THE ALGORITHM FOR FAST FORECASTING OF THE COLLISION DANGER DEGREE WITH SHIPS AND SURFACE OBJECTS IN THE E-NAVIGATION AREA

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Summary. *The article contains the algorithm for fast forecasting of the collision danger degree conducted by a ship computer, which is an e-Navigation component. Further studies suggest forming a new user interface with the formation of augmented reality to accelerate and facilitate the navigator's decision as an element of the marine ergatic system.*

1 INTRODUCTION

One of the most important trends in the sphere of providing both safe and secure navigation at sea, taking into account the fast implementation of transport information technologies is the development of universal information space (UIS), which will give participants of technological process as well as experts the opportunity to interact in the real time framework. The current methodology of ships collision prevention does not completely meet the amended requirements of the safety Collision Regulations-72. Considering the tendency of unmanned ships in the water transport known as People Less Navigation (PLN) the importance of human element is increasing in the process of decision making. For the complex solution to the current problems on the improvement of the decision making process, while safe maneuvering and collision prevention, it is proposed to create «an intelligent water area» based on the key initiative implemented by IMO, namely e-Navigation concept [1]. The possibility of ship's maneuvering forecasting has become most topical during the search of the closed approach, forming a principally new user interface. It is crucial to take into consideration an increase in ships number and the speed of each participant of the transportation process. The functional particulars of the alarm system on the availability of the collision danger are still based on regular algorithms. These algorithms are reliable but sometimes not very efficient due to the fact that in some cases the number of active alarm indicators on the bridge exceeds the ability of a navigator to percept and efficiently handle this information, while the appropriate maneuver choice.

The proposed algorithm for fast forecasting is intended for a ship computer with the use of software by the e-Navigation system. The collision danger degree is recalculated every second and visialization of fast forecasting is presented in 3 D format. As a result a navigator can observe the real picture of forecasting, which reduces the cognitive load as well as the time of decision making. The current user interface (ARPA, ECDIS) is of Head Down Display type and mainly focused on the Human Computer Interaction. In this case the navigator's temporary and cognitive abilities are used irrationally. Constant improvement of technologies gives an opportunity for the foundation of innovative paradigms of the user interface.The augmented reality (AR) techology allows to improve the navigator's interface in the Head Up Display format and carry out the transition to the improved interaction with the environment (Human Environment Interaction). The present research is an attempt to unite the abilities of artificial intelligence (algorithm of computer forecasting, including software in the C++ programming language) and the augmented reality technology (visualization of virtual information, including software in the C# programming language) in the marine ergatic system e-Navigation.

2 GENERAL SPECIFICATIONS

Considering the prominent technological development of the shipping industry in the perspective it is possible to further e-Navigation's development strategy and its limited connection with «an intelligent water area» concept as precise in the issues of the maritime safe navigation, including collision prevention, dangerous incidents, environmental protection and economic efficiency system. Forming «an intelligent water area» involves universal assessment and handling of the developing navigational communication information system as well as the complexes of ship and shore hierarchical infrastructure in the concept of e-Navigation framework. E- ships should be equipped with test ECDIS samples adapted to solving e-Navigation tasks. The development of the e-Navigation concept will make it possible to formalize Collision Regulation – 72 requirements and provide each navigator with a duly warning on the collision danger.

The technological systems with an automated process and decision support such as ARPA, AIS make it possible to select an alarm system for the dangerous situation. But it is a navigator who takes a decision and this situation can be characterized as the situation, which does not have a clear definition. Collision Regulation – 72, Rule 8 «Action to avoid Collision», states that the action taken to prevent collision with another ship should be carried out in such a way so as to provide a safe distance after the completion of the maneuvering [2]. For the duly assessment of a distance requirement for ships safe maneuvering and decision making regarding its danger or safety we offer below the solution to forecasting tasks between two ships in «an intelligent water area».

3 OBJECTIVE

While considering the steady ship motion of both ships, to determine the distance up to the target and its position, when the distance has the minimum value.

