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Original Article

Design of New Fuzzy System to Determine the Three-Zone around the Ship

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Abstract *- To maintain the safety of sailing, it is necessary to determine the relationship between the vessel and any obstacle that may appear on its way. This relationship is essentially the distance of the obstacle from the vessel. Therefore, it is very important to identify a zone or zones surrounding the ship that determine the location of the target for it to prevent the presence of any obstacle within it.*

In this research, a fuzzy system is designed to calculate the radius of three proposed zones, namely the forbidden, dangerous, and safe zone, based on human experience, considering the rules of COLREGS (International Regulations for Preventing Collisions at Sea). This system is Multi-Input Multi-Output (MIMO) and has three inputs: the length, speed of the vessel, and sea state; and it has three outputs that are the radius of the three zones (forbidden, dangerous and safe zones). The proposed system is adjustable according to the length and speed of the vessel and sea state. The system is designed and tested using MATLAB. The results were shown to marine experts, who said that they were good.

Keywords *- fuzzy system, collision avoidance, COLREGS.*

I. INTRODUCTION

Collision avoidance is an important issue for the International Maritime Organization (IMO), so it issued the International Regulations for Preventing Collisions at Sea in 1972 to guarantee a high level of safety at sea [1]. According to the agreement, ships must take other vessels into account and monitor their movements, taking advantage of their capabilities, whether visual, radar, or others, for the risk of collision. The agreement has determined that uncertainty about the risk of collision happening means that the danger exists, in which case the agreement regulates the relationship between the ships. The concept of risk includes two issues: the risk of collision or uncertainty and the other is the case when the ship is not maneuvering while it must maneuver to avoid the collision.

A collision is when the distance between two ships is less than the safety distance that must be kept free of any target [2]. There are many studies on the dimensions and the shapes of the safety zone. The zone has many shapes for the contour of the vessel, such as circles and ellipses, etc.[3]. The safety distance is determined as 2.5NM[4], while the Dimensions of this area were determined for a 261m long, 48-meter-width vessel with 11 knots at $2.04 \times 0.88NM$[5], and in [6], the dimension of the safe zone is 1.4 nmx0.37Nm. All studies reviewed identified the safe zone within 2.5NMand 1.4NM.In [7], the contour of the vessel is divided into only two safe and dangerous zones, but study [8]divided it into four sections: safety zone, deliberative collision zone, reactive collision zone, and forbidden zone.A fuzzy system was designed to find the radius of the safety zone, where the input was the sea state, the speed of the vessel, and its length [9], [10].

The safety zone was fixed dimensional for a single ship, but it varies from one ship to another and is assumed at the economic speed of the vessel [4], [5], [6], and [7]. A fuzzy system is designed to identify three zones around the ship in this research. The most important feature of this system is its ability to be adjustable according to the ship's speed, length, and sea state to increase ship safety during the sailing.

II. DANGEROUS AND SAFE ZONES OF THE SHIP

Identifying the dangerous and safe zones of the own ship is important to determine the risk of the targets (other ships) around it and to take the appropriate decision by the captain to maintain safety. Based on the COLREGS Rules, Rule 22 specifies the vision range of navigational lights according to the vessel's length [1]. It is defined as the maximum range of 6NM for ships with a length greater than 50 meters and a minimum of 2NM for less than 12 meters. There are also many classifications provided by several studies such as [8], [10], and [11], and taking into account, the expertise of the maritime experts consulted, their views were summed up below. It is theoretically possible that, in very simple cases, a collision avoidance maneuver can be delayed to prevent the target from reaching the limits of the forbidden zone (that is called the forbidden zone in this research) or contacting; these cases fit small-sized vessels, even medium speeds and regular sea states (called "gentle" in this research). However, in cases with medium- and large-sized vessels, large speeds, and dangerous sea states (called "rough" in this research), an early collision avoidance maneuver should begin to prevent the target from reaching the forbidden zone limits, especially in cases where the target must maneuver and not maneuver. This situation has happened for one of the two main reasons: a defect in the target vessel prevents it from controlling its course or poor experience and mistrust of the captain; in cases where there is no collision, there is no need to take any action. Therefore, an algorithm was proposed to identify three zones around the vessel that determine the risk of the target.

Fig. 1 shows the three proposed zones around the vessel. The first one is the forbidden zone with a "forb" radius, in which the presence of any target within it is prevented. The second is the danger zone with a "dang" radius, where the collision prevention maneuver should be carried out, whether maneuvering is due to the ship or the target. Finally, a safe zone with a "safe" radius where there is no need for any maneuver to avoid the collision is nil.

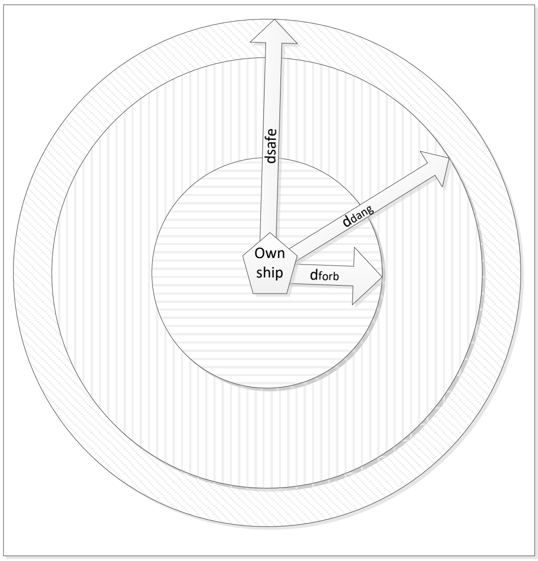

Fig. 1 The three proposed zones of the vessel: are forbidden, dangerous, and safe.

