APPLICATION NOTE

NONDESTRUCTIVE INTERNAL QUALITY ASSESSMENT OF FRUITS

SUMMARY

Nondestructive methods utilizing visible/near-infrared (VIS/NIR) spectroscopy have been extensively applied in the assessment of fruit internal quality. One common example of such an application is estimating the soluble solids content (SSC) in apples (and/or other fruits). These methods have proven effective in providing rapid, accurate, and nondestructive analysis, making them suitable for real-time quality assessment in the fruit industry. A significant advantage of VIS/NIR spectroscopy is its ability to perform measurements without altering the fruit's integrity.

It is important to note that the performance of data-driven approaches is heavily influenced by both the amount of input data and the calibration methods employed. Consequently, this application note presents a simplified setup that demonstrates the capabilities of VIS/NIR spectroscopy, rather than serving as an accurate representation of the model performance typically observed in the fruit industry. The goal of this application note is to provide an example of using an Avantes AvaSpec-VRS2048CL-EVO spectrometer for collecting fast and accurate spectral data for estimating internal quality of fruits. For this purpose, the absorbance was calculated and plotted for the desired wavelength range (600nm - 1100nm) for different apple types. Then a regression-based model was employed to calculate SSC (°Brix) of apples.

In conclusion, this application note illustrates the capability of VIS/NIR spectroscopy for rapid, nondestructive fruit quality assessment, utilizing a simplified setup to estimate SSC in apples. Avantes spectrometers, known for their high sensitivity and fast data acquisition, further enhance the efficiency and accuracy of such analytical applications in the agricultural industry.

INTRODUCTION

Quality assessment of fruits is crucial in the agricultural sector, driven by the need to classify products based on their appearance, texture, flavor, and internal attributes. Apples are one of the most widely consumed fruits globally, known for their nutritional value and health benefits [1]. Evaluating the quality of apples—considering both external characteristics like color, size, and shape, as well as internal attributes such as firmness, acidity, and soluble solids content (SSC)—is a critical process in the fruit industry. This evaluation process is essential not only for ensuring consumer satisfaction but also for enhancing apple production practices and making informed decisions regarding sorting [2]. Advances in technology have equipped the fruit industry with both destructive and nondestructive methods for analyzing key quality parameters.

The exploration of nondestructive techniques, particularly visible/near-infrared spectroscopy (VIS/NIR), has been pivotal in modernizing quality assessment procedures for fruits. VIS/NIR spectroscopy provides a rapid, non-destructive means of evaluating fruit quality, offering several advantages such as minimizing fruit wastage, reducing labor costs, and optimizing processing efficiency [3], [4].
By focusing on the visible and near-infrared regions of the electromagnetic spectrum, VIS/NIR spectroscopy leverages the interaction of light with the fruit to provide detailed insights into both external and internal quality attributes. Furthermore, thanks to the integration of advanced chemometric models, precise nondestructive quantification of internal fruit quality has become possible. Multivariate statistical techniques, such as principal component analysis (PCA) and partial least squares (PLS) regression, are frequently used within these chemometric models to extract meaningful features from raw spectral data [3]. These models facilitate accurate predictions of fruit quality, enhancing the ability to monitor and control production standards throughout the supply chain [5].

One of the key indicators of apple quality is the soluble solids content (SSC), which directly correlates with sweetness and overall flavor profile. SSC is a crucial measure of apple maturity and plays a significant role in consumer appeal and purchasing decisions [2], [3], [4]. The SSC is most commonly expressed in terms of °Brix which represents the amount of sucrose in 100 grams of solution at a specific temperature [2]. As the demand for high-quality apples continues to rise, the ability to assess SSC with precision and efficiency becomes increasingly important. Nondestructive techniques like VIS/NIR spectroscopy, coupled with advanced chemometric models, offer a promising solution for accurately determining SSC and other key quality attributes without damaging the fruit. Thanks to their high sensitivity and speed, Avantes' spectrometers are widely used in the fruit sorting industry.

In this application note, an example of using an Avantes AvaSpec VRS2048CL-EVO spectrometer and chemometric modeling for sorting apples based on their SSC values is explained.

