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Original Research Article

DESIGN AND SIMULATION OF INTERACTIVE DYNAMICAL PROCESS WITH USING THE COLOURED PETRI NET

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Abstract: - Primary properties of the offered method of coloured Petri net are given on the basis of analysis of the worked out intelligence systems which support computing research and simulation of difficult technical objects. For decision of the problem of effective research of dynamic interactive processes, algorithm which allow to analyze basic properties of the coloured Petri net is worked out. As results the matrix expressions are given and graph-scheme providing realization of machine experiments in accordance with properties of the coloured Petri net is built.

Keywords: Coloured Petri net, design of the intelligence system, attainability of the model.

I. Introduction

As known process of design of the intelligence systems like programmatic-analyzing facilities is accompanied on stages of research and with computer experiments. Taking into account of complication of structure of the intelligence system for its effective planning on the stage of system-technical development, the methods of the algorithmic, mathematical, programmatic and informative providing are demanded.

One of actual problem of theory of the intelligence systems is investigation of dynamic interactive processes which function in the conditions of complication [1], [2], [4], [6]. The difficulties bound by the decision of this problem depend on the row of factors to that it is necessary to take the first of all following: presence of plenty of associate elements with difficult structural and functional relations; functioning separate elements does not carry independent character and conditioned by their places in the system on the whole; functioning separate elements takes place asynchronously, where rule of their cooperation described by means of difficult logical terms.

Basis for such construction of Petri net became application of the coloured nets that could describe asynchronous interactive processes with the set exactness.

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Coloured Petri net (PN) [3] is natural interpretation of the real systems. Attributes correspond to the positions of the coloured Petri net where them name are colors. The rules of excitation of transitions are complemented by terms, supposing the stream of marks with certain colors of position. Executions of transitions are accompanied by a parcel in position of marks with created values of color. Coloured PN [8] reflect the logical sequence of events; the streams of information allow tracing, reflecting parallel interprocess communication. Advantage of this type of models is simplicity of understanding at engineering level and quickness of reading of graphic characters. Reproducing of dynamics of marks on the screen of display allows to trace motion and quality descriptions of processes and effectively to interpret the dynamics of the coloured nets.

For expansion of possibilities of description of the states of simulating object it is required to take into account the order of receipt of markers of different colors in certain positions of the net. Thus the model of object appears as PN with varicolored markers. The analysis of basic descriptions of object is taken of basic properties of net with varicolored markers. The analysis of other properties (for example, properties of liveliness) depends on the analysis of color attainability of nets with varicolored markers. For the analysis of color attainability of regenerating nets, description of count of color attainability and creation it is needed to use matrix of colour attainability. But, the matrix of color attainability for arbitrary nets can be built only after the receipt of all its marking attainability from initial. From this point of view, first a network with varicolored markers appears in private regeneration form and then analysis of color attainability is executed. In the article designs of dynamic interactive processes are considered with the use of coloured PN.

II. Determination of function of distribution of colors of markers entrance and output positions of transitions of net

PN with varicolored markers is determined formally as a set of kind [7] $N = (P, T, \Omega, F, H, \lambda, \Psi, \mu_0)$, where $P = \{p\}$ is nonempty finite set of positions; $T = \{t\}$ is an nonempty finite set of transitions; $\Omega=\{\omega\}$ is an nonempty finite set of colors of markers; $F: P\times T \to \{0,1,2,\dots\}$ and $H: T\times P \to \{0,1,2,\dots\}$ - according to the function of incident of great numbers of positions and transitions ; $\lambda : (P \times \Omega) \times T \to (0,1)$ is a function of distribution of colors of markers on entrance positions of transitions of the net; $\psi: T\times(P\times\Omega)\to(P\times\Omega)$ is a function of distribution of colors of markers on output positions of transitions of the net; $\mu_0: P\times\Omega\to \{0,1,2,\dots\}$ is the initial marking of the net. Functions λ and Ψ define the rules of executing transitions and determine distribution of colors of markers on positions of net in the process of its functioning.

Marking the positions of the net is represented as a matrix to the dimension $|P| \times |\Omega|$ where $\mu_i(p,\omega)$ is a number of markers of color ω in position of p.

