Virtual Testbed for Marine Objects Behaviour Investigation

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ABSTRACT

Features of virtual testbed development for modelling of complex systems behaviour in various operation conditions are considered. Dynamic knowledge base of virtual testbed is developed on the basis of principles of information processing in multiprocessor computing environment with use fuzzy and neural network models, virtual reality and multiagent systems. Integration of various computer resources is carried out with the help of GRID technologies. Practical example of virtual testbed is shown.

KEYWORDS

Virtual testbed; mathematical modelling; GRID computing; problem solving environment.

INTRODUCTION

Design of complex technical objects and marine operations planning are result of complicated joint work of many various specialists. Traditional procedure of such work is long and requires carrying out of model or full scale experiments, calculations, variations, decision making. New information technology takes possibility to reduce terms of design, to develop virtual environment where specialists can carry out modelling, check many variants, to improve quality and complexity of result. Now it is possible to consider GRID technology as a tool that combine various resources and organizations in common recourse (in terms of GRID it names virtual organization) (see Foster, 2001). Such integration results in organization of problem solving environment.

Necessity of information technologies integration has arisen both in sphere of straight analysis of complex situations, and synthesis of models for situations simulation at decisions making. In problems of decision-making in safety navigation maintenance and aircrafts landings in sea conditions this integration is concretized both in development of complex systems modelling like «virtual testbed», and real time intelligent systems for monitoring and control of complex dynamic objects. At that «virtual testbed» concept in considered field is connected with development of new intellectual support tools. These tools are related with methods of decision-making in the worst-case and extreme situations.

VIRTUAL TESTBED CONCEPT

Modern transport objects (ship, airplane, helicopter, etc.) have reached such high level of complexity and functionality, that mistakes made by operators can result in dangerous consequences. The operated object is more complex and the environment is more aggressive and unpredictable, the consequences of critical situations can be more serious. Therefore development of decision support systems with a view of monitoring and prevention of dangerous situations is urgent question now. Such systems have to be used in operators training to behaviour tactics in extreme situations.

The proposed concept defines organization of modelling control complex, as complicated multilevel intelligent system consisting of the following core components:

- hierarchies of imitating models specifying considered problem areas;
- hierarchies of analytical models giving simplified description of various parties of modelled phenomena;
- information system including DB and KB based on methods and models of AI;
- control systems and interfaces providing interaction of all system component and interactive work with operator.

"Virtual testbed" development represents complex multistage iterative process. The basic feature of this process consists in necessity to carry out coordination (at conceptual, algorithmic, information and program levels) of heterogeneous models describing various parties of functioning of investigated objects. Choice of admissible alternatives is based on compression of considered variants set by alternatives analysis in complex, especially in non-standard (supernumerary and extreme) situations. Concept of such analysis assumes that estimations of expenses for realization of obtained decisions (expenses for the charge of used resource) do not decrease and become more and more exact in process of admissible alternatives set narrowing. Thus it is considered that control processes by structural dynamics of system have multilevel, multistage and multifunctional character.

Functioning of system is carried out on the basis of a special firmware in accordance with the structure presented on Fig.1. (Bogdanov, et al, 2004, 2005)

