Interpretation of Forecast State of Dynamic Objects by Images Recognition And Evolutionary Computation

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Abstract

The problem of forecasting of conditions of complex objects which characterized by time functions is considered. This problem of forecasting is reduced to the decision of problem of stochastic programming with probable restrictions. As restrictions there are inequalities, formalizing the requirements of hit of the control trajectory's predicted part to classes with probabilities, satisfying to the set of restrictions. For the decision of the received problem of optimization the genetic algorithm of given problem with stochastic specificity is under construction.

Keywords: *Control Object, Estimation, Trajectory, Evolutionary Algorithms, Population, Genetic Algorithm.*

Let

$$\{Q_1, Q_2, ..., Q_m\} \tag{1}$$

represents final set of some complex, dynamic objects, which conditions are described by Q set (vector) of signs

$$\tilde{x}(t) = (x_1(t), x_2(t), \ldots, x_n(t)). \tag{2}$$

The set of objects is considered as admissible if signs (2) are defined by areas of corresponding values G_i, that is

$$x_{ui}(t_k) \in G_i, i = \overline{1,n} \tag{3}$$

for all $u = 1,2,\ldots m$ and for each moment of time

$$0 < t_0 < t_1 < \ldots t_\delta = T + \Delta t. \tag{4}$$

Constellation of every possible sets of signs' value (2) forms signs' space of dimension *n*. Objects $Q_i, i = \overline{1,m}$ which conditions are described by vectors (2) during each moment $t_k \in [0, T + \Delta t], k = \overline{0,\tau},$ have the same length and the same structure of components. Such objects are called as *homogeneous*. In signs' space (2) each object $Q_i \in \{Q_1, Q_2, \ldots, Q_m\}$ corresponds to the discrete trajectory, which simulates functioning of object conforming to it, observed on time part $[t_0, t_\tau]$.

If changing process of objects' conditions (1) is considered as casual process, then signs (2) represent functions of the valid parameter $t \in [t_0, t_\tau]$ which values at everyone t are random variables, and their set can be considered as some realisation of observable casual process.

Part $[t_0, t_\tau]$ is segmented $\lfloor t_0 = 0, t_p = T \rfloor$. $[0, T]$ is an interval of prehistory for control trajectories $p < \tau$, where T is the moment of forecast; $\lfloor t_p = T, t_\tau = T + \Delta t \rfloor$ is an anticipation interval, that is $\Delta t = t_\tau - t_p > 0.$

For training sample [10,11] we accept a set of objects, $\{Q_\nu, \nu = \overline{1,N}\} \subseteq \{Q_1, Q_2, \ldots, Q_m\}, \quad N \le m,$ to which in signs' space set of trajectories

$$\{L_\nu, \nu = \overline{1,N}\}, \tag{5}$$

defined at all time part $[t_0, t_\tau]$, corresponds. By definition training sample (5) is considered broken into a final set of classes $K_j, j = \overline{1,l}, l \ge 2$, so

$$L_\nu \in k_j, \;\; N_{j-1} + 1 \le \nu \le N_j, N_0 = 0, N_l = N, \tag{6}$$

thus

$$\{L_1, L_2, \ldots, L_\nu\} = \bigcup_{j-1}^{l} K_j,$$
$$K_j \bigcap K_{j_2} = \theta, j_1 \ne j_2. \tag{7}$$

Let's notice, that at the moment of time $t_\tau = T + \Delta t$ splitting (6) and (7) take place. As control objects we will consider the sets

$$\{Q'_\mu, \mu = \overline{1,q}\}, \tag{8}$$

which elements are defined on time interval $\lfloor t_0, t_p \rfloor$, are described by signs (2) and concern to type of homogeneous objects, as set (1). As, it is offered, that the accessory of objects $Q'_1, Q'_2, \ldots, Q'_q$ to classes $K_1, K_2, \ldots, K_l$ at the moment of time $t_\tau = T + \Delta t$ is known.

