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Research Paper

Comparison of leaf surface roughness analysis methods by sensitivity to noise analysis

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Surface roughness is of great interest in agricultural spraying because it is used to characterise leaf surface wettability to predict the behaviour of droplets on a leaf surface. In recent years, the use of texture analysis to estimate surface roughness has emerged. In this paper we propose to estimate leaf surface roughness by using an optimisation of the Generalized Fourier Descriptors method. This approach is then compared with two other standard methods in the literature, one based on grey level intensity variation and the other on wavelet decomposition. Since roughness has many definitions and each method is calculated differently, we propose a new approach to compare the results based on the sensitivity of each method according to surface roughness variations. These variations were introduced by adding different kinds of noise to the image. Gaussian and salt & pepper noise are added to simulate rapid changes and peak impulses on the surface topography, whereas a Structural noise (sinusoidal signal) is added to simulate depth on the surface topography. The novelty of this contribution is the use of a new approach and procedure for agronomic application (leaf surface roughness). The results obtained are expected to be used to characterise the adhesion mechanisms of liquid droplets on a leaf surface.

1. Introduction

Leaf roughness and/or micro-roughness are very different from one leaf to another. The roughness of plant surfaces (micro relief) is mainly caused by surface contour, hairiness, trichomes and waxes, and may be further altered by environmental factors such as dust and moisture deficit (Journaux et al., 2011) The leaf roughness serves different purposes and is often involved in the mechanism of water adhesion and retention. The retention of water drops by leaves can be measured as the amount of surface water per unit leaf area at a point when additional water drops can no longer be retained and they start to drip off (Wohlfahrt, Bianchi, & Cernusca, 2006). Leaf water adhesion varies among species from 0.1 to 500 g m^{-2} (Raupach, Finkele, & Zhang, 1997; Wohlfahrt et al., 2006). The difference in degree of adhesion is determined using water by Fernández et al. (2014). The spread of liquid on the leaf surface is dependent on the leaf wettability or hydrophobicity of the leaf itself. The wettability is characterised

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by the static contact angle between the water droplet and the surface, (Bhushan & Jung, 2011; Holder, 2007). Nanko, Watanabe, Hotta, and Suzuki (2013) and Nairn, Forster, and van Leeuwen (2011) estimated the ratio of mean water droplet adhesion values over a range of drop sizes and leaf surfaces. Holder (2007) observed the amount of water retained on leaf surfaces. All found that one factor governing water retention was leaf wettability or hydrophobicity.

In industrial and scientific areas, the problem of surface roughness characterisation is generally well recognised (Myshkin, Kim, & Petrokovets, 1997; Thomas, 1999). Several devices have been developed to measure surface roughness (Myshkin et al., 1997). The simplest procedure is based on visual comparison with an established standard (Thomas, 1999). The stylus method (Radhakrishnan, 1970) is the most popular approach, and is used in several manufacturing areas (Bhushan, Wyant, & Koliopoulos, 1985; Whitehouse, 1994). The principle of this method is to employ a stylus to trace over the surface being investigated and to record a magnified profile of the irregularities.

However, the methods based on stylus trace the surface roughness in one dimension and could damage the surface during the mechanical contact with the stylus. Therefore, new alternative methods that do not damage the surface have been investigated (Kalpakjian, Schmid, & Kok, 2008; Lange & Bhushan, 1988; Wyant, Koliopoulos, Bhushan, & George, 1984) These methods have been developed for the evaluation of surface topography properties, and include atomic force microscopy (Binnig & Rohrer, 2000), phase shifting interferometry (Magonov & Whangbo, 2008), stereo scanning electron microscopy (Bhushan et al., 1985), and laser confocal scanning microscopy (Podsiadlo & Stachowiak, 1997). Usually with interferometry, the surface roughness is characterised by a set of statistical features determined from a surface profile or 3D surface map. These features, such as arithmetic roughness 'Ra', maximum height roughness 'Rz' and arithmetical mean height of the surface 'Sa', are commonly accepted and have been used in some national standards for 2D characterisation (ISO 25178) (Blanc, Grime, & Blateyron, 2011). However, the most valuable information about the spatial organisation of a surface can be lost, and overall, the interferometer is not suitable for all types of surface, and one excluded is the leaf surface.

