375d A New Bayesian Approach for Improved State Estimation in Semiconductor Manufacturing Processes

Jin Wang and Q. Peter He

Today, the semiconductor industry is moving toward more flexible manufacturing processes, characterized by multiple-specification and multiple-product operations on the same process tools. Meanwhile, as device dimensions decrease, process control demands have become more stringent. Therefore, control strategies and controller algorithms for flexible manufacturing processes are needed to maximize process capability and quickly recover processes after process changes and disturbances [1]. Many run-to-run (R2R) control and state estimation applications have been reported recently to address this aspect [4-7].

Currently, the Exponentially Weighted Moving Average (EWMA) is the most widely applied state estimator due to its simplicity and robustness. EWMA estimates the future state using an exponentially weighted average of all prior states. Due to process and metrology noises and recipe/product changes, disturbances (most frequently impulse and step disturbances) to the process occur throughout the normal operation of the process. However, in EWMA estimator, same weighting is applied to the new measurement no matter it is a normal point or an outlier, which leads to the slow track of step changes if the state estimator is tuned to reject noise well; on the other hand, if the state estimator is tuned to track process changes quickly, it will be quite sensitive to process noises. Therefore, it is highly desirable to detect the changes and adapt state estimation accordingly so that the effect of disturbance on the state estimation can be minimized.

Bayesian statistics has been applied to address this problem [1, 2]. The center of Bayesian statistics is Bayes Theorem [3]. In words, Bayes theorem states

Posterior = (likelihood x priori) / evidence

Hu et. al. [1] calculates the posterior probability of the step change using Bayes Theorem and a rapid model modification is triggered if the step change is confirmed. Their experiments show that this Bayesian approach significantly improved the state estimation for process changes with rather large magnitude. However, there are some limitations associated with Hu's approach and two of them are discussed here. First, it requires a SPC chart to identify the process changes. However, under closed-loop control, most step changes will not trigger SPC alarms therefore Hu's approach is not applicable to those disturbances. Second, the posterior probability of a single point is calculated and compared with certain threshold to determine whether a step change did occur, which results in at least 3 or 4 runs delay in classifying the disturbance type. This delay makes Hu's approach less attractive for the step changes with short duration.

In this work, a new Bayesian approach is developed to address these two aspects. First, we introduce the receding horizon approach which includes a pre-change window and a post-change window. By assuming the first point in the post-change window is the onset of a disturbance, and then by calculating the posterior probability in the post-change window, we either confirm or reject this hypothesis. In this way, we eliminate the need of SPC chart to identify the process changes, and we can handle the changes whose magnitude is not big enough to trigger SPC alarm. Besides, we consider the pattern of the posterior probability sequence in the post-change window instead of the value of the posterior probability of a single point. By matching the pattern of the posterior probability sequence to patterns generated by different disturbance, the classification delay can be reduced and the classification results are more robust than comparing a single posterior probability to a threshold value. Furthermore, in semiconductor manufacturing processes, step disturbances with short duration (2 to 4) are very common.

It was found that it would be more beneficial to treat these short step disturbances as elongated impulse disturbance instead of two step disturbances with opposite direction. In this work, an overlapping receding horizon approach using Bayesian statistics is developed to detect and classify different types of disturbances, including impulse, step, and short step disturbances with different durations (2 to 4). By applying different window settings and calculating the posterior probability in different ways, the developed algorithm can classify different disturbances with no addition delay other than an inherent delay. By combining the developed Bayesian approach with EWMA, i.e., adapting the state estimation based on the disturbance detection and classification results, the state estimation can be significantly improved. Both simulation and production examples are given to illustrate the performance of the developed algorithm.

Key words: Bayes theorem, posterior probability, pattern matching, state estimation, EWMA

Reference:

1. A.K. Hu. An Optimal Bayesian Process Control for Flexible Manufacturing Processes. Ph.D. Dissertation, MIT, 1992

2. E. Sachs, A.K. Hu and A. Ingolfsson. Run by Run Process Control: Combining SPC and Feedback Control. IEEE Transactions on Semiconductor Manufacturing. Vol 8 (1), 1995

3. R.O. Duda, P.E. Hart and D.G. Stork. Pattern Classification. John Wiley & Sons, Inc., 2001

4. S.J. Qin, G.W. Scheid and T.J. Riley. Adaptive Run-to-run Control for Intermittent Batch Operations. Proceedings of American Control Conference, 2168-2173, Anchorage, AK, May 8-10, 2002

5. E. Del Castillo and J. Yeh. An Adaptive Run-to-run Optimizing Controller for Linear and Non-linear Semiconductor Processes. IEEE Transaction on Semiconductor Manufacturing, Vol. 11, 285-295, 1998

6. N.S. Patel, G.A. Miller, C. Guinn, A.C. Sanchez and S.T. Jenkins. Device Dependent Control of Chemical-Mechanical Polishing of Dielectric Films. Ieee Transactions on Semiconductor Manufacturing, Vol. 13, 331-343, 2000

7. J. Wang, Q.P. He, S.J. Qin, C.A. Bode and M.A. Purdy. Recursive Least Squares Estimation for Run-to-Run Control With Metrology Delay and Its Application to STI Etch Process. IEEE Transaction on Semiconductor Manufacturing, Vol. 18, 309-319, 2005