The feature set (2) as a number of supervision on the part $[t_0, t_\tau]$ for objects $Q_1, Q_2, \ldots Q_N$, which can be present in the form of matrixes of dimension $(\tau + 1) \times n$ is considered. It is obvious, that, number of matrixes will be N (number of objects), thus lines are object conditions, and columns are values of signs (2), namely

$$\| x_{\nu 1}(t_k) \ldots x_{\nu i}(t_k) \ldots x_{\nu n}(t_k) \|, \tag{9}$$

where $\nu = \overline{1,N}; k = \overline{0,\tau}$.

Similarly, signs' values (2) of objects $Q_1', Q_2', \ldots, Q_q'$, which turn out by tests, realised during the discrete moments of time

$$0 = t_0 < t_1 < \ldots < t_k < \ldots < t_p = T, \qquad (10)$$

also are represented in the form of matrixes of dimension $(p+1) \times n$, that is

$$\left\| x_{\mu 1}'(t_k) \ldots x_{\mu i}'(t_k) \ldots x_{\mu n}'(t_k) \right\|, \qquad (11)$$

where $\mu = \overline{1,q}$; $k = \overline{0,p}$

In signs' space of objects

$$\{L_1', L_2', \ldots, L_q'\}, \qquad (12)$$

defined on piece $[0,T]$, which continuations on an anticipation interval remain unknown, are corresponded to Q_μ', $\mu = 1,2,\ldots,q$. It is required to construct continuations of sample (12) on an interval of anticipation $[T, T+\Delta t]$ concerning a characteristic, with due regard for restrictions at the moment $T + \Delta t$, that is to solve a problem of forecasting of control trajectories on an interval of anticipation $[T, T+\Delta T], \Delta t > 0$ with restrictions is required. Restrictions are reduced to the requirement of hit (12) at the moment of $t = t_\tau$ in classes $K_1, K_2, \ldots, K_l$ with probabilities, which satisfied to the given of restrictions.

Let's enter some function

$$f(t, \widetilde{x}(t)) = f(t, x_1(t), x_2(t), \ldots, x_n(t)),$$

which is substantially connected with each object from set

$$\{Q_1, Q_2, \ldots, Q_N; Q_1', Q_2', \ldots, Q_\varepsilon'\}. \qquad (13)$$

Function $f(t, \widetilde{x}(t))$ characterised any kind of a resource which is necessary for transfer of corresponding object (13) from one condition to another. And function $f(t, \widetilde{x}(t))$ for every $Q_\nu, \nu = 1,2,\ldots,N$ in points $t_0, t_1, \ldots, t_\tau$ is defined by values

$$f_\nu(t_k, x_{\nu 1}(t_k), \ldots, x_{\nu n}(t_k)),$$
$$\nu = \overline{1,N}; k = \overline{0,\tau} \qquad (14)$$

and for each object $Q_\mu', \mu = \overline{1,q}$ in points (10) of part $[0,T]$ by values

$$f_\mu'(t_k, x_{\mu 1}'(t_k), \ldots, x_{\mu n}'(t_k)),$$
$$\mu = \overline{1,q}; k = \overline{0,p}. \qquad (15)$$

Considering (14), (15) we will expand matrixes of the initial information (9), (11) by addition of one column in the following form for training objects $Q_1, Q_2, \ldots, Q_N$ with matrixes of dimension $(\tau+1) \times (n+1)$, that is

$$\left\| x_{\nu 1}(t_k) \ldots x_{\nu n}(t_k)\ f_\nu(t_k, x_{\nu 1}(t_k), \ldots, x_{\nu n}(t_k)) \right\|, \qquad (16)$$

where $\nu = \overline{1,N}$; $t_k \in [0, T+\Delta t]$; $k = \overline{0,\tau}$

Similarly, the information about control objects $Q_1', Q_2', \ldots, Q_q'$ is represented on the part $[0,T]$ by corresponding expanded matrixes of dimension $(p+1) \times (n+1)$, namely,

$$\left\| x_{\mu 1}'(t_k) \ldots x_{\mu n}'(t_k)\ f_\mu'(t_k, x_{\mu 1}'(t_k), \ldots, x_{\mu n}'(t_k)) \right\| \qquad (17)$$

where $\mu = \overline{1,q}$; $t_k \in [0,T]$; $k = \overline{0,p}$.

