ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 9 , September 2017

Monitoring and control of dynamic systems in fuzzy conditions

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ABSTRACT: In the article consider the question of the use of stochastic methods for monitoring and process control in some situations it is difficult due to the lack of probability distributions of parameters. The difficulty of obtaining numerical results when working with random variables also reduces the practical value of stochastic algorithms.

KEYWORDS: fuzzy, stochastic methods, process control, fuzzy,

I. Introduction

Using stochastic methods for monitoring and process control in some situations it is difficult due to the lack of probability distributions of parameters. The difficulty of obtaining numerical results when working with random variables also reduces the practical value of stochastic algorithms. In the case of incomplete information about the complex process is more convenient to represent inexact set parameters in the form of fuzzy variables and the use proposed in this paper, the methods of working with them.

The coefficients of a number of models in fact depend on many factors, the actual process is not taken into account in the model. In describing the processes of two-dimensional models, we replace the third dimension of a homogeneous layer and the values of the coefficients for him determine the average, weighted average, etc. Trying to make a model in consideration of a number of factors, the introduction of the third dimension leads to considerable complication of the model and a sharp increase in the dimension of the problem. Moreover, in such a complicated model parameters appear, which is extremely difficult or impossible to measure. When their job again introduce some assumptions that only hinder and affect the accuracy of the solution [1].

As practice shows, the use of deterministic models with precise parameter values (even if the adaptation process of refinement by solving inverse problems) leads to the fact that the model is too rough. interval analysis techniques make it possible to build a model for the case of each of these factors is given range of acceptable values. However, in practice, due to the availability of information that any values for the coefficients are allowed more than others, a description of these factors in the form of fuzzy sets is more successful. In this case, the range is further defined by the membership function.

Information about the difference admissibility is statistical in nature, this function can be determined objectively, if not - it is subjective and based on the approximate expert reflection in aggregate available non-formalized his ideas about the value of this ratio.

Naturally, administration of the fuzzy factors complicating the modeling process, however, in this case the solution becomes adequate taken simplifications, for example, to the exclusion of the third coordinate z concept at the point (x, y) becomes blurred, fuzzy, since it refers not to the point, and the interval [2].

II. PROBLEM DEFINITION

In general, the dynamics of the discrete systems can be represented by the equation of state:

$$x_{k+1} = F(x_k, u_k), k = \overline{O, N}\ , \qquad (1)$$

$$x_1 \in X, u_k \in U\ , \qquad (2)$$

where X - the state space, U- set of admissible controls, the F - state transition function, in general, non-linear

$$F: X \times U \rightarrow X \qquad (3)$$

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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This system is deterministic, if at any time k can unambiguously determine its new state at time (k + 1) 1 on the current status and u_k management.
For stochastic systems transfer function can be written as:

$$F: X \times U \rightarrow XP, \quad (4)$$

where XP - the set of probability distributions on X. To account for the uncertainties in the model are introduced random variables or factors. However, these models need to have the information for the construction of probability distributions.
Incomplete certain processes can be modeled using fuzzy sets. Odds and some values may be given in the form of membership functions. Then the dynamics of the system is described by fuzzy relations

$$F: X \times U \times X \rightarrow X[0,1], \quad (5)$$

representing a fuzzy subset of the Cartesian product $X \times U \times X$.
The value of $F(x_k, u_k, x_{k+1})$is considered as the intensity of the transition, or, more precisely, as the degree of x_ element accessories *(k + 1)* image pairs (x_k, u_k) under the mapping F, that the main characteristic of the system is a membership function $\mu(x_{k+1}|x_k, u_k)$.
Using the concept of fuzzy relations, you can enter the following ways to define a function F:
1. If there is no model of the process and there is only a linguistic description of the desired behavior of the type system "if the gas pressure is very large, to significantly increase consumption." Similar expressions give information about what should happen in the system of admission to the input control actions in the form of fuzzy sets defined on universal sets "gas pressure" and "consumption". Then a fuzzy conditional statement is a fuzzy relation, which is defined as

$$F(x,u) = min\big(\mu(x), \lambda(x)\big); \quad (6)$$
$$\mu: X \rightarrow [0,1]; \ \lambda: X \rightarrow [0,1].$$