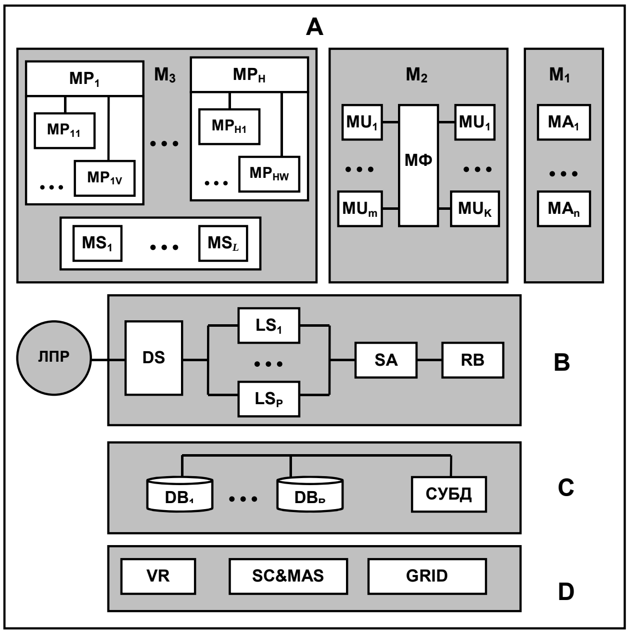

Fig. 1: Structure of virtual testbed: A is a block of models; B is a block of control and interpretation; C is a block of dataware; D is a block of information technologies; M_1 is a block of models for estimation of dynamic object (DO), navigation and operation situation; MA_i (i=1,…,n) are models for analysis of DO and environment behaviour; M_2 is a control models block; MΦ are models of central control and on-board systems functioning; MU_j (j=1,…,m) are control complex elements interaction; MU_k (k=1,…,K) are models of DO systems interaction; M_3 is a planning block; MP_h (h=1,…,H) is a block for long-term and operative planning by elements of virtual testbed; MP_{11} … MP_{1V} are long-term planning models; MP_{H1} … MP_{HW} are operative planning models; MS_l (l=1,…,L) are control models for component structures of virtual testbed; DS is dialog system for virtual testbed control; LS_p (p=1,…,P) are local control systems; SA is a block of scenarios and adaptation; RB is a block of practical recommendations; DB_r (r=1,…,R) are data bases about virtual testbed state, DO and environment; VR are virtual reality technologies; SC&MAC are soft computing and multiagent technologies; GRID is a technology for virtual testbed

COMPLEX MODELLING ENVIRONMENT

Complex modelling environment of a high degree of adaptability is based on use of multiagent systems (Gorodetsky, 1996), "soft calculations” concept (Zadeh, 1994, Bogdanov et al., 2001) and real time systems (Degtyarev, 2003, On-board, 2006). It allows to involve in such environment additional resources. They could be both new computers, and various modelling environment elements (dynamic objects, information systems, sources of measuring information, etc.). Offered «virtual testbed» essentially differs from existing information systems and simulators and provides the complex problem decision.

Increase of complexity in situations estimation and forecast reliability at virtual testbed functioning is achieved with use of new approach to information processing based on development of “soft computing” concept. This approach is based on two theoretical principles allowing providing the rational organization of computing technology of parallel information processing in the problem of analysis and forecast of extreme situation development. Also it exploits the possibility to formalize information stream at realization of fuzzy inference models in multiprocessor computing environment (Nechaev, 2002).

Competition principle provides comparative analysis of results of situation estimation with the help of traditional algorithms and neural network models. Relevant procedures of parallel information processing reflect the process of virtual testbed functioning from the moment of the information inflow from measuring system up to procedure of inference and practical recommendations generation.

Principle of fuzzy information formalization in multiprocessor computing environment allows carrying out of parallel chains of fuzzy conclusions in continuously changing conditions of dynamics of object and environment. It uses also the possibilities to make programs for complex models of representation and processing of knowledge fuzzy system; to provide functioning of complex in real time; to cut down expenses on hardware development and to remove problems of parallelization of computing processes with essential irregularity characteristic for the integrated complexes

Realization of the above theoretical principles enables to increase efficiency of functioning of virtual testbed under continuously changing external conditions and dynamics of modelled objects and systems. The practical importance of information streams processing in real time is caused by aspiration to increase the speed of machine calculations by the way of computing algorithms parallelization and their realization on supercomputer platforms. Check of a correctness of control algorithms and decision-making is carried out by the formal way on the basis of the general requirements to algorithmic maintenance of the system. With reference to parallel algorithms of logic control the concept of correctness is connected with the specific properties of such algorithms as consistency, stability and a self-coordination.

Various approaches are used at the synthesis of algorithms for analysis and forecast of dynamic situations in virtual testbed. Among them the deterministic and stochastic approaches and the approach on the basis of principle of nonlinear self-organizing are most interesting. First two approaches assume presence of full information basis in initial data, i.e. all defining parameters and factors which are necessary for considering of the situation analysis and decision-making. The major principle of virtual testbed management is the principle of fast and proved reaction on a change of environmental situations. Thus, realization of the above principles of information processing at the analysis and synthesis of methods and models of virtual testbed functioning demands great volume of computing operations. These operations are connected with estimation and forecast of objects dynamics at various control strategies on the basis of mathematical modelling of situations with the subsequent formulation corresponding criteria estimations, alternatives analysis and decision-making.

