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[Multiscale-Multiway PCA for time-series-data in production process - Keisuke Nogami]

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In recent semiconductor Fabs, Fault Detection and Classification (FDC) systems equipped with Multivariate SPC (MSPC) are installed. Those systems are capable of not only FDC but also that of collection time-series-data. However, conventional MSPC systems monitor a few indices derived from summarized data such as averages, maximums and minimums of the time-series-data. Since summarized data can describe only partial information on the time-series-data, the conventional MSPC systems have a risk of missed alarms and false alarms. Multiscale Principal Component Analysis[1)] (PCA) has been proposed as a fault detection (FD) method for the time-series-data. This method combines the ability of PCA to extract the relationship among variables, then, to decorrelate the cross-correlation with that of wavelet analysis to decompose the time-series-data into several frequency scales. The advantage of Multiscale PCA is to detect unusual waveform in the time-series-data such as spikes at high frequency and fluctuations at low frequency occurred in abnormal process operations by monitoring only the two indices, T^2 and Q statistics. Meanwhile, Multiway PCA[2)] is effective in FDC for a time-series-data on a batch process. This method unfolds three-dimensional data to two-dimensional data and makes MSPC applicable to batch process. Therefore we propose the FD method that combines Multiscale PCA with Multiway PCA to execute FDC on batch processes with frequency analysis. The proposed method has reduced the ratio of missed alarms from 50% to 0% and the ratio of false alarms from 11.1% to 7.7% compared to the conventional MSPC in our FD simulation.

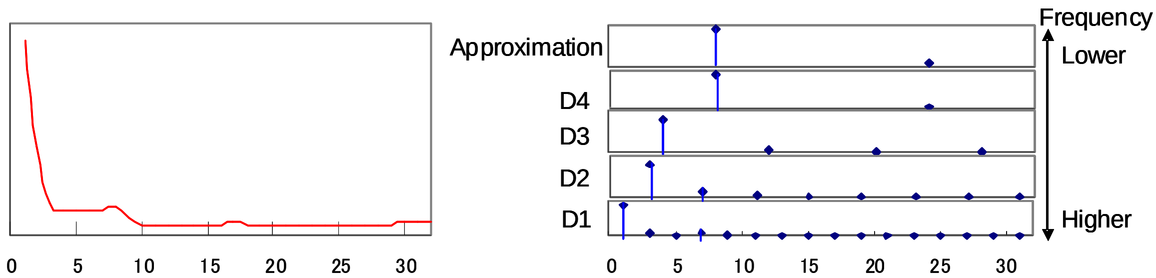
Figure 1(a) shows a Radio Frequency (RF) time-series-data of a dry etch process examined in this work. The wavelet coefficients derived from the RF signal is shown in Fig. 1(b). The original signal is decomposed into five frequency scales; D_1 to D_4 and Approximation. The highest frequency and the lowest frequency are shown as D_1 and Approximation respectively. The steps in the proposed Multiscale-Multiway PCA (M-M PCA) are shown in Fig. 2 and the off-line procedure for developing a FD system is as follows:

1. Acquire time-series-data $\boldsymbol{X}$ from certain amount of normal operation.
2. Generate wavelet coefficients matrices, $\boldsymbol{D}_j$ {j = 1,...,L: decomposition level}, and Approximation matrix, $\boldsymbol{A}$.
3. Apply Multiway PCA to the matrices, $\boldsymbol{D_j}$ and $\boldsymbol{A}$.
4. Select appropriate number of Principal Components (PCs).
5. Determine the control limits of the calculated indices, T^2 and Q at each scale.
6. Reconstruct the approximated time-series-data through an inverse wavelet transform at selected scales. There are 2^{L+1} combinations for selected scales.
7. At all combinations of the selected scales, apply Multiway PCA to the reconstructed data matrix.
8. Select appropriate number of PCs.
9. Determine the control limit of the calculated indices, T^2 and Q.

