THE RESEARCH OF PROCESS MONITORING BASED ON DATA FUSION THEORY

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Abstract: This paper explores the multisensor process monitoring system which sampling is synchronous and transmission delay is less than one sampling period; A new process monitoring algorithm is put forward through introducing recursive least square estimate and combing the multisensor data fusion theory with the traditional process monitoring technology based on principle components analysis. Firstly, the paper analyzes the existing questions about the traditional process monitoring methods based on measurement in detail; secondly, in single sensor case it extends the analysis founded on measurement matrix to that based on state estimate value matrix by using least square estimate. So it can filter the measurement noise effectively. Afterwards it proposes that it can fuse the measurement of every sensor which gets to central processor step by step through using recursive least square estimate in multisensor case; finally, we can use the principle components analysis to realize real-time monitoring for complex process. The proposed method can improve the accuracy and enforceable ability of process monitoring technology effectively, and reduce false alarm. Computer simulations show the validity of the proposed method. *Copyright © 2006 IFAC*

Keywords: synchronous sampling; data fusion; process monitoring; transmission delay; recursive least square; principle component analysis

1. INTRODUCTION

As the fast development of modern manufacture and science technology, the structure of large-scale equipment becomes more and more complex and the investment also becomes greater, such as nuclear power station, space shuttle, large chemical associated device and large building including reservoir and bridge etc... Accordingly these systems go into frailty terribly. In the case that they appear big faults it will bring on tremendous economic loss and person casualty (Hu and Sun, 1999). For instance, the east chemical plant of Beijing occurred blasting of ethane device in 1997 and the direct economic loss achieved one billion Yuan and the indirect loss is imponderable. During the ten months from August in 1998 to May in 1999, three rockets of America occurred five launch failing and the direct loss was $3 billion (Zhou and Ye, 2000). Lacking monitor and control to unwonted cases occurring in process has resulted in about two billion dollars losses in petrol-chemistry industry of America every year (Fault, 2001). So it is very important to effectively monitor and early advance alarm for an unwonted instance by using statistical process monitoring (SPC). The economic benefit using the technologies of abnormal detecting and monitoring is obvious. For example, the investigation finished in two thousand factories of U.K. shows that it can save 300 million pounds in device servicing every year after they made use of the technologies of monitoring and fault diagnosis, but the diagnosis expenses is only 50 million pounds. But the device servicing expense of metallurgy industry in China has achieved 25 billion yuan. If we generalize the technologies of abnormal monitoring, detecting, and diagnosis, then the economic benefit is very considerable. For instance we can reduce percent 50 to 70 accidents and save percent 10 to 30 expenses of device servicing.

Through the effort of numerous researchers in last decades, we have established a series of monitoring, detecting, and diagnosis methods in practical engineering application. In the traditional

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multivariate SPC, Principle Component Analysis (PCA) is one of the usual methods. The basic idea is that it confirms the status of principle component (PC) in terms of these eigenvalues of data matrix covariance; accordingly get the principle component of every level orderly. PCA possesses not only the capability of removing data correlation, reducing noise, and data compress, but also gets extensive application in fault diagnosis, signal processing and pattern reorganization and so on(Zhao*, et al*., 2004; Jolliffe, 2002; Jackson, 1980).

Data fusion is a new technology in information science field. It is a process to process and integrate the information gained from multi-source or multi-sensor and the purpose is to obtain more accurate and full estimate and judge. The structure of modern chemical industry becomes more and more complex and the functions are more perfect. And the character of system need be described by multivariate usually, such as temperature, flow rate, pressure and thickness etc., so it exists impersonally using different type sensors to observe object. Because of the limitation of data gained, the measurement reliability is lower. Then the phenomenon of distort and losing diagnosis in detecting process increases gradually (Wu, 2001). Therefore in the case that the object observed or identified possesses multi-property or disturbed by multi-uncertainty factors, it is certain choose that using multisensor cooperate in order to achieve common detect task.