GRID technologies play a very important role in “virtual testbed” concept realisation. They determine infrastructure development providing global integration of information and computation resources. Complicated modelling on remote supercomputers, joint visualisation of very large scientific data sets, distributed processing for data analysis, linking of scientific tools with remote computers and archives are among GRID technologies.

Functioning as the virtual dynamic environment, GRID ensures end users functioning and applications performance as uniform computer system uniting not only separate systems, but organizations, various computer architectures and software also. Thus unlimited power, opportunity of teamwork and information access is offered to all users of GRID-network. Strategy of GRID-technologies at virtual testbed development allows to provide the following advantages:

- increase of efficiency of computing resources using of each organization and all other organizations providing functioning of the system;
- foundation of virtual organization (testbed) that work at joint problems allowing to use applications and data and providing reduction of aggregate computation value by the way of separate using and control of computer resources;
- possibility to work at big problems requiring huge computer power and permitting to joint computations, storages and other resources.

CHARACTERISTICS OF "VIRTUAL TESTBED" FUNCTIONING

Complex environment "virtual testbed" is complex informational object combining characteristics of corporate system and instrumental tool for high performance modelling. Reasoning from these base principles complex environment is assigned for decision of the following problems in real time:

- collecting and analysis of information about current DO and environment condition, remote monitoring of objects condition;
- estimation and coordination of joint functioning of DO and aircraft proceeding from current conditions;
- centralized decision-making support in DO control systems in complex, especially in non-standard (supernumerary and extreme) situations;
- computer modelling of possible scenarios of situations development with the purpose of optimum strategy choice;
- centralized control of completely automated (pilotless) technical means;
- data assimilation in dynamic databases.

Complex environment is distributed system uniting base information resources (server) and on-board systems of separate objects (client). Principle scheme of such environment organization is shown on Fig.2.

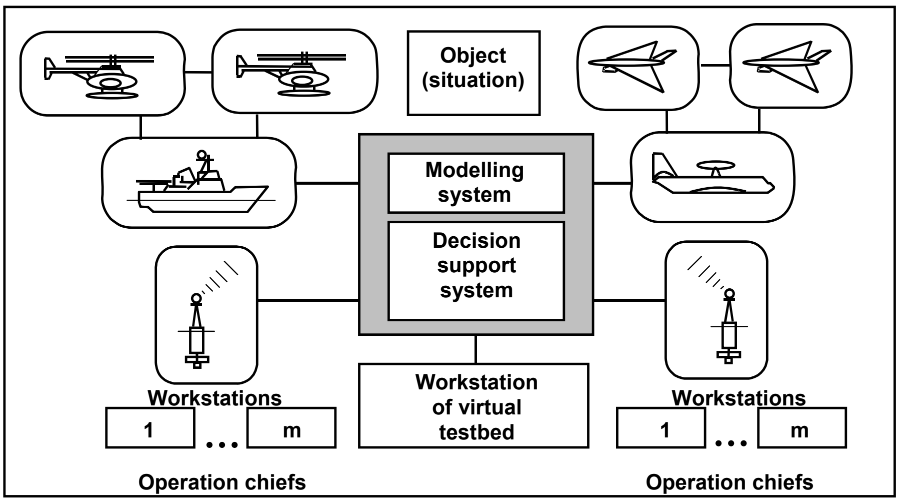

Fig.2. Principle scheme of complex environment organization

Here information streams (links) are considered as virtual (obtaining from modelling process) or real information sources about environment and control object state. In first case realization is full-scale simulator ("virtual testbed"), in second case it is complex system for monitoring and control of complicated technical objects and systems.

Server part of the complex environment is realized on multiprocessing computers. It allows to carry out basic operations on information reception and analysis from various sources, computer models of environment and DO, forecasting, scenarios generation and competing inference (Nechaev, 2002). Interaction with server part of the system is carried out by means of some workplaces. They include workstations of operators who are responsible for uninterrupted functioning of separate blocks during operation, and experts who are increase reliability of accepted decisions in especially important situations. Workstations with elements of virtual reality and cognitive graphics (Zenkin, 1991, Nechaev et al, 2002) are provided also. On these workstations all information obtained in environment is condensed. It is necessary for ground of decision-making by persons who control operation.

