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Application note

LightScatter: A comprehensive software package for non-destructive monitoring of horti-food products by monochromatic imaging-based spatially-resolved light scattering technology

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ABSTRACT

The horticulture and food industry are faced with a range of control measures to supply good quality and safe products to the market. Over the past four decades, a number of techniques have been developed to measure such control criteria in a non-destructive manner. This paper presents a new comprehensive software developed with MATLAB to help scientists and experts to easily and quickly implement light scattering imaging technology, as a non-invasive tool, in the horticulture and food industry. *LightScatter* is designed as a user friendly software so that interaction with it is done via a coding-free modern graphical user interface (GUI). This software package is equipped with various advanced tools for image acquisition, image pre-processing, feature extraction, and prediction/classification model generation. *LightScatter* also provides a powerful tool as a standalone application for use of light scattering imaging in the real-time mode. The latter can be activated manually by the user or automatically by an external trigger signal. The software response can be displayed on the monitor screen or transmitted over a serial port for further analysis or for activating electro-mechanical actuators. By the use of this software, light scattering imaging technology can be implemented in both the stationary mode, like a laboratory monitoring tool, and in the dynamic stop and go measuring mode, like sorting/grading machines. An updated *LightScatter* version is made publicly available and can be obtained upon request by sending an e-mail to the corresponding author.

1. Introduction

Various techniques have been introduced and developed by researchers over the past four decades based on mechanical, electrical, optical, and chemical principles to non-invasively assess quality and safety of horti-food products in terms of intrinsic characteristics. Some have reached the practical implementation stage while others are still being developed. Year after year, these techniques become more advanced in order to reduce the costs, increase speed, and improve accuracy and reliability. Among the various optical approaches developed so far, light backscattering imaging (LBI) is known as an effective monitoring tool, offering relatively low instrumentation cost, capability of online monitoring without touching the samples, reasonable processing time, and good accuracy. Besides, it is an easy to implement technology that can be attached alongside different postharvest and food production processes, and also, obtaining information through the deep penetration of light in the sample, something that some of the other optical approaches cannot do. The scientific origin of this technology dates back to the 19th century when the concept of Rayleigh scattering was introduced (Backman and Wax, 2010). As the first application of light scattering in agricultural and food industry, scattering properties of white potato flesh tissue and pork meat were measured based on the Kubelka–Munk model in the late 1970s (Birth, 1978; Birth et al., 1978). After the advent of powerful computers in the early twenty-first century, agricultural and food scientists adapted methods developed in the physics and biomedical fields to discover further applications of light scattering for property, quality, and safety assessment of agro-food materials (Mollazade et al., 2012).

Spatially-resolved (steady-state), time-resolved, and frequency domain are the main methods developed so far to indirectly measure the optical properties (absorption and scattering coefficients) of biological materials using light diffusion theory model. Among these, spatially-resolved is more appropriate for use in horti-food industry because of lower instrumentation cost, measurement time, and implementation complexity (Qin, 2007). Technically, in the spatially-resolved method, light is injected as a concentrated constant intensity beam, monochrome or broadband, into the sample. In terms of sensing configurations, spatially-resolved method can be implemented by optical fiber

