Transactions on Ecology and the Environment vol 24, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

The safe ship control with minimum risk of collision

J. Lisowski & M. M. Seghir
Gdynia Maritime Academy, Department of Ship Automation
83 Morska Str., 81-225 Gdynia, Poland
EMail: jlis@wsm.gdynia.pl, mosem@wsm.gdynia.pl

Abstract

In this paper, safe ship trajectory in collision situation is presented as multistage decision-making in a fuzzy environment[1]. The model of process takes under consideration the Collision Avoidance Regulations, the manoeuvrability parameters of ship and the navigator's subjective assessment in making a decision. The time of taking the observation of an object and the time of collision avoidance manoeuvre are determined on the membership function of the fuzzy set of a collision risk. The algorithm has been worked out with regard to an on-line control status. A situations of a multiship encounter have also been simulated.

1 Introduction

The problem of collision avoidance has become an urgent issue, therefore it is necessary to describe the process of collision avoidance more accurately.

To assure safety ship navigation is one of the most important problems in the marine navigation. It is difficult to make correct decision in a collision situation because of growing size, velocity and the number of the ships which are taking part in the maritime transport. A contemporary tendency in the domain of ship control concerns automation process of choosing

optimal manoeuvre or optimal safe trajectory bases on the information from the anticollision system.
In the proposed paper the solution of base task of the determining ship's position, in every stage of ship trajectory, based on process kinematics model is discussed. It is assumed that the motion of encounter targets is straight-line and uniform.

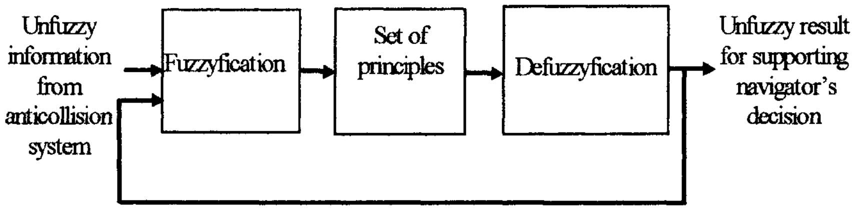

Figure 1: Fuzzy phases to determine ship's optimal safe trajectory in collision situation.

Because of process fuzziness, cased from the subjectivity characterising the direct role of officer-navigator in a decision-making in the process also ambiguously describing safe distance of approach and safe time to make avoidance collision manoeuvre[3], it is assumed that an optimal safe trajectory in collision situation as multistage decision-making in fuzzy environment (Fig. 1).
Safe ship driving depends on continuing observation of the situation at sea, determination the anticollision manoeuvre, the realization of it and safe travel to the aim point. So it is important to determine safe trajectory of ship as sequence of a single manoeuvres of ship course changing. Every manoeuvre is done on the bases of information from the anticollision system.
In this paper the safe ship control taking into account passing with many motional objects in a collision situation as multistage decision making in fuzzy environment has been presented.

1.1 Nomenclature

X - Set of state,
U - Set of control,
G - Fuzzy set of goal,

C - Fuzzy set of constraint,
D - Fuzzy set of the decision,
X(t) - Vector of real co-ordinates of ship position
u(t) - Vector of control,
ψ - Ship course before manoeuvre,
ψ^* - Ship course after manoeuvre,
ψ_{opt} - Optimal course
x,y - Co-ordinates of ship's position,
v - Ship speed,
v_{opt} - Optimal ship's speed,
DCPA - Time to distance of closest point of approach,
TCPA - Distance of closest point of approach,
μ_R - Membership function of fuzzy set collision risk
μ_{Rsafe} - Value of μ_R, at which the process is assumed as safe
μ_G - Membership function of fuzzy set of goal
μ_C - Membership function of fuzzy set of constraint
μ_D - Membership function of fuzzy set of the decision
$\lambda_c, \lambda_d, \lambda_{Rd}, \lambda_{Rt}$ - Navigator's subjective parameters