Strategy of general problem decision of virtual testbed functioning and set of corresponding procedures is based on the concept multiagent systems (MAS) (Gorodetsky, 1996)). It allows to carry out cooperation of users (operators of system) at collective performance of complex technical decisions. A set (community) of intellectual agents (IA) and their functions are defined in conformity with specially constructed decision trees – a tree of the purposes and a tree of estimation criteria. With the help of such trees which tops are corresponding macro procedures, algorithm of problem decision is mapped. Each such procedure is realized by special IA. As a result efficiency of complex functioning, validity of accepted decisions are increased.

Architecture of IA of considered distributed system can be developed within the frameworks of the general complex structure presented on Fig.3. Its realization as a part of the lower level is carried out in the form of classical MAS multilevel model. The top level of MAS represents a meta-level to which coordination of agents' activity of all system is assigned. This level realizes global strategy of complex problem decision in a view of general factors influencing on the result. Multilevel representation of IA knowledge simplifies their mapping to memory, repeated use and updating. Such levels are the following:

- level of subject domains knowledge and about initial conditions of problem decision where necessary knowledge of subject domain are reflected;
- level of cooperation rules knowledge and agents' interaction at the collective decision of a challenge;
- level of operating knowledge (here knowledge about procedures sequence decision control are contained);
- level of new knowledge generation, where rules of inference of new knowledge obtaining are presented.

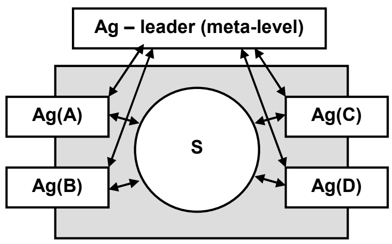

Fig.3 Typical scheme of MAS

The basic idea of agent functioning consists in the following. The agent "observes" environment and builds its model. Further the agent, using given strategy, transforms initial model to the model displaying modified environment. Comparing these two models the agent builds function which determines the purpose of its functioning. If the obtained estimation satisfies the agent, it realizes strategy which is presented by corresponding operation.

MAS focused on the decision of virtual testbed problem functioning is shown on Fig.3. Here S is environment of functioning, where agent Ag-leader determines meta-level of the system, and agents A – D are intended for decision of specific targets. Each of agents A – D depending on complexity of solved problem can contain a set of lower level agents.

SCENARIOS CONSTRUCTION AND ESTIMATION OF DECISIONS EFFICIENCY

The model «entity – association» is used in development of "virtual testbed" knowledge base (Maynika, 1981, On-board, 2006). Analysis of basic information objects allows to assign the following sets: S is scenarios set (contains scenario description and corresponding corrections in model's parameters); W is set of variants (concrete conditions described by information model); R is set of inferences (description of calculation results of concrete scenario for each variant); C is set of associations (they are entered for aggregation into semantic network of tuple {S, W, R}; these sets contain only references to copies of sets S, W, R).

In process of knowledge base filling by R-objects the semantic network is under construction. Frames realizing copies of sets S, W, R, C are located in network nodes. Frame of each type corresponds to one of sets S, W, R, C and includes set of this type frame copies: $S = \{S_i \mid i=0, \ldots, m\}$; $W = \{W_j \mid j=0, \ldots, n\}$; $R = \{R_i \mid i=0, \ldots, m\}$; $C = \{C_r \mid r=0, \ldots, k\}$.

Decision-making is carried out in conditions of uncertainty and time deficiency. Thus there is risk of wrong operator's actions. In this situation fuzzy models are used for intellectual operator support. Specificity of such models consists in use of fuzzy estimations $\mu(H)\in[0,1]$ and graph-interpretations allowing to relate formation of operator actions to combinatory problems on graphs. The area of admissible decisions in this case is determined by α-level of graph fuzziness which corresponds to fuzzy estimation $\mu(H)$. Giving by value $\mu(H)$, it is possible to determine constraint region, and then to search optimum decisions on graphs in this region (Maynika, 1981).

