Fault detection based on NIR for crude oil desalting process

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Desalination and Dehydration of Crude Oil

▶ Why desalination and dehydration ?

Crude oil extracted from underground contains water and salts, which will:

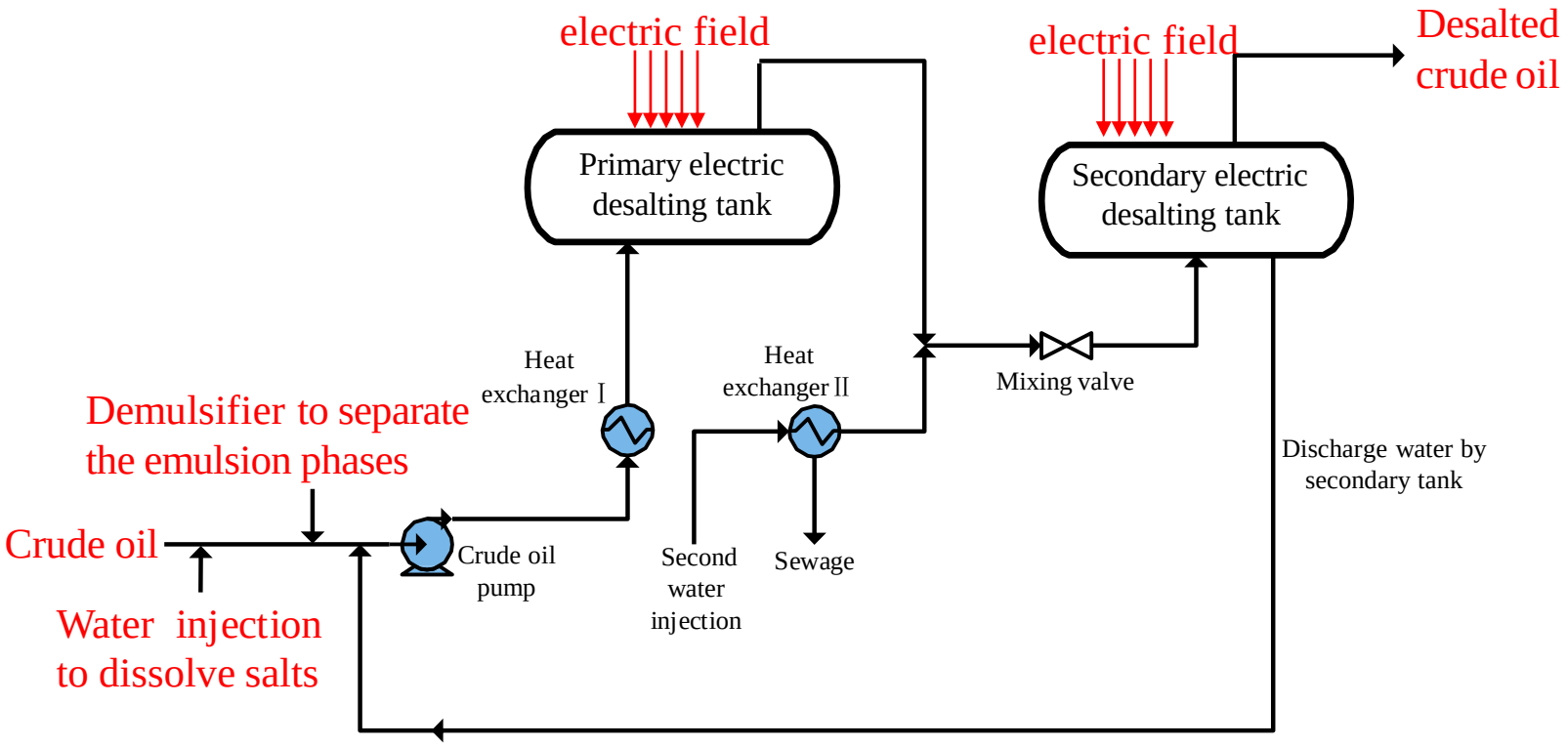
(1) corrode crude oil processing equipment;

(2) poison the catalyst;

(3) affect the quality of petroleum products, etc.

