Dependence of the elements of relative movement on the true parameters of the movement of ships

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Abstract. The article describes the dependence of the elements of relative motion on the true elements of the movement of ships. Complete information about the situation can be determined only after analyzing the true movement of ships and their relative convergence. To introduce a relative plotter of the analyzed situation, we use the same radar measurements that were carried out when determining the parameters of true motion. In this case, we represent the way to find the point of intersection of the vessel A with the course of the vessel B, taking into account that the position of the point of the closest approach and the intersection, the predicted period of time \( t_{ca} \) and \( t_{int} \) are calculated. The hazard level after any maneuver largely depends on the time of its execution.

Keywords: in a vector expression, certain courses and speeds, line of relative movement, line of true movement, the hazard level.

1. Introduction

This article is developed at the navigation training complex Polaris (Norway) of the Caspian University of Technology and Engineering named after Sh. Yessenov, by Doctor of Technical Sciences, Professor of the Maritime Academy Zh.Zhumaev, relying on the joint work of the second mate on the tanker "Marlin Marshall" of Columbia Shipmanagement K. Zh. Zhumaeva (Fig. 1.) [1].

This article has been prepared as additional material for navigators dealing with the radar simulator in the course "Radar observation and laying". It can be used on ships both for self-training and for training navigators at maritime academies.

The article consists of an addition to the main course and recommendations on the use of ship radars to prevent collisions of ships and shows the dependence of the elements of relative movement on the true parameters of the movement of ships.

The material shows the dependence of the elements of relative movement on the true parameters of the movement of ships.
The experience of working on the radar training complex has shown that the level of the navigator's competence in processing and using information largely depends on a deep understanding of the very process of movement of ships relative to each other in direction and time.

The goal is the increasing of navigator's understanding of this process. The ability to describe it in vector terms determines the quality of graphic constructions on maneuvering or mirror boards when conducting radar plotting. Thus, the quality of programming the development of the situation in time from the beginning of its development to complete divergence improves the use of information from the automatic radar plotting system.

Under this condition, various factors which can positively or negatively affect the situation, are fully taken into account. The interpretation and application of the International Rules for the Prevention Collisions at Sea (COLREGs-72) are fully carried out both when assessing the situation and when choosing and justifying the type of maneuver [2].

2. The dependence of the elements of relative movement on the true elements of ship movement
Following a given course and speed, the navigator constantly receives information about the position of his vessel relative to the planned track. In this case, the navigation problem should be solved considering the navigation information.

If there are ships in the same water area, then a situation of their approach and the danger of collision may arise.

To avoid unwanted convergence, in addition to the navigation task, navigators must solve the problem of divergence with existing vessels. To solve this problem, certain information from the radar station (radar-ARPA) is required [3]:
- bearing and distance trends;
- time and distance of the closest approach,
- the perspective of the observed vessel and its position relative to the beam,
- other information to assist the navigator in complying with the COLREGs requirements i.e. disperse safely.

In good visibility, the divergence is "easier" to accomplish than in limited visibility as obtaining the required information is not complicated, and the COLREGs clearly define the responsibilities of each party. The divergence in limited visibility is associated with certain difficulties in obtaining the required information. In this case the source of the information is the radar, on the screen of which the environment is displayed in the form of echoes, the direction of movement of which depends on many components, as well as on the selected operating mode of the radar. In this case, the COLREGs are required from each of them to take such actions that will lead to a safe divergence.

There are several graphical methods for processing radar information to solve the divergence problem, the knowledge of which is mandatory for all navigators.
Before revealing the essence of these methods, it is necessary to dwell on the patterns of relative movement, which determines the movement of ships relative to each other (see Fig. 2). Figure 2 shows the true movement of vessels A and B.

Observing several local objects relatively certain, as landmarks, it is possible to determine the distance between the location of objects and their position on the ground. If you have a plan of the terrain or a satellite image in advance, you can scale the image to the observed landmarks, providing the tasks of visual control of the terrain, or geodetic measurements.

Both vessels follow certain courses and speeds to the buoy area. In good visibility, navigators can determine the perspective of the other vessel by eye and make sure that the courses intersect and are directed towards the buoy area. In addition, if the trend of change in the bearing is determined, it is easy to conclude that there is a danger of collision or the vessels will disperse cleanly.

