Procedure for Selection of Suitable Resources in Interactions in Complex Dynamic Systems Using Artificial Immunity

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Abstract :

The dynamic optimization procedure for n-dimensional vector function of a system, the state of which $x = (x_1,..., x_n)^T$ is interpreted as adaptable immune cell, is considered Using the results of the theory of artificial immune systems. The procedures for estimate of monitoring results are discussed. The procedure for assessing the entropy is recommended as a general recursive estimation algorithm.

The results are focused on solving the optimization problems of cognitive selection of suitable physical resources, what expands the scope of Electromagnetic compatibility.

Key wards: complex dynamics, artificial immunity, interactions

الخلاصة

ان الاجراءات الديناميكية المثلة لعدد من المتجهات في النظام ، والتي $x = (x_1,..., x_n)^T$ دالة اتجاهية تفسر كتكيف الخلايا المناعية ، تؤخذ بالاعتبار مستخدمتا نتائج نظرية جهاز المناعة الاصطناعية . ومناقشة تقييم الاجراءات لنتائج المراقبة . والنتائج تركز على حل مشكلة التحسين التي تعمل على تحديد المصادر الفيزيائية المناسبة ، والتي توسع مجال التكيف الكهرومغناطيسي .

الكلمات المفتاحية : الحركية المعقدة، التداخلات، الصناعية.

1.Introduction :-

Interactions between individual elements of the systems may be divided into conflicting, cooperative or single-sided (a game with nature: strategy of indifference [CamererC,et all,2004]. At the system level of interactions between elements of a large-scale system, apart from the mentioned, duel ones, multiple, intrasystem and intersystem ones may occur as well. They tend to arrange such interactions respectively in object-oriented dynamic systems. Achievement of an equilibrium state in a game appears to be optimal for a functioning system [CamererC,et all,2004]. However, in such a setting, solution to the task often turns out to be complicated and is found only in simple situations, with a limited number of interacting elements.

There is a large number of simpler optimization solution methods for certain individual situations. Such methods should include models and methods of collective behaviour [CamererC,et all,2004], resource distribution methods, decision making methods, and artificial immunity methods (AIM) [Nisan N,et.all,2007], etc.

AIM belongs to a class of genetic algorithms and allows, in a group of interacting elements, to select more effective, resource-saving or valuable states of those elements meeting a certain criterion by a specific attribute [ITU-R SH,1997].

Current radio electronic means (REM) for telecommunications, radio detection and ranging, medicine, etc., operate under conditions of limited physical resources, what results in multiple mutual interferences. The resulting problem of electromagnetic compatibility (EMC) may not be solved in a duel setting. For it to be solved, a system approach is required, an attempt to demonstrate it is a subject matter of this article.

2.Characteristics of a subject of research:

In problems of planning, applying, ensuring EMC, etc., a multidimensional vector space of parameters characterizing a set of REMs has to be considered. The entire set of REM parameters consists of the following subsets: $\{F\}$ - frequency, $\{T\}$ - temporal, $\{G\}$ - spatial, $\{p\}$ - polarization, $\{P\}$ - power [[ITU-R SH,1997]:

$$\{\text{REM}\} = \{F^R, T^R, G^R, p^R, P^R\} + \{F^T, T^T, G^T, p^T, P^T\}, \quad (1)$$

where indexes $R\text{и}T$ belong to parameters of receiving and transmitting REM equipment, respectively.

Among a set of parameters (1) a group (permissible set of states of this system), most suitable, meeting REM quality criteria on the functioning time interval $\Phi(x(t)) \rightarrow$ extr has to be selected for solving certain practical problems.

Set (1) may be considered as a vector function of parameters of some dynamic system. For dynamic systems developing on the time interval $t \in T = [t_0, t_N]$, vector (1) determining state of parameters of the system $x(t)$ shall be supplemented with a vector of control parameters $u(t)$, $u \in U$, U - a set of permissible controls maintaining state $x(t)$on a required level or transferring the system into a required phase state according to the criterion $\Phi(l, x, u) \rightarrow$ extr. Equation of state of the controlled dynamic system in general is represented in the following form:

$$\mathrm{dx}(t)/\mathrm{dt} = f(t, x(t), u(t)), t \in T = [t_0, t_N], \quad (2)$$

where$f(t, x, u) = (f_1(t, x, u), ..., f_n(t, x, u))^T$is an n-dimensional vector function of the state of the system in question developing along the trajectory on the set time interval.

