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Strategies for Synchronizing Chocolate Conching Data Using Dynamic Time Warping

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Abstract : Batch processes are widely used in food industry and have an important role in the production of high added value products, such as chocolate. Process performance is usually described by variables that are monitored as the batch progresses. Data arising from these processes are likely to display a strong correlation-autocorrelation structure, and are usually monitored using control charts based on multiway principal components analysis (MPCA). Process control of a new batch is carried out comparing the trajectories of its relevant process variables with those in a reference set of batches that yielded products within specifications; it is clear that proper determination of the reference set is key for the success of a correct signalization of non-conforming batches in such quality control schemes. In chocolate manufacturing, misclassifications of non-conforming batches in the conching phase may lead to significant financial losses. In such context, the accuracy of process control grows in relevance. In addition to that, the main assumption in MPCA-based monitoring strategies is that all batches are synchronized in duration, both the new batch being monitored and those in the reference set. Such assumption is often not satisfied in chocolate manufacturing process. As a consequence, traditional techniques as MPCA-based charts are not suitable for process control and monitoring. To address that issue, the objective of this work is to compare the performance of three dynamic time warping (DTW) methods in the alignment and synchronization of chocolate conching process variables' trajectories, aimed at properly determining the reference distribution for multivariate statistical process control. The power of classification of batches in two categories (conforming and non-conforming) was evaluated using the k-nearest neighbor (KNN) algorithm. Real data from a milk chocolate conching process was collected and the following variables were monitored over time: frequency of soybean lecithin dosage, rotation speed of the shovels, current of the main motor of the conche, and chocolate temperature. A set of 62 batches with durations between 495 and 1,170 minutes was considered; 53% of the batches were known to be conforming based on lab test results and experts' evaluations. Results showed that all three DTW methods tested were able to align and synchronize the conching dataset. However, synchronized datasets obtained from these methods performed differently when inputted in the KNN classification algorithm. Kassidas, MacGregor and Taylor's (named KMT) method was deemed the best DTW method for aligning and synchronizing a milk chocolate conching dataset, presenting 93.7% accuracy, 97.2% sensitivity and 90.3% specificity in batch classification, being considered the best option to determine the reference set for the milk chocolate dataset. Such method was recommended due to the lowest number of iterations required to achieve convergence and highest average accuracy in the testing portion using the KNN classification technique.

Keywords : batch process monitoring, chocolate conching, dynamic time warping, reference set distribution, variable duration
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