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Safe ship automatic control taking into consideration fuzzy properties of the process

SUMMARY

In the next decade fully automated surface ships will be seen on major world shipping routes. In order to have an intelligent supporting system for collision avoidance automation we need to carry out research in this field by simultaneously incorporating navigational environment, ships manoeuvrability and subjectivity of decisions made by the navigator who has a considerable role in the decision-making process. The present paper is a continuation of the paper published in the proceedings of IFAC workshop CAMS'92 in Genova. In this paper the authors present a model of the process, control algorithm, simulation, sensitivity analysis of the algorithm and a functional model of a safe ship manoeuvre system.

INTRODUCTION

Collision accidents are increasing as ships increase in size, in speed and in number. The problem of collision avoidance has thus become an urgent issue, therefore it is necessary to describe the process of collision avoidance more accurately. The history of the evolution of international ship collision avoidance research is presented by Zhao Jinsong and his co-authors [9]. Simulation models of the process are based on the collision risk, which is dependent on the distance of the closest point of approach (DCPA) [1,5,9] and /or/ time to the closest point of approach (TCPA) [9]. In simulation models of DCPA decision it is necessary to manoeuvre in such a way that the distance of the closest point of approach must always be larger than fixed values and cannot be determined [9]. A simulation model of TCPA decision has been developed to determine the time to take collision avoidance action at a fixed distance [9]. In order to take into consideration the subjectivity of navigators in the process, papers have been written [2,3,6,7,8] on the application of the fuzzy set theory. The present authors analysed all types of encounters and researched fuzzy-probability properties of the process [8]. To continue, the authors describe the process by a model of decision making in fuzzy environment in the second part, and present the control algorithm in the third part. Simulation and sensitivity of algorithm are discussed in the fourth and the fifth part.

SIMULATION MODEL AS DECISION MAKING IN FUZZY ENVIRONMENT OF A COLLISION AVOIDANCE PROCESS

Generally, ship manoeuvre process in a collision situation consists of two phases :

- Tracing targets and base of DCPA and TCPA to asses a collision risk.
- Collision avoidance manoeuvre as a determination of a manoeuvre direction, to determine the time to take collision avoidance action and to determine the anticollision manoeuvre in this time .

In order to describe the safe ship manoeuvre, a motion of a ship returning by rudder in deep water is worked out by Lisowski [4] , but they are slightly useful to synthesis of safe ship manoeuvre.To evaluate the dynamic properties of the ship we use the parameters of the transmitation function or the advance time and maximal angle speed [5]. With a negligence of speed decrease on the course manoeuvre, the ship's kinematic relative motion, with giving consideration to dynamic properties, becomes :

$$x_j(t) = x_j(0) + (v_j \sin\psi_j - v_o \sin\psi_o) t_w + $$
$$+ (v_j \sin\psi_j - v_o^* \sin\psi_o^*)\left(\frac{1}{\omega_o} tg\left|\frac{\psi_o^* - \psi_o}{2}\right| + t\right)$$

$$y_j(t) = y_j(0) + (v_j \cos\psi_j - v_o \cos\psi_o) t_w + \qquad (1)$$
$$(v_j \cos\psi_j - v_o^* \cos\psi_o^*)\left(\frac{1}{\omega_o} tg\left|\frac{\psi_o^* - \psi_o}{2}\right| + t\right)$$

In the case of speed manoeuvre relative motion becomes :

(2)

$$x_j(t) = x_j(0) + (v_j \sin\psi_j - v_o \sin\psi_o) T_{ok} + $$
$$+ \int_{T_{ok}}^{t} \left(v_j \sin\psi_j - \left(v_o^* + (v_o - v_o^*)\exp\left(-\frac{t - T_{ok}}{T_k}\right)\right)\sin\psi_o\right) dt$$

$$y_j(t) = y_j(0) + (v_j \cos\psi_j - v_o \cos\psi_o) T_{ok} + $$
$$+ \int_{T_{ok}}^{t} \left(v_j \cos\psi_j - \left(v_o^* + (v_o - v_o^*)\exp\left(-\frac{t - T_{ok}}{T_k}\right)\right)\cos\psi_o\right) dt$$

Then DCPA between the ship and "j" target is determined by the equation (3) :

$$DCPA_j(t) = \frac{x_j(t)(v_j \cos\psi_j - v_o(t)\cos\psi_o(t))}{(v_j^2 + v_o^2(t) - 2 v_j v_o(t)\cos(\psi_o(t) - \psi_j))^{1/2}} + $$
$$- \frac{y_j(t)(v_j \sin\psi_j - v_o(t)\sin\psi_o(t))}{(v_j^2 + v_o^2(t) - 2 v_j v_o(t)\cos(\psi_o(t) - \psi_j))^{1/2}}$$

and TCPA becomes (4) :

$$TCPA_j(t) = -\frac{x_j(t)(v_j \sin\psi_j - v_o(t)\sin\psi_o(t))}{v_j^2 + v_o^2(t) - 2 v_j v_o(t)\cos(\psi_o(t) - \psi_j)} + $$
$$+ \frac{y(t)(v_j \cos\psi_j - v_o(t)\cos\psi_o(t))}{v_j^2 + v_o^2(t) - 2 v_j v_o(t)\cos(\psi_o(t) - \psi_j)}$$

