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SIS 2010
Riunione Satellite

Realtime multivariate statistical quality monitoring in the manufacturing of high value added products

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Development of multivariate and multiresolution statistical techniques for industrial applications

Successful applications of multivariate statistical methods to different industrial applications:

1. realtime monitoring of **industrial manufacturing of resins and coatings**:
   - online estimation of the product quality
   - batch length prediction
   - automatic adaptation to changes
2. defect detection/localization in the manufacturing of **integrated circuits**:
   - image analysis of semiconductors
3. characterization in **nanofiber membrane** fabrication:
   - artificial vision system for the measurement and the estimation of chemical and physical attributes
4. standardization of **near-infrared instrumentation**:
   - estimation of the quality of forages for bovine feeding

Multivariate and multiresolution statistical methods

Multivariate statistical methods:
- deal with data collinearity, correlation and noise
- principal component analysis, PCA [1]
- projection on latent structures, PLS [2]

Multiresolution approach (frequency domain):
- decomposes signals in different resolution scales with no loss of spatial/temporal information
- wavelet convolution [3]

Challenge: dealing with data space/time evolution

PCA

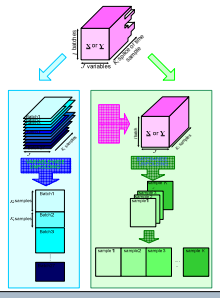
$$\mathbf{X} = \sum_{a=1}^{A} \mathbf{t}_a \mathbf{p}_a^T + \mathbf{E} \quad \text{with } A \le J$$

PLS

$$\begin{cases} \mathbf{X} = \mathbf{T}\mathbf{P}^T + \mathbf{E} \\ \mathbf{Y} = \mathbf{U}\mathbf{Q}^T + \mathbf{F} \end{cases}$$

wavelet convolution

$$T(a,b) = \int_{-\infty}^{+\infty} x(t)\psi_{a,b}^*(t)\mathrm{d}t$$



Quality monitoring in fine chemicals manufacturing

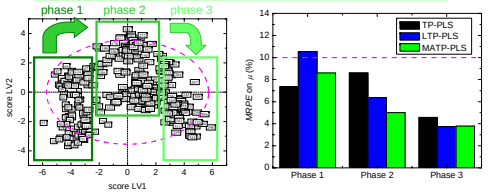
Challenges:
1. the plant is almost fully manually driven
2. midcourse correction of the recipe
3. different initial state of the pieces of equipment, of the utilities and of the raw materials

Issues:
1. scarce number of **delayed quality lab analysis**
2. **unpredictable batch length**

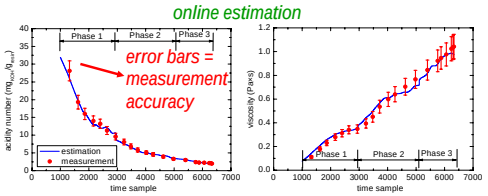
Soft sensor for the estimation of quality

Adaptive multiphase moving-average PLS **soft sensor**:
- multiphase structure compensates non-linearity
- moving average gives memory to the estimator [4,6]
- **frequent estimations with high accuracy** (10-12%)

mean relative error $MPRE = \frac{100}{N}\sum_{n=1}^{N}\frac{\sqrt{(y_n - \hat{y}_n)^2}}{\hat{y}_n}$



online estimation

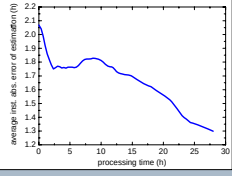


Batch length prediction

Time evolving PLS models [5] to predict the production stages length:
- prediction accuracy increases with time
- few hours after batch start the **prediction accuracy is very high** (1-3h)

$$AAE = \frac{1}{I_{val}} \times \sum_{i=1}^{I_{val}} \left[\frac{1}{t^*} \int_0^{t^*} \left| \hat{\tau}_i(t) - \tau_i \right| \mathrm{d}t \right]$$

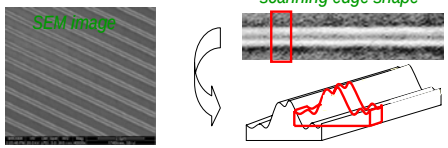
$$\begin{cases} \tau_i = \text{length of the stage} \\ \hat{\tau}_i(t) = \text{prediction at time } t \end{cases}$$



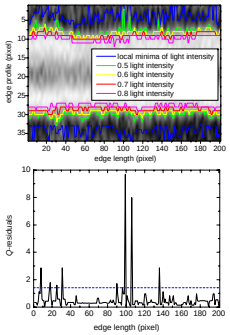
Artificial vision systems for the characterization of nanomaterials

Semiconductor fabrication

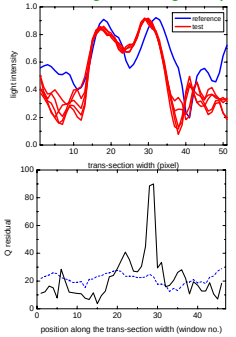
Effective defect detection and localization from **multivariate image analysis** [7]:
- roughness of the line edge
- edge shape



monitoring of line edge roughness



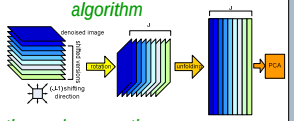
monitoring of the edge shape



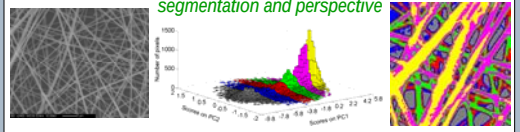
Nanofiber membranes

Measurements and estimations from **image analysis** [8]:
- pore size distribution
- fiber size distribution
- permeability (texture)

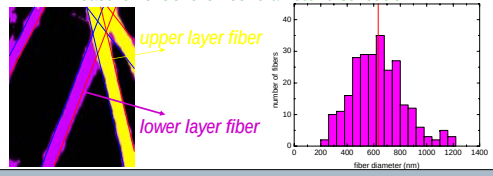
algorithm



segmentation and perspective



measurement of the fiber diameter distribution

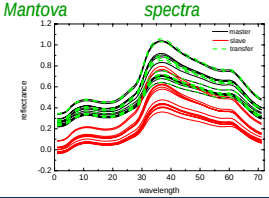


Standardization of NIR spectrometers for the estimation of forage quality

Objectives:
- even responses in diverse NIRS
- limited calibration effort through PLS
- reduced number of calibration samples
- **accurate prediction of the quality of bovine foodstuff**

AgriNIR®, DinamicaGenerale, Mantova

spectra



Conclusions and future perspectives

Multiresolution and multivariate statistical techniques demonstrate to be highly beneficial in the industrial application of quality control paradigms.
Great benefits are expected in the processing of pharmaceuticals, foodstuff, wood, textiles, etc…

References

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