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Modeling communication processes in maritime transport using computing with words

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ABSTRACT
The paper deals with communication processes between ship navigators based on standard marine communication phrases. The authors consider information exchange, message perception and interactions, e.g. negotiations. For this purpose navigational information and communication ontologies have been complemented by elements of the protoform theory. The considerations include inference processes, related to additional information acquisition and negotiations. Computing with words is applied to the modelling of communication processes.

KEYWORDS: automatic communication, inference rules, computing with words, e-navigation

1. Introduction

The process of ship conduct requires constant exchange and processing of navigational information. Whether decisions are correct or not depends on information scope, accuracy and reliability as well as its proper perception. Navigators steering their ships are required to use all available means to evaluate the navigational situation. This includes the use of equipment and ship systems, such as AIS, ARPA, ECDIS, voice communication and others. Voice communication is a channel for obtaining additional information and, where appropriate, agreements. Analysis of maritime court decisions indicates that in the event of collision, failure to establish voice communication with the ship concerned is one of the charges against ships involved in a collision. Bad decisions may be made due to either a failure to establish voice communication or its improper conduct or lack of understanding of transmitted information. At the root of these errors may be fatigue and stress, leading to, among others, reduction of mental toughness, reduced personal safety, lower self-esteem and situational awareness, disorders of leadership qualities, prolonged decision-making, but also a poor knowledge of the English language. Hence, signalling the advisability to establish direct ship-to-ship communication and the automation of communication processes can reduce wrong decisions and consequently, avoid erroneous actions resulting in marine accidents. This mainly applies to dangerous situations that require decisive action to avoid a collision, or a close quarters situation, in which, to avoid a collision, navigators of the meeting ships have to take joint actions. These actions are referred to as last-minute maneuver intended to avoid a collision, and when it is impossible, to minimize its effects, and should be made in unison, as a result agreed activities.

2. Processes of communication

The concept of communication is often defined as a process of transmission of information and interaction, or social interaction using symbols [1, 2]. Communication takes many forms, but their common features are the existence of at least two participants in the process, the system of signs and a message. In this article we are considering communication as a process of transmitting information between a sender and a receiver through a specific system based on ontology.

Communication processes can also be seen in various categories, for instance [3] as the exchange of information, message perception and interaction, e.g. negotiations. These processes concern different spheres of human activity, including communication at sea. The communication process in this case may encompass:

- acquisition, processing, transfer and sharing of information using standard devices and navigation systems.
- selective acquisition of information (the information needed in a given situation) to determine or clarify the description, interpretation, evaluation of the current and/or projected situation, beliefs, desires and intentions of traffic participants,
- mechanisms of cooperation and negotiations for the safe operation of the vessel, avoiding hazards and preventing or limiting the effects of accidents.

In the first case, the process is wholly or largely automated. In the other two cases, the degree of automation is much lower. This is due to the use of voice communication as a channel for acquisition of additional information, and in some cases, making arrangements.

The principles of ship-to-ship and ship-to-shore communication are governed by the relevant regulations (SOLAS Convention, requirements and performance standards for navigation systems, GMDSS, AIS, Admiralty List of Radio Signals, Standard Marine Communication Phrases SMCP [6]), as well as good sea practices. Although the regulations impose certain obligations on vessel traffic participants, they do not eliminate the possibility of dangerous situations, caused by failure to communicate or communication errors: misunderstanding of a message, improper message or misinterpretation of the information exchanged.

One can expect that due to the complexity of communication the transformation of verbal communication into a fully automated exchange between shipboard or land-based systems will take place in stages:

- Stage 1: human - human, through a computer system,
- Stage 2: human - computer system (in both directions and at any range)
- Stage 3: computer system - computer system.
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The system should take into account applicable regulations as well as established practices and principles of voice communication. IMO's Standard Marine Communication Phrases [6] were introduced in order to facilitate exchange of important information by standardizing the language used in communication at sea, on approach channels, waterways and in ports. Computing with words is one tool enabling formal recording of messages conveyed in the natural language and making inferences.