MATERIALS & METHODS

INSTRUMENTATION

Spectrometer:

Specification	Description
AvaSpec	AvaSpec-VRS2048CL-EVO, VARIUS™ fiber-optic spectrometer, 75mm AvaBench, 2048-pixel CMOS detector 14 x 200 µm, USB powered, high-speed USB 2.0 and ETH interface.
Grating	300 Lines/mm with 1 µm Blaze
Range	600 nm – 1100 nm
Slit	100 µm

Accessories:

Type	Description
*ATT-DA	Direct-attach fiber-optic attenuator, 0-100%, SMA-connector
**COL-UV/VIS-25	Collimating lens

* An attenuator was attached to the spectrometer to prevent detector saturation when measuring the bright reference.

** A collimating lens was attached to the optical fiber end in order to maximize light input to the spectrometer when placing apples in front of the light source.

Light Source:

Type	Power	Voltage	Color temperature
Halogen bulb	50 W	220 V_{AC}	2700 K

Software:

Type	Version number
AvaSoft	8.16.1
AvaSpecX64-DLL	9.14.0.0
Python	3.12.5

Optical fiber:

Type	Diameter	Length	Shielding
FC-UVIR600-2-BX	600 µm	2 m	Stainless Steel

SAMPLES

Apple Type	Quantity
A	10
B	10

DATA ACQUISITION

At the beginning of each measurement session, both a dark and bright reference were captured for absorbance (transmittance) calculations. The dark reference was recorded with the spectrometer's attenuator closed (fully obstructing the light path), while the bright reference was taken with the attenuator set to allow the maximum amount of light into the spectrometer without saturating the detector, using a 1.5ms integration time. Afterward, spectral data were collected by placing each apple between the halogen bulb and the collimating lens attached to the optical fiber. Since the apple is an opaque object, the attenuator was fully opened, and the collimating lens was positioned at approximately -45° angle to the axis of the halogen bulb (Figure 1) to optimize the light captured on the other side.

For each sample, several scans were captured while it was moving on a conveyor belt. This was done to include the maximum variation in the collected spectral data which is the input for the chemometric model.

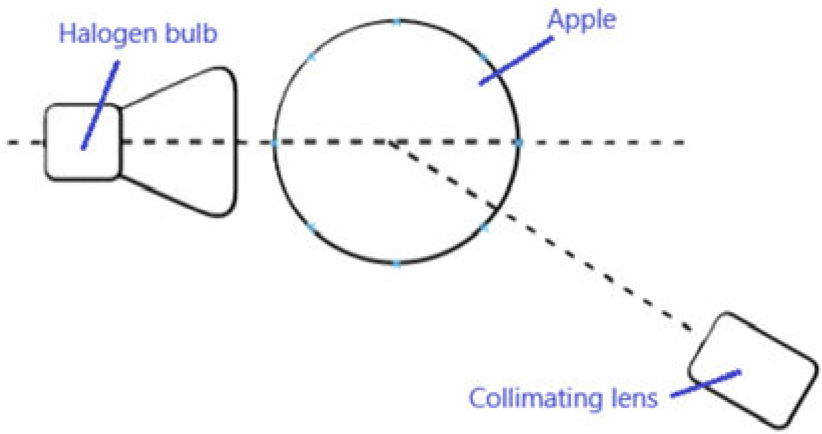

FIGURE 1: Schematic top view of the measurement setup

ACQUISITION PARAMETERS:

Parameter	Value
Integration time	1,5 ms
*Smoothing pixels	3
**Averaging	1

* This value for smoothing pixels is to be used in combination with a 100µm slit. For other slit/fiber sizes different values for smoothing pixels may apply.

**Averaging was set to 1 so that the maximum number of scans were captured when apples are put on the conveyor belt at fruit-sorting factories. For such setup, utilizing a trigger cable and an obstacle sensor is necessary.

PRE-PROCESSING

Data pre-processing is crucial in eliminating noise and improving the accuracy of predictions. The spectral data acquired during the tests underwent preprocessing steps (in Python) which included Asymmetric Least Squares (ALS) baseline correction, smoothing via a Savitzky–Golay filter, and normalizing to rescale the spectral data between 0 and 1.

