III INTERNATIONAL CONFERENCE
TRANSPORT SYSTEMS TELEMATICS TST`03

ZESZYTY NAUKOWE
POLITECHNIKI ŚLĄSKIEJ 2003
TRANSPORT z.51, nr kol. 1608

ship control,
distributed artificial intelligence,
communication and cooperation of ship's

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SEA-GOING VESSEL CONTROL IN THE VESSEL COMMUNICATIONS AND CO-OPERATION SYSTEM

A system of ships communication and cooperation is presented. The system, implemented using the multi-agent technology, is supposed to assure proper communication between ships and the coordination of their actions. The paper discusses problems connected with the implementation of a decision module: analysis and assessment of a navigational situation (encounter situation) and solutions to collision situations in the sea-going ship control.

STEROWANIE STATKIEM MORSKIM W SYSTEMIE KOMUNIKACJI I KOOPERACJI STATKÓW

W artykule przedstawiono system komunikacji i kooperacji statków, realizowany w technologii multi-agentów. Zadaniem systemu jest zapewnienie właściwej komunikacji i koordynacji działań statków. Artykuł porusza problemy związane z wdrożeniem modułu decyzyjnego: analizy i oceny sytuacji nawigacyjnej (spotkanie statków) oraz rozwiązania sytuacji kolizyjnej w zadaniu sterowania statkiem morskim.

1. INTRODUCTION

Constant enhancement of the safety and service effectiveness of the marine transport calls for the implementation of increasingly modem tools supporting the ship management process. Navigational decisions made on board refer to different time ranges, including both voyage planning and the actual passage. Voyage planning requires strategic decisions, taking into account changes in the conditions during a voyage. Operational decisions include safe ship-handling along a determined route – prevention and avoidance of collisions. In such situations three basic functions are performed:

– information: acquisition and distribution of navigational information,

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- decision: analysis of a navigational situation, solving of collision situations, ship handling,
- communicative: communications, co-operation and co-ordination of actions with commanders of other ships.

More and more attention is paid to problems of communication and co-ordination between ships. These are in many cases indispensable in restricted areas. The manoeuvres of passing or overtaking another ship within fairways require coordinated manoeuvres of both ships. In open sea areas, too, direct exchange of information between ships may enhance the safety of navigation. The information may include: messages on present parameters of the ship state vector (position, course, speed), messages on commencing certain manoeuvres, messages confirming the fact or intention of executing a manoeuvre by a target ship. Thanks to such messages the actions of both ships can be coordinated. Consequently, it is possible to avoid a hazard of collision resulting from correct or incorrect actions of the target ship or from misinterpretation of the target ship's action.

2. THE SYSTEM OF SHIP COMMUNICATION AND COOPERATION

Each ship represents an autonomous object executing individual goals and tasks. The improvement of communications and co-operation between ships may considerably enhance the safety and effectiveness of the transport process. The acquisition of accurate data on ship's parameters requires direct communication. The work [10] proposes a system of communication and cooperation implementing the technology of multiagents (Distributed Artificial Intelligence). The system makes it possible to take over navigator's tasks by intelligent agents representing individual ships (Fig.1). Each of the agents executes three basic functions:

- acquisition and distribution of navigational information,
- analysis of a navigational situation and collision situation solution,
- communication, cooperation and coordination of actions with agents representing other vessels and interaction with a supervising navigator.

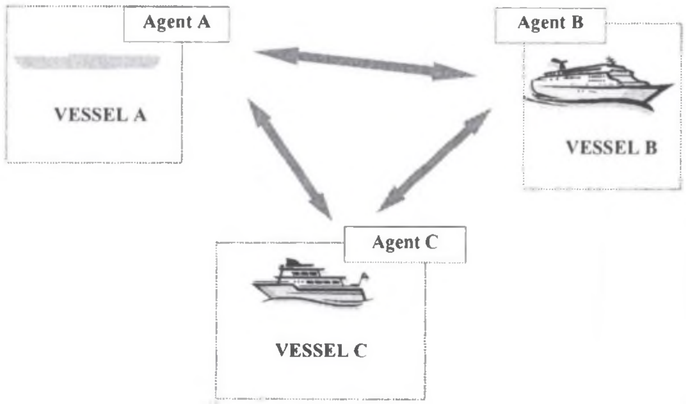

Fig.1. Vessel communication and cooperation system based on intelligent agents technology

To what extent the decisions taken are correct depends on many factors. These are the scope, kind and quality of available information describing a particular navigational situation.

