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Issues for Design of Information System for Supervision and Control of Dynamic Systems

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Abstract. A new method for a creation of the information system for sequential identification of states of technological processes or other dynamic systems for their supervision and control is considered. The states of dynamic system can be unknown and can change themselves abruptly or slowly. The method is based on a sequential nonlinear mapping of many-dimensional vectors of parameters (collection of which describes the present state of dynamic systems) into two-dimensional vectors in order to reflect the states and their changes on the PC screen and to observe the situation by means of computer. The mapping error function is chosen and expressions for sequential nonlinear mapping are obtained. The mapping preserves the inner structure of distances among the vectors. Examples are given.

Key words: information system, identification of states, sequential nonlinear mapping.

1. Introduction

Technological processes have to be supervised for their control. The states of the technological processes or other complicated dynamic systems (DS) such as power stations, manufacture supervision, production control and so on are described by many parameters that define the present state of the DS. The purpose of this paper is to present a new method for discrete sequential detection of states of the DS for their control in real time. While supervising a technological process or other DS there is a necessity to identify the DS states or to detect their abrupt or slow changes. As the state of DS changes, L parameters (of any physical nature) which describe the state change as well. If the DS state is described by a random process generated by this object, then the state is described by the L parameters characterising the random process. The DS can have several unknown states and we need to observe the states and detect their changes sequentially and independently of the history. It is convenient to observe the DS states and their changes marking them by some mark on the PS screen. According to the mark position we can make a decision on the DS state and its change, if the mark position changes.

To solve these problems it is necessary to have a method for sequential detection of many changes in several unknown properties of a random process. There are many methods of detection of changes in the properties of random processes in the scientific publications (Basseville and Benveniste, 1986; Kligienė and Telksnys, 1984; Nikiforov, 1983), but there are no methods to solve the above mentioned problems. A nonlinear mapping algorithm (Sammon, 1969) does not fit for the sequential representation of data. A triangulation method for the sequential mapping (Lee *et al.*, 1977) preserves only two distances to vectors previously mapped and, in addition, it uses the spanning tree and, in such a way, makes the mapping dependent of the history, hence we can not use it for our task.

In the paper, we present a method for discrete sequential identification of states and for detection of many abrupt or slow changes in several unknown states of DS, based on sequential nonlinear mapping onto the plane of vectors of the L parameters given by DS. The mapping error function is chosen and expressions for sequential nonlinear mapping are presented along with some experimental results.

The technique described in this paper can be useful in industry, at the control desk, in identification and control of technological processes, and in many regions where it is possible to get parameters describing the states of some dynamic objects. The experiments given below illustrate that.

2. Problem Formulation

Let a DS be in any state of the S possible states. We can observe the vector of L parameters at the output of the DS. By the way, these parameters can be of any physical nature (then we must introduce scale coefficients for each parameter). At the output of the DS we can watch a random process as well. The process may be described by a proper mathematical model, e.g., autoregressive sequence. Then the DS state is defined by a vector consisting of all L autoregressive parameters.

For detection of states of the DS it is necessary at discrete time moments to map the L-dimensional vectors sequentially and nonlinearly into two-dimensional vectors (preserving the inner structure of distance among the vectors) in order to represent the present state by some mark on the PC screen and, having in mind the existence of particular states, to identify the current state, a deviation from it or a transition to another state when the mark changes its position.

The mapping result of the sequentially receiving parameter vectors has to be independent on the mappings of the earlier received vectors (independence of the history).

3. Sequential Mapping Algorithm

The sequential nonlinear mapping requires for the existence of earlier mapped vectors. Hence the mapping procedure consist of two stages.

The first stage. At the very beginning we have to carry out the nonlinear mapping of M vectors ($M \geqslant 2$) simultaneously. We shall use for that the expressions in (Sammon, 1969).

The second stage. Afterwards, we need to map sequentially and nonlinearly the received parameter vectors and, in such a way, to identify the present state, its changes and deviations from it for a practically unlimited time. In order to formalise the method we denote by N the number of the sequentially received vectors of parameters which describe the present states of DS.