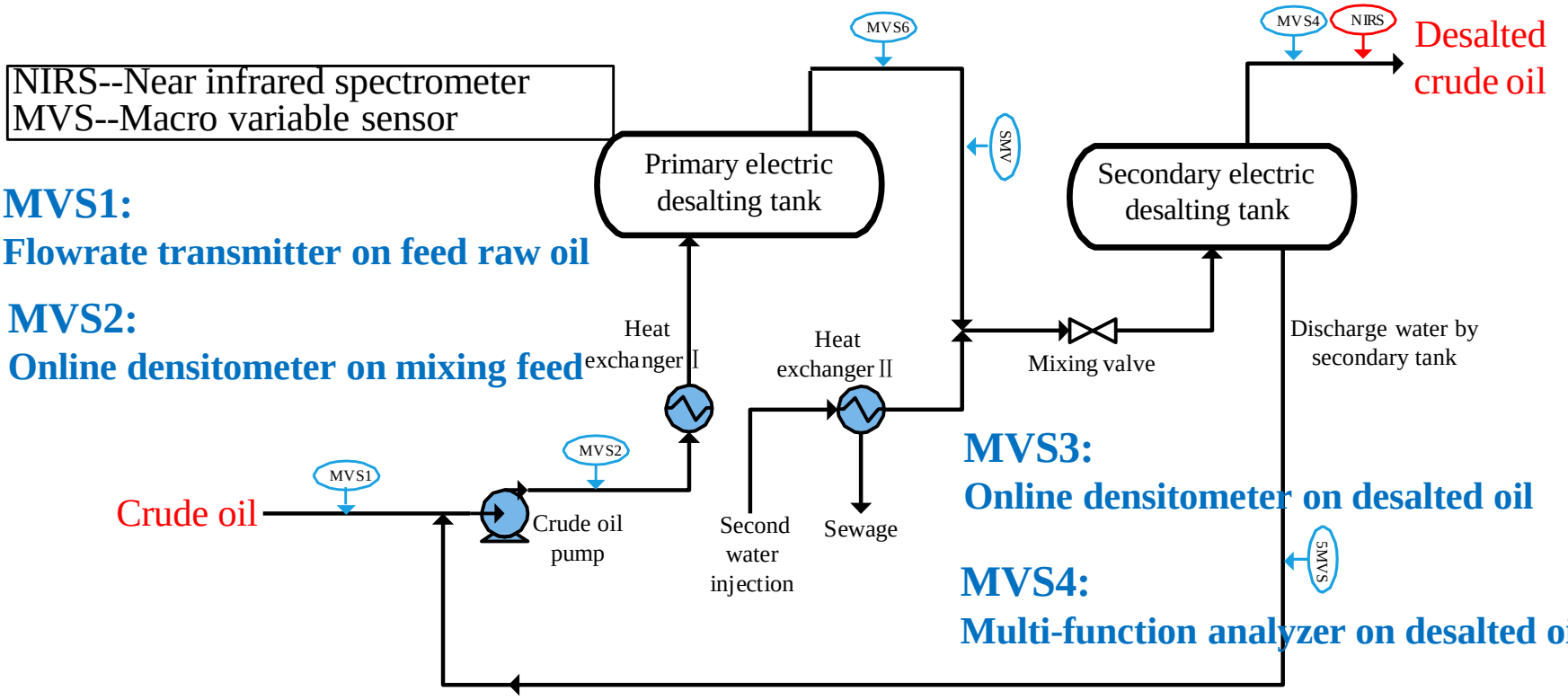
Desalination and Dehydration of Crude Oil

How desalination and dehydration ?



Desalination and Dehydration of Crude Oil

▶ Traditional way to monitor the process



It could not detect the fault in time

Traditional Analyzer vs NIR

- **Traditional analyzer:**

  To analyze macro-process variable (MPV), to taste sample, smell sample, weighting or scaling sample, etc...

- **NIR-"eyes of a superman":**

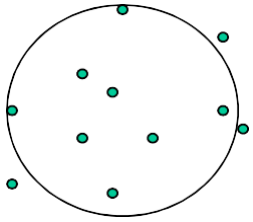
  To look into molecular structures through their vibrations, to calculate the properties by using Chemometrics.

- **What can be seen and reported by this "superman"?**

  Almost "any" properties! Because the molecular structures and vibrations are the fundamentals of matter "property".

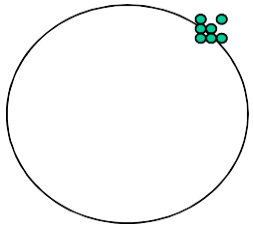
Traditional Analyzer:

Good accuracy
Poor repeatability



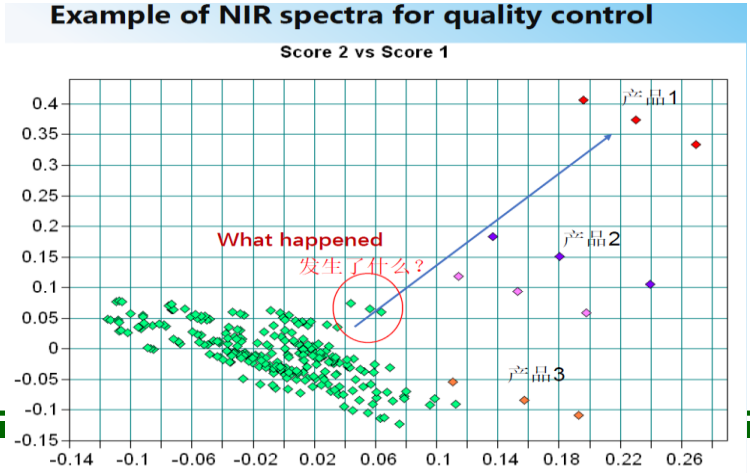
NIR:

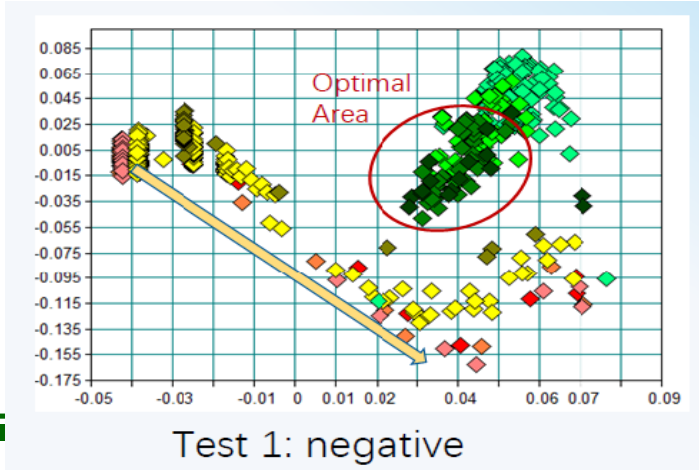
Good repeatability
Accuracy-depends on model?



What Areas Can Use NIR?

Monitoring, Quality control, and Reverse product design for mining, mineral and metal processing





NIR-Based Fault Detection

- Fault detection for crude oil desalting process in Petro-Canada:

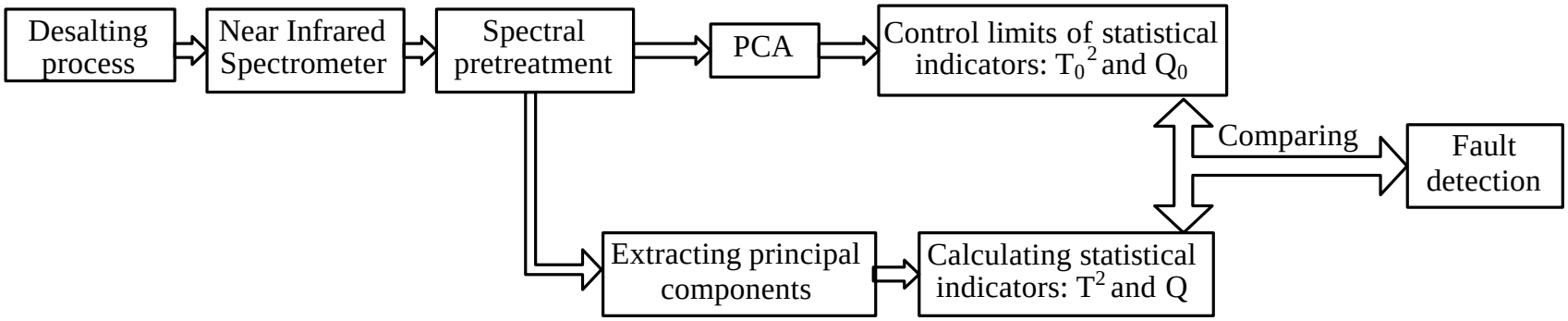
Method 1. Fault detection via PCA and statistics

