USE OF HIGH PERFORMANCE COMPUTER TECHNOLOGIES AT THE ORGANIZATION OF ONBOARD COMPUTING SYSTEMS

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Abstract:

In the work the state-of-the-art in the field of supercomputer technologies application for naval hydrodynamics and ship design is considered. The place and role of supercomputer technologies (high performance computing, complex information systems, real time intelligent systems, etc.) in problems of ship stability and seaworthiness are discussed. The special attention is given to methods of design of onboard computer systems (BCS) for monitoring of navigation safety and intelligent complexes (IC) for decision support.
The review of development of supercomputers of the parallel and vector architecture, the corresponding software and tendencies in this field is given.
In the article great experience of design of various purposes cluster systems assembled from standard accessories is described. Problems of achievement of the best ratio “price/performance” in similar computer systems and applications of GRID technology are discussed.

1. INTRODUCTION

The increase of the power of computers, used for critical problem analysis nowadays, is surprising but even more surprising is the fact, that for many important cases it is not supported by dramatic increase of computational possibilities, especially when the number of nodes in computations is high. After some analysis it does not seem so strange since with the increase of number of parallel computational processes the price, which we pay for exchange of data between processes, is becoming more and more heavy load, that make the increase of number of nodes ineffective. At the same time the challenges of the fundamental research in natural sciences and several critical industrial application request the use of most powerful systems, designed up to day, consisting of many hundreds of processors.
Let us define the area of high performance computer technology its application in marine engineering and shipbuilding. It does not matter to consider fields of activity where efficiently and for a long time personal computers are used. There are simple calculations, documentation preparation, etc. But from the other hand it is much more ineffective to apply personal computers in such areas where application of high performance technologies are preferable. Among such fields we can point the following:

- “hard calculations” such as problems of computational fluid dynamics, Navier-Stokes problem, direct stochastic simulation of complex problems, problems which numerical solution take many hours or days on personal computers;
- visualization problems in visual reality mode (there are many details in the screen, we have rendering in real time, etc.);
- “hard” CAD/CAM/CAE systems utilizing virtual design concept (combination of data base of the design object, recalculation of all object characteristics under changes of any constructions, end-to-end design, etc.);
- real-time systems (on-board information or intelligent systems where we have to obtain the result in limited time).

For example monitoring of safety of navigation and ship control with the help of on-board IC represents a combination of simultaneously executable diverse procedures. In conditions of time limitation for decision making IC should have serious computing and communication resources, and also the high-performance software [13]. Integration of the given measurements, mathematical models and structured knowledge base (KB) is intended for complex solution of many subtasks in BCS: collection, processing and assimilation of the data from diverse sensors, navigation problem solving, choice of optimal ship course angle and speed from the point of view of seaworthy qualities and operation requirements, unsinkability problem solving, etc. Real time BCS is the complex multitask corporate system combining as high requirements to information component (organization of access to the big databases and KB of the controlled object, environment and other participants of mission), and to the computing component realizing the procedures of inference [8], digestion and monitoring of the information, simulation modelling and playing of scripts [17]. These tasks in aggregate demand greatly bigger computing resources, than usual personal computer can give. It is necessary for such tasks:

- the greater speed.
- the greater size of the RAM.
- a lot of simultaneously serviced clients.
- processing and storage of the big information content.

The structural organization of BCS permitting to satisfy these requirements, should be grounded extremely on high performance computer systems of the parallel architecture. Similar arguments could be presented also in other fields counted above.