Fuzzy logic is used to determine these zones employing the proposed Safe and Dangerous Zoning System, based on

three parameters of input: the velocity of the vessel (v_o [knot]), the length of the vessel (L [m]), the state of the sea (U_{state}[Bal]).

III.FUZZY THREE ZONES IDENTIFICATION SYSTEM

The proposed fuzzy three zones identification system is shown in Fig.2.It has three inputs: sea state U_{state}[Bal], the length of the vessel L [m], and the sailing velocity of the vessel v_o[knot]; and it has three outputs: the radius of the forbidden zone$d_{for\,b}$, the radius of the danger zone d and the radius of the safe zone $_{d\,safe}$. As shown in Fig. 3 fuzzy sets of the input parameters, Fig.4 shows the fuzzy sets of the output. This system was built using Mamdani fuzzy inference system (FIS).

The first input sailing velocity of the vessel [v_o] has been divided into three fuzzy sets as suggested by the maritime experts consulted (Fig. 5).

1. The first set represents the slow speed and has been selected with a trapezoid; its range is [0-10] knot.
2. The second set***m*** represents the medium sailing velocity and has been selected with a trapezoid; its range is [5-25] knot.
3. The third set***f*** represents the fast sailing velocity and has been selected with a trapezoid; its range is [20-30] knot.

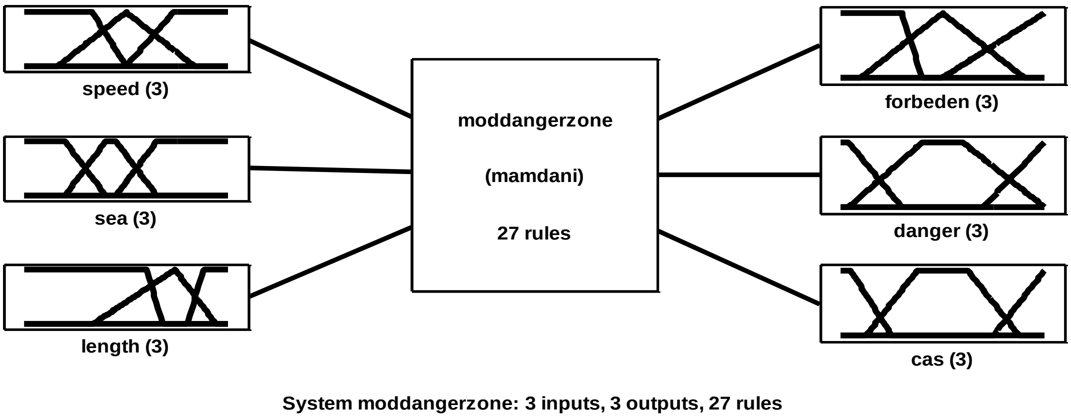

Fig. 2 Fuzzy Three Zones Identification System.

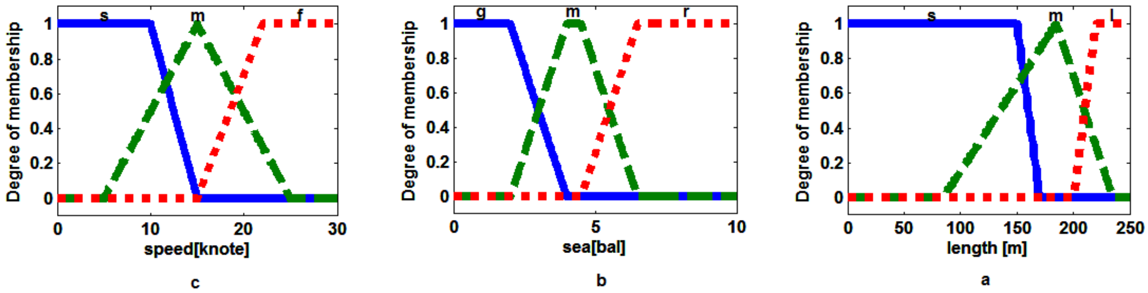

Fig. 3 Fuzzy sets of system inputs: a- Length of the vessel (L [m]), b- Sea state (U_{state} [Bal]), c- Sailing velocity of the vessel (v_o [knot]).