Method 2. Fault detection via process pattern and potential function




Fault Detection via PCA and Statistics

Basic procedures



Calculation of statistics

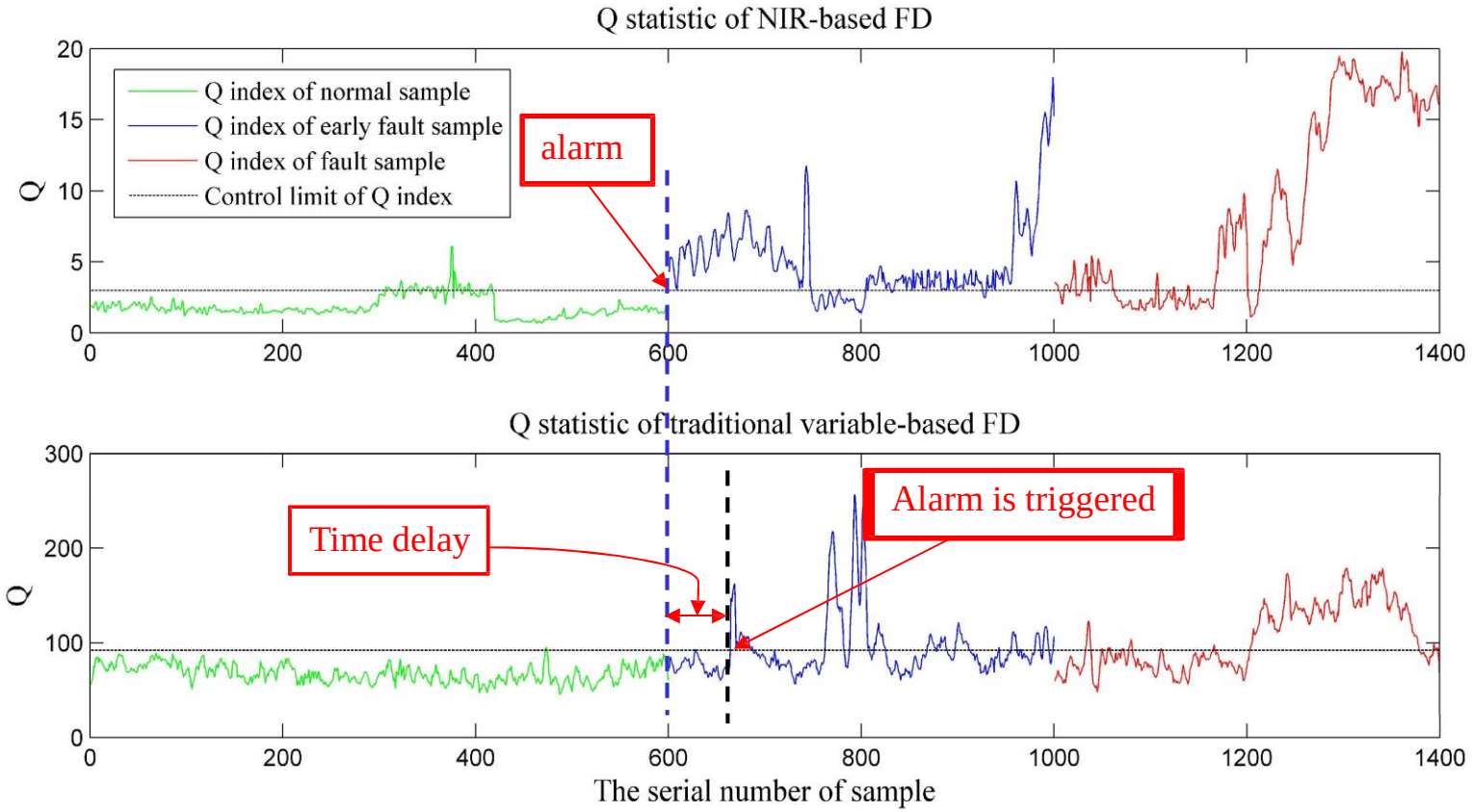
$$T^2 = \frac{k(n-1)}{n-k} F_\alpha(k, n-k)$$

$$Q = \theta_1 \left(1 + \frac{C_\beta \sqrt{2\theta_2 h_0^2}}{\theta_1} + \frac{\theta_2 h_0 (h_0 - 1)}{\theta_1^2}\right)^{1/h_0}$$

$$\theta_l = \sum_{j=k+1}^{s} \lambda_j^l \, (l = 1,2,3), \; h_0 = \frac{1 - 2\theta_1 \theta_3}{\theta_2^2}$$

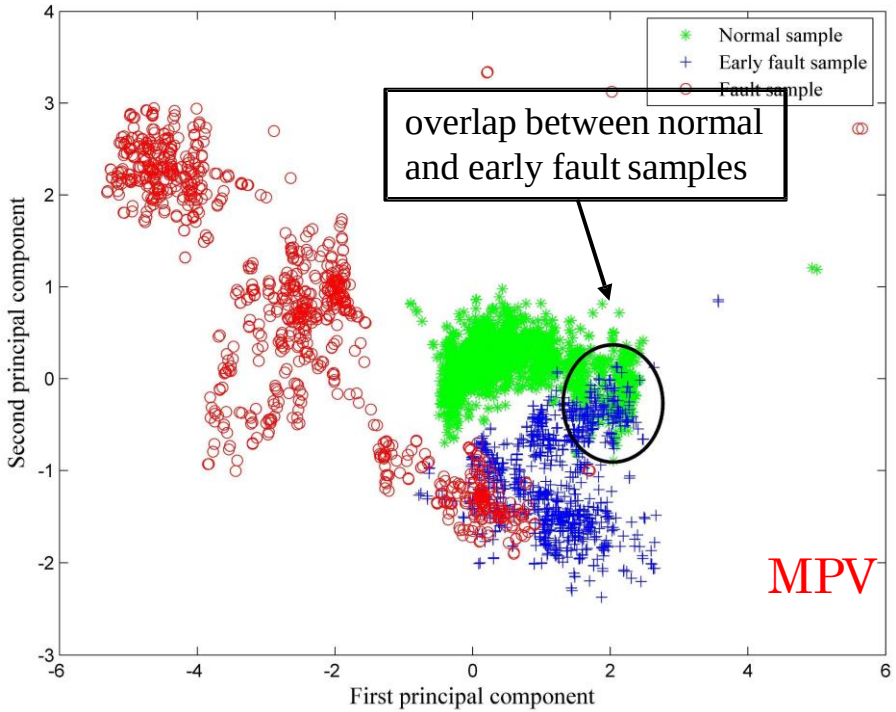
Comment: PCA-statistics is the most commonly used multi-statistic process monitoring (MSPM) method in industry.