If *F* will be a fuzzy function, the fuzzy state of the system at time (k + 1) is conditional on x_k and u_k fuzzy set characterized by a membership function $\mu(x_{k+1}|x_k, u_k)$.
Is possible to use the existing model of the system to set the function *F*. Let us consider the dynamics of a free system and construct the first case of recurrent procedure for evaluating the dynamic state of the system in fuzzy conditions.
Currently, state estimation of dynamic systems in optimal estimation theory widely spread Bayesian approach. However, quite acceptable for the practical implementation of the results obtained in the case of a linear dynamic systems with Gaussian noise. For assessment of these systems can be performed using recursive Kalman filter [3].
It was considered as methods of using the Kalman filter for nonlinear systems with respect to state and non-Gaussian noise [4]. This involves pre-linearization of nonlinear equations of the object and the channel observations and non-Gaussian noise is approximately Gaussian approximated, resulting in deterioration of the accuracy of the results.
In practice, the situation is also complicated by the partial or complete lack of information on the statistical characteristics of the noise. Therefore, the authors propose to solve the estimation problem to apply the theory of fuzzy sets.
Consider the nonlinear dynamical system with discrete time:

$$x_{k+1} = F_k(x_k, w_k), k = 1,2, \ldots, \quad (7)$$

for which the measurement system and the state are related:

$$z_k = H_k(x_k, v_k) \quad (8)$$

In these equations corresponds to the index k k-th point in time;
F_k, H_k- nonlinear functions relevant arguments;
x_k - the state of the dynamic system,
w_k - fuzzy interference set for each time point k membership function $\mu(w_k)$;
- Measurement error with a certain membership function;
It is assumed known and the membership function for the initial state $\mu(w_k)$.
- Measurement error with a certain membership function;
It is assumed known and the membership function for the initial state $\mu(x_0)$.

III. SOLUTION OF THE TASK

During operation of the system in general, fuzzy initial state media expands. To reduce the uncertainty of the situation when making decisions, it is necessary to use additional information about measurements and studies in the system.

We assume independence of measurement errors, noise, and the state in the sense of independence of fuzzy values. For a given conditional membership functions $\mu(x_k|\overline{zk})$ state x_k if there is a clear measurement sequence is the best assessment of the state at time k can be found from the relationship:

$$\mu(x_k^0) = \max_{x_k} \mu(x_k|\overline{z}_k)$$

Since the real processes function $\mu(x_k|\overline{z}_k)$ and $\mu(x_{k+1}|\overline{z}_k)$ are unimodal, the peak finding procedure is quite simple. To assess the state derive recursive procedure for the membership function $\mu(x_{k+1}|\overline{z}_{k+1})$. Based on the definition of conditional membership functions can be written that

$$\mu(x_{k+1}|\overline{z}_{k+1}) = \mu(x_{k+1}|\overline{z}_{k+1}) = \mu(x_{k+1}, \overline{z}_k, z_{k+1}) \quad (9)$$

where the vector represented as $\overline{z}_{k+1} = \{\overline{z}_k, z_{k+1}\}$

Using the definition (9) and the equation for the measurement error we get

$$\mu(x_{k+1}, \overline{z}_k, z_{k+1} = \sup_{V_{k-u}=H_{k-u}^{-1}(x_{k-u}, z_{k-u})} \mu(V_{k+1}, X_{k+1}, \overline{z}_k$$

and the conditions of independence v_{k+1}, x_{k+1}, $\overline{z}_k$ follows that

$$\mu(x_{k+1}, \overline{z}_k, z_{k+1}) = \mu(x_{k+1}, \overline{z}_k) \wedge \sup_{V_{k-u}=H_{k-u}^{-1}(x_{k-u}, z_{k-u})} \mu(V_{k+1}). \quad (10)$$

Conditional membership function can be determined based on system dynamics equations with the definition of conditional membership functions:

$$\mu(x_{k+1}|\overline{z}_k) = \mu(x_{k+1}, \overline{z}_k) = \mu(x_{k+1}, x_k, \overline{z}_k) = \max_{x_k} \left\{ \sup_{V_{k-u}=H_{k-u}^{-1}(x_{k-u}, z_{k-u})} \mu(w_k, x_k, \overline{z}_k) \right\} \quad (11)$$

