4th IFAC Conference on Modelling and Control in Agriculture,
Horticulture and Post Harvest Industry
August 27-30, 2013. Espoo, Finland

Optical sensoring of internal hollow heart related defects of potatoes ⋆

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Abstract: Internal defects of potatoes are difficult to detect. Defect potatoes need to be removed as they cause complaints from customers and may spoil a whole patch in later food processing stages. We evaluated light transmittance for the sensing of internal defects in their different stages. The results are very promising: the classification rate for healthy and defect potatoes with skin is 90 % and without skin 92.5 %.

Keywords: Potato, VIS/NIR spectroscopy, defect, detection, transmission, hollow heart, discoloration.

1. INTRODUCTION

In 2008, the crop yield of potato exceeded 325 million tonnes in the whole world (see e.g. International year of potato 2008 (2008)). It is a stable and in many countries important source of energy and nutrient. Many studies has been thus made for accessing potato quality.

The quality factors can be divided into two groups, internal and external quality. Many of the external quality factors are detectable in the visible wavelengths. These factors include defects like cracks, greening and scab and properties like shape and size. Many real-time systems based on a color camera has been already tested, see for example, Noordam et al (2000), Razmjooy et al (2012), and Rios-Cabrera et al (2008) for visible surface defects. Still the spectral data contain more information and can be used for certain defects like scab Dacal-Nieto et al (2011).

Many studies use spectral data to determine the contents of potatoes. The dry matter is a parameter which have been considered in several studies like e.g. Peiris et al (1999) (cutted potatoes), Fernandez-Ahumuda et al (2006) (mashed potatoes), Helgerud et al (2012) (whole, unpeeled potatoes), Haase (2003) (potato mash, also starch was determined), Dull et al (1989) (sliced and intact tubers), Dijk et al (2002) (steam-cooked potatoes), Hartmann and Büning-Pfaue (1998) (homogenized peeled potatoes) Scanlon et al (1999) (cut potatoes), and Subedi and Walsh (2009) (intact, peeled and sliced potatoes).

NIR has been used also for determining moisture (or water) (Chen et al (2009), Singh (2005)). It seems to be suitable also for carbohydrate (Chen et al (2009)), protein (Haase (2006), Chen et al (2009), Fernandez-Ahumuda et al (2006)), starch (Haase (2006), Fernandez-Ahumuda et al (2006)), amylase (Chen et al (2009), carotenoid content (Bonierbale et al (2009)), and sugar content (Yaptenco et al (2000), Groinig et al (2011)).

It seems that NIR spectral measurements are very suitable for potato evaluation Porteous et al (1981). There are already some prototypes available. For example, a NIR based prototype for off-line detection of dry matter, protein, and starch has been already developed for semi-industrial applications (Brunt and Drost (2010), Brunt et al (2010)).

The internal quality defects have also been the subject of some studies. As early as 1960, Birth (1960) published an article of detecting internal discolorations using a special light transmittance system. Later, Vanoli et al (2012) applied time-resolved reflectance spectroscopy to internal brown spot detection and Dacal-Nieto et al (2011) used NIR (900-1700 nm) for hollow heart detection. Katrandzhiev et al (2008) suggested a method modelling virtual peeling of potatoes.

In this paper, we study methods applicable in visible and short-wave near-infrared wavelengths for sensing internal defects, which have several developing phases.

The internal defect develops as a function of time. In the first phase, an area of discoloration is found inside the potato. Next, this area gets larger and produces some hollow spaces. In the final phase, a hollow heart has formed inside the potato. The earlier stages of the defect are difficult detect.

The potato with this internal defect should be removed because customers find it as poor quality. It also may spoil a whole batch in the later processing phases.

2. DESCRIPTION OF BACKGROUND AND MATERIAL

We have obtained healthy and defect potatoes from a potato processing company. The defect potatoes have

⋆ We thank Sapuska program of Tekes (the Finnish Funding Agency for Technology and Innovation) for financial support.