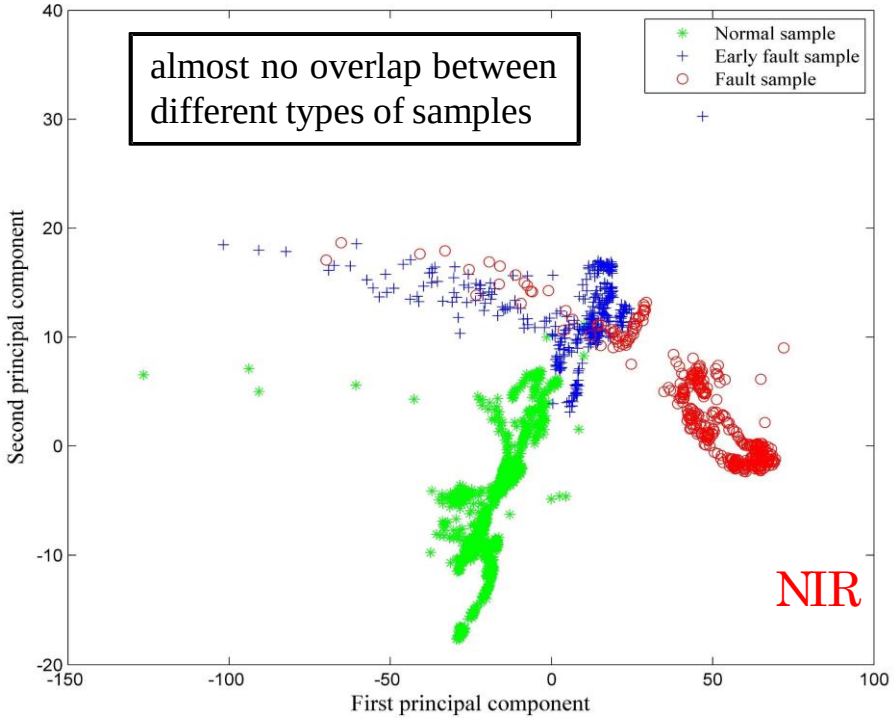
Fault Detection via PCA and Statistics



Changes in the molecular level can be identified earlier than the physical appearances on the process

Fault Detection via PCA and Statistics

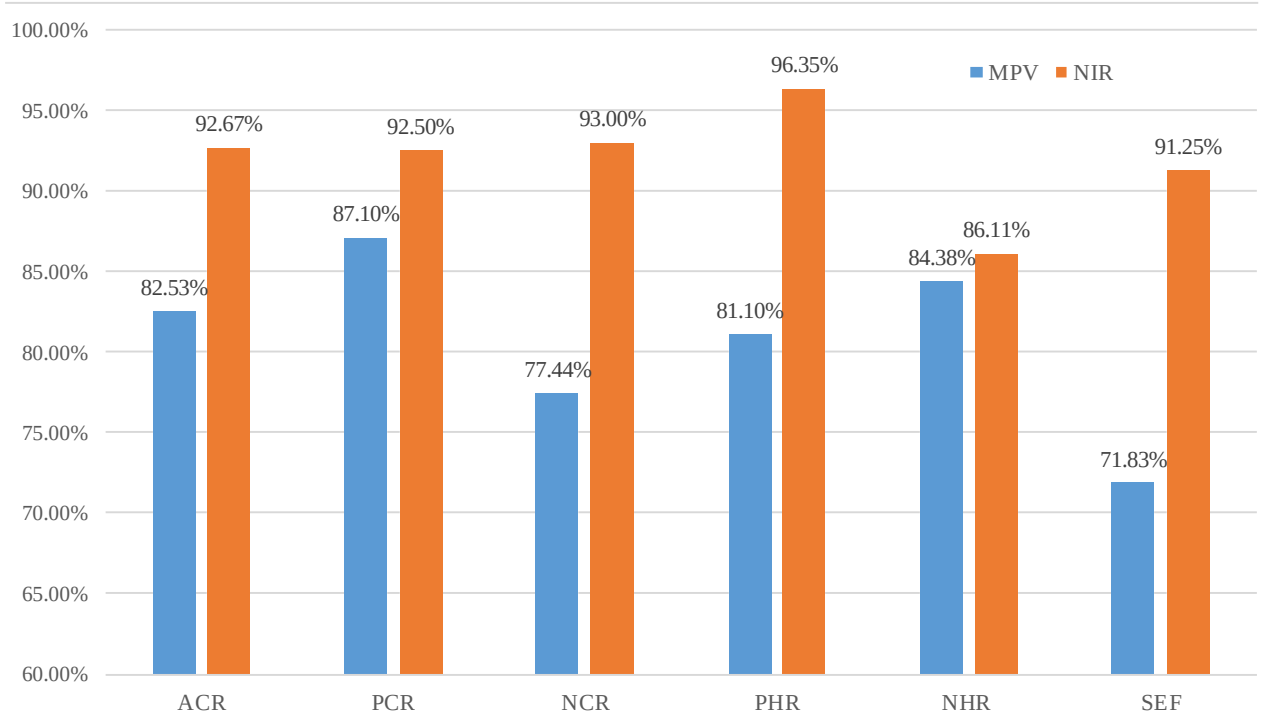




Molecular vibration-based NIR can more quickly sense system's anomalies and be more sensitive to early failures compared to traditional process variable.

