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Information Exchange Automation in Maritime Transport

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ABSTRACT: To ensure the safety of maritime transport the access to information must be provided through a commonly used services. However, an equally important task is to determine or agree on interpretation of incoming data and assessment of a current and predicted navigational situation and, in further step, intentions of the participants in the transport process. Thanks to the standardization of information format, automatic information exchange gets increasingly wider. Another step ahead is automatic interpretation of information and automation of negotiation processes - intelligent communication. Rapid development of IT and ICT technologies creates such opportunities. This article presents the results of research on a system of automatic communication and co-operation in maritime transport.

1 INTRODUCTION

Safe navigation and vessel traffic management require access to relevant information and its proper use. More and more information systems are installed on ships and in land-based centres. These systems process data of various content and form, essential for transport process participants: navigators, shipowners, marine agents, shipchandlers, recipients of goods and services, port operators, vessel traffic services and others. The variety of physical characteristics, sources, types and scope of navigational information hampers its acquisition, collection, management, processing and presentation to decision makers. The development of information technologies makes it possible to standardize the form of navigational information and interchange processes, which may significantly contribute to the enhancement of shipping safety and effectiveness. To this end such concepts as e-maritime and e-navigation are developed along with implementation of international projects, including those executed within the EU (e.g. MARNIS [5], MonaLisa [6]).

The assurance of safe shipping, *eo ipso* the safety of personnel, cargo, ships and environment depends, apart from information access and possibility of its automatic interpretation, on communication aimed at determining or accurately specifying the interpretation and assessment of a current and predicted situation as well as intentions of other transport process participants. In maritime shipping the principles of communication between navigators steering their respective ships and navigators and land-based canters are set forth in relevant regulations. Although the regulations impose certain obligations on traffic participants, they do not eliminate possibilities of dangerous situations, resulting from failure to start communication or from errors in communications. Examples of the latter are: improper choice of means of communication, wrong information, misunderstanding or misinterpretation of interchanged information. One way to solve this problem can be the development of principles of automatic communication and co-operation, based on standards of navigational information. This means the need to extend navigational ontology with a sub-ontology for communication processes, and application of a formal language to write it down.

2 STANDARDIZATION OF INFORMATION FORM

Many systems and equipment for marine navigation, supporting decision processes on board, have been designed and developed for years. Their variety calls for standardization of navigational information format. One such example is S-57 standard for hydrographic data, used in electronic navigational charts.

Authors of the S-100 standard (version 4.0 of S-57) [3] aimed at creating possibilities for an interchange, through this standard, of more source hydrographic data and related products. In practice it means the handling of various data: matrix, raster, technical 3-D, time-varying (x, y, z, time) and new applications, for instance high-density bathymetry, bottom classifications, marine GIS. The S-100 standard may also be useful in services, based on Internet technologies, offering searching, viewing, analysis and transmission of any type of hydrographic data.

The S-100 standard offers wide possibilities of its implementation in any structures, with the use of data formats selected by the user.

The standard has the following characteristics:
- flexibility in introducing changes; future specifications of products will be based on one main data model, that will be expanded depending on the needs of various user groups;
- archive located on the IHO website will include dictionaries of features and attributes (without obligatory relations between them) and product specifications, which will enable their flexible development;
- separate folders for each user group; one of them - folder S-57 will comprise new features and attributes and additional specifications of products that may be made, specification of user data exchange standard.

The sub-standard S-101 [3] is a new ENC specification based on the S-100 concept, i.e. flexibility and arbitrariness of using source data based on catalogues and rich geometric models, information types and their attributes. Such form of data distribution enables introduction of new functionalities in ENC charts, such as dynamic presentation of tidal streams or very accurate bathymetric data. Utilizing such an amount of data may contribute to making better decisions and avoiding errors in port approach channels or when a ship proceeds in heavy traffic waters. The specification of products based on bathymetric data is found in S-102 sub-standard [8] that can be developed independently or in combination with S-101, e.g. in ECDIS.

