Building of Collision Avoidance Algorithm based on CBR

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Abstract

Ship's collision avoidance is a skill that masters of merchant marine vessels have acquired through years of experience and that makes them feel at ease to guide their ship out from danger quickly compared to inexperienced officers. Case based reasoning(CBR) uses the same technique in solving tasks that needs reference from variety of situations. CBR can render decision-making easier by retrieving past solutions from situations that are similar to the one at hand and make necessary adjustments in order to adapt them. In this paper, we propose to utilize the advantages of CBR in a support system for ship's collision avoidance while using fuzzy algorithm for its retrieval of similar navigational situations, stored in the casebase, thus avoiding the cumbersome tasks of creating a new solution each time a new situation is encountered. There will be two levels within the Fuzzy-CBR. The first level will identify the dangerous ships and index the new case. The second level will retrieve cases from casebase and adapt the solution to solve for the output. While CBR's accuracy depends on the efficient retrieval of possible solutions to be adapted from stored cases, fuzzy algorithm will improve the effectiveness of solving the similarity to a new case at hand.

Key Words : CBR, Fuzzy algorithm, Retrieve, Accuracy, Similarity

1. Introduction

There has been a number of instruments used to guide bridge officers to make decisions in avoiding collision whenever they are in congested areas. These navigational instruments like the RADAR-ARPA and ECDIS simply give the bridge officer an idea of what is happening, however, it is still up to him to decide based on his experiences, how to avoid collision.

There has been previous papers made, whose aim is to develop a system that would help avoid collision situations between ships[1,2]. They even have considered the International Regulations for Preventing Collisions at Sea in their proposed systems and used KT mathematical model for the simulation of ship maneuverability. On the other hand, case base reasoner (CBR)[8]with its advantages in retrieving and reusing past solutions from past cases have been applied successfully in other area of interest.

This paper will propose a new system using the advantages of CBR in retrieving past similar cases and adapting its solution to a present case while fuzzy logic will help solve the fuzziness that exist in every unique situation and explain the similarity as well as revising past solutions to be adapted that is lengthy to solve with mathematical methods. The output of this fuzzy CBR will be new heading to be taken by own ship (OS)[5,6,7].

There will be two levels inside the Fuzzy-CBR in retrieving and adapting old solutions from cases stored in the casebase (CB) which will be discussed further in Part 2 of this paper.

In Part 3, a situation will be presented involving multiple ships or targets making it complicated and time consuming for the bridge officer to use the mathematical method to avoid collision with other ships, than to act right away according to past knowledge acquired and applied to the present situation. This past knowledge are not always available for inexperienced bridge officers, newly hired, and left to decide on how a ship will be steered out of danger. It would then be helpful to be able to have a Fuzzy-CBR support system for ship's collision avoidance to assist an inexperienced bridge officer in the absence of an experienced bridge officer.

2. Ship's Collision Avoidance Support System Using Fuzzy-CBR

This Fuzzy-CBR support system will be using the advantages of CBR to retrieve cases similar to the navigational situation at hand and find the most similar case inside the CB, whose solution will be adapted or reused to the present navigational situation which is the new case. Fuzzy logic will be utilized in order to describe qualitatively such ambiguous linguistic values like "small" or "big" and "far" or "near" that can't be explained by classical logic. It

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will help make human-like decisions in the retrieval of cases stored inside the CB that would likely be having a solution adaptable to the new case. While all inputs will be taken into consideration, distance at closest point of approach (DCPA) will be an important input for it will determine whether the ship encountered will be in collision with OS if the right alteration of heading is not executed.

2.1 Interpretation of DCPA.

The DCPA is the input that will be implicated using the rule base inside the case base. While DCPA is the distance when OS is closest to the ship encountered, its numerical sign indicates which side of OS, the relative motion line (RML) will pass. Figure 1 shows the orientation of the encountered ship or target ship (TS) when it passes closest to OS. When DCPA is negative (-), their relative or apparent motion will be moving to the right towards OS. When the sign is positive (+), it will go apparently towards the left.

