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Implementation of a preliminary inference algorithm for an automatic communication system

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Abstract

One of the factors affecting a ship's safety during its voyage is the ability to detect encounter situations. Navigators mostly use two parameters: closest point of approach (CPA) and time to CPA (TCPA). Their limit values, considered as safe, depend on the parameters of the vessel, geographic area, and weather conditions. These limits are set by the navigator and are based on his experience; however, in specific situations, there is a need to use other parameters, such as ship domain. It is very important for the automated communication system to determine the critical moment when intership communication should be started. The article presents an algorithm of automatic detection of situations where the communication should be initiated. The influence of data relating to the vessel, geographic area, and weather conditions can be taken into account. The output produced by the program, based on the authors' algorithm, is presented.

Introduction

A review of maritime court decisions indicates that human errors are among the major causes of marine accidents. Reduction of such errors should enhance maritime safety. The new IT and ICT systems installed on the bridge give a more comprehensive overview of the situation. On the other hand, this equipment can lead to information overload, which in turn could result in safety reduction. New solutions should provide automatically generated proposals, based on the interpretation of the navigational situation and give the navigator the possibility to review the original data used to develop them. In any case, the navigator conducting the ship should take the final decision.

One of the solutions leading to improved safety at sea and reducing information overload is an automatic communication and negotiation system (Pietrzykowski et al., 2006). In such systems, decisions are worked out through reasoning processes that comprise effective information acquisition, analysis and interpretation, including negotiation processes. The use of this system on board is intended to facilitate decision-making. The proposed system does not relieve the navigator from responsibility – it only suggests a solution to the current navigational situation developed in cooperation with other ships.

This article presents the implementation of a preliminary inference module of an automatic maritime communication system. The decision-making mechanism is explained on the basis of a test situation. The proposed solution is universal and may be used in any application that needs such a module.

Inference model

Inference processes taking place in the communication of ship navigators are divided into several stages (Pietrzykowski et al., 2013; 2014): preliminary inference, followed by navigational situation recognition and understanding, and finally communication, based, among other things, on the messages received from other ships. The inference stages are realized by the system whose main algorithm is shown in Figure 1.

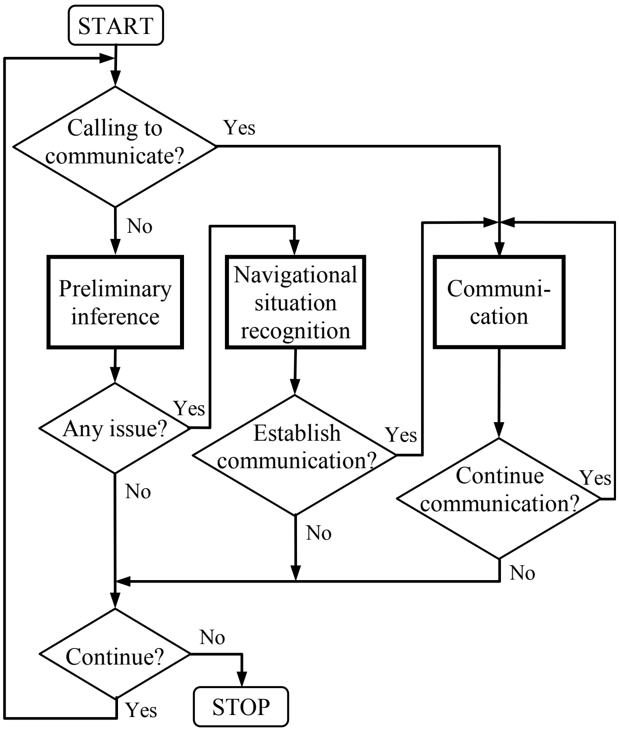


Figure 1. Inference processes in an automatic maritime communication system (Wójcik, Banaś & Pietrzykowski, 2014)

The blocks shown in the diagram have these functions:

- **Preliminary inference** – initial identification of the navigational situation as safe or potentially unsafe (requiring further analysis). The CPA and TCPA parameters are used in the calculations. It is also possible to use other parameters such as ship domain.
- **Navigational situation recognition** – classification of the current navigational situation (ship has the right of way or not, necessity to perform manoeuvres, etc.) and determination of communication requirements.
- **Communication** – receiving and understanding the incoming message and generating an outgoing message. The structure of this block is presented in Figure 2 and described further in this section.