2. CHARACTERISTICS OF MULTIPROCESSOR COMPUTER ARCHITECTURE

The concept of high performance system architecture is rather wide as long as we can understand architecture as the way of parallel data processing used in the system, both organization of memory, and topology of link between processors, and a way of arithmetic operations performance. The earliest and the most known is classification of computer architectures offered by M.Flynn in 1966 [12]. Classification is based on concept of stream, which is understood as a sequence of units, commands (instructions) or data processed by the processor. On the basis of the number of streams of instructions and data flows Flynn considerers four classes of architectures:

SISD – single stream of instructions and the single dataflow
MISD – multiple streams of instructions and the single dataflow
SIMD – single stream of instructions and multiple data flows
MIMD – multiple streams of instructions and multiple data flows

Existing parallel computers are belonged to MIMD class (in majority). They form some subclasses in which basis of classification the structurally functional approach lays. There are SMP, MPP, NUMA, PVP and cluster architecture.

2.1. SMP (symmetric multiprocessing)

The symmetric multiprocessor architecture. Key feature of systems with SMP architecture is presence of the common memory divided by all processors. It takes possibility for flexible programming and easy mapping of source code. Such systems are very good for scientific calculations and programmers with rather low qualification. Disadvantage of such systems is rather high cost and impossibility of good scalability (increasing of processors number).

2.2. MPP (massive parallel processing)

The massive parallel architecture. Key feature of such architecture is *physical division* of memory. In this case the system is designed from the individual units containing the processor, local bank of on-line storage (RAM), two front-end processors (routers) or network adapter, sometimes there are hard disks and/or other I/O devices. Such computers can have large number of processors and reach high performance. However using of such computers requires high qualification from programmer. Special tools like MPI, PVM are necessary for effective using of such computers. The most appropriate problems which could solved on such type of computers are coarse-grained problems.

2.3. NUMA (nonuniform memory access)

The hybrid architecture. Key feature of such architecture is inhomogeneous (nonuniform) memory access. It combines convenience of systems with the shared memory and relative cheapness of systems with separate memory. Essence of this architecture is special memory organizations, namely: memory is physically distributed by various parts of the system, but so logically divided that the user sees uniform address space. Such systems used for visualization problems, CAD/CAM/CAE and “hard” calculations.

2.4. PVP (Parallel Vector Process)

The parallel architecture with vector processors. The main characteristic of PVP systems is presence of special vector-pipeline processors. They have commands for one-type processing of independent data vectors effectively fulfilled on pipeline functional devices. Such computers can effectively solve numerical problems where calculation is based on vector operations (linear algebra, differential equations, etc.). Solution of some small-grained problems is very good.

Consideration of alternative multiprocessor systems is conditioned by relatively high price of computers manufactured by brand name firms. First of all our attention point to cluster systems.

Under ***the cluster system*** one understands a set of workstations (or even personal computers) of general purpose connected by standard network technologies (Fast/Gigabit Ethernet, Myrinet, SCI, etc.) on the basis of the bus architecture or the commutator. Such computer systems are the cheapest, as assembled on the basis of standard computer units ("off the shelf"), processors, commutators, hard disks and peripherals.

There are some classes of cluster systems:

– farm – loosely-coupled computer system;
– system of high reliability with multiple power reservation;
– united computer system – closely coupled cluster.

Architecture of cluster system (a way of processors connection with each other) in a higher degree determines its productivity than the type of used processors. A bottleneck influential in the value of productivity of such system is the distance between processors.

For obtaining more compact configuration it is necessary to solve the problem about finding the figure having maximum size at minimum surface square. In three-dimensional space such property has a sphere. But as it is necessary to construct the nodal system, one use a cube or a hypercube instead of a sphere. The architecture of a hypercube is the second on efficiency but the most visual.

The most effective is the architecture with topology of "fat-tree” (hypertree) offered by Leizerson in 1985. Processors are localized in leaves of tree while internal nodes of tree are composed in the internal network. Subtrees may communicate among themselves and do not affect higher levels of the network.

As long as the way of processors connection with each other is more important than the type of used processors, we can meet such situation when more cost effective system consists of the greater number of cheap computers than of smaller number of expensive one.

The given statement is easily illustrated by only theoretical calculations. The model of a cluster may be considered, as a first approximation, as Ising model [17]. Such model is valid when nodes of processors lattice are evenly loaded, and efficiency of link between nodes is associated with “order” value of Ising model.

