COLLISION AVOIDANCE ACTIONS IN THE AREA OF EXCESSIVE APPROACH

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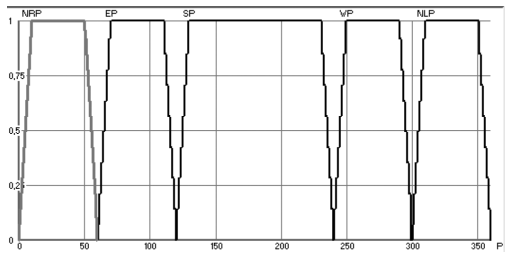
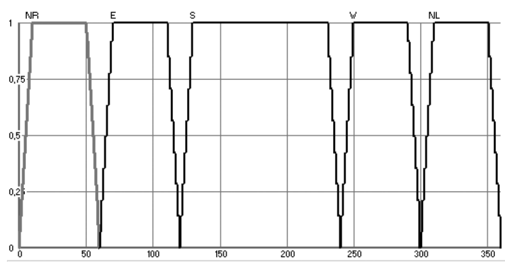
ABSTRACT

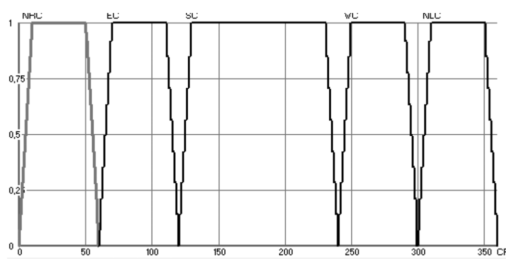
A fuzzy model is proposed for collision avoidance actions of ships in the zone of excessive approach, consisting of four input linguistic variables – line of bearing, course of the vessel- operator, course of the vessel- target, speed of the vessel-target, and one output linguistic variable – course of the vessel- operator. The article provides a technique of forming fuzzy production rules, the base of which contains 525 rules, using maneuvering board.



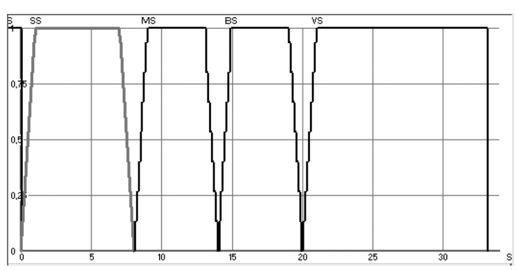
Pic. 1. Membership functions for input variable P.



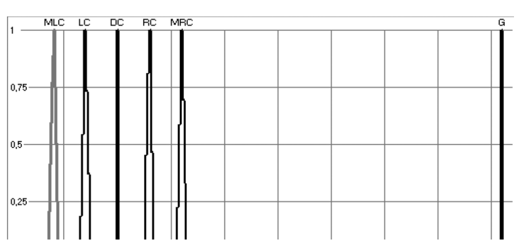
Pic. 2. Membership functions for input variable CC.



Pic. 3. Membership functions for input variable CP.



Pic. 4. Membership functions for input variable S.



Pic. 5. Membership functions for the output variable CC.

ENGLISH SUMMARY

Background. *One of the main problems of maritime navigation is safe passing of vessels. Statistics show that more than 80% of all emergencies are caused by human errors [1]. Only due to the organizational and technical measures, strengthening of requirements for training of specialists it becomes possible to prevent the growth in the number of collisions. However, and despite this, the problem of collision avoidance actions remains relevant and requires serious preventive measures, for example practical application of automatic decision making system.*

Study of existing capabilities has been intensively conducted since the beginning of the application of computers on board of the vessels to solve problems on the bridge, that is, for nearly forty years. During this time, various options of mathematical description were proposed related to situations generated by the vessels and boundaries of the navigable water area, formalization of International Regulations for Preventing Collisions at Sea, synthesis of strategies for collision avoidance. Less attention is paid to the development of visual models, providing a high level of understanding of the situation and facilitating the selection of maneuvers for passing of vessels [2].

This paper presents a fuzzy model (hereinafter- FM) of passing of vessels in the area of excessive approach, which takes into account following assumptions and restrictions: the problem is considered in good visibility, i. e. Rule 19 of IRPCS is not considered [5]; the vessel is equipped with a radar station or two radar stations (depending on the gross tonnage of the vessel); in a simulated situation, we assume that the vessel-operator (VO), as well as vessel-target (VT) are power-driven vessels; VO speed is constant and equal to 15 knots; VT is located at a distance of 2 miles from VO, i. e. it is located in the zone of excessive approach; VT is the only dangerous target (FM can be extended to a large number of dangerous targets, in this case the most dangerous one is determined, a manoeuvre is undertaken for collision avoidance after that the next target is taken which is selected according to the danger level scale).

