



Subsurface inspection of food safety and quality using line-scan spatially offset Raman spectroscopy technique



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ABSTRACT

Subsurface inspection of food and agricultural products is challenging for optical-based sensing techniques due to complex interactions between light and heterogeneous or layered samples. In this study, a method for subsurface food inspection was presented based on a newly developed line-scan spatially offset Raman spectroscopy (SORS) technique. A 785 nm point laser was used as a Raman excitation source. The line-shape SORS data from the sample was collected in a wavenumber range of 0–2815 cm^{-1} using a detection module consisting of an imaging spectrograph and a CCD camera. Two layered samples, one by placing a 1 mm thick plastic sheet cut from original container on top of cane sugar and the other by placing a 5 mm thick carrot slice on top of melamine powder, were created to test the subsurface food inspection method. For each sample, a whole set of SORS data was acquired using one CCD exposure in an offset range of 0–36 mm (two sides of the incident laser point) with a spatial interval of 0.07 mm. Raman spectra from the cane sugar under the plastic sheet and the melamine powder under the carrot slice were successfully resolved using self-modeling mixture analysis (SMA) algorithms, demonstrating the potential of the technique for authenticating foods and ingredients through packaging and evaluating internal food safety and quality attributes. The line-scan SORS measurement technique provides a rapid and nondestructive method for subsurface inspection of food safety and quality.

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1. Introduction

Safety and quality examination is an important step in food production process, as many factors, such as stricter rules from regulatory agencies, customers' demands for safer and higher quality foods, and increasing foodborne illness outbreaks, have been continuously putting challenges on food inspection technologies. A variety of optical sensing techniques (e.g., ultraviolet, visible, fluorescence, Raman, infrared, and terahertz) have been researched for food safety and quality applications, in which the majority has focused on inspecting food surfaces using spectroscopy and imaging techniques. Subsurface inspection of food and

agricultural products, such as detection of food adulterants through packaging and evaluation of flesh quality under fruit skin, is a challenging task for optical-based techniques due to complex interactions between light and heterogeneous or layered samples. Advanced sensing techniques that are routinely used in the medical field, such as ultrasound (Awad, Moharram, Shaltout, Asker, & Youssef, 2012), x-ray (Mathanker, Weckler, & Bowser, 2013), and magnetic resonance imaging (MRI) (Schmidt, Sun, & Litchfield, 1996), have been adopted to evaluate internal attributes of the food, such as detecting foreign objects and defects in food materials and estimating internal physical structure of the food. However, these techniques generally cannot be used for food composition analysis due to lack of compound-specific spectral information.

Spatially resolved spectroscopy techniques have been investigated for obtaining subsurface composition information. The basic principle is to separate a point light source and a detector to allow light to travel through deep area of a sample so that subsurface

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signals can be retrieved from the light coming out of the sample surface. The concept has been adopted by reflectance and fluorescence measurement techniques, such as spatially resolved diffuse reflectance (Dam et al., 2001), fluorescence (Hyde, Farrell, Patterson, & Wilson, 2001), hyperspectral reflectance imaging (Qin & Lu, 2008), and visible/near-infrared spectroscopy (Xiong, Li, & Lin, 2012). Since visible, near-infrared, and fluorescence spectra are typically characterized by broad peaks, the mixed spectra from different sample layers are generally difficult to be mathematically resolved and assigned to the individual components. Also, light penetration depth in the reflectance and fluorescence measurements is usually limited by the relatively low intensity of the light sources (e.g., halogen and LED lights).

Raman spectroscopy is a technique capable of analyzing composition of a target with high specificity using narrow and sharp peaks typically shown in a spectrum, and it is able to obtain surface and subsurface sample information using powerful narrowband lasers as excitation sources. Three major Raman measurement modes are illustrated in Fig. 1. Backscattering geometry (Fig. 1a) is the most widely used mode owing to its simplicity and convenience. In a typical setup, a laser and a detector are arranged on the same side of the sample. The detector acquires backscattered Raman signals from the laser incident point. The backscattered Raman signals have a strong contribution from the surface layer of the sample, which generally cannot be used to retrieve internal information from heterogeneous or layered samples. In transmission geometry (Fig. 1b), the laser and the detector are arranged on the different sides of the sample. The detector acquires forward-scattered Raman signals that pass through the sample. The practical use of the transmission Raman spectroscopy was improved during its development for pharmaceutical

applications (Matousek & Parker, 2006). The technique greatly suppresses the Raman and fluorescence signals originated from the sample surfaces (e.g., tablet coatings and capsule shells), making it suitable for bulk composition analysis of diffusing and translucent materials, such as composition analysis of single soybeans (Schulmerich et al., 2012) and corn kernels (Shin, Chung, & Kwak, 2012), and differentiation of geographical origins of rice (Hwang, Kang, Lee, & Chung, 2012). However, the transmission method cannot resolve the spectra from individual layers of the sample.