Thus, let us have $M + N$ vectors in the L-hyperspace. We denote them by X_i, $i = 1, \dots, M$; and X_j, $j = M+1, \dots, M+N$. The M vectors are already simultaneously mapped into two-dimensional vectors Y_i, $i = 1, \dots, M$, using the expressions in (Sammon, 1969). Now we need to sequentially map the L-dimensional vectors X_j into two-dimensional vectors Y_j, $j = M+1, \dots, M+N$, with respect to simultaneously mapped the M initial vectors. Here the simultaneous nonlinear mapping expressions will change into sequential nonlinear mapping expressions, respectively. First, before performing iterations it is expedient to put the two-dimensional vectors being mapped in the same initial conditions, i.e., $y_{jk} = C_k$, $j = M+1, \dots, M+N$; $k = 1, 2$. It is advisable to put C_k close to the average of simultaneously mapped M initial vectors. Note that in the case of simultaneous mapping of the first M vectors, the initial conditions are chosen in a random way (Sammon, 1969). Let the distance between the vectors X_i and X_j in the L-hyperspace be defined by d_{ij}^X and on the plane – by d_{ij}^Y, respectively. This algorithm uses the Euclidean distance measure, because, if we have no a priori knowledge concerning the data, we would have no reason to prefer any metric over the Euclidean metric.

Notice, that it is very important to choose a mapping error function because the mapping precision depends on it.

For computing the mapping error of distances E we can find at least three expressions (Duda and Hart, 1973):

$$E_1 = \frac{1}{\sum_{i=1}^{M} \left(d_{ij}^X\right)^2} \sum_{i=1}^{M} \left(d_{ij}^X - d_{ij}^Y\right)^2, \quad j = M+1, \dots, M+N; \tag{1}$$

function E_1 reveals the largest errors independently of magnitudes of d_{ij}^X; but if d_{ij}^X is small then the mapping error can be comparable with the same distance;

$$E_2 = \sum_{i=1}^{M} \left(\frac{d_{ij}^X - d_{ij}^Y}{d_{ij}^X}\right)^2, \quad j = M+1, \dots, M+N; \tag{2}$$

function E_2 reveals the largest partial errors independently of magnitudes of $\left|d_{ij}^X - d_{ij}^Y\right|$; but, in this case, big distances will have rather a great mapping error;

$$E_3 = \frac{1}{\sum_{i=1}^{M} d_{ij}^X} \sum_{i=1}^{M} \frac{\left(d_{ij}^X - d_{ij}^Y\right)^2}{d_{ij}^X}, \quad j = M+1, \dots, M+N; \tag{3}$$

function E_3 is a useful compromise and reveals the largest product of the error and partial error. So we choose the third expression for computing the mapping error of distances E.

For the correct mapping we have to change the positions of vectors Y_j, $j = M + 1, \dots, M + N$ on the plane in such a way that the error E would be minimal. This is achieved by using the steepest descent procedure. After the r-th iteration the error of distances will be

$$E_j(r) = \frac{1}{\sum_{i=1}^{M} d_{ij}^X} \sum_{i=1}^{M} \frac{\left[d_{ij}^X - d_{ij}^Y(r)\right]^2}{d_{ij}^X}, \quad j = M+1, \dots, M+N; \tag{4}$$

here

$$d_{ij}^Y(r) = \sqrt{\sum_{k=1}^{2} \left[y_{ik} - y_{jk}(r)\right]^2}, \quad i = 1, \dots, M; \; j = M+1, \dots, M+N. \tag{5}$$

During the $r + 1$-iteration co-ordinates of the mapped vectors Y_j will be

$$y_{jk}(r+1) = y_{jk}(r) - \mathbf{F} \cdot \Delta_{jk}(r), \quad j = M+1, \dots, M+N; \; k = 1, 2; \tag{6}$$

where

$$\Delta_{jk}(r) = \frac{\partial E_j(r)}{\partial y_{jk}(r)} \Big/ \left| \frac{\partial^2 E_j(r)}{\partial y_{jk}^2(r)} \right|, \tag{7}$$

F is the factor for correction of the coordinates and it is defined empirically to be $\mathbf{F} = 0.35$,

$$\frac{\partial E_j}{\partial y_{jk}} = H \sum_{i=1}^{M} \frac{D \cdot C}{d_{ij}^X \cdot d_{ij}^Y}, \tag{8}$$

$$\frac{\partial^2 E_j}{\partial y_{jk}^2} = H \sum_{i=1}^{M} \frac{1}{d_{ij}^X \cdot d_{ij}^Y} \left[D - \frac{C^2}{d_{ij}^Y} \left(1 + \frac{D}{d_{ij}^Y}\right)\right], \tag{9}$$

$$H = -\frac{2}{\sum_{i=1}^{M} d_{ij}^X}, \quad D = d_{ij}^X - d_{ij}^Y, \quad C = y_{jk} - y_{ik}.$$

When $E(r) < \varepsilon$, where ε can be taken arbitrarily small, the iteration process is over and the result is shown on the PC screen. In fact, it is enough $\varepsilon = 0.05$. In order to have an equal computing time for each mapping we can execute a constant number of iterations R. In practice, it is enough $R = 30$.

