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Hyperspectral Imaging Technology in Food and Agriculture

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ISSN 1571-0297
Food Engineering Series
ISBN 978-1-4939-2835-4 ISBN 978-1-4939-2836-1 (eBook)
DOI 10.1007/978-1-4939-2836-1

Library of Congress Control Number: 2015946871

Springer New York Heidelberg Dordrecht London

Printed on acid-free paper

Springer Science+Business Media LLC New York is part of Springer Science+Business Media (www.springer.com)

Preface

Over the past 15 years, we have witnessed rapid increases in R&D activities and applications of hyperspectral imaging in food and agriculture. Hyperspectral imaging integrates the main features of imaging and spectroscopic techniques so as to expand our capability of detecting minor or more sophisticated features or characteristics of an object both spatially and spectrally that would otherwise be difficult or impossible to accomplish with either imaging or spectroscopic technique. This book is intended to give a broad, comprehensive coverage of hyperspectral imaging technology and its applications in food and agriculture. It is written for both researchers who are currently engaged or interested in this area of research and advanced-level students who want to acquire special knowledge about basic concepts, principles, and applications of hyperspectral imaging. The book is organized into two parts. The first part gives readers a general introduction to the instrumentation and implementation modalities of hyperspectral imaging technology, hyperspectral image processing, and analysis techniques; it starts with basic image and spectroscopic data processing and analysis methods, followed by the specific methods and techniques for processing and analysis of hyperspectral images for quality and safety classification and prediction. The second part, consisting of ten chapters, covers a range of applications of hyperspectral imaging technology from food quality and safety inspection to plant health detection and monitoring to precision agriculture and real-time as well as microscope applications.

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Part I
Image and Spectral Analysis Techniques

Chapter 1
Introduction

Renfu Lu and Bosoon Park

For the past two decades, we have witnessed the rapid developments and wide applications of imaging and spectroscopic technologies in the food and agricultural industries. Conventional imaging technology, whether monochromatic (i.e., white/ black) or polychromatic (i.e., color-based), allows acquiring two- or even three-dimensional spatial information about an object. Using image processing and analysis methods and techniques, we quantify or classify the spatial characteristics or color attributes of food and agricultural products and crops or plants growing in the field. Since surface or external characteristics are important to the consumer's perception about product quality and, in many cases, are also a good indicator of product maturity and/or internal quality, imaging technology is being widely used in inspecting, monitoring, and grading a large class of agricultural and food products based on color, size/shape, and surface texture during postharvest handling, packing, and processing (Ruiz-Altisent et al. 2010; Davies 2010). Applications of imaging technology are also increasing in production agriculture such as precision chemicals application, crop yield monitoring, vision guidance for off-load vehicles, and robotic or automatic agricultural operations from seeding to weeding to harvesting (Lee et al 2010). Despite all these successful applications, conventional imaging technology generally is not suitable for detection or assessment of intrinsic properties and characteristics of products, whether they are physical and/or chemical (e.g., moisture, protein, sugar, acid, firmness or hardness, etc.).

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B. Park, R. Lu (eds.), *Hyperspectral Imaging Technology in Food and Agriculture*,
Food Engineering Series, DOI 10.1007/978-1-4939-2836-1_1

Spectroscopy, on the other hand, represents another major class of optical technology, which has been increasingly used in food and agriculture in recent years. It normally covers a portion of the electromagnetic spectrum (e.g., from x-ray to ultraviolet to visible and to infrared), and enables acquiring spectral absorption and scattering information from an object. The technology is especially suitable for quantitative or qualitative analysis of product composition and properties, because the absorption characteristics or spectral signatures of food and agricultural products are related to the chemical properties or composition as well as structural characteristics. In the early days, spectroscopy technology was primarily used as a laboratory tool due to high cost in instrumentation and slow speed or complexity in measurement. However, advances in optics, computer, and chemometric or mathematical methods for analyzing spectral data, along with dramatic reduction in instrument cost, have enabled spectroscopy technology to go well beyond the traditional domain of application nowadays. For instance, near-infrared spectroscopy is now being used for real-time, rapid online analysis, monitoring and inspection of the physical and chemical properties and compositions of many food and agricultural products (Nicolai et al. 2007). The miniaturization of spectrophotometers has further made it possible for on-site, low-cost measurement of the quality or maturity of crops in both pre- and post-harvest. In contrast to imaging technique, spectroscopic measurements normally do not provide spatially-resolved information about products.

