Prediction of apples' internal transmittance - utopia or a reality ?

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Abstract

The aim of this research is to verify the possibility of using the STL method (Seeing Through Layers)[1] for classification of apples according to their inner quality by excluding the disturbing effect of apples' peel (its colour and thickness). The models created by STL method for prediction of the apples' inner transmittance have been analyzed in order to achieve the aim of the research.

Key words: *seeing through layers, stl, apples, internal transmittance*

Introduction

This publication describes the method "Seeing Through Layers" (STL) for assessment of apples by internal and external quality. After obtaining the NIR - data set of apples, each apple has been evaluated organoleptically. Models for virtual peeling have been created and tested. The accuracy of V-models was analyzed. Apples were virtually peeled for pr5ooving the authentication of the method for predicting the inner transmittance of the apples. Taking into consideration the fact that the method accurately predicts internal transmittance, it is logical conclude that there is higher accuracy of sorting virtually peeled apples than the accuracy of sorting not peeled apples.

Experimental fruit lots (in consumer ripeness stage) were purchased on the fruit market. The fruits were of various appearance and fruit flesh structure and color. A part of them had external and internal defects. Before marketing the fruits had been stored in fruit stores at temperature 0°C and relative humidity 90-92%. Until the NIR measurement they were stored at the same conditions in an experimental refrigerated room. Six varieties were included in this set of samples: Red Delicious – imported from the USA and grown in Bulgaria; Golden Delicious, Idared, Granny Smith – grown in Bulgaria, as well as two unidentified varieties imported from Poland and Macedonia. Data of that sample set were statistically analyzed and the results are reported in this article.

Overall methodology

The basic hypothesis of the STL-method is that fruit and vegetables are approximated to objects with a differentiated three layers structure "skin - flesh - skin" [1,3]. The transmittance of such a structure measured by geometry of direct transmissions (Figure 2) is approximated as $T = T_A T_O T_B$ from where:

$$T_O = T/(T_A T_B)$$

where: T is the overall transmittance of the object measured in the direction A→B, and T_A, T_B are the skin transmittance values in the parts A and B. T_A and T_B can not be measured directly because the parts A and B have one accessible side only, but fruit and vegetables consist of scattering biological material, therefore the spectral transmittance T_A and T_B of the skin and adjacent layers could be measured by means of the respective diffuse reflectance R_A and R_B.

Material and methods

An automatic spectrometric system of BENTHAM Instruments Ltd., UK (www.bentham.co.uk) has been used and a new accessory (camera) that was developed by Food Research and Development

[1] *Seeing Through Layers (STL) method, V-method – a method for virtual peeling of fruits and vegetables [1-4].*

Institute - Plovdiv (www.canri.org)[2] has been attached to the spectrometric system - Figure 1. It allows measuring both the transmittance and reflectance spectra in VIS/NIR regions of various objects (apples, peaches, oranges, potatoes etc.) applying simultaneously two types of geometry: $T_{0/180}$ and $R_{0/45}$.

Figure 1 NIR measurement of an apple with the accessory using the method "Seeing Through Layers".

The camera body is opaque, so the experiment is carried out at an illumination sufficient for the operator. Two variants were made: Option 1 – for smaller objects with diameter up to 50 mm, and Option 2 – for objects with diameter up to 100 mm. In both cases the monochromator optical ray enters the optical system in order to compensate the divergence of the light. Then the optical ray is reflected by a mirror and then goes to the sample - holder. There are detectors for measuring the reflection of the ray situated on the sample - holder. There is a diaphragm in front of the mirror in order to restrict the multiple reflecting of the ray.

The measurement is done for on whole intact and for peeled fruits. The object is fixed in two different positions towards the incident beam direction as its initial position is followed by a rotation at 180°. In this way of each apple fruit 8 spectra are obtained within the range 600 – 1100 nm, 4 of them in transmittance and another 4 in reflectance. Outside the measurement area remain the apples stem end pit and the blossom pit.

Procedure for obtaining NIR - data:

1st stage. The following spectra data of each apple have been measured (Figure 2):

- The reflection by side A (I_{RA});
- The transmittance from A to B ($I_{T(A\rightarrow B)}$);
- The reflection by side B (I_{RB});
- The transmittance from B to A ($I_{T(B\rightarrow A)}$).

