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CALCULATION ACCURACY OF SAFE COURSE MADE GOOD IN AN ANTICOLLISION SYSTEM

Summary. The article presents an accuracy analysis of calculation made by a Multiagent Decision-Support System (MADSS) of navigation. On the basis of messages received from Universal Ship-borne AIS system (Automatic Identification System) the system calculates the parameters of vessels' encounter and works out the parameters of own vessel's movement (course or speed), which lead to passing other objects according to a set CPA (Closest Point of Approach).

OCENA DOKŁADNOŚCI OBLICZONEGO BEZPIECZNEGO KĄTA DROGI W SYSTEMIE ANTYKOLIZYJNYM

Streszczenie. W artykule przedstawiono analizę dokładności obliczeń wykonywanych przez multiagentowy system wspomagania nawigacyjnego procesu decyzyjnego (MADSS – Multi-agents Decision Support System). System ten na podstawie komunikatów odebranych z systemu AIS (*Universal Ship borne* Automatic Identification System) oblicza parametry spotkania statków oraz wypracowuje nowe parametry ruchu statku własnego (kurs lub prędkość), które prowadzą do rozminięcia z innymi obiektami na zadane CPA (Closest Point of Approach).

1. INTRODUCTION

Navigation is the process of directing a vessel on a designated way (trajectory) according to a voyage plan and tasks executed, with imposed economic, temporal, geometric, hydrolometeorological and other limitations. This process can be subdivided into certain sub-processes (layers):

- gathering and processing information,
- navigational planning,
- determining the vessel's position and speed vector,
- monitoring location in relation to navigational hazards,
- making decisions,
- controlling a vessel.

An element of the navigational decision-making process is the solving of anticollision tasks. Work [6] proposes an anticollision system based on a system of multiagents using data from own ship's AIS or vessels within the reach of the VHF radio horizon, which permits the complete process automation of obtaining, processing, analysing and working out an anticollision decision. What follows below is an accuracy analysis of own vessel's safe course made good. Respective formulae have been derived with the assumption of linear approximation of particular functions serving the purpose of calculating appropriate navigational parameters (expansion in Taylor series) [2], whereas the accuracy of input data was assumed from the research performed [1], [3], [5]. Simulation research of anticollision situations conducted at the ECDIS laboratory of Maritime University of Szczecin has been made use of in the analysis.

2. ERROR OF OWN VESSEL'S COURSE MADE GOOD

During solving the task of an anticollision manoeuvre the particular main and auxiliary parameters are calculated according to the following dependences:

- bearing to the strange vessel

$$NR = \operatorname{arctg}\frac{Y}{X} \tag{1}$$

where: X – distance between vessels along axis x, Y – distance between vessels along axis y,

- auxiliary angle

$$\gamma = \arcsin\frac{CPA_{LIMIT}}{R} \tag{2}$$

where: CPA_{LIMIT} – assumed distance of vessels passing, R – distance between vessels,

- course made good of strange vessel

$$K_{TG} = 270^0 - \operatorname{arctg}\frac{V_{TG(x)}}{V_{TG(y)}} \tag{3}$$

where: $V_{TG(x)}$, $V_{TG(y}$ - component velocities of strange vessel,

- relative course made good

$$K_w = NR + 180^0 + \gamma \tag{4}$$

- auxiliary angle

$$\alpha = K_{TG} - K_w = 90^0 - \operatorname{arctg}\frac{V_{TG(x)}}{V_{TG(y)}} - \operatorname{arctg}\frac{Y}{X} - \arcsin\frac{CPA_{LIMIT}}{R} \tag{5}$$

- auxiliary angle

$$\beta = \arcsin\left(\frac{V_{TG}}{V_{OS}}\sin\alpha\right) \tag{6}$$

- safe course made good of own vessel

$$KDd = K_w - 180^0 - \beta = NR + 180^0 + \gamma - 180^0 - \beta = NR + \gamma - \beta =$$
$$= \operatorname{arctg}\frac{Y}{X} + \arcsin\frac{CPA_{LIMIT}}{R} - \arcsin\left(\frac{V_{TG}}{V_{OS}}\sin\alpha\right) \tag{7}$$

In a general case error transfer law (for independent errors) is expressed by the following formula [2]:

$$\sigma_z = \sqrt{\left(\frac{\partial z}{\partial x_1}\right)^2 \sigma_{x_1}^2 + \ldots + \left(\frac{\partial z}{\partial x_n}\right)^2 \sigma_{x_n}^2} \tag{8}$$