In regenerating the net (RN) executing any transition of t is settled at presence of in all entrance positions of $p\in {}^{\bullet}t$ markers of one color $\omega_i\in\Omega$. After executing this passing to all its output positions the markers of color $\omega_i\in\Omega$ are placed. Function λ which actives again the net is given as follows:

$$\lambda({}^{\bullet}C_t)=\begin{cases}1, & \text{if distribution } {}^{\bullet}C_t \textit{ is possible for } \text{a transition } t;\\ 0-\text{otherwise},\end{cases}$$

Where ${}^{\bullet}C_t$ – distribution of kind:

$${}^{\bullet}C_t=[(p_{i1},\omega_i),\dots,(p_{in},\omega_i)];\ p_{ik}\in{}^{\bullet}t,\ k=\overline{1,n};\ n=|{}^{\bullet}t|,\ \omega_i\in\Omega.$$

The function Ψ in PN takes on values from an area

$$C_t^{\bullet}=\{[(p_{t_1},\omega_j),\dots,(p_{i_m},\omega_j)]\}=\{C_{t\omega_j}^{\bullet}\},\ p_{ik}\in t^{\bullet};\ k=\overline{1,m};\ m=|t^{\bullet}|,\ \omega_j\in\Omega$$

If $\psi({}^{\bullet}C_t)=C_t^{\bullet}$, then transition of t regenerates markers of color ω_i to the markers of color ω_j. Terms of wearing-out of transition of $t\in T$ at marking μ for PN is written as follows [5]

$$\forall p\in P,\ \exists\omega\in\Omega,[\mu(p,\omega)-F(p,t)+1]\cdot\lambda({}^{\bullet}C_t)=1.$$

The new marking μ' got as a result of execution of transition of t at fixed C_t is determined by means of a formula [9]:

$$\mu'(p,\omega) = \mu(p,\omega) - \delta_t(\omega)F(p,t) + \gamma_t(\omega)\cdot H(t,p);$$
$$\forall p \in P; \forall \omega \in \Omega,$$

where

$$\delta_t(\omega) = \lambda\,({}^{\bullet}C_t);\ \gamma_t(\omega) = \begin{cases} 1, \text{at } \psi\,({}^{\bullet}C_t) = C_t^{\bullet}; \\ 0 - \text{otherwise} \end{cases}$$

Taking into account foregoing the algorithm of analysis of color attainability of coloured PN is worked out.

III. Algorithm of analysis of attainability of the painted Petri net

At solution of practical problems matrix decision of structure of coloured PN is used. Process of structure forming, dynamical status of the net, redistribution of chips on positions and new marking are defined by the following algorithm:

Step 1. Creation of incidence of great numbers of positions of $F=[f_{ij}]$, ($i=\overline{1,n}$, $j=\overline{1,m}$); where n and m sizes of nonempty finite sets of positions of $P=\{p\}$ and transitions of $T=\{t\}$ accordingly. At $p_i \in {}^{\bullet}t_j$ the value of element of f_{ij} is equal to 1, otherwise equal to 0.

Step 2. Creation of incidence of great numbers of transitions of $H=[h_{ji}]$, ($i=\overline{1,n}$, $j=\overline{1,m}$). At $p_i \in t_j^{\bullet}$ the value of element of h_{ji} is equal to 1, otherwise equal to 0.

Step 3. Creation of matrix of the initial marking $\mu=[\mu_{i\ell}]$, ($i=\overline{1,n}$, $\ell=\overline{1,k}$) where ℓ equal to the size of nonempty finite set of colors of markers. $\mu_{i\ell}$ is equal to the number of markers of color ω_ℓ in position of p_i.

Step 4. Creation of matrix of determination of distribution of colors of markers on entrance positions of transitions $\lambda=[\lambda_{j\ell}]$, ($j=\overline{1,m}$, $\ell=\overline{1,k}$). At ($\overrightarrow{{}^{\bullet}t,\omega_\ell}$) $\in {}^{\bullet}C_t$ the value $\lambda_{j\ell}$ is equal to 1, otherwise equal to 0.

Step 5. Creation of matrix of determination of distribution of colors of markers on output positions of transitions $\psi=[\psi_{j\ell}]$, ($j=\overline{1,m}$, $\ell=\overline{1,k}$). At ($\overrightarrow{t^{\bullet},\omega_\ell}$) $\in C_t^{\bullet}$ the value $\psi_{j\ell}$ is equal to 1, otherwise equal to 0.