At present the research in theory and application of multisensor data fusion (MSDF) have been obtained a series of achievements, and many of achievements have get successful application in military and civil fields. Accordingly they promote the research and development of this field (Wu, 2001; Yuan, *et al*., 1999; He, *et al*., 2000; Zhang, *et al*., 2001; Y. Bar-Shalom, *et al*., 2000). Because multisensor information fusion technology possesses lots of advantages, such as, increasing the information reliability, adding measurement space dimension, and improving dependability of system, so it can detect fault effectively. Thereby the application research of MSDF in multivariate statistical process monitoring gains more extensive attention. Wu (2001) researches the key problems of MSDF in art factitious process application, and designs a process monitoring and fault diagnosis system of distributed multisensor, multi-parameter centralized control and processing. This system can realize monitor to abnormal fault on different fusion level; the researcher, Yuan etc., discusses the possibility and advantages that MSDF applies in the application of industry control, accordingly presents a structure of control and monitor based on MSDF (Yuan*, et al*., 1999).

But from analysis we can know that the traditional monitoring methods all use measurements directly, so it has following questions:

1) Because measurements include various noises, so it can bring the uncertainty of monitor result and produce fault alarm when we use the measurements to monitor the process directly;

2) Due to PCA selects principle component through global variable, however every measurement is local, namely it only observes partial system variable. So it's very difficult to get an integrated and standard measurements matrix which strictly accords with the requirement of PCA in practical system;

3) For there is delay in the transmission process through network and PCA doesn't possess recursive nature, so it can produce estimate delay and system resource wasting etc. if we use the traditional monitoring methods directly;

4) In fact, the chemistry processes are all multisensor environment. But most of the traditional methods don't consider this character. So lots of information can't be used enough;

5) When system sampling is asynchronous, then the mutisensor data matrix which is needed by principle component analysis can't also be gained integrally and synchronously.

Aiming at above questions, we present following solutions:

i) We can use the least square (LS) estimate to solve 1), accordingly extend the traditional analysis based on measurement matrix to that based on state estimate in single sensor. Thereby the monitoring accuracy is improved and false alarm is reduced.

ii) For questions 2)-4), the paper can solve them by introducing recursive least square estimate and data fusion theory. Consequently it presents a new process monitoring algorithm based on data fusion theory. The proposed method can effectively solve the questions which are produced in traditional monitoring methods. But the question 5) is not considered in the paper.

In the paper we present the basic frame of the proposed monitoring method based on data fusion theory. And it shows the validity of the proposed monitoring method by use of two simulation examples. One is comparison between measurement and estimate in single sensor; another is the comparison between the estimate of single sensor and that of multisensor. These results all show that the proposed method is better than the traditional monitoring methods in monitoring accuracy and stability.

2. DESCRIPTION OF MULTISENSOR MEASUREMENT SYSTEM

Consider a multivariate process, $\mathbf{x}(k) \in R^{n\times 1}$ is state variable of process. A measurement system comprising of N sensors observes the process state vector with synchronous sampling but transmission delay is less than a sampling period. The sampling is shown as Fig.1 and the system measurement equation is as follows:

$$\mathbf{z}_i(k) = \mathbf{C}_i(k)\mathbf{x}(k) + \mathbf{v}_i(k) \qquad (1)$$

where $i = 1,2,\cdots,N$; integer $k \geq 0$ is discrete time variable. $\mathbf{z}(k) \in R^{p_i\times 1}$ $(p_i \leq n, i = 1,2,\cdots,N)$ is the measurement value of state $\mathbf{x}(k)$; $\mathbf{C}_i(k) \in R^{p_i\times n}$ is measurement matrix of sensor i ; measurement noise $\mathbf{v}_i(k) \in R^{p_i\times 1}$ is the sequence of Gaussian white noise possessing statistic property as follows: