Expert system based on fuzzy rules for maritime search and rescue

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Abstract

Search and rescue (SAR) plan decides the result of SAR activity, and relates with the safety of life and property at sea. To improve the efficiency and standard of SAR, and give the SAR officer support to make better decisions, expert system (ES) is been researched by this paper, and the ES based on fuzzy rules for maritime SAR is proposed. Firstly, the structure of ES based on fuzzy rules for SAR is designed. Secondly, we have researched SAR knowledge acquisition and knowledge representation, chosen five ways to acquire SAR knowledge. At last, we designed the inference engine of ES for SAR, and introduced it in an example.

Keywords: fuzzy rules, expert system, supporting system, search and rescue

1 Introduction

With the economic development exchange of commodities among countries become more frequent, the amount of ship being engaged in transporting is increasing continuously, and the scale of maritime activities is more and more big, which make the task of maritime search and rescue (SAR) more heavy [1]. SAR is not only a difficult task, but international responsibility [2]. The safety of shipping has been improved by the advanced navigation technical. However there are complex and unpredictable situation at sea, and maritime accident still happens frequently. For example, in June 2013 "Asian Express" ship with Maldives nationality damaged and sunk after floated two days in heavy weather because of power lost in Arabian Sea. In 2011, general cargo vessel "Swanland" sunk in Irish Sea due to hull damage. In June 2008, passenger ship "Star Prince" sunk in waters of the central Philippines after encountered typhoon and more than 700 people lost their lives. In February 2006, passenger sip "Salamu 98" sunk after explosion, and more than 1000 people were killed. After maritime accident the life of passengers and crew is under threat, and SAR is very necessary. Maritime SAR is not only the method to guarantee the safety of life and property but the expression of international humanitarian.

SAR refers to the search and rescue action made by search and rescue force except the ship in distress after they acquire distress message, which contains search section and rescue section. Search means to determine the location of people in distress with the coordination of SAR coordination centre, and rescue indicates to save the people in distress, provide preliminary medical service and other necessary service for them, and move them to safe place [3]. In order to improve the efficiency of SAR, researchers in different country has done a lot of work about SAR, and the emphasis of their work would be shown in the following:

(1) The search area. For example, reference [3] proposed an ensemble drift model of search objects based on stochastic particle simulation approach to determine the search area.

(2) Optimal model for the selection of search and rescue force at sea. For example, reference [4] constructs the optimal model for search force selection at sea, solves the model, and simulates the search situation.

(3) Supporting system for maritime SAR. Because the SAR problem is very complex, commanding officer cannot make perfect SAR plan according to his own experience. In response to this situation, decision supporting system based on cases [5] and expert system [6-10] were used in SAR; assist the officer to make SAR plan.

Expert system (ES) is one part of artificial intelligence, and is a computer program that solves the specialized problems at the level of a human expert [11]. Compared with human experts, the characteristic of ES is that it can study and explain the process of inference, adapt difficult environment, inference and deal with big data. If the ES is used, the efficiency of SAR would be improved. Nowadays, there are different kinds of ES, mainly contains ES based on rules, ES based on frame, and ES based on cases. Among them ES based on rules is widely used because of its simple development tool and successful example, so this paper researched the ES based on fuzzy rules for maritime search and rescue.

2 Search and Rescue Expert System

2.1 STRUCTURE OF SAR ES

The basic structure of ES based on rules was proposed

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by Newell and Simon in Carnegie Mellon University, which contains five parts. They are respectively knowledge base, database, inference engine, explanatory equipment and user interface. On this basis, this paper designs the structure of ES based on fuzzy rule for maritime search and rescue, and its structure is shown in Figure 1. The system contains six parts, they are respectively SAR Knowledge base, SAR work memory, inference engine, explanatory program, knowledge acquisition, and user interface.