Minimum necessary value of the M is obtained in (Montvilas, 1995).

Next we present the two more characteristic experiments.

4. Experiment 1

Let a technological process or DS be described by $L = 5$ parameters defining its states and be in any state of the S possible states. Let $S = 4$ and we detect the states of DS(4) at $M + N = 18$ time moments. Let us take the case when the number of initial simultaneously mapped vectors is $M = 2$ and does not involve all the possible states of DS(4). Afterwards we detect the states of DS(4) at the time moments $N = 3 \div 18$ sequentially. A priori the states of DS(4) are known at the time moments (see Table 1).

In Fig. 1 the mapping results are presented, where at the first $M = 2$ time moments the state vectors mapped simultaneously are denoted by mark $\times$ with an index that means the time moment number, and the state vectors mapped sequentially are denoted by mark $+$ with the respective index.

Table 1

The states of DS(4) at the time moments $M + N = 2 + 16 = 18$

MAPPING	SIMULTANEOUS (i)		SEQUENTIAL (j)															
MARK	$\times$		$+$															
TIME MOMENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
STATE	1	2	3	4	2	1	3	3–4	4	4	2	2–3	3	1	2	1	4	3

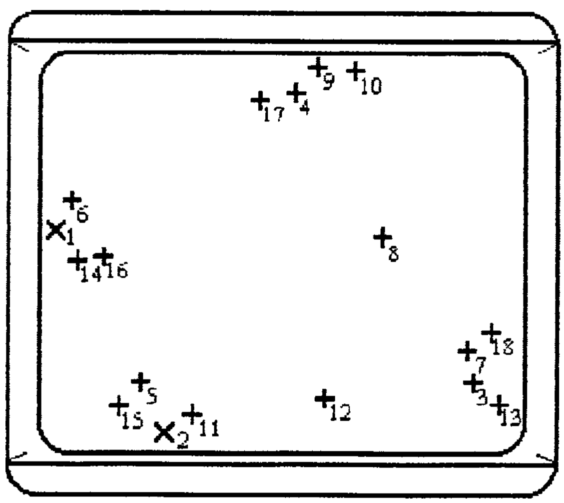

Fig. 1. The view on the PC screen of the ends of mapped vectors of DS(4) for 18 time moments.

At the time moments number 8 and number 12 there were slow changes of the states of DS(4) and it was between the states number 3 and number 4 and between the states number 2 and number 3, respectively. In Fig. 1 this situation is clear.

5. Experiment 2

Let a dynamic system be described by $L = 6$ parameters defining the states and be in any state of the S possible states. Let $S = 5$ and we detect the states of DS(5) at the $M + N = 50$ time moments. Let us take $M = \min(S, L + 1)$ (Montvilas, 1995). In our case $M = 5$. Afterwards we detect the states of DS(5) at the time moments $N = 6 \div 50$ sequentially. A priori the states of DS(5) are known at the time moments (see Table 2).

At the time moment number 50 the DS was out of order: one parameter of 6 ones, describing the 4-th state of the DS became to be zero (one physical parameter of DS disappeared).

In Fig. 2 the mapping results are presented on the screen where the state vectors are denoted by mark $\times$ with an index that means the time moment number.

At the time moment number 50 the corresponding mark goes to other place on the screen and indicates the damage of the DS. In Fig. 2 this situation is clear.

Now about borders among different states on the screen. It depends on a concrete situation, on the character of a dynamic system to be identified or controlled. The borders can touch one another, if the DS can not have damaged states in fact, and they can have distances among them, if the DS can have non-technological states or can be damaged. Real regions of states can be found for a concrete object by additional investigations having all data of the states.

The main importance of the method is that it is possible to begin work even when the states are *unknown yet*, and while working one can accumulate the information and use it for determination of states and borders among them.

Table 2

The states of DS(5) at the time moments $M + N = 5 + 45 = 50$

MAPPING	SIMULTANEOUS (i)					SEQUENTIAL (j)					
STATE	1	2	3	4	5	1	2	3	4	5	DAMAGED
TIME MOMENT	1	2	3	4	5	6, 7, 8, 9, 30, 31, 32, 44	10, 11, 12, 13, 28, 29, 41, 42, 43	14, 15, 16, 17, 36, 37, 45, 46, 47	18, 19, 20, 21, 38, 39, 40, 48, 49	22, 23, 24, 25, 26, 27, 35	50

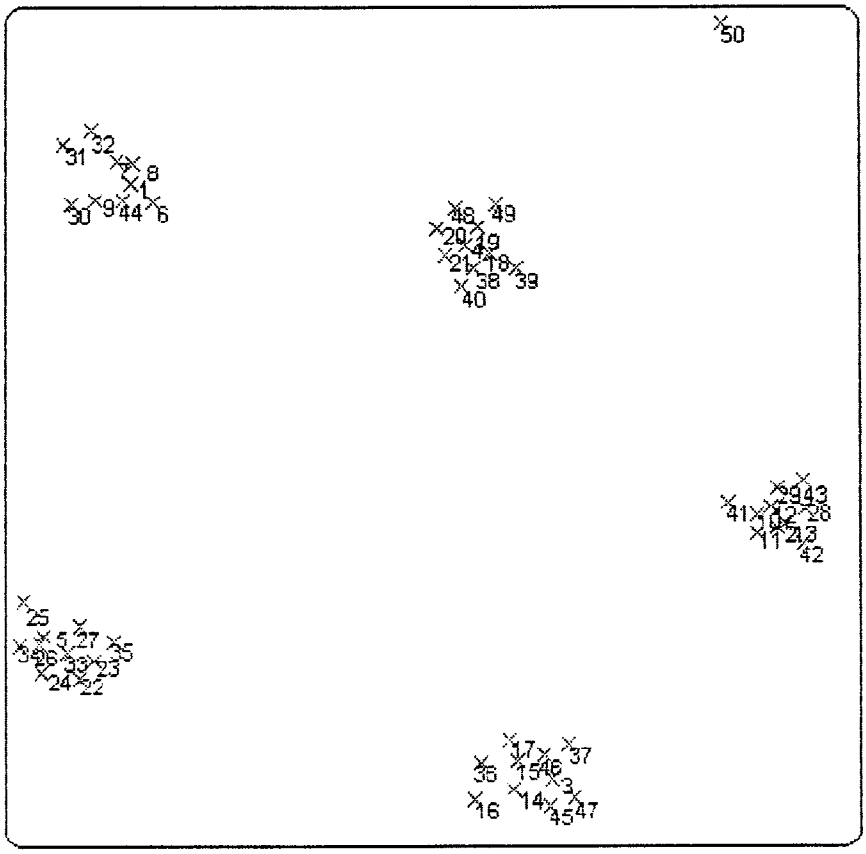

Fig. 2. The view on the PC screen of the ends of mapped vectors of DS(5) for 50 time moments.

6. Conclusions

The described method enables us to construct the information system in order to sequentially detect the dynamic system states, their abrupt or slow changes, rapidly to ascertain the damages and to supervise the situation on the PC screen for DS control.

Before sequential detection of the states, it is sufficient to map simultaneously only $M = \min(S, L+1)$ parameter vectors, where S is the amount of states, L is the dimensionality of parameter vectors which describe the dynamic system states. In the case of $M = L + 1$, these points have to form an L – dimensional space.

The method can be used for the sequential analysis of random processes (classification, clustering, recognition) and for the sequential visualisation of multidimensional data as well.

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Dinaminių sistemų stebėjimo ir valdymo informacinės sistemos sukūrimo klausimai

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Straipnyje nagrinėjamas technologinių procesų ar kitų dinaminių sistemų būsenų bei jų pasikeitimų nuoseklaus nustatymo informacinės sistemos sukūrimas, grindžiamas parametrų, aprašančių būsenas, vektorių nuosekliu netiesiniu atvaizdavimu į dvimatę erdvę ir duomenų pateikimu kompiuterio ekrane.

Parodyta, kad galima nuosekliai nustatinėti staigius arba lėtus dinaminių sistemų būsenų pasikeitimus, aptikti jų gedimus bei stebėti situaciją kompiuterio ekrane.