The automatic information exchange process calls for defining the ontology of navigational information, messages sent and formats of recording. This is important in the process of transmitting an intention, question or request (demand). So far, crisp terms have been used in ship-to-ship or ship-to-shore communication, but under the S-100 standard non-crisp terms will be possible.

Data exchange automation and broadly understood co-operation also require the specification and standardization of data format and scope, and procedures of automatic translation. It seems necessary to develop a sub-standard that would define these parameters of data exchange between vessels (mobile objects) and between land-based centres and vessel operators, automatically, semi-automatically or manually.

3 NAVIGATIONAL INFORMATION ONTOLOGY. A SUB-ONTOLOGY FOR COMMUNICATION

Ontology is a description of a structure and hierarchy of notions, symbols and objects of the world or its part. The term navigational information ontology is understood as a meta-language describing the structure and form of information used in navigation, taking into account information types and scopes. An example classification, definition of set structures and their interrelations are presented in [4]. The mentioned meta-language should also be compatible with already adopted standards referring to selected areas of navigational information.

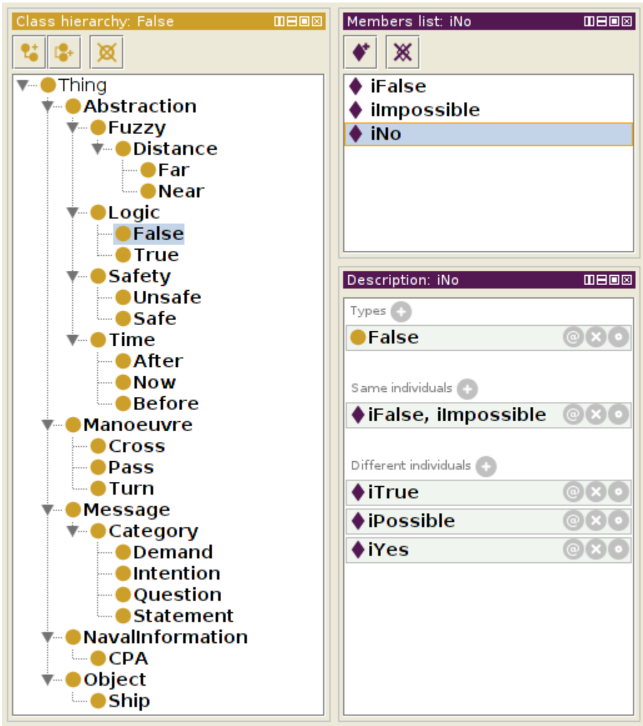

Figure 1. A window of Protége program: fragment of navigational communication ontology.

The construction of ontology requires that both terms and relations between them as well as their attributes should be defined. These are generally simple variables, storing one concrete value represented by one of the simple and enumeration type of data. Examples are such terms as true course, speed or bearing expressed by numerical values, and logical values represented by enumeration type of data (e.g. TRUE-FALSE or TRUE-FALSE-UNKNOWN).

Among others, the following are incorporated in the developed sub-ontology for communication (fragment):

- Types of messages:
  - statement (S)
  - question (Q)
  - intention (I)
  - demand (request) (D)
- Types of navigational information:
  - CPA (C)
  - TCPA (TC)
  - ship's course (G)
  - port side, to port (L)
  - starboard side, to starboard (R)
  - forward, the bow, ahead of (F)
  - aft, the stern, astern of (K)
  - ...
- Other types of information:
  - confirmation (acknowledgement) (H)
  - ...
- Types of manoeuvres:
  - passing (P), related with L and R
  - course alteration (T), related with L and R
  - crossing course (E)
  - ...
- Abstract terms:
  - near, about (N)
  - possible (M)
  - impossible (W)
  - safely (O)
  - dangerous/ly (U)
  - true (V)
  - false (X)
  - ...
- Objects:
  - Ship, related with L, R, F and S
  - ...