Fault Detection via PCA and Statistics

- Accuracy: MPV vs NIR



Fault Detection via PCA and Statistics

- **NIR-based fault detection is better than MPV-based FD !**
- **However, there are still two major problems :**

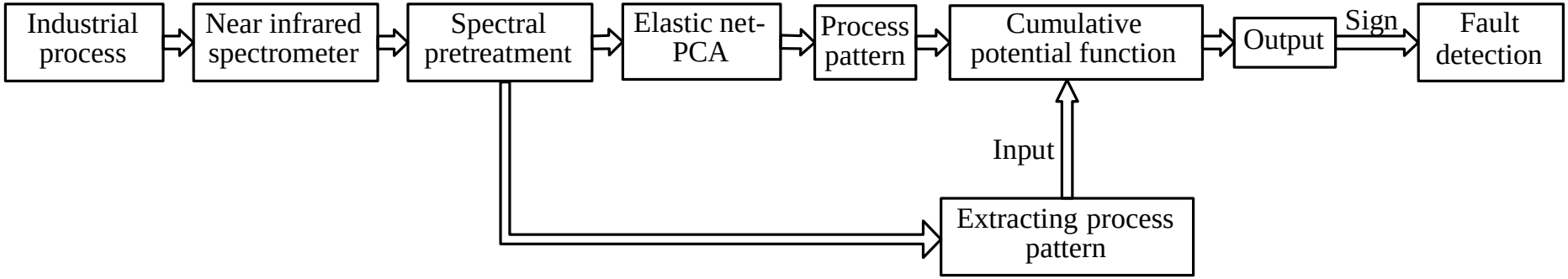
Vast spectral variables and most of them are unrelated to the process.	PCA and statistics require linear separability among different operating status.

- **Solutions :**

Elastic net-PCA: variable selection and extracting comprehensive features .	Potential function: a kind of nonlinear classification with visual performance
Improve the information efficiency of spectral data	**Improve the interpretability and prediction accuracy**