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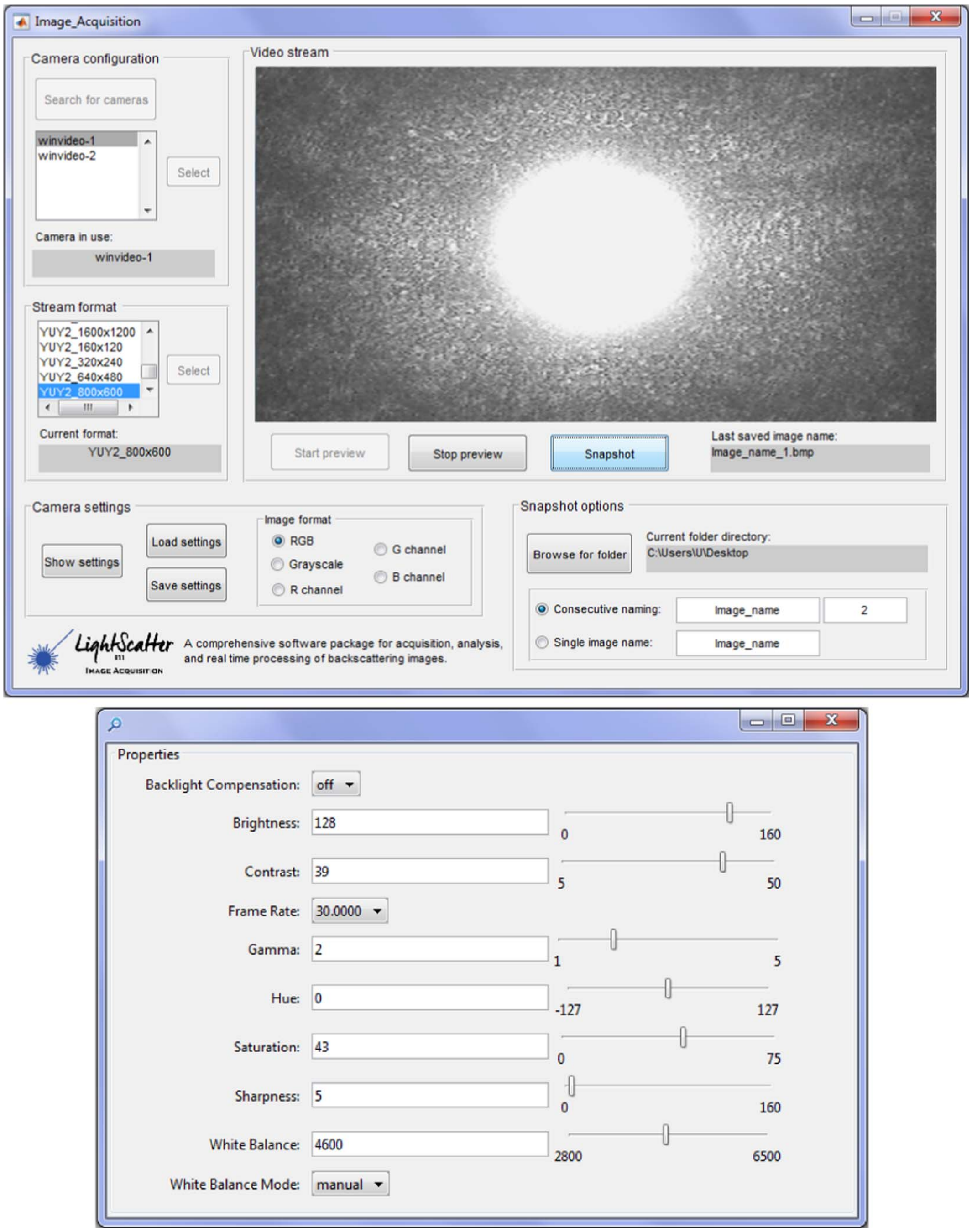

Fig. 1. Top: image acquisition GUI window, Bottom: a sample of camera properties' settings window.

arrays (spectroscopy by one moving or more stationary fiber-optic probe) and reflectance imagery devices (hyperspectral, multispectral, and monochrome). The simplest and cheapest configuration is to use a laser diode, emitting at a specified wavelength associated with the parameter of medium under study, as the light source and a CCD camera, with appropriate sensitivity at the laser working wavelength, as the detector (Cen et al., 2016).

Over the past 15 years, several research groups have focused on the development of light scattering imaging technology, especially in terms of analysis of backscattering images, in order to provide a robust non-invasive evaluation tool. Determining absorption and reduced scattering coefficients of fruits, meat, milk, and fruit juice (Lu and Cen, 2015), evaluating maturity of tomato (Tu et al., 2000) and banana (Adebayo et al., 2016), detection of bruising in apple (Baranyai and Zude, 2008), prediction of fat content in milk (Qin and Lu, 2007), tenderness in meat (Cluff et al., 2008), firmness in plum (Rezaei Kalaj et al., 2016), and moisture content in watermelon (Mohd Ali et al., 2017), and monitoring changes in moisture content and color of fruits and vegetables during drying (Romano et al., 2012, 2016; Udomkun et al., 2014, 2016), are examples of research works done on the application of this technology for assessing properties and quality of food and horticultural materials.

Literature review shows that the image processing methods developed so far are reliable enough to assess quality of horti-food materials by light scattering technology. On the other hand, even though a lot of research and development works have been done concerning the application of light backscattering imaging in horticultural and food industry, no computer application has yet been introduced in this regard. Hence, the objective of the present work is to develop a comprehensive software package, called *LightScatter*, as a user friendly, reliable, robust,