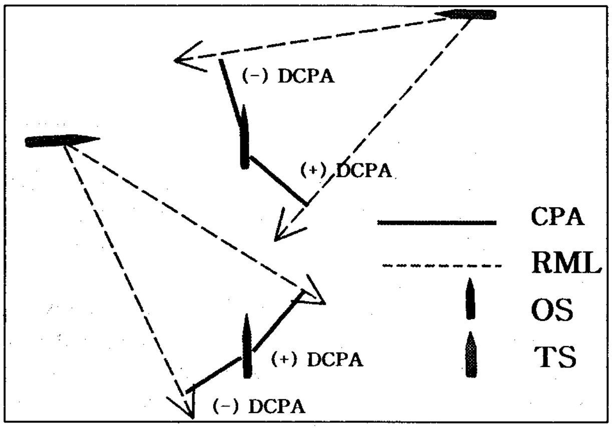

Figure 1. Interpretation of DCPA

2.2 Cases are stored inside the casebase.

The fuzzy inference, representing the cases stored inside the CB, used in this paper can be expressed as Multiple Input, Single Output(MISO) rule set which will have the following rule base[4].

R1 : IF X is A(1) and Y is B(1) THEN Z is C(1)
R2 : IF X is A(2) and Y is B(2) THEN Z is C(2)

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Rn : IF X is A(n) and Y is B(n) THEN Z is C(n)

A(1), A(2), ... , A(n) and B(1), B(2), ... , B(n) and C(1), C(2), ... , C(n) are fuzzy sets of linguistic terms of input variables X, Y and output variable Z. The expression is transformed into a fuzzy relations as follows

R = also (R1,R2, ... ,Rn)

The fuzzy sets used inside an "IF" clause express the DCPA from the most dangerous ships (Ship A and B) observed by OS. The output variable used in a "THEN" clause will give the new direction that OS will take to avoid collision representing the adapted solution.

This stored cases will serve as the acquired knowledge that the Fuzzy-CBR has and ready to be retrieved each time a similar case is encountered in the same way an experienced bridge officer has his acquired knowledge from past experiences.

Figure 2 and 3 shows how the cases, stored inside the CB, will look like in the real situation as well as their respective solutions which will be adapted to the new case and used to get the output.

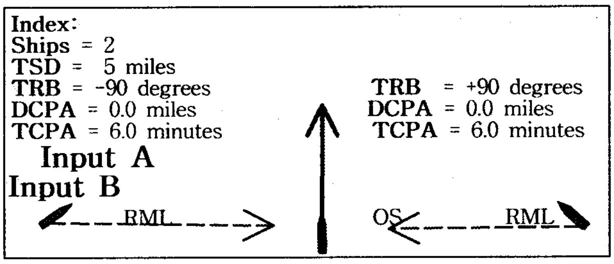

Figure 2. Case 1

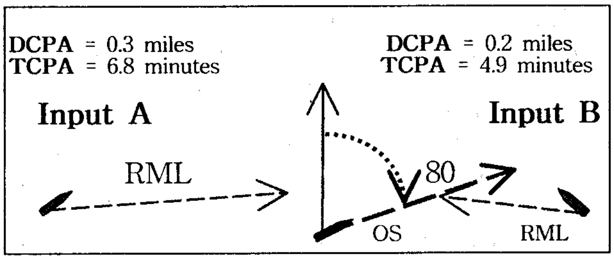

Figure 3. Solution to Case 1

2.3 Parameters of Fuzzy-CBR

TSD - Target ship's distance will be used for indexing in order to know in general the distance of OS away from the dangerous ships.

TRB - Target ship's relative bearing will help determine the type of approach of the dangerous ships as well as in adjusting the solution to be adapted by its similarity from the that in the case base.

TCPA - Time of CPA will be used to determine the CR of each vessel within the dangerous area. It is also used to adjust the solution to be adapted by finding its similarity from that in the case base.

DCPA - Distance at CPA will be used as a fuzzified input implicated by the rules in the case base to produce an adjusted output of new heading.

CR Collision Risk is the result of implicating the TCPA and TRB rules. I will indicate the degree of danger that an approaching ship poses to OS.

2.4 Structure of Fuzzy-CBR

The structure of this Fuzzy CBR will consist of two levels. These levels have specific components that are essential for the before we can adopt a solution for a new case. Figure 4 illustrates the data flow in our system.