CHEMOMETRIC MODEL

Chemometric models, particularly those utilizing PLS regression, have shown effectiveness in the nondestructive prediction of SSC in apples using VIS/NIR spectroscopy [3], [6]. PLS regression was used to estimate SSC values given the absorbance data as input. The reference SSC values which were used for training the model, were measured using a refractometer. 4 out of 10 samples per apple type were used for SSC measurements. As refractometry is a destructive method, those 4 samples were excluded from further data acquisition session. The data captured from the other 6 samples were used to train the chemometric model.

REFERENCE SSC VALUES (°BRIX):

	Apple Type A	Apple Type B
Sample #1	14,6 °Brix	11,4 °Brix
Sample #2	13,4 °Brix	11,8 °Brix
Sample #3	14 °Brix	12,2 °Brix
Sample #4	13,6 °Brix	12,4 °Brix

RESULTS

SPECTRAL DATA

The absorbance curves from each sample are plotted within the desired wavelength range (600nm - 1100nm) for each apple type in Figure 2. Because for each sample multiple scans were captured, each curve is a mean value with a shadowed area depicting the standard deviation of all the scans. As the spectral data were normalized in the preprocessing, absorbance values on the y-axis are between 0 and 1.

The mean absorbance spectra were calculated for each apple type based on the data shown in Figure 2 and then plotted within the desired wavelength range in Figure 3. As can be seen in Figure 3, absorbance curves had peaks at about 675 nm, 760nm, and 970 nm. Furthermore, the ratio between the 675nm peak and 970nm peak seems to differ, looking at the mean absorbance spectra of apple type-A versus apple type-B.

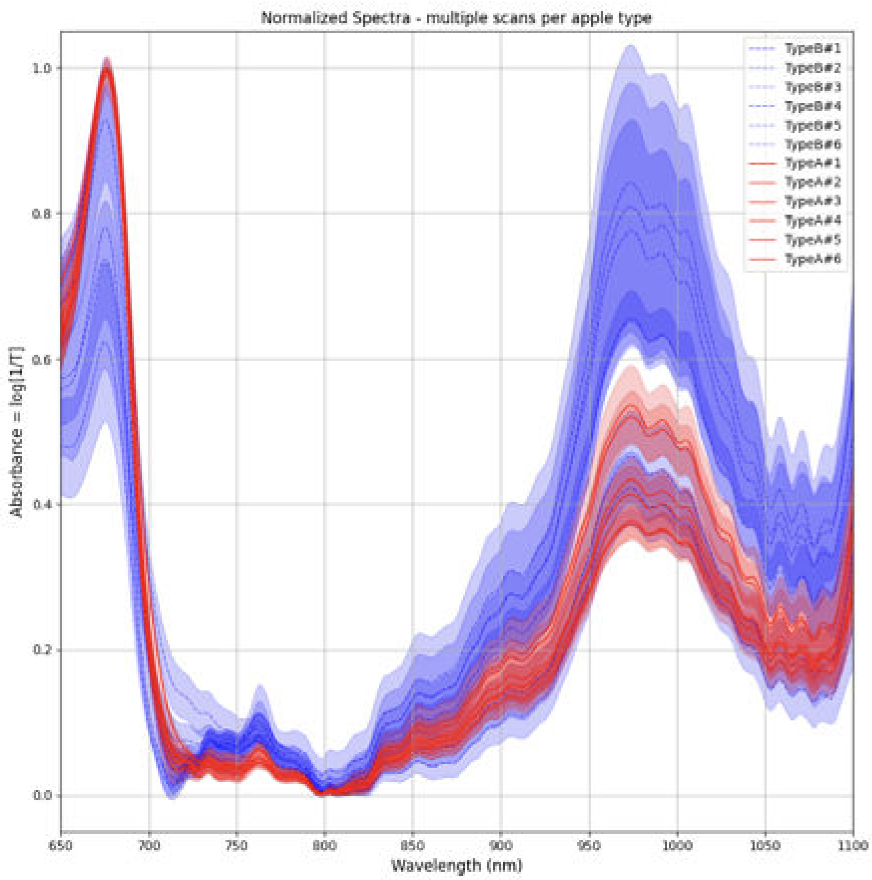

FIGURE 2: Preprocessed absorbance spectra - multiple scans per sample.