2 Kinematics model of process

In order to describe the safe ship trajectory, a motion of a ship returning by rudder in deep water is in work[4], but they are slightly useful the synthesis of safe ship trajectory, to evaluate the dynamic properties of the ship we use the parameters of the transfer function or the advance time and maximal angle speed (Fig. 2)[3].
With a negligence of speed decrease on the course manoeuvre, the ship's kinematics real motion, with giving consideration to dynamic properties, becomes:

$$x(t) = x(t-1) + (t_W + \frac{1}{\omega} tg\frac{|\psi^* - \psi|}{2})(v\sin\psi - v\sin\psi^*) + vt\sin\psi^* \qquad (1)$$

$$y(t) = y(t-1) + (t_W + \frac{1}{\omega} tg\frac{|\psi^* - \psi|}{2})(v\cos\psi - v\cos\psi^*) + vt\cos\psi^* \qquad (2)$$

Transactions on Ecology and the Environment vol 24, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

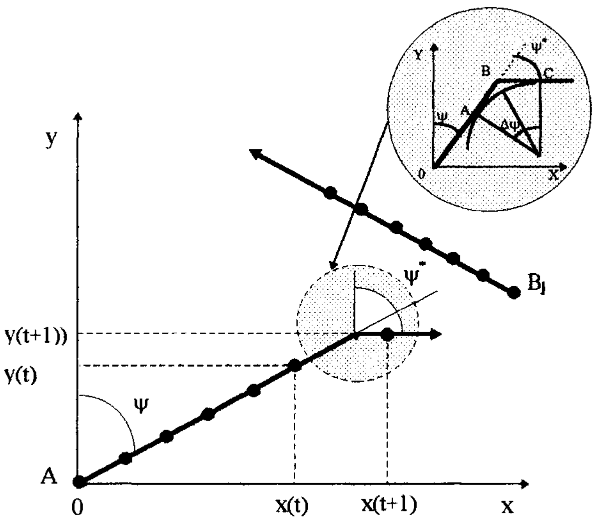

Figure 2: Simplified presentation during manoeuvre of the ship motion.

3 Model as a multistage decision making in fuzzy environment

Model of safe ship trajectory can be represented by the state equation:

$$\mathbf{f}\,(\mathbf{X}, \mathbf{U}) \rightarrow \mathbf{U}\times\mathbf{X} \tag{3}$$

$$X(t+1) = f\,(X\,(t)\,,\,u(t)), \qquad t= 1, 2, ..., N \tag{4}$$

where:

$X(t+1)\,,\, X(t) \in \mathbf{X} = \{x_0\,,\, x_1\,,\, ...,\, x_j)$ - set of real ship position co-ordinates

$u(t) \in \mathbf{U} = \{u_0\,,\, u_1\,,\, ...,\, u_j)$ - control set

The process comes to an end when a ship attains back points (final points) called the final states $\mathbf{W} \subset \mathbf{X}$:

Transactions on Ecology and the Environment vol 24, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

$$\mathbf{W} = \{ x_{p+1} , x_{p+2} , x_N \} \tag{5}$$

The set of final states must satisfy this condition :

$$< u_{opt} , \mu_R \leq \mu_{Rsafe} > \tag{6}$$

where:

$u_{opt} = <\psi_{opt} , V_{opt}>$ - optimal control,

μ_R - membership function of fuzzy set collision risk

This membership function of fuzzy set collision risk can be presented in the form:

$$\mathbf{Z} \subseteq \mathbf{XxX} \tag{7}$$

$$\mu_R : \mathbf{XxX} \rightarrow [0,1] \in \mathbf{R} \tag{8}$$

$$\mu_R = \frac{1}{\exp(\lambda_{RD}(k,j) D_{CPA}^2 + \lambda_{RT}(k,j) T_{CPA}^2)} \tag{9}$$

Similarly, the membership function of fuzzy set of goal can be written in the form:

$$\mathbf{G} \subseteq \mathbf{XxU} \tag{10}$$

$$\mu_G : \mathbf{XxU} \rightarrow [0,1] \in \mathbf{R} \tag{11}$$

$$\mu_G (k, j) = 1 - \frac{1}{\exp(\lambda_d(k,j) D_{CPA}^2)} \tag{12}$$

Now, it must be defined a membership function of fuzzy set constraints as constraints of manoeuvre at each step:

$$\mathbf{C} \subseteq \mathbf{XxU} \tag{13}$$

$$\mu_C\text{: } \mathbf{XxU} \rightarrow [0,1] \in \mathbf{R} \tag{14}$$

$$\mu_C\,(k) = \frac{1}{\exp(\lambda_c(k)(V\cos\psi(k) - V\cos\psi(k-1))t_k{}^2)} \tag{15}$$