Using the definition of the design operations and taking into account the relation (7), the equation (11) can be written as

$$\mu(x_{k+1}|\overline{z}_k) = \max_{x_k} \left\{ \mu(x_k, z_k) \wedge \sup_{w_k=F_{k-u}^{-1}(x_{k-u}, z_k)} \mu(w_k) \right\}$$

$$= \max_{x_k} \left\{ \mu(x_k, \overline{z}_k) \wedge \sup_{w_k=F_{k-u}^{-1}(x_{k-u}, z_k)} \mu(w_k) \right\} \quad (12)$$

Finally recurrence relations to find a posteriori the membership function for the fuzzy state of the system at any step (k + 1) in view of (9) can be written:

$$\mu(x_{k+1}|\overline{z}_{k+1}) = \mu(x_{k+1}|\overline{z}_k) \wedge \sup_{V_{k-u}=H_{k-u}^{-1}(x_{k-u}, z_{k-u})} \mu(v_{k+1}) \quad (13)$$

$$\mu(x_{k+1}|\overline{z}_k) = \max_{x_k} \left\{ \mu(x_k, \overline{z}_k) \wedge \sup_{w_k=F_{k-u}^{-1}(x_{k-u}, x_k)} \mu(w_k) \right\} \quad (14)$$

For the case of steady-state $x_{k+1} = x_k$ only the expression (13), which in this case takes the form

$$\mu(x_{k+1}|\overline{z}_k) = \mu(x_k, \overline{z}_k) \wedge \sup_{V_{k-u}=H_{k-u}^{-1}(x_{k-u}, z_{k-u})} \mu(v_{k+1}) \quad (15)$$

If the measurement is not available, the recursive procedure is reduced to the relation

$$\mu(x_{k+1}|\overline{z}_k) = \mu(x_{k+1}) = \max_{x_k} \left\{ \mu(x_k) \wedge \sup_{w_k=F_{k-u}^{-1}(x_{k-u}, x_k)} \mu(w_k) \right\} \quad (16)$$

The recurrence relation is particularly simple in the case where the fuzzy noise w_k k system and measurement errors v_k are included in (7), (8) is linear:

$$x_{k+1} = F_k(x_k) + w_k \quad (17)$$

$$z_k = H_k(x_k) + v_k \quad (18)$$

In these equations, the correspondence between v_k and w_k, z_k *and* v_k to-one, so for the procedure (13) expression of the form

$$\sup_{V_{k-u}=H_{k-u}^{-1}(x_{k-u}, z_{k-u})} \mu(v_{k+1})$$

It can be represented in the following form:

$$\sup_{V_{k-u}=H_{k-u}^{-1}(x_{k-u}, z_{k-u})} \mu(v_{k+1}) = \sup_{V_{k-u}=z_{k-u}-H_{k-u}(x_{k-u})} \mu(v_{k+1}) =$$

$$= \mu(z_{k-u} - H_{k+1}(x_{k+1})), \quad (19)$$

and equation (14) expression of the form $\sup_{w_k=F_{k-u}^{-1}(x_{k-u}, x_k)} \mu(w_k)$ *can be transformed as follows:*

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

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$$\sup_{w_k=F_{k-u}^{-1}(x_{k-u},x_k)} \mu(w_k) = \sup_{w_k=z_{k-u}-F_k(x_k)} \mu(w_k) = \mu(x_{k+1}-F_k(x_k))$$

Then the recursive procedure (13) (14) is considerably simplified and can be represented as:

$$\mu(x_{k+1}|\overline{z}_{k+1}) = \mu(x_{k+1}|\overline{z}_k)^\wedge(z_{k+1}-H_{k+1}(x_{k+1}))\ ; \qquad (20)$$

$$(x_{k+1}|\overline{z}_k) = max_{x_k}\{\mu(x_k|\overline{z}_k)^\wedge\mu(x_{k+1}-F_k(x_k))\}.$$

(20) Recurrence relations snap implemented in practice, irrespective of the types of functions F_k, H_k and membership functions $\mu(x_0)$, $\mu(v_k)$ and $\mu(w_k)$.