If the bearing from one vessel to another does not change noticeably, this means that both vessels will arrive almost simultaneously at the same point in the area, i.e. there is a risk of collision.

If the bearing to another vessel changes towards the bow, it means that the other vessel is crossing the course of the observing vessel.

If the bearing changes to the stern, this means that the observed vessel will pass astern, i.e. the observer vessel has crossed or will cross the course of the observing vessel at its bow. The described information only partially reflects the picture of the approach of ships, because it shows only the presence of a collision hazard. It should be borne in mind that a change in bearing to the observed vessel, including radar bearing, indicates the absence of a collision, but does not exclude a situation of excessive approach.

Complete information about the situation can be determined only after analyzing the true movement of ships and their relative convergence.
3. True plotting
To determine the elements of the true movement of the observed vessel, it is enough to carry out a true plotting from the position of the observing vessel (Fig. 3).

The initial information in this case is the bearing and distance, determined at regular intervals \( \Delta t \), as well as the true movement line (TML) of the observer's vessel A (TML-A).

From the first point A1 on TML-A along the line of bearing P1, the distance D1 is plotted and the position B1 of the vessel B is fixed at the time of the first determination. During the period \( \Delta t \) of the vessel A moves to point A2. At this moment, the second measurements P2, D2 are performed and the second position B2 is fixed.

A line of the true movement of the vessel B TML-B is drawn through two points. The angle between the direction of the TML and the meridian is the course of the vessel B. The speed is determined by the length of the segment B1 and B2 traversed during the time \( \Delta t \).

From the stated above and Fig. 3 we can see that two determinations of the position of the vessel B are practically enough to determine the course \( (C_v) \) and speed \( (V_v) \) of the vessel B, as well as to predict its future position on TML-B in time.

The prediction shows that ship A will cross the course of ship B at time T (in the example, if \( \Delta t = 6 \) minutes, \( T = 17 \) minutes).

Further definition of P3, D3, P4, D4 clarifies the data obtained earlier. True plotting helps to determine \( C_v \) and \( V_v \), but does not show the movement of vessel B (observed vessel) relative to vessel A (observing vessel), i.e. does not give visual information about the approach of ships relative to each other.

To determine the situation of convergence, in addition to the course and speed of the observed vessel, it is necessary to know the following elements of relative movement:
- distance of the closest approach \( D_{ca} \);
- relative speed \( V_r \);
- the predicted time period until the closest approach \( t_{ca} \);
- the period of time before crossing the course \( t_{int} \).

All of these elements are identified using relative plotting.
4. Relative plotting

To conduct the relative plotting of the analyzed situation, we use the same radar measurements \( P_1 D_1, P_2 D_2, P_3 D_3, P_4 D_4 \), which were carried out when determining the parameters of true motion [4]. We should define the elements showing the movement of the vessel B relative to the vessel A (Fig. 4).

Distances \( D_1, D_2, D_3, D_4 \) are plotted from the point A which indicates the point of location of the vessel’s radar antenna, relative to which the movement of vessel B is determined, along the bearing lines \( P_1, P_2, P_3, P_4 \).

At the time of the first measurements, vessel B was relative to vessel A at point \( B_1 \), at the time of the old measurements it is already at point \( B/2 \), at the moment of the third at point \( B/3 \), at the moment of the fourth, and at point \( B/4 \).

A line drawn through points \( B_1, B/2, B/3, B/4 \) shows the direction of movement of the vessel B relative to the vessel A. This line is called the relative movement line (RML). The angle between the meridian and the directions of the RML is called the relative course \( C_r \).

The point of the shortest approach is determined by the perpendicular lowered from point A to the RML, its value \( AC \) shows the distance of the closest approach \( D_{ca} \) on the selected scale.

In Fig. 4 it can be seen that two points of definitions are sufficient for RML to predict the value of \( D_{ca} \), as well as the time period \( t_{ca} \), the time of movement of the vessel B from point \( B/2 \) to the point of the closest approach.

The time period \( t_{ca} \) can be calculated by the formula:

\[
t_{ca} = \Delta t \frac{B/2 C}{B_1 B_2} \quad \text{или} \quad t_{ca} = \frac{S_r}{V_r}
\]

(1)

where \( S_r \) is a relative course \( B/2 C \),

\( V_r \) is the relative speed, i.e. speed of movement of vessel B relative to vessel A.

\[
V_r = \frac{B_1 B_2}{\Delta t}
\]

(2)

where \( B_1 B_2 \) is a segment of the relative path of the vessel B for the selected interval \( \Delta t \) between the first and second definitions.