SAR knowledge base contains all knowledge about maritime search and rescue domain. In this system, SAR knowledge is represented with a lot of fuzzy rules. Each rule indicates a relationship, suggestion, instruction, tactic, or heuristic method, and has IF (LHS: Left-Hand-Side) THEN (RHS: Right-Hand-Side) structure. When the LHS is met, the rule is aroused, and the RHS is implemented. According to the function of SAR knowledge, we can divide them into maritime search knowledge and maritime rescue knowledge. The former is used to decide the location of people in distress, and search plan. The latter is used to save the people in distress after they are discovered. Therefore, the search knowledge is basic of SAR plan, and the rescue knowledge is the leader of rescue scene.
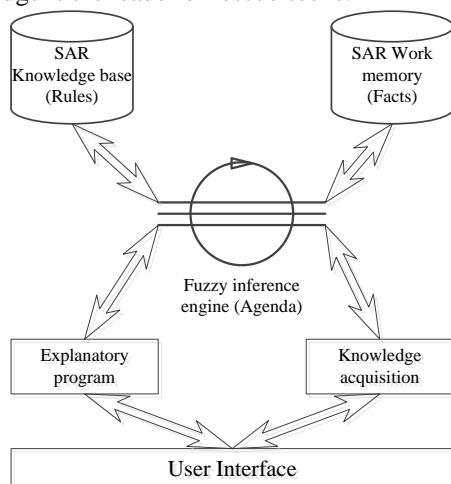

FIGURE 1 The Structure of ES based on fuzzy rules for SAR

SAR work memory contains a set of facts, which is used to match LHS part of knowledge base. These facts refer to the maritime SAR information, which has a good variety, and contains the information of ship in distress, SAR force, and meteorology and sea condition. Fuzzy inference engine's mission is to find the reasonable SAR plan according to SAR knowledge and SAR information. Additionally, explanatory program explains the inference process for user, which can be regarded as the basis of SAR plan. Knowledge acquisition is used to add new knowledge to system, and self study. User interface is the bridge between the user, human experts, knowledge engineers and ES.

2.2 DEVELOPMENT TEAM OF SAR ES

In order to introduce the development of ES, this part would introduce the development team of SAR ES. It contains five parts: SAR domain experts, knowledge engineers, programmers, manager and users, and the relationship among them are shown in Figure 2. Knowledge engineers are responsible for the work to design, construct, and test the ES, programmers are responsible for code, manager leads the process of development and coordinates other members, and users are mainly the officers who make SAR plan or commanding officer in rescue scene.

SAR domain experts should have the knowledge about shipping, maritime, aeronautics, medical, environment, petrochemical, ocean engineering, and meteorology. They are members of development team of ES, because they have experience in SAR. In SAR domain, experts work at maritime search and rescue centre or SAR scene. However, it is very difficult to let them represent their experience with rules. Additionally, the SAR knowledge provided by them is often fuzzy, for example, they may tell us that if the weather is bad, we should access the man overboard from the leeward. Therefore, we do not know when this rule should be activated due to "bad" is a fuzzy concept. Compared with traditional ES, such as EMYCIN, PROSPECTOR, the knowledge of ES for SAR is just experience, and variable. In addition, it can be represented by fuzzy rules.
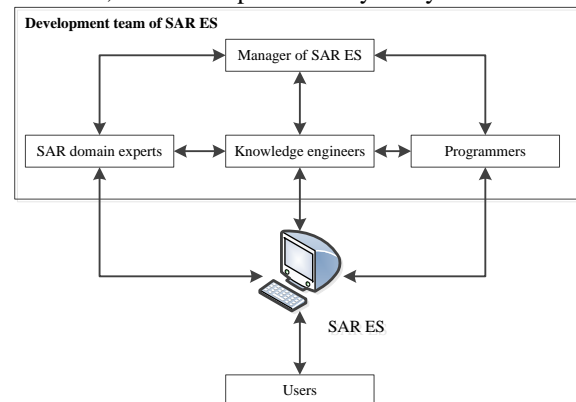

FIGURE 2 The development team of ES for SAR

3 Search and Rescue Knowledge

3.1 SAR KNOWLEDGE ACQUISITION

SAR knowledge acquisition is very important for the development of ES. During the process of development we carried different kinds of method to acquire knowledge, which contains International search and rescue manual, SAR expert interview, blind test, search and rescue cases, and other literatures. The source of SAR knowledge is shown in Figure 3.
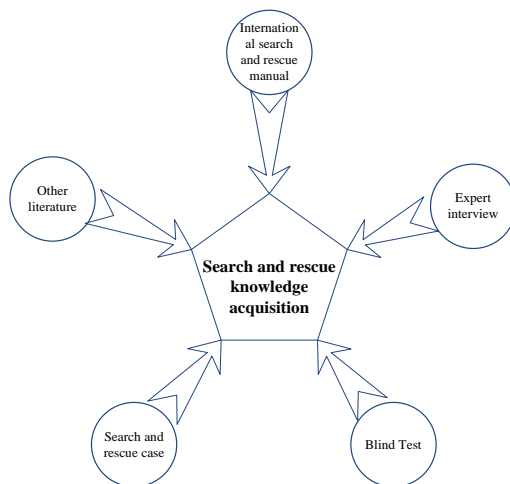
FIGURE 3 SAR knowledge acquisition