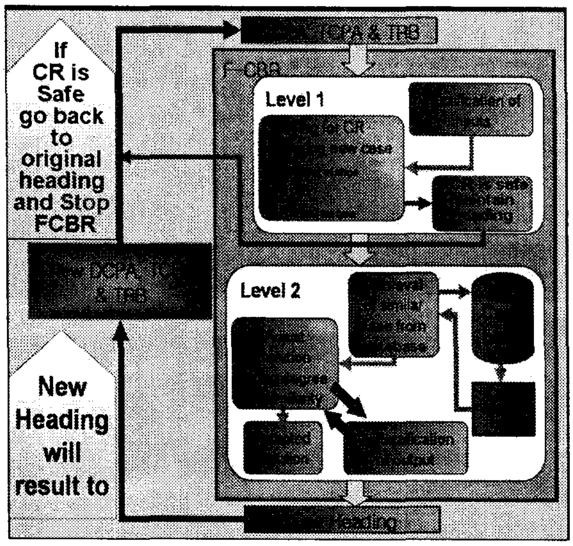

Figure 4. F-CBR Data Flow

2.4.1 In Level 1, the inputs DCPA and TCPA will be used to obtain the value of collision risk (CR) and the new case will be indexed. Indexing is essential for the efficient retrieval of similar case from CB. The input and output variables for the fuzzy rule in solving for CR is shown below:

$$(DCPA\ ,\ TCPA) \rightarrow CR\ .$$

It is expressed as a MISO which will have the rule base:

$$IF\,DCPA\ is\,X(1)\ \text{and}\ TCPA\ is\,Y(1)\ THEN\,CR\ is\,Z(1)$$
$$IF\,DCPA\ is\,X(2)\ \text{and}\ TCPA\ is\,Y(2)\ THEN\,CR\ is\,Z(2)$$
$$\vdots$$
$$IF\,DCPA\ is\,X(n)\ \text{and}\ TCPA\ is\,Y(n)\ THEN\,CR\ is\,Z(n)$$

Table 1. Reasoning rules of CR

		TCPA							
		SAN	**DAN**	**VDN**	**VDP**	**DAP**	**MEP**	**SAP**	**VSP**
D	**SAN**	SAN	SAN	SAN	SAP	SAP	VSP	VSP	VSP
C	**MEN**	SAN	MEN	DAN	DAP	MEP	SAP	VSP	VSP
	DAN	SAN	MEN	DAN	VDP	DAP	MEP	SAP	VSP
P	**MEP**	SAN	MEN	DAN	DAP	MEP	SAP	VSP	VSP
A	**SAP**	SAN	SAN	SAN	SAP	SAP	VSP	VSP	VSP

Where SAN=Safe Negative, MEN=Medium Negative, DAN=Dangerous Negative, VDP= Very Dangerous Positive, DAP= Dangerous Positive, MEP= Medium Positive, Safe Positive, VSP= Very Safe Positive

The new case as well as the cases inside the fuzzy-CBR are indexed for fuzzy and non fuzzy indices as follows:

a. No. of Ships (non fuzzy)
b. TSD (non fuzzy)
c. Type of encounter based on TRB.
   ex. * Right/Left (Both sides)
       * Left/left (All from left side)
       * Right/Right(All from right side)

2.4.2. In Level 2, cases similar to the new situation will be retrieved from CB. When a similar case have been retrieved, the DCPA will be the input in order to solve for the output which is the new heading to take by OS to avoid collision. The input and output variables for the fuzzy rule in solving for new heading (NH) is:

$$(DCPA_{(A)}\ ,\ TCPA_{(B)}) \rightarrow NH$$

$$IF\,DCPA_{(A)}\,is\,X(1)\ \text{and}\ DCPA_{(B)}\,is\,Y(1)\ THEN\,NH\,\mathbf{is}\,Z($$
$$IF\,DCPA_{(A)}\,is\,X(2)\ \text{and}\ DCPA_{(B)}\,is\,Y(2)\ THEN\,NH\,\mathbf{is}\,Z($$
$$\vdots$$
$$IF\,DCPA_{(A)}\,is\,X(n)\ \text{and}\ DCPA_{(B)}\,is\,Y(n)\ THEN\,NH\,\mathbf{is}\,Z($$

Table 2. Reasoning rules of New Heading

Case 1		DCPA (B)				
		SAN	**MEN**	**DAN**	**MEP**	**SAP**
D	**SAN**	ZE	SP	BP	ZE	ZE
C	**MEN**	ZE	SP	BP	ZE	ZE
P	**DAN**	BP	BP	BP	BP	BP
A	**MEP**	ZE	ZE	BP	SN	SN
(A)	**SAP**	ZE	SP	BP	SN	ZE

Where SAN = Safe Negative, MEN = Medium Negative, DAN = Dangerous, MEP = Medium Positive, SAP = Safe Positive, ZE= Zero, SP= Small positive, BP= Big positive, SN= Small Negative and BN= Big negative.