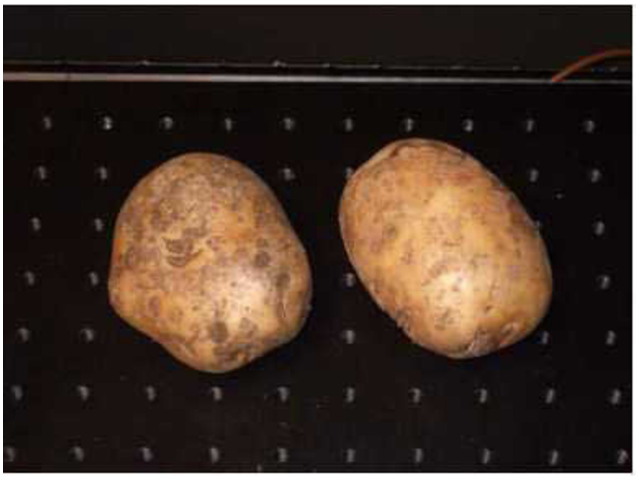

Fig. 1. A good potato is shown on the left and a defect potato on the right. The defect is not visually detectable.

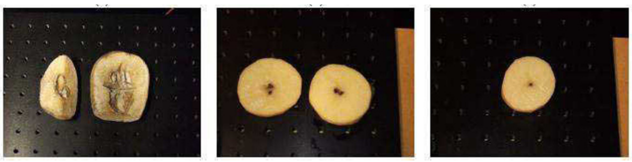

Fig. 2. The stage of the inner defect development inside the potato from left to right: two early stage discolorations and final phase (hollow heart). The potato with hollow heart floats but the potatoes with discolorations do not.

an internal defect which causes hollow heartness and discoloration. This defect type cannot be seen by naked eye (see Fig. 1).

The inner defect develops during the growth and storage phases of the potato. In Fig. 2, the final stage (hollow heart) and two earlier stages (discolorations) are shown. Currently the food processing company use a floating test to separate defect potatoes. In the floating test, the potatoes are conveyed into a water pool. The potatoes with hollow heart will float because their average density is smaller than that of water. The healthy potatoes will sink. The problem is that the early stages (discoloration) do not float and thus they may go directly to customers or further processing.

3. MEASUREMENTS AND SPECTRAL DATA

The measurement set-up is shown in Fig. 3. The spectral measurements were done with a spectrometer from Ocean Optics (Florida, USA) which wavelength range includes visible wavelengths and short near infrared (195.8 -1118.5 nm). The target was illuminated with a Velleman halogen lamp 1000P64S which input power is 1000W.

The lamp is too intense for direct transmittance measurements, so the light is directed through a shutter (Venetial blight) and reflected from the mirror through a hole to the potato sample (Fig. 4). The hole has smaller size as the potatoes. The spectral transmittance was measured using an integrating sphere. The halogen lamps provide low input power under wavelength of 450 nm. Due to this

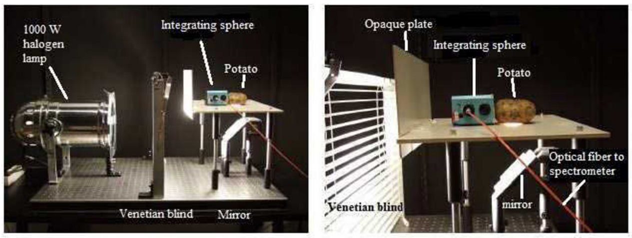

Fig. 3. Measurement set-up: on the left: the whole measurement set-up. On the right: a closer look on the the actual measurement situation

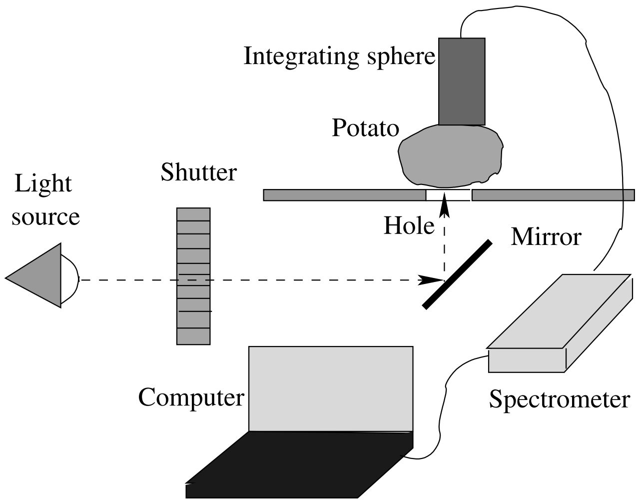

Fig. 4. A schematic diagram for the whole measurement set-up. Light passes through a shutter and is reflected by a mirror. The potato transmittance spectrum is measured by an integrating sphere connected by a fiber with a spectrometer. The computer controls the spectrometer and displays the measured spectrum.

and characteristic spectra of potatoes we used only spectra starting at 500 nm.

