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An assessment of ship encounter situations based on predicted points of collision

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Abstract

A number of factors affect the safety of navigation, the collision of two ships being one of them. In ship encounter situations, certain principles of behaviour set forth by regulations are in force. Traditionally, a navigational situation is evaluated by identifying the closest point of approach for the passing ships and by comparing it with the assumed safe distance. Then it is necessary to use technical aids: radar and Arpa (depending on the regulations). In Arpa, navigational situation information is mainly presented in the form of vectors. The other presentation that can be used in an encounter situation is the predicted point of collision (PPC). This is the point or points toward which one's own ship should steer at her present speed (assuming that the target does not manoeuvre) in order for a collision to occur. This paper presents original results of a study into the assessment of ship encounter situations based on PPC. The methods (analytical and graphical) of PPC as a set of circles are elaborated and an analysis of a ship encounter situation performed.

Introduction

The navigator's principal task is to steer the ship safely and cost-effectively until it arrives at the port of destination. Safe navigation may be defined as the process in which undesired events have not occurred, i.e., marine or navigational accidents resulting in losses have not taken place. Among various kinds of loss, the most important ones are the loss of human life or health, damage to or loss of the ship and cargo, marine environment pollution or damage to port or navigational facilities. A number of factors affect the safety of navigation, a collision of two ships being one of them. Undoubtedly, the higher the traffic density, the more likely a collision. Traffic density is understood as the number of vessels in a given area. Restricted areas are a special type of navigational area, where the vessel density is higher due to such parameters as area depth and width. Consequently, distances between vessels decrease and collision probability becomes higher.

In open seas, vessels can choose any routes, and the choice is occasionally limited by hydrological and meteorological conditions (storms). Therefore, traffic density and the probability of collision should be incomparably lower than in restricted areas. However, this is not the case. Due to the requirement of effective ship conduct (route optimisation) and the fact that route optimisation is implemented by position identification systems (satellite navigational systems), in certain open sea areas vessel traffic becomes surprisingly dense.

In ship encounter situations certain principles of behaviour set forth by regulations are in force. Such situations become critical in restricted visibility. Then it is necessary to use technical aids: radar and Arpa (depending on the regulations). These allow evaluation of a situation regarding a possible collision of ships. The evaluation requires a radar plot to provide a navigator with a set of data on the encounter situation. Traditionally, a navigational situation is evaluated by identifying the closest point of approach for the passing ships and by comparing it with the assumed safe distance.

If this condition is not satisfied, then a state of hazard exists, i.e. a state that may lead to a dangerous state, i.e. a collision. If this is the case, the navigator should take action to restore a safe state, i.e. a state in which two ships are capable of passing each other at a safe distance (Zhao-Lin, 1984). To this end the navigator should plan a collision avoiding manoeuvre by using a set of data from a radar plot (course, real speed of the encountered ship and aspect) (Riggs, 1975). First, an adequate change in one's own ship's course and/or speed has to be determined. Before performing an intended manoeuvre, the navigator must ensure that it has been correctly determined, and that the manoeuvre will not make the situation worse in relation to other ships not currently in hazard.

The philosophy behind the evaluation of an encounter situation based on a radar plot has been transferred to the Arpa. Basically, navigational situation information is presented in the form of vectors (IMO, 1987; Bole, Dineley & Wall, 2005). The simulation capability (Trial) facilitates the navigator's task. It enables the verification of the effects of a planned collision avoidance manoeuvre, although in many situations it appears insufficient. This refers to situations where a number of ships are involved and the navigator in charge is not experienced. By using the trial-and-error method, they may lead their ship into a dangerous situation. Thus other methods of collision avoidance have been described. There have been analytical (Szałapczyński, 2009) and graphical approaches. Especially useful are those displaying the ship encounter situation based on the *predicted area of danger* (PAD) (Riggs, 1975; Bole, Dineley & Wall, 2005) and the *sector of danger* (SOD) (Lenart, 2010, 2015). This is due to the fact that, in this approach, the navigator concentrates on the assessment of an encounter situation not knowing what danger threatens them further away from the ship in question and from other ships in the vicinity.

