MULTI-AGENT SYSTEM FOR SIMULATION OF SURROUNDING THE SEA VESSEL

Petr Sosnin
Computer Department,
Ulyanovsk State Technical University,
Severny Venetc, Ulyanovsk, 432027, Russia
E-mail: sosnin@ulstu.ru

KEYWORDS
Multi-agent system, radar station, sea vessel.

ABSTRACT
There are many different tasks which are to be solved on a sea vessel on the base of the primary information from radar stations (RSs) about moving objects in the vessel surrounding. Frequently enough such information is being entered from several RSs with different characteristics. The redundancy of informational flows is used for achieving many positive effects, for example for increasing the adequacy of vessel environment models. The processing of such redundant information is named as data fusion. The article presents the multi-agent system (MAS) for solving the data fusion task on the sea vessel. The suggested MAS uses the program agents not only for dynamic objects but for units of informational flows as well.

INTRODUCTION
The rationality of the sea vessel navigation essentially depends on adequate monitoring the above-water and air environment. In the general case such environment includes different kinds of moving the water and air objects with different characteristics and some of them can be combined in groups (Waard 2008).

The different kinds of vessels navigation equipment and other outside navigation systems are appointed to gathering the necessary information for solving the data fusion task. All of these means are combined in a multi-sensor multi-target tracking system (MTTS) of the vessel. Such MTTS is very important for the warship. Let us mark that “Data fusion is now the recognized term for the processing needed to convert the data into an up-to-date model (or picture) of the world-of-interest, suitable for human decision making ((Waard 2008).”

In this article the multi-agent approach to solving the data fusion task in the frame of the MMTS is presented. The solution is aimed at the simulation of the targets picture around the vessel $V_0$ of the warship type.

First of all agents are used for modeling the targets each of which can be a vessel or an air object. But agents also are used for presenting features (characteristics) of discovered targets.

The suggestion takes into account that several radar stations (RS) are used on the vessel as sources of primary informational flows about observing targets. Moreover, different RSs can have different time of observing (scan time $T_s$) and can generate the information with different types of targets characteristics.

The use of agents simplifies the solution of the data fusion task in described conditions. The agent approach to the simulation of the vessels movement is applied to the collision avoidance task as well. In this task the agent model of the own vessel $V_0$ is created and combined with agents of other vessels moving inside the investigating area.

Requirements of suggestion means are defined for their implementation in the Question-Answer Instrumental System WIQA (Sosnin 2009). That helps to adjust and unite the tasks of identifying targets and their groups with tasks of visualizing the targets picture around the vessel $V_0$ and with the collision avoidance task of vessels. The model of the international rules for vessels collision avoidance was created and included into the developed multi-agent system named MasWIQA.

RELATED WORKS
The data fusion task can be divided on subtasks by different ways. But in any case the division will include the subtask of normalizing data flows from different sensors, the subtask of the data association, the subtask of targets grouping (on the sea surface and in the airspace) and the visualization task which simulates the targets picture around the vessel $V_0$. All of these basic subtasks are solving in MasWIQA with the help of a set of tasks which are being solved by software agents. Moreover, the special means are included to MasWIQA for solving the collision avoidance task for vessels on the base of data obtained from the data fusion task.

These positions were taken into account for analyzing the related works. The analyses has helped to define three important types of related works connected with...
the data association, collision avoidance and the usage of software agents in named tasks and subtasks.

For the data association task it is possible to indicate the following algorithmic versions:

1. Algorithms based on statistical properties of estimations of coordinates and parameters of the targets, namely, algorithms existential association (Capponi et al. 2004; Kaplan et al. 2008).
3. Algorithms based on the usage of additional sources of the information (Bar-Shalom et al. 2005).
4. Algorithms of the data association based on the usage of Neural Networks (Chung et al. 2007).

As a rule, for the majority of the marked algorithms (and related them) the association is fulfilled on two stages. The first association stage consists of integrating the corresponding data values in current moments of the modeling time. At the second stage the received groups of data are being identified with already available trajectories of targets, on the base of various properties of the received data.

It is necessary to notice that the Internet-search of publications about data fusion with multi-agent solutions has been without interesting results. For decreasing the risks of collisions, the international rules for avoidance (COLREG-72) are agreed for their execution by vessels of various types (Cockcroft 2003). In general case the vessel collision avoidance is a complicated dynamic process the exact theoretical description of which is impossible even for two moving ships. Therefore such processes are being fulfilled on the base of precedents, simple models of situations and decisions of the responsible persons.

