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Soft sensor design by multivariate fusion of image features and process measurements

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ABSTRACT

This paper presents a multivariate data fusion procedure for design of dynamic soft sensors where suitably selected image features are combined with traditional process measurements to enhance the performance of data-driven soft sensors. A key issue of fusing multiple sensor data, i.e. to determine the weight of each regressor, is achieved through multivariate regression. The framework is described and illustrated with applications to cement kiln systems that are characterized by off-line quality measurements and on-line analyzers with limited reliability. Image features are extracted with a multivariate analysis technique from RGB pictures. The color information is also transformed to hue, saturation and intensity components. Both sets of image features are combined with traditional process measurements to obtain an inferential model by partial least squares (PLS) regression. A dynamic PLS model is obtained by filtering the original data block augmented with time lagged variables such that improved predictive performance of the quality variable results. Key issues regarding data preprocessing and extraction of suitable image features are discussed with a case study, the on-line estimation of nitrogen oxides (NOx) emission of cement kilns. On-site tests demonstrate improved performance over soft sensors based on conventional process measurements only.

1. Introduction

Conventional process measurements of physical properties are readily available for most industrial processes, such as the flowrate, temperature and pressure. However, the lack of sufficiently accurate and reliable on-line measurements of, e.g. chemical compositions and related properties, poses difficulties for effective monitoring, fault diagnosis or predictive control of many chemical processes. For example, measurements related to the type and movement of flotation froth are based on visual inspection of human operators in most plants. In the cement industry, operators usually judge the operating conditions using a video signal from the camera looking into the cement kiln. Advances in digital image processing techniques enable the quantification of the video signal, thereafter extraction of features of interest such as color and brightness [1]. Combined with traditional process measurements, the resulting large number of data resources commonly leads to a problem of high dimensionality for extracting information which is pertinent for monitoring, fault diagnosis and control. This paper presents a multivariate procedure for data-driven soft sensor design by fusing traditional process measurements and suitable image features with applications to cement kilns.

A soft sensor is an inferential model developed from process knowledge and observations. Soft sensors have been reported as supplement to online instrument measurements for process monitoring and product quality control, which can be classified into two categories: model-based and data-driven. A model-based soft sensor often suffers from computational intensity for real time applications. Modern measurement techniques enable a large amount of operating data to be collected, stored and analyzed, thereby rendering data-driven soft sensor development a viable alternative. The high dimensional data often show strong collinearity. Multivariate analysis is, therefore, necessary to extract process information that is statistically significant. Development of soft sensors has been recently reviewed by Kadlec et al. [2] and a systematic approach based on conventional measurements presented in [3]. Soft sensors may be used both in continuous and in batch processes. A particular feature is that through suitable design soft sensors may be used for predictive purposes which can be very important for their applications in model predictive control. For a batch chemical process, this predictive capability was illustrated in [4] and for a biochemical process in [5] where the entire batch run was shown to be predictable *a priori*.

Multisensor data fusion refers to the acquisition, processing and synergistic combination of information gathered by various

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