In the case of controlled dynamic systems is also possible to use the existing model to define the function F. For example, in the case of the linear model $(x_{k+1} = Ax_k + Bu_k)$ (22)

where the condition and management imposed restrictions and fuzzy set fuzzy goal of the system functioning for membership functions using the definition of the image of a fuzzy set can be written the following relationship:

$$\mu(x_{k+1}) = sup_{x_k\ +u_k\ =x_{k-u}}\left[sup_{Ax_k=x_k}\ \mu(x_k) \wedge \sup_{Bu_k=u_k} \mu(u_k)\right] = sup_{Ax_k+Bu_k=x_{k-u}}[\mu(x_k)\wedge(u_k)] \qquad (23)$$

During operation of the system in general, fuzzy initial state media expands. To reduce the uncertainty of the situation when making decisions need to use additional information about ongoing investigations and measurements in the system.

It is assumed that a direct measurement of the entire vector x_k current state of the system is not possible, and the process of indirect observation is described by the equation

$$z_k = H(x_k), \qquad (24)$$

where - fuzzy vector measurements; H - measurement function

For the linear model (23) and linear equations for measurements

$$z_k = Hx_k \qquad (25)$$

we can write the following system of recurrent equations

$$\mu(x_{k+1,k+1}) = \sup_{z_{k-u}=Hx_{k-u}} \mu(x_{k+1,k}, z_{k+1}) = \mu(x_{k+1,k})\wedge \sup_{z_{k-u}=Hx_{k-u}} \qquad (26)$$

$$\mu(x_{k+1,k}) = \sup_{Ax_k+Bu_k=x_{k-u}} \{\mu(x_{k,k})\wedge\mu(u_k)\}. \qquad (27)$$

In general, the functions F and H nonlinear, equation (27) (28) can be written as:

$$\mu(x_{k+1,k+1}) = \vee_{z_{k-u}}\ \mu_H(x_{k+1}|z_{k+1})\wedge\mu(z_{k+1})\wedge\mu(x_{k+1,k}); \qquad (28)$$

$$\mu(x_{k+1,k}) = \underset{x_k u_k}{\vee\vee} \mu_F(x_{k+1,k}|x_{k,k}, u_k)\wedge\mu(x_{k,k})\wedge\mu(u_k). \qquad (29)$$

Let us now consider the principles of fuzzy dynamic system control function F of the form (6). Assume that the control action u_k at each time k fuzzy constraints imposed $C_k \subset U$, characterized by a membership function μ (C_k) (u_k), and set the initial state x_0. Let $G_N \subset X$ - fuzzy goal that must be achieved at time N. This target is characterized by membership function μ (C_N) (x).

Optimal control actions clear $u_0^0, u_{1..}^0 u_{N-1}^0$ can be defined as follows [5]:

$$\mu_D(u_0^0, \dots, u_{N-1}^0) =$$
$$\max_{u_{a-},u_{N-2}} \max_{u_{N-1}}\{u_{C_0}(u_0)\wedge \dots \wedge\mu_{C_{N-1}}(u_{N-1})\wedge\mu_{C_N}(F(x_{N-1}, u_{N-1}))\} =$$
$$\max_{u_{a-},u_{N-2}} \{u_{C_0}(u_0)\wedge \dots \wedge\mu_{C_{N-2}}(u_{N-2})\wedge\mu_{C_{N-1}}(x_{N-1})\} \qquad (30)$$

were

$$\mu_{C_{N-1}}(x_{N-1}) = \max_{u_{N-1}}\{u_{C_{N-1}}(u_{N-1})\wedge\mu_{C_N}(F(x_{N-1}, u_{N-1}))\} \qquad (31)$$

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 9 , September 2017

The function can be regarded as a membership function for the fuzzy goal at time N-1 induced the ultimate goal for the moment N. solution of the problem can be found using the dynamic programming method, the following recurrent procedure for intermediate target at the time of N-j :

$$\mu_{C_{N-j}}(x_{N-j}) = \max_{u_{N-j}} \left\{ u_{C_{N-j}}(u_{N-j}) \wedge \mu_{C_N-j}(x_{N-j+1}) \right\} \quad (32)$$

$$\text{где } x_{N-j+1} = F(x_{N-j}, u_{N-j}), j = \overline{1, N}. \quad (33)$$

IV. CONCLUSION

Thus, knowing the current fuzzy condition $\mu(x_k)$), fuzzy constraint $\mu_{C_k(u_k)}$and induced fuzzy goal $\mu_{C_k(u_k)}$ at the time k we can find an effective precise control u_k^0 to (30), (31).

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