If there are m objects in a collision situation, the model of safe manoeuvre process can be represented by the state equation :

$$\overline{X}(t+1) = f(\overline{X}(t), \overline{U}(t)) \qquad t = 0,1,2,\ldots, \qquad (5)$$

where :

$$\overline{X}(.) = \begin{bmatrix} X_1(.) \\ X_2(.) \\ \cdot \\ \cdot \\ X_{2j-1}(.) \\ X_{2j}(.) \\ \cdot \\ \cdot \\ X_{2m-1}(.) \\ X_{2m}(.) \end{bmatrix} = \begin{bmatrix} DCPA_1(.) \\ TCPA_1(.) \\ \cdot \\ \cdot \\ DCPA_j(.) \\ TCPA_j(.) \\ \cdot \\ \cdot \\ DCPA_m(.) \\ TCPA_m(.) \end{bmatrix}, \overline{X}(.) \in R^{2m}$$

$$\overline{U}(.) = \begin{bmatrix} U_1(.) \\ U_2(.) \\ U_3(.) \\ U_4(.) \\ U_5(.) \\ U_6(.) \\ \cdot \\ \cdot \\ U_{4j+2-3}(.) \\ U_{4j+2-2}(.) \\ U_{4j+2-1}(.) \\ U_{2j+2}(.) \\ \cdot \\ \cdot \\ U_{4m+2-3}(.) \\ U_{4m+2-2}(.) \\ U_{4m+2-1}(.) \\ U_{4m+2}(.) \end{bmatrix} = \begin{bmatrix} \psi_o(.) \\ v_o(.) \\ x_o(.) \\ y_o(.) \\ \psi_1(.) \\ v_1(.) \\ \cdot \\ \cdot \\ x_j(.) \\ y_j(.) \\ \psi_j(.) \\ v_j(.) \\ \cdot \\ \cdot \\ x_m(.) \\ y_m(.) \\ \psi_m(.) \\ v_m(.) \end{bmatrix}, \overline{U}(.) \in R^{4m+2}$$

It is important to remember that inputs ψ_o, v_o, ψ_j, v_j $j = 1,2,\ldots,m$ are freely determined in accordance with International Rules . x_j, y_j $j = 1,2,\ldots,m$, are the results of the action of inputs ψ_o, v_o, ψ_j, v_j $j = 1,2,\ldots,m$, and are closely connected with the ship's dynamic properties. In this way we take into consideration the ship's dynamic properties kinematic model of safe manoeuvre process (Fig. 1) .

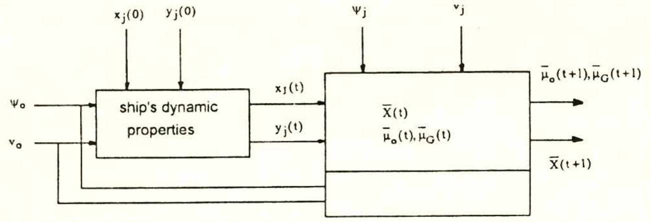


Fig. 1. Block diagram of kinematic model taking into consideration the ship's dynamic properties

In order to assess the collision risk, the authors formulate a fuzzy set "collision risk" on state vector $\overline{X}(.)$. The membership function (μ_{oj} $j=1,2,\dots,m$) of the fuzzy set "collision risk" can be presented in the form:

$$\mathbf{O}_j \subseteq \overline{X}\times\overline{X}, \quad (j=1,2,3,\dots,m)$$

$$\mu_{oj}:\overline{X}\times\overline{X}\rightarrow[0,1]\in\mathbf{R}$$

$$\mu_{oj}=\begin{cases}\exp(\lambda_{odj}X_{2j-1}^2-\lambda_{otj}X_{2j}^2), X_{2j}\geq 0\\ 0, X_{2j}\langle 0\end{cases} \tag{6}$$

Then the vector of these membership functions becomes:

$$\overline{\mu}_o{}^T=[\mu_{o1},\mu_{o2},\dots,\mu_{om}]. \tag{7}$$

Analogically, the fuzzy set " safe manoeuvre " as goal of determinate on state vector $\overline{X}(.)$ or input vector $\overline{U}(.)$ has membership function in the form :

$$\mathbf{G}_j^* \subseteq \overline{X}, \qquad j=1,2,3,\dots,m$$

$$\mu_{Gj}^*:\overline{X}\rightarrow[0,1]\in\mathbf{R}$$

$$\mu_{Gj}^*=\begin{cases}1-\exp(\lambda_{dj}X_{2j-1}^2), X_{2j}\geq 0\\ 1, X_{2j}\langle 0\end{cases} \tag{8}$$

or from equation (5), (8) :

$$\mathbf{G}_j \subseteq \mathbf{U}, \qquad j=1,2,3,\dots,m$$

$$\mu_{Gj}^*:\mathbf{U}\rightarrow[0,1]\in\mathbf{R}$$

$$\mu_{Gj}^*=\begin{cases}1-\exp(\lambda_{dj}X_{2j-1}^2(u)), X_{2j}(u)\geq 0\\ 1, X_{2j}(u)\langle 0\end{cases} \tag{9}$$