TABLE 1 SAR rules from international SAR manual

Rule 34	**IF**	Ship does not arrive beyond its expiry date
	AND	Ship does not report.
	THEN	The ship is in an unknown phase, inquire it first time.
Rule 35	**IF**	There is no result after inquire it first time
	OR	There is information to indicate the ship has been damaged.
	THEN	Alarm
	AND	Inquire it once again by expanding the inquiry scope
Rule 36	**IF**	There is still no result after second inquiry
	OR	There is information to indicate the ship is in distress
	THEN	The ship is in distress

International SAR manual: international SAR manual mainly contains handbook of international aviation and maritime search and rescue, merchant ship search and rescue handbook and maritime search and rescue handbook. These handbooks contain much SAR knowledge, are crystal of SAR workers' wisdom. They provide us with organization method, search method, and rescue method. The SAR knowledge from these handbooks has authority. After analysed them, this paper generalized many SAR rules. There are some examples shown in Table 1.

Expert interview: expert interview can let us know what is necessary for SAR inference, regard them as node, and then we can acquire the relation between cause and effect of each node. By the interview with experts we can understand the influence of each factor on the SAR process. In order to construct the ES for SAR, we interviewed the workers in maritime search and rescue center, professors in SAR domain, and captain with experience.

Blind test: let expert to deal with different kind of SAR problem, and don't provide them with any SAR information. In the process of blind test we just give experts the SAR information which they asked. With this method we can describe dynamically the information which is need to inference, and understand the relationship of SAR information.

SAR cases: we can acquire SAR knowledge from SAR cases.

Other literatures: other researchers have worked for SAR knowledge; it is an important part of SAR knowledge acquisition, for example, the SAR knowledge in reference [5, 10, 12].

3.2 SAR KNOWLEDGE REPRESENTATION

After research the process of maritime search and rescue, we find that knowledge which was used to infer the SAR plan is fuzzy. For example, we provide the following knowledge for the rescue of man overboard.

If the weather is well, we should launch life boat to rescue the people in distress directly.

If the weather is bad, we should navigate the ship to downwind district of people in distress, and launch life boat just help him as a transit station beside the ship.

We generalized the rules in Table 2from the rescue knowledge.

TABLE 2 Rules about man overboard rescue

Rule 65	**IF**	The weather is well
	THEN	Launch safe boat
	AND	Rescue the people in distress in distress
Rule 66	**IF**	The weather is bad
	THEN	Navigate the ship to downwind district of the people in distress
	AND	Launch life boat just help him as a transit station beside the ship

In Rule65 and Rule66, the "Well" set and "Bad" set of the weather are fuzzy set. For human experts, they can infer whether the weather is "Well" or "Bad". However, it is very difficult for expert system to judge the condition of weather from meteorological information. In SAR, and there are much knowledge like this. Therefore, we represent the SAR knowledge with fuzzy rules. Take the weather for an example. Assume the weather relates with wind, wave and rainfall, and we have the rule in Table 3.

TABLE 3 Rule about weather

Rule 50	**IF**	Wind is wild.
	OR	Wave is high.
	OR	Rainfall is heavy.
	THEN	The weather is bad.

Figure 4 shows the fuzzy sets of wind scale, and we discuss 3 fuzzy sets, which are Light (Wind is light), Medium (Wind is medium) and Wild (Wind is wild). Assume the scale of wind is 10, and then we can get formula (1), (2) and (3):

$$\mu\left(Wind = L\right) = 0, \tag{1}$$

$$\mu\left(Wind = M\right) = 0.2, \tag{2}$$

$$\mu\left(Wind = H\right) = 0.8, \tag{3}$$

where $\mu\left(Wind = X\right)$ refers to the membership degree of wind in fuzzy set X.

