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Review

Recent advances in emerging imaging techniques for non-destructive detection of food quality and safety

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A B S T R A C T

Food quality and safety issues are increasingly attracting attention. Emerging imaging techniques have particular advantages in non-destructive detection of food quality and safety. This review looks at the trends in applying these emerging imaging techniques to analysis of food quality and safety, in particular, hyperspectral imaging, magnetic resonance imaging, soft X-ray imaging, ultrasound imaging, thermal imaging, fluorescence imaging, and odor imaging. On the basis of the observed trends, we also present the technical challenges and future outlook for these emerging imaging techniques.

Contents

1. Introduction

Food is any substance consumed to provide nutritional support for the human body. It is usually of plant or animal origin, and contains essential nutrients, such as carbohydrates, fats, proteins, vitamins and minerals. Today, most of the food energy consumed by the world population is supplied by food industry. Food quality and safety control, which directly relates to human health and the sustainable development of a country, has received special emphasis from government and has attracted great social concern and global attention. With the rapid development of economies, consumers' rising and persistent demand for safe food and better quality of food and beverage is emphasized. Food quality involves the quality characteristics of food that are acceptable to consumers, including such external factors as appearance (size, shape, col-

Abbreviations: ANN, Artificial neural network; BAI, Backscattered amplitude integral; BIL, Band interleaved by line; BIP, Band interleaved by pixel; BSQ, Band sequential; CCD, Charge-coupled device; CNR, Contrast-to-noise ratio; CT, Computed tomography; FI, Fluorescence imaging; FMI, Fluorescence microscopic imaging; FPA, Focal plane array; HCA, Hierarchical clustering analysis; HSI, Hyperspectral imaging; IR, Infrared; LCSM, Laser confocal scanning microscopy; LDA, Linear discriminant analysis; LED, Light-emitting diode; MFA, Multifractal analysis; MLR, Multi-linear regression; MRI, Magnetic resonance imaging; NMR, Nuclear magnetic resonance; OI, Odor imaging; PCA, Principal component analysis; QA, Quality assurance; QC, Quality control; VIS/NIR, Visible/Near infrared; RBF, Radial basis function; RF, Radio frequency; RFC, Radio frequency correlation; RFS, Radio frequency sampling; RMI, Raman microscopic imaging; SVM, Support vector machine; 3D, Three-dimensional; TI, Thermal imaging; UI, Ultrasound imaging; VOC, Volatile organic compound; XRI, X-ray imaging.

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or, gloss and consistency), texture, and flavor, and other internal factors (chemical, physical and microbial).

Food quality is an important food-manufacturing requirement, because consumers are susceptible to any form of contamination that may occur during the manufacturing processes. Besides ingredient quality control (QC), there are also sanitation requirements. It is important to ensure that the food-processing environment is as clean as possible in order to produce the safest possible food for the consumer. Food quality also needs a product traceability and recall system. It also deals with labeling issues to ensure there are correct ingredient and nutritional information.

Food safety is a scientific discipline describing handling, preparation, and storage of food in ways that prevent foodborne illness. Food hazard can be divided into three parts:

- physical hazards (staples, nails, screws, bolts, glass particles and splinters);
- chemical hazards (pesticides, mold, herbicides, contamination from rodents, grease, heavy metals, washing and sanitary compounds);
- environmental pollution and pollution caused by human activity (pathogenic bacteria from soil, excrements, parasites and viruses).

Pathogenic bacteria can be transferred by means of poor hygiene, human diseases and contaminated water or compost [1]. Food can serve as a growth medium that consists largely of water, protein, lipid and polysaccharides for bacteria that can cause food poisoning. Debates on genetic food safety include such issues as impact of genetically-modified food on the health of further generations and genetic pollution of the environment, which can destroy natural biological diversity. It is especially important for foods and agricultural products to have a high degree of safety, and inspections for QC include biological, chemical and physical tests.