4 SOURCE DATA

Means of satellite navigation provide the current information about ship's movement every second and UIS concept being realized will allow delivering the information about traffic of all ships within e-Navigation «intelligent water area» to e-ship. NMEA protocol on information share with GPS/GLONASS transmitter determines the format of message, containing in particular:

- the current location of the transmitter (φ, λ) – latitude and longitude. They will be expressed in radians, where South latitude and Western longitude both have negative values;
- magnitude of velocity v and heading angle θ of moving transmitter;
- instant of time *t*, which the above mentioned values are related to.

The above mentioned values related to the e-ship will be marked by zero index: (φ_0, λ_0), v_0, θ_0, t_0. The unmarked clue will relate to the target. The collision possibility with this ship is subject for the investigation [3].

5 THE SYSTEMS OF COORDINATES

The projection of the location of the transmitter fitted in the e-ship to the water surface will be referred as mark-point of the ship. So the data (φ, λ), v, θ, t describe the movement of the mark-point of the ship under consideration.

Three coordinate systems will be applied in the calculation.

1) geographical coordinates (φ, λ) of the target. It is a curve coordinate system.

2) Cartesian coordinate system $Ox'y'$ with the origin of coordinate system of e-ship, axis Ox' is directed towards the East, axis Oy' to the North. This coordinate system is located in the plane touching the water surface in the origin of the coordinate system. The transition from (φ, λ) to $Ox'y'$ is fulfilled by the map projection. In the calculations the isometric azimuthal Lambert projection is used [4]. If the projection center is considered beginning with the mark-point of the e-ship, this projection provides target bearing without any distortions as well as the distance to the target. Since we use this projection not for map drawing purposes, but for calculation, by using a sophisticated computer we have an opportunity to have the «map center» always at the mark-point of the e-ship.

3) Cartesian coordinate system Oxy with the origin at the mark-point of the e-ship, axis Oy is directed towards the ship's course; axis Ox is athwart to the course to the starboard side.

This coordinate system is available in the same plane. The transition from coordinates $Ox'y'$ to coordinates Oxy is realized by the rotation matrix

$$\mathbf{T} = \begin{pmatrix} \cos\theta_0 & -\sin\theta_0 \\ \sin\theta_0 & \cos\theta_0 \end{pmatrix}. \tag{1}$$

6 Illustrations

«Ideal ship's collision» («ideal» in mathematical sense) is presented by the coincidence of the mark-points of both ship at some definite moment of time. In coordinate $Ox'y'$ it is presented in figure 1.

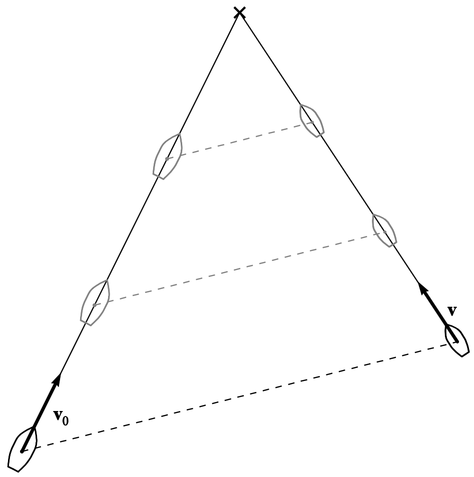

Figure 1. Collision of the ship with a constant target bearing in the coordinate system $Ox'y'$

That is why Collision Regulation – 72, Rule-7 «Risk of Collision» states:
(i) such risk shall be deemed to exist if the compass bearing of an approaching vessel does not appreciably change;
(ii) such risk may sometimes exist even when an appreciable bearing change is evident, particularly when approaching a very large vessel or a tow or when approaching a vessel at close range.

With constant bearing we have «ideal ship's collision» (in a mathematical sense). Under the small bearing deviation the minimal distance $d_{\min}$ to the closest point of approach is miserably small. The value of $d_{\min}$ may be determined best of all in the coordinate system Oxy moving along with e-ship (figure 2).

In this case the target velocity vector related to e-ship is not directed strait per bearing, so the target course line does not meet the mark-point of the e-ship.