Acceleration of such cluster system asymptotically may be represented as follows [10]

$$S_n = \frac{n}{1-\alpha+\alpha n+\beta\gamma n^3} \quad (1)$$

Here n is a quantity of nodes

α is the coefficient presented a part of calculations which cannot paralleling in principle (compilation, data origination, other delays)

β is the coefficient presented the architecture (diameter of the system)

γ is the coefficient equal to the ratio of productivity of a node (processor) to productivity of link (link speed).

Let us consider (1). It shows that S_n has a maximum. It means that there is some optimal quantity of nodes (processors) at which efficiency of a cluster appears the greatest. S_n achieves a maximum at the following quantity of processors

$$n_{opt} = \sqrt[3]{\frac{1-\alpha}{2\beta\gamma}} \quad (2)$$

Therefore, the optimal quantity of nodes of a cluster most essentially depends on diameter of the system and the ratio of productivity of node to productivity of link. In a point of maxima the following acceleration will be approximately observed

$$S_n(n_{opt}) = \frac{1}{\alpha+\dfrac{3\cdot(1-\alpha)}{2n_{opt}}} \quad (3)$$

On fig 1 change of acceleration is illustrated (α=0.05 that corresponds to algorithm with well parallelization, β=0.2 that corresponds to small diameter of plane lattice, γ=0.05 that is rather quite good ratio of productivity of the processor and link).

From the fig.2 follows that in a case even a small part of sequential operations which are present at anyone ideally paralleling program,

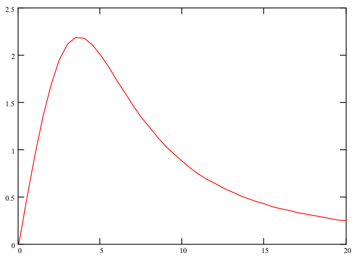

Fig. 1. Characteristic view of the curve of acceleration of the cluster system from number o

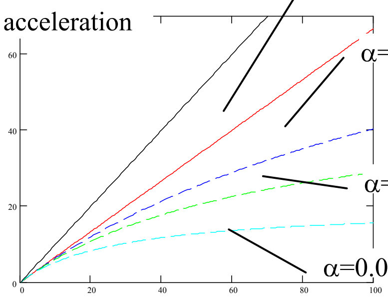

Fig 2 Dependence of acceleration of the cluster system at optimal number of processors at a various part α of sequential calculations.

curves of acceleration have saturation. Only in theoretical case α=0 acceleration achieves only two thirds of maximum degree of parallelism.

Such superficial consideration of cluster systems shows that we can obtain only 8-16 processors in high performance computer systems for computational problems without special approaches in design of self-made systems. So the most appropriate field of cluster technology application in shipbuilding is on-board real time IC. Here we can use farm cluster. It is conditioned by necessity to produce many different calculations in a limit time. Using of loosely-coupled cluster takes possibility to provide IC by results of various algorithms which could be compared. This way allows to propose new principle for inference design in real-time IC if we use multiprocessor computer as hardware for such systems.

3. ORGANIZATION OF THE INFERENCE IN THE HIGH PERFORMANCE BCS

Peculiarities of information technology of real time IC in BCS consist in usage of the new approach to information processing based on development of "soft computing" concept [1,5, 8,19]. This approach provides usage of two theoretical principles – competition principle and a principle of fuzzy information formalizing (see [6]) permitting to provide rational organization of data processing [2,3,9]. Implementation of marked principles allows to improve IC operation in complex situations. Fuzzy logical basis of adaptive component is realized on the basis of supercomputer platforms. In result possibility of new information transformation technology development is opened. It permits to carry out fuzzy inference for complex knowledge models without usage of fuzzy logic processor.

Competition principle is used for implementation of inference chains with a view of reliability of system operation. Here comparative analysis of situation with usage of traditional algorithms and neural network models in the multiprocessor computing environment is provided (fig.3).