Mathematical model of decision-making in conditions of indeterminacy represents the ordered set $\langle X, Y, F(x,y)\rangle$, where alternative $x\in X\subset R^n$ provides problem decision in conditions of indeterminacy $y\in Y\subset R^m$ in assumption that set of alternatives X, uncertainty set Y and criterion F(x,y) on direct product $X\times Y$ are known. Risk function $\Phi(x,y)$ is constructed using these data. Two-criterial problem of alternative $x\in X$ choice is considered in conditions of indeterminacy $\langle X, Y, \{F(x,y), \Phi(x,y)\}\rangle$. Thus probably greater outcome F(x,y) is provided at smaller risk $\Phi(x,y)$ (Bogdanov et al, 2001, 2004, 2005).

Increase of estimation adequacy and situation forecast is reached with the help of dynamic measurements data and competing computing technologies. Analysis and forecast of events chains determined by various scenarios of extreme situations development are carried out on the basis of f mathematical modelling methods and neural network technologies. Scenarios formulation is carried out on the basis of forecast data by results of dynamic measurements of DO and environment parameters. Mathematical models and their factors are specified by results of measurements onboard of DO.

EXAMPLE OF "VIRTUAL TESTBED" FUNCTIONING

Concrete definition of theoretical principles incorporated in "virtual testbed" concept is considered on example of realization of unsinkability algorithms (grounding, shipwreck, ship collision, etc.). The sequence of operations which are carried out by "virtual testbed" at the decision of these problems is the following (Bogdanov et al., 2004, 2005, Boukhanovsky et al., 2001):

- modelling of wind, waves and ship motion; analysis of external excitation characteristics and dynamics of "ship – environment" interaction;

- parameters determination for mathematical models correction (estimation of situation danger, forecast of its development);
- situation control and practical recommendations formulation during maintenance of buoyancy and stability of damaged ship.

This problem is solved on the basis of IS «Unsinkability». This module allows to realize continuous control of dynamics of damaged ship in various environment conditions. Software functioning is carried out in view of continuous change of damaged ship and environment dynamics on the basis of algorithms with a high degree of parallelism. It takes possibility to provide decision making for unsinkability maintain. Developed methodology allows to realize problem of control and forecast of emergency situation development in real time (Fig.4).

As a result of identification operation performance flooded compartment (group of compartments) pops up on the scheme (Fig.5). General dynamic characteristics defining current values of equilibrium angular of heal θ_0 and trim ψ_0, average draft ζ, and also metacentric height h and critical time interval τ_{CR} (limit time in extreme situation) are displayed in real time on the right side of the screen (Nechaev, 2002, Degtyarev, 2003). At achievement of any of these limiting characteristics (critical values) corresponding value is highlighted on red background on the screen.

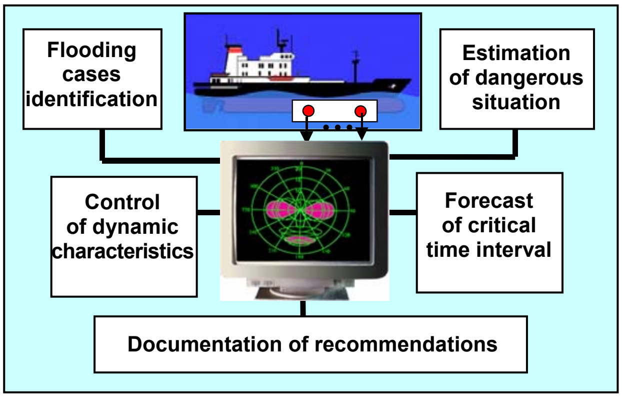

Fig.4. Information flow in IS "Unsinkability"

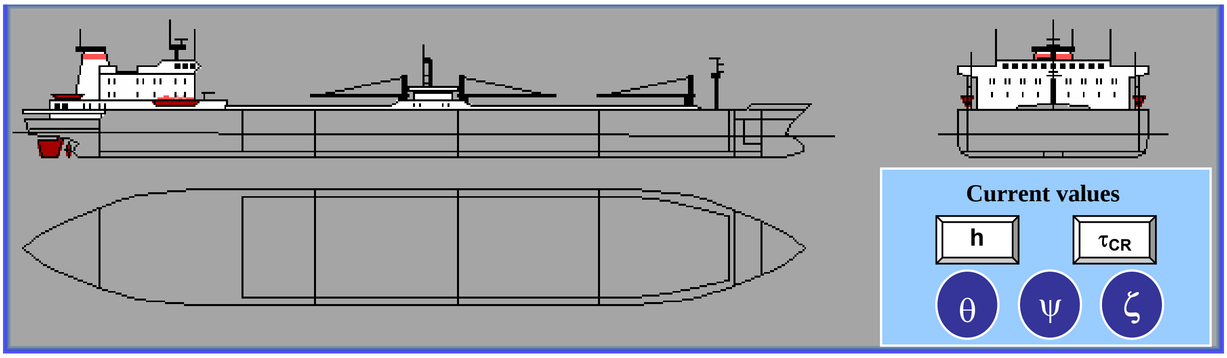

Fig.5 Scheme of ship's compartments (inboard profile)