[2] *The data has been obtained by the author while accomplishing „ Non-Destructive NIR Technology For Fruits And Vegetables Internal Quality Assessment Eliminating The Skin Disturbing Effect" (NIQAT) project that was a part of the V framework program coordinated by Dr. Raina Chalucova.*

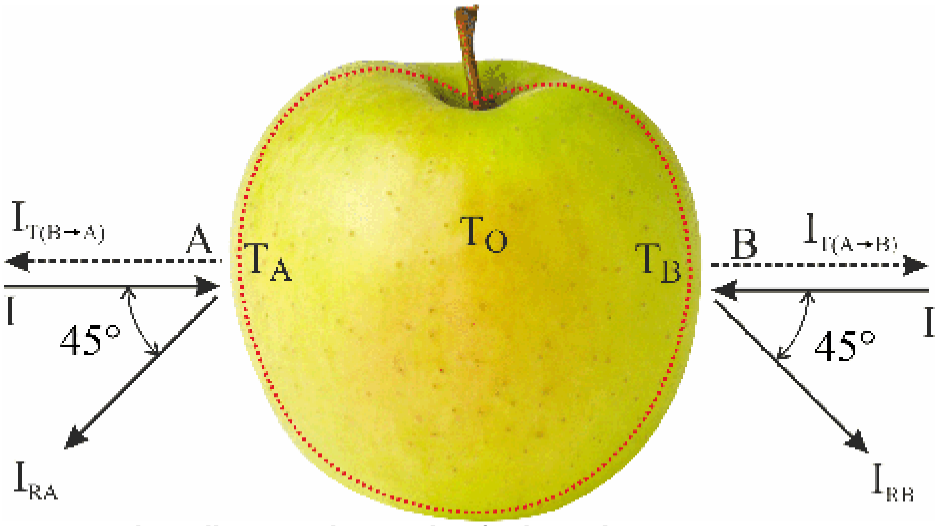

Figure 2 Scheme illustrating the procedure for the nondestructive measurement of real product flesh transmittance T_O

2nd stage. The rind of the fruit has been mechanically (really) removed with a manual instrument.
The average thickness of the peeled layer is approximately 1.3 mm.

3rd stage. The transmittance of the peeled fruit has been measured:
- From A to B;
- From B to A.

4th stage. The peeled fruit has been assessed by its organoleptic features and categorized to one of the groups - C1, C2, C3 and C4.

At the end of the procedure there was already data that was used to create three models for virtual peeling (M6D6Ro, M61 and M6D6Ro2) and one model based only upon the transmittance of the apples (M60T). The methodology has been described in details in the patent of Prof. Krivoshiev [2, 3], and the results of applying the method STL for potatoes are described in [1, 4, 5].

Results and Discussion

Generation of mathematical models for apples

Statistical analysis was made using the software GRAM02, developed in CANRI, and Unscrambler 6.1 version of CAMO, Norway. In its essence the computational procedure consists of determination of coefficients of MLR models with pre-selected architecture for each wavelength from 610 nm to 1090 nm with a gap 10 nm (i.e. totally 49 wavelengths). Three models which combine both transmittance and reflectance (M6D6Ro, M61 and M6D6Ro2) were tried as well as the model M60T based on transmittance only.

The analysis showed that:

- Within the range 610-710 nm the models based on virtual peeling the fruits skin ensure higher correlation and lower error values than the ones obtained by the model based on transmittance only;
- Within both ranges – 710 to 940 nm and 1040 to 1090 nm with the application of the models it is achieved correlation coefficient near to or higher than 0.9, i.e. the fruits internal optical density is rather accurately predicted;
- Of the three experimentally tested V-models the best results gives the model M6D6Ro, although both the correlation and error values of the other two models (M61 and M6D6Ro2) are very close.

In Figure 3 are shown the values of correlation coefficient calculated by means of the four mathematical models while Figure 4 presents the mean square root error in relation to the reference quality variation range.