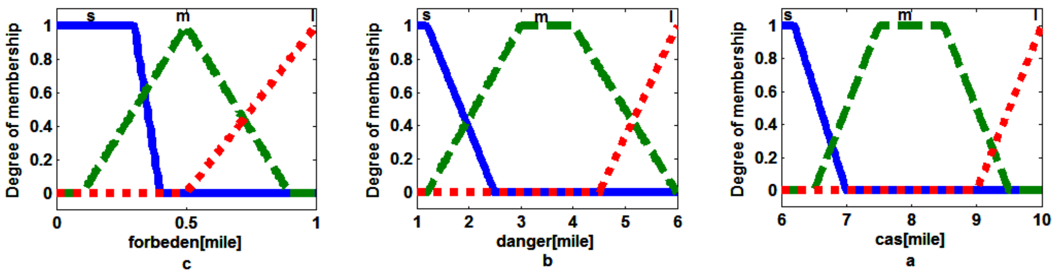

Fig. 4 Fuzzy sets of system outputs: a- Radius of the safe zone d_{safe}, b- Radius of the danger zone d_{dang}, c-Radius of the forbidden zone $d_{for\,b}$.

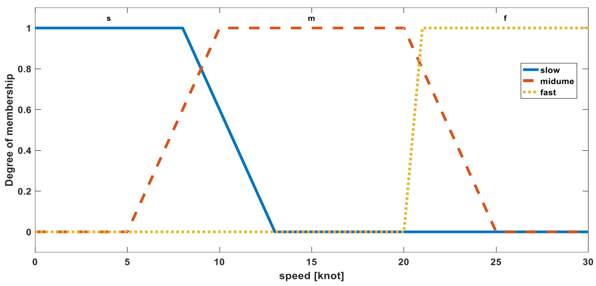

Fig. 5 the fuzzy sets of sailing velocity input.

The second input sea state U_{state}has is divided into three fuzzy sets (Fig. 6).

1.The first set***g*** represents the normal (gentle) state of the sea, which is considered the best case of the sea for sailing [9]; it has been selected with a trapezoid, and its range is [0-4] Bal.

2. The second set***m***represents a medium sea state with waves up to 3m, which is more difficult to sail, but it is possible [9]; it has been selected with a trapezoid, and its range is [2-6] Bal.

3.The third set, ***r*** represents the state of the rough sea, which is dangerous and prevents sailing [9]; it has been selected with a trapezoid, and its range is [4-10] Bal.

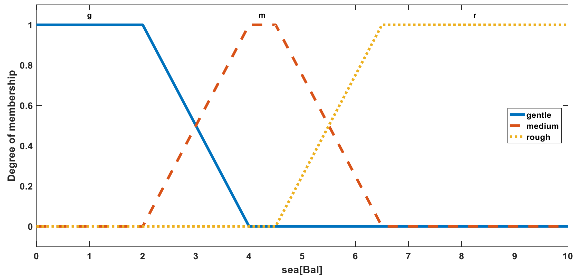

Fig. 6 Fuzzy sets of sea state input.

The third input length of the vessel L has divided into three fuzzy sets in Fig. 7.

1. The first set ***s*** represents the vessels whose length is up to 170m; it has been selected with a trapezoid; its range is [0-170] m.
2. The second set ***m*** represents the vessels whose length is between 85m to 230m; it has been selected with a triangle; its range is [85-230] m.
3. The third set, ***l*** represents the vessels whose length is between 200m to 250m; it has been selected with a trapezoid; its range is [200-250] m.

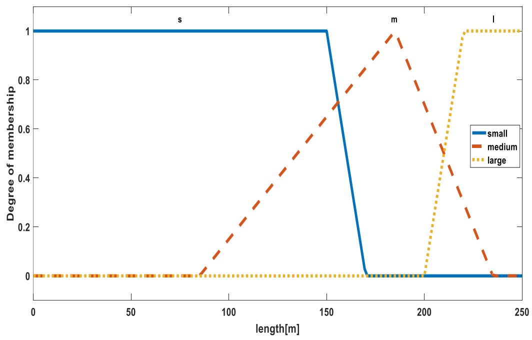

Fig. 7 Fuzzy sets of vessel length input.

The outputs of the system, which represent the radius of the three zones around the vessel (forbidden, danger, safe), are as follows.

The first output, the radius of the safe zone d_{safe}, has divided into three fuzzy sets in Fig. 8.

1.The first set (small): has been selected with a trapezoid; its range is [0-0.4] NM.

2.The second set***m*** (medium): has been selected with a triangle; its range is [0.1-0.9] NM.

3.The third set, ***l*** (large): it, has been selected with a triangle; its range is [0.5-1] NM.

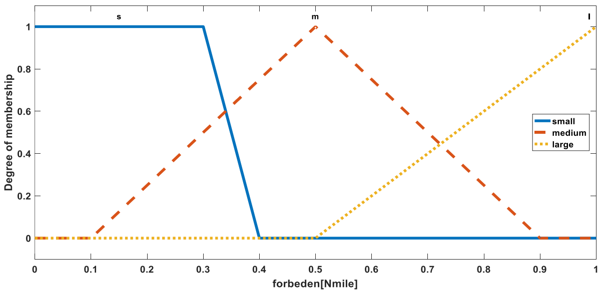

Fig. 8 Fuzzy sets of the radius of the safe zoned_{safe} output.

The second output, the radius of the danger zone d_{dang}, has been divided into three fuzzy sets in Fig. 9.

1.The first set (small): has been selected with a trapezoid; its range is [1-2.5] NM.

2.The second set***m*** (medium): has been selected with a trapezoid; its range is [1.2-6] NM.