To improve the safety of vessels the different kinds of expert systems have been created, for example in the paper (Grabowski and Wallace 1993) on the base of gaming, in the paper (Tran et al. 2000) on the base of journey planning and in the paper (Liu et al. 2006) on the base of Fuzzy-Neural Network possibilities. It is necessary to notice that in all named papers normative rules of the COLREG-72 is not mentioned.

The expert system described in this paper uses the multi-agent technique and modeling the reasoning. The possibilities of multi-agent modeling the vessels are presented in the paper (Liu and Yang 2007) where agents are used for simulation aims but without direct access to COLREG rules. The principal role of case-based reasoning in the collision avoidance task is presented in the paper (Liu et al. 2008). But combining the multi-agent analysis with question-answer reasoning is not used in related papers.

MODEL OF INFORMATIONAL FLOWS

In the developed simulation system as in related systems the first step of the data fusion process begins with solving the subtask of normalizing data flows from different sensors. The solution of this subtask is based on the following mathematical model of a set of informational flows:

\[ \mathbf{G} = \mathbf{G}^p \cup \mathbf{G}^s = \{ \mathbf{G}^p_k \} \cup \{ \mathbf{G}^s_k \} \]

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It is necessary to notice that the presented model opens possibilities for the parallel processing informational flows and such possibilities are used in their multi-agent version.

MULTI-AGENT MODELING THE DATA FUSION

The mathematical model of the set of informational flows helps to single out the flow for each characteristic of any target. It, in turn, allows to start the process of the informational redundancy for each target characteristic, for example, such as the bearing or distance each of which has a probabilistic type and is measured with definite accuracy.

The next step in processing of data is connected with solving the data association task and task of targets grouping. Each of these tasks must be solved for vessels and air objects differentially. The last data fusion process provides gathering the values of characteristics into the navigational model for each
observed target for following use in decision-making on the vessel V₀. The described chain of actions has led the author to its multi-agent structure presented in Fig. 1.

The following responsibilities are appointed to classes of agents:
- class $\mathcal{A}^0$ of “agents” represents sensors means (SM), in particular, radar stations $RS^p$ which send flows of the primary information to MasWIQA (“agents” of this class is out the range of MasWIQA);
- class $\mathcal{A}^1$ named “N_Agents” provides normalizing data flows from different sensors;
- class $\mathcal{A}^2$ named “Ch-agents” each of which processes the redundant information about the definite characteristic from its normalized flows;
- class $\mathcal{A}^3$ named “Agents-Ch” solves the data association task and the task of grouping the targets;
- class $\mathcal{A}^4$ named “T_Agents” the agents of which assemble data for targets such as vessels $\{V_m\}$, air objects $\{P_q\}$ and their groups $\{G_r\}$.

The structure of MasWIQA as a whole describes by the following symbolic expression:
$$\text{MasWIQA} = (\text{WIQA, Env}(t), S(\mathcal{A}^1, \mathcal{A}^2, \mathcal{A}^3, \mathcal{A}^4), t)$$
$$\text{Env}(t) = (\text{Cart}(t), \text{Aer}(t), \text{Isom}(t))$$

All agents which are existing in MasWIQA in definite modeling time $t$, are implemented with the usage of WIQA means added by plug-ins visualizing and simulating the targets picture as the views composition of an environment Env(t) around the vessel V₀. The targets picture consists of three views one of which is view Chart(t) presented in Fig. 2. It shows all vessels on the map of the definite part of the sea (the cartesian system of coordinates).

Two other views are shown in Fig. 3 where the view Air(t) registers all air objects as usually they are viewed on the RS screen and the view Isom(t) which presents all targets in an isometric picture.
QUESTION-ANSWER PROCESSOR WIQA

The toolkit WIQA (Working In Questions and Answers) is intended for the maintenance of question-answer reasoning (QA-reasoning) in the collective problem-solving and decision-making in the designing of software intensive systems. This toolkit helps to create and use the QA-model for any task including its subtasks during the conceptual solving this task. Any QA-model is developing during solving process and its finishing state is a pseudocode program of the corresponding task.

WIQA has been implemented in several versions. Its last versions named WIQA.Net, has been created on C# at the platform of Microsoft.NET 3.5. This version of WIQA gives the possibility to execute any pseudocode program created with its help and for this reason WIQA.net can be named as the processor (QA-processor).

The main interface form of WIQA is presented in Fig. 4. This form gives the visual and touchable access to the tasks tree of the conceptual design and the QA-model of any task of this tree.

