The Canadian Society for Bioengineering
The Canadian society for engineering in agricultural, food, environmental, and biological systems.

CSBE | SCGAB

La Société Canadienne de Génie Agroalimentaire et de Bioingénierie
La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement

Design of a multispectral imaging system for detecting mildew damage on wheat kernels

Muhammad A. Shahin

Canadian Grain Commission, 1404-303 Main Street Winnipeg, MB, R3C 3G8

Stephen J. Symons

Canadian Grain Commission, 1404-303 Main Street Winnipeg, MB, R3C 3G8

Abstract. *Mildew fungus imparts a grey discolouration on wheat kernels causing a loss in value of grain. Mildewed kernels in a wheat shipment are undesirable as they have a negative impact on flour colour. In an earlier study (Shahin et al. 2009), we found that hyperspectral imaging (HSI) in the 400-1000 nm range could be used for predicting mildew levels in wheat samples, however, the HSI system has little practical value due to prohibitively high cost of the system. The objective of this study was to design a low cost multispectral system. A set of 4 key wavelengths was identified which performed equally well as the full-spectrum HSI system. Computer simulations of optical filters characteristics showed a close match between the simulated multispectral and the target hyperspectral data at selected wavelengths with an error of less than 1%. Hardware implementation and performance evaluation of the proposed low cost system is planned next.*

Keywords. Hyperspectral, multispectral, wheat, mildew.

INTRODUCTION

Mildew is a serious degrading factor especially in the Eastern Canadian wheat classes (Dexter and Edwards 1998). Mildew fungus imparts a grey discolouration on wheat kernels causing a loss in value of grain. Mildewed kernels in a wheat shipment are undesirable as they have a negative impact on flour colour. Flour milling performance is lower because flour is darker. There is an increase in the negative impact on flour colour with increasing infection by mildew spores. Severely damaged kernels can be identified through human inspection; however, quantification of the extent of mildew damage through visual inspection remains a challenge. The grain industry requires fast and accurate objective methods for detection and quantification of mildew damage to meet the needs of national as well as international trade.

The identification of mildew damaged regions of kernels by imaging appears to be a logical solution, however, conventional imaging instrumentation lacks the ability to measure material composition through spectral analysis. On the other hand , conventional spectroscopy which is commonly used to assess composition of agricultural commodities through spectral analysis lacks in spatial information. As a remedy to this situation, hyperspectral imaging combines the complementary approaches of spectral analysis and image processing, thus offering the potential for defect recognition and quantification of their magnitude. As hyperspectral hardware has advanced over the past 10 years and computer processing speed has risen, the popularity of hyperspectral image analysis has grown in the agricultural and food research community. Hyperspectral imaging applications have been reported for quality assessment of fruits (Kim et al. 2002, Lu 2003), vegetables [Chang et al. 2004, Gowen et al. 2008], poultry (Park et al. 2002), beef steaks (Naganathan et al. 2008) and cereal grains (Cogdill et al. 2004, Lin et al. 2006, Goretta et al. 2006, Shahin and Symons 2008). Recent studies have shown that hyperspectral imaging could distinguish sprout damaged (Singh et al. 2009, Xing et al. 2009) as well as stained and fungal infected (Berman et al. 2007, Singh et al. 2007) wheat kernels from sound kernels. Spectral characteristics of mildewed wheat kernels have been reported to be significantly different from those of sound undamaged kernels (Shahin and Symons 2007).

Hyperspectral imaging is often used as a precursor to developing dedicated multispectral machine vision systems where useful wavelengths are identified through hyperspectral image analysis that can be packaged in a dedicated multispectral image analysis inspection system. In a recent study, Shahin et al (2009) has investigated the use of hyperspectral imaging in the visible/near-infrared wavelength range to assess the amount of mildew damage in wheat samples. Spectra over the 450-950 nm range was used to develop PLS models that predicted mildew levels with an R^2 of 0.9 in comparison with the visual inspection scores. This system in its present form has little practical value due to prohibitively high cost of the system. The objectives of this study were: (a) to select a set of 3-5 important wavelengths capable of achieving a similar performance for predicting mildew levels in wheat samples, and (b) to investigate through simulation if the selected wavelengths can be packaged as a low cost multispectral imaging system without compromising the performance. The design and implementation issues of a low cost system are discussed in this paper.