3. Computing with words

Computing with words is a methodology of using words to replace numbers present in calculations and inference. This is necessary in situations where the information is too vague to be written with numbers alone. Some of the words of natural language, such as *much*, *close* or *safely* are examples of imprecise information. Computing with words, therefore, allows carrying out calculations on words and propositions taken from natural language to model human reasoning and inference. The human brain has the ability to manipulate perception, especially concerning shape, distance, time, etc. described with quantities (words) imprecise in the numerical sense.

The structure of computing with word is schematically shown in Figure 1 [9]:

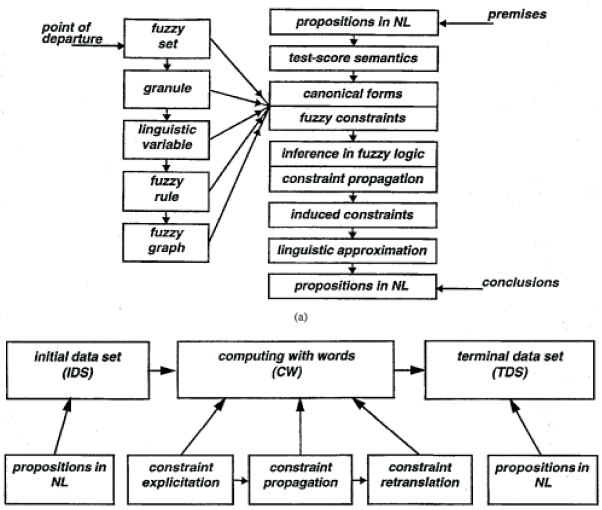

Fig. 1. Conceptual structure of computing with words [9]

The basic terms used in computing with words are the linguistic variable and granule. The linguistic variable is a variable whose values are not numbers, but words or statements formulated in a natural or artificial language. [7]. The granule is a clump of points (objects) drawn together by indistinguishability, similarity, proximity or functionality [10]. In computing with words the granule is a constraint of a word presented as a fuzzy constraint of a variable. Through constraint propagation we move from premises to conclusions, and the information is transmitted by reducing the value of variables.

Premises written in a natural language are converted into a canonical form. The canonical form is to reveal a fuzzy constraint hidden in a proposition p, which can be written as:

$$p \rightarrow X \text{ is } R \quad (1)$$

where:
R is a fuzzy constraint and X is a variable being constrained.

Constraint propagation, which is a form of inference for fuzzy constraints, leads to conclusions in the form of induced fuzzy constraints, which are then processed by linguistic approximation to a natural language.

In the system of automatic communication we consider the exchange of information as well as the perception of a message and interactions. For correct interpretation of transmitted messages and formal description including interactions, we need an ontology of communication.

4. Ontology

Ontology refers to a common understanding of a given field [5], which can be used as an aid in solving problems of communication and cooperation.

We intend to use the concept of ontology understood as the formalization of knowledge of marine navigation to standardize the meaning of navigational terms and imprecise terms, to be able to build an acceptable method of communication. However, this communication and correct "understanding" of the information transmitted between navigators (ship-to-ship), as well as in ship-to-shore exchanges is intended to be automatic communication through the system, such as the one described in the article [4].

Two areas were comprised when creating the ontology: navigational information and communication, plus an interface, as shown in Figure 2

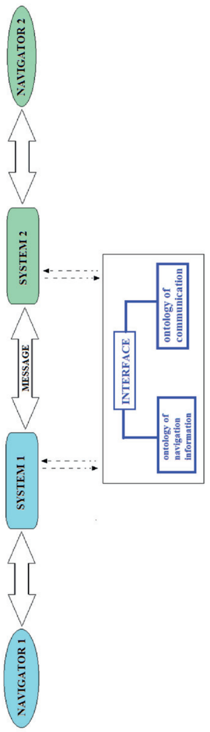

Fig. 2. Diagram of an automatic system-system communication [own study]

The ontology of navigational information is created on the basis of the standard marine communication phrases [6], divided into external (ship-to-ship) and internal phrases for onboard communication. Navigational terms are divided into entities (the main classes) and instances (elements belonging to individual sets).