In the process of SAR, there are many fuzzy concepts, such as the level of grounding, the speed of sinking, and the level of damage. Not only the knowledge provided by experts is fuzzy, but also the SAR information we can acquire is fuzzy. That is to say, it is appropriate to represent SAR knowledge with fuzzy rules.
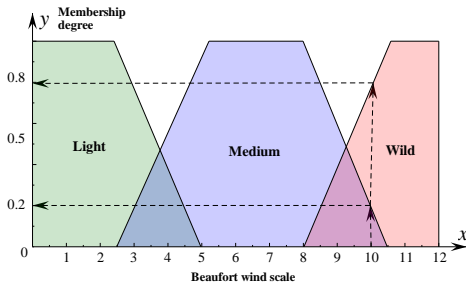

FIGURE 4 Fuzzy sets for the strength of wind

4 Inference engine of ES for SAR

The function of inference engine of ES for SAR is to generalize the SAR plan (results) from SAR knowledge (fuzzy rules) and SAR information (facts), the principle of inference engine of ES for SAR is shown in Figure 5. We can know that the inference engine is the core of ES, and relates with the SAR plan closely. It can deal with the SAR knowledge and SAR information. The former has been introduced, and then we would show the latter.
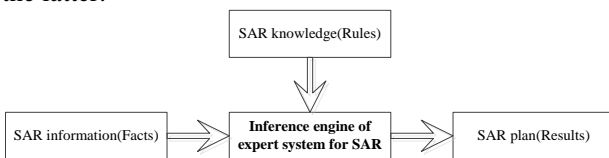

FIGURE 5 Inference engine of expert system for SAR

According to the source of SAR information, it can be divided into information of ship in distress, information SAR power (which means the ship or helicopter engaged in search and rescue), and information of meteorology and sea condition.

The work flow of inference engine is shown in Figure 6. The process of inference contains 4 steps, and they are respectively fuzzification of SAR information, evaluate the SAR information based on fuzzy rules, aggregate the output of rules, and inverse fuzzification of output.
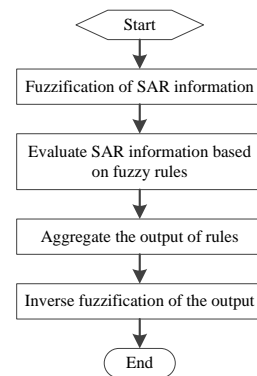

FIGURE 6 The workflow diagram of SAR inference engine

(1) Fuzzification of SAR information is to decide the membership degree of SAR information in appropriate fuzzy set. Fuzzy sets mentioned here corresponds to the fuzzy sets in SAR knowledge base, such as the fuzzy set about the strength of wind "Light", "Medium", and "Wild" sets. Generally speaking, the SAR information input into ES is a series of specific data. For example, the scale of wind is 9, height of wave is 3 meters, and flow velocity is 5kh. It is very difficult to match these data with fuzzy rules in ES, so fuzzification of SAR information is necessary. The key of fuzzification is to select the membership degree function. In order to improve the efficiency of ES the membership degree function is selected by experts.

(2) Evaluating the SAR information based on fuzzy rules is to match the SAR information with the left-side-part (LHS) of the fuzzy rules, and get the right-hand-side (RHS). If there is only one item in LHS, membership degree of RHS equals the LHS's. For example, there is a rule in Table 4.

TABLE 4 A simple rule with one item in LHS

Rule 12	**IF**	Wind is light.
	THEN	Weather is Well.

And we have formula (4):

$$\mu\left(Wind = L\right) = 0.9 \,. \tag{4}$$

According to the principle, we have formula (5):

$$\mu\left(Weather = Well\right) = \mu\left(Wind = L\right) = 0.9 \,. \tag{5}$$

If the number of item in LHS is more than one, fuzzy operation (AND operation, OR operation) should be used when we evaluate the SAR information. For example, there is a rule in Table 5.

TABLE 5 A simple rule with more than one item in LHS

Rule 15	**IF**	Wind is Wild.
	OR	Wave is High.
	OR	Rain is Heavy.
	THEN	Weather is Bad.

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And we have formulae (6-8):

$$\mu\left(Wind = Wild\right) = 0.6 , \quad (6)$$

$$\mu\left(Wave = High\right) = 0.8 , \quad (7)$$

$$\mu\left(Rain = heavy\right) = 0.4 . \quad (8)$$

After fuzzy operation, we can get formula (9):

$$\mu\left(Weather = Bad\right) = \max\left\{0.6, 0.8, 0.4\right\} = 0.8 \quad (9)$$

(3) Aggregate the output of rules

There are so many rules about the same thing, so it is necessary to aggregate the output of rules. Fuzzy inference is used in ES for SAR, so the result of inference is series of membership degree of rescue operation in fuzzy set. For example, ES provides the following rescue method. Rescue method is to Launch safe boat(0.8), Rescue method is to use hook to clasp him(0.1), in which the value in parentheses refers to the membership degree. Generally, a SAR operation belongs to several fuzzy sets. In order to find the appropriate SAR plan, we should aggregate the output of rules.