MATERIAL AND METHODS

In an earlier study (Shahin et al. 2009), 65 samples of CESRW were analysed for mildew damage with a hyperspectral imaging system in the 400-1000nm range. They developed PLS models using the spectra from 450-950nm range to predict mildew levels in comparison with inspectors' visual scores on a scale of 1-9, where 1 represented top of grade 1 and 9 represented bottom of grade 3.

In this study, regression coefficients of the best PLS model of Shahin et al. (2009) were investigated to select a set of 3-5 most important wavelengths (Fig 1). Using the selected

wavelengths, a PLS model was re-developed for predicting mildew levels, and results were compared with those of the full wavelength range model (Table 1) in terms of coefficient of determination (R^2) and root-mean-squared-error (RMSE).

Computer simulation of a multispectral system was implemented with a computer program written in IDL (Version 7.0.2; ITT Visual Information Solutions, Denver, CO, USA) which modeled the characteristics of optical filters to generate images at selected wavelengths from previously scanned hyperspectral images. To check for spectral similarity, simulated images were compared on a pixel-by-pixel basis with the image bands at selected wavelengths in the hyperspectral images (Fig 2). A close match would indicate the preservation of spectral characteristics as an indicator of a high probability of success for mildew predictions with a multispectral system scanning at selected wavelengths.

A PLS regression model was developed based spectral data from simulated multispectral images to predict mildew levels in wheat samples. Results were compared with those from the original full-wavelength model (Shahin et al. 2009) and the model using selected narrowband wavelengths.

RESULTS AND DISCUSSION

Wavelength selection

A plot of the PLS regression coefficients of the original fill-wavelength model (Shahin et al. 2009) is shown in Fig 1. Coefficients with a large magnitude indicate important wavelengths of considerable contribution towards the PLS model. As pointed out with arrow, a set of 4 or 5 wavelengths might contain sufficient information to predict mildew levels in wheat samples.

A PLS model built with 4 wavelengths (450, 561, 861 & 917 nm) achieved the maximum performance (Table 1). Adding more wavelengths did not improve the model. The 4-wavelength model performed as well as the original model based on the full-wavelength spectra. R^2 and RMSE in both the models were comparable.

Multispectral system simulations

Simulated filter outputs at selected wavelengths were higher in magnitude than corresponding values in the hyperspectral images. Band ratios, however, at selected wavelength were maintained indicating preservation of spectral characteristics. When normalized to the area under the filter response curve, the simulated values closely matched the corresponding target values (Fig 3). Maximum error observed was less than 1%. These results strongly indicated that images captured with a multispectral system would match the corresponding image bands in the hyperspectral images. Next step would be the hardware implementation of the multispectral imaging system.

For hardware implementation of filters, the choice is between using tunable filters or band-pass filters in a motorized filter wheel. Liquid-crystal and Acousto-optic tunable filters (LCTF& AOTF) can be tuned to any wavelength of choice. These are fast but expensive. An LCTF with a wavelength range of 400-1000nm costs approximately $30,000. Band-pass optical filters in a motorized filter wheel offer a relatively slower but much less expensive solution.

CONCLUSIONS

Based on the results of this study it can be concluded that a PLS model using 4 wavelengths can predict mildew levels in wheat samples as accurately as a model using full-spectrum (400-1000nm). Spectral data from a simulated multispectral system match the target hyperspectral data

for the selected wavelengths within less than 1%. Low cost hardware implementation can be achieved with band-pass filters in a motorized wheel.

REFERENCES

1. Berman, M., Connor, P.M., Whitbourn, L.B., Coward, D.A., Osborne, B.G., Southan, M.D., 2007. Classification of sound and stained wheat grains using visible and near infrared hyperspectral image analysis. J. Near Infrared Spectroscopy 15, 351-358.

