



# Line-scan Raman imaging and spectroscopy platform for surface and subsurface evaluation of food safety and quality



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## ABSTRACT

Both surface and subsurface food inspection is important since interesting safety and quality attributes can be at different sample locations. This paper presents a multipurpose line-scan Raman platform for food safety and quality research, which can be configured for Raman chemical imaging (RCI) mode for surface inspection and spatially offset Raman spectroscopy (SORS) mode for subsurface inspection. In the RCI mode, macro-scale imaging was achieved using a 785 nm line laser up to 24 cm long with a push-broom method. In the SORS mode, a 785 nm point laser was used and a complete set of SORS data was collected in an offset range of 0–36 mm with a spatial interval of 0.07 mm using one CCD exposure. The RCI and SORS modes share a common detection module including a dispersive imaging spectrograph and a CCD camera, covering a Raman shift range from  $-674$  to  $2865\text{ cm}^{-1}$ . A pork shoulder and an orange carrot were used to test large-field-of-view (230 mm wide) and high-spatial-resolution (0.07 mm/pixel) settings of the RCI mode for food surface evaluation. Fluorescence-corrected images at selected Raman peak wavenumbers were used to view Raman-active analytes on the whole sample surfaces (e.g., fat on the pork shoulder and carotenoids over the carrot cross section). Also, three layered samples, which were created by placing carrot slices with thicknesses of 2, 5, and 8 mm on top of melamine powder, were used to test the SORS mode for subsurface food evaluation. Raman spectra from carrot and melamine were successfully resolved for all three layered samples using self-modeling mixture analysis. The line-scan Raman imaging and spectroscopy platform provides a new tool for surface and subsurface inspection for food safety and quality.

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## 1. Introduction

Current research on optical sensing technologies for food safety and quality is focused on inspecting food surfaces using a range of spectroscopy and imaging techniques, such as ultraviolet, visible, fluorescence, Raman, infrared, and terahertz. Evaluating subsurface of food and agricultural products is also important because some safety and quality attributes cannot be directly accessed from the sample surface (e.g., authenticating powdered food through packaging and inspecting fruit flesh quality under skin). Subsurface

inspection is challenging because of interference from the top layer. Advanced medical sensing technologies, such as ultrasound (Awad et al., 2012), x-ray (Mathanker et al., 2013), and magnetic resonance imaging (MRI) (Schmidt et al., 1996), have been used to assess internal characteristics of the food (e.g., foreign object detection and internal structure estimation). However, food composition information usually cannot be obtained owing to the lack of compound-specific information from these methods. One promising technique for subsurface composition analysis is spatially resolved spectroscopy, in which the incident energy from a point light source and the emerging energy from the sample surface are spatially separated. Light can emerge from interior regions of the object having undergone redirection by refraction and particle interface reflection. The measurement idea has been used in diffuse reflection (Dam et al., 2001; Qin and Lu, 2008) and fluorescence techniques (Hyde

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et al., 2001), by which subsurface detection capabilities are usually limited by short light penetration depths due to the relatively low intensities (e.g., halogen and LED lights) and high absorption of the medium. Also, considering the broad and overlapped peaks and shoulders naturally in visible, near-infrared, and fluorescence spectra, it is not easy to mathematically resolve the spectra of individual components from the mixed spatially resolved spectral data.

Raman spectroscopy is an optical sensing technique utilizing frequency shift of inelastically scattered light generated in laser-molecule interactions. The technique can be used for surface composition analysis based on sharp peaks typically observed in a Raman spectrum, and for subsurface detection using powerful narrowband lasers as excitation sources. Traditionally, a Raman measurement is conducted on a point on the sample surface due to the natural size of the laser spot, which generally cannot cover a large-size sample area. Hence spatial information cannot be obtained by the spectroscopy method. Raman chemical imaging (RCI) (Fig. 1a) is a technique equipping Raman spectroscopy with the capability of acquiring spatial information (Zoubir, 2012). Raman spectral image data (i.e., hypercube) have three dimensions including two spatial dimensions ( $x$  and  $y$ ) and one spectral dimension ( $\nu$ ). The Raman images are usually acquired with tens or hundreds of wavebands. Each pixel in the hypercube can provide a full Raman spectrum, which can be used to obtain physical/chemical/biological information of every pixel for inspection purposes. Chemical images can be created using both Raman and spatial information to visualize interesting targets on the sample surface at pixel level. Point lasers, line lasers, and global (wide-field) excitation lasers are three main types of excitation sources used in Raman imaging systems. Correspondingly there are three major methods

to collect Raman spectral images: point-scan, line-scan, and area-scan methods. Driven by growing interests from both academia and industry, the RCI technique has been researched and developed as a powerful tool with applications in many disciplines, such as agriculture, archeology, biomedicine, forensics, mineralogy, pharmaceuticals, and threat detection (Stewart et al., 2012).