From a set of values $f_i(t, x, u), i = \overline{1, n}$along the trajectory on the entire time interval Tor on every discrete portion of this interval Δt_k,$k = 1,2, ..., N$, a required number of values of these vector functions $m < n$ meeting the given selection criterion shall be selected.

$$J(t, x, u) = \min_{x,u}. \quad (3)$$

In the result of possible states selection,

$$X = \{(x_1^i, ... x_n^i)^T, i = 1,2, ..., k\}, \quad (4)$$

$m$of permissible ones that may be considered as populations x^k, determined on each of the time interval Δt_k, $k = 1, ..., N$, is selected. Thus, criterion (3) may be considered as a fitness function (FF). This process (ITU-R SH,1997 and de Castro L.N,et all,2007) resembles a function of an immune cell (IC) x_i, adjusting to a changing situation and producing necessary antibodies. Problems of IC selection targeting $x = (x_1, ..., x_n)^T$ according to FF are addressed in a theory of artificial immune systems [de Castro L.N,et all,2007 and Dasguptra D,1999]. The selection procedure results in replacement of less adjusted ICs with new ones satisfying FFs. The major difference between artificial immunity (genetic algorithm) methods and standard optimization procedures lies in the fact that at every k-step of computations one has to deal with several values of vector x, forming a population rather than a single extreme value. Eventually, a new population is formed developing in time along the trajectory of this dynamic system.

3.Setting up a problem :

A functional reflecting the extreme point of the vector function on the observation interval T is selected as a criterion $J(t, x, u)$ taking into account the measure of the system state values $x_c^k, k = 1, ..., N$ proximity to the required level:

$$f(x\quad) = \min_{x \in X} f(x), \; x = (x_1, x_2, ..., x_n)^T. \quad (5)$$

For further solution, from n values of the system states, the initial population is determined from m of ICs on a set of permissible control values U.

Normalized representation is often used as FF:

$$J(x\ \ ) = \frac{f(x\ \ )-f_{\min}}{f_{\max}-f_{\min}}, \tag{6}$$

where $f_{\max}$, $f_{\min}$ are respective extreme values of the function f.

It is obvious that practical solution to the problem on the time interval is only possible provided the observability (supper-intelligent players) is ensured, that is subject to availability of vector monitoring results $y(t,x)$, which may be represented accordingly in the form of a linear (7) or nonlinear (8) function:

$$y(t) = \mathrm{h}x(t) + \xi(t), \tag{7}$$

$$y(t) = h(x(t),t) + \xi(t), \tag{8}$$

where $\xi(t)$ is errors in measurement of vector parameters $x(t)$ usually approximable with white Gaussian noise.

4.Problem solution:

The optimization procedure of population formation may be limited to various varieties corresponding to biological operations: selection, cloning, crossingover, and mutation.

The selection lies in the fact that ICs most meeting FF are selected from the studied parameter set (1) and respective vector functions $f(t,x,u)$ by a certain feature. Processes of selection of suitable frequencies in problems of cognitive radio may be provided as an example.

Cloning is based on selection solutions, while l-clones are generated for selected ICs. This procedure lines up with solutions ensuring EMC in cellular or satellite systems in case of repeated use of frequencies.

Crossingover is a process of "crossing" when two or more ICs exchange the available resource:

$$x_i' = x_i + \Delta x_{i+1}, x_{i+1}' = x_{i+1} + \Delta x_i.$$

Mutation lies in a random change of IC parameters when some modification of the state happens at every further step:

$$x_k' = x_k \oplus \Delta\sigma_k,$$

where $\Delta\sigma$ is a modifying addition, $\oplus$ is a modification symbol.

Solution in relation to the system (2) is found in the form of the set $k \in [1,N]$ of piecewise-constant n-dimensional vector functions meeting FF

$$J(t,x,u) = J(t,x_k^i(t),u_k^i(t)), i = \overline{1,n}, k = \overline{1,N}, \tag{9}$$

forming n-dimensional state trajectory:

$$x(t_i) = \{x(1),x(2),...,x_N\}^T \tag{10}$$

and respective control trajectories:

$$u(t_i) = \{u(1),u(2),...,u_N\}^T. \tag{11}$$

Thus, the procedure for solving this problem is limited to the following order:

1. Obtaining a sequence of monitoring results forming the set

$$Y = (Y_1^i, Y_2^i,..., Y_n^i), k = \overline{1,N}. \tag{12}$$

According to (7), (8), each of the vectors Y^i is a reference value of n-dimensional random process. In this case, for purpose of preserving correlations between neighbouring time intervals Δt_i and Δt_{i+1}, periodicity of reference values y_n^k shall be selected from the condition

$$\Delta t_k << \tau_{\text{кор}}, \tag{13}$$

where τ_{cor} is a correlation window of observed processes (2). Experience has shown [6], that sufficient conditions for fulfillment (13) are $\tau_{\text{cor}} \geq 10\Delta\tau_k$.

2. Selection of the control procedure. According to the optimal-control theory [6], control values of the random system $u_i(t)$ are found on the basis of the state

vector x_i during stochastic observations (7), (8). In Gaussian situation, a theorem on division [6] is applied allowing using the determined control procedure according to the stochastic estimate of the state $\hat{x}_i$:

$$u_i(t) = A\hat{x}_i(t), i = \overline{1,n}. \tag{14}$$

The control (14) is performed according to Watt principle, that is by deviation [6].

3. Estimate of the selected attribute. The estimate $\hat{x}_k$ is discovered by results of monitoring. In the assumption $h(\cdot) = 1$ in equations (7), (8), the analytic form of the recursive algorithm of estimate is represented in the form of [Popovskij V,et,all.2011]:

$$\hat{x}_{k+1} = \gamma y_k + (1-\gamma)\hat{x}_k, k = 1,\ldots, N, \tag{15}$$

whereγ is a coefficient ensuring algorithm stability and convergence and is selected from the condition $0 < \gamma \leq 1$.