3.The third set, ***l*** (large), has been selected with a triangle; its range is [4.5-6] NM.

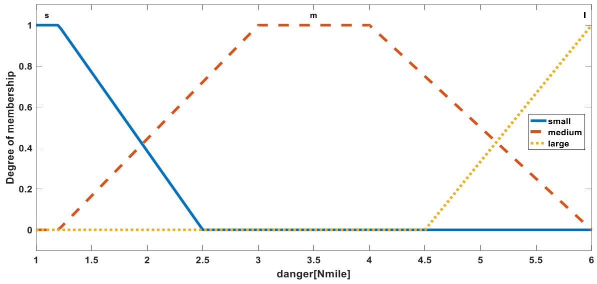

Fig. 9 Fuzzy sets of the radius of the danger zone d_{dang} output.

The third output, the radius of the safe zone d_{safe}, has divided into three fuzzy sets in Fig. 10.

1.The first set (small): has been selected with a trapezoid; its range is [6-7] NM.

2.The second set***m*** (medium): has been selected with a trapezoid; its range is [6.5-9.5] NM.

3.The third set, ***l*** (large): it, has been selected with a triangle; its range is [9-10] NM.

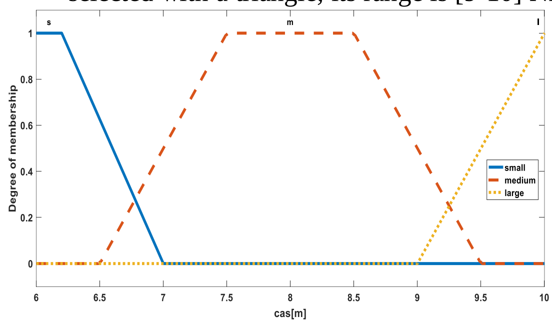

Fig. 10Fuzzy sets of the radius of the safe zone d_{safe} output.

The if..then expressions were used to build the rule base of the system, which is shown in the FAM Tables that are in tables 1, 2, and 3, each table for one output: forbidden, danger, and safe, respectively. The rule base consists of 27 rules depending on the human experts.

Table 1. fam table of forbidden radius zone output.

	Speed	**s**			**m**			**f**		
	Sea	**g**	**m**	**r**	**g**	**m**	**r**	**g**	**m**	**r**
length	**s**	s	m	m	s	l	l	m	l	l
	m	m	m	l	m	l	l	m	l	l
	l	m	l	l	m	l	l	l	l	l

Table 2. Fam table of danger radius zone output.

	speed	**s**			**m**			**F**		
	sea	**g**	**m**	**r**	**g**	**m**	**r**	**g**	**M**	**r**
length	**s**	s	m	m	s	m	l	m	M	l
	m	s	m	l	m	m	l	m	L	l
	l	m	l	l	m	l	l	m	L	l

Table 3. **Fam table of safe radius zone output.**

	speed	**s**			**m**			**F**		
	Sea	**g**	**m**	**r**	**g**	**m**	**r**	**g**	**m**	**r**
length	**s**	s	m	m	s	m	l	s	m	m
	m	s	m	l	m	m	l	m	m	l
	l	m	l	l	m	l	l	m	l	l

IV.RESULTS

The system has been tested for a specific vessel length that moves from slow to fast in various sea states. The vessel's length has changed according to the same scenario so that the lengths of the vessels range from small to large.

Fig. 11 shows the results of the system of a small vessel with a length of fewer than 50 meters (22m). Each line corresponds to a sea state of 1-10 Bal. The first column represents the radius of the forbidden zone related to speed, the second column represents the radius of the danger zone related to speed, and the third column represents the radius of the safe zone related to speed.

Fig.12 shows the results of the system for a medium vessel with a length of 85m. Each line corresponds to a sea state of 1-10 Bal. The first column represents the radius of the forbidden zone related to speed, the second column represents the radius of the danger zone related to speed, and the third column represents the radius of the safe zone related to speed.

Fig. 13 shows the results of the system for a large vessel with a length of 220 m. Each line corresponds to a sea state of 1-10 Bal. The first column represents the radius of the forbidden zone related to speed, the second column represents the radius of the danger zone related to speed, and the third column represents the radius of the safe zone related to speed.

Fig. 14 shows the three outputs of the system for100-meter vessel length and a 2Bal sea state. It can be seen how the dimensions of the forbidden zone change from 0.15NM (277.8m) at slow speeds up to 0.5NM (926m) at high speeds. The dimensions of the danger zone change from 1.1NM (2037.2m) at slow speeds up to 3.5NM (6,482m) at high speeds. The safe zone dimensions change from 6.1NM (11297.2m) at slow speeds to 8NM (14816M).

