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New Automaton-Game Theory Method for Modeling of Reliability and Flexibility Valuation for CAD-CAM Systems

The method of reliability and flexibility valuation for computer aided design and flexible manufacture interpreted as an indivisible purposeful system, which is based on purposeful automaton theory, automaton-game simulation of design and cluster analyses, developed by the authors, is also investigated herein. The necessity to develop adaptable self-training systems for the study of these units is grounded.

Introduction

Computer aided design (CAD) and flexile manufacturing systems (FMS) for computer aided manufactory (CAM) are now considered to be of the highest engineering level. Although the major part of the research in this field is divided into two separate directions, concerning CAD and CAM. This fact contradicts the system theory approach.

In this paper same features of CAD-CAM, which determine their efficiency and expedience, are discussed. The basic principles for this are: purposefulness, evolution ability, system analysis, complexity and man-computer integration [1], [2], [3].

Task definition. Let general aim Fs to create system S, which has a number of characteristics Hs as well as resources Rs and time-limit Ts, be formulated and besides

$$Fs = (f1 , \dots , fi. , \dots ,fn),$$

where fi is local aims (criteria).

The aim Fs I Ts, Rs is achieved. If $Ts^* \le Ts$, $Rs^* \le Rs$,

$$fi^* = \text{opt } fi \text{ I} (Hs, Rs\ Ts) \text{ for all } I = 1,\dots,n , \qquad (1)$$

where Ts*, Rs*, fi* are actual values for design-time, resources and local aims. Now we want to select the factors, which first of all influence the task (1), expected to be solved by CAD-FMS unit; further this unit is referred to as CAD-CAM.

Models and Methods

Automaton-game model. Let's observe the discrete process of designing and creating system S. Design problem is described as purposeful finite discrete indeterminate automaton functioning [1], [4]:

$$A1 = \langle X1, Y1, Z1, \xi 1, \psi 1, F1 \rangle, \qquad (2)$$

where X1, Y1 , Z1 are inputs, outputs and state factors,

$\xi 1 = X1 \times Z1 \times F1 \Rightarrow Z1$ is transaction function, $\psi 1 = X1 \times Z1 \times F1 \Rightarrow Y1$ – outputs function, F1 is the aim of system S design, F1 belong to Fs .

The manufacturing problem can be given in the same way

$$A2 = \langle Y1, Y2, Z2, \xi 2, \psi 2, F2 \rangle , \quad (3)$$

where $\xi 2 = Y1 \times Z2 \times F2 \Rightarrow Z2$, $\psi 2 = Y1 \times Z2 \times F2 \Rightarrow Y2$.

On the whole the constructing of S is realized by the automaton Ao :

$$Ao = A1 \cup A2,$$

or

$$Ao = \langle X1, Y2, Z, \xi o, \psi o, Fs \rangle, \quad (4)$$

$$Z = Z1 \cup Z2, \quad \xi o = X1 \times Z \times Fs \Rightarrow Z, \quad \psi o = X1 \times Z \times Fs \Rightarrow Y2.$$

The Ao-automaton processes data, energy and materials, therefore it consists of three local automata Ai , Al, Am described in (1), (2):

$$Ao = Ai \cup Al \cup Am. \quad (5)$$

The models (2)-(5) formulate the whole engineering problem in terms of purposeful technological designer activity. The structure of automaton (2) examples the set of sub automata A1d , A1r , A1c, which represent supervisor, computer and controller, fig.1.

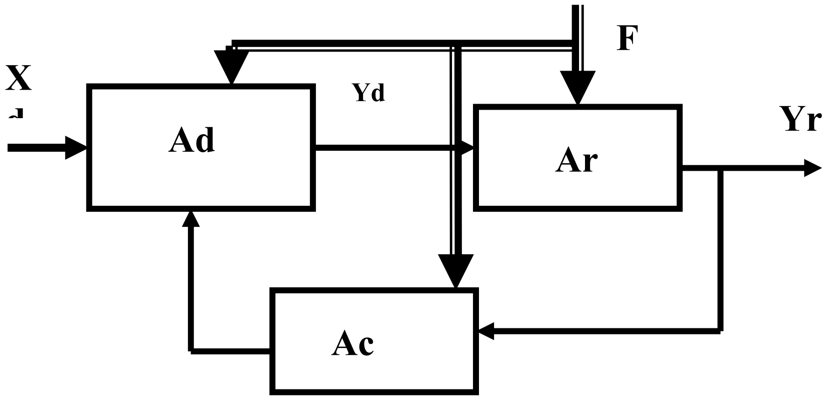

Figure1. A common model of automata ergamat, where Ad is subautomata supervisor, Ar- subautomata is computer, Ac is subautomata-controller, F is aim of system