The calibration of the transmittance measurement needs to be carefully planned as there is no standard bodies as with reflectance measurements. We calibrate a spectrometer using a reference white and a reference black. For the last one we simply switch off the light. The reference white cannot be directly measured using the light of the illuminant, because this gives too small signal from light passing through a potato. The calibration formula is a fraction where the numerator is the difference between the object spectrum and the reference black spectrum, and the denominator is the difference between the reference white and the reference black spectra. Therefore we attenuate light using shutter and placing on the top of a panel, over the hole, two white office papers.

We measured and analysed two sets of potatoes: with and without skin. The total number of measurements of potatoes with skin was 100. Both good and defect classes had 50 measurements. In the skinless set, the total number was 99. The good class had now 49 and defect class 50 potatoes. The classes were confirmed after the measurements by slicing the potatoes.

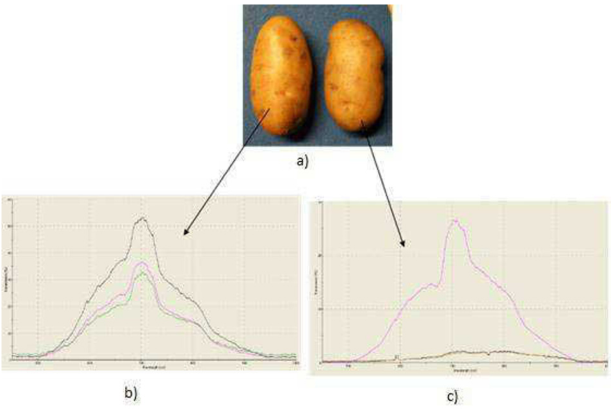

Fig. 5. a) A healthy and a defect potato. b) Uncalibrated spectral transmittances for the good potato. c) Uncalibrated spectral transmittances for the defect potato. The inner defect is present only at certain points.

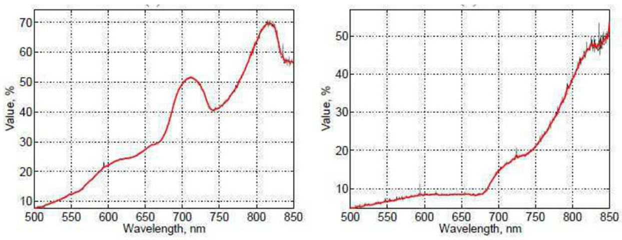

Fig. 6. Calibrated spectral transmittance for a good (left) and a defect (right) potato. In the figure, the original spectrum is marked with the black line while the red line indicates the spectrum smoothed using B-splines.

The potatoes were measured along its largest axis. For each axis, 3-5 measurement points were selected depending on the size of the potato.

Uncalibrated spectral transmittance results for a good and a defect potato are shown in Fig. 5. The inner defect clearly reduces the light transmitted through a potato. It seems to be possible to use a ratio between suitably selected wavelengths to separate the defect and healthy classes. Since the defect may appear anywhere inside the potato, an imaging based solution would be ideal for the automated sorting in a factory unit.

The spectral transmittances were calibrated using the reference measured earlier. The calibrated spectral transmittances are shown in Fig. 6. The defect potato has no peak at 720 nm and before that value, its transmittance is much lower. Also the 2nd peak around 820 nm is missing as well as the valley after it.

4. ANALYSIS AND RESULTS

The input data are spectra measured in the range approximately 195-1118 nm. The number of wavelengths was 3648. After preprocessing by fitting B-splines into the data we cropped spectra to a smaller range, e.g. 500-850 nm (Fig. 6). For spline fitting, the number of spectral control points was 140.