For many years, through the emergence and development of image processing, several methods based on texture and computer vision have evolved, enabling researchers to focus on the assessment of surface roughness. Al-Kindi, Baul, and Gill (1992) examined the use of a digital image system in the assessment of surface quality. They used a statistical measure of grey-level images in the spatial domain; the measure of surface roughness is based on spacing between grey level peaks and the number of grey level peaks per unit length of scanned line in the grey level image.

This 1-D based-technique does not fully use the 2-D information of the surface image. Moreover, it is particularly sensitive to illumination and noise. Luk, Huynh, and North (1989) used the grey-level histogram (distribution) of the surface image to characterise surface roughness. Since this method is based only on a gray-level histogram, it is sensitive to the uniformity and the degree of scene illumination. In addition, no information regarding the spatial distribution of periodic features can be obtained from the gray-level histogram. Hoy and Yu (1991) adapted the algorithm of Luk et al. (1989)to characterise the surface quality of turned and milled specimens. In their experiments, the authors found one exception where the ratio of the spread and the mean of the grey-level distribution was not a monotonically increasing function of surface roughness; therefore, the value of the ratio may lead to an incorrect measurement. Furthermore, the same research work (Hoy & Yu, 1991) addressed the possibility of using the Fourier transform (FFT) to characterise surface roughness in the frequency domain. However, only simple visual judgement of surface images in the frequency plane was discussed. No quantitative description of FFT features for the measurement of surface roughness was proposed.

Other research has investigated fractal dimension to estimate surface roughness and has described many methods to estimate fractal dimension. Based on our assessment, the most efficient method in terms of execution is Differential Box Counting (Sarkar & Chaudhuri, 1994; Sarkar & Chaudhuri, 1992). Nairn et al. (2011) used fractal dimension analysis on the Cryo-SEM micrographs of 10 different plant species in an attempt to quantify the relative leaf surface roughness. They looked at the effect of scanning electron microscopy (SEM) magnification on fractal dimension analysis, and found only one SEM magnification correlated well with spray droplet adhesion. Tsai and Tseng (1999) proposed to estimate surface roughness by using a power spectrum of Fourier transform. The power spectrum is then divided into several ring regions. A feature is calculated for each ring region to obtain a representative vector of the original image roughness. Many statistical measures have also been proposed to determine the roughness of an image. In a similar way, using a power spectrum of Fourier transform and, entropy and energy of co-occurrence matrix, Bediaf, Journaux, Sabre, and Cointault (2013) estimated the optical roughness of vine leaves using a neural network. This study was based on the hypothesis that arithmetic roughness is correlated with optical roughness.

In this paper, a new approach to estimate leaf surface roughness is proposed using image processing. In the context of precision spraying, the main goal is to optimise the spray application input and reduce the environmental impact (Robert & Stafford, 1999). To this end, several researchers have developed models (Forster, Kimberley, & Zabkiewicz, 2005) to improve the efficiency and the accuracy of spray application. Most studies reveal that the relationship between the spray target and the efficiency of the spray application remains a challenge and is a complex topic in agricultural spray technology. The adhesion, retention and distribution of agrochemical sprays on plant surfaces are influenced by the target roughness as demonstrated in Nairn et al. (2011).

In this paper, an approach based on Generalized Fourier Descriptors is proposed, in order to assess leaf surface roughness. The proposed approach will be compared with two other methods existing in the literature. The first method was originally applied to an image of a work piece and the second one was on leaf surfaces. The comparison between the methods was not direct because each method defined