Predicted points of collision (PPC)

The above problem can be solved by an analysis which uses PPC with encountered ships (Pedersen, Inoue & Tsugane, 2003; Bole, Dineley & Wall, 2005). The PPC can be defined as:

- a position in which a collision of ships may take place;
- a heading which the ship should steer maintaining its speed, which will lead to a collision.

The identification of a potential point of collision makes a qualitative change in the possibility of encounter situation assessment. Instead of enquiring whether the present parameters of one's own ship are leading to a hazard (dangerous situation), the navigator receives a response informing them what parameters will lead to a collision. Consequently, the phase in which the situation is evaluated and a collision avoiding manoeuvre is developed. According to the definition of PPC, the navigator knows which course is dangerous and can evaluate the situation by comparing it with the present course. If the situation is found to be dangerous, the navigator is able to alter course so that the situation becomes safe again. The knowledge of PPC brings a new quality in ship encounter assessment, as it allows:

- evaluation of an encounter situation in terms of possible collision;
- promptly working out a collision avoiding manoeuvre in relation to all the observed ships.

In an encounter situation at the moment t_o, the encountered ship is in position defined by its bearing and range (*NR*, *D*) determined in relation to one's own ship. If one's own ship proceeds at speed V_w along any course, and the encountered ship proceeds at speed V_0 along any course, then the positions of the two ships after time t will be found on the circles with radii proportional to their speeds. By transforming the polar co-ordinates system into the Cartesian system in which the origin is indicated by own ship's position and the vertical axis indicates north

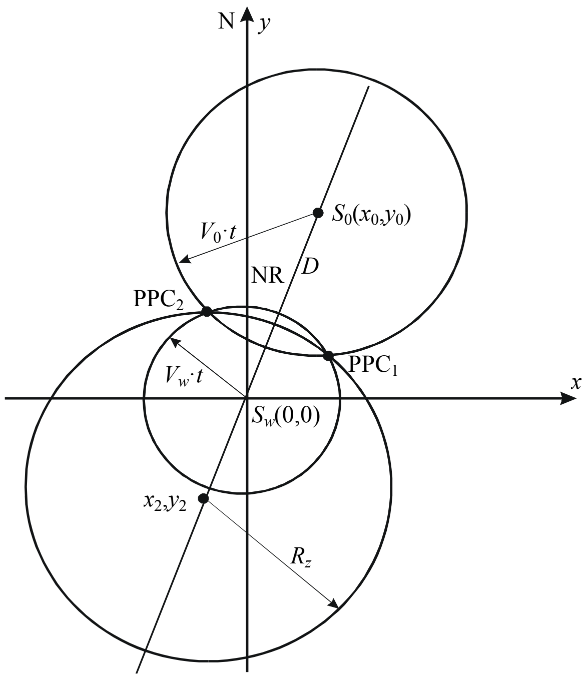

Figure 1. A ship encounter situation

(Figure 1), the equation of both ships' positions can be written as:

$$x^2 + y^2 = (V_w \cdot t)^2 \quad (1)$$

$$(x - x_0)^2 + (y - y_0)^2 = (V_0 \cdot t)^2 \quad (2)$$

where V_w is one's own ship's speed, V_0 the encountered ship's speed, x_0 and y_0 are encountered ship's position co-ordinates transformed from bearing and range and t is time counted from the moment of identifying the encountered ship's initial position.

It should be noted that as the time t increases, the radii of both ships' position circles will be increasing as well. At a certain moment the two circles will intersect. The points of intersection are potential points of collision.

The set of these points makes up a figure that may be determined by solving the system of equations (1 and 2). We assume that the ratio C of both ships' speeds is constant and equals:

$$C = \frac{V_0}{V_w} \quad (3)$$

Then, after transformations, we receive a circle described by the equation:

$$(x - x_R)^2 + (y - y_R)^2 = R_Z^2 \quad (4)$$

where x_R, y_R are co-ordinates of the centre of the circle PPC and R_Z is radius of the circle PPC.

The co-ordinates of the centre of the circle PPC can be calculated as:

$$x_R = \frac{x_0}{1 - C^2} \quad (5)$$

$$y_R = \frac{y_0}{1 - C^2} \quad (6)$$

and the radius of the circle PPC as:

$$R_Z = \left| \frac{CD}{1 - C^2} \right| \quad (7)$$

The above formula has been discussed in detail in Galor (1978).