We had two classes including measurements of healthy potatoes and of hollow potatoes. The potato set with skin

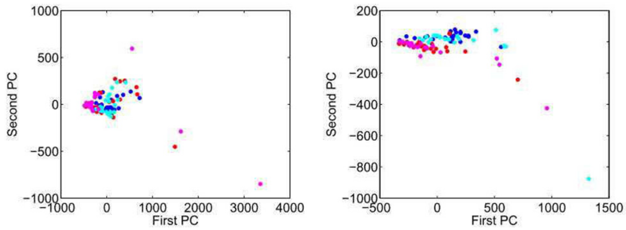

Fig. 7. Feature space spanned by eigenvectors for potatoes with skin (left) and peeled potatoes. A healthy potato is marked with blue (training set) and cyan (validation set) dots. A defect potato is marked with red (training set) and magenta (validation set) dots. As anticipated, the skin seems to reduce the separation between classes.

was divided into two sets, training and validation sets. The training set included measurements of 30 good and 30 defect potatoes while the validation set had 20 for each class. The potato set without peel had also a training group (30 defect and 29 good potato measurements) and a validation group (20 potato measurements for each class).

For classification we used principal component analysis and a support vector (kernel) classifier. The principal component analysis (PCA) was applied on the transmittance data. The first two eigenvectors (PC) are shown for visualization in Fig. 7. The figure indicate that different classes produces two different group of dots even in this feature space. The classes will be most likely more separate in the higher-dimensional spaces.

The outliers might be also due to errors during measurement process or shape of the target. The measurement with the high illumination power used required holding the potato at a position for several seconds so it is susceptible to human error of removing it too early from its position. Since the potatoes are irregularly shaped it is possible that some exterior light has reached the integrating sphere and thus the spectrometer.

We use a support vector classifier (SVC) which is a useful technique for data and signal classification. The SVC implicitly maps the training input data, i.e. input features generated by PCA, into a higher-dimensional space and computes a function implementing the decision rule. When new spectral data arrives the SVC assigns it to one of the predefined classes. The classifier was implemented using MATLAB and LIB-SVM library (Chang and Lin (2001)).

To define the number of principal components we use the fraction of the variance to be kept for computing

$$\frac{\sum_{i=1}^{m} \lambda_i}{\sum_{i=1}^{n} \lambda_i}, \tag{1}$$

where λ_i is an i^{th} eigenvalue, n is the total number of principal components, and m is the first m principal components. Fig. 8 shows the fraction of the variance for potato sets. We selected the first four principal components containing over 99% of the variance.

The classifcation rate and confusion matrices for the first four principal components for the validation sets are shown in Table 1 for potatoes with skin and in Table 2 for peeled

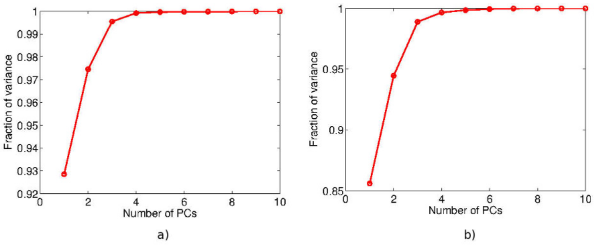

Fig. 8. a) The fraction of the variance for potatoes without skin. b) The fraction of variance for potatoes with skin

potatoes. For both cases, the validation set had 20 healthy and 20 defect potatoes.

The peeled potatoes have a better classification rate but both rates are at least 90% which is a good result considering that only point measurements were done. Only in a couple of cases healthy potatoes were classified as defect potatoes.

Table 1. Potatoes with skin. Classification rate: 90 %

Class	Good	Defect
Good	16	4
Defect	0	20

Table 2. Peeled potatoes. Classification rate: 92.5 %

Class	Good	Defect
Good	17	3
Defect	0	20

5. CONCLUSION

We have studied the sensing of an inner defect with optical means. The results are very promising.

The analysis indicates that the potato skin lower the classification rate (from 92.5% to 90%) but the difference was so small that both methods suggested are applicable.

It seems that a defective potato may be recognized just looking how light passes through it. If a potato is good then a lot of light passes through it and it looks shiny. If it is a defect one, then less light pass through it. This will be a part of our future investigations.

We also noticed that the internal defect was not present in anyone of the very small potatoes.

ACKNOWLEDGEMENTS

We thank Tekes for providing funding via its Sapuska programme.

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