Today, the agricultural and food industries are increasingly concerned about the sustainable production and delivery of consistent, high quality and safe food products. For many applications, there is a need for more accurate assessment and classification of food and agricultural products based on their intrinsic characteristics and properties, which may be difficult to achieve with conventional imaging or spectroscopy technology. Food and agricultural products are known for their large variations in properties and composition within and between individual product items. For instance, the quality of individual kernels, in terms of protein and moisture content, for the same lot of wheat can vary greatly (Dowell et al. 2006). Fruit growing in the same orchard or even on the same trees can have large variations in maturity and other postharvest quality attributes. Meat tenderness is greatly influenced by the type, location and direction of meat muscles (Prieto et al. 2009). The soluble solids content and textural properties like firmness vary with location and/or orientation within the same apple fruit and melon (Abbott and Lu 1996; Sugiyama 1999). In the past decade, food safety and security has received increased attention from the government as well as the general public. Prevention and early detection of food contaminants and pathogens is critical to ensure safe production and delivery of food products to the consumer. Pathogen contamination caused by animal feces is one common food safety concern, and there is zero tolerance for fecal contamination on poultry and meat products, which has been imposed in the United States and many other countries. It is difficult to achieve accurate detection of fecal matter from the products using color or monochromatic imaging technology because fecal contaminants on meat and poultry products can be indistinctive, in some cases, from the bovine animal or poultry carcasses. While visible/near-infrared spectroscopy can achieve superior detection results, it cannot pinpoint the exact location and, thus, would miss contaminants that are confined to small areas on the products. In these and many other instances, conventional imaging or spectroscopy technology has been proven insufficient to meet the food safety inspection requirements (Park et al. 2006). Thus, it is desirable or even necessary to develop and deploy a new, more effective inspection system to measure the spatial and temporal variations in the quality and condition of food products and crops growing in the field, and to detect food safety hazards that are present in harvested or processed food products.

In view of the respective merits and shortcomings of imaging and spectroscopy technologies, it is clear that great advantages can be gained if we can combine the major features of these two platforms into one single platform. The integration of imaging and spectroscopy has led to an emerging, new generation of optical technology, called *hyperspectral imaging* or *imaging spectroscopy*. Hyperspectral imaging combines the main features of imaging and spectroscopy to acquire spectral and spatial information from products simultaneously. Depending on application needs, a hyperspectral imaging system can cover a specific spectral range in the ultraviolet (UV), visible, near-infrared (NIR), or shortwave infrared (SWIR) region. The emergency of hyperspectral imaging is closely related to the advances in imaging, spectroscopy, and computer technologies in the past two decades. In the late 80s and early 90s, hyperspectral imaging technology was first used in satellite remote sensing for environmental monitoring, geological search or mineral mapping, atmosphere composition analysis and monitoring, military reconnaissance or target detection, and crop yield or growing condition monitoring or prediction (Moran et al. 1997). Development and application of hyperspectral imaging for quality and safety inspection of agricultural products has not begun until the late 1990s (Lu and Chen 1998; Martinsen and Schaare 1998). Since then, we have seen significant increases in R&D activities in hyperspectral imaging for food and agricultural product evaluation due to the advances in the high-performance digital camera and imaging spectrograph, two key optical components in the hyperspectral imaging system. Over the past 10 years, many technical symposia dedicated to hyperspectral imaging in food and agricultural applications have been held by professional societies like the American Society of Agricultural and Biological Engineers (ASABE), International Society for Optical Engineering (SPIE), and International Commission for Agricultural and Biological Engineering (CIGR). The international journal "*Sensing and Instrumentation for Food Quality and Safety*" (now renamed "*Journal of Food Measurement and Characterization*") published the first special issue "Hyperspectral and Multispectral Imaging for Food Quality and Safety" in 2008 (Lu and Park 2008). Several review articles have been written in recent years about hyperspectral imaging technology and its applications in food and agriculture (Gowen et al. 2007; Ruiz-Altisent et al. 2010). The increasing interest in hyperspectral imaging for food and agriculture applications has been further demonstrated by the exponential increase in the number of scientific