Visible/Near-infrared Spectroscopy and Spectral Scattering for Automatic Grading of Apples for Firmness and Soluble Solids Content

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INTRODUCTION

Apple is an important agricultural commodity in the global fresh produce market. Today consumers are demanding better quality and more consistent apples in taste and texture. Hence, appropriate quality control and inspection procedures must be implemented to assure the eating quality of individual apples .

Currently, apples are sorted, using machine vision systems, mainly by color, shape, size or weight. However, a study by Harker et al. (2003) found that about 70% U.S. consumers considered the eating quality to be the most important factor in purchasing apples. Texture, taste, and flavor define the eating quality of apples, and among them, texture is considered the predominant quality attribute by U.S. consumers.

Hence, the demand for high quality fruit calls for reliable and rapid sensing technologies for nondestructive measurement and sorting of apples based on multiple quality attributes. Among many nondestructive sensing techniques that have been researched or developed, visible and near-infrared spectroscopy and spectral scattering show great potential for sorting and grading apples for internal quality, including firmness and soluble solids content (SSC), two important quality attributes for apples.

OBJECTIVE

The objective of this research was to assess visible and shortwave near-infrared (Vis-SWNIR) spectroscopy and spectral scattering techniques for sorting apples into two quality grades (i.e., premium and regular) by firmness, SSC, or their combination using a simple statistical classifier. For testing the robustness of the classification models, a total of 8,491 apples from three varieties (i.e., 'Jonagold', 'Golden Delicious', and 'Delicious') harvested in 2009, 2010 and 2011 were used in this study.

INSTRUMENT SETUP & EXTRACTED FEATURES

Two nondestructive sensing techniques for measuring the firmness and SSC of apple fruit were used in this study:

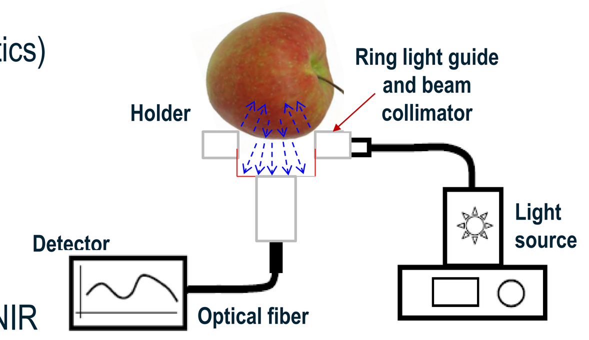
1. Visible and shortwave near-infrared (Vis-SWNIR) spectroscopy

Hardware:

- A miniature Vis-SWNIR spectrometer (S400, Ocean Optics) operating in the spectral range of 460–1,100 nm in an interactance mode
- Quartz tungsten halogen lamp (Oriel Instruments)

Extracted Features & Preprocessing:

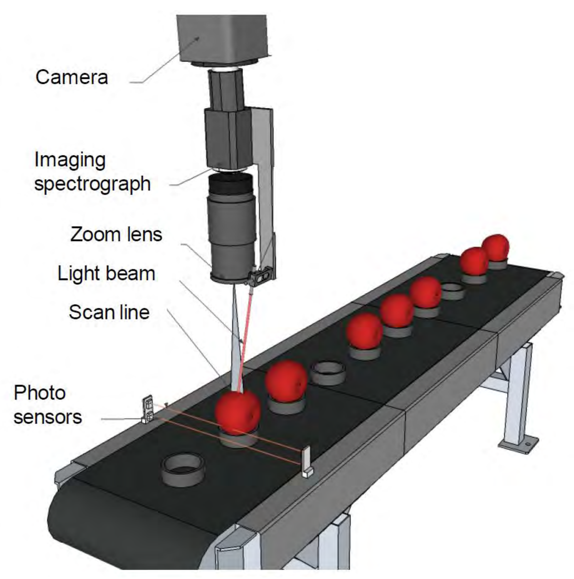
- After dark and white reference corrections, the Vis-SWNIR data was preprocessed by performing first derivatives and 641 data points were obtained for further analysis.