Practical recommendations on survivability preservation of emergency vessel stand out at a special window together with the instruction of flooding character. Regarding «Estimation of situation danger» result of the first stage of inference functioning is displayed. Regarding «Situation identification. Practical recommendations» result of the second stage of inference functioning is displayed, namely prospective cause of current situation (accident) is set, and practical recommendations are offered. In case of good situation it is specified, that the considered situation does not represent danger and recommendations are reduced to maintenance of the accepted strategy of vessel control.

CONCLUSIONS

Current research permits to draw the following conclusions:

1. The concept of virtual testbed as complex high-level intellectual system is developed. This is high-availability system for complicated objects dynamic control in marine conditions.
2. Principles of dynamic knowledge base development are formulated. Fuzzy method for indeterminateness formalization, neural network and multi agent technologies, and virtual reality tools are used.
3. Organization of high performance calculations at analysis and forecast of dynamic situations development in the multiprocessor computing environment is proposed on the basis of GRID-technologies

Proposed intelligent technology will promote for increasing of taken decisions level and for development of high performance tools for information processing.

REFERENCES

Bogdanov A., Degtyarev A., Nechaev Yu. Fuzzy Logic Basis in High Performance Decision Support Systems. //in book "Computational Science - ICCS 2001", LNCS 2074, Springer, part II, pp.965-975.

Bogdanov A.V., Degtyarev A,B., Nechaev Yu.I. Problems of virtual testbed development for complicated dynamic objects modelling. //Proceedings of International conference “Supercomputer systems and its applications”, Minsk, 2004, pp.31-37 (in Russian)

Bogdanov A.V., Degtyarev A,B., Nechaev Yu.I. Parallel algorithms for virtual testbed // Proceedings of International conference CSIT-2005.Yerevan. Armenia.2005, pp.393-403.

Boukhanovsky A.V., Degtyarev A.B., Rozhkov V.A. Peculiarities of computer simulation and statistical representation of time–spatial metocean fields. LNCS 2073, Springer–Verlag, (2001), pp.463–472

Degtyarev A.B. Use of high performance computer technologies at the organization of onboard computing system // Proc. of the International conference STAB'2003, Madrid, 2003, pp.485-494

Foster, I., Kesselman, C. and Tuecke, S. The Anatomy of the Grid: Enabling Scalable Virtual Organizations. //International Journal of High Performance Computing Applications, 15 (3). 200-222. 2001.

Gorodetsky V.I. Multiagent systems: modern research condition and perspectives of application // News of artificial intelligence. 1996. №1,c.44-59. (in Russian)

Maynika E. Algorithms of optimization on network and graphs.– Moskow, Mir,1981. (in Russian)

Nechaev Yu.I. Mathematical modeling in on-board real-time intelligence systems // Proceedings of conference «Neuroinformatic-2002». Moscow.: MIFI. 2002. Lecture on neuroinformatic. Part 2, pp.119-179. (in Russian)

Nechaev Yu.I., Degtyarev A.B., Boukhanovsky A.V. Cognitive computer graphics in information interpolation in real time intelligence systems //in book "Computational Science-ICCS 2002", LNCS 2329, Springer, part I, 2002, pp.683-692

On-board intelligence systems. Part 2. Ship systems. – Moskow. Radiotechnik, 2006. (in Russian)

Winston P.N. Artificial intelligence. – Addison Wesley Publishing Company. USA.1993.

Zadeh L. Fuzzy logic, neural networks and soft computing // Commutation on the ASM-1994. Vol.37. №3, p.p.77-84.

Zenkin A.A. Cognitive computer graphic. – Moskow: Science, 1991 (in Russian)