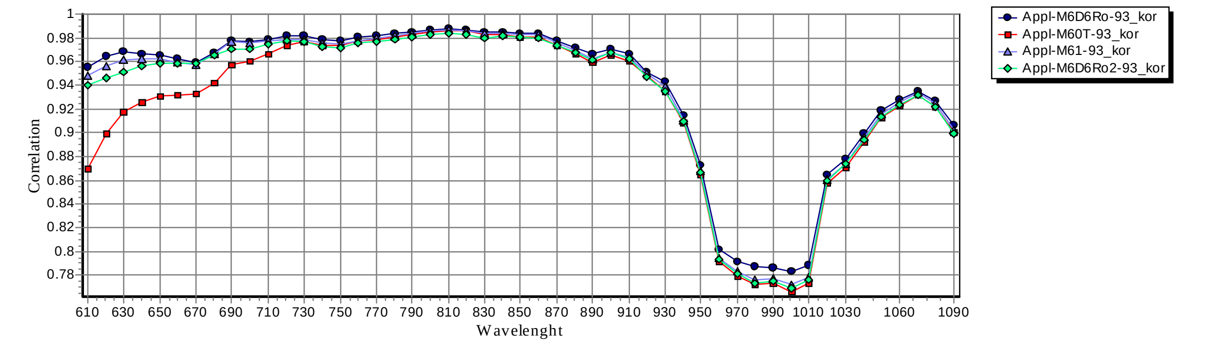

Figure 3 Correlation coefficient obtained with the four models on a set of 93 apple fruits

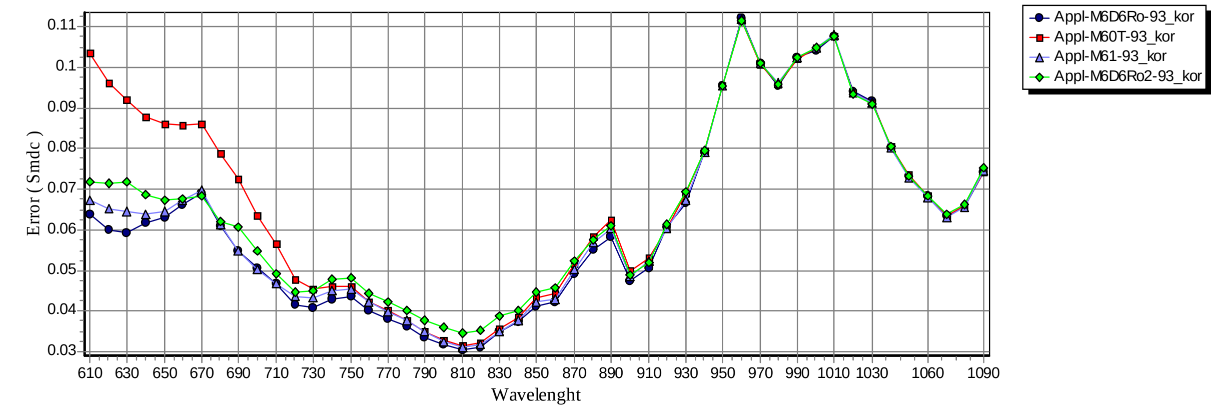

Figure 4 Standard Error of Calibration of apples data (related to the reference quantity variation range)

The spectra data were divided into 2 sets – a calibration (69 samples of apples) and validation (24 samples of apples) - total 93 samples of apples.

The validation set comprised spectra randomly selected but representing all 6 varieties tested as well as various fruit flesh status. Rather than carrying out an assessment of each model at each wavelength, 12 wavelengths had been selected as those most likely to be useful for classification of apples on the basis of their internal structure: 610, 630, 650, 670, 680, 690, 700, 710, 800, 920, 930, 1080 nm. Models were developed for each of the wavelengths following the formulae written by prof. Krivoshiev [2, 3].

Predictor formula 1: M60T
Predictor formula 2: M61
Predictor formula 3: M6D6Ro2 with scattering power (Sp) = 1
Predictor formula 4: M6D6Ro2 with Sp = 0.5
Predictor formula 5: M6D6Ro2 with Sp = 2

All calculations were made using macros developed with Mini Tab V13. The performance of each model was assessed by means of the residual standard deviations for both calibration and validation sets. The results for each of the variations assessed for the calibration set are given in Table 1 and those for the validation set in Table 2.

Generally one would expect that adding predictors would improve the calibration error variance. This is seen in Table 1 when one compares the results from using predictor formula 2 with those from using predictor formula 1. However, both predictor formulae 2 and 3 also benefit from reflectance data as a part of the assessment of the performance of the STL-method and so an assessment of the effect of the additional data is required.