Writing down navigational information according to the adopted ontology necessitates coding it in a specific formal language, such as **XML** (eXtensible Markup Language). This enables automatic generation, validation and interpretation of XML messages in data communications systems. For that purpose the XML Schema can be used, as it can describe the content and structure of XML documents in XML.

4 AN EXAMPLE OF COMMUNICATION

The developed ontology of navigational information and sub-ontology for communication allow to formally write down simple messages as well as a dialog between two ships (navigators) or between a ship and a land-based centre, in which questions, intentions and other linguistic functions can be taken into consideration. To exemplify this, let us take a look at communication taking place in a very common situation: an encounter of two ships at sea. We present an automatic exchange of information that could successfully complement, and in the future partly or fully replace verbal communication.

Two motor-powered vessels (A, B as objects of type *ship*) are on crossing courses. In this situation, according to COLREGs, one ship has the right of way (ALPHA) and the other is a give-way vessel (BRAVO) (Fig. 2).

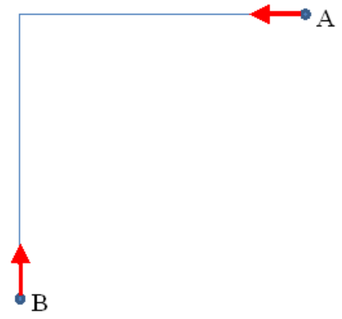

Figure 2. An example of navigational situation in stage 1.

Stage 1: When the ships are at approx. 7.5 Nm from each other, they establish contact:

1 ALPHA: CPA is 0 Nm and TCPA is 15
2 ALPHA: Pass astern of me.
3 BRAVO: OK., I will alter course to starboard.
4 ALPHA: OK.

After a certain time, the distance between ships decreased to 4,5 Nm (Fig. 3). The give-way vessel (BRAVO) has performed the mentioned manoeuvre but insufficiently – the risk of collision is still significant. The encounter comes into another stage and additional actions to prevent collision is required.

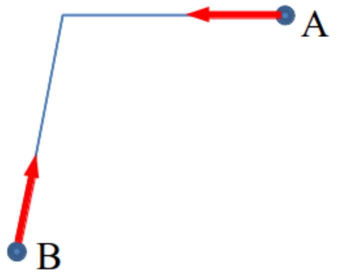

Figure 3. An example of navigational situation in stage 2.

Stage 2: When the distance decreases to 4.5 Nm, the following messages are exchanged:

1 ALPHA: CPA is 0.7 Nm and TCPA is 10
2 ALPHA: Alter course to starboard to keep 1.0 Nm astern of me.
3 BRAVO: OK., I will alter course 15 degrees to starboard.
4 ALPHA: OK.

Using the ontology of navigational communication, we can present the above messages mathematically (formal notation), that enables generating and interpreting of messages and their further processing in computer systems:

1 ALPHA: CPA is 0 Nm and TCPA is 15
2 WARNING ((CPA(Alpha, Bravo) is 0) and (TCPA(Alpha, Bravo) is 15))→ **W((C(A, B) is 0) and TC(A, B) is 15))**
3 ALPHA: Pass astern of me.
4 DEMAND (CROSS (Bravo, Alpha.Stern) is TRUE) → **F(E(B, A.K) is V)**
5 BRAVO: OK., I will alter course to starboard.
6 INTENTION(TURN(Bravo, Starboard) is TRUE) → **I(T(B, R) is V)**

7 ALPHA: OK.
8 STATEMENT (CONFIRMATION (Alpha) is TRUE) → **S(H(A) is V)**
9 ALPHA: CPA is 0.7 Nm and TCPA is 10
10 WARNING ((CPA(Alpha, Bravo) is 0.7) and (TCPA(Alpha, Bravo) is 10))→ **W((C(A, B) is 0.7) and TC(A, B) is 10))**
11 ALPHA: Alter course to starboard to keep 1.0 Nm astern of me.
12 DEMAND ((TURN(Bravo, Starboard) is TRUE) and (DISTANCE(Alpha, Bravo) is 1.0)) → **F ((T(B, R) is V) and (D(A, B) is 1.0))**
13 BRAVO: OK., I will alter course alter course 15 degrees to starboard.
14 STATEMENT((Bravo) is TRUE) and (COURSE(Bravo) is COURSE(Bravo)+15)) → **S((H(B) is V) and (G(B) is (G(B)+15))**
15 ALPHA: OK.
16 STATEMENT(CONFIRMATION (Alpha) is TRUE) → **S(H(A) is V)**

