

Spectrometric imaging: Modalities, advancements, applications.

Olivia White*

Department of Imaging Chemistry, University of Queensland, Brisbane, Australia

Introduction

Hyperspectral imaging combines spectroscopy and imaging, offering detailed spatial and spectral information. This review details its principles, various data acquisition methods, and highlights its diverse applications, especially in food quality assessment for non-destructive detection and analysis [1].

Mid-infrared (MIR) spectrometric imaging has become a powerful tool in biomedicine, providing molecular-specific information from tissue samples without labels. This article discusses the latest innovations in MIR imaging techniques and their growing impact on disease diagnosis and understanding biological processes [2].

Raman spectroscopic imaging offers label-free, chemically specific insights into biological samples. This review provides an overview of its principles, instrumentation, and various applications in biological and medical research, emphasizing its ability to resolve cellular and subcellular structures based on molecular composition [3].

Mass spectrometric imaging (MSI) allows for label-free visualization of molecular distributions directly within tissue sections. This paper reviews the significant progress in MSI techniques, including new ionization methods and instrumentation, and highlights its expanding role in pharmacokinetics, disease biomarker discovery, and clinical diagnostics [4].

Near-infrared hyperspectral imaging is proving invaluable for non-destructive quality assessment in the agri-food sector. This review comprehensively covers its application for fruits and vegetables, detailing how it identifies ripeness, detects defects, and measures internal quality attributes, reducing waste and improving product consistency [5].

Coherent Raman imaging, encompassing CARS and SRS, provides fast, label-free chemical imaging with high sensitivity and spatial resolution. This article discusses its recent breakthroughs and expanding clinical utility, particularly in cancer diagnosis, neuroscience, and drug delivery studies, showcasing its potential for real-time pathology [6].

Deep learning methods have revolutionized hyperspectral image

analysis by offering superior performance in feature extraction, classification, and unmixing. This review summarizes the cutting-edge deep learning architectures and techniques tailored for hyperspectral data, detailing their advantages in remote sensing, environmental monitoring, and target detection [7].

Terahertz (THz) spectrometric imaging, operating in a unique spectral window, offers non-ionizing, label-free chemical identification and depth penetration. This article reviews the advancements in THz imaging systems and their diverse applications in security screening, biomedical diagnostics, and material characterization, highlighting its potential for non-destructive testing [8].

Fourier Transform Infrared (FTIR) spectrometric imaging provides detailed molecular maps of biological tissues. This review delves into its current state and emerging prospects in clinical diagnostics, illustrating its utility in identifying disease markers, grading tumors, and monitoring therapeutic responses, emphasizing its label-free and non-invasive nature [9].

Ultrafast spectrometric imaging allows for rapid acquisition of chemical information across a sample, pushing the boundaries of real-time analysis. This paper explores the fundamental principles and recent technological breakthroughs enabling high-speed chemical mapping, demonstrating its applications in reaction monitoring, flow cytometry, and dynamic biological processes [10].

Conclusion

Spectrometric imaging is a dynamic and evolving field, presenting a suite of powerful, label-free analytical techniques for comprehensive molecular analysis across diverse scientific, industrial, and medical applications. This collection of reviews and articles highlights a range of advanced imaging modalities. Hyperspectral imaging, encompassing both broad hyperspectral and specialized Near-infrared (NIR) variants, delivers detailed spatial and spectral information, proving indispensable for non-destructive quality assessment, particularly in the agri-food sector where it identifies ripeness and defects [1, 5]. Mid-infrared (MIR) and Fourier Transform Infrared (FTIR) spectrometric imaging are crucial for biomedicine and clinical diagnostics, providing precise molecular maps of tissue

*Correspondence to: Olivia White, Department of Imaging Chemistry, University of Queensland, Brisbane, Australia. E-mail: olivia.white@uq.edu.au

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samples and aiding in disease marker identification, tumor grading, and monitoring therapeutic responses [2, 9]. Raman spectroscopic imaging, including its advanced Coherent Raman forms (CARS and SRS), offers chemically specific insights into biological structures at high sensitivity and resolution, with significant utility in cancer diagnosis, neuroscience, and real-time pathology [3, 6]. Mass Spectrometric Imaging (MSI) provides label-free visualization of molecular distributions within tissue, expanding its impact on pharmacokinetics and biomarker discovery [4]. Additionally, Terahertz (THz) spectrometric imaging leverages a unique spectral window for non-ionizing chemical identification and depth penetration, applicable in security, biomedicine, and material characterization [8]. Crucially, methodological advancements like deep learning are revolutionizing hyperspectral image analysis, improving feature extraction and classification for remote sensing and environmental monitoring [7]. The development of ultrafast spectrometric imaging further pushes the boundaries for real-time chemical mapping, enabling the study of dynamic biological processes and reaction monitoring [10]. Collectively, these innovations significantly advance non-destructive testing, enhance diagnostic capabilities, and deepen fundamental biological understanding.

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