Therefore, the set of potential points of collision of ships proceeding at constant speeds is a circle. The analysis of the properties of the circle (Galor, 1997) shows that:

- in an encounter situation of two ships they may choose such courses that there always is a possibility of collision;
- a set of potential points (positions) of collision is a circle with a known radius and position;
- the circle centre is always found on a line crossing the initial positions of the meeting ships;
- the radius of the circle depends on the relations between the two ships: it will increase if the ships' speeds are similar.

Figure 2 presents circles of potential points of collision for encountering ships with various speed ratios.

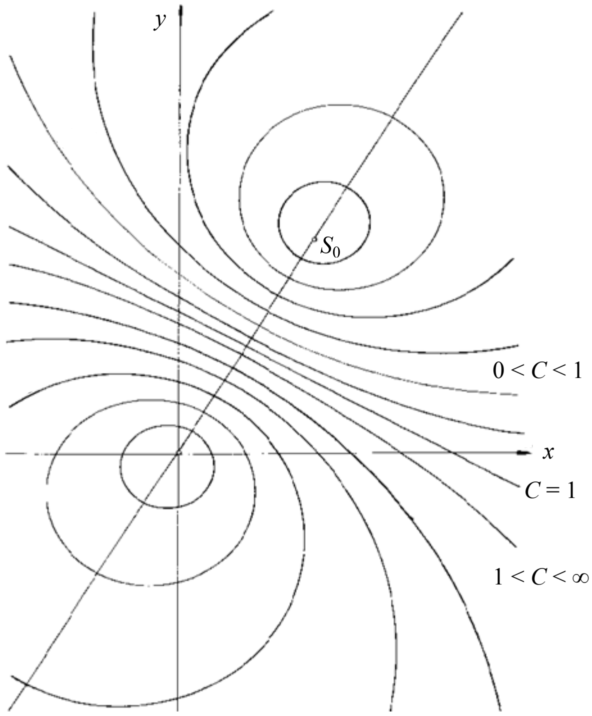

Figure 2. A network of circles defined by predicted points of collision

Analysing that situation we find that:

- when $C = 0$ (observed ship does not move) the circle of potential points of collision is in fact a point in the position of the observed ship;
- for values of C growing in the interval $(0,1\rangle$ i.e. when the speed of one's own ship is higher than that of the observed ship, the radius of the circle of potential points of collision increases, and its centre moves away from the position of the observed ship along the bearing line;
- when the speeds of both ships are equal ($C = 1$) the radius tends to the value ∞, while the circle changes into a line perpendicular to the bearing, running halfway between the two ships;
- for the value C on the interval $\langle 1, \infty)$ i.e. when the speed of one's own ship is lower than that of the observed ship, the circle radius decreases from the value ∞, and its centre gets closer to the position of one's own ship along the opposite bearing;
- for $C = \infty$, i.e. when one's own ship is not moving, the circle transforms into a point overlapping one's own ship's position.

In practice, in most cases ratios of the two ships' speeds (value C) do not constitute a large interval. In general, they are found on the (0.25–4) interval. This means that the navigator will meet ships proceeding slower or faster (in particular cases those proceeding at the same speed). Figures 3 and 4 illustrate the examples of encounter situations where the speed ratio is 2:1 and 1:2 (the encountered ship is moving, respectively, faster and more slowly than one's own ship). In the first case (Figure 3), if the course of the observed ship is found in the course sector ΔKR_0 bounded by the two lines tangent to the circle PPC, then a collision may happen in one (tangent line) or two points (PPC_1, PPC_2). Obviously, this will happen only if we choose the course of our ship so that it will intersect go through a potential point of collision. As the speeds of both ships tend to equality, the other potential point of collision will move farther and farther away.

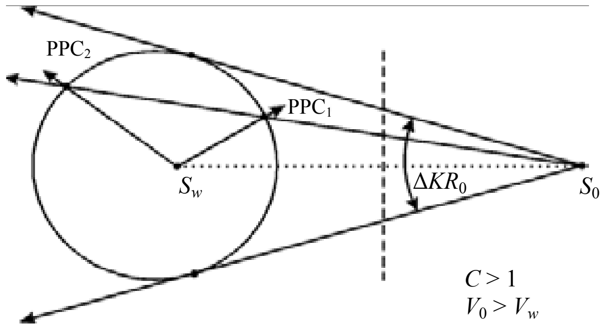

Figure 3. The observed ship's speed is higher than that of own ship

In the second case (Figure 4), regardless of the observed ship's course, there may be a collision if the own ship chooses a course in the ΔKR_w sector bounded by the line tangent to the circle PPC.

