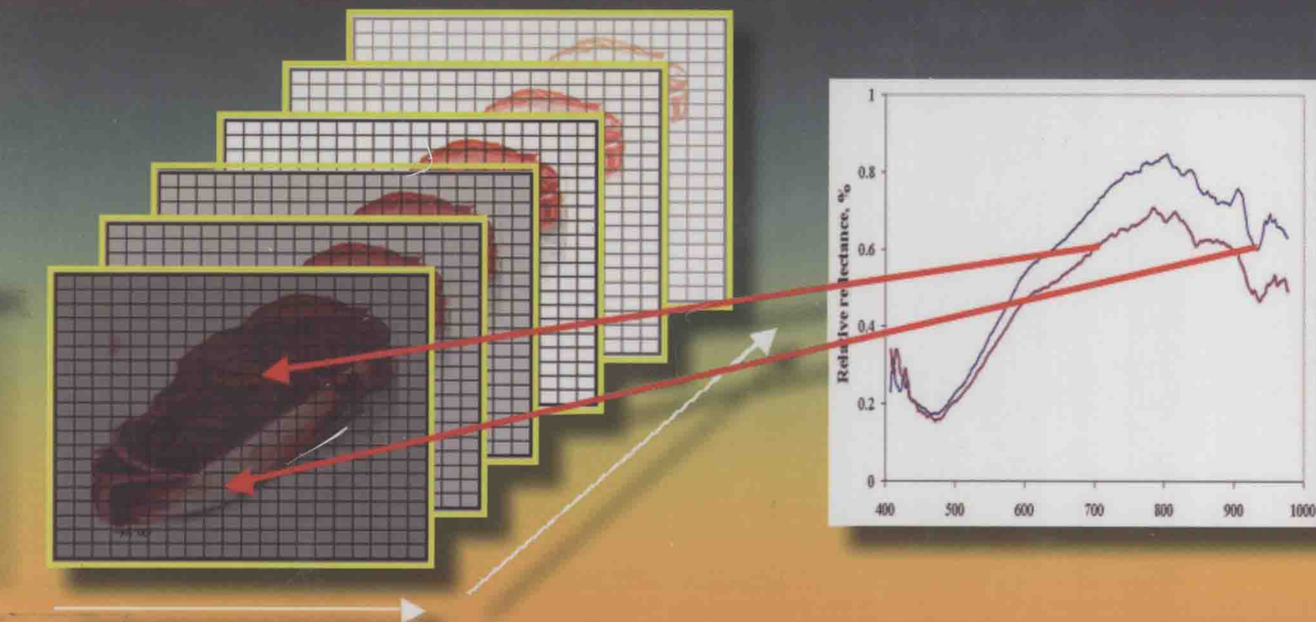
HYPERSPECTRAL IMAGING FOR FOOD QUALITY ANALYSIS AND CONTROL



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Hyperspectral Imaging for Food Quality Analysis and Control

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32 Jamestown Road, London NW1 7BY, UK
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
525 B Street, Suite 1900, San Diego, CA 92101-4495, USA

First edition 2010

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British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN : 978-0-12-374753-2

For information on all Academic Press publications visit our website at elsevierdirect.com

Typeset by TNQ Books and Journals Pvt Ltd.
www.tnq.co.in

Printed and bound in United States of America

10 11 12 13 14 15 10 9 8 7 6 5 4 3 2 1

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Hyperspectral Imaging for Food Quality Analysis and Control

About the Editor

Born in Southern China, Professor Da-Wen Sun is a world authority in food engineering research and education, he is a Member of Royal Irish Academy which is the highest academic honour in Ireland. His main research activities include cooling, drying, and refrigeration processes and systems, quality and safety of food products, bioprocess simulation and optimisation, and computer vision technology. Especially, his innovative studies on vacuum cooling of cooked meats, pizza quality inspection by computer vision, and edible films for shelf-life extension of fruit and vegetables have been widely reported in national and international media. Results of his work have been published in more than 200 peer-reviewed journal papers and over 200 conference papers.

He received a first class BSc Honours and MSc in Mechanical Engineering, and a PhD in Chemical Engineering in China before working in various universities in Europe. He became the first Chinese national to be permanently employed in an Irish University when he was appointed College Lecturer at National University of Ireland, Dublin (University College Dublin) in 1995, and was then continuously promoted in the shortest possible time to Senior Lecturer, Associate Professor and Full Professor. Dr Sun is now Professor of Food and Biosystems Engineering and Director of the Food Refrigeration and Computerised Food Technology Research Group at University College Dublin.