Step 6. Search of the settled transition. For every transition of t_j, $j=\overline{1,m}$ the condition of wearing-out is checked up :

a) from the matrix of F all entrance positions of transition t_j are determined:

$p_{i_1}, p_{i_2}, \ldots, p_{i_z}$, where $z = \left|{}^{\bullet}t_j\right|$;·

b) from the matrix λ all accessible distributions of colors are determined on entrance positions of t_j:

$\omega_{\ell_1}, \omega_{\ell_2}, \ldots, \omega_{\ell_p}$, $p \in [1,k]$;

v) from a matrix μ the numbers of certain color of markers get out in all certain entrance positions of transition of t_j:

$\mu_{i_z \ell_p} = \left(p_{i_z}, \omega_{\ell_p}\right)$, $z = \overline{1,\left|{}^{\bullet}t_j\right|}$, $p = \overline{1,k}$;g) if for $\forall i_z$ $\exists$ ℓ_p exists,□ that $\mu_{i_z \ell_p} \geq f_{i_z j}$, then the transition of t_j is settled and a step is executed 8.

Step 7. If for a transition the t_j condition is not executed, then the index of j increases on 1: $j=j+1$. If $j \le m$ then it comes true passing to the point of a), in otherwise reported about the dead-locked state.

Step 8. Calculation of elements of matrix μ':

$$\mu'_{i\ell} = \mu_{i\ell} - \lambda_{j\ell}\cdot f_{ij} + \psi_{ij}\cdot h_{ji},\quad i=\overline{1,n}, \ell=\overline{1,k}.$$

Step 9. Passing to the step 6. A process proceeds to the receipt of the sought after marking.

Analyzing basic properties limit (extremity of the states of separate elements of the system) nature, safety (number of the states no more of one), savings (impossibility of elimination and origin of additional resources), liveliness (absence of the dead-locked states in the process of functioning of the system), attainability (sequence of transitions, translating the systems from one state in other) can be estimated behavior of the designed system.

IV. Model of simulation of the flexible manufacture module of tooling

Let's consider the model of simulation of the flexible manufacture module (FMM) of tooling. FMM of tooling includes: the personal entrance store equipment 1; personal entrance store equipment 2; equipment 1 for treatment of the first type of detail; equipment 2 for treatment of the second type of detail; personal output store equipment 1; personal output store equipment 2; an industrial robot (IR) for loading and unloading equipment 1 and equipment 2 accordingly.

Connection of the module with previous and subsequent the modules takes place accordingly by means of foregoing stores. On the module two types of details are processed. The module works as follows: details act on the personal entrance stores and expect treatment; at presence of details of entrance stores of IR an equipment carries out loading 1, after equipment 2, after treatment of details there is their unloading and cycle recurs.

In the imitation model [10] made by means of coloured PN (fig.1) status of FMM tooling are described by next positions: p_0 - IR is executed by the operations of loading-unloading equipment 1 and equipment 2; p_1 is the personal entrance store of equipment 1; p_2 is the personal entrance store of equipment 2; p_3 - completed IR loading equipment 1 and equipment 1 in the state implementation of operation; p_4 - completed IR loading equipment 2 and equipment 2 in the state implementation of operation; p_5 is an equipment 1 completed operations and in a state of unloading; p_6 is an equipment 2 completed operations and in a state of unloading; p_7 is the personal output store of equipment 1; p_8 is the personal output store of equipment 2; p_9 is an equipment 1 it is not unloaded and will not be loaded; p_{10} is an equipment 2 it is not unloaded and will not be loaded.

Possible events in the module of tooling are described by transitions: t_1 - IR is executed by the operations of loading equipment 1; t_2- IR is executed by the operations of loading equipment 2; t_3 is an equipment 1 execute an operation above a detail; $t_4 -$ equipment 2 executes an operation above a detail; $t_5 -$ IR is off-loaded equipment 1; t_6 - IR is off-loaded equipment 2.

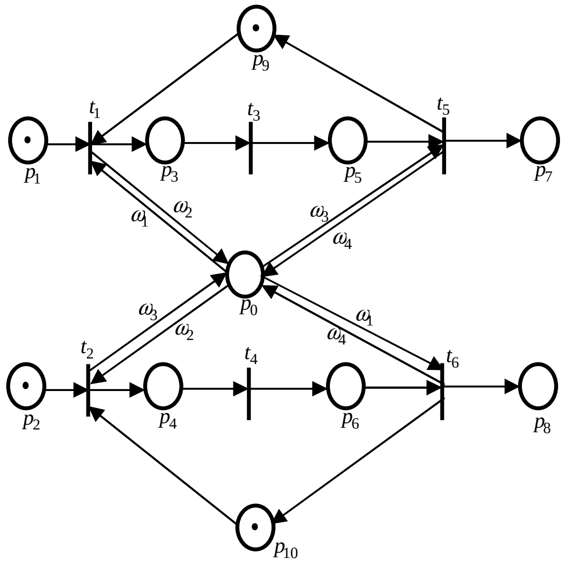

Fig. 1. Graph-scheme of functioning FMM of tooling.