Inference performed at each stage of the communication process is based on simple principles of two-valued logic and knowledge base containing rules of inference. If necessary, the process may be complemented with elements of fuzzy logic (the third step of inference). Preliminary inference is based on an analysis of basic parameters describing a given encounter situation. In the example, CPA and TCPA are used, but other parameters like ship domain can also be taken into account. The navigators define minimal values of CPA and TCPA that ensure safe navigation. These values are denoted as CPA_{Limit} and $TCPA_{Limit}$. When the limit values are exceeded, the navigator has to take action to avoid a collision. In addition, the ship domain is also used as one of the criteria of encounter situation preliminary recognition. Ship domain is defined as an area around the ship that the navigator wants to keep clear of other vessels and objects (Pietrzykowski & Uriasz, 2009).

The limit values of parameters are used as input data for the systems available on the ship. To determine these values, the navigator takes into account different factors, such as weather conditions. These limit values are pre-determined for very good sea state and visibility conditions; however, when hydrometeorological conditions deteriorate, the system determines new parameters, subsequently displayed to the navigator. The parameters values depend on factors such as:

- ship size;
- type of shipping;
- type of cargo carried;
- weather conditions;
- geographical features;
- local vessel traffic intensity;
- navigator's individual preferences and experience.

To take into account these factors, we can use fuzzy logic with properly adjusted linguistic modifiers.

Preliminary inference algorithm

The algorithm is intended for any possible application, but in reference to marine automatic communication it will be presented with the CPA and TCPA parameters.

Figure 2 illustrates an algorithm of preliminary inference used in the process of automatic communication at sea (Banać, Wójcik & Pietrzykowski, 2013). The following functional blocks are distinguished:

- **Collect parameters** – gets the parameters of encounter situation, decodes them and calculates values needed for selection of rules used in inference. In this block, any number of parameters that may influence the inference process may be used.
- **Make a list of rules** – selects the rules from knowledge base that will be used during inference and formulates them in a list. In most applications, the sequence of rules on the list is not important,

but there is the possibility to enforce a predetermined order, if needed – the proper control rules may be stored in knowledge base.

- **Execute the rule from the list** – takes the first non-processed rule from the list prepared in the previous block, executes it and stores the result.
- **Compute the results of inference** – collects the results of rules executed in the previous steps and calculates the results of inference. The control rules for this block are stored in the knowledge base.
- **Prepare the solution** – formulates the proper solution based on the results of inference computed in the previous step. The form of the solution depends on the application of the entire algorithm.

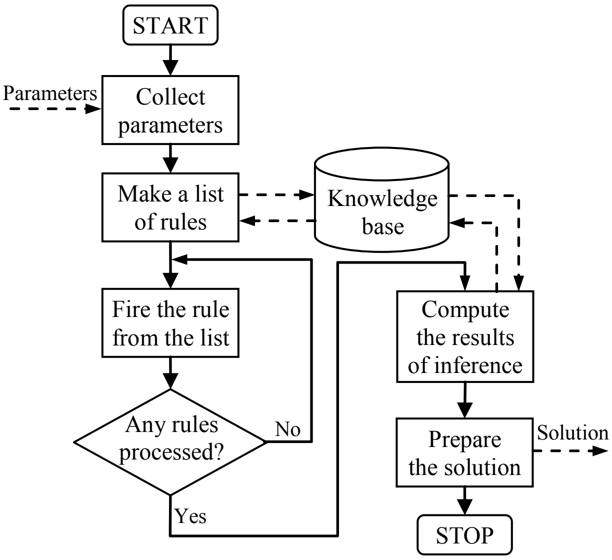


Figure 2. Preliminary inference algorithm

In very good visibility, the system having the input parameters CPA and TCPA, makes classic reasoning based on the following implication:

$$\text{If CPA} < \text{CPA}_{\text{Limit}} \text{ and TCPA} < \text{TCPA}_{\text{Limit}} \text{ then RISK OF A COLLISION} \quad (1)$$