Used procedures of parallel information processing at implementation of this principle show the process of IC operation (from the moment of information obtaining from sensors up to the procedure of the inference and practical recommendations).

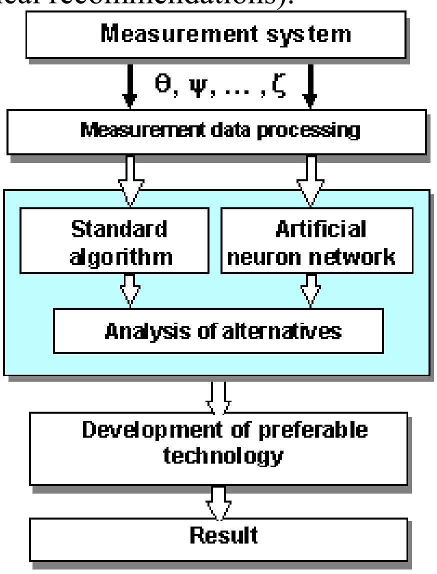

Fig.3. Information flow in competition principle realization.

Advantages of competition principle:

- taking into account uncertainty of environment and object dynamics;
- improvement of results analysis reliability;
- support of algorithm speed.

Usage of modern resources of computer facilities opens perspectives of solution of complicated problems of information analysis and interpretation in conditions of continuous environment and object dynamics changing. At the same time formal model of fuzzy inference in identification problems and situation forecast contains complex built-in procedures. These procedures demand big computing resources and complicating of hardware construction. Difficulties of hardware usage are explained by the following reasons:

- available processors of fuzzy logic are oriented to parallel implementation of rather simple models of fuzzy knowledge;
- development of technology of special hardware creation intended for transformation of complex information stream is connected with unjustified economic expenses;
- application of multiprocessor platforms allows to design the system of parallel information processing within the framework of fuzzy logical basis and practically to realize the developed structure of model.

Investigation of information stream in multiprocessor environment has resulted in usage of a new principle of information transformation within the framework of fuzzy neuron network logical basis (fig.4). This principle allows to carry out parallel chains of fuzzy inference in continuously varying conditions of situation development.

Developed fuzzy model consists of a set of conditional linguistic operators specifying concrete situations in formalized KB.

Conversion of fuzzy sets within the framework of formal procedures of information processing in the multiprocessor environment is connected with coding and parallel processing of arrays of fuzzy rules

$$(X_1 \rightarrow Y_1),\ldots,(X_m \rightarrow Y_m). \quad (4)$$

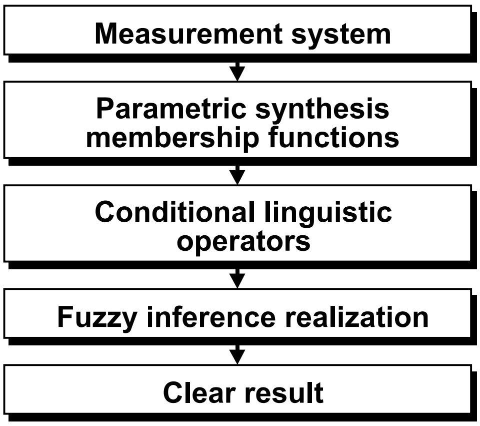

Fig. 4 Information stream at implementation of fuzzy inference formalization in multiprocessor environment.

Each fuzzy system A_i (i=1,…, m) makes active all rules forming fuzzy associative memory. Appropriate output fuzzy set unites these fuzzy sets Y_i^* (i=1,…, m):

$$A \rightarrow \left| \begin{matrix} (A_1 \rightarrow B_1) \rightarrow B_1^* \\ \cdots \\ (A_m \rightarrow B_m) \rightarrow B_m^* \end{matrix} \right| \begin{matrix} \xrightarrow{W_1} \\ \xrightarrow[W_m]{} \end{matrix} \sum \rightarrow B \rightarrow Df \rightarrow Y \quad (5)$$

4. ALGORITHMS FOR STABILITY CONTROL USING IN REAL TIME IC

We can subdivide all algorithms applying in real time IC for safety navigation on some classes:

- algorithms for ship behavior analysis;
- algorithms for ship behavior forecast.