As constraint of manoeuvre the autors present the fuzzy set " way loss " on the input vector $\overline{U}(.)$. They have the membership function μ_c in the form :

$$\mathbf{C}\subseteq\mathbf{U}$$

$$\mu_c:\mathbf{U}\rightarrow[0,1]\in\mathbf{R} \tag{10}$$

$$\mu_c(u)=\exp(-\lambda_c(v_o-v_o^*\cos(\psi_o-\psi_o^*))^2T_{mz}^2)$$

In the first phase of the safe manoeuvre process it is necessary to trace these targets, whose μ_{oj} exceed fixed value μ_{os}:

$$\mu_{oj}\geq\mu_{os} \tag{11}$$

From the equation (6), (11) time to tracing of the target is determined by the equation:

$$T_{sj}=\sqrt{\frac{-\ln\mu_{os}-\lambda_{odj}X_{2j-1}^2}{\lambda_{otj}}} \tag{12}$$

In the collision situation, at a given time , the most dangerous target is that, whose μ_{ODT} is the largest:

$$\mu_{oj}=\max_{j\in(1,m)}\mu_{oj} \tag{13}$$

In the second phase, in a multiship encounter, manoeuvre direction is determined in respect to the most dangerous target in accordance with International Rules [5,7].The time to collision avoidance action is determined

$$\exists_{j\in(1,m)}\mu_{oj}\geq\mu_{om}$$

$$T_m=\sqrt{\frac{-\ln\mu_{om}-\lambda_{odj}X_{2j-1}^2 2}{\lambda_{otj}}} \tag{14}$$

As a fuzzy environment of the problem it can be described as the four element set :

$$\langle\mathbf{U},\mathbf{G},\mathbf{C},\mathbf{D}\rangle \tag{15}$$

The fuzzy set decision is determined as the fuzzy set $\mathbf{D}\subseteq\mathbf{U}$, and it is a result of an aggregation "o" of these sets **G** and **C** :

$$\mathbf{D}=\mathop{*}_{j=1}^{m}\mathbf{G}_j\circ\mathbf{C} \tag{16}$$

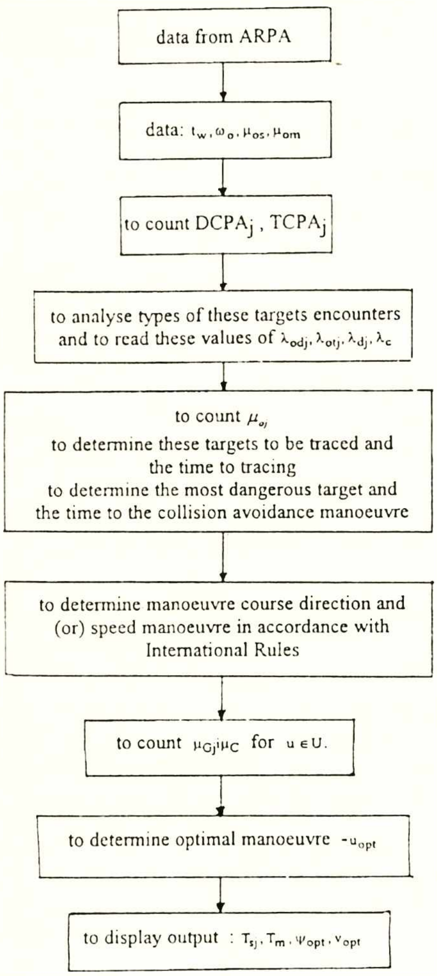
$$\mu_D(u)=\mathop{*}_{j=1}^{m}\mu_{Gj}(u)\circ\mu_C(u). \tag{17}$$

the decision-making is brought to determine u_{opt} , then

$$u_{opt} = \langle \psi_{opt}, v_{opt} \rangle = \{ u / \mu_D(u) \rightarrow \max \} \quad (18)$$

ALGORITHM

The algorithm of the decision making in a fuzzy environment can be represented in the block diagram :



SIMULATION

The authors simulate single and multiship encounter situations consisting of all types of these encounters. For example, the authors present the result of the simulation of the collision situation in good and poor visibility and for three types of decision :
-type "minimum" (0) ,
-type "multiplication" (1) ,
-type "combination" (2) .
Data of the situation is in Tab. 2a. The result of observation phase for good visibility is presented in Tab. 2b, and for poor visibility in Tab. 2c. In poor visibility the time to tracing is earlier (from 12 minutes to 20 minutes) than in good visibility, especially for the second target, because the ship has no priority for this target in poor visibility. The result of the manoeuvre phase is presented in Tab. 2d.

Tab. 2a. Data of situation simulated

N° target	D_j [nm]	N_j [°]	ψ_o [°]	v_j [Kn]
1	2	235	8	20
2	5.6	297	57	18
3	10.1	320	90	15
4	9.9	15	200	16
5	6	48	270	9
6	8	35	200	15
7	7.3	16	155	11
8	3.1	130	340	11

where:

ship has course 0[°] , speed 18[Kn].

