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A segmentation and classification algorithm for online detection of internal disorders in citrus using X-ray radiographs

M. van Dael[a,*], S. Lebotsa[b], E. Herremans[a], P. Verboven[a], J. Sijbers[c], U.L. Opara[b], P.J. Cronje[d], B.M. Nicolaï[a]

[a] Flanders Centre of Postharvest Technology/BIOSYST-MeBioS, University of Leuven, Willem de Croylaan 42, 3001 Leuven, Belgium
[b] Faculty of AgriSciences, Stellenbosch University, Private Bag X1, 7602 Matieland, Stellenbosch, South Africa
[c] iMinds-Vision Lab, Department of Physics, University of Antwerp, Universiteitsplein 1, B-2610 Wilrijk, Belgium
[d] Citrus Research International, Department of Horticultural Sciences, Stellenbosch University, Stellenbosch 7602, South Africa

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ABSTRACT

Oranges and lemons can be affected by the physiological disorders granulation and endoxerosis respectively, decreasing their commercial value. X-ray radiographs provide images of the internal structure of citrus on which the disorders can be discerned. An image processing algorithm is proposed to detect these disorders on X-ray projection images and classify samples as being affected or not. The method automatically segments healthy and affected tissue, calculates a set of image features and uses these to classify the images using a naïve Bayes or kNN classifier. The developed method avoids the need for labour-intensive destructive sampling and allows for non-destructive inspection of all fruits while preventing losses due to destructive sampling. The proposed algorithm classifies 95.7% of oranges and 93.6% of lemons correctly. The classification method is fast, robust to noise and can be applied to any existing inline X-ray radiograph equipment.

1. Introduction

Citrus fruit are the largest fruit crop in international trade in terms of value (Moltó and Blasco, 2008), with an estimated total annual production over 123 million tons in the period 2009–2010 of which approximately 55% were oranges and 10% were lemons. World production of citrus has experienced continuous growth in the last decades, mainly due to an increase in cultivation area and the change in consumer preferences towards healthier food consumption (UNCTAD.org). Because of an ever increasing demand for a high and uniform food quality, fresh produce is subject to strict quality requirements.

Most citrus types, and Navel oranges in particular, can be severely affected by granulation. This disorder manifests itself through different symptoms, from dehydration of the juices vesicles at the pedicel-end to a gel formation in the juice vesicles at the pedicel-end and into the central axis (Fig. 1). It is often associated with fast growth and occurs more in large fruit, on young trees, in humid climates and on trees growing on sandy soils. The fruit develops a flat, insipid taste as they lose some of their sugar and acid content resulting in a lower commercial value (Kahn et al., 2007; Peiris et al., 1998; Wang et al., 2014). The severity of the disorder increases during storage as the fruit lose more moisture from the juice vesicles.

Lemon fruit can develop a physiological disorder called endoxerosis, or internal drying, characterized by the destruction of the edible part of the fruit, i.e., the endocarp, especially at the stylar end (Fig. 1). The disorder occurs in all lemon production areas of South Africa and is more prevalent in the first part of the season. During hot summer months up to 60% of fruits can be affected, especially in young, vigorous trees with a high level of vegetative development (Bartholomew, 1937; Rose, 1943). The preliminary symptoms of endoxerosis are the browning of the vascular bundles at the stylar-end of the fruit followed by a clogging of the bundles by a pinkish to rust brown deposit of gum. The juice sacs of the pulp adjoining the rind at the stylar-end become affected and lose water and collapse. The dehydration of the pulp, which starts at the stylar-end, progresses down to the centre of the fruit (Sinclair, 1984).

At present, the most reliable detection method to determine the incidence of internal disorders such as endoxerosis and granulation is to sample every batch supplied for an orchard and destructively evaluate the sample fruits by cutting them open (Shewfelt and Prussia, 2012). Progress has been made in the

* Corresponding author.
E-mail address: mattias.vandael@biw.kuleuven.be (M. van Dael).

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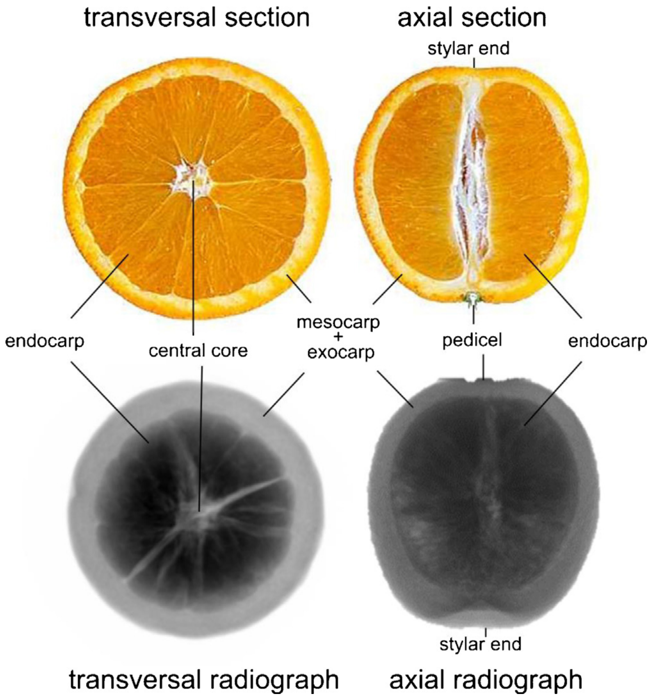

Fig. 1. Citrus fruit anatomy identified on sections and X-ray radiographs of an orange fruit. Sections and radiographs show different samples.