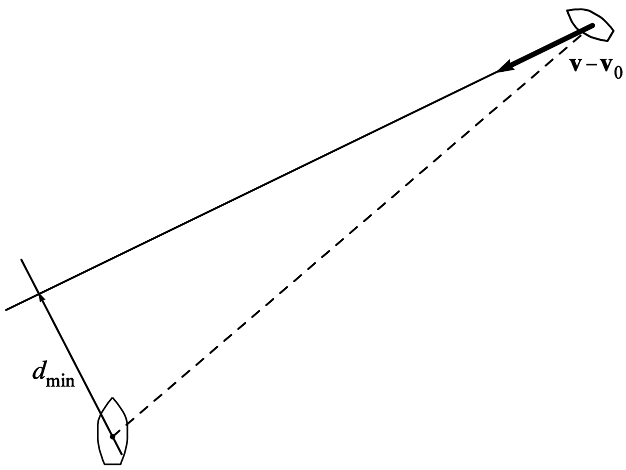

Figure 2. The minimal distance between ships determined in the coordinate system to e-ship

If $d_{\min}$ is less than some critical value (which is subject for further determination), then we decide that such a movement of the ships is dangerous.

Note that the forecast for the value of $d_{\min}$ may be based on single measurements only, no time is required for continuous observation of the target's bearing alteration.

7 TASK SOLVING

For the spherical Globe surface model the equations of Lambert's projection are given below (2).

$$k' = \sqrt{\frac{2}{1+\sin\varphi_0 \sin\varphi + \cos\varphi_0 \cos\varphi \cos(\lambda-\lambda_0)}};$$

$$x' = R_G\, k' \cos\varphi \sin(\lambda-\lambda_0); \tag{2}$$

$$y' = R_G\, k' [\cos\varphi_0 \sin\varphi + \sin\varphi_0 \cos\varphi \cos(\lambda-\lambda_0)]$$

where R_G is the radius of the Globe.

The target vessel speed vector $(v\sin\theta, v\cos\theta)^{\mathsf{T}}$ in (φ, λ) axis is presented by the formula $\frac{v}{R_G}(\frac{\sin\theta}{\cos\varphi}, \cos\theta)^{\mathsf{T}}$. For the $Ox'y'$ system the same vector is represented as:

$$\begin{pmatrix} v_{x'} \\ v_{y'} \end{pmatrix} = \frac{v}{R_G} \cdot \mathbf{D} \cdot \begin{pmatrix} \frac{\sin\theta}{\cos\varphi} \\ \cos\theta \end{pmatrix},$$

where **D** is the matrix of partial derivatives:

$$\mathbf{D} = \begin{pmatrix} \dfrac{\partial x'}{\partial \varphi} & \dfrac{\partial x'}{\partial \lambda} \\ \dfrac{\partial y'}{\partial \varphi} & \dfrac{\partial y'}{\partial \lambda} \end{pmatrix},$$

calculated at the point (φ, λ) in accordance with the above equations (2).

When we calculate the velocity vector, the Globe radius R_G is eliminated in equation, thus its value can be ignored (referred as 1).

Now we make a transition of the reference system into Oxy:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \mathbf{T}\begin{pmatrix} x' \\ y' \end{pmatrix}, \tag{3}$$

where **T** is a matrix for the origin rotation by the angle θ_0, ref. (1).

Finally, the target vessel velocity vector in the relation to reference system Oxy moving along with e-ship is obtained by the subtraction of the e-ship's own velocity vector:

$$\begin{pmatrix} v_x \\ v_y \end{pmatrix} = \mathbf{T}\begin{pmatrix} v_{x'} \\ v_{y'} \end{pmatrix} - \begin{pmatrix} 0 \\ v_0 \end{pmatrix}, \tag{4}$$

As the sampling time for both systems may be different, the initial values are subject to be determined for the same initial time t_0. According to the hypothesis of the steady ship motion the position of target ship at time t_0 is obtained as follows:

$$x^* = x - (t - t_0)v_x, \quad y^* = y - (t - t_0)v_y,$$

where x, y, v_x and v_y calculated by equations (3)–(4).

So, the ship's movement in the coordinate system Oxy is described by the parametric equations

$$\begin{cases} x(t) = x^* + t \cdot v_x, \\ y(t) = y^* + t \cdot v_y, \end{cases} \tag{5}$$

where *t* is the proposed time from the moment of observation t_0. The trajectory line has an equation

$$Ax + By + C = 0,$$

where $A = v_y$, $B = -v_x$, $C = v_x y^* - v_y x^*$.