The communication ontology presently in the process of creation is based on the fuzzy logic theory and the protoform theory [8]. With fuzzy logic we can formally define imprecise and ambiguous terms, which are often used in verbal language, e.g. *low risk*, *good situation*.

The interface, linking navigational information with the ontology of communication, incorporates types of messages: question, request, etc. [4]. It is defined as a system (with or without software) for connection, cooperation and exchange of signals of the particular form between devices connected through that system, in compliance with the relevant technical specification.

The interface and navigational information are not sufficient to interpret the meaning of information, as a non-standard word or phrase (imprecise term) in the transmitted information may occur, so the ontology of communication is essential.

The program Protégé is a tool for building an ontology. It is used for object modelling, supports the process of designing ontologies, databases and complex formal models. Presented below is a sample of the ontology operating in the Protégé program. The fragment includes three main planes and individual entities. Instances, defining the individual words - elements in the class, are assigned to each entity.

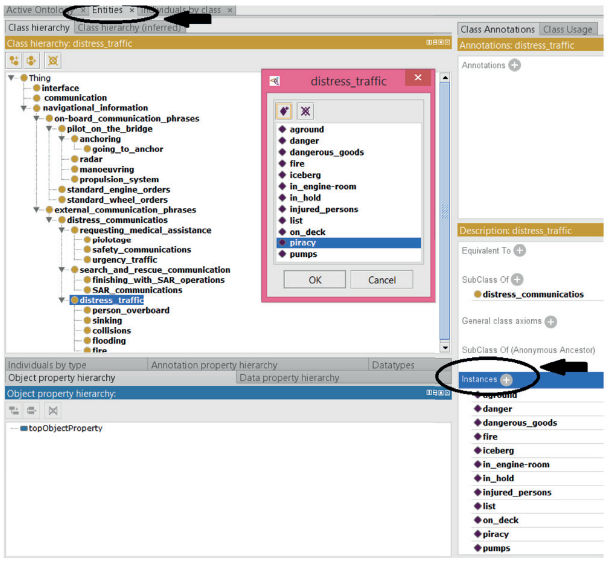

Fig. 3. Ontology in the Protégé program, including instances [own study]

5. Processes of inference

The system of automatic communication, being developed for the shipping industry, uses the model communication processes depicted in Figure 4 [4].

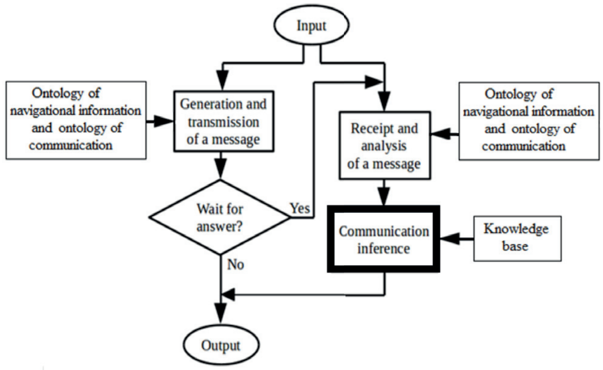

Fig. 4. Diagram of the communication process [4]

Let us consider two cases:

- the system identifies a situation that requires establishing communication,
- the system is called by another ship (by receiving a message).

After the received message is interpreted using the ontology of navigational information and communication ontology, the data are transmitted to the Communication Inference block. The input data to this block are messages received from another ship or a coast station in the text form (natural language) as well as data from shipboard systems. If input data are crisp, performed inference is of classical type using the knowledge base. If input data include imprecise terms, the data are presented in the form of fuzzy values, used in the premises. Inference is based on fuzzy rules and the rules of computing with words and makes use of the knowledge base containing the collision regulations. After making a linguistic approximation we obtain conclusions that will be generated as a message to be sent to the ship or the coast station concerned, in the form of a text (natural language) or as suggested actions (maneuvers). Inference processes taking place in this block are shown in the diagram, Figure5.