Food quality assurance (QA) has always been one of the most difficult problems associated with handling, processing, sorting and ensuring safety in the food industry. Food quality is monitored traditionally by human panel test, chemical analytical measurement and mechanical methods. The human panel test has been widely used in food-quality assessment, for example, tea-quality grade identification, wine-quality analysis and dairy-product evaluation. However, this method is time consuming and purely subjective, and is affected by external factors (e.g., adaptation, fatigue and state of mind) [1]. For the determination of the components related to food quality and safety, conventional chemical analysis is generally adopted. But this method is expensive, laborious, and invasive, and it is possible only in laboratories since instruments are required for the purpose. Moreover, complicated sample preprocessing is usually required, and causes difficulty for real-time and on-line monitoring in food manufacturing. At present, foreign substances in food are detected using mainly mechanical and optical methods. These techniques detect a large portion of the foreign substances due to their difference in mass (mechanical sieving), color (optical method) and surface density (ultrasonic detection). Despite the numerous different methods, a considerable proportion of the foreign substances remain undetected [2]. Thus, non-destructive, non-contact and fast measurement methods are in great demand for on-line industrial QC tasks.

In recent years, imaging technologies have become valuable tools in all major areas of application, particularly due to recent technological developments in camera technology and the processing power of computer hardware. This review looks at the status in the application of emerging imaging techniques to detection of food quality and safety especially reviewing the applications of hyperspectral imaging (HSI), magnetic resonance imaging (MRI), X-ray imaging (XRI), ultrasound imaging (UI), thermal imaging (TI), fluorescence imaging (FI) and odor imaging (OI). Each of the wide range of different imaging modalities has its own individual characteristics. For example, XRI is appropriate if a fracture is suspected, because X-rays are good at imaging bones [3]. The relative advantage of any particular modality lies essentially in the mechanism of the contrast in the images that it produces. In this respect, UI is rather versatile [4].

Previous research papers and reviews, complementary to the scope of this review, have covered broader and related areas of research. Señorans et al. [5] reviewed a group of new analytical techniques, including food image analysis, and their use for food and process control. Du et al. [6] summarized recent developments in image-processing techniques for food-quality evaluation; image acquisition, image segmentation, feature extraction and classification methods were reviewed. Mathiassen et al. [7] reviewed imaging technologies for inspecting fish and fish products, which included visible/near-infrared light (VIS/NIR) imaging, VIS/NIR spectral imaging, computed tomography (CT) XRI, and MRI.

Herein, we review in detail the trends in the application of emerging imaging techniques to analysis of food quality and safety, particularly HSI, MRI, soft XRI, UI, TI, FI and OI techniques. We also present the technical challenges and future outlook for these emerging imaging techniques.

2. Emerging imaging techniques

2.1. Hyperspectral imaging

The HSI technique, as a chemical or spectroscopic imaging analytical tool, has found application in diverse fields, such as astronomy, agriculture, pharmaceuticals, and medicine. It is an emerging technique that integrates conventional imaging and spectroscopy to attain both spatial and spectral information from an object. The images obtained, commonly called hypercubes, are three-dimensional (3D) data cubes, which are made up of hundreds of contiguous wavebands for each spatial position of a target studied, as shown in Fig. 1. Consequently, spectra of each pixel can be used to characterize the composition of that specific position, and surface-feature information can be obtained according to the spatial images. There are two conventional methods for hyperspectral image acquisition namely, the "staring imager" configuration and "push-broom" acquisition [8].

The "push-broom" acquisition involves acquisition of simultaneous spectral measurements from a series of adjacent spatial positions – this requires relative movement between the object and the detector. Some instruments produce hyperspectral images based on a point step and acquiring mode: spectra are obtained at single points on a sample, and then the sample is moved and another spectrum taken. Hypercubes obtained using this configuration are stored as the band interleaved by pixel (BIP) format. Advances in detector technology have reduced the time required to acquire hypercubes. Line-mapping instruments record the spectrum of each pixel in a line of sample that is simultaneously recorded by an array detector; and the resultant hypercube is stored in the band interleaved by line (BIL) format [8]. HSI systems based on the "push-broom" acquisition typically contain the following components: objective lens, spectrograph, camera, acquisition system, translation stage, illumination and computer. Fig. 2(a) shows an HSI system based on a "push-broom" acquisition, and a 3D data cube, often called "hypercube", was obtained using this system, as shown in Fig. 2(b).