In practice, \( t_{ca} \) is calculated using a logarithmic scale or an approximate method using a meter.

Figure 5 shows the movement of ship A relative to ship B.

For plotting, the same distances \( D_1, D_2, D_3, D_4 \) were used, as well as reverse bearings \( RB_1, RB_2 \), etc. The plot shows a mirror projection of the relative situation that was observed from vessel A. In this case, the point where vessel A crosses the course of vessel B is clearly marked, while from the position of vessel A it is
impossible to determine the point of intersection of the course of vessel B from the position of vessel A without knowing course of the vessel B.

The verified analysis shows that the main elements characterizing the movement of the observed vessel B relative to the observing vessel A are the direction of the RML, the relative speed and the values $D_{ca}$ and $t_{ca}$ dependent on them, which determine the mutual hazard level for the vessels. The moment of the closest approach $T_{ca}$ is calculated by the formula:

$$T_{ca} = t_{ca} + \Delta t$$  \hspace{1cm} (3)

Additional information includes $t_{int}$ is the time of approach to the point of intersection of the course by vessel B.

This information depends on $V_r$ and the course of the observed B.

It should be emphasized that the definitions of $D_{ca}$ and $t_{ca}$ (the hazard level) are of primary interest to the navigator. There is no need to know the course and speed of the target vessel, as well as to use data on the movement elements of his own vessel. In other words, the navigator receives information about the hazard level by linear and time factors immediately, as soon as the vector of the relative speed of the observed vessel is plotted on the radar plate [5]. However, for complete information or a complete assessment of the situation and the possibility of the subsequent correct choice of maneuver for divergence. It is also necessary to determine the elements of the movement of target vessels, both dangerous and potentially dangerous. For a better understanding of the relationship between the elements of true and relative movement, we will conduct a joint analysis of the true and relative plotting of the above-described situation of the approach of vessels A and B.

![Fig. 5. Movement of vessel A relative to vessel B.](image)

Figure 6 combines the true and relative plotting of the situation of the approach of ships. Point B1 is the common point from which the LID and LOD of the vessel B.
The direction of the segment B1B2 of the line of true movement determines the course, and its value shows the path traveled by the vessel during the time \(\Delta t\), i.e. its speed. Based on these characteristics, we denote the segment B1B2 by the target speed vector \(V_c\). Since the direction of the segment B1B2, the lines of relative motion determine the relative heading, and its value shows the relative way of the ship B made during the same time \(\Delta t\), i.e. relative speed, then the segment B1B2/2 will be denoted by the vector of the relative speed \(V_r\).

Based on similar reasoning, the segment A1A2 of the line of the true movement of our vessel (observer) [6] will be denoted by the vector of our speed \(V_n\). Connecting point B2 with point B/2 with a line, we form a triangle B1B2 B/2. Since in the geometric four-sided figure A1 A2 B2 B/2 the sides A1 B/2 and A2 B2 corresponding to P2 D2 (from the true and relative spacers) are equal and parallel, then the other two sides A1 A2 and B / 2 B2 are also equal and parallel. That means that in the selected triangle side B/2 B2 is the vector of our speed \(V_n\).

Thus, in the selected triangle, all sides are designated as vectors \(V_c\), \(V_n\), \(V_r\), vectors characterizing both the elements of the true movement of our ship and the observed ship [7], and their relative approach. This proves that while conducting a relative plotting on the maneuvering tablet, to determine the elements of the movement of the target vessel, it is enough to apply the vector \(V_n\) parallel to the vector that is located at the center of the tablet and then connect the first point (beginning of \(V_r\)) with the end \(V_n\) from the second point of definitions (from the end of \(V_r\)). This segment will be \(V_c\), like the third side of the triangle. This kind of construction of a vector triangle is called inverse, the vectors \(V_n\) and \(V_c\), set aside by the movement of ships, converge at their ends at one point. Using similar reasoning, it is possible to construct a vector triangle in which the vectors \(V_n\) and \(V_c\) are drawn in the direction of the movement of ships and their origins are at the same point. Such a construction is called direct. In Figure 6, the triangle is shaded. \(T_r\) determine the elements of the true movement of the target \((C_c V_c)\) and calculate the maneuver for divergence, it is more convenient to use the direct construction of the vector triangle.