The crisp output is obtained by using the centroid technique. The crisp output is adjusted by the similarity of the attributes before adapting them. We calculate similarity with the equation like the one used by Watson[3], using TCPA and TRB as the attributes to adjust or adapting the output of the solution of the selected case.

$$\text{similarity}\ (T,S) = \sum_{i=1}^{n} f(T_i, S_i) \times w_i$$

where w is the importance weighting attribute of i, f is the similarity function, and T and S are the values for individual attribute i in the input and retrieved cases respectively. This solution will be used to produce the output.

The input for finding similarity by fuzzy inferencing used in this paper is the difference between T and S for every attribute i.

similarity input = $T_i - S_i$

The input and output variables for the fuzzy rule in solving for similarity (sim) is:

$$(T_i - S_i) \rightarrow sim$$

It is expressed as a sinle input single output (SISO) which will have the rule base:

$$IF(T_i - S_i)\ isX(1)\ THENsimisZ(1)$$
$$IF(T_i - S_i)\ isX(2)\ THENsimisZ(2)$$

.

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$$IF(T_i - S_i)\ isX(n)\ THENsimisZ(n)$$

Table3. Reasoning rules for similarity of attributes TCPA or TRB between New Case and CB

Difference in atrributes of TCPA or TRB										
[illegible]	BN	MN	SN	VSN	ZE	VSP	SP	MP	BP	VBP
[illegible]	[illegible]	MD	MS	SM	VS	SM	MS	MD	DF	VD
Similarity Factor										

Where VBN=Very Big Negative, BN=Big negative, MN=Medium Negative, SN=Small Negative, VSN=Very Small Negative, ZE=Zero, SP=Small Positive, MP= Medium positive,BP=Big Positive and VBP=Very Big Positive, VD=Very Different, DF=Different, MD= Medium Different, MS= Medium Similar, SM= Similar, and VS=Very Similar.

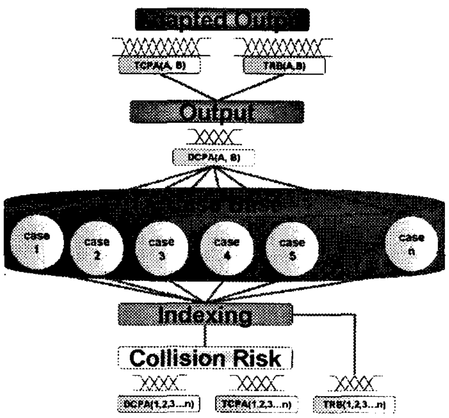

Fig. 5. The F-CBR structure

3. Adaptation of Fuzzy-CBR to a Collision Avoidance Problem

With the cases stored inside CB we will now show how the fuzzy-CBR will adapt past cases to new ones with the navigational situation that we will present.

Both examples will deal with two dangerous ships involved. While other ships may be in the vicinity the fuzzy-CBR will identify the most dangerous ships and adapt solutions from CB and use it to take a safer way away from the danger of collision with the other ships in the area

3.1 Problem with ships coming from both sides

Fig 6. Navigational traffic situation.

Table 4. Details of Ships in the vicinity

Ship A		**Ship B**	
TSCo	= 240 degrees		= 270 degrees
Speed	= 20 knots		= 15 knots
TSB	= 050 degrees		= 015 degrees
TSD	= 5.0 miles		= 6.0 miles
DCPA	= 0.89 miles		= -3.58 miles
TCPA	= 9.5 minutes		= 13.0 minutes
Ship C		**Ship D**	
TSCo	= 260 degrees		= 195 degrees
Speed	= 10 knots		= 25 knots
TSB	= 025 degrees		= 357 degrees
TSD	= 7.5 miles		= 9.0 miles
DCPA	= -1.73 miles		= -2.50 miles
TCPA	= 22.1 minutes		= 13.3 minutes
Ship E		**Ship F**	
TSCo	= 180 degrees		= 087 degrees
Speed	= 25 knots		= 37 knots
TSB	= 350 degrees		= 290 degrees
TSD	= 6.0 miles		= 7.0 miles
DCPA	= 1.41 miles		= 0.13 miles
TCPA	= 9.0 minutes		= 11.5 minutes

