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Possible Method of Clearing-up the Close-quarter Situation of Ships by Means of Automatic Identification System

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ABSTRACT: The tonic discussed is an non-traditional approach to the earliest possible clearing up of the head-on situation, consisting in defining the time of simultaneous approach to same latitudes and longitudes, bearing in mind that the information about the ships' movement was received by means of Automatic Identification System. If the time the ships proceed to these latitudes and longitudes is the same the collision of the ships is unavoidable and by the time identified the head-on situation is immediately indicated. If the time is different the ships will not be able to reach the same point and the collision will be avoided. The attempts have been also made to evaluate the minimal admitted inequality of time when the ships' safe passage without maneuvering is considered possible.
This method is rather attractive because it does not require any additional measurements and it is not necessary to attract the Officer-in-Charge away from his main responsibility – to control the situation round the ship.

1 INTRODUCTION

Earlier we were discussing non-traditional approach to the earliest possible clearing up of the head-on situation the essence of which is in defining the time of simultaneous approach the same latitudes and longitudes taking into account the fact that the information about ship's movement was received by means of Automatic Identification System (AIS) (Bukaty, V. M. 2005. Research…; Bukaty, V. M. 2006. Non-traditional…)

2 FUNDAMENTALS OF METHOD

When using AIS at a given instant of time t_1 positions φ_{g1} and λ_{g1} speed v_g and track angle TA_g of a given vessel and positions φ_{o1} and λ_{o1}, speed v_o and track angle TA_o of an oncoming vessel (target). At instant of time t_2 positions φ_{g2} and λ_{g2} of the given vessel and positions φ_{o2} and λ_{o2} of the oncoming vessel will be:

$$\varphi_{g2} = \varphi_{g1} + v_g (t_2 - t_1)\cos TA_g = \varphi_{g1} + v_g t \cos TA_g \quad (1)$$

$$\lambda_{g2} = \lambda_{g1} + v_g (t_2 - t_1)\sin TA_g \sec\varphi_m = \lambda_{g1} + v_g t \sin TA_g \sec\varphi_m (1) \quad (2)$$

$$\varphi_{o2} = \varphi_{o1} + \mathrm{v_o}(\mathrm{t_2} - \mathrm{t_1})\cos \mathrm{TA_o} = \varphi_{o1} + \mathrm{v_o t}\cos\mathrm{TA_o} \quad (3)$$

$$\lambda_{o2} = \lambda_{o1} + v_o (t_2 - t_1)\sin TA_o \sec\varphi_m = \lambda_{o1} + v_o t \sin TA_o \sec\varphi_m \quad (4)$$

In equations (1), (2), (3) and (4) $t = t_2 - t_1$, φ_m -an average latitude between vessels .

If in a period of time t the vessels are in the same position it will mean that $\varphi_{g2} = \varphi_{o2}$, $\lambda_{g2} = \lambda_{o2}$. Then taking into account (1), (3) and (2), (4) we can put it as:

$$\begin{aligned} &\varphi_{g1} + v_g t_\varphi \cos TA_g = \varphi_{o1} + v_o t_\varphi \cos TA_g \\ &\lambda_{g1} + v_g t_\lambda \sin TA_g \sec\varphi_m = \\ &= \lambda_{o1} + v_o t_\lambda \sin TA_o \sec\varphi_m \end{aligned} \quad (5)$$

In equations (5) we provided the value t with indices "φ" and "λ" to indicate the time of vessels' reach the same latitude and longitude.

Equations (5) follows:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g \cos TA_g - v_o \cos TA_o} \quad (6)$$

$$t_\lambda = \frac{\lambda_{t1} - \lambda_{o1}}{(v_g \sin TA_g - v_o \sin TA_o)\sec\varphi_m}. \quad (7)$$

If $t_\varphi = t_\lambda$, that is the vessels reach the same position simultaneously, the collision is unavoidable.

The value of $t_\varphi = t_\lambda$ then helps to obtain the time of meeting. If $t_\varphi \neq t_\lambda$, the vessels are not able to reach the same latitude and longitude simultaneously, that is they are not able to be in the same position and their meeting is impossible.