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As a leading educator in food engineering, Professor Sun has significantly contributed to the field of food engineering. He has trained many PhD students, who have made their own contributions to the industry and academia. He has also given lectures on advances in food engineering on a regular basis in academic institutions internationally and delivered keynote speeches at international conferences. As a recognized authority in food engineering, he has been conferred adjunct/visiting/consulting professorships from ten top universities in China, including Zhejiang University, Shanghai Jiaotong University, Harbin Institute of Technology, China Agricultural University, South China University of Technology, and Jiangnan University. In recognition of his significant contribution to food engineering worldwide and for his outstanding leadership in the field, the International Commission of Agricultural Engineering (CIGR) awarded him the CIGR Merit Award in 2000 and again in 2006, the Institution of Mechanical Engineers (IMechE) based in the UK named him "Food Engineer of the Year 2004", and in 2008 he was awarded CIGR Recognition Award in honour of his distinguished achievements as one of the top one percent of agricultural engineering scientists in the world.

He is a Fellow of the Institution of Agricultural Engineers and a Fellow of Engineers Ireland (the Institution of Engineers of Ireland). He has also received numerous awards for teaching and research excellence, including the President's Research Fellowship, and has twice received the President's Research Award of University College Dublin. He is a Member of CIGR Executive Board and Honorary Vice-President of CIGR, Editor-in-Chief of *Food and Bioprocess Technology – an International Journal* (Springer), Series Editor of the "Contemporary Food Engineering" book series (CRC Press/ Taylor & Francis), former Editor of *Journal of Food Engineering* (Elsevier), and Editorial Board Member for *Journal of Food Engineering* (Elsevier), *Journal of Food Process Engineering* (Blackwell), *Sensing and Instrumentation for Food Quality and Safety* (Springer), and *Czech Journal of Food Sciences*. He is also a Chartered Engineer.

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Preface

Based on the integration of image processing and spectroscopy techniques, hyperspectral imaging is a novel technology for obtaining both spatial and spectral information from an object. In recent years, hyperspectral imaging has rapidly emerged as and matured into one of the most powerful and fastest-growing non-destructive tools for food quality analysis and control. Using the hyperspectral imaging technique, the spectrum associated with each pixel in a food image can be used as a fingerprint to characterize the biochemical composition of the pixel, thus enabling the visualization of the constituents of the food sample at pixel level. As a result, hyperspectral imagery provides the potential for more accurate and detailed information extraction than is possible with any other type of technology for the food industry.

In order to reflect the rapid developing trend of the technology, it is timely to publish *Hyperspectral Imaging for Food Quality Analysis and Control.* The book is divided into two parts. Part 1 deals with principles and instruments, including theory, image data treatment techniques, and hyperspectral imaging instruments. Part 2 covers its applications in quality analysis and control for various foods and agricultural products.

As the first book in the subject area, *Hyperspectral Imaging for Food Quality Analysis and Control* is written by the most active peers in this field, with both academic and professional credentials, highlighting the truly international nature of the work. The book is intended to provide the engineer and technologist working in research, development, and operations in the food industry with critical and readily accessible information on the art and science of the hyperspectral imaging technology. The book should also serve as an essential reference source to undergraduate and postgraduate students and researchers in universities and research institutions.

Contents

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PART 1

Fundamentals

CHAPTER 1

Principles of Hyperspectral Imaging Technology

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CONTENTS

1.1. INTRODUCTION

During the past few decades a number of different techniques have been explored as possible instrumental methods for quality evaluation of food products. In recent years, *hyperspectral imaging* technique has been regarded as a smart and promising analytical tool for analyses conducted in research, control, and industries. Hyperspectral imaging is a technique that generates a spatial map of spectral variation, making it a useful tool in many applications. The use of hyperspectral imaging for both automatic target detection and recognizing its analytical composition is relatively new and is an amazing area of research. The main impetus for developing a hyperspectral imaging system was to integrate spectroscopic and imaging techniques to enable direct identification of different components and their spatial distribution in the tested sample. A hyperspectral imaging system produces a two-dimensional spatial array of vectors which represents the spectrum at each pixel location. The resulting three-dimensional dataset containing the two spatial dimensions and one spectral dimension is known as the *datacube* or hypercube (Chen *et al.*, 2002; Kim *et al.*, 2002; Mehl *et al.*, 2004; Schweizer & Moura, 2001). The advantages of hyperspectral imaging over the traditional methods include minimal sample preparation, nondestructive nature, fast acquisition times, and visualizing spatial distribution of numerous chemical compositions simultaneously. The hyperspectral imaging technique is currently tackling many challenges to be accepted as the most preferable analytical tool in identifying compositional fingerprints of food