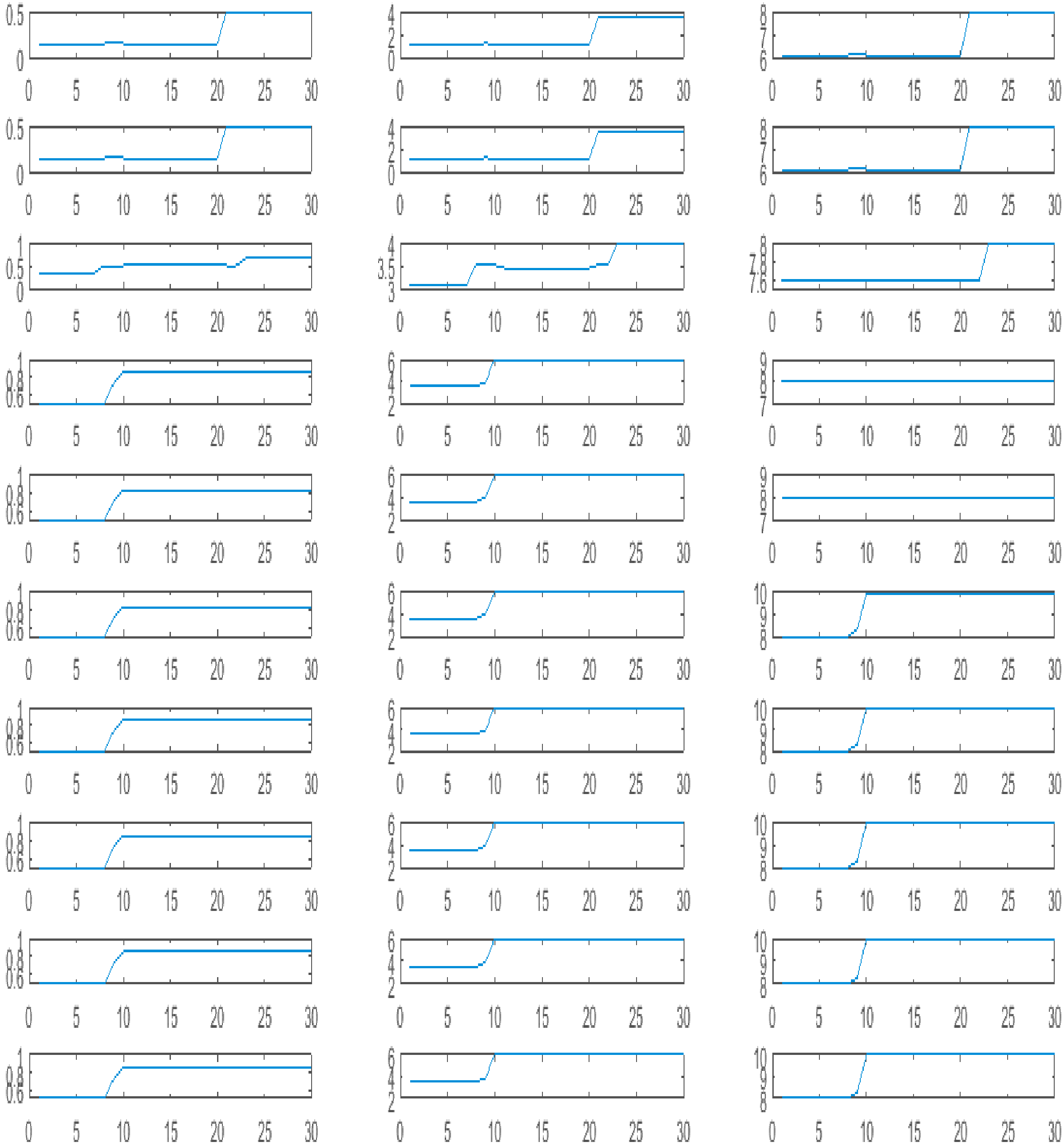

Fig. 11 Results of the system for small vessels (22 m).