3 INDIVIDUAL CASES OF THE GIVEN METHOD

The analysis of (6) and (7) shows:

1 In head-on situation when vessels run the longitude they will reach the same latitude (meet) in a period of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g + v_o}$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

2 When vessels run the longitude the same track one after another they will reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

However, if $v_g < v_o$, vessels will reach the same latitude in a period of time equal to:

$$t_\varphi = -\frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

This will mean that the speed of the given vessel is lower than the speed of the target vessel.

Or, if $v_g = v_o$, vessels will reach the same latitude in a period of time equal to:

$$t_\varphi = \infty$$

and reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0} .$$

This will mean that that the speeds of vessels are equal.

3 In head-on situation when vessels run the latitude they will reach the same longitude (meet) in a period of time equal to:

$$t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sec\varphi_m}$$

and reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{0}{0}$$

4 When vessels run the latitude the same track one after another they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{0}{0}$$

However, if $v_g < v_o$

$$t_\lambda = -\frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_\varphi = \frac{0}{0}$$

It will mean that the given vessel is moving more slowly than the target vessel.
Or, if $v_g = v_o$

$$t_\varphi = \infty$$

and they will reach the same longitude in a period of time equal to:

$$t_\lambda = \frac{0}{0}$$

This will mean that that the speeds of vessels are equal.

5 When vessels run different longitudes on reciprocal tracks they will reach the same latitude in a period of time equal to

$$t_{\varphi} = \frac{\varphi_{o1} - \varphi_{g1}}{v_g + v_o}$$

and they will reach the same longitude in a period of time equal to:

$$t_{\lambda} = \infty$$

6 When vessels run different longitudes on the same track they will reach the same latitude in a period of time equal to:

$$t_{\varphi} = \frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and they will reach the same longitude in a period of time equal to:

$$t_{\lambda} = \infty$$

However, if $v_g < v_o$, vessels will reach the same latitude in a period of time equal to

$$t_{\varphi} = -\frac{\varphi_{o1} - \varphi_{g1}}{v_g - v_o}$$

and they will reach the same longitude in a period of time equal to

$$t_{\lambda} = \infty$$

It will mean that the given vessel is moving more slowly than the target vessel.
If $v_o = v_g$, vessels will reach the same latitude in a period of time equal to:

$$t_{\varphi} = \infty$$

and they will reach the same longitude in a period of time equal to:

$$t_{\lambda} = \infty$$

This will mean that that the speeds of vessels are equal.

7 When vessels run different latitudes on reciprocal tracks they will reach the same longitude in a period of time equal to:

$$t_{\lambda} = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_{\varphi} = \infty$$

8 When vessels run different latitudes on the same track they will reach the same longitude in a period of time equal to:

$$t_{\lambda} = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_{\varphi} = \infty$$

However, if $v_g < v_o$, vessels will reach the same longitude in a period of time equal to:

$$t_{\lambda} = -\frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sec\varphi_m}$$

and they will reach the same latitude in a period of time equal to:

$$t_{\varphi} = \infty$$

It will mean that the given vessel is moving more slowly than the target vessel.
If $v_g = v_o$, vessels will reach the same longitude in a period of time equal to:

$$t_{\lambda} = \infty$$

and they will reach the same latitude in a period of time equal to:

$$t_{\varphi} = \infty$$

This will mean that that the speeds of vessels are equal.

9 When vessels meet head and head on reciprocal arbitrary tracks, they will reach the point of meeting in a period of time equal to:

$$t_{\varphi} = \frac{\varphi_{o1} - \varphi_{g1}}{(v_g + v_o)\cos TA_g} =$$

$$= t_{\lambda} = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sin TA_g \sec\varphi_m}$$

10 When the vessels run the same arbitrary tracks they will reach the point of meeting in a period of time equal to:

$$t_{\varphi} = \frac{\varphi_{o1} - \varphi_{g1}}{(v_g - v_o)\cos TA_g} = \; =$$

$$t_{\lambda} = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sin TA_g \cos\varphi_m}$$

However, if $v_g < v_o$, vessels will reach the point of meeting in a period of time equal to:

$$t_{\varphi} = -\frac{\varphi_{o1} - \varphi_{g1}}{(v_g - v_o)\cos TA_g} = $$
$$=$$
$$t_{\lambda} = -\frac{\lambda_{o1} - \lambda_{g1}}{(v_g - v_o)\sin TA_g \ \sec\varphi_m}$$

It will mean that the given vessel is moving more slowly than the target vessel.