Thus, the automata (2), (3) possess all general features of actual control systems; that's why model (2) can simulate the CAD and (3) can simulate the FMS-CAM-systems. Hence, figure (4) is the model of CAD-CAM. The functions ξo , ψo are the most complex members in the automaton Ao. For their playing models of vector-games (V-games) are used [2]. In general a V-game is defined as follows

$$G = \langle \{Ik\}, \{Nk\}, \{Fk\}, \{Rk\}, \pi \rangle, \quad (6)$$

where Ik is any gambler from the set {Ik} which has it's own vector-strategy Nk, aim Fk and resource Rk; π is game rules. The local aims Fk in a complex hierarchical man-computer CAD CAM-system are not collinear, but subordinate to general purpose Fs. Therefore approaching the aim Fs under conditions (1) (or evolution of the automata (2), (3), (41, (5)) can be interpreted as running of the finite V-games set (6), defined on some net structure of Ao-automaton [1], [2]. After that follows $\xi o \approx G\xi$, $\psi o \approx G\psi$, where $G\xi$, $G\psi$ are V-games, which causes changing the state Z and outputs Y2 for Ao then figure (4) shows

$$Ao = < X1, Y2, Z, G\xi, G\psi, Fs >. \tag{7}$$

The model (7) is called automaton-game model (AG-model) for CAD-CAM. The aims Fx, which appear in Ao , are vectors too, that is Fk = (fk1 , ... , fkn). Some reasons of conflicts among the members of Ao have been investigated earlier [2]. For a couple of gamblers Ik, Il) I Fk, Fl the antagonism can be introduced

$$akl(G) = (n - no)/n, \quad 0 \le akl \le 1,$$

where no is the set amount for those components fki belong to Fk and fil belong to Fe, whose interests are collinear, no ≤ n . Obviously, any game is fully antagonistic, if no = O or if no = n, then it is completely non-conflict. That's why akl can indicate the reliability and flexibility of A1·, A2, Ao, and the control strategy for CAD-CAM is how to obtain akl ~minimum at each design step and time discrete ti belong to Ts .

Reliability characteristics definition. Let the system S be a Bs composition of members bj,

$$Bs = \{bj\}, j = 1,., m.$$

Then we divide Bs into three clusters using the following conditions: Bα is α-cluster, if any single failure of member by α belong to Bα, Bα belong to Bs, causes the S-failure as a whole. Bβ is β-cluster, if any single by β-failure inside the time interval [0, tjβ], bjβ belong to Bβ, Bβ =Bs\ (Bα belong to Bs) only decreases the S-efficiency. Bγ is γ-cluster, if no single by γ -failure within [o, tγ] influences the S-efficiency at all, but all the by γ - failure inside [0, tγ] or even single one within [tγ,ts] decreases S-efficiency. The components by α belong to Bα cover the basic structure of S-system. To design some objects from Bα, Bβ, Bγ there are correspondent clusters α1, β1, γ1 of subautomata

A1α, A1β, A1γ for A1 and the same are α2, β2, γ2 of A2α, A2β, A2γ for A2.

These clusters realize the design decisions obtained on A1α, A1β, A1γ. Let T1 be time interval for S-design, T2 be the interval of design realization on A2, T2 = Ts - T1.

If a single task from α1-cluster is unsolved w1thin T1, then the whole project iconsidered be not realized. If the same takes place for β1-cluster, the project is not optimal. Now the project is not realized if no tasks at all from β1-cluster are solved inside T1. What's else, we specify the whole project as not-realized, if at least one single task from γ1 -cluster remained unsolved in TS. The system S is considered be not-operational if a single decision at least from cit-cluster is not realized through the subautomata α2 within T2. The S is not considered optimal if any one decision from β1 has been unaccomplished by the β2-subautomata in T2, and S is un operational if all the decisions from β1 are not implemented in T2. At last, the S 1s not optima 1f all the γ1-decisions are not realized in T2 or even one of them during the test maintenance within the time discrete Δt belong to ts.