Tab. 2b. Process of observation in good visibility

t [min]	tag j	D_j [nm]	N_j [°]	ψ_j [°]	v_j [Kn]	$DCPA_j$ [nm]	$TCPA_j$ [min]	μ_O
23	4	8.24	16.14	200	16	0.97	14.65	0.05
24	4	7.68	16.62	200	16	0.97	13.65	0.06
25	4	7.13	17.19	200	16	0.97	12.65	0.06
26	2	3.88	296.34	57	18	0.15	13.55	0.06
26	4	6.58	17.85	200	16	0.97	11.65	0.07
27	2	3.6	296.16	57	18	0.15	12.55	0.09
27	4	6.02	18.62	200	16	0.97	10.65	0.08
28	2	3.31	295.96	57	18	0.15	11.55	0.12
28	4	5.47	19.56	200	16	0.97	9.65	0.08
29	2	3.02	295.72	57	18	0.15	10.55	0.17
29	4	4.93	20.71	200	16	0.97	8.65	0.09
30	2	2.74	295.43	57	18	0.15	9.55	0.23
30	4	4.38	22.14	200	16	0.97	7.65	0.1
31	2	2.45	295.07	57	18	0.15	8.55	0.3
31	4	3.84	23.97	200	16	0.97	6.65	0.1
32	2	2.17	294.62	57	18	0.15	7.55	0.39
32	3	5.41	319.83	90	15	0.03	13.86	0.06
32	4	3.3	26.41	200	16	0.97	5.65	0.11
33	2	1.88	294.03	57	18	0.15	6.55	0.48
33	3	5.02	319.8	90	15	0.03	12.86	0.08
33	4	2.77	29.79	200	16	0.97	4.65	0.11
34	2	1.6	293.23	57	18	0.15	5.55	0.57

Tab. 2c. Process of observation in poor visibility

t [min]	tag j	D_j [nm]	N_j [°]	ψ_j [°]	v_j [Kn]	$DCPA_j$ [nm]	$TCPA_j$ [min]	μ_o
6	2	9.61	297.63	57	18	0.15	33.55	0.06
7	2	9.32	297.6	57	18	0.15	32.55	0.07
8	2	9.03	297.57	57	18	0.15	31.55	0.08
9	2	8.75	297.54	57	18	0.15	30.55	0.09
10	2	8.46	297.51	57	18	0.15	29.55	0.11
11	2	8.18	297.47	57	18	0.15	28.55	0.13
11	4	14.91	13.12	200	16	0.97	26.65	0.05
12	2	7.89	297.44	57	18	0.15	27.55	0.15
12	3	13.22	320.05	90	15	0.03	33.86	0.06
12	4	14.35	13.26	200	16	0.97	25.65	0.06
13	2	7.6	297.4	57	18	0.15	26.55	0.17
13	3	12.83	320.04	90	15	0.03	32.86	0.07
13	4	13.79	13.42	200	16	0.97	24.65	0.07
14	2	7.32	297.35	57	18	0.15	25.55	0.19
14	3	12.44	320.04	90	15	0.03	31.86	0.08
14	4	13.24	13.59	200	16	0.97	23.65	0.08
15	2	7.03	297.31	57	18	0.15	24.55	0.21
15	3	12.05	320.03	90	15	0.03	30.86	0.09
15	4	12.68	13.77	200	16	0.97	22.65	0.09
16	2	6.74	297.25	57	18	0.15	23.55	0.24
16	3	11.66	320.03	90	15	0.03	29.86	0.11
16	4	12.12	3.97	200	16	0.97	21.65	0.1
17	3	6.46	297.2	57	18	0.15	22.55	0.27
17	2	11.27	320.02	90	15	0.03	28.86	0.12
17	4	11.57	14.19	200	16	0.97	20.65	0.11
18	2	6.17	297.14	57	18	0.15	21.55	0.3
18	3	10.88	320.01	90	15	0.03	27.86	0.14
18	4	11.01	14.43	200	16	0.97	19.65	0.12
19	2	5.89	297.07	57	18	0.15	20.55	0.34
19	3	10.49	320.01	90	15	0.03	26.86	0.16
19	4	10.46	14.7	200	16	0.97	18.65	0.13
20	2	5.6	297	57	18	0.15	19.55	0.37
20	3	10.1	320	90	15	0.03	25.86	0.19
20	4	9.9	15	200	16	0.97	17.65	0.14
21	2	5.31	296.92	57	18	0.15	18.55	0.41
21	3	9.71	319.99	90	15	0.03	24.86	0.21
21	4	9.34	15.33	200	16	0.97	16.65	0.16
22	1	1.89	54.88	8	20	0.07	34.15	0.05
22	2	5.03	296.83	57	18	0.15	17.55	0.45
22	3	9.32	319.98	90	15	0.03	23.86	0.24
22	4	8.79	15.71	200	16	0.97	15.65	0.17
23	1	1.83	54.82	8	20	0.07	33.15	0.06
23	2	4.74	296.73	57	18	0.15	16.55	0.49
23	3	8.93	319.97	90	15	0.03	22.86	0.27
23	4	8.24	16.14	200	16	0.97	14.65	0.18
24	1	1.78	54.75	8	20	0.07	32.15	0.07
24	2	4.46	296.61	57	18	0.15	15.55	0.53