The structure of WIQA, its functional possibilities and positive effects are described in a set of publications among which the sufficient full description is given in the article (Sosnin 2009).

The features of WIQA are reflected by its general components structure presented in Fig 5. A set of specialized plug-ins have been developed in the creation of MasWIQA.

![Figure 4. The main interface of WIQA](image)

![Figure 5. Components structure of WIQA](image)

![Figure 6. Connection of agent with its surrounding](image)
DATA ASSOCIATION TASK

After processing the entrance information by agents which are provided the normalization of informational flows, the data association subtask must be solved. This subtask can describe by the following statement:

“The set of normative flows of targets characteristics values presents the processed primary information about the definite set of targets each of which could be named variously in targets lists of different RSs. It is required to appoint the unique name for each target in all normalized informational flows corresponding to this target (if target exists in the vessel surrounding).”

This task is solved for vessels and planes a little variously but with the usage of the techniques based on the statistical hypothesis testing in both cases. The essence of the decision we shall explain on an example for two RSs which are interacting with the definite quantity of targets.

In case when N vessels are moving inside the investigated area the first RS\(^1\) can register N\(^1\) targets and the second RS\(^2\) can register N\(^2\) targets. It is possible that N\(^1\)≠N\(^2\) and even N\(^1\)>N\(^2\). For each pair of targets Ob\(_i\) and Ob\(_j\) from targets lists of both RSs let’s create two probabilistic variables (with the normal distribution)

\[
\xi^a = b^a_i - b^a_j,
\]

\[
\xi^\beta = d^\beta_i - d^\beta_j,
\]

where b\(^a\)_\(_i\) and d\(^\beta\)_\(_j\) are the registering values of the bearing and distance for targets correspondingly.

If objects Ob\(_i\) and Ob\(_j\) represent the same object then \(M\xi^a = 0, M\xi^\beta = 0\) where M is mean (hypothesis H\(0\)); otherwise (hypothesis H\(1\)) even one of the mentioned population means should be distinct from zero.

As random variables \(\xi^a\) and \(\xi^\beta\) are considered independent the probability of a correct identification is defined by the following expression:

\[
P_\Phi = p^{\text{hit}}_0 \times p^{\text{hit}}_\beta,
\]

where \(p^{\text{hit}}_0\) — probability of a correct identification of the bearing, and \(p^{\text{hit}}_\beta\) — probability of a correct identification of the distance.

In presented case for estimations of samples the following critical values are used:

\[
\gamma_\Phi = \sigma_\Phi \Phi^{-1}\left(\sqrt{1 - \epsilon}\right),
\]

\[
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\]

On the base of such estimations a group of software agents belonged to class A\(^3\) was created. These agents take into account all pairs of targets. They use statistics of samples and solve the appointment task by the Hungarian method.

It is necessary to notice that the data association task for air targets is solved by the similar way. In this case three random variables \(\xi^a\), \(\xi^\beta\) and \(\xi^\gamma\) are took into account. The third variable \(\xi^\gamma\) reflects the difference between targets heights.

In MasWIQA the task of targets grouping is solving by software agents as well. This task is defined as a task of image recognition the statement of which is oriented on the proximity of targets in their dynamic characteristics. The task of grouping is solving for vessels and air targets differentially.

SIMULATION OF SURROUNDING

The last subtask in data fusion is the targets visualization task. The main aim of this task is to present the targets picture in forms which are suitable for the decision-making.

A very important measure of the suitability is the accessible possibilities for estimations of the targets picture by persons who are responsible for decisions. For this reasons in all views of the targets picture the screenshots of which are presented above the distance measures are opened for their visual applying (without the use of computing).

The possibilities of estimating for air targets are supported by the use of the model of the radar screen which is added by the column of air echelons of the flight. MasWIQA opens such possibilities not only for RS\(\text{es}\) operators but for sailors on duty as well.

MasWIQA is developed as the training system. Therefore it gives the possibility for initial creating the targets picture including vessels and air targets and for appointing them random values of characteristics. The simulation process can be activated after the initial assigning.

The simulation of the targets moving is also used for solving the collision avoidance task for vessels. This task is being solved in the training regime with the usage of the specialized Expert System (ES) which is emulated by means of MasWIQA.

The simulation is aimed at the estimation of the collision threat for own vessel V\(_0\) with others moving vessels. The estimation includes two line of the behavior for the sailor on duty and for agents modeling vessels.

The sailor on duty must act in accordance with COLREG’72 but this document is a very complicated. Therefore all rules of COLREG’72 have been transformed to precedents models and have been included to the knowledge base of the ES.