The probability P(Fs} of the aim Fs achievement under conditions (1) depends on the A1 -, A2 -reliability:

$$P\{Fs) = P(A1) .P(Az), \tag{8}$$

where P(A1) is non-failure probability for A1 in [o,T1], P(A2) for A2 in [T1, Ts].

According to the concepts of reliability theory we take the consequent way of subautomata connection and the parallel one for the clusters. Then the probabilities of subautomata norm l functioning indicate

$$P(\alpha 1) = \prod P(A1\alpha 1),\ P(\beta 1 \} = \prod P(A1\beta 2),\ \ldots,\ \prod P(A2\gamma 6)$$

and now

$$P(A1) = 1\ ((1-P(\alpha 1))\ (1-P(\beta 1))\ (1-P(\gamma 1)) \tag{9}$$

$$P(A2) = 1 - ((1 - P(\alpha 2))\ (1 - P(\beta 2))\ (I - P(\gamma 2)). \tag{10}$$

The A1 mainly transforms the input data X1 into the output Y1. Therefore it's more relevant to Ai' in (5), and now

$$P(A1) = P(Ai).$$

The A2 takes data Y1,the aims F2, Fs and then transforms energy and materials, approaching to S. That's why the A2 is to be described as Al U Am and P(A2) ~ P(Al U Am). From this point of view we shall select factors which have the strongest influence

on P(Ai) and P(Al U Am) .

Considering (6), (7) the CAD-CAM functioning can be approximated by the purposeful general exercising of the V-games set, where the P(Fs)-factor somehow depends on the values of akl for any couple of interconnected subautomata in A1 , A2 , on a12 for the couple (A1 , A 2) and on ao1, a02 while automata A1 ,A2 performs V-games with nature-partner (external actions). To solve such games the efficient principle of pat tern strategy has been developed. Obviously, antagonism degree of akl considerably influences the task solving probability for the subautomata of alI the clusters. Thus all the members

$$P(\alpha 1),\ \ldots,\ P(\gamma 2),$$

are functions of all in their own clusters. '!he general strategy of Ao-functioning demands completely to eliminate antagonism each step of making decisions. Now if for some couples of subautomata in α1 or in α2 cluster is valid

$$aklI\alpha 1 = 1 \text{ or } aKll\alpha 2 = 1 \text{ then } P(A1) = 0 \text{ or } P(A2) = 0$$

what in any case gives P (Fs)≠ 0. The results in clusters β1, β2, γ1, γ2 are defined in the same way, but herein P (Fs) ≠ 0 except the above mentioned case. The problem of antagonism degree elimination in CAD-CAM is under investigated and its research is now very important; this causes new problem of artificial intellect in CAD-CAM.

CAD-CAM readiness. Let's define the factor maintenance-readiness of A1 as

$$K(A1) = (T1 - \textstyle\sum c\ tc\ ) / T1,\quad c = 1, \ldots ,6,$$

where t1 is the time interval necessary for conflicts to be eliminated, which may appear as a consequence of incorrect tasks, indefinite aims or function distribution, t2 is period within the automaton is waiting for instructions, t3 is delay time determined by computers and peripheries, t4 is pauses because of hard- and software defects, t5 is time spent to locate and prepare the data, t6 is time for project coordination. For A2 is valid

$$K(A2) = (\ T2 - \textstyle\sum t'c\ ) / T2,\ c = 1, \ldots, 6.$$

t3 is time lost because of hardware; t4 is time lost, because of the defects appeared in the software of computer controlled machinery and robots, involved in manufacturing system S; t5 is time extent necessary for decision correction and mistakes elimination; t6 – preparation time for the task YI received from A1.

Then

$$K(Ao) = (Ts - \sum tc - \sum t'c) / Ts .$$

So the main factors that determine CAD-CAM readiness are: management, efficiency, data- and software quality, machinery reliability.

CAD-CAM flexibility. We want to study the flexibility concept in two aspects: in local and general. We define the loca1 flexibility we define as automaton Ao feature to provide an optimal output Y2 in [O,Ts] inspire of X1 and (or) Fs changes, while the Ao-structure is constant. This is functional Ao-flexibility. We understand the general flexibility as automaton ability quickly tune on the new aim F's in Δ τ-time and (or-) on the new input X'1 to get corresponding output Y'2 inside the subject oriented sphere of aims Δ Fs . This is structure functional flexibility of Ao .