If $v_g=v_o$, vessels will reach the point of meeting in a period of time equal to:

$$t_{\varphi} = \infty$$

$$t_{\lambda} = \infty$$

This will mean that that the speeds of vessels are equal.

11 When vessels run reciprocal arbitrary parallel tracks, they will reach the same latitude in a period of time equal to:

$$t_{\varphi} = \frac{\varphi_{o1} - \varphi_{g1}}{(v_g + v_o)\cos TA_g}$$

and they will reach the same longitude in a period of time equal to:

$$t_{\lambda} = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g + v_o)\sin TA_g \ \sec\varphi_m},$$

however, there is always inequality $t_{\varphi} \neq t_{\lambda}$.

12 When vessels run the same arbitrary parallel tracks the times of their reach to the same latitude and the same longitude in general case is calculated by formulas (6) and (7). Here we can speak about different combinations of values t_{φ} and t_{λ} depending on relation of speeds ($v_g<v_o$, $v_g>v_o$, $v_g=v_o$), vessels' position at the time instant t_1 ($\varphi_{g1} > \varphi_{o1}$ or $\varphi_{g1} < \varphi_{o1}$, $\lambda_{g1} > \lambda_{o1}$ or $\lambda_{g1} < \lambda_{o1}$) and values of track angles TA.

In this case negativity of one of the times and positivity of another or negativity of the both times mean that vessels will never reach the same latitude ($-t_{\varphi}$) or the same longitude ($-t_{\lambda}$), or will never reach the same latitude or the same longitude ($-t_{\varphi}$ and $-t_{\lambda}$)

13 When vessels run arbitrary tracks the time of their approach to the same latitude and the same longitude is calculated by formulas (6) and (7). If $t_{\varphi} = t_{\lambda}$, it will mean that vessels are going to meet; but if $t_{\varphi} \neq t_{\lambda}$ they will not meet.

14 When vessels run arbitrary tracks there can be situations when $t_{\varphi}=0$ and $t_{\lambda} \neq 0$, or vice versa, t_{λ} = =0 and $t_{\varphi} \neq 0$, though vessels can simultaneously be at the same point. For example, it can happen when vessels at starting position are on the same latitude or the same longitude. Thus, if $\varphi_{g1} = \varphi_{o1}$, $\lambda_{g1} \neq \lambda_{o1}$ or $\varphi_{g1} \neq \varphi_{o1}$, $\lambda_{g1} = \lambda_{o1}$ and vessels run crossing tracks, (6) and (7) follow:

in the first case

$$t_{\varphi} = 0, \ t_{\lambda} = \frac{\lambda_{o1} - \lambda_{g1}}{(v_g \sin TA_g - v_o \sin TA_o)\sec\varphi_m};(8)$$

in the second case

$$t_{\varphi} = \frac{\varphi_{o1} - \varphi_{g1}}{v_g \cos TA_g - v_o \cos TA_o}, t_{\lambda} = 0, \qquad (9)$$

In both cases $t_{\varphi} \neq t_{\lambda}$, but meeting of vessels is not improbable. For example, if $\varphi_{g1} = \varphi_{o1} = 0^{O}$, $v_g=v_o$, $TA_g = TA_o \pm 90^{O}$, it is clear that vessels will meet despite the fact that $t_{\varphi} \neq t_{\lambda}$. In this case we can clear up the situation in the following way. By calculated value t_{λ}, if t_{φ} =0, or by calculated value t_{φ}, if t_{λ} = 0, are calculated by the formulas:

$$\varphi_{t2} = \varphi_{t1} + v_t t_{\lambda} \cos TA_t, \qquad (10)$$

$$\lambda_{t2} = \lambda_{t1} + v_t t_{\varphi} \sin TA_t \sec\varphi_m \qquad (11)$$