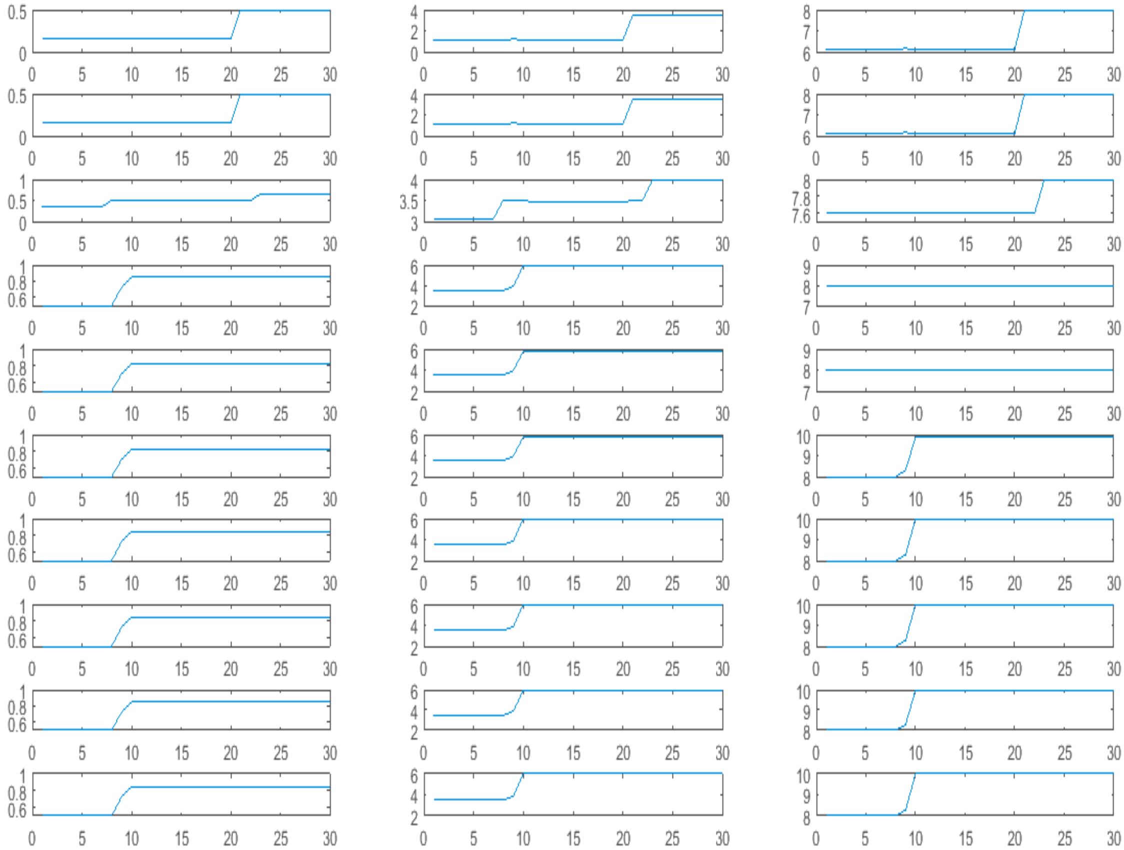

Fig. 12 Results of the system for medium vessel 85 m.

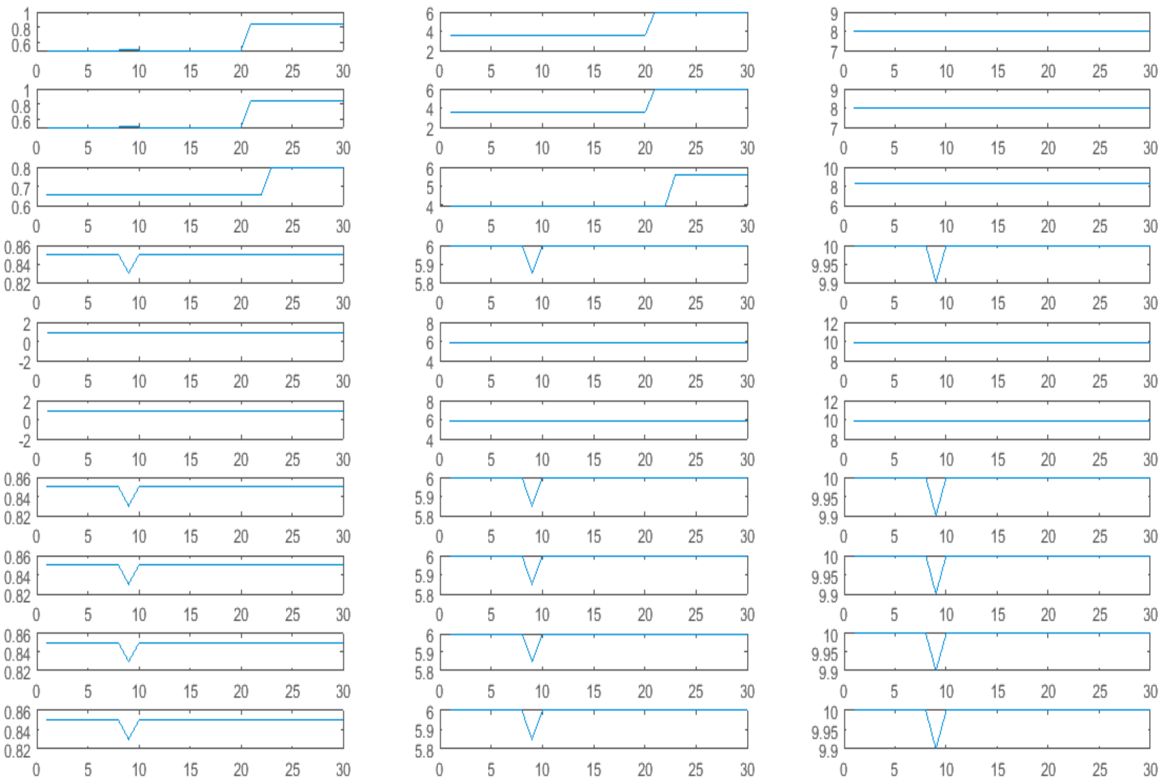

Fig. 13 Results of the system for large vessels (220m).

Fig. 15 shows the three outputs of the system for 100-meter vessel length and 5Bal sea state. It can be noticed how the dimensions of the forbidden zone change from 0.5NM (926m) at slow speeds up to 0.825NM (1527m) at high speeds. Also, the dimensions of the danger zone change from 3.5NM (6482m) at slow speeds up to 5.28NM(9772m) at high speeds, while the dimensions of the safe zone are fixed at 8NM (14816m).

Fig. 16 shows the three outputs of the system for 100-meter vessel length and 10Bal sea state. It shows how the dimensions of the forbidden zone change from 0.5NM (926m) at slow speeds up to 0.85NM (1542m) at high speeds. The dimensions of the danger zone change from 3.5NM (6482m) at slow speeds up to 6NM (11112m) at high speeds. The safe zone dimensions change from 8NM (14816m) at high speeds to 10NM (18520m).