Figure 7 shows an example of a relative plotting with a direct vector triangle.
The initial situation shows the position of the vessel B (vector $V_b$), in the vector it moves relative to the vessel A. Knowing the position of $V_b$, the point where the vessel A crosses the course by the vessel B is determined. To get this information, line is drawn from the center of the tablet parallel to the vector $V_b$, before crossing with the RML. Thus, the point of intersection of the vessel A with the course of the vessel B is found. Taking into account the position of the point of the closest approach and crossing, the predicted time period $t_{ca}$ and $t_{int}$ are calculated. Applying any type of vector triangles to the tablet, the vector of relative velocity $V_r$ is always used as the main element of the relative plotting, which determines the hazard level. The vector triangle reveals the geometric dependence of the elements of the relative movement on the true elements of the movement of our ship and the target ship [8], since the direction and magnitude of either side of the triangle depend on the direction or magnitude of the other two sides and the angle $\beta$ between them.

Thus, we can make the main conclusion that:
- the direction and magnitude of the vector $V_b$ depend on the direction or magnitude of the vectors $V_c$ and $V_n$, i.e. on the courses and speeds of our and the target vessel;
- a change in any of these four elements of true movement (or several of them at the same time) during the development of a situation causes a change in the direction and magnitude of $V_r$, i.e. changes in the relative movement of ships, the direction of the RML and the value of $D_{ca}$, the relative speed and time of convergence change, i.e., the situation changes in direction or time, worsening or improving.

Let us examine several cases of changes in the elements of relative movement from changes in the elements of true movement. In Figure 8, our ship decreases its speed, i.e., the vector $V_n$ decreases and the vector of relative speed changes in direction and magnitude.
The value of $V_r$ tends to the value $V_c$. $V_r$ changing direction changes the direction of the boat with a tendency “from stern to bow” of our vessel. The relative position of the vessels changes markedly. The degree of change will largely depend on the moment of the maneuver [9].

Thus, if the speed of ship A is halved at the 6th minute, the RML₁ will cross the heading line, i.e. ship B will pass along the bow of ship A. The RML will change its direction by an angle $\alpha$. If this happens at the 12th minute, then an excessive convergence of ships is possible. If later, then the expected line of relative motion (ERML) will go up, but vessel B will pass along the stern of vessel A.

Figure 9 describes maneuvering from the position of ship B in a mirror projection.

The tendency of change in RML is reversed as it is “from bow to stern”.

Figure 10 shows the same maneuver in true plotting.
sufficiently large value. The value of $V_r$ decreases, the relative speed will also decrease, and the time for the approach of ships will increase.

Figure 11 shows that changes course of the vessel A towards the vessel B change the elements of the relative movement.

![Fig. 11. Changes of the elements of relative movement](image)

The angle $\alpha$ noticeably increases, the value of the relative speed increases, and the time of approach of the ships sharply decreases.

From the position of ship B, this maneuver will be noticeable immediately after it starts. In true plotting, the change in the course of ship A is also sharply noticeable (Fig. 12).

![Fig. 12. Changes in the course of ship A in true plotting](image)

The hazard level after any maneuver largely depends on the time of its execution [10].

5. Conclusion

The mutual hazard level of ships and magnitude of the vector $V_r$, the direction of the RML, $D_{sa}$ and $t_{sa}$, depend on the elements of true movement $C_n$ and $V_n$, $C_v$ and $V_v$. Therefore, any change in the magnitude and direction
of the vectors $V_n$ or $V_v$ will entail a change in the magnitude and direction of $V_r$ and, accordingly, the values
of $D_{ca}$ and $t_{ca}$. Having complete information about the degree of danger and elements of target movement, the
navigator can calculate his maneuver by changing the course (thereby changing the direction of the $V_n$ vector),
changing the speed (changing the magnitude of the $V_n$ vector) or changing the course and speed simultaneously
(changes the magnitude and direction of the $V_n$ vector). Any of these types of maneuvers can be effective
only with the right choice of maneuver and the divergence distance.

In order to have complete information about the situation and its further development, further studies will
be aimed at determining indicators of the effectiveness of maneuvers to avoid unwanted convergence of ships,
in order to have complete information about the situation and its further development.

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