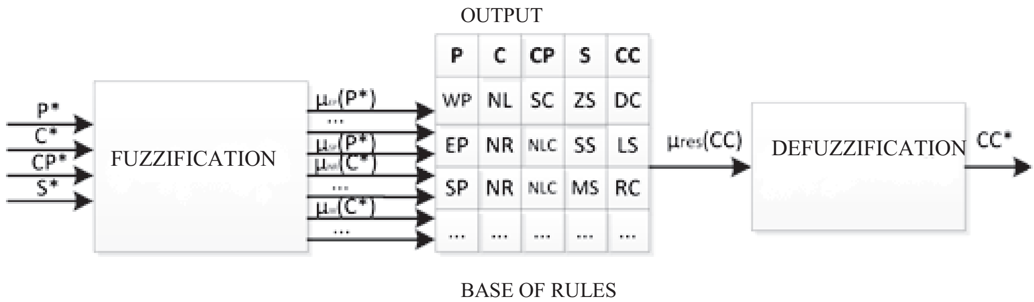
Objective. *The objective of the author is to present a fuzzy model of vessels' passing at sea in the zone of excessive approach and to demonstrate its advantages.*

Methods. *The author uses descriptive method, analysis and modeling, methods of fuzzy logic, algorithms, and linguistic variables.*

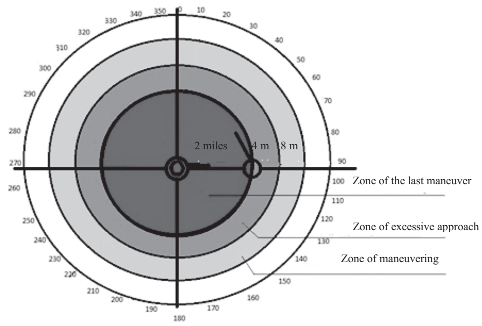
Results.

1. Description of the fuzzy model

The developed FM for passing of vessels is implemented based on Mamdani algorithm [3] and consists



Pic. 6. Scheme of fuzzy model of passing of vessels in the zone of excessive approach.



Pic. 7. Scheme of the second situation.

of four input linguistic variables (hereinafter-LV) [9-12] that significantly affect the determination of the course of VO. The first input LV «Peleng» (hereinafter – P) is characterized by a ground set [0˚; 360˚]and includes five terms of the base term set: EastPeleng (EP) as bearing for East; WestPeleng (WP) as bearing for West; NordLeftPeleng (NLP); NordRightPeleng (NRP); SouthPeleng (SP). Membership functions for the terms of the first input LV are shown in Pic. 1. They have a trapezoidal shape with the parameters for the function EP: a = 60, b = 70, c = 110, d = 120; for the function WP: a = 240, b = 250, c = 290, d = 300; for the function NLP: a = 300, b = 310, c = 350, d = 360; function NRP: a = 0, b = 10, c = 50, d = 60; for the function SP: a = 120, b = 130, c = 230, d = 240.*

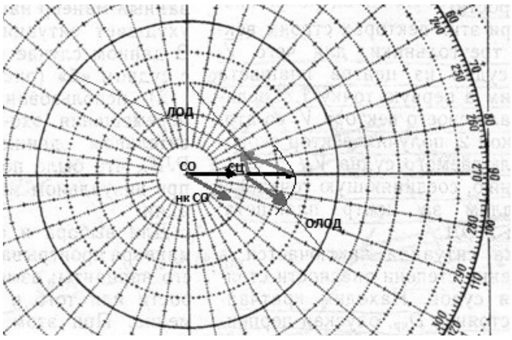
The second input LV «The course of the vessel-operator» (Course – CC) is characterized by a universal set [0 ˚; 360 ˚], and the base term set consists of following elements: NordRight (NR) – course to the north; NordLeft (NL) – course to the north; East (E) – course to the east; South (S) – course to the south; West (W) – course to the west. Membership functions for the terms of the second input LV are shown in Pic. 2. They have a trapezoidal shape with the parameters for the function NR: a = 0, b = 10, c = 50, d = 60; for the function NL: a = 300, b = 310, c = 350, d = 360; for the function E: a = 60, b = 70, c = 110, d = 120; for the function S: a = 120, b = 130, c = 230, d = 240; for the function W: a = 240, b = 250, c = 290, d = 300.