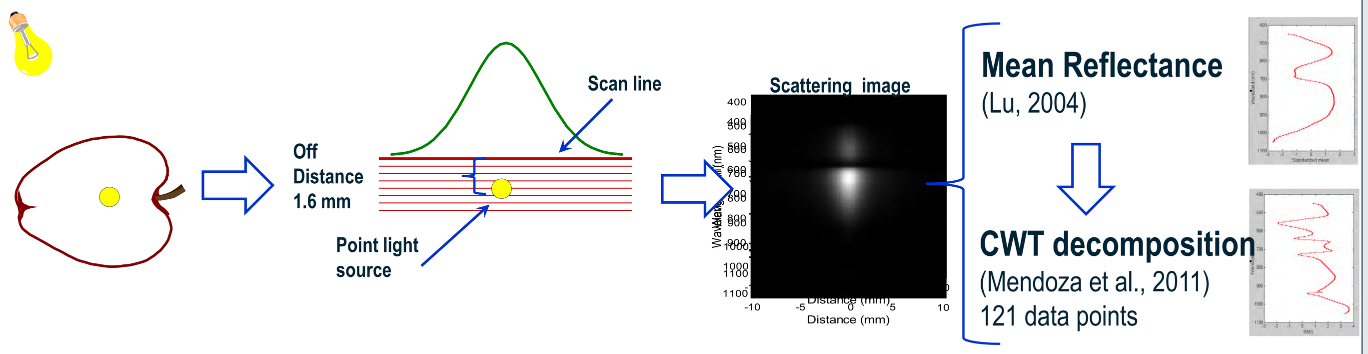
2. Online Hyperspectral Scattering System

Hardware:

- A prototype system using a back-illuminated electron-multiplying CCD camera
- Imaging spectrograph (ImSpector V10E) operating in the spectral range of 450 – 1,050 nm
- Quartz tungsten halogen lamp with a point light beam of 1.5 mm in size
- Integration time of 120 ms



Imaging & Extracted Features:



QUALITY GRADING CRITERIA

The quality grades for firmness (N) and SSC (°Brix) were defined as follows:

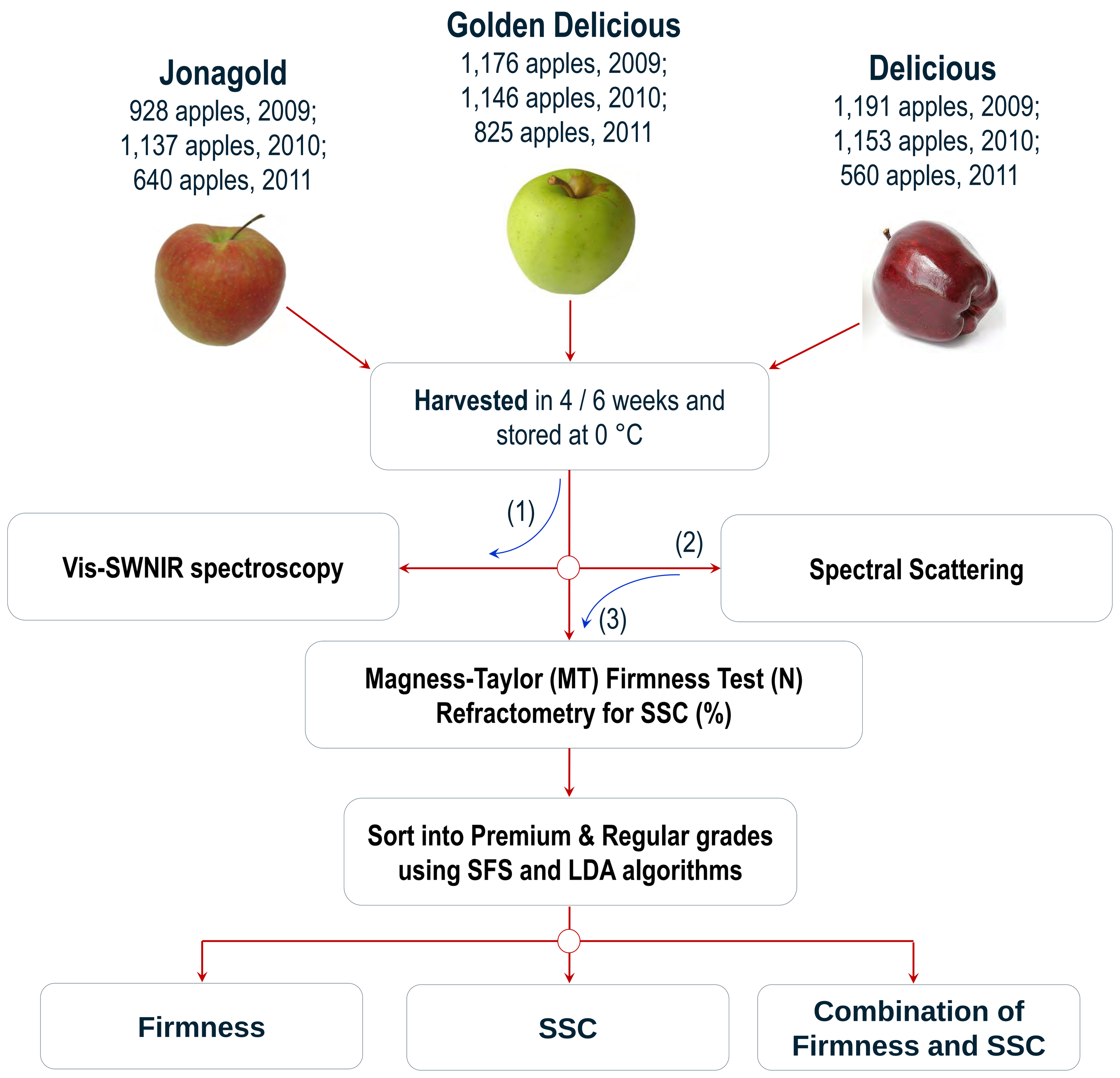
Table 1

Cultivar	Premium grade	Regular grade
Jonagold	≥ 60 N & ≥ 12 °Brix	Firm/non-sweet,
Golden Delicious	≥ 55 N & ≥ 12 °Brix	Soft/sweet,
Delicious	≥ 60 N & ≥ 11 °Brix	Soft/non-sweet

EXPERIMENTAL PROCEDURE

'Jonagold' (JG), 'Golden Delicious' (GD) and 'Delicious' (D) apples were harvested in 2009, 2010 and 2011 from an orchard of Michigan State University's Clarksville Horticultural Experiment Station in Clarksville, MI.

After the data acquisition, the extracted spectral features were independently tested and compared for sorting JG, GD and D apples into two quality grades based on: 1) firmness, 2) SSC, and 3) using both firmness and SSC together. Sequential Forward Selection (SFS) method and Linear Discriminant Analysis (LDA) were used for analysis. The overall procedure is depicted below.



RESULTS

CLASSIFICATION BY Magness-Taylor (MT) FIRMNESS

Table 2 summarizes the average number of variables, overall performance and standard deviation for the validation sets using MT firmness as a classification criterion for JG, GD and D apples harvested in the three seasons.

TABLE 2	JONAGOLD		GOLDEN DELICIOUS		DELICIOUS	
	No. Variables	Accuracy (± std.) (%)	No. Variables	Accuracy (± std.) (%)	No. Variables	Accuracy (± std.) (%)
Vis-SWNIRS						
2009	17	**97.6** (0.1) [a]	19	**89.6** (0.9) [a]	19	**89.6** (0.9) [a]
2010	19	**90.8** (0.7) [b]	19	**90.5** (1.5) [a]	18	**87.6** (1.3) [b]
2011	18	**87.3** (0.6) [c]	18	**92.0** (0.4) [b]	-	-
Spectral Scattering						
2009	13	**98.2** (0.3) [e]	19	**90.1** (1.0) [a]	18	**86.8** (2.1) [b]
2010	18	**89.1** (0.6) [f]	17	**88.9** (1.1) [e]	18	**85.0** (1.4) [e]
2011	16	**93.2** (0.3) [g]	17	**91.4** (0.2) [f]	-	-

[a, b, c, d, e, f, g] Values in the same columns with different letters are statistically different ($p<0.05$).