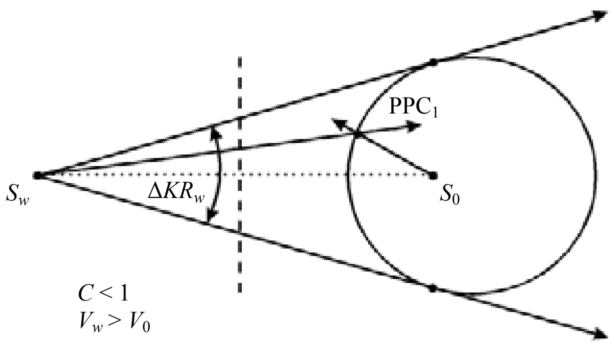

Figure 4. Own ship's speed is higher that of the observed ship

When the two speeds become equal ($V_0 = V_w$) the circle PPC transforms into a straight line (Figure 2). In this case a potential point of collision will be identified when the courses of both ships are included in sectors ±90° from the line of one's own ship's bearing or the observed ship's counter opposite bearing line.

Methods of PPC circle determination

It is convenient to use the Cartesian co-ordinate system instead of the navigational co-ordinates for calculations performed by computers. Simple analytical and graphical methods should be used by a navigator keeping watch on the bridge. PPC circles can be a basis for a simple method of calculating the circle parameters. To this end only one co-ordinate can be taken, i.e. range. That is because, regardless of the bearing on the observed ship, the circle PPC parameters depend on the initial range D. Consequently, the PPC circle parameters may be identified using (see Figure 5):

- position of its centre as the distance D_Z from own ship's position (on the line intersecting the positions of both ships);
- radius R_Z.

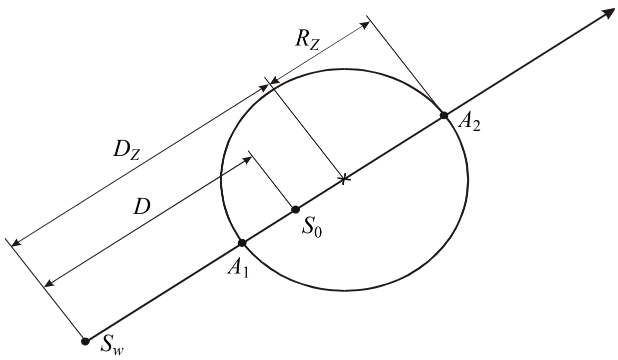

Figure 5. PPC circle parameters

The calculations aim at finding the points A_1 and A_2. These are respective potential points of collision that would happen if two ships were proceeding on courses opposite to each other (A_1) or conforming (A_2). The distance between the points A_1 and A_2 will be the diameter of the circle PPC; half the distance will be its radius. With these assumptions, the circle PPC has the following parameters:

$$D_Z = \frac{D}{1-C^2} \tag{8}$$

$$R_Z = \frac{DC}{1-C^2} \tag{9}$$

where D_Z is the distance between the centre of the PPC circle and one's own ship's position, R_Z is the radius of circle PPC and C is the ratio of the encountered ship's speed to one's own ship's speed.

In order to simplify the calculations, the graphical method can be employed, as illustrated on Figure 6.

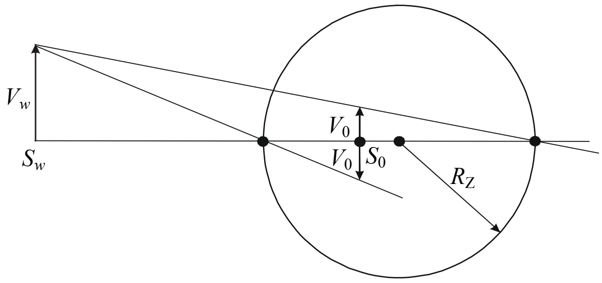

Figure 6. The graphical method of determining the PPC circle

In this method, ship speed vectors are drawn starting at their positions; both vectors are perpendicular to the line joining both positions. It will be noted that for the observed ship, the vector is laid out in both directions perpendicular to the position-joining line. By connecting the ends of speed vectors we obtain potential points of collision as follows:

- if speed vectors have a conforming direction, then the intersecting/crossing line joining the vectors with the line going through both ships' positions determines/indicates the extreme PPC corresponding to a situation when both ships proceed on the same course (one is following/running after the other);
- if speed vectors have opposite directions, then the intersection of a straight line joining these vectors and the line going through the ships' positions determines a potential point of collision when the two ships are proceeding on opposite courses.