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products and their authentication. The need for fast and reliable methods of authenticity and object identification has increased the interest in the application of hyperspectral imaging for quality control in the agricultural, pharmaceutical, and food industries. Moreover, enhancement in instrumental developments, the availability of high-speed computers, and the development of appropriate chemometric procedures will allow this technique to be dominant in the future. This chapter presents the fundamentals, characteristics, configuration, terminologies, merits and demerits, limits and potential of hyperspectral imaging. Basics and theoretical aspects relating to this technique, the information that can be supplied, and the main features of the instrumentation are presented and briefly discussed. The final part of the chapter concerns a general overview of the main steps involved in analyzing hyperspectral images. The potential applications of hyperspectral imaging in food analysis will be explained in more detail in the relevant chapters of this book

1.1.1. The Necessity for Automating Quality Assessment

With increased expectations for food products with high quality and safety, the need for accurate, fast, and objective quality determination of these characteristics continues to grow. Quality assurance is one of the most important goals of any industry. The ability to manufacture high-quality products consistently is the basis for success in the highly competitive food industry. It encourages loyalty in customers and results in an expanding market share. The quality assurance methods used in the food industry have traditionally involved human visual inspection. Such methods are tedious, laborious, time-consuming, and inconsistent. As plant throughput increased and quality tolerance tightened, it became necessary to employ automatic methods for quality assurance and quality control (Gunasekaran, 1996). Also, the increased awareness and sophistication of consumers have created the expectation for improved quality food products. Consumers are always demanding superior quality of food products, i.e., higher quality for an individual food item, consistency of products in a batch, and enhanced food safety as a whole (Nagata *et al.*, 2005). This in turn has increased the need for enhanced quality monitoring. In general, automation of a quality assessment operation not only optimizes quality assurance but more importantly it also helps in removing human subjectivity and inconsistency. Moreover, automation usually increases the productivity and changes the character of the work, making it less arduous and more attractive. Considering the fact that the productivity of a person working in a mechanized and automated environments is approximately ten times that of a manual worker, this has stimulated progress in the development of many novel sensors and instruments for the food industry, often by technology transfer from other industrial sectors, including medical, electronic, and nonclinical sectors (Abdullah *et al.*, 2004). If quality evaluation is achieved automatically, production speed and efficiency can be improved drastically in addition to increased evaluation accuracy, with an accompanying reduction in production costs.

1.2. RELATIONSHIP BETWEEN SPECTROSCOPY, IMAGING, AND HYPERSPECTRAL IMAGING

In the past two decades, considerable progress has been accomplished in the development of new sensing technologies for quality and safety inspection of agricultural and food products. These new sensing technologies have provided us with unprecedented capabilities to measure, inspect, sort, and grade food products effectively and efficiently. Consequently, some smart methods to evaluate quality and quality-related attributes have been developed using advanced techniques and instrumentation. Most recently, the emphasis has been on developing sensors for real-time, nondestructive systems. As a result, automated visual inspection by computer-based systems has been developed in the food industry to replace the traditional inspection by human inspectors because of its cost-effectiveness, consistency, superior speed, and accuracy. *Computer vision* technology utilizing image processing routines is one alternative which became an integral part of the industry's move towards automation. Combined with an illumination system, a computer vision system is typically based on a personal computer in connection with electrical and mechanical devices to replace human manipulative effort in the performance of a given process (Du & Sun, 2006). Image processing and image analysis are the core of computer vision, involving mathematics, computer science and software programming. This system has a great ability in evaluation cycle to apply the principle: several objects per second instead of several seconds per object.

Unfortunately, the computer vision system has some drawbacks that make it unsuitable for certain industrial applications. It is inefficient in the case of objects of similar colours, inefficient in the case of complex classifications, unable to predict quality attributes (e.g. chemical composition), and it is inefficient for detecting invisible defects. Since machine vision is operated at visible wavelengths, it can only produce an image registering the external view of the object and not its internal view. Situations exist whereby

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