CLASSIFICATION BY SOLUBLE SOLIDS CONTENT (SSC)

Table 3 shows the results for sorting 'Premium' from 'Regular' grade apples by SSC. Overall the SSC sorting results were lower than those sorted by firmness.

TABLE 3	JONAGOLD		GOLDEN DELICIOUS		DELICIOUS	
	No. [1] Variables	Accuracy (± std.) (%)	No. [1] Variables	Accuracy (± std.) (%)	No. [1] Variables	Accuracy (± std.) (%)
Vis-SWNIRS[2]						
2009	19	**82.0** (1.3) [a]		-	18	**77.1** (1.1) [a]
2010	20	**88.7** (0.6) [b]	18	**86.0** (1.6) [a]	20	**92.3** (0.7) [b]
2011	18	**83.6** (0.9) [c]	18	**86.0** (0.4) [a]	18	**83.9** (1.4) [c]
Spectral Scattering[3]						
2009	17	**81.1** (1.4) [a]	-	-	15	**77.0** (2.0) [a]
2010	13	**86.0** (1.4) [e]	17	**79.3** (0.6) [e]	17	**91.7** (1.0) [b]
2011	8	**62.0** (1.0) [f]	13	**64.9** (1.3) [d]	16	**81.4** (0.4) [g]

CLASSIFICATION BY MT FIRMNESS AND SOLUBLE SOLIDS CONTENT

Table 4 summarizes the overall performance for the validation sets using both firmness and SSC as the classification criterion. In general, the classification accuracies were lower than those sorted by MT firmness alone, and in a few cases were higher than those sorted by SSC.

TABLE 4	JONAGOLD		GOLDEN DELICIOUS		DELICIOUS	
	No. [1] Variables	Accuracy (± std.) (%)	No. [1] Variables	Accuracy (± std.) (%)	No. [1] Variables	Accuracy (± std.) (%)
Vis-SWNIRS[2]						
2009	26	**89.2** (1.6) [a]	18	**85.5** (1.2) [a]	20	**78.7** (1.8) [a]
2010	17	**80.9** (1.5) [b]	19	**82.1** (1.2) [b]	19	**78.4** (1.3) [a]
2011	19	**85.5** (1.9) [c]	18	**90.1** (1.0) [c]	15	**75.7** (0.9) [b]
Spectral Scattering[3]						
2009	13	**91.5** (0.7) [d]	17	**88.6** (1.7) [d]	18	**69.7** (2.1) [c]
2010	14	**78.4** (1.3) [e]	15	**76.5** (2.4) [e]	17	**74.5** (1.9) [d]
2011	17	**74.7** (2.6) [f]	15	**86.5** (0.6) [a]	13	**75.9** (0.3) [b]

[a, b, c, d, e, f, g] Values in the same columns with different letters are statistically different ($p<0.05$).

CONCLUSIONS

- Good sorting results for firmness (ranging between 77.9-98.2%) and moderate sorting results for SSC (ranging between 62.0-91.7%) were obtained using scattering technique.
- Vis-SWNIR technique showed slightly better results in sorting for firmness (ranging between 87.3-97.6%) and good results in sorting for SSC (ranging between 77.1-92.3%).
- When the classification involved both firmness and SSC, the sorting accuracy decreased, ranging between 75.7-90.1% for Vis-SWNIR and between 69.7-91.5% for spectral scattering.
- Both techniques using a simple discriminant analysis showed potential for online sorting and grading of apples by firmness or/and SSC. Further improvement, however, is needed for sorting apple fruit based on the two quality attributes. More sophisticated classification techniques, such as probabilistic neural network, decision tree and among others, could be useful for more accurate, consistent and robust models for online sorting and grading of apples.

REFERENCES

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