(4) Inverse fuzzification of output

After aggregate the output of rules we get membership degree of rescue in several fuzzy sets. In order to decide which method should be taken, inverse fuzzification of the output is done. For common ES they would export a value, so centroid technique is used in inverse fuzzification of the output. Unlike them, ES for SAR need export a complete plan, that is to say we should know which fuzzy set the operation belongs to. So we use the maximum membership degree for inverse fuzzification.

5 SAR case

An example about rescue of man overboard is shown in this part to explain the inference engine of ES for SAR.

There are two rules shown in Table 6. In which x, y, and z (Weather, Man overboard, Rescue method) are variables in ES for SAR, A1 and A2 (Well, Bad) are fuzzy sets on field X (Weather), B1 and B2 (Near, Far) are fuzzy sets on field Y (Man overboard), C1 and C2 (Safe boat, Hook) are fuzzy sets on field Z (Rescue method). The membership function of A1, A2, B1, and B2 are shown in Figure 7.

TABLE 6 rules of Expert System for SAR

Rule 1		SAR Knowledge(Introduction)
IF	x is A1	*Weather* is well
AND	y is B2	*Man overboard* is far away from ship
THEN	z is C1	*Rescue method* is to Launch safe_boat
Rule 2		SAR Knowledge(Introduction)
IF	x is A2	*Weather* is bad
AND	y is B1	*Man overboard* is near from ship
THEN	z is C2	*Rescue method* is to use hook to clasp him

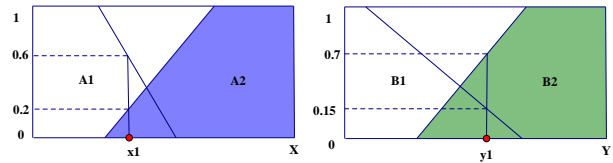Assume x=x1 and y=y1, the process of inference would be shown in the following.

FIGURE 7 Fuzzification of SAR information

Step1: Fuzzification of SAR information. We can get formulae (10) and (11):

$$\begin{cases} \mu\left(x = A_1\right) = 0.6 \\ \mu\left(x = A_2\right) = 0.2 \end{cases}, \quad (10)$$

$$\begin{cases} \mu\left(x = B_1\right) = 0.15 \\ \mu\left(x = B_2\right) = 0.7 \end{cases}. \quad (11)$$

Step 2: Evaluate the fuzzy rules. After evaluate the fuzzy rules, we can get formula (12), and the result is shown in Figure 8.

$$\begin{cases} \mu\left(z = C_1\right) = 0.6 \\ \mu\left(z = C_2\right) = 0.15 \end{cases}. \quad (12)$$
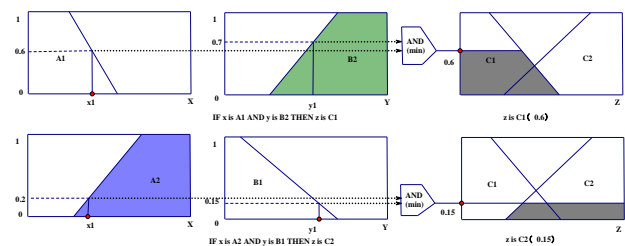

FIGURE 8 *Evaluate* fuzzy rules

Step 3: Aggregate the output of rules. The result is shown in Figure 9.
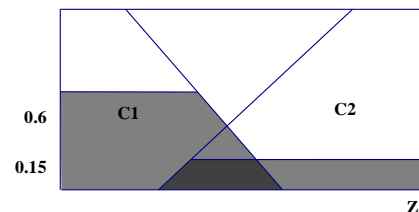

FIGURE 9 Aggregate the output of rules

Step 4: Inverse fuzzification of output of rules. The result is "z is C1", that is to say "Rescue method is to Launch safe boat".

The result of inference indicates that if weather is well, and the man overboard is far away from the ship, we should launch the life boat to rescue him.

6 Conclusion

ES for SAR can improve the efficiency of SAR, reduce the damage of life and property caused by search and

rescue delay. Compared with human SAR experts, ES can study new knowledge quickly and explain the whole process of inference. Additionally, ES can adapt complex work environment, and deal with large amounts of data. Due to the complex situation at sea SAR information is incomplete. Fuzzy rules are used to represent SAR knowledge. On the basis of fuzzy rules this paper has designed the structure of ES for SAR, and researched the SAR knowledge acquisition, representation and inference engine.

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