This form of representing certain procedures and intentions will enable using them in decision support systems. In addition, if it is presented in a readable manner (graphical or digital), it could be a valuable supplement to verbal communication, allowing to avoid ambiguity in expressing intentions and to formally acknowledge intentions. Additionally in order to such dialogue had place to appear navigation situation must be identify as requiring communication. based on CPA, TCPA values and inference methods the identification can be achieved [11].

5 NON-CRISP TERMS

Interpersonal communication in a natural language makes use of expressions with terms whose attributes assume crisp or non-crisp values. Non-crisp values, or precisely, the values of their attributes, may come directly from a natural language, e.g. "near", "far", "safely", "dangerously", "about", "safe distance", "dangerous distance". In the process of navigation, i.e. safe ship's proceeding in water area from point A to point B, such information attributes may be generated by shipboard equipment and determine ship's status as a state of a moving object in relation to other mobile or stationary objects. In the decision making process the navigator-operator accepts deviations within the assumed safety limits. Occurrence of non-crisp values appearing in a specific communication between human operators is a significant difficulty for formal description of such communication. For navigational communication ontology to offer its convenient use in a real navigational environment, it has to describe both crisp and non-crisp (fuzzy) terms.

Examples of non-crisp terms can be found in the criteria for safety assessment, namely CPA (*Closest Point of Approach*) and TCPA (*Time to Closest Point of Approach)*. This criteria are commonly used in ship encounter situations. Taking into account uncertainties (inaccuracies) in assessing safety is possible when we use, e.g. fuzzy logic, that allows to describe the safety level with linguistic values such as used by humans. This consists in assigning a degree of membership $\mu(x) \in \langle 0, 1\rangle$ to crisp values, e.g. measured distance x. It means that, apart from membership (1) or no membership (0) – as in the classical set theory – membership maybe partial. In case of CPA it means that, for a value CPA_L preset by the navigator, an interval of tolerance is assumed to exist $\langle CPA_{Lmin}, CPA_{Lmax}\rangle$ such that ($CPA_{Lmin} \le CPA_L \le CPA_{Lmax}$), and any value of CPA is assigned a degree of membership to the fuzzy set CPA_{LF}, described by a membership function $\mu(x)$ of this set (Fig. 4) [9].

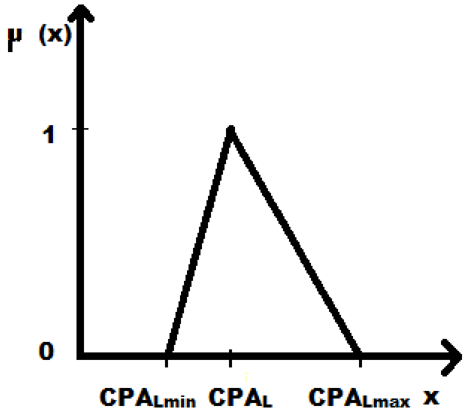

Figure 4 Membership function of a fuzzy set *fuzzy* CPA_{LF}.

Similarly for a value $TCPA_L$ also preset by the navigator, an interval of tolerance is assumed to exist $\langle TCPA_{Lmin}, TCPA_{Lmax}\rangle$ such that ($TCPA_{Lmin} \le TCPA_L \le TCPA_{Lmax}$), and a membership function $\nu(x)$ ($\nu(x) \in \langle 0,1\rangle$) for degree of membership to the fuzzy set $TCPA_{LF}$ is described by analogous function.

The criteria of ship domain and ship fuzzy domain can be similarly considered [8].