8 CONCLUSIONS

The target ship will cross the course line of the e-ship at the point $(0, \frac{C}{v_x})$. If $\frac{C}{v_x} > 0$ (C and v_x have the same sign) then the cross point will be ahead on the course, if $\frac{C}{v_x} < 0$ then cross point will be astern on the course. It will happen at the time moment $t = -\frac{x^*}{v_x}$. If $t > 0$ then the cross time is in the future relating the time of observation, if $t < 0$ then the cross time is in the past.

The target ship will cross the e-ship's abreast (that is perpendicular to the course line) at the point $(-\frac{C}{v_y}, 0)$. If $-\frac{C}{v_y} > 0$ (C и v_y have different signs) then the ship meets abreast on the starboard side, if $-\frac{C}{v_y} < 0$, on the port side. It will happen at the time moment $t = -\frac{y^*}{v_y}$. If $t > 0$ then the cross time is in the future relating to the time of observation, if $t < 0$, the cross time is in the past.

If $v_x x^* + v_y y^* \geq 0$ then the target ship moves away and is not in danger. Otherwise, the least distance to the target ship is equal to

$$d_{\min} = \frac{|C|}{\sqrt{A^2 + B^2}} = \frac{|v_y x^* - v_x y^*|}{\sqrt{v_x^2 + v_y^2}}.$$

It will happen at the moment $t_{\min} = -\frac{v_x x^* + v_y y^*}{v_x^2 + v_y^2} > 0$. The position of the least distance in the coordinate system with the static origin (that is, the point on the water surface) may be obtained according to (5):

$$\begin{cases} x(t) = x^* + t_{\min} \cdot v_x, \\ y(t) = y^* + t_{\min} \cdot (v_y + v_0), \end{cases} \tag{6}$$

Further investigations involve the development of a new user interface (navigator, pilot, VTIS operator and others) for the visualization of the proposed solutions in the e-Navigation zone, without any control distraction for the real navigational situation (figure 3). The user interface in particular will be applied to mark potentially dangerous targets by special markers of the different colors (green – safe, yellow – attention, red – dangerous) attracting the navigator's attention during the decision making process [5, 6].

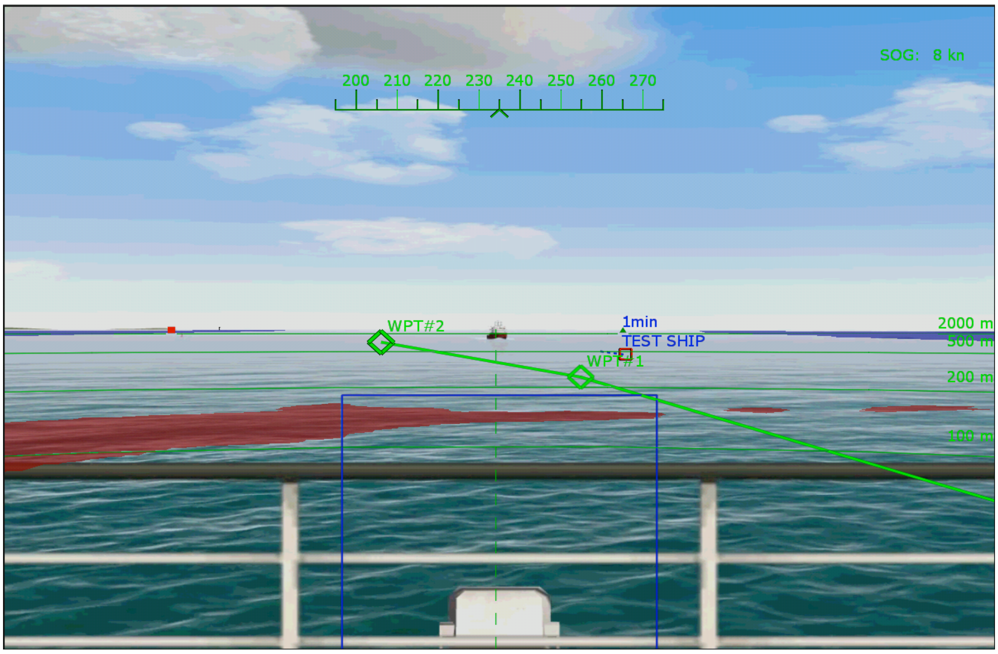

Figure 3. AR interface

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