Spatially offset Raman spectroscopy (SORS) (Fig. 1c) is a technique that intends to retrieve layered subsurface information by collecting Raman scattering signals from a series of surface positions laterally offset from the excitation laser (Matousek et al., 2005). The offset spectra exhibit different sensitivities to the Raman signals from the surface and the subsurface layers. The contribution of the Raman signals from the deep layers gradually outweighs that from the top layer as the source-detector distance increases. Spectral mixture analysis algorithms can be applied to an array of the SORS data to extract pure Raman spectra of the individual layers. Hence physical/chemical/biological information of the subsurface layers can be obtained based on the comparisons between the decomposed spectra and the reference Raman spectra. The SORS technique was initially developed for biomedical and pharmaceutical applications, such as noninvasive evaluation of human bone *in vivo* (Matousek et al., 2006) and authentication of pharmaceutical products through packaging (Eliasson & Matousek, 2007). Recently the technique has been used for evaluating food and agricultural products, such as nondestructive evaluation of internal maturity of tomatoes (Qin, Chao, & Kim, 2012) and quality analysis of salmon through the skin (Afseth, Bloomfield, Wold, & Matousek, 2014).

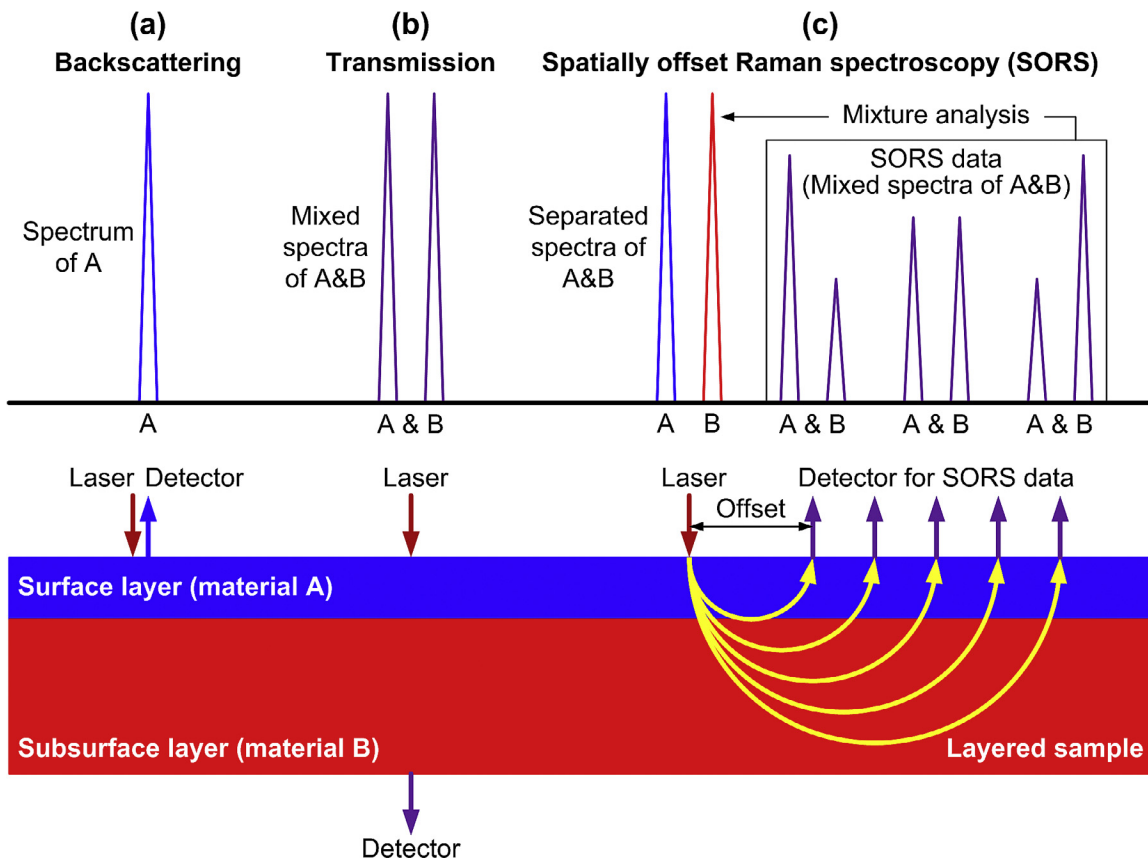


Fig. 1. Raman measurement modes: (a) backscattering, (b) transmission, and (c) spatially offset Raman spectroscopy.

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