Let's notice, that strokes in a matrix (17) as in all previous records, and more low, are a sign of accessory of these elements to control sample $\{Q_\mu', \mu = \overline{1,q}\}$ [11].

The matrix (16) is called *training information*, and (17) - *control information* describing elaboration's prehistory of objects $Q_1', Q_2', \ldots, Q_q'$.

Let it is given

$$I_0(K_1, K_2, \ldots, K_l; L_1', L_2', \ldots, L_q')$$

as the initial information [9] that is data of matrixes (17) and conditions (6), (7); $0 \le A_{\mu j} \le 1, \mu = \overline{1,q}; j = \overline{1,l}$ are given quantities. We will consider function $f'(t)$, which characterises trajectories L_μ' of object number Q_μ', that is time- and signs- dependent resource function,

$$f'(t) = f'(t, x_1'(t), x_2'(t) \ldots\ldots\ldots, x_n'(t)). \qquad (18)$$

Reasoning for one number μ that is fair for all $\mu \in$ *{1,2, … …, q}* are hereinafter conducted. Therefore further for compactness we lower index μ. We will offer, that function $f'(t)$ is provided as

$$f'(t_k) = \sum_{i=1}^{n} c_i x_i'(t_k) + \varepsilon(t_k),$$
$$t_k \in [0,T], k = \overline{0,p} \qquad (19)$$

where $c_i, i = \overline{1,n}$ are some unknown constants which are must be defined. $f'(t_k)$ and $x_i'(t_k)$ are known corresponding values of $f'(t)$ and $x_i'(t)$ in points $t_k, k = \overline{0,p}$. $\varepsilon(t_k)$ - casual deviations in the same points. The system (19) can be presented in a matrix form as

$$f' = A \cdot \overline{c} + \overline{\varepsilon}, \qquad (20)$$

where $f' = (f'(t_o), f'(t_1), \ldots. f'(t_p))^t$ is a vector of values of function $f'(t)$ on $[O,T]$; $\overline{c} = (c_1, c_2, \ldots, c_n)^t$ is an unknown vector; $\overline{\varepsilon} = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n)^t, \varepsilon_i = \varepsilon(t_i), i = \overline{1,p}$ is a vector of casual deviations

$$\| x_i'(t_k) \|, i = \overline{1,n}; \kappa = \overline{0,p} \qquad (21)$$

It is supposed, that $\bar{c} \in R^n$ is a casual vector $\bar{\varepsilon} = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_p) - M(\bar{\varepsilon}) = 0$ or $M(\varepsilon(t_k)) = 0, k = \overline{0, p}$.

Further for any $t_k \neq t_1, M(\varepsilon(t_k)\varepsilon(t_i)) = 0; M(\varepsilon^2(t_k)) = \sigma^2 =$ $t_k \in [0, T], k = \overline{0, p}$.

Here σ^2 is a dispersion of deviations. Besides it is supposed, that the rank of a matrix (21) is equal *n*.

At these assumptions for estimation of an unknown vector on interval $[O, T]$ the method of the minimal squares of deviations is used. According to this method the sum of squares of deviations is minimised, that is

$$J(\overline{C}) = \sum_{k=0}^{p} \varepsilon^2(t_k) = \bar{\varepsilon} \cdot \bar{\varepsilon}^t = = (f' - A\overline{C})^t \cdot (f' - A\overline{C}), \quad (22)$$

where $\bar{\varepsilon} = (f' - A\overline{C})$ is a vector of the "estimated" deviations. Function (22) is reached a minimum in a point

$$\overline{C}^* = (A^t \cdot A)^{-1} \cdot A^t \cdot f'. \quad (23)$$

The estimation (23) is the estimation of minimal squares' method [1].

On the interval of forestalling $[T, T + \Delta t]$ an average value of forecast function is defined by linear function

$$\hat{f}(t_k) = \sum_{i=1}^{n} C_i^* X_i'(t_k), t_k \in [T, T + \Delta t], \quad (24)$$

where coefficients $C_i^*, i = \overline{1, n}$ are calculated by formula (23). As on interval $[T, T + \Delta t]$ values of signs in (24) are unknown, there is a necessity of forecasting of values $x_i'(t_k), i = \overline{1, n}$ in points $t_k, k = \overline{p+1, \tau}$. For the decision of a problem of forecasting of values $x_i'(t_k)$ for each trajectory $L_\mu' \in \{L_1', L_2' \ldots, L_q'\}$ it is possible to take advantage of autoregressional model $[x \times x]$, or exponential smoothing [1,7].