Hence, after calculating appropriate derivatives we will obtain the following expression for the error of determining the safe course made good of own vessel:

$$\sigma_{KDd} = \sqrt{\frac{\sigma_X^2}{R^2 - CPA_{LIMIT}^2} + \frac{V_{TG}^2 \cdot \cos^2\alpha}{V_{OS}^2 - V_{TG}^2 \cdot \sin^2\alpha}\sigma_\alpha^2 + \frac{(1+V_{TG}^2)\cdot \sin^2\alpha}{V_{OS}^2 - V_{TG}^2 \cdot \sin^2\alpha}\sigma_V^2} \tag{9}$$

where: σ_α - error of auxiliary error α, expressed by the formula:

$$\sigma_\alpha = \sqrt{\frac{\sigma_V^2}{V_{TG}^2} + \frac{\sigma_X^2}{R^2 - CPA_{LIMIT}^2}} \tag{10}$$

σ_x – coordinate error of strange vessel (simplifying it is accepted that $\sigma_x = \sigma_y$),
σ_V – vessel speed error (simplifying it is accepted that errors of own and strange vessel are of the same order)

3. ACCURACY ANALYSIS EXAMPLES OF SAFE COURSE MADE GOOD OF OWN VESSEL

The fig. 1 below presents encounter situations of vessels. Objects OS 1, TG 1 and TG 2 are mechanically propelled vessels underway, whereas TG 3 is a hampered vessel. In the table there are the vessels' movement parameters (course and speed) and encounter parameters, that is CPA and TCPA calculated in relation to own ship.

Tab. 1 below presents the true bearings and distances between own vessel and strange ones (initial navigational situation).

Tab.1

Distances and true bearings between vessels

Strange vessel	Distance [m]	True bearing [^{0}]
TG 1	5 024.9	095.7
TG 2	8 000.0	0.0
TG 3	8 271.0	345.3

Source: own study.

The examples below illustrate the course of accuracy analysis of safe course made good of own vessel calculated in a multiagent anticollision system.