The use of fuzzy logic, methods and tools of fuzzy sets in particular, enables a formal description of non-crisp terms, their inclusion in messages and their interpretation and processing in computer systems, e.g. in inference processes. This description requires, among others, the defining of rules for mathematical notation of a message sent. The basic notation of message (p) is as follows:

$$p \rightarrow X \ is \ R$$

where X is a variable, ***is*** – sentence-forming functor, R – relation constraining the variable X.

Dealing with a more extensive message, we can additionally define a wider range of variable origin as a function and write the message notation in this form:

$$p \rightarrow A(X) \ is \ R$$

where A is a group in the sub-ontology to which X belongs.

In a natural language there are various types of sentences, e.g. affirmative (statement) or interrogative (question). For precise interpretation of message content we can additionally adopt a function identifying sentence form, where the whole message notation is an argument of that function.

6 SUMMARY

Safe navigation often depends on information access and capabilities of automatic exchange and interpretation of relevant information. These requirements are facilitated, among others, by the standardization of information content and form. Fast advancements in IT and ICT technologies broaden possibilities of automating communication processes so far executed verbally. This, however, necessitates construction of navigational information ontology, including a sub-ontology for communication. The authors present in this article the results of research on a system of automatic intership communication and co-operation. Based on the developed sub-ontology for communication, an example communication established between two ships in an encounter situation is presented. The authors propose to extend information ontology by including non-crisp terms, typical of verbal communication.

REFERENCES

[1] Banaś P., Using the Protégé environment for building ontology for automated communication system at sea, Zeszyty Naukowe nr 30, Maritime University of Szczecin, 2012, pp. 12-17

[2] IMO, Maritime University in Szczecin, Standardowe Zwroty Porozumiewania się na Morzu, Standard Marine Communication Phrases, translated by E. Plucińska, J. Kłosiński, Maritime University of Szczecin, 1997

[3] International Hydrographic Organization, http://www.iho.int

[4] Kopacz Z., Morgaś W., Urbański J., Information of Maritime Navigation; Its Kinds, Components and Use, European Journal of Navigation, vol. 2, no. 3, Aug 2004, pp. 53-60

[5] Maritime Navigation and Information Services MarNIS, Final Report 2009, http://www.marnis.org

[6] Motorways&Electronic Navigation by Intelligence at Sea MONALISA, http://www.monalisaproject.eu

[7] Pietrzykowski Z., Chomski J., Magaj J., Niemczyk G. 2006, Exchange and Interpretation of Messages in Ships Communication and Cooperation System, Advanced in Transport Systems Telematics, Ed. J. Mikulski, Publisher Jacek Skalmierski Computer Studio, Katowice 2006, pp. 313-320

[8] Pietrzykowski Z., Uriasz J., The ship domain - a criterion of navigational safety assessment in an open sea area, The Journal of Navigation (2009), 62, The Royal Institute of Navigation, Cambridge, pp. 93-108

[9] Pietrzykowski Z., Magaj J., Wołejsza P., Chomski J., Fuzzy logic in the navigational decision support process onboard a sea-going vessel, Lecture Notes in Computer Science, Volume 6113 / 2010: Artificial Intelligence and Soft Computing - ICAISC 2010, Eds. L Rutkowski, R.Scherer, R. Tadeusiewicz, L.A. Zadeh, Springer-Verlag Heidelberg, Part I, pp. 185-193

[10] Pietrzykowski Z., Hołowiński G., Magaj J., Chomski J., Automation of Message Interchange Process in Maritime Transport, Monograph International Recent Issues about ECDIS, e-Navigation and Safety at Sea, Advances in Marine Navigation and Safety of Sea Transportation, Ed. A. Weintrit, CRC Press/Balkema, 2011, pp. 119-124

[11] Banaś P., Pietrzykowski Z., Wójcik A., Wołejsza P., Automation of processes of identifying navigational situations requiring communication to be established by a sea-going vessel, Zeszyty Naukowe nr 36, Maritime University of Szczecin, 2013, pp. 15-21