Backscattering geometry is broadly used in the Raman imaging technique for surface inspection, which generally cannot provide internal information from heterogeneous or layered samples. Spatially offset Raman spectroscopy (SORS) is a technique that was originally developed for biomedical applications, such as noninvasive evaluation of human bone *in vivo* (Matousek et al., 2006) and early diagnosis of breast cancer as an adjunct to mammography (Stone et al., 2007). The SORS technique (Fig. 1b) can obtain layered surface and subsurface information by acquiring Raman spectra at a series of surface locations laterally offset from the incident laser point (Matousek et al., 2005). The offset spectra introduce sensitivity variations to the Raman signals originated from the top and the underneath layers. The spectra collected in the SORS measurement are mixed, in which the surface contribution is steadily diminished whereas the subsurface contribution is steadily amplified with the increasing of the laser-detector distance. Pure Raman spectra of the individual sample layers can be extracted from an array of the SORS data that is processed by a spectral mixture analysis algorithm. By comparing to the reference spectra, the resolved Raman spectra can be used to identify physical/chemical/biological information of the surface and subsurface layers. Besides the biomedical applications, the SORS technique has also been used in other fields, such as identification of raw pharmaceutical materials through packaging (Bloomfield et al., 2013), subsurface analysis of painted sculptures and plasters (Conti et al.,

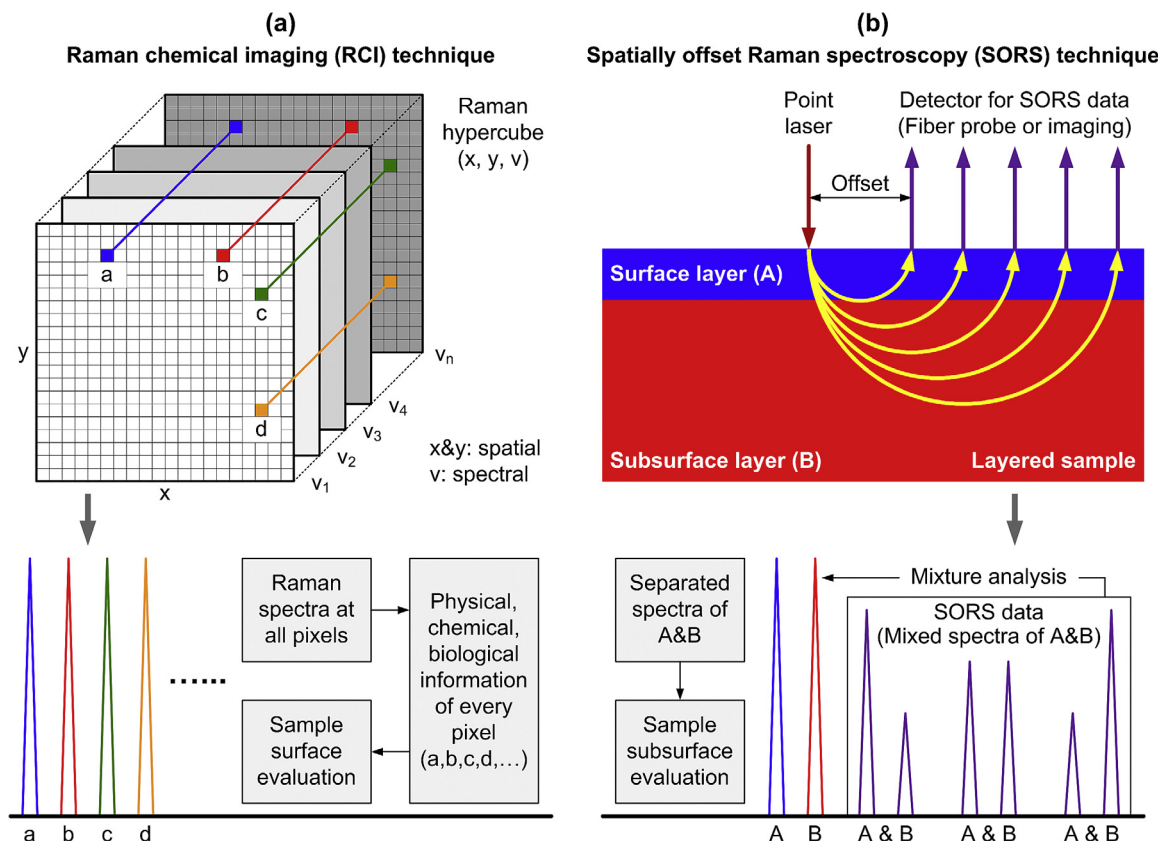


Fig. 1. (a) Raman chemical imaging (RCI) technique and (b) spatially offset Raman spectroscopy (SORS) technique.

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