The fuzzy set decision is determined as the fuzzy set $\mathbf{D} \subseteq \mathbf{XxU}$, it's a result of an operation "*" of the fuzzy set of goal and fuzzy set of constraints:

$$\mathbf{D{=}G{*}C} \tag{16}$$

$$\mu_D\,(.,.) = \mu_C\,(.,.) * \mu_G\,(.,.) \tag{17}$$

4 Algorithm

A fuzzy decision is a result of a certain compromise between these sets **G** (fuzzy set of goals) and **C** (fuzzy set of constraints), if the trajectory is called sequence states attained, then membership function of fuzzy set decision define as :

$$\mu_D = (u_0\,,\, u_1\,,\, \dots\,,\, u_{N-1}\,,|\, x_0) = \mu_C{}^0(u_0/x_0) * \mu_G{}^1(u_1/x_1) * \dots * \mu_C{}^{N-1}(u_{N-1}/x_{N-1}) * \mu_G{}^N(u_N/x_N) \tag{18}$$

To maximise a membership function of fuzzy set decision, at using minimum type, we obtain the optimal decision :

$$\mu_D = (u_0^*,\ u_1^*,\, \dots\,,\, u_{N-1}^*,|x_0) = \bigvee_{u_0, u_1, \dots, u_{N-1}} (\mu_C{}^0(u_0/x_0) \wedge \mu_G{}^1(u_1/x_1) \wedge \dots \wedge \mu_C{}^{N-1}(u_{N-1}) \wedge \mu_G{}^N(X_N) \tag{19}$$

The decision process can be conveniently represented in the form of a decision tree (Fig. 3), the root of the tree is the initial state $x_0{}^2$. We start

from x_0, and looking for the optimal decision, after that to put it to control u_0 and we pass to state x_1. We determine again the optimal decision u_0 and we pass to the next state, until we attain the final state. In this manner we obtain sequence of states which present a ship's optimal safe trajectory.
In Figure 3 it is shown the decision tree algorithm with application branch and bound method. In the form of example we analyse two types of ship's encounter in the following point.

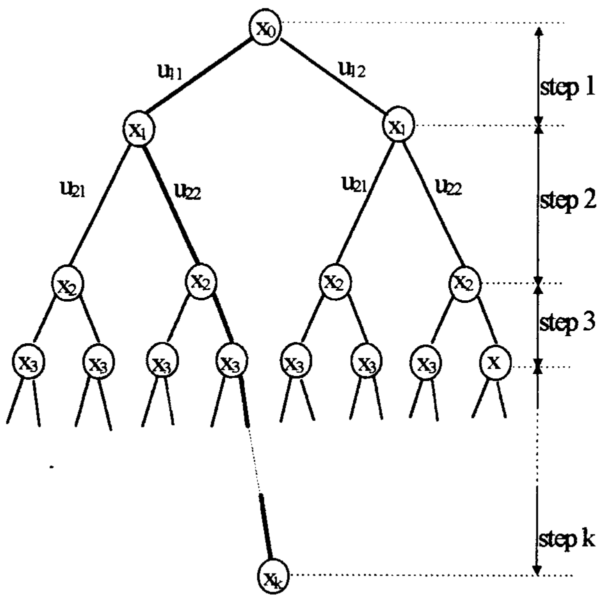

Figure 3: Decision tree with application branch and bound algorithm.

5 Simulation

In this paper the authors analysed two types of ship's encounters simulated with PC computer.

Table 1: Data of navigation situation in case of passing with three motional targets.

	D_J [Mm]	N_J [o]	ψ_J [o]	V_J [kn]
own ship			0	14
target1	4.24	315	90	19
target2	3.01	1.9	182	14
target3	3.16	18.5	175	17