Another interpretation of the algorithm other than (15) is often used and is called Robbins-Monro procedure:

$$\hat{x}_{k+1} = \hat{x}_k + \gamma[y_k - \hat{x}_k], \tag{16}$$

where the expression in brackets is called a residual error [6]. The resulted value of the estimate (15), (16) is used further for discovery of the control (14).

4. In the result of the procedures undertaken: monitoring, state estimate (15, 16) and control (14) by means of FF a respective selection is performed, m of permissible values of vector population (4) is formed. A number of efficient methods may be used for such selection, for example: cluster analysis, rank methods, etc.

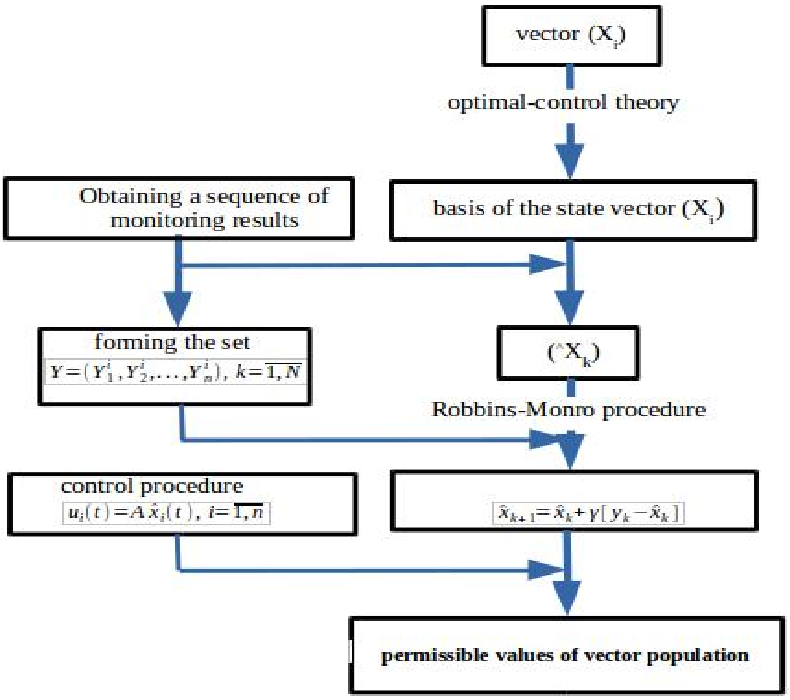

Chart showing the steps solution

5.Methods of formation of an estimate algorithm for information attribute:

As an object forming a state attribute, let's select amount of information obtained in the result of n-dimensional vector (12) monitoring at every step of discretisation (13). This amount of information shall be determined by the measure:

$$H_k(x_i) = -\sum_{i=1}^{n} p_k(x_i)\log_2 p_k(x_i), i = \overline{1,n}, k = \overline{1,N}. \tag{17}$$

where$p(x_i)$ is a probability of state of observed i-dimensional vector (12).

According to the system dynamics, at every next $k+1$ step, amount of information is changed by a value

$$I_{k+1/k} = H_{k+1}(x_i^{k+1}) - H_k(x_i^k) = \Delta H_{k+1}(x_i^{k+1}). \quad (18)$$

Vector sequence $H_k(x_i)$or $I_{k+1/k}$ represents n-dimensional random process of (7), (8) type. These values are subject to estimate procedure (15), (16): $\hat{H}_k(x_i)$, $\hat{I}_{k+1/k}$.

Entropy (17) estimate is obtained according to algorithm (16):

$$\hat{H}_{k+1}(x_i) = \hat{H}_k(x_i) - \gamma[H_{k+1}(x_i) - \hat{H}_k(x_i)]. \quad (19)$$

Probability density $p_k(x_i)$ required for discovery of the entropy has a posteriori nature and is formed on the basis of the sample of realizations previous to the step $k+1$.

The procedure for selection of suitable m of values from $i = n$ estimates of vector $\hat{H}_i$ is implemented based on certain conditions of the problem to be solved. It is obvious that m of values selected according to the fitness function contains the amount of information required for the problem to be solved.

6.Conclusions:

1. Artificial immunity methods make it possible to solve a wide range of problems related to selection of properties of dynamic system elements. This grade of problems occur when electromagnetic compatibility is ensured in REM groups, when cognitive radio problems are solved, etc., that may be limited to respective biological operations: selection, cloning, crossingover, and mutation.
2. Possibility to use standard recursive procedures like stochastic approximation and obtaining estimate of the selected evidence of fitness for selection of m suitable component vector functions of the state of the stochastic dynamic system was shown.
3. The suggested procedures for selection of suitable physical resources implemented in real time of operation, allow using limited collective resources of multidimensional dynamic systems far more efficiently. The analysis shows that transition from a method of using fixed resources to dynamic cognitive procedures allows increasing efficiency of implementation of resources made available by 40-60 percent of resources.

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