It can be seen that at low wavelengths, the addition of reflectance data did improve the fit substantially (Table 2) when used in predictor formula 2. However at higher wavelengths there was less of an improvement. When predictor formula 3 was assessed in the same way, it can be seen that the residual variances were consistently higher than for predictor formula 2 in both the calibration and validation data sets but were lower than those for predictor formula 1 for shorter wavelengths, particularly for the validation set.

The effect of varying Sp values was assessed using Sp = 0.5, 1 and 2. When assessing Sp = 0.5, however, the program was found to generate an error and so further work with this value was aborted. However, when a value of 2.0 was tried, the columns for Sp = 2 were almost identical for those using Sp = 1. Therefore it is conjectured that the exact choice of Sp is not important.

Table 1 Model residual standard deviations in calibration data sets

Wavelength (nm)	Predictor formula 1	Predictor formula 2	Predictor formula 3	Predictor formula 4	Predictor formula 5
610	0.373	0.255	0.337	-[1]	0.338
630	0.304	0.229	0.289	-	0.289
650	0.279	0.219	0.275	-	0.275
670	0.309	0.253	0.312	-	0.313
680	0.291	0.232	0.298	-	0.299
690	0.231	0.185	0.248	-	0.247
700	0.193	0.169	0.205	-	0.205
710	0.194	0.157	0.205	-	0.205
800	0.090	0.091	0.137	-	0.137
920	0.173	0.173	0.175	-	0.175
930	0.206	0.203	0.211	-	0.211
1080	0.190	0.191	0.192	-	0.192

[1]*Error in calculations, further work aborted*

Table 2 Model residual standard deviations in validation data sets

Wavelength (nm)	Predictor formula 1	Predictor formula 2	Predictor formula 3	Predictor formula 4	Predictor formula 5
610	0.446	0.256	0.384	-[1]	0.385
630	0.395	0.246	0.356	-	0.357
650	0.396	0.277	0.375	-	0.376
670	0.378	0.301	0.360	-	0.362
680	0.361	0.264	0.344	-	0.346
690	0.259	0.169	0.230	-	0.230
700	0.257	0.170	0.251	-	0.250
710	0.222	0.163	0.227	-	0.226
800	0.112	0.111	0.152	-	0.152
920	0.225	0.228	0.250	-	0.250
930	0.270	0.258	0.277	-	0.277
1080	0.258	0.253	0.270	-	0.270

[1]*Error in calculations, further work aborted*

It is clear that although there were differences between the residual standard deviations obtained for predictor formulae 1, 2 and 3, in some cases these differences were small. To test their statistical significance, therefore, Bartlett's test was used. The differences in residual variance between predictor formulae 1, 2, and 3 were not significant at any wavelength other than 610 nm ($p = 0.034$), perhaps because the sample sizes of 24 were not sufficiently large for discrimination. Nevertheless, the predictor formula 2 gave the lowest standard deviation at all wavelengths except for 800, 920 and 1080 nm (and in these cases gave very close or identical results to predictor formula 1). As a result, it may be concluded that the STL-method gives benefit over the use of transmission data when attempting to collect spectra representing the flesh only from intact apples. However, this improvement is more marked for predictor formula 2 with the results obtained for predictor formula 3 being poorer, irrespective of the Sp value used. Even, in this case, however, the validation set results were still better than those obtained using transmission data only for 610, 630, 650, 670, 680, 690 and 700 nm and so this approach may have application where only these wavelengths are used.

Although the differences between the various predictor formulae were only significant at one wavelength, the results obtained using the STL-method as developed for predictor formulae 2 and 3 were generally superior to those obtained when using transmission values alone from the intact fruit. Of these two models, predictor formula 2 was found to give the best results overall. It may be concluded, therefore, that the STL-method is beneficial for the spectroscopic assessment of the internal structure of intact apples.

As an evidence of the applicability of the STL-method Figures 5 and 6 are enclosed. They show that practically there is no difference between virtual and physical peeling of the apples.