3.1.1 Solving for CR and indexing(Level 1)

With the navigational traffic situation in Figure 14, six ships were found within 10 miles from Own Ship (OS). Their deatails are shown in Table 2.

Collision risk (CR) was determined by the DCPA and TCPA as inputs while using fuzzy inference.

Collision risk indicates to what degree should we consider the dangerous targets.

After inferencing using fuzzy variables in Figure 5, 6, and 7 the ships were categorized according to their collision risk values. A CR value of 0 means it is the mos dangerous while 1 means it is very safe. In cases where collision risk values aie the same, DCPA is compared then TCPA. When values CR, DCPA and TCPA of more than two ships remain the same, the index of number of ships involved are increased.

Table 5. Ships categorized according to CR.

ShipF: CR = **DA** = **0.27**
ShipA: CR = **VS** = **0.80 (DCPA=0.898 miles)**
ShipE: CR = VS = 0.80 (DCPA=1.41 miles)
ShipC: CR = VS = 0.80(DCPA=-1.73 miles)
ShipD: CR = VS = 0.80(DCPA=-2.50 miles)
ShipB: CR = VS = 0.80(DCPA=-3.58 miles)

Based on Table 3, ships F and A are the most dangerous targets. The details of the two ships will be used for indexing as well as input of a new case in the fuzzy-CBR.

Input A = ShipF (DCPA, TCPA, TSD, TRD)
Input B = ShipA (DCPA, TCPA, TSD, TRD)

Indices of New Case:

New case: No. ships = 2 Type: Right/Left
TSD: 5 to 10 miles TRB: L -80 / R +40

Input A:	Input B
DCPA: = 0.13 miles	DCPA: = 0.89 miles
TCPA: = 11.5 minutes	TCPA: = 9.5 minutes
TSD: = 7.0 miles	TSD: = 5.0 miles
TRB: =-80 degrees	TRB: = 40 degrees

3.1.2. Retrieval of similar case and adaptation of solution (Level 2).

Only the similarity of attribute TCPA from the ship with the most dangerous CR and the similarity of the widest TRB among the dangerous targets will be used for adapting the solution.

Similar Case stored at Case-base (CB):
Case 1.No. ships = 2 Type: Right/Left
TSD: 5 to 10 miles TRB: L -90 / R +90

CB A:
TCPA: 6 minutes / weight = 0.2
TRB: -90 degrees / weight = 0.8

CB B:
TCPA: 6 minutes / weight = 0.2
TRB: 90 degrees / weight = 0.8
New case: No. ships = 2 Type: Both sides
TSD: 5 to 10 miles TRB: L 80 / R +50

Input A:

DCPA: = 0.13 miles
TCPA: = 11.5 minutes
difference in attributes= (11.5 - 6 = 5.5)
TRB: =-80 degrees
difference in attributes= (-90 - -80 = -10)

Input B
DCPA: = 0.89 miles, TCPA: = 9.5 minutes
TRB: = 50 degrees

Note: Input A has the most dangerous CR and widest TRD.

The similarity values after inferencing the difference in attributes using fuzzy variables in Fig 10,11,12 and 13 were:

DCPA sim = 0.91, TRB sim = 0.79

Take the sum of the similarities multiplied by the weights from Inputs A or B. TCPA was assigned with the weight value of 0.4 while TRB has the wight value of 0.6.

sim = DCPA sim x weight = 0.91 x 0.4 =0.36
sim = TRB sim x weight = 0.79 x 0.6 =0.47

Total similarity =0.83

This is equivalent to 83% similarity compared to the case from the CB which will be used as a factor for adjusting the result obtained from the CB solution to be adapted in the new case.

Find the affected rule with DCPA as input to similar case from CB and apply the intersection by fuzzy inferencing. The fuzzy rules are shown in Figures 8 and 9.