The function of incident of great numbers of positions appears the matrix of F [10, 6]:

F	t_1	t_2	t_3	t_4	t_5	t_6
p_0	1	1	0	0	1	1
p_1	1	0	0	0	0	0
p_2	0	1	0	0	0	0
p_3	0	0	1	0	0	0
p_4	0	0	0	1	0	0
p_5	0	0	0	0	1	0
p_6	0	0	0	0	0	1
p_7	0	0	0	0	0	0
p_8	0	0	0	0	0	0
p_9	1	0	0	0	0	0
p_{10}	0	1	0	0	0	0

The function of incident of great numbers of transitions appears the matrix of H [6, 10]:

H	p_0	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}
t_1	1	0	0	1	0	0	0	0	0	0	0
t_2	1	0	0	0	1	0	0	0	0	0	0
t_3	0	0	0	0	0	1	0	0	0	0	0
t_4	0	0	0	0	0	0	1	0	0	0	0
t_5	1	0	0	0	0	0	0	1	0	1	0
t_6	1	0	0	0	0	0	0	0	1	0	1

The incidence matrix of entrance and output function is represented by means of the matrix D [6, 10]:

D	p_0	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}
t_1	0	–1	0	1	0	0	0	0	0	–1	0
t_2	0	0	–1	0	1	0	0	0	0	0	–1
t_3	0	0	0	–1	0	1	0	0	0	0	0
t_4	0	0	0	0	–1	0	1	0	0	0	0
t_5	1	0	0	0	0	–1	0	1	0	1	0
t_6	1	0	0	0	0	0	–1	0	1	0	1

Distribution of colors of markers on entrance positions of transitions of the net The incidence matrix of entrance and output function is represented by means of the matrix λ [6, 4]:

λ	ω_1	ω_2	ω_3	ω_4
t_1	1	0	0	0
t_2	0	1	0	0
t_3	0	0	0	0
t_4	0	0	0	0
t_5	0	0	1	0
t_6	0	0	0	1

Because a model appears the selective coloured net, matrix of distribution of colors of markers on entrance positions of transitions of the net coincide with a matrix:

$\lambda : \psi[j,k] = \lambda[j,k],\ j = \overline{0,10}\,;\ k = \overline{1,4}$.

The initial marking is represented by means of the matrix μ [10, 4]:

μ	ω_1	ω_2	ω_3	ω_4
p_0	1	1	0	0
p_1	0	0	0	0
p_2	0	0	0	0
p_3	0	0	0	0
p_4	0	0	0	0
p_5	0	0	0	0
p_6	0	0	0	0
p_7	0	0	0	0
p_8	0	0	0	0
p_9	0	0	0	0
p_{10}	0	0	0	0

The state corresponds the initial marking, when on an entrance store each the equipment there are details and IR are adjusted on implementation of operation of loading first equipment.

The worked out model, presenting process, is in the system robot-serviced, on that the great number of the colors bound to the marks and arcs of the net is accepted $c = (\omega_1, \omega_2, \omega_3, \omega_4)$. A mark, imitating work of robot, and arcs enroute robot, is coloured in the net. Other arcs, and also marks-wares and marks-managements are not coloured. Initial color of mark in p_0 equal ω_1 and an arc (p_0, t_1) is coloured in ω_1. Therefore the condition of excitation is executable for a transition t_1 . After the wearing-out of passing t_1 to positions p_0 a mark returns, having a color ω_2, as an arc (t_1, p_0) is coloured in a colour ω_2. Coloring arcs provides excitation only one of transitions following p_0, at any state of the system. At this coloration the route of robot is presented by the sequence of working transitions t_1, t_2, t_5, t_6, i.e. there is loading equipment 1, after loading equipment 2,

V. Conclusion

The algorithm of analysis of colour attainability of coloured PN is offered and worked out. The offered algorithm forms the matrices of color attainability, determines the functions of distribution of colors of markers entrance and output positions of transitions and allows to analyze basic properties of coloured PN.

On the basis of the offered algorithm, its software is worked out by means of the system DELPHI 7.0. The resources of modern computers allow to decide problems with the matrices of largeness enough, that fully satisfies to the requirements, produced to simulation of really of difficult objects.

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