2. Cheng, X., Chen, Y.R., Tao, Y., Wang, C.Y., Kim, M.S., Lefcourt, A.M. 2004. A novel integrated PCA and FLD method on hyperspectral image feature extraction for cucumber chilling inspection. Transactions of the ASAE 47(4), 1313-1320.

3. Cogdill, R.P., Hurdburgh, C.R., Rippke, G.R. 2004. Single kernel maize analysis by near-infrared hyperspectral imaging. Transactions of the ASAE 47, 311-320.

4. Dexter, J.E., Edwards, N.M. 1998. The implications of frequently encountered grading factors on the processing quality of common wheat. Association of Operative Millers – Bulletin, 7115.

5. Goretta, N., Roger, J. M., Aubert, M., Bellon-Maurel, V., Campan, F., Roumet, P. 2006. Determining vitreouness of durum wheat kernels using near infrared hyperspectral imaging. J. Near Infrared Spectroscopy 14, 231-239.

6. Gowen, A.A., O'Donnell, C.P., Cullen, P.J., Downy, G., Frias, J.M. 2007. Hyperspectral imaging - an emerging process analytical tool for food quality and safety. Trends in Food Science & Technology 18, 590-598.

7. Gowen, A.A., O'Donnell, C.P., Taghizadeh, M., Gaston, E., O'Gorman, A., Cullen, P.J., Frias, J.M., Esquerre, C., Downey, G. 2008. Hyperspectral imaging for the investigation of quality deterioration in sliced mushrooms (Agaricus bisporus) during storage. Sensing and Instrumentation for Food Quality and Safety 2(3), 133-143.

8. Kim, M.S., Lefcourt, A.M., Chao, K., Chen, Y.R., Kim, I., Chan, D.E. 2002. Multispectral detection of fecal contamination on apples based on hyperspectral imagery. Transactions of the ASAE 45(6), 2027-2037.

9. Lin, L.H., Lu, F.M., Chang, Y.C. 2006. Development of a near-infrared imaging system for determination of rice moisture. Cereal Chemistry 83, 498-504.

10. Lu, R. 2003. Detection of bruise on apples using near-infrared hyperspectral imaging. Transactions of the ASAE 46, 523-530.

11. Naganathan, G.K., Grimes, L.M., Subbiah, J., Calkins, C.R., Samal, A., Meyer, G.E. 2008. Partial least squares analysis of near-infrared hyperspectral images for beef tenderness prediction. Sensing and Instrumentation for Food Quality and Safety 2(3), 178-188.

12. Park, B., Lawrence, K.C., Windham, W.R., Buhr, R.J. 2002. Hyperspectral imaging for detecting fecal and ingesta contaminants on poultry carcasses. Transactions of the ASAE 45, 2017-2026.

13. Shahin, M.A., Symons, S.J., 2008. Detection of hard vitreous and starchy kernels in amber durum wheat samples using hyperspectral imaging. NIR News 19(5), 16-18.

14. Shahin, M.A., Symons, S.J., 2007. The use of hyperspectral imaging to characterize wheat grading factors. Prococeedings of the 13th International Conference on NIR, Umea, Sweden.

15. Singh, C.B., Jayas, D.S., Paliwal, J., White, N.D.G. 2007. Fungal detection in wheat using near-infrared hyperspectral imaging. Transactions of the ASABE 50, 2171-2176.

16. Singh, C.B., Jayas, D.S., Paliwal, J., White, N.D.G. 2009. Detection of sprouted and midge-damaged wheat kernels using near-infrared hyperspectral imaging. Cereal Chemistry 86(3), 256-260.

17. Xing, J., Hung, P., Symons, S., Shahin, M., Hatcher, D. 2009. Using a SWIR hyperspectral imaging system to predict alpha amylase activity in individual Canadian Western wheat kernels. Sensing and Instrumentation for Food Quality and Safety (In Press).

Table 1. Comparison of PLS regression models built with full range spectra and selected wavelengths as model input.