This implication is represented as a set of rules stored in the knowledge base, such as:

$$\text{If CPA} < \text{CPA}_{\text{Limit}} \text{ then RESULT[1] = TRUE} \quad (2)$$

$$\text{If TCPA} < \text{TCPA}_{\text{Limit}} \text{ then RESULT[2] = TRUE} \quad (3)$$

When it is necessary to take into account factors influencing the limits of encounter situation parameters, fuzzy logic methods are used. Depending on the included conditions, the modifiers might be as follows: operator of concentration (CON()), operator of expansion (dilution, DIL()), or contrast intensification operators (Int(), Blr()), described by the following formulas:

$$\mu_{\text{CON}(A)}(x) = \text{CON}(\mu_A(x)) = \mu_A(x)^2 \quad (4)$$

$$\mu_{\text{DIL}(A)}(x) = \text{Dil}(\mu_A(x)) = \sqrt{\mu_A(x)} \quad (5)$$

$$\mu_{\text{INT}(A)}(x) = \text{Int}(\mu_A(x)) = = \begin{cases} 2(\mu_A(x))^2 : \mu_A(x) < 0.5 \\ 1 - 2(1 - \mu_A(x))^2 : \mu_A(x) \geq 0.5 \end{cases} \quad (6)$$

$$\mu_{\text{BLR}(A)}(x) = \text{Blr}(\mu_A(x)) = = \begin{cases} 1 - 2(1 - \mu_A(x))^2 : \mu_A(x) < 0.5 \\ 2(\mu_A(x))^2 : \mu_A(x) \geq 0.5 \end{cases} \quad (7)$$

where $x \in X$ (Banaś, Wójcik & Pietrzykowski, 2013). The knowledge base also stores additional control rules. These are used to associate the above inference rules with the process of recognition of collision risk during an encounter situation. This feature allows the preparation of an adequate list of rules. The results of the execution of rules are stored in the logic array called RESULT. When the process of executing the rules is finished, the logic values stored in the RESULT array are processed according to a control set of rules. In this case there is only one control rule, which applies the logic function AND to all values of the RESULT array. The result of the AND function is interpreted in the last block.

Example of using preliminary inference

In preliminary inference the ship's right of way is irrelevant. It is only important to detect a risk of collision. The navigational situation is identified in another module. Here we illustrate an example of the use of preliminary inference.

There are two ships on crossing courses:

- Alpha – own ship, where the automatic communication system is in operation;
- Beta – other ship manoeuvring in the vicinity of the Alpha.

The Alpha sets $\text{CPA}_{\text{Limit}}$ to 1.2 Nm and $\text{TCPA}_{\text{Limit}}$ to 10 minutes.

The stages of the ship encounter are the following:

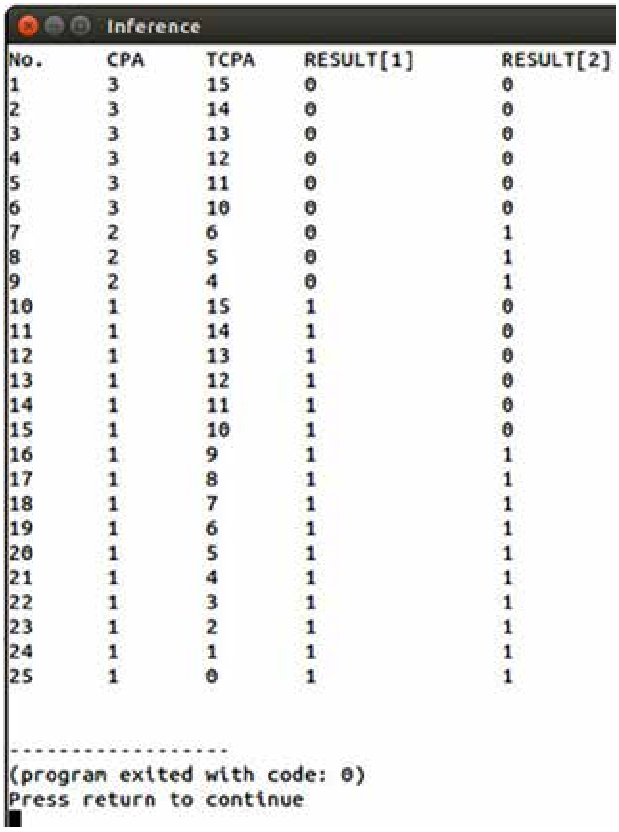
1. Alpha detects a crossing course relative to Beta, CPA = 3 Nm, TCPA = 15 minutes and decreases the latter value to 10 minutes (the stage continues for 5 minutes)
2. Beta changes its course, CPA = 2 Nm, TCPA = 6 minutes, which is decreased to 4 minutes (the stage continues for 2 minutes).

3. Beta slows down, CPA = 1 Nm, TCPA = 15 minutes, which decreases to 10 minutes (the stage continues for 5 minutes).
4. As time passes by, the TCPA decreases below 10 minutes.

The preliminary inference algorithm is launched in selected periods of time. During all of the stages of the encounter, the same set of rules is selected – formulas No. 2 and 3. The results of inference are presented in the Table 1.

Table 1. Results of preliminary inference in different stages of an encounter

Stage of encounter	CPA	TCPA range	RESULT [1]	RESULT [2]	Inference result
1	3	15 – 10	FALSE	FALSE	Safe, no action needed
2	2	6 – 4	FALSE	TRUE	Safe, no action needed
3	1	15 – 10	TRUE	FALSE	Safe, no action needed
4	1	below 10	TRUE	TRUE	Risk of collision, need of navigational situation recognition



Inference

No.	CPA	TCPA	RESULT[1]	RESULT[2]
1	3	15	0	0
2	3	14	0	0
3	3	13	0	0
4	3	12	0	0
5	3	11	0	0
6	3	10	0	0
7	2	6	0	1
8	2	5	0	1
9	2	4	0	1
10	1	15	1	0
11	1	14	1	0
12	1	13	1	0
13	1	12	1	0
14	1	11	1	0
15	1	10	1	0
16	1	9	1	1
17	1	8	1	1
18	1	7	1	1
19	1	6	1	1
20	1	5	1	1
21	1	4	1	1
22	1	3	1	1
23	1	2	1	1
24	1	1	1	1
25	1	0	1	1

```
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(program exited with code: 0)
Press return to continue
```

Figure 3. The output of reasoning process in a client program

All the stages continue for some time and the inference process is carried out at specified intervals. The interval length is a defined parameter. The results of computation stored in the array RESULT do not change until the encounter passes to the next stage.

The program for inference process implementation was designed as a service without user interface. Figure 3 presents an output of a simple text client program, which collects results from an inference process. To ensure readability, the time interval of data presentation was set at one minute, while the CPA and TCPA values were rounded to the nearest integer values.

System components that will use the solution calculated in the preliminary inference module are under development.

Conclusions

This article presents the implementation of preliminary inference module for an automatic maritime communication system. The mechanism of decision-making is designed to use any set of parameters that can be of aid in recognizing the moment in which communication might be needed. An example scenario involving two ships illustrates the use of CPA and TCPA. The algorithm was developed and implemented into a program whose output has been shown. The proposed solution can be used in various applications that require this kind of reasoning process.

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