Moreover we have to apply different algorithms in these two classes for instant and damaged ships.

Let us consider briefly algorithms proposed by author and his colleagues for analysis and forecast of environment and ship behavior.

Analysis algorithms are used for ship behavior modeling. In on-board systems we use some simple models describing different special regimes of ship motion (main rolling resonance, parametric excitation, broaching, etc.). After modeling in real time scale it is possible to compare modeling results with actual ship motion. Such analysis takes possibility to identify the phenomenon [13,20]. It is possible to use any model of different phenomena. The main characters of utilized models are simplicity (for quick calculation) and exact correspondence to considered phenomenon (for exclusion of other phenomena). In this case applied models could be rather rough but they have to “catch” the kernel of the problem, which mostly consists in nonlinearity [13]. Last note especially concerns damaged ship behavior. Difficulties of modeling in this case are related with evolutionary nonstationarity of such motion [21]. So the model for analysis of damaged ship behavior has to be as simple as it possible for qualitative reproduction of reality, e.g.

$$(J_x + \lambda_{44})\ddot{\theta} + M_R(\dot{\theta}) + M(\theta,t,F) = M(t) \quad (6)$$

where M_R is damping function, $M(t)$ is random function of exciting moment in irregular waves, $M(\theta,t,F)$ is multivalued non-linear function of righting moment of damaged ship, F is form-factor taking into account view of non-linear function in considered flooding case. Real-time modeling of random waves acting on ship is carried out with the help of quick algorithms based on autoregression (see, e.g. [13, 15, 21]). Determining of adequacy of the model to considered situation is carried out by the way described in [14].

Algorithms for ship behavior forecast are first of all identification, classification and data assimilation [9] algorithms. Practically in on-board real time systems the following problems are solved:

- identification of sea waves parameters [17];
- stability assessment;
- estimation of safety of various operations in sea (reloading, helicopter landing, etc.);
- complex risk estimation [22].

Stability assessment in conditions of growing storm includes:

- estimation of real stability in extreme situation;
- forecast of wind and wave excitation variation and intensity of icing (ice load);
- forecast of critical time interval of ship in extreme situation;
- estimation of real speed loss in sea;
- estimation of extreme situation and possibility of practical recommendations achievement.

Well known model for GM assessment depend on relationship of frequencies of natural and exciting oscillations is the following [13]

$$GM = c^2 B^2 / \{\bar{\tau}\Phi(x)[1-\Phi(y)]\Phi(Fr)\}^2 \qquad (7)$$

where c is the coefficient determined during full-scale test; $\bar{\tau}$ is the average period of large oscillations (s); $\Phi(x)$, $\Phi(y)$, $\Phi(Fr)$ are functions taking into account relationship of frequencies of natural and exciting oscillations, nonlinearity of GM curve and Froude number influence.

Estimation of safety of various operations in sea is short term forecast class of algorithms. For example for safety helicopter landing it is necessary that the probability

$$p = P\left[|\zeta| < \zeta_0, |\Theta| < \Theta_0, |\psi| < \psi_0, |\dot{\zeta}| < \dot{\zeta}_0, |\dot{\Theta}| < \dot{\Theta}_0, |\dot{\psi}| < \dot{\psi}_0\right] \times P[V < V_0] \qquad (8)$$

does not higher of some level p_0. Here ζ is heaving, θ is rolling, ψ is pitching, V is wind speed. Limit level p_0 is defined by expert.

For reasonable forecast and safety helicopter landing it is necessary choose appropriate time interval ("window of safety landing") for operation. It requires calculations in real-time scale.