Thus, the calculation of values of function $f'(t, \tilde{x}(t))$ on an forestalling interval (i.e. forecasting) can be executed by the formula

$$\hat{f}(t_k) = \hat{f}(t_k, \hat{x}_1(t_k), \hat{x}_2(t_k), \ldots, \hat{x}_n(t_k)) =, = \sum_{i=1}^{n} C_i^* \hat{x}_i(t_k) \quad k = \overline{p+1, \tau} \quad (25)$$

where $\hat{x}_1(t_k), \hat{x}_2(t_k), \ldots, \hat{x}_n(t_k), t_k \in [T, T + \Delta t]$ are values of the signs' forecast in points $t_{p+1}, t_{p+2}, \ldots, t_\tau$.

Let's designate true unknown values of resource function in points of forestalling interval through $\tilde{f}(t_k), t_k \in [T, T + \Delta t], k = \overline{p+1, \tau}$ and also we assume, that this function is presented as

$$\tilde{f}(t_k) = \sum_{i=1}^{n} \tilde{c}_i x_i(t_k) + \varepsilon(t_k), k = \overline{p+1, \tau} \quad (26)$$

where $\tilde{c} = (\tilde{c}_1, \tilde{c}_2, \ldots, \tilde{c}_n)$ is a vector of unknown factors; $x_1(t_k), x_2(t_k), \ldots, x_n(t_k)$ is the random variables, which average values coincide with values of the signs' forecast, that is $MX_i(t_k), t_k \in [T, T + \Delta t], i = \overline{1, n}$.

Let $Q_i' \in K_j$ and

$f^u(t_\tau, x_1(t_\tau), x_2(t_\tau), \ldots, x_n(t_\tau)) = f^u(t_\tau)$,

u = 1,2, …., l are some values of resource function, characterising an accessory of training trajectories $L_\nu, \nu = \overline{1, N}$ to classes K_1, K_2, …., K_l at the moment of $t_\tau = T + \Delta t$. If $0 \leq A_u < 1$, $u = 1,2, \ldots, l$ are given values limiting probabilities of hits in classes $K_u, u = \overline{1, l}$ of the predicted part of control trajectory $L_i' \in \{L_1', L_2', \ldots, L_q'\}$ and $\tilde{\varepsilon} > 0$ is some positive number, then the inequalities

$$\left.\begin{aligned} P\left\{\left(\sum_{i=1}^{n} \tilde{C}_i X_i(t_\tau) - f^j(t_\tau)\right)^2 < \varepsilon^2\right\} \geq A_j \\ P\left\{\left(\sum_{i=1}^{n} \tilde{C}_i X_i(t_\tau) - f^u(t_\tau)\right)^2 < \varepsilon^2\right\} \leq A_u \end{aligned}\right\}, \quad (27)$$

u = 1,2, …., j - 1, j + 1, …., l are the analytical expression of the hit requirement of trajectory L_i' of object Q_i' to the class K_j with probability not less than A_j and to other classes $K_u, u = 1,2, j-1, j+1, \ldots, l$ with probabilities not big than A_u, *u = 1,2, …, j - 1, j + 1, …, l* at the moment of $t_\tau = T + \Delta t$. Thus $A_u, u = \overline{1, l}$ are set as follows:

$$A_j = \max_{1 \leq S \leq l} A_s \text{ And } \sum_{s=1}^{l} A_s = 1 \quad (28)$$

As criterion of the best forecast on an interval of forestalling $[T, T + \Delta t]$ let's consider following functional

$$\tilde{J}(\tilde{C}_1, \tilde{C}_2, \ldots, \tilde{C}_n) = = M\left\{\sum_{k=p+1}^{\tau}\left[\hat{f}(t_k) - \sum_{i=1}^{n} \tilde{C}_i X_i(t_k)\right]^2\right\}, \quad (29)$$

where M - expectation value by all $X_i(t_k), i = \overline{1, n}$; $t_k \in [T, T + \Delta t]$.