InputA: InputB:
DCPA: 0.13 miles DCPA: 0.89 miles

Take the union of the rules affected by the DCPAs of Input A and Input B we obtained the following results and take the centroid.

Output = 58.24 degrees

Use the total similarity obtained above.
Output x Total similarity = Adapted output
58.24 x 0.83 = 48.34 degrees

Adapted output +OS Heading = New Heading
48.34 + 10 = 58.34
New Heading = 58.34 degrees true

Applying the new heading to OS, we have the change of DCPA of Ship A & Ship F .

DCPA after Alteration to new heading:

Ship A:	New DCPA	= -0.76 miles
	Old DCPA	= 0.89 miles
Ship F:	New DCPA	= 0.93 miles
	Old DCPA	= 0.13 miles
Ship B:	New DCPA	= -4.90 miles
Ship C:	New DCPA	= -3.00 miles
Ship D:	New DCPA	= -5.10 miles
Ship E:	New DCPA	= -5.00 miles

The resulting DCPA, TCPA and TRB were again used as input to F-CBR until a safe CR result was obtained. Figures 7,8 and 9 shows the resulting track of own ship.

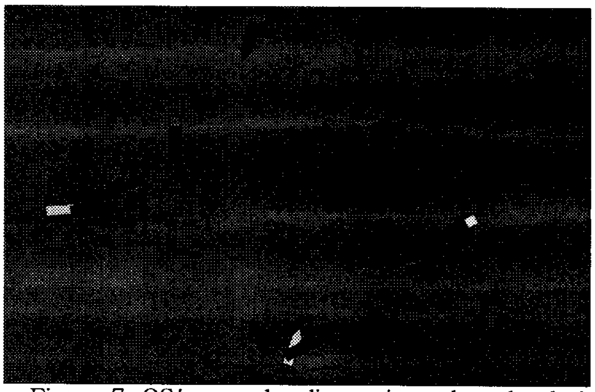

Figure 7. OS's new heading using adapted solution.

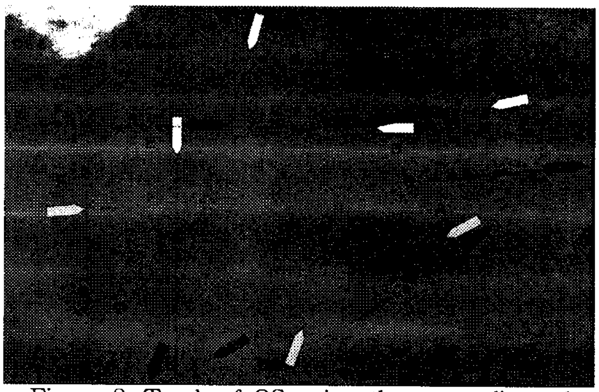

Figure 8. Track of OS using the succeeding adapted solutions.

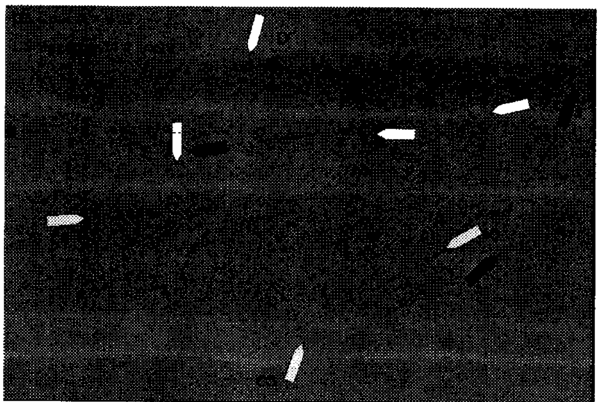

Figure 9. Track of OS until it was back to original heading.

4. Conclusion

We have discussed our Fuzzy-CBR support system for ship's collision avoidance by using past case solutions stored in the CB. The output or new heading, after adaptation of CB solutions, have improved the resulting DCPA of both examples

Its validity was shown by the difference between the new DCPA and the old DCPA when the solution of the similar case from CB was adapted to solve for the new heading and applied in the navigational situation example as shown in Figures 7,8 and 9.

The fuzzy-CBR support system for ship's collision avoidance will be improved in the future by adding more cases. It will take into consideration the relative speed of ships encountered and used as an input to be implicated together with DCPA.

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