Development and application of FT-NIRs model for online monitoring the quality of cut tobacco in primary processing line

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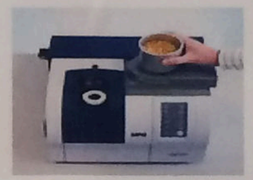
Abstract

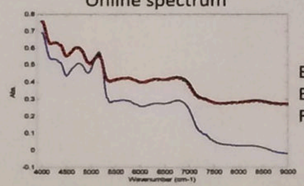
- Near infrared (NIR) spectroscopy is especially suitable for online monitoring of productive process due to its fast and nondestructive detecting feature.
- The objective of this study was to develop a simple method, which can help to obtain the online NIR models quickly for the monitoring of cut tobacco.
- A rotating plate was designed to simulate the tobacco conveyor, so that standard samples were obtained as well as their spectra in different conditions for model transferring.
- A Chemometric method, Spectral Space Standardization (SST), was successfully utilized to transfer the offline predictive models of tobacco powder to online models of cut tobacco.
- Experimental results of tobacco combustion heat show that the average prediction relative error (APRE) is decreased from 6.5% (before model transferring) to 2.7% (after model transferring), which is close proximity to that of offline model (2.0%).

Spectra of Standard Samples in Different Conditions and Transfer

Online spectrum

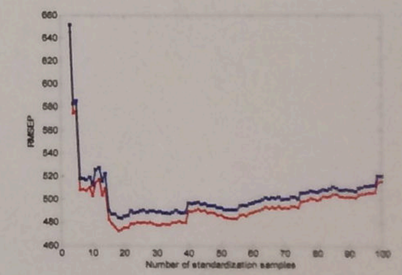


Offline spectrum



Blue line: Online spectrum
Black line: Offline spectrum
Red dotted line: Transferred spectrum

Number of Standard Samples needed



20 samples are enough for the model transformation.

Spectral Space Standardization: SST

$$\mathbf{X}_{comb} = [\mathbf{X}_1, \mathbf{X}_2]$$

$$\mathbf{X}_{comb} = [\mathbf{U}_s, \mathbf{U}_n]\begin{bmatrix}\Sigma_s & 0\\ 0 & \Sigma_n\end{bmatrix}[\mathbf{V}_s, \mathbf{V}_n]^{\mathrm{T}} = \mathbf{T}_s\mathbf{P}_s^{\mathrm{T}} + \mathbf{E} = \mathbf{T}_s[\mathbf{P}_1^{\mathrm{T}}, \mathbf{P}_2^{\mathrm{T}}] + \mathbf{E}$$

$$\mathbf{T}_s = \mathbf{U}_s\Sigma_s \quad \mathbf{P}_s = \mathbf{V}_s \quad \mathbf{E} = \mathbf{U}_n\Sigma_n\mathbf{V}_n^{\mathrm{T}} \quad \mathbf{P}_s^{\mathrm{T}} = [\mathbf{P}_1^{\mathrm{T}}, \mathbf{P}_2^{\mathrm{T}}]$$

$$\mathbf{X}_{comb} = [\mathbf{X}_1, \mathbf{X}_2] = \mathbf{C}\cdot[\mathbf{S}_1^{\mathrm{T}}, \mathbf{S}_2^{\mathrm{T}}] + \mathbf{E}$$

$$\mathbf{C}\mathbf{S}_1^{\mathrm{T}} = \mathbf{T}_s\mathbf{P}_1^{\mathrm{T}} \qquad \mathbf{C}\mathbf{S}_2^{\mathrm{T}} = \mathbf{T}_s\mathbf{P}_2^{\mathrm{T}}$$

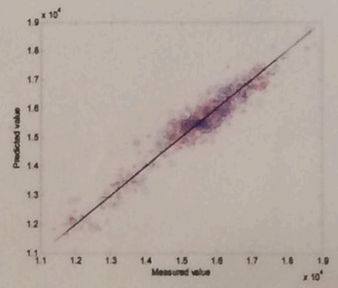
$$\mathbf{S}_1^{\mathrm{T}} = (\mathbf{C}^{\mathrm{T}}\mathbf{C})^{-1}\mathbf{C}^{\mathrm{T}}\mathbf{T}_s\mathbf{P}_1^{\mathrm{T}} = \mathbf{R}\mathbf{P}_1^{\mathrm{T}} \quad \mathbf{S}_2^{\mathrm{T}} = (\mathbf{C}^{\mathrm{T}}\mathbf{C})^{-1}\mathbf{C}^{\mathrm{T}}\mathbf{T}_s\mathbf{P}_2^{\mathrm{T}} = \mathbf{R}\mathbf{P}_2^{\mathrm{T}}$$

$$\mathbf{R} = (\mathbf{C}^{\mathrm{T}}\mathbf{C})^{-1}\mathbf{C}^{\mathrm{T}}\mathbf{T}_s$$

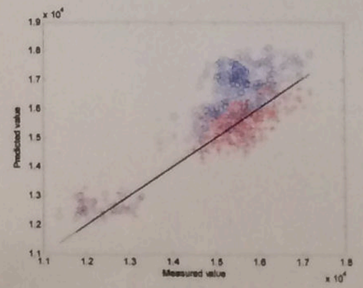
$$\mathbf{x}_{trans} = \mathbf{c}_{test}\mathbf{S}_1^{\mathrm{T}} + \mathbf{x}_{test} - \mathbf{c}_{test}\mathbf{S}_2^{\mathrm{T}} = \mathbf{x}_{test}(\mathbf{S}_2^{\mathrm{T}})^{+}\mathbf{S}_1^{\mathrm{T}} + \mathbf{x}_{test} - \mathbf{x}_{test}(\mathbf{S}_2^{\mathrm{T}})^{+}\mathbf{S}_2^{\mathrm{T}}$$

$$\mathbf{x}_{trans} = \mathbf{x}_{test}(\mathbf{P}_2^{\mathrm{T}})^{+}\mathbf{P}_1^{\mathrm{T}} + \mathbf{x}_{test} - \mathbf{x}_{test}(\mathbf{P}_2^{\mathrm{T}})^{+}\mathbf{P}_2^{\mathrm{T}}$$

The model of combustion heat



Calibration samples: +,
RMSEP: 332 J/g, ARPE: 1.7%
Test samples: o,
RMSEP: 358 J/g, ARPE: 1.9%



Online spectra : o
RMSEP= 1179 J/g, APRE= 6.5%
Transformed spectra: +,
RMSEP= 499 J/g, APRE=2.7%

Conclusion

- SST can eliminate the systematic difference between offline and online spectra of a same sample, and the prediction accuracy of online models is almost the same with offline models.
- It is proved that no more than twenty standard samples are needed for model transfer, so the actual workload to implement the model transfer can be done in one day, which insures the proposed method can be applied to any spot of cut tobacco process and tobacco threshing and re-drying process.