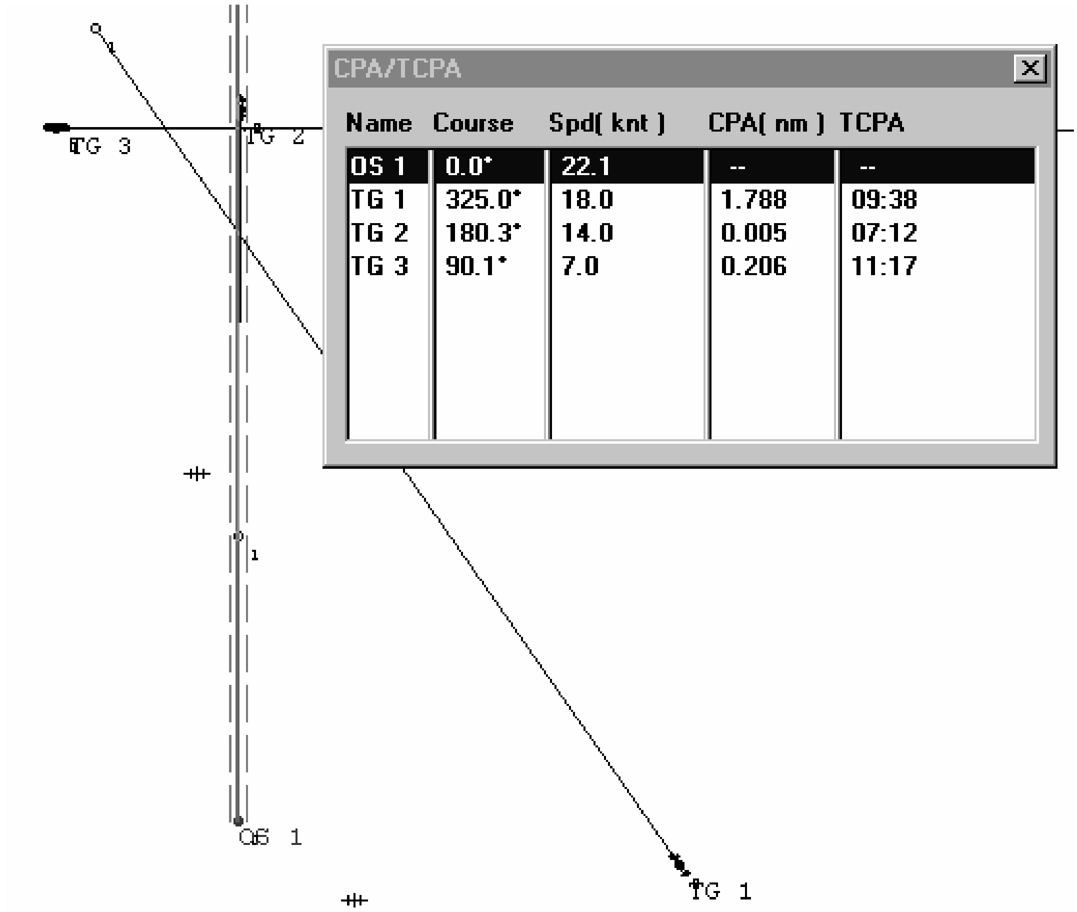

Fig.1. Vessel encounter situation
Rys. 1. Sytuacja spotkania statków

EXAMPLE 1

Let us consider an encounter situation of own ship (OS 1) with target TG 1 (Fig. 1). We assume minimum distance of vessels passing equal to CPA_{LIMIT} = 1 nm. On the basis of research we assume the error of coordinate determination (X or Y) equal to: σ_x = 10 m, which gives an error of determining coordinate difference (between OS 1 and TG 1): $\sigma_{\Delta x} = \sigma_{\Delta y} = 10\sqrt{2}$ m [1, 3], and vessel's speed error: σ_V = 0.026 m/s [4].

There are calculated successively:

bearing to strange vessel: $NR = \text{arctg}\dfrac{Y}{X} = 095.7^0$,

auxiliary angle: $\gamma = \arcsin\dfrac{CPA_{LIMIT}}{R} = 21.6^0$,

relative course made good: $K_{wz} = NR + 180^0 + \gamma = 297.3^0$,

auxiliary angle: $\alpha = K_{TG} - K_{wz} = 27.7^0$,

auxiliary angle: $\beta = \arcsin\left(\dfrac{V_{TG}}{V_{OS}}\sin\alpha\right) = 22.2^0$, own ship's course made good: $KDd = K_{wz} - 180^0 - \beta$ = 095.1^0,

mean error of determining own vessel's safe course made good: σ_{KDd} = 1.19^0.

EXAMPLE 2

Let us now consider an encounter situation between own ship (OS 1) with target TG 2. After calculations we have (with the same assumptions as in Example 1):

bearing to strange vessel: NR = 000.0^0,
auxiliary angle: γ= 13.4^0,
relative course made good: K_w = 193.4^0,
auxiliary angle: α = 131.6^0,
auxiliary angle: β = 28.3^0,
own vessel's safe course made good: KDd = 021.8^0,
mean error of determining own vessel's safe course made good: σ_{KDd} = 0.45^0.

EXAMPLE 3

Let us now consider an encounter situation between own ship (OS 1) with target TG 3. With assumptions from Example 1, we will get:

bearing to strange vessel: NR = 345,3^0,
auxiliary angle: γ= 12,9^0,
relative course made good: K_w = 178,2^0,
auxiliary angle: α = 268,2^0,
auxiliary angle: β = 18,5^0,
own vessel's safe course made good: KDd = 339,7^0,
mean error of determining own vessel's safe course made good: σ_{KDd} = 0,97^0.

Tab. 2 presents collective calculation results of determining the accuracy of safe course made good.

Tab. 2

Accuracies of determining safe course made good

Strange vessel	σ_{KDd} [^{0}]
TG 1	1.19
TG 2	0.45
TG 3	0.97

4. CONCLUSIONS

Errors in determining own vessel's safe course made good obtained by calculation are minutely small with reference to the vessels' sizes, assumed *CPA*, and what is also important – with reference to the parameters worked out in radar anticollision systems, which is why these errors have negligible effect on the vessels' anticollision manoeuvre. They should be taken into account, on the other hand, when calculating the parameters of "last minute" manoeuvre (small distances between vessels comparable with their sizes).

On the basis of results obtained the following detailed conclusions can also be drawn:

- the error of determining own ship's safe course made good is of the order of 1^0,
- when relative speed decreases, error values increase,
- when distance between vessels decreases, error values increase as well.

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