logika, sistem za pomoč pri odločanju

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