Functional (29) characterises a total error of a deviation of forecast trajectories of object $Q_i' \in \{Q_1', Q_2', \ldots, Q_q'\}$ on an interval of forestalling $[T, T + \Delta t]$ from a true unknown trajectory. The mathematical formulation of prolongation problem of trajectory L_i' of object $Q_i' \in K_j$ is reduced to the following:

- According to $f^j(t_\tau), j = \overline{1,l}$, characterising values of resource function of each class $K_u, u = \overline{1,l}$, $f^j(t_\tau)$ usually is defined from (16) as an average of value of function $f(t)$ for the objects belonging to class K_j at the moment of $t_\tau = T + \Delta t$;
- Set $A_u, u = \overline{1,l}$ for object $Q_i' \in K_j$ and $\widetilde{\varepsilon}_u, u = \overline{1,l}$;

It is required to minimise functional

$$J\left(\widetilde{C}_1, \widetilde{C}_2, \ldots, \widetilde{C}_n\right) = \\ = M\left\{\sum_{k=p+1}^{\tau}\left[\hat{f}(t_k) - \sum_{i=1}^{n}\widetilde{C}_i X_i(t_k)\right]^2\right\} \qquad (30)$$

with restrictions

$$\left.\begin{array}{l} P\left\{(\sum_{i=1}^{n}\widetilde{C}_i x_i(t_\tau) - f^j(t_\tau))^2 < \widetilde{\varepsilon}_j^{\,2}\right\} \geq A_j \\ P\left\{(\sum_{i=1}^{n}\widetilde{C}_i x_i(t_\tau) - f^u(t_\tau))^2 < \widetilde{\varepsilon}_u^{\,2}\right\} \leq A_u \end{array}\right\} \qquad (31)$$

u = 1,2, ..., j - 1, j + 1, ..., l where $\hat{\varepsilon}_u, u = \overline{1,l}$ are defined as:

$$\widetilde{\varepsilon}_u = \frac{1}{2}\max_{\alpha,\beta}\left|f_\alpha^i(t_\tau) - f_\beta^j(t_\tau)\right|, u = \overline{1,l}.$$

Here $f_\alpha^j(t_\tau), f_\beta^j(t_\tau)$ accordingly characterises value of function $f(t)$ of trajectories L_α, L_β from class $K_j, j = \overline{1,l}$.

The problem (30) and (31) is a problem of stochastic programming with probabilistic restrictions [4,7]. In works [7, 8, 9], the definition of optimum values $\widetilde{C}_1^*, \widetilde{C}_2^*, \ldots, \widetilde{C}_n^*$ (for each object $Q_i' \in \{Q_1', Q_2', \ldots, Q_q\}$) was reduced to the decision of a problem of stochastic programming (30) and (31).

In given work, for the decision of a problem (30) and (31), pursuant to works [2,3], the method which is based on algorithm of an J. Lamarck's evolutionary principle is offered. J. Lamarck's evolutionary model is based on the assumption, that the characteristics got by the individual during a life, are inherited by descendants. In contrast to the simple genetic algorithm which is based on Ch. Darvin's model, the given model is the most effective when population tends convergence in the zone of the local optimum. We will result the modified scheme of algorithm.

The evolutionary theory approves, that each biological kind (a biological population) purposefully develops and changes in current of several generations. History of evolutionary calculation began from development of some various indefinite models of evolutionary process. Unlike the evolution occurring in the nature, evolutionary algorithms only model those processes in a population, which are essential to development [13,14].

The natural selection is the basic mechanism of Darwin's evolution. By Charles Darwin's principle biological populations develop in current of several generations, submitting to laws of natural selection and "the most adapted survived". Basic Lamarck's idea was that organisms change under influence environments and conditions of their ability to live. The main difference from Darwin's theories is that by Lamarck's authority species can change in current of the life, and not just at a genetic level. On the Lamarck's theories of evolution typical specifics of an organism got as a result of its adaptation during the life of this organism, can be hand down its descendants.

