Multivariate Statistical Process Monitoring Using Classical Multidimensional Scaling

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Abstract

A new Multivariate Statistical Process Monitoring (MSPM) system, which comprises of three main frameworks, is proposed where the system utilizes Classical Multidimensional Scaling (CMDS) as the main multivariate data compression technique instead of using the linear-based Principal Component Analysis (PCA). The conventional method which usually applies variance-covariance or correlation measure in developing the multivariate scores is found to be inappropriately used especially in modelling nonlinear processes, where a high number of principal components will be typically required. Alternatively, the proposed method utilizes the inter-dissimilarity scales in describing the relationships among the monitored variables instead of variance-covariance measure for the multivariate scores development. However, the scores are plotted in terms of variable structure, thus providing different formulation of statistics for monitoring. Nonetheless, the proposed statistics still correspond to the conceptual objective of Hotelling’s T2 and Squared Prediction Errors (SPE). The first framework corresponds to the original CMDS framework, whereas the second utilizes Procrustes Analysis (PA) functions which is analogous to the concept of loading factors in PCA for score projection. Lastly, the final framework employs dynamic mechanism of PA functions as an alternative for enhancing the procedures of the second approach. A simulated system of Continuous Stirred Tank Reactor with Recycle (CSTRwR) has been chosen for the demonstration and the fault detection results were comparatively analyzed to the outcomes of PCA on the grounds of false alarm rates, total number of detected cases and also total number of fastest detection cases. The last two performance factors are obtained through fault detection time. The overall outcomes show that the three CMDS-based systems give almost comparable performances to the linear PCA based monitoring system when dealing the abrupt fault events, whereas the new systems have demonstrated significant improvement over the conventional method in detecting incipient fault cases. More importantly, this monitoring accomplishment can be efficiently executed based on lower compressed dimensional space compared to the PCA technique, thus providing much simpler solution. All of these evidences verified that the proposed approaches are successfully developed conceptually as well as practically for monitoring while complying fundamentally with the principles and technical steps of the conventional MSPM system.