The most important algorithms are related with unsinkability problems. These models allow to perform operative control of emergency situation during compartments flooding. They provide solution of the most important practical problems [13]:

- calculation of equilibrium ship's waterline in waves;
- identification of flooding case;
- time interval prediction in an extreme situation up to critical state (loss of buoyancy or stability).

The balance emergence waterline evaluation is reduced to analysing given measurements of emergency ship non-linear oscillations with regard to the balance position (the position of equilibrium) defined by heel angles Θ_0 trim ψ_0 and the mean draught value T_0 of the ship in a seaway.

For defining the characteristics we use the mathematical model in the form.

$$X_0 = \bar{X}\left[1 + F\left(X_m, \ddot{X}\right)F\left(X_1, X_2\right)\right], \qquad (9)$$

where $\bar{X}$ is the mean value of the process of oscillations; $F\left(X_m, \ddot{X}\right)$ is the function depending on the main amplitude of oscillations and actual accelerations; $F\left(X_1, X_2\right)$ is the function defined by the amplitudes of asymmetric oscillations [13].

Identification of flooding case is performed with using of multidimensional optimisation of the discrepancy function with regard to the parameters characterising metacentric height GM, heel and trim equilibrium angles θ_0, ψ_0, ζ_0.

$$\Phi(GM, \theta, \psi, \zeta) \rightarrow \min, \qquad (10)$$

with quadratic criterion using

$$\Phi(GM, \theta, \psi, \zeta) = \alpha(h)h^2 + \beta(\theta)\theta^2 + \gamma(\psi)\psi^2 + \chi(\zeta)\zeta^2$$

where $GM = GM_i - GM_0$; $\theta = \theta_i - \theta_0$; $\psi = \psi_i - \psi_0$; $\zeta = \zeta_i - \zeta_0$; GM_i, θ_i, ψ_i, ζ_i are parameters for i-compartment; $\alpha(h)$, $\beta(\theta)$, $\gamma(\psi)$ $\chi(\zeta)$ are weight coefficients.

The concrete case of flooding (number of watertight compartment or their combination) is $N = \min \Phi(GM_N - GM_0, \theta_N - \theta_0, \psi_N - \psi_0, \zeta_N - \zeta_0)$.

It is necessary to note that some nontrivial terms have to be included in criterion (10). Let us show it on calculation situation (during testing of real IC KB) with tanker DW 28400 ton: GM = 0,8 m; θ = 5°, ψ = -2°. For expression with unitary weights in IC we have the following inference:

"Asymmetric flooding of engine room, pumping compartment, tank N3 of oily waste

and compartments over after-peak” with parameters *GM* = 0,4 m, θ_0 = 5,5°, ψ_0 = -4,8°
If we include nontrivial weights that quite another situation is identified:
“Symmetrical flooding of cargo tank N7 of port and starboard with parameters *GM* = 0,95 m, θ_0 = 0°, ψ_0 = -1,9°.
In the first case good correspondence is for heel only when *GM* and trim angle have big difference. In the second case we have acceptable fit on other parameters too. Nonzero heel could be result in nonstationary flooding.
Another very perspective way for identification of flooding case is “soft computing” concept using [1,5,6,8,16]. Combination of traditional algorithms and “soft computing” improve inference in real time scale (see previous chapter).

5. WAY OF MULTIPROCESSOR BCS DESIGN FOR REAL TIME IC

In [10] three levels of parallel organization of computing process are marked out. There are
- parallelization at the level of jobs;
- parallelization on the data;
- parallelization of the individual task.

Monitoring and control of a complex dynamic object is a combination of some simultaneously running processes (e.g. parallel development of different approaches in competition principle). So in this case we mainly have to consider first level and partially second level of parallelization. Third level is mostly important in scientific computation and complicated modelling. Using of cluster technology is the best way in BCS design.
Structure and power of multiprocessor BCS depend on solving problems and using algorithms. Taking into account above mention reasoning about cluster architecture characteristics and specific character of ship board IC problems [1, 5, 9, 13-17] it is possible to propose method for BCS design (the number and of processors, type of links, type of interconnection topology, etc.) [11].