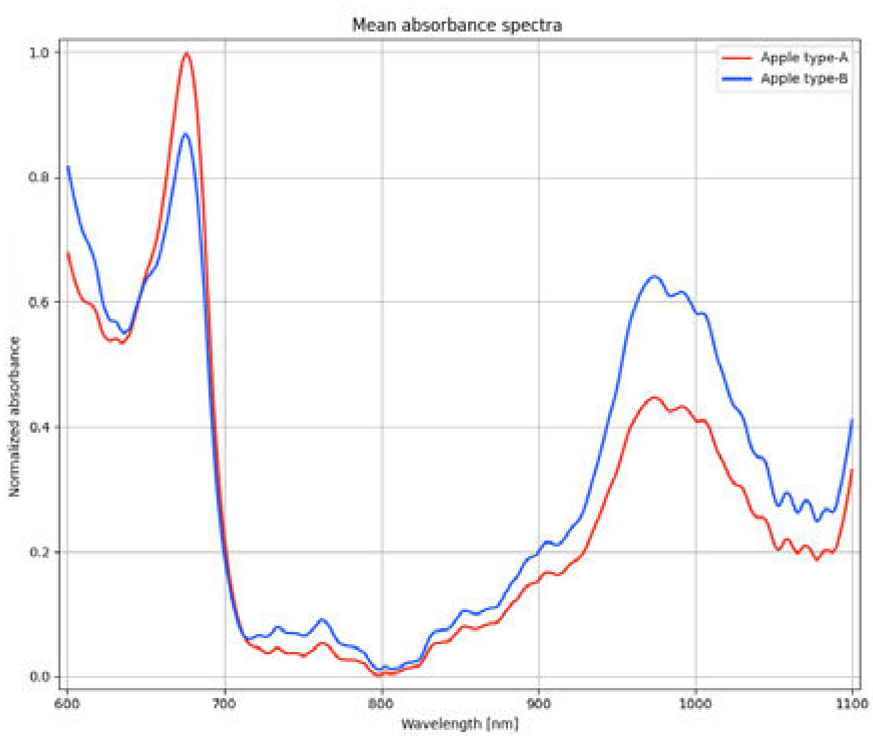

FIGURE 3: Mean absorbance of spectral data captured per apple type.

CALCULATED SSC VALUES USING PLS REGRESSION

After preprocessing the spectral data (inputs for the model), a 5-Fold Cross-Validation was used to split the data to train and test sets. The validation was repeated 3 times and the average of R^2 scores were calculated as a measure of accuracy. The estimated SSC values are plotted versus the reference SSC values in Figure 4.