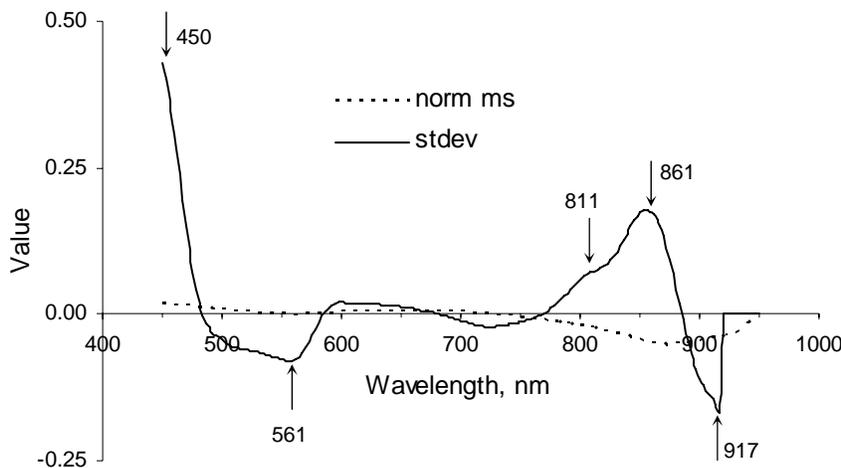| PLS model input data	Calibration		Validation	
	R^2	RMSE	R^2	RMSE
Spectra over the entire wavelength range (450-950nm)	0.893966	0.671744	0.874292	0.731103
Spectra at 4 selected wavelengths	0.890219	0.683511	0.871316	0.739506

Figure 1. Regression coefficients for normalized image mean (norm ms) and image standard deviation (stdev) spectra with arrows pointing to 5 selected wavelengths.
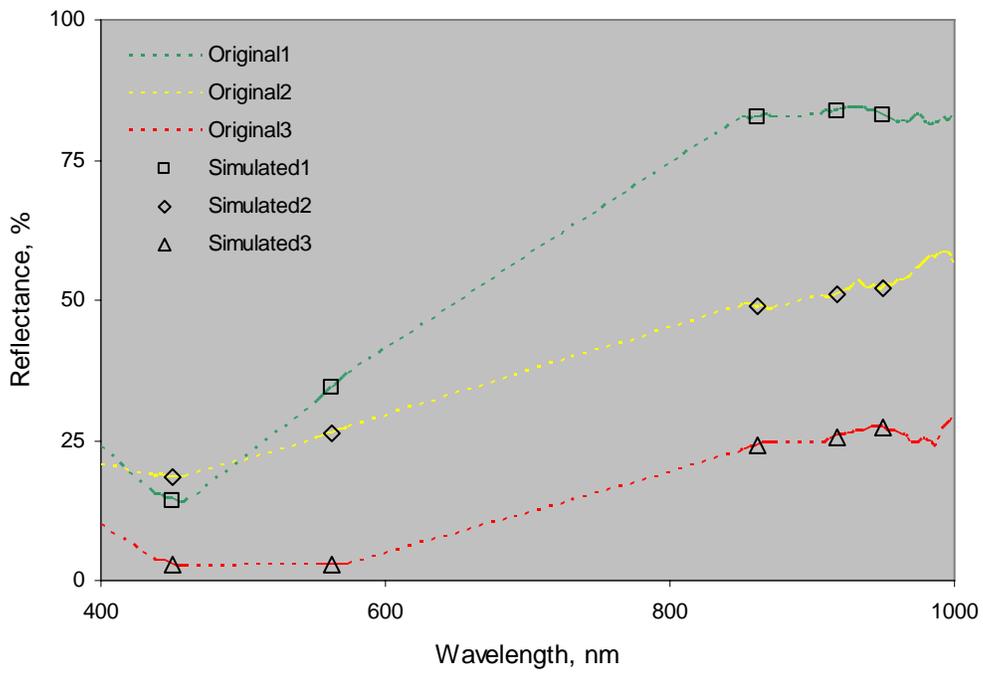
Figure 2. Spectral characteristics of the original hyperspectral and simulated multispectral at different areas marked and encircled on the image (A).