development of non-destructive imaging techniques to detect spatially distributed internal disorders (Magwaza and Opara, 2014; Nicolaï et al., 2014). Techniques such as magnetic resonance imaging (MRI, Clark et al., 1999; Defraeye et al., 2013; Hernández-Sánchez et al., 2006; Lammertyn et al., 2003a,b; Zhang and McCarthy, 2013 Lammertyn et al., 2003a,b; Zhang and McCarthy, 2013), nuclear magnetic resonance (NMR, Defraeye et al., 2013; Lammertyn et al., 2003a,b; Zhang and McCarthy, 2013), visible/near infrared spectroscopy (Magwaza et al., 2014, 2012; Nicolaï et al., 2007), hyperspectral imaging (Haff et al., 2013; Xing et al., 2007) and optical coherence tomography (OCT, Magwaza et al., 2013; Verboven et al., 2013), as well as X-ray radiographs and X-ray computed tomography (CT, Donis-González et al., 2014; Herremans et al., 2013; Kotwaliwale et al., 2014; Lammertyn et al., 2003a,b Herremans et al., 2013; Kotwaliwale et al., 2014,b; Lammertyn et al., 2003a,b) have been subjects of research into non-destructive evaluation of internal quality in fresh food products. The advantages of X-ray methods are the sensitivity to spatial density differences inside an object and the excellent penetration properties of X-rays in fruit and vegetables to detect internal disorders.

X-rays cover wavelengths between 10 and 0.01 nm. When passing through an object, these X-rays physically interact with the object material and are partly absorbed, scattered or reflected (Barrie Smith and Webb, 2010). The remaining X-rays are recorded on a detector, resulting in an X-ray radiograph, an image containing superimposed information or a projection of the 3D object in a 2D plane. In this image defects can be detected using machine vision and image processing techniques. Currently X-ray radiograph is mainly used for the detection of foreign objects with strong contrasting density from the food, but has received attention as well for detecting internal disorders in fruit and vegetables (Hansen et al., 2005; Jiang et al., 2008; Kim and Schatzki, 1999).

In X-ray computed tomography (CT) multiple radiographs of the same object, taken from different angles, are combined to produce a 3-dimensional image using a mathematical algorithm (Magwaza and Opara, 2014). The resolution varies from 1 mm in medical scanners down to the micrometer level on dedicated micro-CT scanners (Verboven et al., 2008). X-ray CT has been used successfully to detect internal disorders in pear (Lammertyn et al., 2003a), apple (Herremans et al., 2014; Nicolaï et al., 2014; Schatzki et al., 1996) and pineapple (Haff et al., 2006). However, the equipment is expensive and the 3-dimensional reconstruction comes at a high computational cost making it difficult to apply into existing sorting lines. To render X-ray radiography viable for internal disorder detection, accurate and fast detection algorithms need to be developed suited to the application. Detection algorithms combine image processing with classification algorithms. Image processing typically relies on segmentation of the disorder from the healthy fruit tissue (Lammertyn et al., 2003b; Kim and Schatzki, 20001). For classification, different approaches can be followed. Naive Bayesian classifiers determine the Bayesian distribution of every supplied feature and assign a posteriori scores to new samples based on these distributions. While they are very basic since they do not account for interactions between the features, in many situations they have proven to outperform more advanced classifiers due to their simplicity (Larsen, 2005).

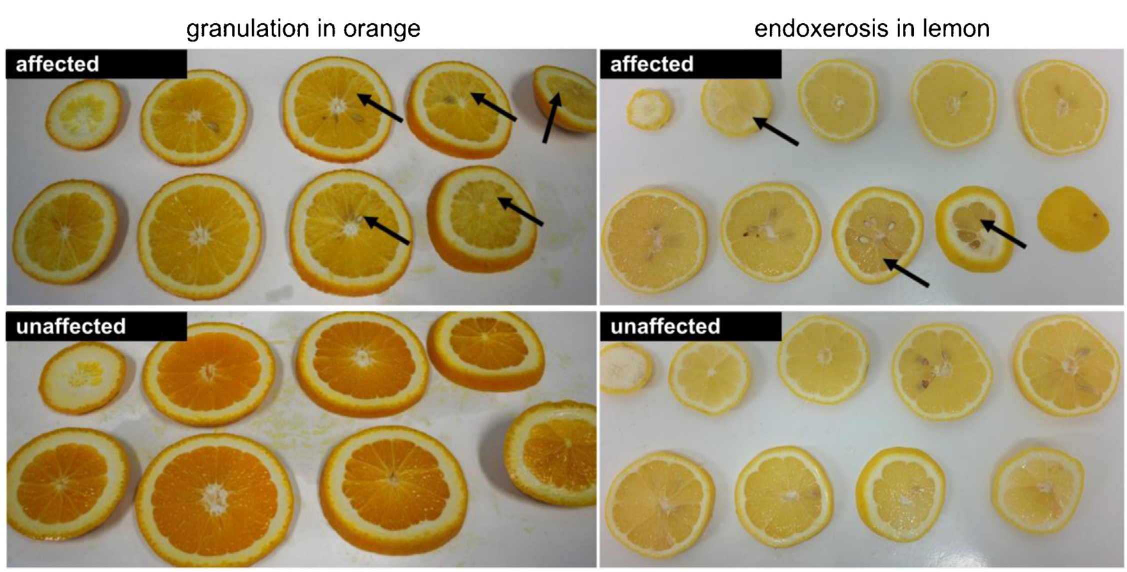

Fig. 2. Destructive visual inspection of granulation in oranges (left) and endoxerosis in lemons (right). Affected regions are indicated with an arrow.