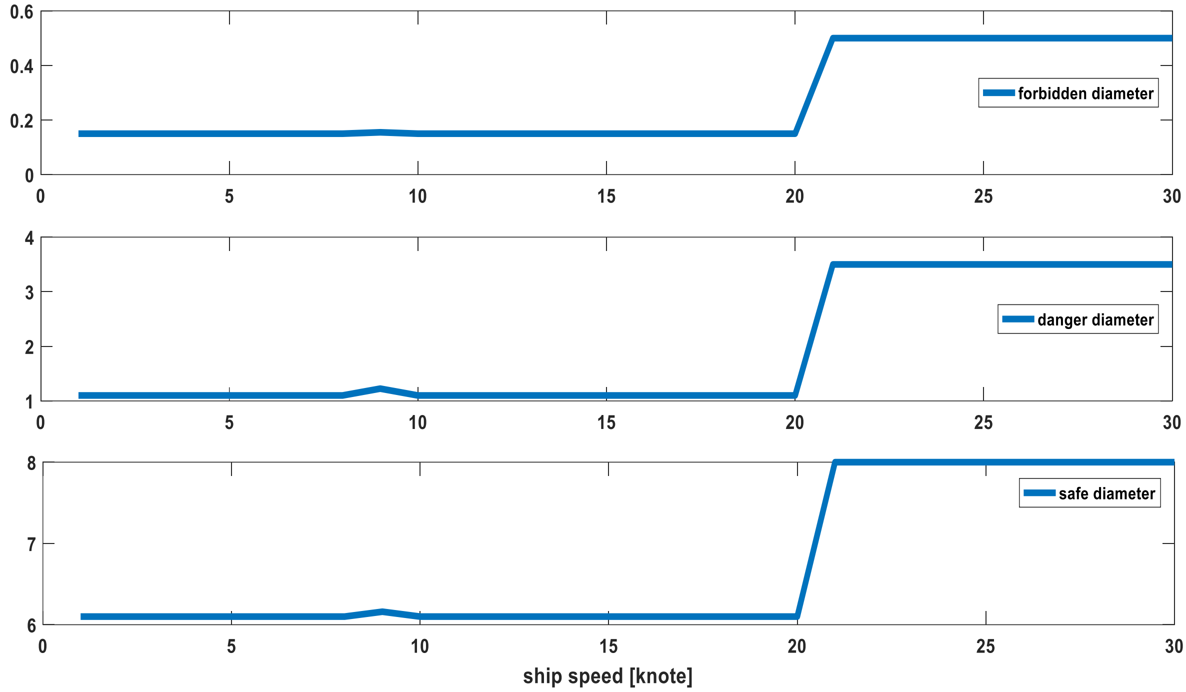

Fig. 14 The three outputs of 100 m vessel length and 2 Bal sea state.

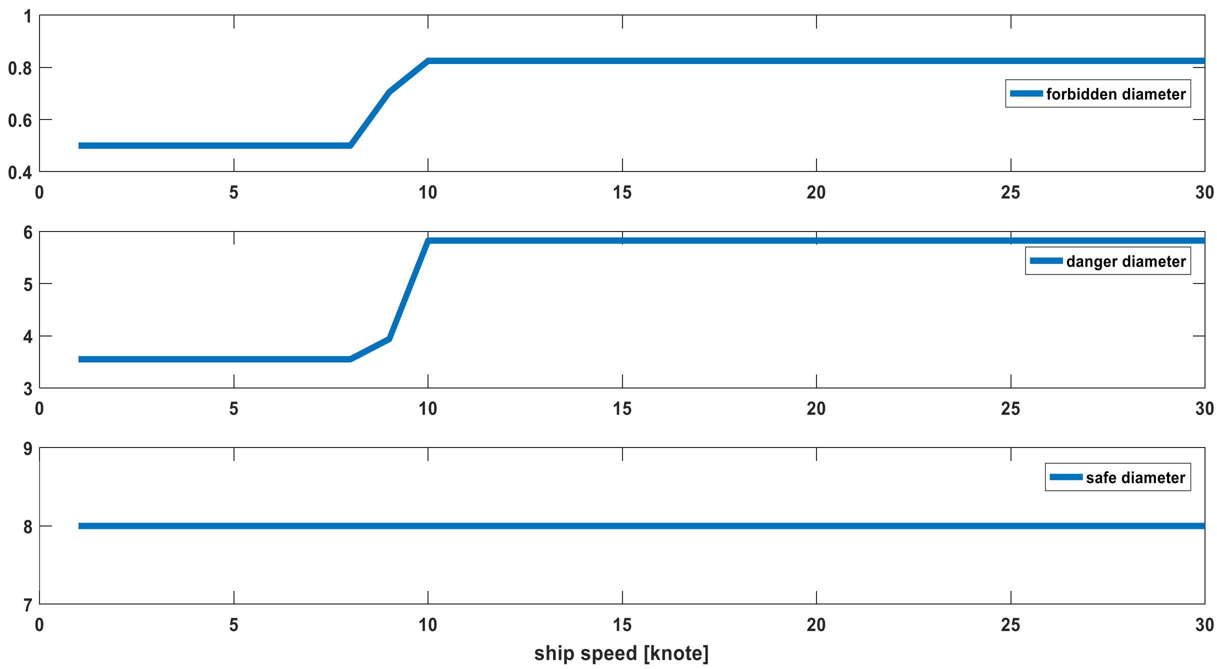

Fig. 15the three outputs of 100 m vessel length and 5 Bal sea state.

