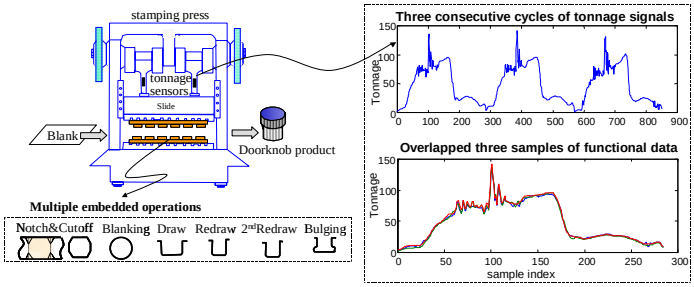
Engineering-Driven Wavelet Analysis of Cyclic Functional Data for Multiple Embedded Operations Diagnosis

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Motivation

- Many complex manufacturing processes consist of multiple embedded operations. It is impossible or unaffordable to directly measure all individual operations separately. The available sensing signals are usually the combined/mixed responses of multiple operations.
- It is highly demanded to develop a general methodology for effectively monitoring the combined sensing signals to detect and diagnose the change of individual operation conditions.



State-of-the-Art

Data transform methods

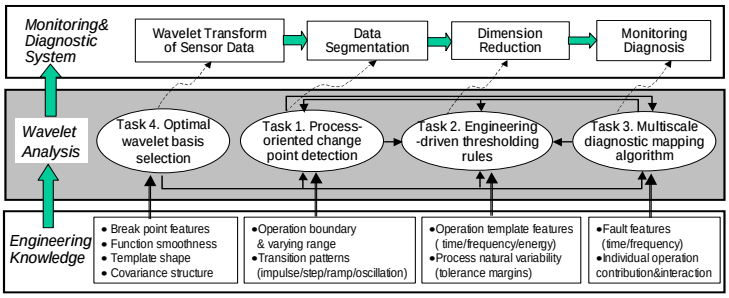
- Fourier transform is effective in the analysis of stationary periodic signals, but not efficient in the representation of local discontinuities and sharp changes of waveform signals.
- PCA (Principle Component Analysis) method is effective in representing the major variation patterns, but is generally lack of the physical inference of a signal change.
- Wavelets transform with multiscale analysis capability shows both advantages in the representation of local change-points in the time domain and different operations' frequencies at different scales.

Objective and new features

Develop a mew process control methodology to surpass the existing SPC methods for multiple embedded operations monitoring and diagnosis by fusion of engineering knowledge with wavelets analysis for cyclic functional sensing data, which has the following new features:

- efficient data dimension reduction in representing discontinuities and sharp profile changes of sensing signals;
- explicit physical interpretation of wavelet coefficient changes with the linkage of the characteristic frequencies of individual operations;
- quick root causes diagnosis of individual operation conditions through data segmentation and signal change-point detection between operations.

Proposed approaches



Research scope

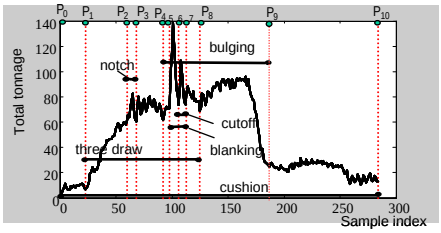
Common characteristics of cyclic sensing signals:

- **Cyclic signal:** repetitive operations generate a series of cyclic sensing signals, which can be represented by multiple samples of high dimensional curves with the natural variability.
- **Segmental signal:** each operation is only reflected on a certain segment of signals, which can help localize root causes through data segmentation.
- **Non-stationary signals in both time and frequency domains:** different operations generate different means, variances, and frequencies components, which provides more diagnosability by multiscale analysis.

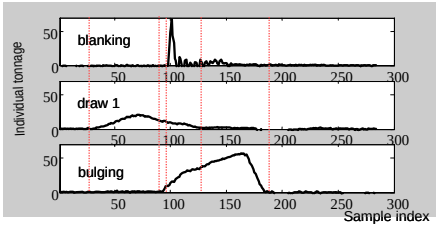
Accomplishments

Operation-based signal segmentation

Combined signals of multiple Operations



Individual operation signals

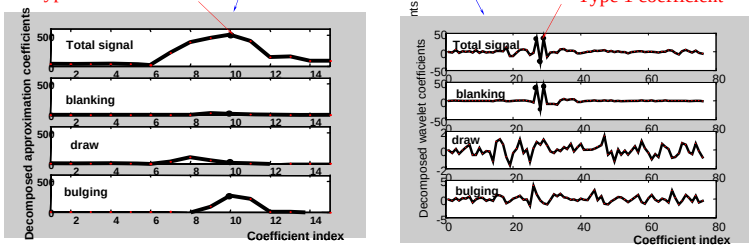


Multiscale diagnostic feature extraction

- ❖ Type 0 coefficient: the wavelet coefficient that does not relate to any operations of interest;
- ❖ Type 1 coefficient: the wavelet coefficient that only relates to a single operation;
- ❖ Type 2 coefficient: the wavelet coefficient that relates to more than one operations.

$$f(x) = \sum_{k \in Z} c_{s,k}\phi_{s,k}(x) + \sum_{j=s,k \in Z}^{\infty} d_{j,k}\psi_{j,k}(x)$$

Type 2 coefficient — Type 1 coefficient



Impact of Work

- Develop a general methodology to effectively monitor and analyze high dimensional cyclic sensing data for better process control and quality improvement.
- The developed methodology can be applied to a broad class of processes/systems which contain repetitive discrete operations to generate cyclic waveform signals, such as stamping, forging, taping operations, etc.

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