Then t_{φ} and t_{λ} are calculated by formulas:

$$t_{\varphi} = \frac{\varphi_{t2} - \varphi_{t1}}{v_o \cos TA_o}; \qquad (12)$$

$$t_{\lambda} = \frac{\lambda_{t2} - \lambda_{o1}}{v_o \sin TA_o \sec\varphi_m} \qquad (13)$$

If calculated values t_{φ} (12) or t_{λ} (13) are equal to

earlier calculated values t_{φ} (8) or t_{λ} (9), the vessels are going to meet. Otherwise they will not meet. For example, if $\varphi_{g1}=\varphi_{o1}=0^{O}$, $\lambda_{g1}=0^{O}$, λ_{g2}= =0°10′E, $\varphi_m=0^{O}$, $v_g=v_o=10$ *kts*, $TA_g=45^{O}$, $TA_o=315^{O}$, according to (8) t_{φ} =0, t_{λ} = 42 min 25.6 sec. In accordance with this value t_{λ} according formula (10) φ_{o2} = 0°05′N. Then according to (13) we have t_{λ} =42 min 25.6 sec. As $t_{\varphi} = t_{\lambda}$, the vessels in the given example are going to meet.

Similar example can be given for the case when $t_{\varphi} \neq 0$, and $t_{\lambda} = 0$. If φ_{g1} =0°05′N, φ_{o1} = 0°05′S, $\lambda_{g1} = \lambda_{o1} = 0^{O}$, $\varphi_m = 0^{O}$, $v_g=v_o$=15 kts, $TA_g=135^{O}$, $TA_o=45^{O}$, according to (8) and (9) t_{λ}=0, t_{φ}= =28min17.1sec. In accordance with this value t_{φ} by formula (11) is calculated λ_{o2} =0°05′E. Then according to (13) we have t_{λ} =28min 17.1sec. As $t_{\varphi}=t_{\lambda}$, the vessels in the given example are also going to meet.

4 CONCLUSION

It follows from the our analysis that:

1 The sign of the situation when vessels are meeting is the equality of the time of their reach to the same latitude or the same longitude in general case ($t_\varphi = t_\lambda$), or equality of uncertainty $\frac{0}{0}$ of one of the times of their approach the same latitude or longitude when the vessels run the latitude or longitude respectively

2 The sign of the situation when vessels run reciprocal parallel tracks in general case is inequality of times of their reach to the same latitude and longitude, both values of times being positive. The sign of the situation when vessels run reciprocal parallel tracks in particular case is infinity of times of their reach to the same latitude and longitude when running the latitude or longitude the target vessel is overtaking. If they are equal to infinity, vessels are moving at the same speed. At the same time if t_φ or t_λ are positive, the vessel is the given vessel is overtaking. If t_φ or t_λ are negative, the target vessel is overtaking. If $t_\varphi = \infty$ and $t_\lambda = \infty$, vessels are moving at the same speed.

3 The sign of the situation when vessels run the same parallel tracks in general case is inequality of times of their reach to the same latitude and longitude. If both values of the times are positive, the given vessel is overtaking. If they are negative, the target vessel is overtaking. If they are equal to infinity, vessels are moving at the same speed. At the same time if t_φ or t_λ are positive, the vessel is the given vessel is overtaking. If t_φ or t_λ are negativ, the target vessel is overtaking. If $t_\varphi = \infty$ and $t_\lambda = \infty$, vessels are moving at the same speed.

Realization of the non-traditional approach to clearing up the situation when vessels are meeting is possible with the help of automatic calculating device, information to which comes from AIS and results are presented in the form of messages on the display of ECDIS and in the form of warning sound signals about the threat of collision.

Non-traditional approach is in no way considered to be an alternative for the traditional way of assessment of head-on situation based on radar or AIS data and on making up relative plotting which allows to define a distance and shortest time of vessels meeting. We consider it to be an addition to the traditional method allowing to assess head-on situation in due time at distance between ships equal to operating distance of AIS (about 20 miles) without measurements and relative plotting, and consequently without distracting Officer of Watch from controlling the situation round the ship.

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