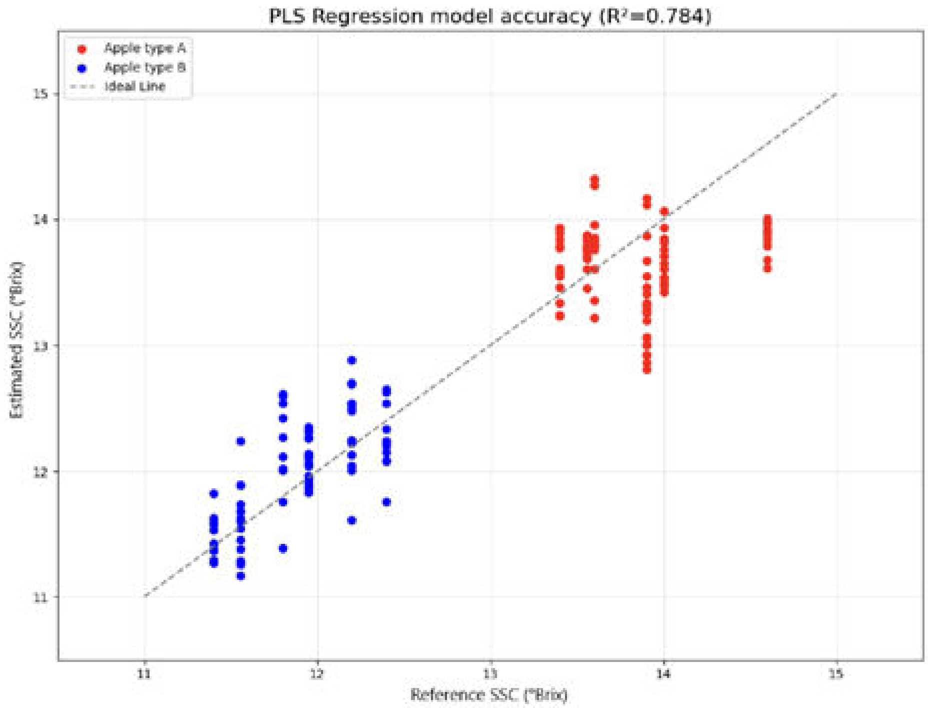

FIGURE 4: Estimated SSC values plotted versus the reference SSC values

DISCUSSION

As shown in Figure 3, absorption peaks are observed around 675 nm, 760 nm, and 970 nm. These peaks are crucial for assessing apple quality, as they may correspond to chlorophyll, C-H, and O-H absorption bands, which are associated with the internal composition, including minerals and water content [5]. Although the absorbance data reveals significant peaks at specific wavelengths, the relationship between these features and the internal content is not straightforward, as the data contains redundancy. Therefore, applying data-driven approaches requires feature extraction to reduce data dimensionality, which helps create a more robust predictive model that is less sensitive to unrelated variations in the absorbance spectra.

Furthermore, the performance of the PLS regression model was evaluated by calculating the R^2 scores (average 0.784). As the fruit orientation during spectrum collection, preprocessing of spectral data and the number of samples used for training the model greatly affect the performance, optimization of these parameters ensures improved model accuracy [1], [5].

As a data-driven approach, chemometric modeling requires a large dataset to more effectively capture the variability in factors such as sample shape, SSC, and placement relative to the light source. Therefore, the accuracy of the model can be improved by increasing the number of samples in the future. Additionally, implementing temperature compensation methods can increase the model's adaptability to varying conditions [5].

Beyond sample size and temperature, factors like fruit orientation during spectral measurement, and effective wavelength selection play significant roles in ensuring accurate SSC prediction. For instance, certain orientations and taking more averages can improve the signal-to-noise ratio in collected spectra. To further enhance the accuracy and robustness of internal quality assessments in fruits, it is recommended to use localized calibration approaches. These approaches customize the calibration subset to match the specific characteristics of the sample, thereby improving robustness through greater sample homogeneity [4]. Additionally, variable selection techniques, such as competitive adaptive reweighted sampling (CARS) and successive projections algorithm (SPA), are essential for refining PLS models [7]. Finally, the application of advanced data processing techniques, including machine learning, will provide faster and more accurate results [2].

CONCLUSION

ity of spectral analysis in assessing the internal quality of fruits, specifically apples. Spectral data were first captured using an Avantes AvaSpec-VRS2048CL-EVO spectrometer, and then processed through several preprocessing steps, including ALS baseline correction, Savitzky–Golay filtering, and normalization, to prepare the data for chemometric modeling. A PLS model was then employed to estimate the SSC (°Brix) of apples, achieving an average R^2 score of 0.784. This approach represents a simplified version of the data-driven methods used in the fruit sorting industry. The ongoing advancement and application of VIS/NIR spectroscopy holds significant potential for enhancing the efficiency and sustainability of fruit grading and quality assessment in agriculture. These developments help to overcome current challenges while enabling more precise quality control that aligns with the evolving demands of the industry.

Avantes spectrometers are engineered to meet the demands of high-speed, high-accuracy applications like fruit sorting and internal quality control. With exceptional sensitivity, fast integration times, and precise timing capabilities, our instruments enable rapid data acquisition—even in dynamic, real-time environments such as conveyor belt systems.

In addition, our spectrometers offer flexible I/O options and seamless integration with external systems, making them ideal for automation in industrial settings. This combination of speed, precision, and flexibility makes Avantes spectrometers a trusted choice for advancing nondestructive quality assessment in the agricultural industry.

For more information, advice or guidance, visit our website or contact us. We are happy to help!

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