Tab. 2d. Results of decision of safe ship manoeuvring

situat.	type decis.	ship	t [min]	ψ_0 [°]	V_0 [Kn]	tag j	D_i [nm]	N_i [°]	ψ_i [°]	V_i [Kn]	$DCPA_i$ [nm]	$TCPA_i$ [min]	μ_0
good visibility	min. (0)	tw=3 [min] ωo=0.7 [rad/ min]	34	58	18	1	1.16	66.29	8	20	1.03	-1.94	0
						2	0.75	287.42	57	18	0.48	-109.54	0
						3	3.34	317.81	90	15	2.31	15.18	0
						4	0.7	287.25	200	16	0.64	0.15	0.39
						5	1.95	309.59	270	9	1.71	2.17	0
						6	4.05	316.39	200	15	4.03	-0.76	0
						7	3.38	291.36	155	11	3.36	1.15	0
						8	4.27	346.56	340	11	4.11	3.67	0
	mul. (1)	tw=3 [min] ωo=0.7 [rad/ min]	34	58	18	1	1.16	66.29	8	20	1.03	-1.94	0
						2	0.75	287.42	57	18	0.48	-109.54	0
						3	3.34	317.81	90	15	2.31	15.18	0
						4	0.7	287.25	200	16	0.64	0.15	0.39
						5	1.95	309.59	270	9	1.71	2.17	0
						6	4.05	316.39	200	15	4.03	-0.76	0
						7	3.38	291.36	155	11	3.36	1.15	0
						8	4.27	346.56	340	11	4.11	3.67	0
	com. (2)	tw=3 [min] ωo=0.7 [rad/ min]	34	58	18	1	1.16	66.29	8	20	1.03	-1.94	0
						2	0.75	287.42	57	18	0.48	-109.54	0
						3	3.34	317.81	90	15	2.31	15.18	0
						4	0.7	287.25	200	16	0.64	0.15	0.39
						5	1.95	309.59	270	9	1.71	2.17	0
						6	4.05	316.39	200	15	4.03	-0.76	0
						7	3.38	291.36	155	11	3.36	1.15	0
						8	4.27	346.56	340	11	4.11	3.67	0
poor visibility	min. (0)	tw=3 [min] ωo=0.7 [rad/ min]	24	32	18	1	1.67	58.88	8	20	1.51	-5.19	0
						2	3.47	295.49	57	18	1.13	25.29	0.03
						3	7.11	319.17	90	15	2.57	24.55	0
						4	5.47	17.83	200	16	0.81	9.59	0.35
						5	3.52	61.83	270	9	0.69	8.62	0.34
						6	4.41	58.23	200	15	2.31	6.85	0
						7	4.15	36.57	155	11	1.79	8.74	0
						8	3.43	330	340	11	3.38	2.44	0
	com. (2)	tw=3 [min] ωo=0.7 [rad/ min]	24	98	18	1	1.66	70.15	8	20	1.61	-0.91	0
						2	3.73	298.68	57	18	2.81	-11.69	0
						3	7.43	319.86	90	15	1.07	-116.82	0
						4	5.71	15.6	200	16	4.12	8.98	0
						5	3.55	56.55	270	9	2.22	6.16	0
						6	4.46	54.06	200	15	0.71	10.26	0.3
						7	4.32	32.75	155	11	2.01	15.14	0
						8	3.1	329.47	340	11	1.49	6.5	0
	mul. (1)	tw=3 [min] ωo=0.7 [rad/ min]	24	32	18	1	1.67	58.88	8	20	1.51	-5.19	0
						2	3.47	295.49	57	18	1.13	25.29	0.03
						3	7.11	319.17	90	15	2.57	24.55	0
						4	5.47	17.83	200	16	0.81	9.59	0.35
						5	3.52	61.83	270	9	0.69	8.62	0.34
						6	4.41	58.23	200	15	2.31	6.85	0
						7	4.15	36.57	155	11	1.79	8.74	0
						8	3.43	330	340	11	3.38	2.44	0

The collision avoidance manoeuvre is done 10 minutes earlier in poor visibility than in good visibility . The ship must do a collision avoidance manoeuvre when the second target does not manoeuvre (at distance D = 1.6 nm) in good visibility . The simulation results show that it is the best in the type "minimum" (tab.2d) , and after the anticollision manoeuvre these situations become safe /μ_{oj} (j=1,...,m)<0.5 (are less than fixed value μ_{om})/.

In other simulation situations the time to tracing and to collision avoidance action is earlier -from 1 minute to 5 minutes for a bigger ship in the same visibility. The simulation result shows that the model as decision making in fuzzy environment is able to solve the problem with a high degree of accuracy . The worked out program simultaneously gives all results such as the time to tracing, the time to anticollision manoeuvre, the manoeuvre type / by course and (or) by speed /, the manoeuvre direction in accordance with International Rules and collision avoidance manoeuvre taking into consideration the ship's dynamic properties.

AN ALGORITHM OF SENSITIVITY ANALYSIS

In order to use the algorithm in practice it is necessary to carry out sensitivity analysis of the ship safe control program for the accuracy of the ARPA (ANTICOLLISION RADAR PLOTTING AID) information to concern the actual approach situation, for the change of the model parameters, the relative measure for the sensitivity is represented in the form:

$$S_{ij}(P_{ij},P_{ij}^{'})=\frac{\left|\mu_{ij}(P_{ij},P_{ij}^{'})-\mu_{ij}(P_{ij})\right|}{\mu_{ij}(p_{ij})}, \quad (19)$$

$$j=1,2,3,\ldots,m$$

where:

S_{1j} - the relative sensitivity of the membership function μ_{oj} of the fuzzy set "collision risk" in respect to "j" target.