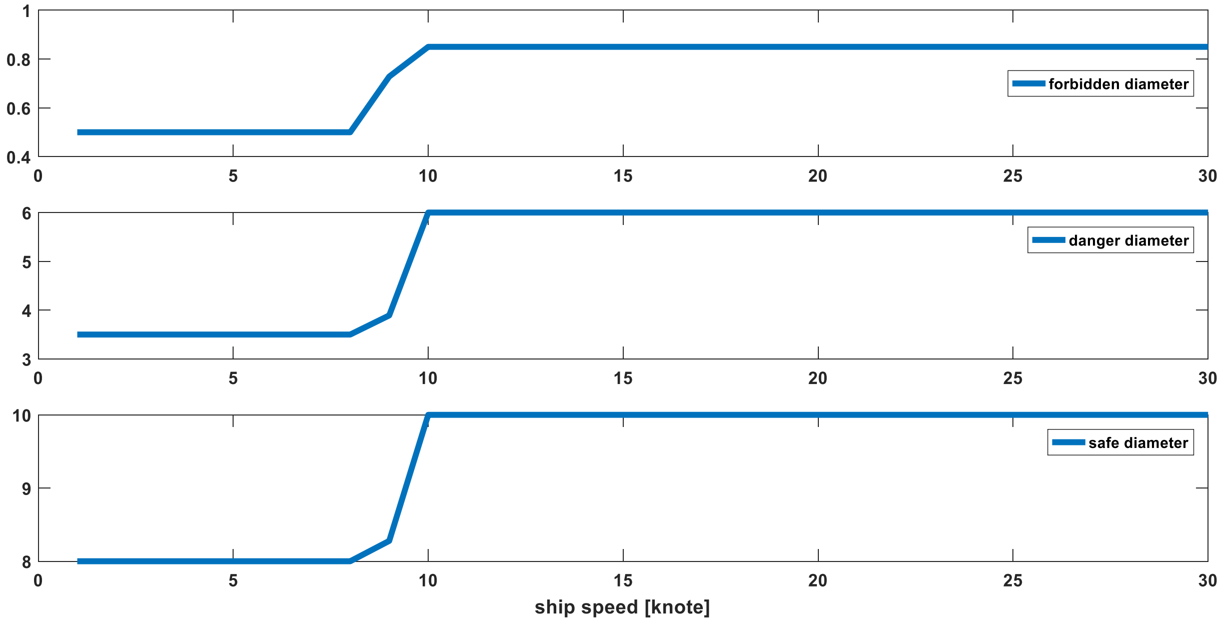

Fig. 16 The three outputs of 100 m vessel length and 10 Bal sea state.

Figs. 14, 15, and 16 show that the three zones around the vessel expand with sea state and vessel velocity increasing, and it also expands with the increase of vessel length, as shown in Figs. 11, 12, and 13. The distinctiveness of the proposed system is its capability to be adjusted according to sea state, vessel length, and sailing velocity depending on the human expert using fuzzy logic. Marine experts approved the results.

The maximum value of the forbidden zone radius for the proposed system is 1NM, equal to the radius in [10], where the system is designed to determine only the forbidden zone radius. At the same time, it was 2NM in [9].

For the proposed system, the maximum value of the danger zone radius is 5NM which is equal to the diameter of the forbidden zone in [7], where it divides the vessel contour into only two zones: danger and safe zones. While in [9] and [10], there was only one zone, the forbidden zone.

In the proposed system, the maximum value of the radius of the safe zone is 5NM which is defined as 10NM in [7], where the vessel contour was divided into only fixed two zones: danger and safe, that has the sizes: 5NM and 10NM for the danger zone and the safe zone, respectively.

The proposed system determined the radiuses of three zones in the contour of the vessel, which are the forbidden, danger, and safe zones. Its radiuses are adjustable to sea state, vessel length, and sailing velocity.

V. CONCLUSION

Most studies are concerned with only the forbidden zone. This zone was determined for a certain vessel with a fixed length and at the economic velocity of the vessel. The proposed system determines the radiuses of the three zones around the vessel. It is a MIMO (Multi Input Multi Output) system. It has three inputs (sea state, vessel length, and sailing velocity) to determine the three zones (forbidden, dangerous, safe) radiuses around the vessel. Therefore, the zones are related to sea state, vessel length, and sailing velocity. The proposed system is suitable for working with all the vessels, whatever their lengths and velocities, under all sea states.

The proposed system is designed to consider the marine expertise and the maritime rules to work well for all types of vessels in all sailing situations. The determination of safe and dangerous zone dimensions, apart from the short, direct vision or the long radar one related to the sea environment situation, will accurately determine the dangerous collision situations as soon as possible, which increases sailing safety, especially in the future rough sea state.

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