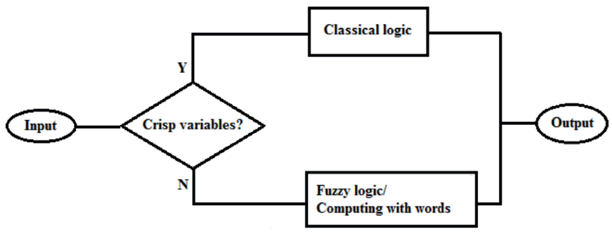

Fig. 5. Diagram of inference processes in communication [own study]

The knowledge base includes:

- the data on navigational situation from shipboard systems, continuously stored in the knowledge base; these are accurate data and are the basis for preliminary inference,
- knowledge base derived from the Collision Regulations,
- experts' knowledge
- base of rules used during inference; these are the rules of fuzzy inference and rules from computing with words,
- other, e.g. decisions of the ship's watchkeeping navigator.

6. Example

Let us consider an encounter situation with ships A and B. Ship A is underway, ship B is adrift. There is good visibility and no other ships in the vicinity. Ship B is drifting on ship's A planned route. A simplified example dialog in this situation, may go like this:

A: Vessel in position fi lambda, distance 10 Nm. This is m/v Navigator.
B: This is m/v Seismic.
A: What are your intentions?
B: I am drifting.
A: OK. I will pass you on your port side
B: OK, I advise you to keep minimum distance of 1 Nm from me because I am repairing my towing gear.
A: OK, I will follow.

Table summarizes the communication represented by the above dialog. Once the situation is determined (navigational situation recognition) by the automatic communication system, it identifies the need to establish communication. The system on ship A generates a message and transmits it to ship B, specifying additional information (position fi lambda, distance 10Nm) and a question about the intentions of ship B. After the response is received, it is interpreted and inference is made. The message from ship B delivers crisp data, which activates classical inference based on implications from the knowledge base. A message is now prepared to inform ship B on intention of own ship ("I will pass you on your port side"). As a feedback, the system obtains information on the distance that ship B wishes to maintain clear of other ships. Inference is activated again, this time to consider possibility of satisfying the conditions of the target ship, and another message confirming the intended manoeuvre is generated.

Incoming message	Activity / action	Outcoming message
	-Inference from navigational situation recognition -Generation of a message	
		A: Vessel in position fi lambda, distance 10 Nm. This is m/v Navigator.
	-Transmission of a message -Waiting for answer	
B: This is m/v Seismic.		
	-Receipt and analysis of a message -Communication inference -Generation of a message	
		A: What are your intentions?
	-Transmission of a message -Waiting for answer	
B: I am drifting		
	-Receipt and analysis of a message -Communication inference -Generation of a message	
		A: OK. I will pass you on your port side
	-Transmission of a message -Waiting for answer	
B: OK, I advise you to keep minimum distance of 1 Nm from me because I am repairing my towing gear		
	-Receipt and interpretation of a message -Communication inference -Generation of a message	
		A: OK, I will follow
	-Transmission of a message	

The above processes are modelled in the Matlab environment and systematically implemented in the programming language C++.

7. Conclusion

One of the causes of marine accidents is the lack of or inadequate communication between the navigators on board. Automation of the communication processes can help eliminate or reduce these shortcomings. Rapid development of information technology and knowledge engineering provide opportunities for creating automatic communication systems. The ongoing work is aimed at developing information and communication ontologies and knowledge base covering inference processes for obtaining additional information and negotiations. Computing with words is used for modelling these processes.

The article analyzes processes of communication between navigators. This issue takes on additional importance in the case of unmanned remote controlled vehicles, autonomous vehicles in particular. Designers of automatic communication systems for such craft can use solutions proposed for manned ships.

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