EXPERT SYSTEM

The adaptation of MasWIQA to the decision of expert system tasks in collision avoidance situations is presented in Fig. 7. This “Block and line” view is chosen specially, so that it is corresponded to the typical scheme of the ES. In Fig. 7 the structure of the ES is presented against background of the QA-model to emphasize functional character of immersing the ES to the data model of the QA-type.
The initiator of the second version of the interaction with agents is the user. The information from agents about their actual relations with the COLREG gives the user the possibility to compute a set of potential facts about changing the vessels movement in the chosen interval of time.

**SIMULATION OF PRECEDENTS**

The precedents in accordance with their types and structures are filled by the informational content extracted from the COLREG-72 and from informational sources about “a good sea practice”. The kernel of the knowledge base includes 145 rules (precedents) each of which corresponds of the definite COLREG rule or its detailed version. The content of precedents will be demonstrated on the example of “Rule 15” which regulates the normative behavior in situations of crossing for power-driven vessels $V_{0}^{PD_1}$ and $V_{0}^{PD_2}$.

The textual model of the presented precedent (production) repeats the text of the corresponding rule “When two power-driven vessels $V_1$ and $V_2$ are crossing so as to involve risk of collision, the vessel…”. The predicate model presents the content of the production in the following form:

```
Has1(V_1, VPD1) & Has1(V_2, VPD2) &
& Has2(V_1, place_1) & Has2(V_2, place_2) &
& Has3(V_1, bear_1) & Has3(V_2, bear_2) &
& Has4(V_1, vel_1) & Has4(V_2, vel_2) &
& Has5(V_1, “keep out of the way”) &
& (bear_1 – bear_2 > 11.5°) &
& (CPA - D^{DDA} - ΔD^{DD} ≤ 0) → Manoeuvre Mi,
```

where number “11.5°” is a number from the “good sea practice” and “manoeuvre Mi” is a version of the necessary behavior of the vessel $V_1$.

The QA-model (protocol) of the precedent presents the dialog aimed at the logical estimation of the condition part of the predicate model. The source code is formed as a result of pre-translating the predicate model on the C# code which is compiled to the executable code. The simulation is aimed at the estimation of collision threats for own vessel $V_0$ with others moving vessels. The estimation includes two line of the behavior for the sailor on duty and for agents modeling vessels. The sailor on duty must act in accordance with COLREG’72 but this document is a very complicated. Therefore all rules of COLREG’72 have been

**CONCLUSION**

The paper presents the multi-agent approach to the solution of the data fusion task which is implemented on the base of question-answer means. The suggestions are based on the usage of four classes of agents. The first class of agents is intended for the work with primary information about characteristics of the dynamic objects received from several RSs and equipments of other types. Agents of this class provide transforming the primary informational flows to the
normative forms. Any agent of the second class is responsible for processing the redundant information about definite characteristics from its normalized flows which correspond to the acted RSs. Agents of the third class are solving the data association task and the task of grouping the targets. The solution process of the data fusion task is a continuous work in which the targets visualization supports by agents of the fourth class. Vessels agents included in the fourth class take part in solving the collision avoidance task.

There are a number of positive effects which are achieved in data fusion and in the collision avoidance practice by the usage of agents in the base of the QA-approach and means of MasWIQA:

1. The QA-approach supports the uniform way of modeling any task which is being solved for monitoring the nearby surrounding of the own vessel.

2. QA-means give the possibility for modeling any agent as the specialized task with subordinated subtasks in the tasks tree of the monitoring system MasWIQA.

3. The multi-agent implementation promotes the parallel processing of the informational flows and solving the other presented tasks.

4. Including the multi-agents model to the collision avoidance analysis gives the user the possibility to compute a set of potential facts about changing the vessels movement in chosen interval of time.

5. Uniform QA-means are being used for (preliminary and/or real time) programming and reprogramming any function of MasWIQA and for including the function as the task in the tasks tree in any time.

In this time the described multi-agent system are being investigated and fitted for its developing till the version which could be used in the real sea practice. The main difference between exploitation version and version for training are only in different sources of the input information.

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PETR SOSNIN was born in Ulyanovsk in the USSR, on July 12, 1945. He graduated from the Ulyanovsk Polytechnic Institute (1968). His employment experience includes the Ulyanovsk Polytechnic Institute and Ulyanovsk State Technical University. His special field of interests includes AI applications for the computer aided design. P. Sosnin has defended the doctor degree in Moscow Aviation Institute (1994). He is an author of eight books and more two hundred articles.