Fault Detection via Process Pattern and Potential Function

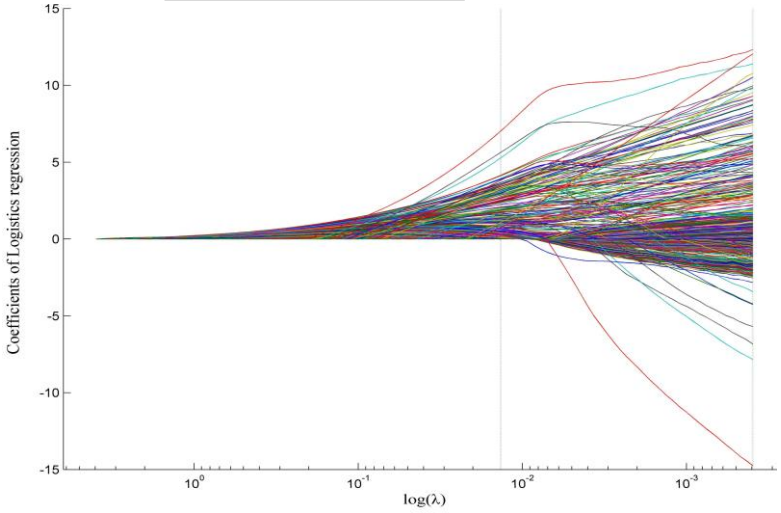
Basic procedures



Constructing the process pattern

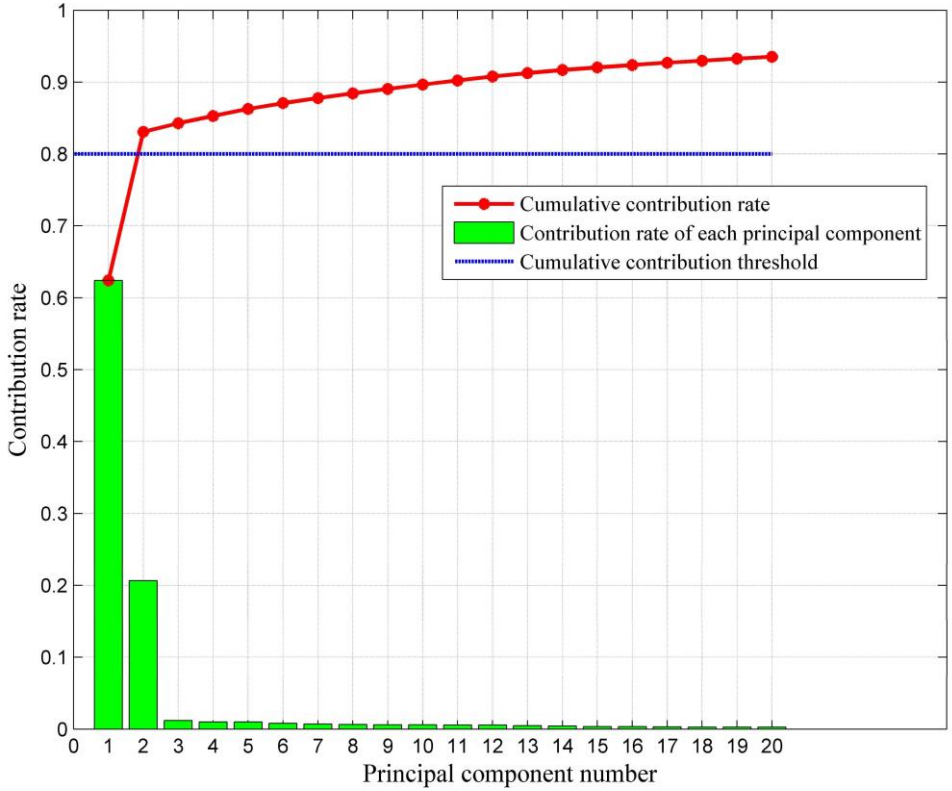
Variable selection-elastic net：

$$\begin{cases} \hat{\beta}(\lambda_1,\lambda_2) = \arg\min_{\beta}\left\{ SSR + \lambda_1 \sum_{j=1}^{m}\left|\beta_j\right| + \lambda_2 \sum_{j=1}^{m}\beta_j{}^2 \right\} \\ SSR = \sum_{i=1}^{n}\left(y_i - \sum_{j=1}^{m} c_{ij}\beta_j \right)^2 \end{cases}$$



NIR-Based Fault Detection via Process Pattern and Potential Function

Extracting comprehensive features-PCA：



Fault Detection via Process Pattern and Potential Function

▶ Potential function discrimination

Train a cumulative potential function：

$$H_{k+1}(X)=H_k(X)+r_{k+1}H(X,X_{m+1})$$

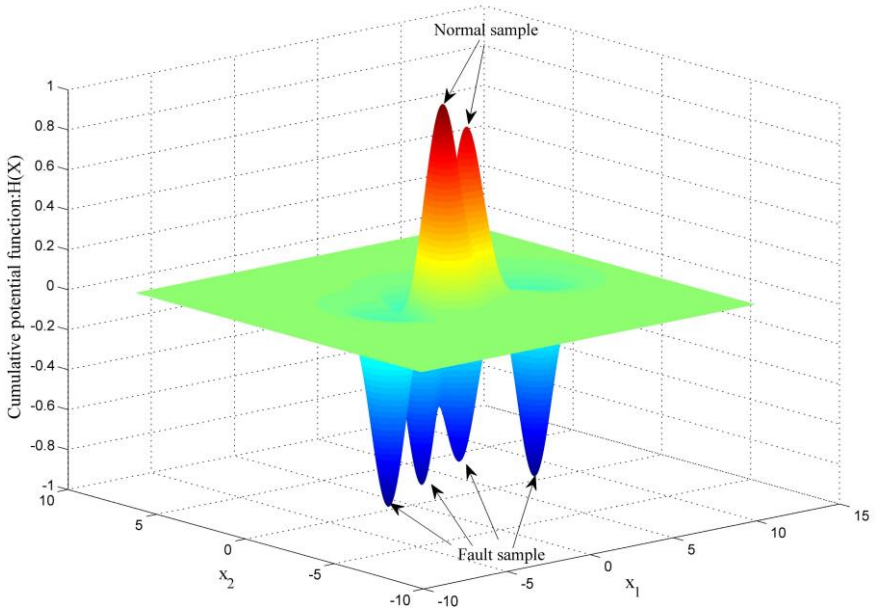
$$r_{k+1}=\begin{cases}0, & X_{m+1}\in\omega_1 \text{ 且 } H_k(X_{m+1})>0\\ 0, & X_{m+1}\in\omega_2 \text{ 且 } H_k(X_{m+1})<0\\ 1, & X_{m+1}\in\omega_1 \text{ 且 } H_k(X_{m+1})\le 0\\ -1, & X_{m+1}\in\omega_2 \text{ 且 } H_k(X_{m+1})\ge 0\end{cases}$$

