320g Statistical Inference Methods for Mimo Control Performance Monitoring

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In a typical industrial process, hundred to thousands of control loops are operating under uncertain and varying conditions. Even if these controllers work properly in the initial period, a surprisingly high percentage of them will encounter various kinds of performance degradation, which result from sensor/actuator failure, equipment fouling, feedstock variability, product changes, seasonal influence and so on. It becomes necessary to design automated, effective and reliable strategies for the control loop performance assessment and monitoring. Although significant progress has been made in the area of control performance monitoring over the past decade, there are still some limitations on the existing work. In a great majority of the literature reports, both univariate and multivariate cases, the minimum variance control (MVC) is used as the preferred control performance benchmark. Definitely, MVC represents the potentially optimal control performance in a theoretical sense, because it provides the lower bound for the output variance and characterizes the most fundamental performance limitation of the system due to the existence of time delays.

In industrial processes, however, there exist many different restrictions on the achievable control loop performance so that the MVC performance is only an idealized lower bound. Moreover, the poor robustness of MVC benchmark is another point of concern for researchers. There is a possibility that the robustness and other important factors are influenced in an adverse direction while trying to reduce the control output variance. Therefore, the loop performance assessment on the basis of MVC benchmark can lead to an unreliable conclusion on the control performance. Though some other complementary benchmarks like linear quadratic Gaussian (LQG) benchmark were ever developed to overcome such drawbacks, a complete priori knowledge of the plant is still needed through some modeling and identification of the processes. Therefore, it seems more realistic and meaningful to employ some easily implemented benchmarks for the control performance monitoring of practical industrial processes. On the other hand, it is far from enough to just determine if an industrial process is performing optimally, adequately, or poorly. A very important and valuable task is to detect and identify the root causes for the performance change of the process, which in turn provides insightful and instructive advices for controller performance improvement, tuning and analysis.

In this presentation, a self-defined benchmark is first proposed to replace the conventional minimum variance benchmark for multi-input multi-output (MIMO) control performance monitoring of industrial processes. Its easy-to-implement nature avoids the great efforts to identify the dynamic model of the system and calculate the process output under minimum variance law. Then, a covariance monitoring framework is integrated with the generalized eigenvalue analysis for the pairwised multi-period performance monitoring qualitatively and quantitatively. The objective is to benchmark the control performance with a period in the history that is considered optimal or satisfactory. One of such periods is right after a controller has been maintained or turned with desirable performance. Since MVC benchmark is not involved, it does neither require any process model nor even the time delay or interactor information.

To further examine the significance and potential for performance improvement, a two-sided statistical hypothesis testing is developed for each generalized eigenvector direction that has apparent performance degradation. The confidence intervals are formulated and derived, and two different estimation procedures are compared using Parallel Analysis (PA) in order to obtain accurate control limits for the generalized eigenvalues. The worse and better characteristic directions can thus be picked out based on the two-sided thresholds. Further, the fault diagnosis strategies from a multivariate statistical perspective are used to find the root causes of both worse and better performance directions in the following fashion. A bootstrap re-sampling technique is implemented to simulate the probability distribution of contributions from each controlled variable (loop). Then they are used to estimate the upper bounds for the contributions of control loops along the previously identified worse and better directions, respectively. The established control limits can be further applied to determine the key variables (or loops) within the multivariate contribution plots for the retuning and redesign of controllers.

As an application example to MIMO processes, the operation data from a wood waste burning boiler are employed to demonstrate the validity and effectiveness of the proposed approach for performance monitoring. The results indicate that, not only the optimal and suboptimal directions can be identified, but their root causes of better and worse loops can also be located. The identification results are in well agreement with the numerical analysis from the variance ratio index. It is shown that the integrated framework does successfully bridge the independent areas of statistical fault diagnosis and control performance monitoring and provide an easy, reliable and adaptive tool for the monitoring of MIMO control performance.