Feasibility study of the proposed method is conducted. The time-series-data of 133 wafers was collected when the dry etch rate were measured. In this data-set, 8 out of 133 wafers are out of the process spec. The collected signals are not only RF but also some other signals critical to the etch rate. M-M PCA is applied to this data-set to evaluate the fault detection capability. In this study, a statistical model was constructed with 117 on-spec wafers, and it was evaluated by the rest of wafers including 8 off-spec wafers. Figure 3 shows a T^2 chart of the conventional MSPC. This system has given 13 false alarms which are black or blue points beyond the control limit, and missed 4 alarms which are red points below the control limit. Figure 4 shows T^2 and Q control charts of M-M PCA. Under the SPC system by using M-M PCA, the number of missed alarms decreased from 4 to 0, and that of false alarms decreased from 13 to 9. As shown in Fig. 4, the control limit of M-M PCA has changed according to the selected scales. This variable control limit is a key feature to reduce false alarms and missed alarms. The ratios have been lower than those of the conventional MSPC.

Reference

1) B. R. Bakshi, AICHE J., 44, 1596-1610 (1998).
2)K. A. Kosanovich, ACC, 2, 1294-1298 (1994).



(a) RF time-series-data of a dry etch process

(b) Wavelet coefficients

Fig. 1. The original signal and the decomposed wavelet coefficients.

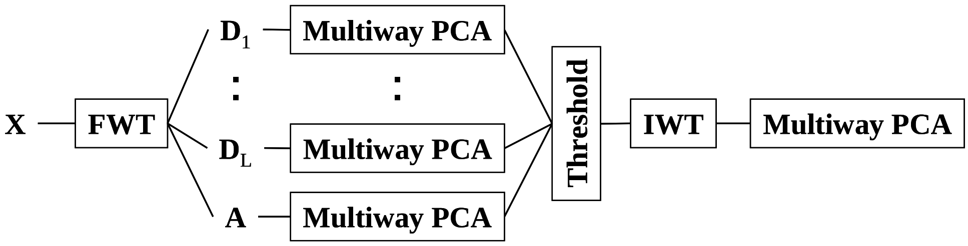


Fig. 2. Statistical process control methodology for M-M PCA

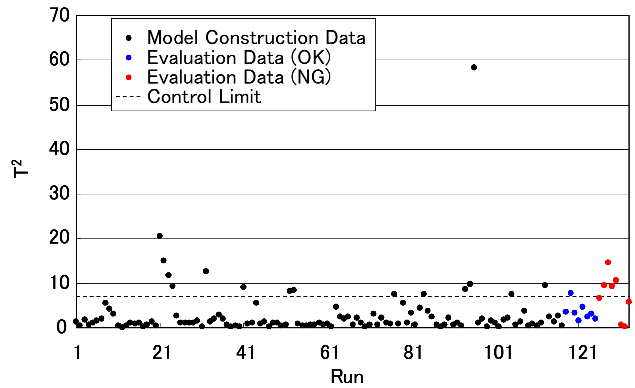
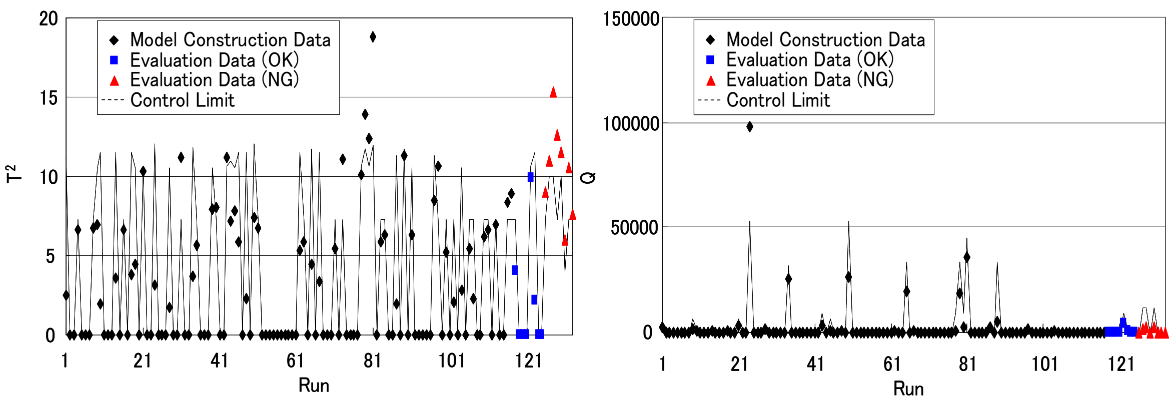


Fig. 3. Conventional MSPC monitoring T^2 of signal average



(a) T^2 Statistics

(b) Q Statistics

Fig. 4. Proposed SPC for M-M PCA