3. SOURCES OF INFORMATION

Each ship carries equipment and systems recording and storing information used in the process of ship navigation. Due to their location, information sources are divided into local, or internal sources (shipboard) and external ones [8]. This is essential from the point of view of information availability. In both cases information can be delivered automatically or manually, at specified times or on request. Local sources of information have a form of written documents carried on board (ship's certificates, navigational publications, crew's documents and others) as well as ship equipment and systems. In the former case, information management is limited and only requires that information be properly recorded. Paper documents are gradually replaced by electronically recorded information that can be used faster and more effectively. Shipboard equipment and systems make it possible to obtain information in electronic form, thus it can be automatically processed in information systems. The log, gyrocompass, radar, echosounder, ARPA (Automatic Radar Plotting Aids), ECDIS (Electronic Chart Display and Information System), and sonar belong to this group of information sources. Information obtained from ECDIS is a sum of data from the components of ECDIS (e.g. log, radar, ARPA, electronic map, echosounder, GPS, DGPS and others).

For some time now external sources of information have been an important supplement. Various means of communications and systems allow to send to a ship navigational information and other supplementary information related to the ship's voyage.

External sources of information include GPS - Global Positioning System, AIS - Automatic Identification System, GMDSS – Global Maritime Distress and Safety System, NAVTEX (a system of automatic reception of navigational warnings and weather forecasts, VTS - Vessel Traffic Service.

4. ANALYSIS AND ASSESSMENT OF A NAVIGATIONAL SITUATION

The navigator's behaviour, i.e. decisions that he makes result from the current navigational situation. His task is to reach the destination while maintaining the conditions of safe navigation. Navigational situations that require action to be taken are as follows:

- ship encounters, and
- situations where stationary objects have to be passed (land, navigational obstructions, seamarks).

While making a decision navigators have to take into account the specific character of a navigational situation, regulations in force [1], and the principles of good maritime practice (ship's commander is obliged to taking actions aiming at avoiding dangerous situations). Numerous factors taken into account by the decision-maker include ship and area properties and parameters, traffic conditions, hydrological and meteorological conditions, etc. The criteria for making a decision (decision-maker's criteria) are essential. Information describing a problem requiring a decision to be made may be of different kind: deterministic, probabilistic, uncertainty, fuzziness.

The analysis and assessment of a navigational situation based on some assumed criteria are most important in the decision making process. From information on the present navigational situation – type of the area, its specific character, encounter situation (ship, stationary objects, navigational obstructions, seamarks) the regulations applicable in a given situation are selected and prioritized. Based on the regulations in force and adequate criteria for the assessment of a navigational situation, a decision whether to take action or not is made. When an action has to be made, its kind and scope is defined. The following criteria for a navigational situation assessment can be distinguished:

- criteria directly imposed by the regulations,
- closest point of approach,
- ship domain,
- fuzzy closest point of approach,
- ship fuzzy domain.

The criterion of the closest point of approach, applied in the automatic radar plotting aid (ARPA), is widely used for navigational situation assessment. It is assumed that the navigator will determine the minimum (limit) distance at which other objects will be passed (CPA_L). An additional criterion is the time to closest point of approach ($TCPA$) – its minimum value $TCPA_L$ is also defined by the navigator.

There are also criteria taking into account both CPA_L and $TCPA_L$ at the same time, and others, making it possible to determine quantitative measures specifying the level of navigational safety.

The area around the vessel that the navigator wants to keep clear of other objects is referred to the ship domain [3]. Any entry into the dangerous zone – ship domain – is interpreted as a threat to navigational safety. The literature on the subject includes both two- and three-dimensional domains. The shapes of two-dimensional domains can be circular, rectangular, elliptical, polygon, or more complex figures.

The term 'ship fuzzy domain' [9] means an area around the ship which should be maintained free from other craft and objects by the navigator; its shape and size depend on the preset level of navigational safety, understood as the degree of membership of a navigational situation to the fuzzy set "dangerous navigation".

Analogous to the concept of fuzzy domain is the fuzzy closest point of approach. Defined by the navigator, the closest point of approach CPA_L is a distance at which two ships should pass each other. When the two ships pass at a slightly greater distance, the safety level will be higher. A 'slightly lowered' value CPA_L ($CPA < CPA_L$) is allowed, as the ships will pass each other anyway and no collision will take place. In this way a tolerance interval $\langle CPA_{Lmin}, CPA_{Lmax} \rangle$ is assumed, describing the fuzzy closest point of approach.

Action will be taken when a hazard is observed. For instance, for the criterion of the closest point of approach the condition for safe passing of a target has this form:

$$CPA \geq CPA_L \tag{1}$$

If this condition is not satisfied, action has to be taken (course and / or speed change) in order to pass a target at a distance not smaller than the assumed CPA_L.

An additional criterion can be used: $TCPA$ – time to the closest point of approach – its minimum value $TCPA_L$ is also defined by the navigator. If the condition (1) is not satisfied, then non-fulfillment of the condition

$$TCPA \geq TCPA_L \tag{2}$$

means that immediate collision avoiding manoeuvre has to be executed for the ship to pass a target at a safe distance.

When no hazards occur, ship control aimed at proceeding on course along a chosen trajectory consists of::

- maintaining a course;
- manoeuvre of altering a course at some turning points.

When a risk of collision is observed, ship control has to focus on collision avoidance and further proceeding towards destination:

- manoeuvre or manoeuvres of course and / or speed change to pass an object (ship) at a safe distance;
- manoeuvre or manoeuvres of course and / or speed change to return to the preset (original) trajectory or preset (original) course.

5. DECISION PROCEDURES

When a danger to navigation (object) appears in the process of safe ship control, the following stages can be distinguished in the navigator's activities:

1) detection and identification of the object;
2) situation analysis and assessment;
3) determination how to solve a collision situation – choice of a preventive manoeuvre – (course or speed change manoeuvres);
4) determination of manoeuvre parameters (moment of starting the manoeuvre and its parameters – new course, speed):
   a) determination of a safe passing distance to the object,
   b) determination of own course and speed in order to pass the object at a safe distance;
5) performing a preventive – collision avoiding – manoeuvre:
   a) ship movement control until safe passing distance is reached: determination of rudder setting and a change in engine setting,
   b) manoeuvre performance control;
6) return manoeuvre performance, in order to reach original movement parameters – course and speed or the original trajectory plus course and speed;
7) manoeuvre performance control;.

The stages 5 and 6 can also be considered as one, particularly in restricted areas, which results from the necessity of possibly quick returning to the original course and trajectory.

The following manner of performing stages 1, 2 and 3 was adopted:

- stage 1 is performed by means of object acquisition and identification systems available onboard,
- it is possible in stage 2 to use the criteria for navigational situation assessment presented in chapter 4,
- procedural principles at stage 3 are defined on the basis of the table containing recommended manoeuvres, in compliance with the regulations in force.

The procedure for planning and execution of manoeuvres (stages 4 to 6) can be described in the form of decision procedures as follows:

a) collision avoidance manoeuvre,
b) manoeuvre of returning to the original course after a collision avoidance manoeuvre,
c) collision avoidance manoeuvre with a return to the original course,
d) return manoeuvre to the original trajectory,
e) return manoeuvre to the original course after a return manoeuvre to the original trajectory,
f) return manoeuvre to the original trajectory and original course,
g) collision avoidance manoeuvre and return manoeuvre to the original trajectory and original course.

According to the principles of good maritime practice the collision avoidance manoeuvre should be executed: 1) in compliance with the regulations, 2) in a noticeable manner, 3) early enough.

6. SHIP CONTROL MODULE

Ship control in an open area has been analysed. In practice, ships execute a collision avoidance manoeuvre and return to their original course. The time of returning to the original trajectory is much longer as the ship does it gradually.

The work [11] proposes the determination of a safe trajectory of the navigator's own ship by means of a modified version of the virtual ship method [5].

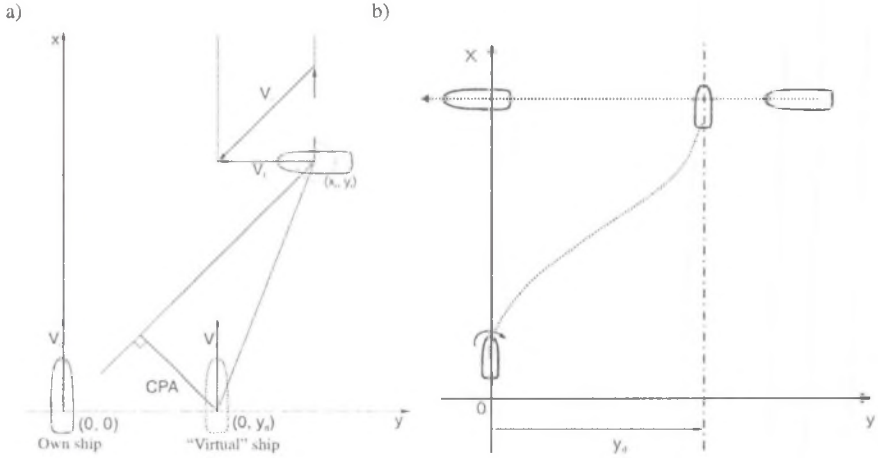

Fig.2. The method for determining a safe trajectory using a 'virtual' ship: a) virtual ship's position; b) parallel trajectory

The execution of a manoeuvre thus planned follows the decision procedure for a collision avoiding manoeuvre and return to the original course. The manoeuvre can be performed automatically with the use of trajectory tracking controllers. The return to the original trajectory and original course can be performed in the same way.

7. PRINCIPLES OF COMMUNICATION

Following AIS standards [13], the authors have assumed the same intervals for sending messages (system AIS, class A) for the system of ship communication and cooperation:

- ships at anchor or moored and moving not faster than 3 knots: three minutes,
- ships at anchor or moored and moving faster than 3 knots: 10 seconds,
- ships proceeding with steady course, at 0-14 knots: 10 seconds,
- ships proceeding at 0-14 knots and altering course: 3.3 seconds,
- ships proceeding with steady course at 14-23 knots: 6 seconds,
- ships proceeding at 14-23 knots and altering course: 2 seconds,
- ships proceeding on constant course at speed over 23 knots: 2 seconds,
- ships proceeding at a speed over 23 knots and altering course: 2 seconds.

AIS systems installed on board ships make it possible to receive information on current movement parameters of other ships which send reports within the system. It is very important to use the information.

In the case of direct communication between ships it is necessary to establish standards for communication. The work [10] proposes the use of **TCP/IP** protocol as a protocol for data transmission. Communication between agents representing individual ships is maintained through the KQML (Knowledge Query and Manipulation Language) [7]. KQML has a design and properties enabling intelligent communication, i.e. it facilitates cooperation, coordination of actions and negotiating processes. KQML is independent of the transporting mechanism, of the language in which the message contents is expressed; it is also independent of ontology. Apart from standard instructions (performatives), the language allows to define the ontology for a uniform manner of information exchange. Accounting for the particular character of ship-to-ship communications, these authors propose that standards described in the works [6, 12] are assumed for the description of marine navigation.

The system may be a component of the marine intelligent transport system, and then, part of designed intelligent transport systems encompassing all modes of transport.

8. SHIP ENCOUNTER SIMULATION

The system of communication and cooperation has been implemented with PC class computer systems operating in a local area network [10]. Each of the agents representing a given object (ship) operated in a separate computer system. Communication between the agents was carried out through the communication platform JatLite. Such platforms feature methods and classes which allow, among others, to establish communication between a few or more computer systems. The communication used the TCP/IP protocol as a protocol for data transmission. The agents communicated one another using KQML, applying the ontology proposed in chapter 7.

The considered encounter situations were those in an open sea area. Ships' dynamics was simulated with the use of a verified ship's analytical model of m/f Sniadecki [2, 4]. The collision regulations in force for good visibility. The assumed frequency of communication (exchange of information) was 10 seconds. It was assumed that there is no AIS system. The simulation was executed in accelerated time.

The simulation produced an encounter of two ships having the same navigational status [1] in an open area covered by the communication and coordination system. In compliance with the regulations in force, in the presented collision situation the ship A is obliged to give way to the ship B. After logging into the system, the ships start sending messages on current movement parameters. After an analysis of a present encounter situation, and observing that the situation may lead to a collision, the ship A sends to the ship B a message recognizing the collision situation and confirms its obligation to execute a collision avoiding manoeuvre. The ship plans a collision avoiding manoeuvre followed by a return to the original trajectory. It sends a message on the planned manoeuvre and the time of its beginning. The ship B confirms the reception of the message on ship's A intention. In compliance with applicable regulations and principles of good maritime practice the ship A makes a preventive manoeuvre and returns to its original trajectory.

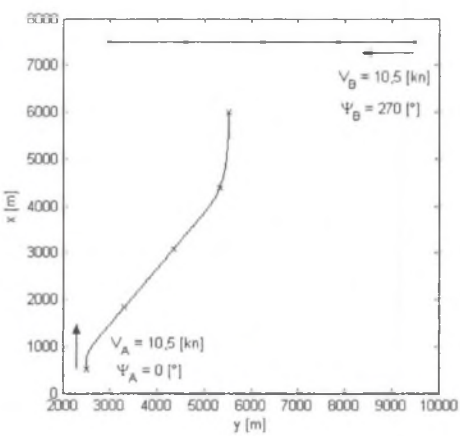

Fig.3. Trajectories of ships in an encounter situation in an open area; simulation time 1200 [s]; positions (x) at 300 [s] time intervals;

02 A	106382035145 (tell :sender A :ontology Shin :content (20 0.0 608.6 2500.0 10.5 0.00) :receiver B :language KQML)
03 A	106382035644 (tell :sender A :ontology Shin :content (30 3.0 663.1 2500.7 10.5 -0.14) :receiver B :language KQML)

Fig.4. A set of messages transmitted from ship A to ship B; Shin –ship's information

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