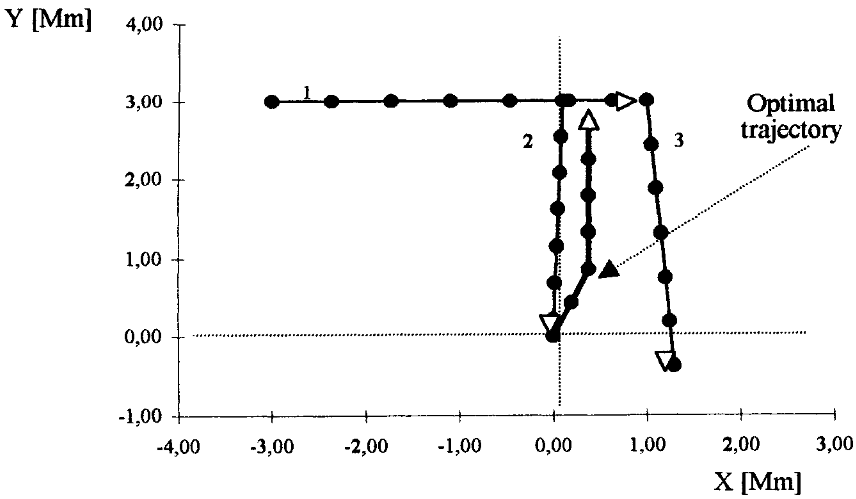

Figure 4: The result of simulation of the collision situation in passing with three motional targets.

Table 2: Data of navigation situation in case of passing with four motional targets

	D_j [Mm]	N_j [o]	ψ_j [o]	V_j [kn]
own ship			0	14
target1	1.53	75	280	16
target2	3.01	1.9	182	14
target3	3.16	18.5	175	17
target4	4.24	315	98	19

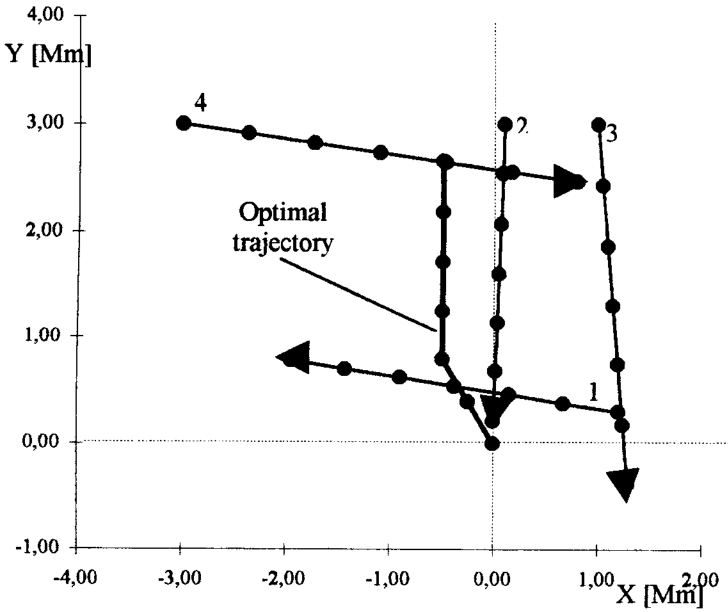

Figure 5: The result of simulation of the collision situation in passing with four motional targets.

6 Conclusion

The present results showed that the proposed concept of the application of fuzzy set theory is a promising way to solve the considered task and design a novel anticollision system in the future. This conception demonstrates that decision making in the fuzzy environment can provide better solution then in models of conventional mathematical apparatus[5,6].

Acknowledgement

This work was financially supported by the state Committee for Scientific Research of the Government of Poland under statute research of Gdynia Maritime Academy No DS/155/98 implemented in 1998.

References

[1] James M. K. Modelling the decision process in computer simulation of ship navigation. Journal of Navigation, vol. 39 n°. 1, p. 32-41, 1986.

[2] Kacprzyk J. A branch-and-bound algorithm for the multistage control of a nonfuzzy system in a fuzzy environment. Control and Cybernetics, vol.7, p.51-64, 1978.

[3] Lisowski J., Pham N. T. Properties of safe fuzzy probability sets in safe navigation. 2nd IFAC Workshop CAMS'92, Genoa, p. 209-219, 1992.

[4] Lisowski J., Pham. N.T., Mohamed-Seghir M. Safe ship automation control taking into consideration fuzzy properties of the process. Polish Maritime Research vol. 1, n°. 2, p. 25-32, 1994.

[5] Lisowski J., Śmierzchalski R. The process avoiding collision at sea as a non-linear programming task. 14th International Congress on Cybernetics, Namur, p. 1-6, 1995.

[6] Lisowski J., Pham. N.T. An algorithm of the safe ship control as a matrix game in fuzzy environment. Conference on Management and Control of Production and Logistics MCPL'97, Campinas, vol. 2, p.563-567, 1997.