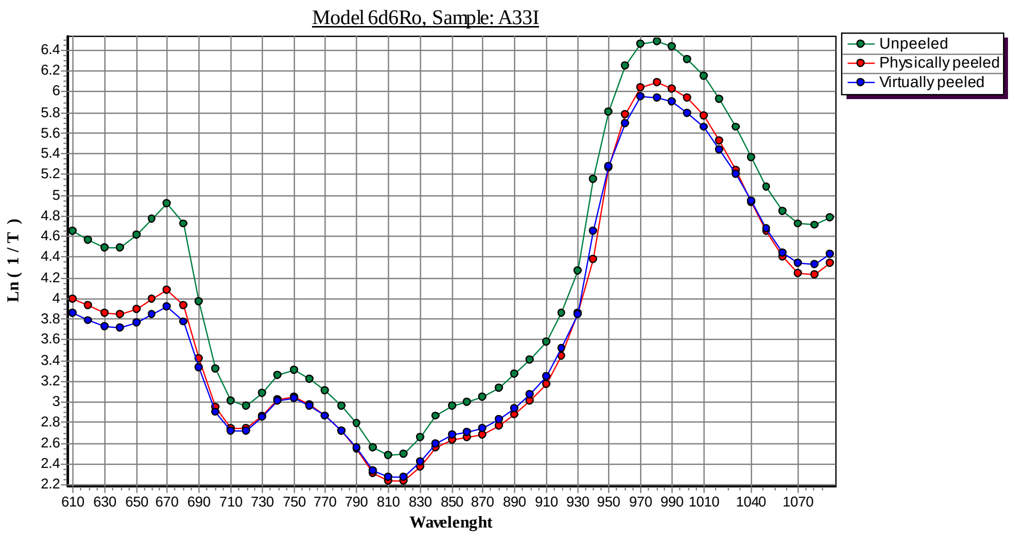

Figure 5 Transmittance spectra of unpeeled, physically, and virtually peeled apple fruit – variety Idared

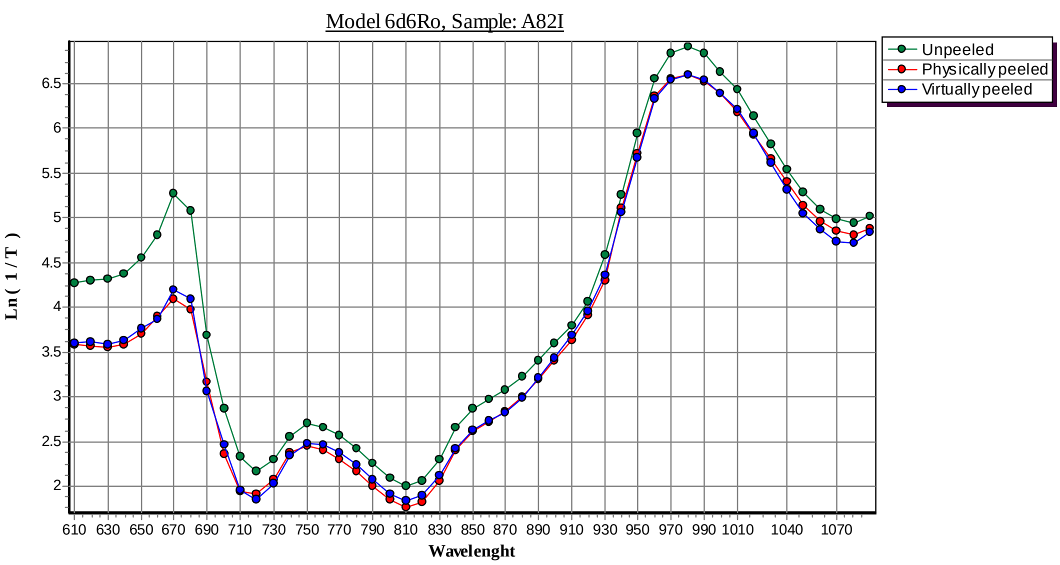

Figure 6 Transmittance spectra of unpeeled, physically, and virtually peeled apple fruit – variety Golden Delicious

Conclusion

Since long time it has been known that the fruits transmittance in the spectral band around 670 nm is related to chlorophyll content and, therefore, brings information about their maturity degree. Recently, in the frame of the Project ASTEQ, supported by the Commission, it has been achieved good classification of apples based on data of measurement in interactance mode within the spectral range 630-700 nm. Now we have established that in the same range the STL method ensures a better prediction of internal transmittance than it is achieved by measuring of only transmittance, respectively interactance. It follows then, that the method has potential of increasing the accuracy of apple classification by degree of maturity. An important feature of the models we have derived is that they are universal in terms of the peculiarities of fruits of 6 different apple varieties. This is an important advantage of the STL method to be further confirmed by other researches.

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