Having determined the points corresponding to the diameter of the circle PPC, we can determine its centre D_Z as the distance relative to one's own ship position and radius R_Z.

Application of predicted points of collision

The determination of the PPC circle is based on the knowledge of ship's movement parameters. For an encounter situation, when the encountered ship proceeds on a specific course, the number of PPC may be two, one or zero (Galor, 1978). If PPCs are determined, we can define dangerous courses for one's own ship. If the present course of one's own ship is such that it will lead to a PPC, then there is a danger of collision. This feature can be used for displaying a navigational situation on an Arpa screen. However, the knowledge of potential points of collision is not sufficient for a full evaluation of an encounter situation. The determination of a PPC is burdened with errors due to the errors made while determining movement parameters of one's own and observed target ships. Besides, the navigator should leave themself a margin for safe passing, to account for such factors as ship size, type of cargo, visibility, kind of area etc. Consequently, passing the observed ship will be safe provided that the minimum passing distance D_B is maintained. To this end, a PPC can be surrounded by PAD. Methods for the determination of PAD are discussed in Galor (1997). Due to the complicated shape of the curve bounding that area, it is generally approximated to the shape of an ellipsis or hexagon.

Undoubtedly, the Arpa mode of presentation of information based on PPC and PAD is more convenient for a navigator than vector presentation. However, this method of navigational situation presentation is not commonly used for various reasons. It can only be found in the Arpa CAS Sperry (IMO, 1987). The limited use results basically from the official requirements (IMO Resolution A.823), according to which vector presentation is mandatory, while other methods can only be used as supplementary.

Conclusions

An analysis of a ship encounter situation by radar mainly uses radar plots. In Arpa units a situation is mainly presented with the use of vectors. The principal disadvantage of this method is that the situation has to be considered separately for each encountered ship. The navigator has to be highly experienced to plan effective collision avoiding manoeuvres. It is difficult to use even though there is a simulation option (Trial). The analysis of an encounter situation based on PPC enables the navigator to obtain information broadly describing a given situation. The application of the method in situation presentation in Arpa units provides an easy assessment of an encounter situation and presents the possibility of choosing the right collision avoidance manoeuvres.

The method is useful and should be promoted, as at present both training programmes and official recommendations do not draw much attention to it.

References

1. Bole, A., Dineley, W. & Wall, A. (2005) *Radar and Arpa Manual.* London: Elsevier.

2. Galor, W. (1978) *Sytuacja nadmiernego zbliżenia w ujęciu analitycznym.* Materiały Seminarium Naukowego WSM Szczecin.
3. Galor, W. (1997) *Model sytuacji spotkaniowej statków.* Materiały II Sympozjum Nawigacyjnego, Gdynia.
4. IMO (1987) *Radar Observation and Plotting*. Model Course 1.07.
5. Lenart, A. (2010) *Approach parameters in marine navigation. Theory and application*. Gdynia: Wyd. AM.
6. Lenart, A. (2015) Analysis of collision threat parameters and criteria. *Journal of Navigation* 68 (05). pp. 887–896.
7. Pedersen, E., Inoue, K. & Tsugane, M. (2003) Simulator studies on a collision avoidance display that facilitates efficient and precise assessment of evasive maneuvers in congested waterways. *Journal of Navigation* 56 (03). pp. 411–427.
8. Riggs, R. (1975) A modern avoidance display technique. *Journal of Navigation* 28 (2). pp. 143–155.
9. Szłapczyński, R. (2009) *Numerical algorithm of planning safe ship trajectory for Arpa system*. Gdańsk: Wyd. PG.
10. Zhao-Lin, W. (1984) Quantification of Action to Avoid Collision. *Journal of Navigation* 37 (03). pp. 420–430.