Let's result classification of models of evolution on which evolutionary algorithms are based [4,5,6]:

Model of Ch. Darwin's evolution is process, by means of which the individuals of some population who have higher functional value (with strong attributes), receive greater possibility for reproduction of descendants, than "weak" individuals. Such mechanism often called as "Survivals of the strongest" method;

Lamarckism or model of J. Lamarck evolution offers the theory based on the assumption, that the characteristics got by the individual (organism) during a life, can be inherited by its descendants. Unlike simple genetic algorithm the given model appears the most effective when the population tends convergence in area of a local optimum;

Saltationizm or model of de Frieze's evolution. In a basis of this model simulating social and geographic accidents leading sharp change of kinds and populations lays. Evolution, thus, represents sequence jumps in development of a population without preliminary accumulation of quantitative changes in evolutionary processes;

K.Popper's model, which considered evolution as developing hierarchical system of flexible mechanisms of management in which the mutation is interpreted as a method of casual tests and mistakes, and selection as one of ways of management with help of elimination of mistakes at interaction with an environment;

The synthetic theory of evolution described by N. Dubinin (attempt of integration of various models of evolution, including Darwin's, J. Lamarck's and de Frieze's). Its cardinal position is the recognition of stochasticity of mutation processes and greater reserves recombination variability. Conditions of an environment - not only factors of exception of the unadapted from the population, but also forming features of the most synthetic theory of evolution.

It is not dependent on ideology of genetic algorithm, the general scheme of evolutionary calculations is defined by following parameters:

1. By way of the coding of the decision (by chromosomes);
2. By function of an optimality (by estimations);
3. By probable parameters of control of evolution convergence;
4. By condition of evolution completion;
5. By completion of operators: selection, recombination and mutation.

For the decision of a problem (30) - (31) the mobile genetic algorithm which is based on lamarckizm or J. Lamarck's models of evolution is used - the chromosome is coded by the list of pairs <gene number, value of a gene>.

Feature of coding of the decision in genetic algorithm (J. Lamarck's model of evolution) is using both incomplete chromosomes, and superfluous. For interpretation of such chromosome the expression rule, that is a rule of activation of genes is entered - genes dominate from left to right, that corresponds to the nature of a problem (30) - (31). Usage of the rule leads to that the most left (dominant) gene is used at calculation of an optimality of a chromosome, but descendants can inherit any of right (recessive) genes. The scheme of genetic algorithm contains essential changes and specifications of the scheme of the evolutionary algorithm which is based on other ideology.

Begin
t=0; *installation of time of evolution*
init - population (p^t); *initialization of initial population*
p^{pp}=preparing_population (p^t); *population saturation by the best chromosomes*
while (not done (termination condition)); *the condition of end of evolution is not satisfied yet*
p^s=selection (p^t); *a choice of individuals*
p^r=cut_or_splice (p^s); *operation of cutting or coupling of chromosomes*
p^m (mutation (p^t)); *a mutation*
p^{t+1}=generation (p^s, p^r, p^m); *formation of a new condition of population*
t=t+1; *transition after evolutionary time*
endwhile
end

At an initialization stage λ -lines are generated in a random way, λ is given by the user. Criterion function (30) is calculated as in using of standard genetic algorithm. The operator of selection for J. Lamarck's model of evolution is calculated on the basis of proportional selection. The operator of selection starts to form $t+1$-generation by t^{th} generation. It is reasonable to enter two pools during program realisation: pools of current and subsequent generations. In a pool of the subsequent generation all selected operators of selection of a chromosome as parents of new generation are brought. Feature of idea of the genetic algorithm which is based on J. Lamarck's model, consists that proportional selection is used only at a stage preparing population - preliminary saturation of population, and further probabilities of operators *cut* and *splice* - p^c, p^s are used. The operator *splice* is carried out with some fixed probability p^s. Operators have two limiting types of behavior. In the beginning of evolution when long chromosomes prevail, *cut* are basically carried out. And then the operator *splice* starts to prevail. The operator of a mutation is a summation of value of a gene and strategic parameter - a deviation set by the user in a casual position of a chromosome. The operator of formation of new generation in the given model of evolution is reduced to transition on the counter of evolutionary time.

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