The third input LV «The course of the vessel-target» (CoursePoint – CP) is characterized by a universal set [0˚; 360˚], and the base term set includes: NordLeftPoint (NLC) – course to the north; NordRightPoint (NRC) – course to the north; EastPoint (EC) – course to the east; SouthPoint (SC) – course to the south; WestPoint (WC) – course to the east. Membership functions for the terms of the third input LV are given in Pic. 3. They have a trapezoidal shape with the parameters for the function NLC: a = 300, b = 310, c = 350, d = 360; for the function NRC: a = 0, b = 10, c = 50, d = 60; for the function EC: a = 60, b = 70, c = 110, d = 120; for the function SC: a = 120, b = 130, c = 230, d = 240; for the function WC: a = 240, b = 250, c = 290, d = 300.

The fourth input LV «The speed of the vessel-target» (Speed – S) is characterized by a universal set [0; 34] of knots, obtained on the basis of information of the Russian Register of Shipping [4]. The terms of the basic term set are: ZeroSpeed (ZS) – fixed target; SmallSpeed (SS) – low speed; MiddleSpeed (MS) – moderate speed; BigSpeed (BS) – high speed; VeryBigSpeed (VS) – a very high speed. Membership functions for terms of the fourth input LV are shown in Pic. 4. They have a trapezoidal shape with the parameters for the function ZS: a = 0, b = 0, c = 0, d = 0; for the function SS: a = 0, b = 1, c = 7, d = 8; for the function MS: a = 8, b = 9, c = 13, d = 14; for the function BS: a = 14, b = 15, c = 19, d = 20; for the function VS: a = 20, b = 21, c = 31, d = 34.

Given the paragraph of the rule 8 of IRPCS [5] that «if there is a sufficient sea space, alteration of the course may be the most effective action to avoid an excessive approach», and the statement of the authors [2] that «a greater part of actions taken to avoid collisions accounts for course maneuvers», a change in the course of the vessel -operator (ChangeCourse – CC) is selected as an output LV. For convenience, we define a universal set in degrees from –90˚ to 360˚, and in the description of the terms in parentheses there are values of the nuclei of fuzzy sets, corresponding to the terms: MaxLeftCourse (MLC) – much to the left (–60 ˚); LeftCourse (LC) – left (–30˚); DirectlyCourse (DC) – directly (without changing course and speed) (0 ˚); MaxRightCourse (MRC) – much to the right (60 ˚); MaxRightCourse

*Russian word «peleng» is originated from Dutch word «peiling» and means «bearing» in navigation. As the author uses term «peleng» in Russian original text and in the developed software in Roman letters we maintained that author's term in translated version, even for abbreviations. – ed.note.



Pic. 8. Decomposition of the second situation on the maneuvering board.

(RC) – to the right (30 ˚); Gyration (G) – Circulation (360 ˚). Membership functions for the terms of output LV are shown in Pic. 5. They have a triangular shape with the parameters for the function MLC: a = –65, b = –60, c = –55; for the function LC: a = –35, b = –30, c = –25; for the function DC: a = 0, b = 0, c = 0; for the function MRC: a = 55, b = 60, c = 65; for the function RC: a = 25, b = 30, c = 35; for the function G: a = 360, b = 360, c = 360.