The mechanism of fault detection：

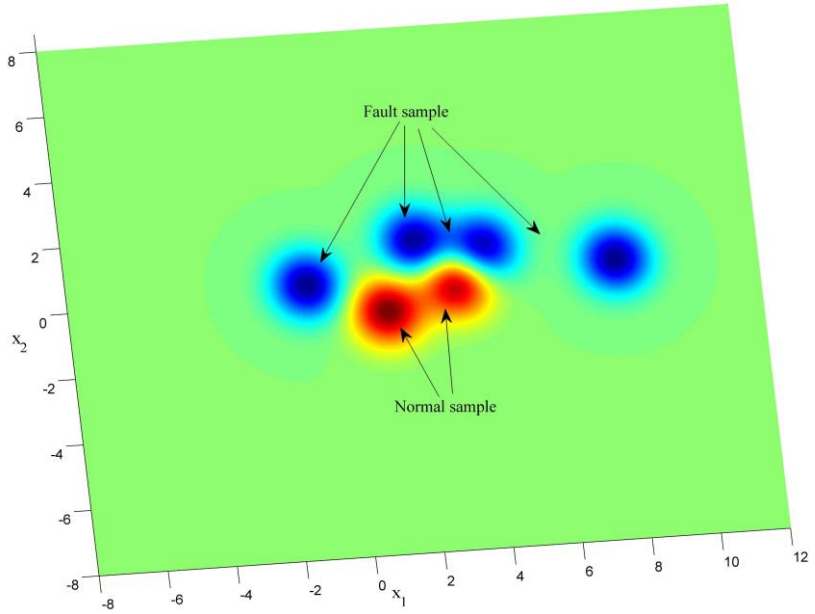
$$\text{The current system is in}:\begin{cases}\text{Normal state}, & H(X)>0\\ \text{Fault state}, & H(X)<0\end{cases}$$

Fault Detection via Process Pattern and Potential Function

Image of the cumulative potential function



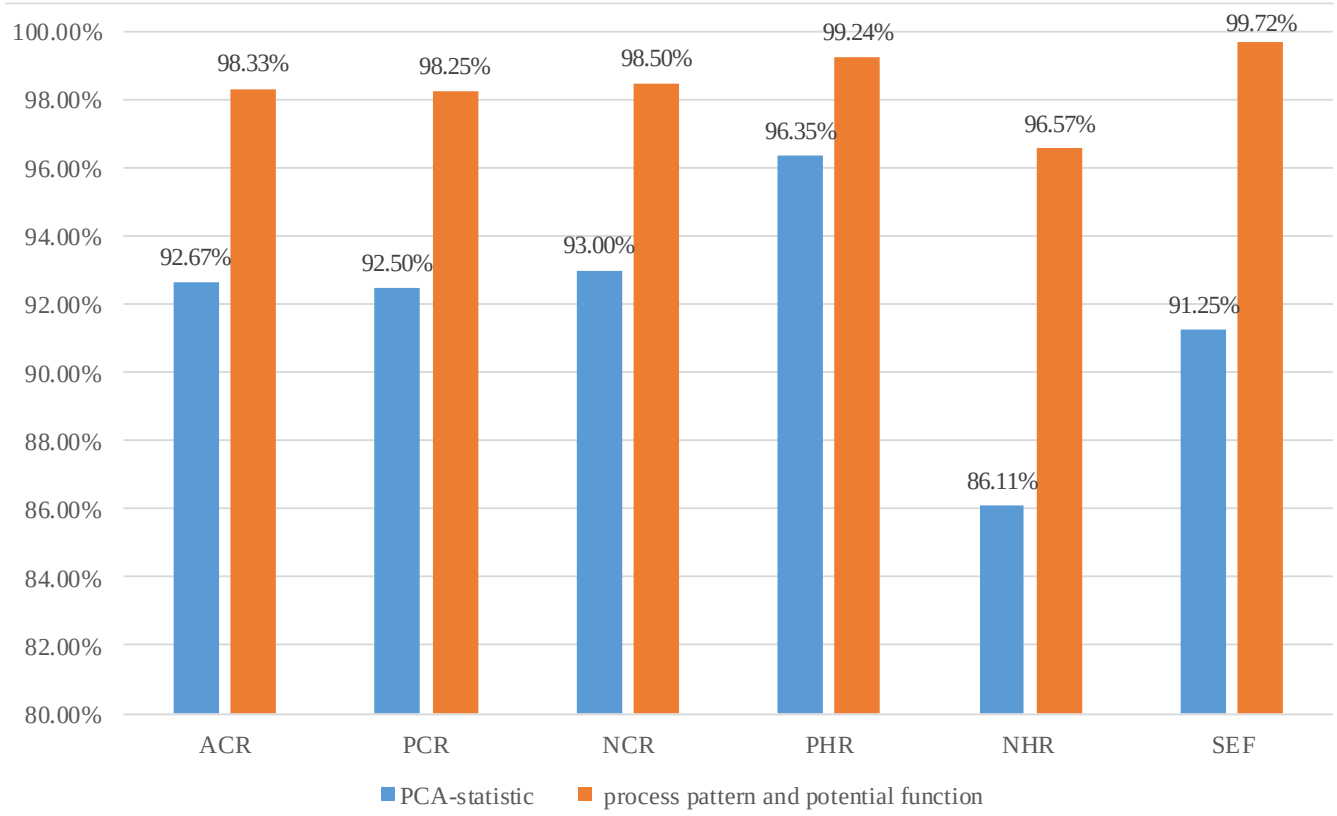
Main view



Top view

Fault Detection via Process Pattern and Potential Function

▶ Accuracy: PCA-statistic vs process pattern and potential function



Thank You !