S_{2j} - the relative sensitivity of the membership function μ_{Gj} of the fuzzy set "safe manoeuvre" in respect to "j" target,

$P_{1j}=\{P_{1aj},P_{1bj}\}, P_{2j}=\{P_{2aj},P_{2bj}\}, j=1,2,3,\ldots,m$ - sets of accuracy information according to membership function μ_{oj} and μ_{Gj}.

$P_{1j}^{'}=\{P_{1aj}^{'},P_{1bj}^{'}\}, P_{2j}^{'}=\{P_{2aj}^{'},P_{2bj}^{'}\}, j=1,2,3,\ldots,m$ - sets of the information with deviation according to membership function μ_{oj} and μ_{Gj}

$$S_i(P_i,P_i^{'})=\frac{\left|\mu_i(P_i^{'})-\mu_i(P_i)\right|}{\mu_i(P_i)}, \quad i=3,4, \quad (20)$$

where :

S_3 - is the relative sensitivity of the membership function of the fuzzy set "way loss",

S_4 - is the relative sensitivity of the membership function of the set of decision ,

$P_3=\{P_{3a},P_{3b}\}$ - the set of the accuracy values of information in respect to the memb-ership function μ_c.

$P_3^{'}=\{P_{3a}^{'},P_{3b}^{'}\}$ - the set of the information with the deviation in respect to the member-ship function μ_c,

$$P_4=\bigcup_{i=2,3,j=1,2,\ldots,m} P_{ij} \bigcup P_3, \quad (21)$$

$$P_4^{'}=\bigcup_{i=1,2,j=1,2,\ldots,m} P_{ij}^{'} \bigcup P_3^{'} \quad (22)$$

The sets $P_{1aj},P_{1aj}^{'},P_{2aj},P_{2aj}^{'},P_{3a},P_{3a}^{'}$ are determined as sets of information of system

$$P_{1aj}=\{v_o,\psi_o,v_j,\psi_j,D_j,N_j\}, \quad (23)$$

$$P_{1aj}^{'}=\{v_o\pm\Delta v_o,\psi_o\pm\Delta\psi_o,v_j\pm\Delta v_j,\psi_j\pm \pm\Delta\psi_j,D_j\pm\Delta D_j,N_j\pm\Delta N_j\} \quad (24)$$

$$P_{2aj}=\{v_o,\psi_o,v_o^{*},\psi_o^{*},v_j,\psi_j,D_j,N_j\} \quad (25)$$

(26)

$$P_{2aj}^{'}=\{v_o\pm\Delta v_o,\psi_o\pm\Delta\psi_o,v_o^{*}\pm\Delta v_o^{*},\psi_o^{*}\pm \pm\Delta\psi_o^{*},v_j\pm\Delta v_j,\psi_j\pm\Delta\psi_j, D_j\pm\Delta D_j,N_j\pm\Delta N_j\}$$

$$P_{3a}=\{v_o,\psi_o,v_o^{*},\psi_o^{*}\}, \quad (27)$$

(28)

$$P_{3a}^{'}=\{v_o\pm\Delta v_o,\psi_o\pm\Delta\psi_o,v_o^{*}\pm\Delta v_o^{*},\psi_o^{*}\pm\Delta\psi_o^{*}\}$$

The sets $P_{1bj},P_{1bj}^{'},P_{2bj},P_{2bj}^{'},P_{3b},P_{3b}^{'}$ of the ship's dynamic parameters and navigator's subjectivity are determined in the form:

$$P_{1bj}=\{t_w,\omega_z,\lambda_{odj},\lambda_{otj}\}, \quad (29)$$

$$P_{1bj}^{'}=\{t_w\pm\Delta t_w,\omega_o\pm\Delta\omega_o,\lambda_{odj}\pm\Delta\lambda_{odj}, \lambda_{otj}\pm\Delta\lambda_{otj}\},$$

(30)

$$P_{2bj}=\{t_w,\omega_o,\lambda_{dj}\} \quad (31)$$

$$P_{2bj}^{'}=\{t_w\pm\Delta t_w,\omega_o\pm\Delta\omega_o,\lambda_{dj}\pm\Delta\lambda_{dj}\} \quad (32)$$

$$P_{3b}=\lambda_c \quad (33)$$

$$P_{3b}^{'}=\lambda_c\pm\Delta\lambda_c \quad (34)$$

As an example, the authors present data and results of the sensitivity research of the navigation situation, as in Tab. 3 and Fig. 3.

From the result of the sensitivity analysis of the control algorithm we notice that:

- the control algorithm is more sensitive for larger deviation of these parameters (showed in Fig. 3);
- the sensitivity of the algorithm is not dependent in some degree on every parameter, that is dependent on the type of encounter. In a head-on encounter the sensitivity of the membership function of the fuzzy set "safe manoeuvre" is most dependent on the bearing N_j, ship's course ψ_o, target's course ψ_j. In a collision encounter the sensitivity of the membership function of the fuzzy set "collision risk" is more dependent on the distance D_j, bearing N_j and parameters $\lambda_{odj},\lambda_{otj}$ (showed in Fig. 3);
- the algorithm is less sensitive for the safer target (Fig. 3).