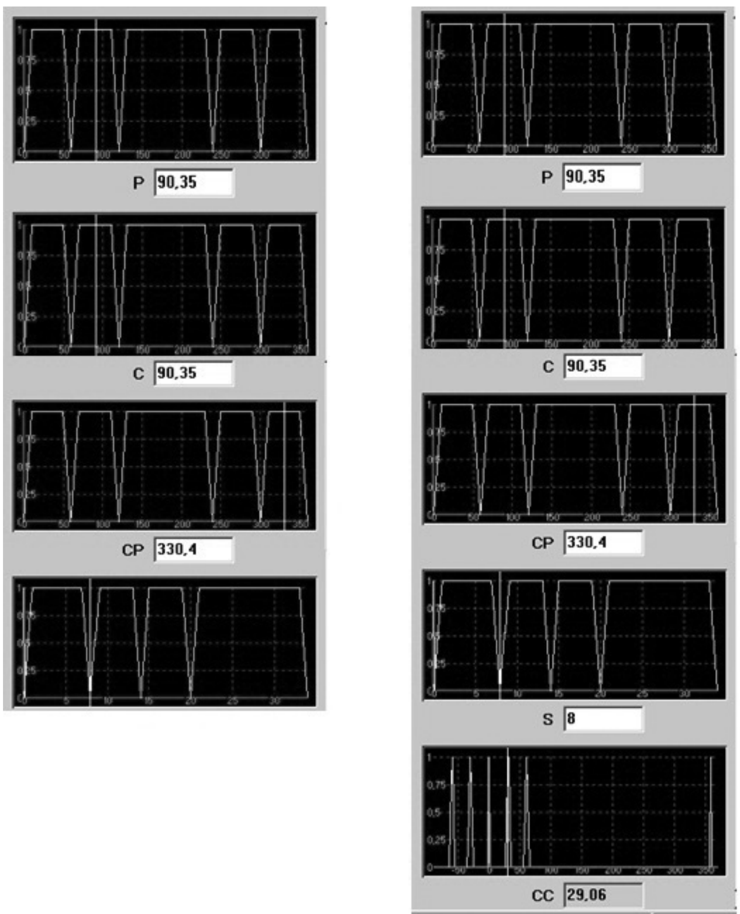
2. The system of fuzzy production rules

Pic. 6 shows the general scheme of FM of passing of vessels in the zone of excessive approach.

The base of fuzzy productions rules (FPR) consists of 525 rules, thus it is necessary to note that they were developed on the basis of information obtained with the help of manoeuvre plot. Methods of setting each rule included the following sub-steps: complete enumeration of a list of different situations that arise in case collision avoidance actions;; establishing of the terms constituting each rule for incorporation into the base FPR; decomposition of each situation on a maneuvering board and the determination of rate of the course change of the VO with account for rules of IRPCS [5], comments to them [6, 7], as well as the recommendations of the so-called «good seamanship»; fixing the terms corresponding to the obtained in the previous sub-step courses of VO, for insertion into FPR base.

For example, considering the first situation, let's assume that the distance to the target is 2 miles, the course of VO is equal to 330 ˚, speed is 15 knots. From the radar station we obtain the following information: the course of VT is 330 ˚, target bearing is 330 ˚, speed of VT is 25 knots. This situation is not considered dangerous, because VO and VT pass at a safe distance from each other and VO does not have to change a course. The analysis for this case made it possible to form FPR № 438.

The second situation. Let's assume that the distance to the target is 2 miles, the course of VO is 90 ˚, speed of VO is 15 knots. From the radar station we get that the course of VT is 330 ˚, the target bearing is 90 ˚, speed of VT is 8 knots (Pic. 7).



Pic. 9. The test situation.

In this situation, VT is right on the course of VO and is a dangerous target, because they pass at a small distance form each other. According to the rule 16 of IRPCS [5], VO must give way to pass with VT. Decomposing the situation on the maneuvering board (Pic. 8) and making all necessary calculations, we find that a new course of VO is 120^0.

As a result, it was required to make a turnaway on 30^0 to the right, and VO will pass VT on the stern at a safe distance. Analysis of the situation allowed to form FPR № 91.

3. The algorithm of fuzzy inference

We show the fuzzy inference algorithm for the consideration of the second situation. In this case, fuzzification of the first input LV leads to a degree of truth, which is equal to 1, at the term EP. Fuzzification of the second and third input LV leads to a degree of truth, which is equal to 1, respectively, at the terms E and NLC. Fuzzification of the fourth input LV is 0, 1, the same is achieved when at the terms MS and SS.

Substituting these terms in the formula of fuzzy productions rules [3], we obtain rules:

R: IF (EP = P) AND (E = C) AND (NLC = CP) AND (SS = S), THEN (y = CC);

R: IF (EP = P) AND (E = C) AND (NLC = CP) AND (MS = S), THEN (y = CC).

The relevant sub-conditions are used jointly in FPR № 91 and 216. These rules are considered activated and participate in the further process of fuzzy inference. Since all conditions specified in the rules are given in the form of fuzzy linguistic utterances of the first kind with the use of fuzzy conjunction operation, the stage of their aggregation is degree of truth of 0,1 for both rules.

The next step of fuzzy inference is the activation of conclusion in rules № 91 and 216. In our case, the method of center of gravity is used for defuzzification. Having tested the situation in the developed application (Pic. 9) we get that the value of the output variable CC is approximately equal to 30. Thus, the turnaway angle of VO at these input parameters is 30^{0}to the right.

Conclusion. *Fuzzification of four input and one output LV was performed for FM of passage of vessels in the zone of excessive approach, the base of fuzzy productions rules, consisting of 525 rules was formed, fuzzy inference algorithm was implemented, user interface of FM of passage was developed. The software application was tested on examples, the analysis of which was done using the maneuvering board. Testing has shown efficiency of an application and the adequacy to test cases.*

Further research may focus on the development of devices to automatically obtain information from the radar station, as well as to transfer an output value obtained from the application of fuzzy model, to actuating devices, in particular to a rudder blade.

Keywords: maritime shipping, control automation, collision avoidance actions, linguistic variable, fuzzy set, line of bearing, vessel course, vessel speed, fuzzy production rule.

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