For these purposes it is necessary to model parallel processes. Let us take into account for complex IC the following items:
- consequent-parallel nature of processes;
- hierarchical organisation of the modelled system;
- joining lower level subprocesses at the higher level with different synchronisation constraints which may be described as logic functions;
- possible time delays in joining processes from lower levels.

In this case we can apply extension of PERT-networks as logical model for such class of processes inside IC.
By means of the developed software tool, realising extended convolution method, we have conducted study of different variants of designing of monitoring and control system for a ship. The goal of the study was determination of efficiency of using a voting function "M from N" with the variable value M for joining consequent computing fragments, realising information handling, coming from measurement system sensors.
Let’s consider a typical parallel process with structure shown in fig.5.

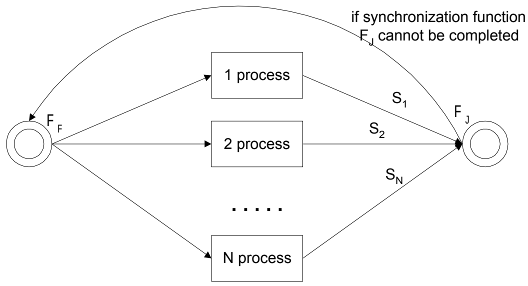

Fig.5. Graph scheme of a typical parallel process

Here F_F is a logic function of consequent fragments fork (running). We shall consider here a case of F_F = “AND”. F_J – subprocesses joining function. S_1, S_2 , …, S_N – time intervals (delays) which characterise time during which 1,2,…,*N*-th subprocess accordingly are waiting for F_J synchronisation constraints should be executed.
If one or several consequent processes have terminated their execution, but synchronisation

conditions are not executed, all the N sequential fragments return to the beginning. Such situation takes place in monitoring and control systems, sometimes working with actual data only. When data and/or decisions "time-to-live" expires, it is necessary to run polling parameters cycle and/or decision making process again.

Diagram in fig.6 shows dependence of population mean of execution time of parallel processes, consisting of 2, 3 and 4 sequential fragments, of value of consequent fragments joining delay. In this example algorithms for identification of sea state parameters and ship stability [9,13,14,17] where used as investigated processes.

As a result of the conducted study, small reduction of parallel computing process execution time under reduction a value of parameter M in a range of 1,…,N was revealed.

Inclusion time interval, greater than zero, to wait for synchronisation function completion, significantly reduces time expenses to conduct modelling process as a whole

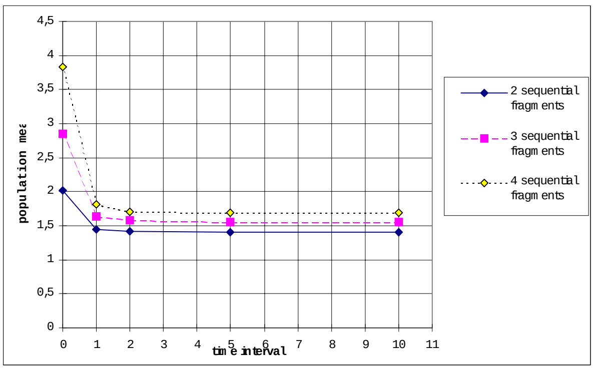

Fig.6. Dependency of population means of parallel processes execution time of value of consequent fragments joining delay

Such procedure for determination of population means of parallel processes execution time could be used in BCS design for concrete on-board IC.

5. CONCLUSION

Main differences of the proposed information technology consist in the following:

[1]. We have perspectives of program implementation of complex models of representation and processing of fuzzy knowledge system;

[2]. Operation of IC in real-time mode is provided. Expenses for development of hardware for fuzzy inference mechanism realization are cut down;

[3]. difficulties of problem solution at parallelization of computing process with an essential irregularity of calculations characteristic for integrated BCS are eliminated.

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