To illustrate this, in Fig. 3 the authors present the encounter situation and diagram of sensitivity for first and second target.

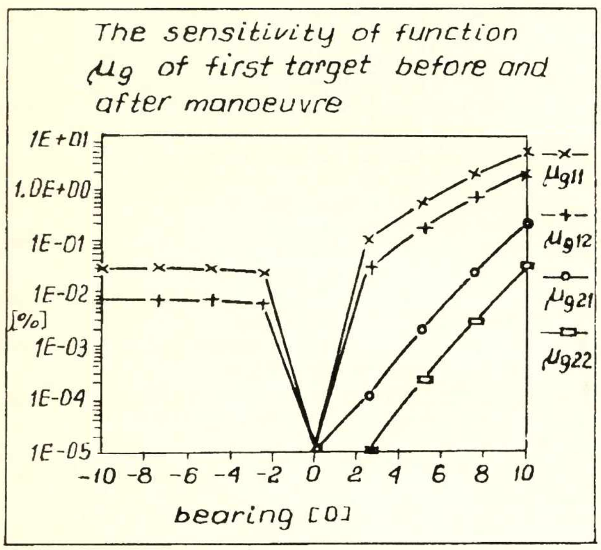
Tab. 3. Data of navigation situation

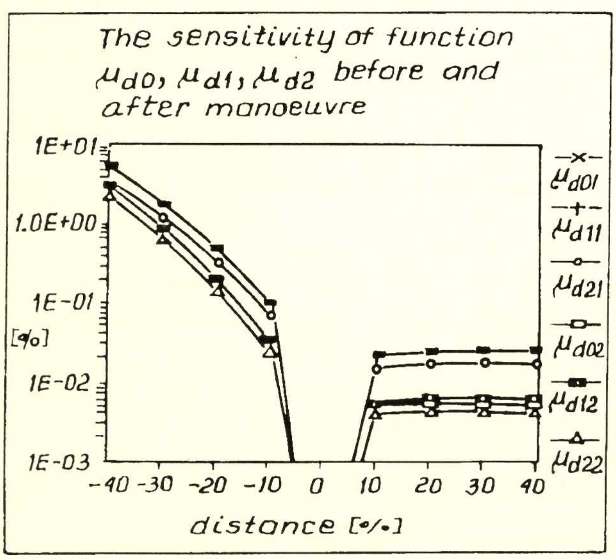
N° target	D_j [nm]	N_j [°]	ψ_o [°]	v_j [Kn]
1	2.5	290	155	19
2	3.5	185	355	19

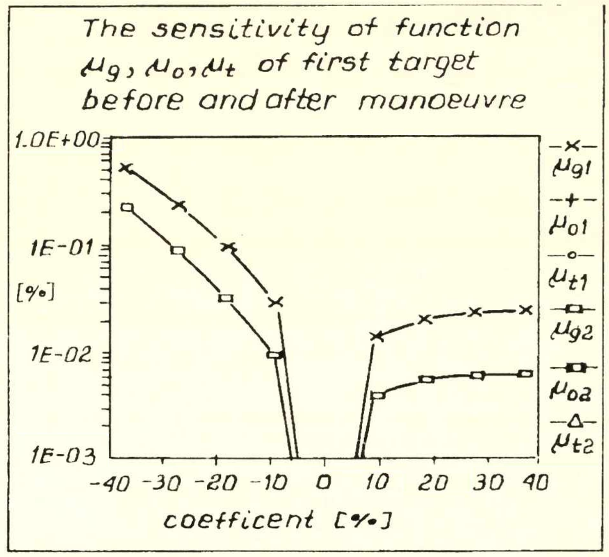
where: ship has course 0[°], speed 18[Kn].

A FUNCTIONAL MODEL OF A SYSTEM OF SAFE SHIP MANOEUVRE

The system of safe ship manoeuvre in a multiship situation is represented in Fig. 4. Information characterizing a navigation situation, such as $D_j, N_j, v_j, \psi_j, v_o, \psi_o$, is determined by radar and the system of data processing. The system automatically determines the time to track a target, the time to anticollision manoeuvre, and safe manoeuvre by course $\Delta\psi_o$ (or/and) by speed Δv_o taking into consideration dynamic properties of the ship and International Rules.