To provide the local Ao-f1exibility it is necessary to, develop and use the discrete adaptive self-training system methods known before. Apparently, the general flexibility expects the local one. To study general flexibility we observe CAD-CAM as a queuing system. Here the successive connected A1 and A2 are servants. The inputs for A1 are X1, Fs. The service manner is determined by the aim F1 C Fs and restricted by T1, Hs, R1 belong to Rs. The inputs for A2 are Y1, F, S; the service is also specified by F2 C Fs and restricted by T2, Hs, R2 C Rs. The Fs has major priority among the inputs of A1, A2. Both inputs are non-stationary. The system A1 starts service actions according F's after result Y1 has been obtained, and A2 starts after Y2. Considering the complexity of automata A1, A2 structure (whose automata are service subsystems), and man-computer relations of those automata as well, we note following theses (which are not detail discussed in this paper).

1. The functioning of A1-input subautomata, which percept X1 (from surroundings, can be specified as Markov's process in [0, τ].

2. In [τ,τs]-interval this process transforms itself into non-Markov's because of:

a) iterate character of A1, A2 and loops in their connections;

b) multicriterial of project decisions and their starting-point compromise indicate the influence on the whole process of project realizing until the end-point Y2 | Fs because of incorrect task and (or) aim formulation.

The automata A1, A2, Ao reliability can be estimated in two meanings as follows.

1. Let t's be the time interval within the aim Fs of creating and maintenance new system S' is constant, e.g. S' is in a constant demand; T's is the interval necessary to create S' using Ao; t'' is the interval for tuning Ao on the new aim F's. Then the flexibility factor is

$$L(Ao) = (t's - T's – t''s)/ t's.$$

If T's $\geq$ t', t''s $\geq$ t's and L(Ao) is negative, then Ao can't manufacture computable production. The Ao is worth if $O < L(Ao) < 1$ Factors L (A1) , L (A2) are defined the same way. These factors determine the functional flexibility of Ao.

2. The structure of automaton Ao can be covered by oriented sectioned net

$$N (A o) == (V1, ... , Vn, \Theta),$$

Where V1,...,Vn are sections of the net-knots representing the subautomata Ao from clusters α1, α2 , Θ - the set of oriented connections [2], [4];

n is the number of knot sections. The entrance-section V1 from A1 takes the input data X 1 I Fs the aims of subautomata in V1,…, Vn are determined by Fs-decomposition; the exit- section Vn'' outputs Y2 I Fs according to (1).

Thus N(Ao) is the structure-functional model of CAD-CAM studied as a queuing system. The N(Ao) can be used for realizing some nets of structures W: anyone of them is able to provide some output Y2i while floating X1 in ΔX1 -interval and (or-) Fs in Δ Fs but considering (1). The structure transformation from Wi (N (Ao)) into W K (N (Ao)) is supposed to occurs in jump-manner when the aim Fs-change quantum is greater then Δ*Fs and (or) input X1-change is greater the Δ*X1. From this point of view the structure flexibility of Ao can be indicated by the set power of W - L*(Ao) = 1, then Ao shoes only the local flexibility.

Conclusion

Methodological basis of CADM simulation as automata target aimed systems and methods of determining their reliability, readiness and flexibility are proposed. It is how that investigation of CADM attar aimed queuing systems is worthy of note. The proposed method of α, β, γ-clustering for CADM tasks and functions allows to classify demands upon CADM reliability, readiness and flexibility in part1cular by paying main attention for creating optimum readjust able basic composition.

In our opinion problems of CADM flexibility are actual, but they are more fully reflected in terms of CADM adaptation and self-organizing as power controlling systems. Received results are perspective for developing and use CADM in theory. Limited volume out this paper does not allow us to consider problems of CADM shaping as a queuing system with non-Markov's process of functioning. These problems demand special investigations as they are raised for the first time.

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Володимир Гарбарчук, Наталія Гоц

Новий автоматно-ігровий метод моделювання надійності і гнучкості автоматизованих систем проектування і виробництва

Розглядається новий метод оцінки надійності і гнучкості системи автоматизованого проектування і виробництва як єдиної цілеспрямованої системи на основі синтезованих автоматно-ігрових моделей, розроблених авторами, кластерного аналізу і векторних ігр.

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