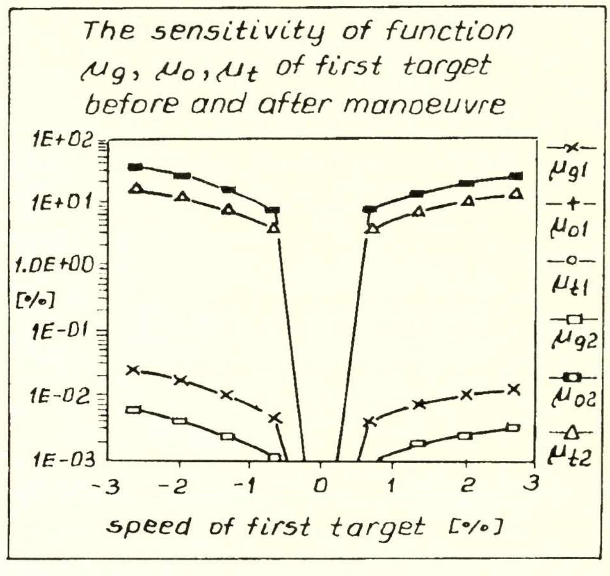


Fig. 3. Sensitivity diagram of the navigation situation μ_G, μ_O

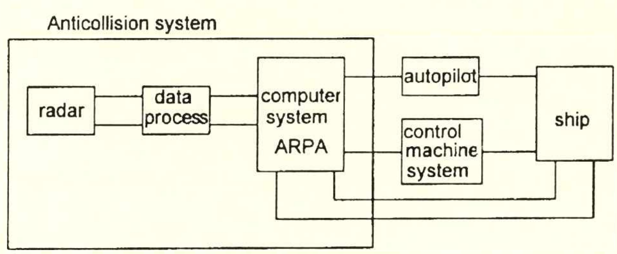


Fig. 4. System of safe ship manoeuvre

CONCLUSION

The present paper and the paper [8] have considered the possibility of constructing an intelligent avoidance collision system that automatically calculates the time to track the target, the time to anticollision manoeuvre and safe manoeuvre by course (or/and) by speed taking into consideration the ship's dynamic properties and International Rules. These simulated ship encounters demonstrate that decision making in the fuzzy environment can provide better solutions than in models of conventional mathematical apparatus.

NOMENCLATURE

Vectors

$\overline{X}$ - Discrete state vector,

$\overline{U}$ - Discrete control vector,

$\overline{\mu}_o^T$ - Vector of membership function of fuzzy sets "collision risk" **O**,

$\overline{\mu}_G$ - Vector of membership function of fuzzy sets "safe manoeuvre" .

Scalar Symbols

C - Fuzzy set of the constraint,

G - Fuzzy set of goal,

D - Fuzzy set of the decision,

x_j, y_j - Target "j" related coordinates of j-th target,

v_o, v_o^* - Ship speed before and after manoeuvre,

ψ_o, ψ_o^* - Ship course before and after manoeuvre,

t_w, ω_o - Ship dynamic parameters,

$DCPA_j$ - Distance of closest point of approach,

$TCPA_j$ - Time to distance of closest point of approach,

m - Quantity of target in encounter situation,

X_{2j-1} - Set of DCPA ,

X_{2j} - Set of TCPA ,

U - Set of control velocities (set of decisions),

$\mu_{oj}, \mu_{Gj}, \mu_C, \mu_D$ - Membership function of sets **O**, **G** , **C** and **D**,

$\lambda_{odj}, \lambda_{otj}, \lambda_{dj}, \lambda_c$ - Navigator's subjective parameters in these membership functions,

μ_{os}, μ_{om} - Fixed values of μ_o ,

T_{sj}, T_m - Time to tracing of j-th target and time to anticollision manoeuvre on scale of $DCPA_j$

$\langle \psi_{opt}, v_{opt} \rangle$ - Optimal manoeuvre.

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Conferences

XIIth National Conference on Automation

XIIth National Conference on Automation was held from 6 to 8 June 1994 in Gdynia, organized by the Merchant Marine Academy in Gdynia in cooperation with Automation Committee of the Polish Society of Measurements, Automation and Robotics - POLSPAR.

140 participants (with some representatives of Russia and Vietnam inclusive) took part in the Conference. Other industries and organizations apart from shipping and shipbuilding were represented too. 106 papers, published in the Confrence proceedings, presented a large variety of problems of automation theory, education and implementation. They were heard and discussed during 3 plenary and 5 topic sessions.

The plenary sessions were focussed on: steering theory of singular linear systems, discrete system designing, steering systems, automatic monitoring and reliability of automation systems.

About half the number of papers presented during topic sessions were devoted to:

- theoretical problems of object description and identification, of object stability assessment, and of steering one- and multi-dimensional systems;
- problems of education of students and practitioners in the field of automation, and of proper outfit of didactic laboratories.

Remaining papers dealt with , a.o., :

- microprocessor systems;
- pneumatics and hydraulics in automation;
- automation systems for marine and land-based power plants;
- automation of electrical drives;
- steering of marine and aeronautical objects;
- computerized supporting systems.

A round table session was also held on present state of automation in Poland and its prospects in new economical conditions.

New products and product designs of AB Micro, Consult-Exim, APENA, and MERA-Pnefal make were presented, but Lucas-Nulle and Armfield showed new equipment for didactic laboratories.

An interesting accompanying program was also offered, viz. round trip onboard of DAR MŁODZIEŻY - school top- sail ship owned by the Merchant Marine Academy in Gdynia, visiting a higly automated ship under construction in Gdańsk Shipyard, visiting several naval vessels, as well as museums.

Tradition Room in the Naval Academy was also presented on the occasion of 75th anniversary of establishment of maritime schools in Poland and 25th anniversary of granting academic status to the Naval Academy in Gdynia.

The next, XIIIth National Conference on Automation will be organized by High Engineering School in Opole.