MULTISENSOR SYSTEMS FOR DETECTING FOOD ALLERGENS: GLUTEN, LACTOSE, PEANUT PROTEIN

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Introduction

Food allergens remain a serious health threat: gluten above 20 ppm triggers celiac disease, lactose over 0.1% causes intolerance in millions, and peanut protein even at 0.2 ppm can lead to anaphylactic shock. Traditional laboratory methods—ELISA for proteins, enzymatic kits for sugars, PCR for DNA—require separate tests, specialized equipment, several hours, and significant costs. Multisensor systems solve this problem radically: a single small sample (0.1–0.5 g) simultaneously passes through multiple analytical channels based on IR spectroscopy, spectrophotometry, and mass spectrometry, with artificial intelligence integrating the data to deliver a complete allergen profile in 10–30 seconds. This approach not only accelerates control but also makes it accessible in field conditions—from production lines to home kitchens.

Main Part

The molecular targets of each allergen determine the choice of technology. Gluten, represented by gliadin and glutenin with peptide bonds rich in proline and glutamine, is optimally detected using IR spectroscopy in ATR-FTIR mode: characteristic peaks in the amide I (1630–1680 cm^{-1}) and amide II (1510–1580 cm^{-1}) regions are reliably captured even in complex matrices—soups, sauces, baked goods. The method requires no reagents, works with any consistency, and achieves sensitivity of 2–5 ppm thanks to chemometric algorithms. Lactose, a disaccharide of galactose and glucose with a β-1,4 bond, is analyzed by spectrophotometry: β-galactosidase hydrolyzes the molecule, glucose is oxidized to form a colored product, and absorption is measured at 540 nm; this is a simple, inexpensive, and fast method with a threshold of 0.01–0.05%, ideal for dairy products. Peanut protein—thermostable globulins Ara h1 (6.3 kDa), Ara h2 (17 kDa), Ara h3 (60 kDa)—requires high specificity, provided by mass spectrometry such as MALDI-TOF or ESI-QTOF: ionized molecules are separated by time-of-flight, forming a unique mass spectrum that distinguishes peanuts from other nuts with sensitivity of 0.1–1 ppm.

The architecture of multisensor platforms is built around a microfluidic cartridge: the sample is homogenized in buffer in 30 seconds, the flow is divided into three channels where measurements occur in parallel—IR beam passes through an ATR cell, the enzymatic reaction is recorded by a photodetector, and molecules are ionized and analyzed in a miniature mass spectrometer. Miniaturization is achieved through MEMS technologies: IR chips 1×1 cm, micropumps for microliter flows, vacuum modules weighing 150 g and consuming 3–5 W. Data processing occurs locally on edge devices with AI models weighing 8–10 MB: a multimodal neural network based on CNN and Transformer combines spectra, color curves, mass peaks, and, if necessary, product photos and label text via OCR, achieving 98% accuracy on tens of thousands of real samples.

The advantages are clear: speed dozens of times higher than laboratory methods, analysis cost of 2–8 dollars, versatility for any matrix, cross-verification of channels. Challenges—matrix interferences, hydrolyzed forms, calibration—are addressed through filtration, AI decomposition, built-in standards, and cloud model updates. Applications span the food industry (HACCP), restaurants, home control, customs, schools, and hospitals. Prospects include expansion to five allergens by 2026, integration with AR glasses in 2027, CRISPR-based biochips by 2028, and wearable systems with real-time saliva analysis by 2030.

Conclusion

Multisensor systems based on IR spectroscopy, spectrophotometry, and mass spectrometry are not just a technological evolution but a revolution in food allergen control. They transform complex, multi-step analysis into a fast, accessible, and reliable process where one check protects against multiple threats simultaneously. The combination of physical methods with artificial intelligence creates a new standard of safety, turning allergy from constant anxiety into a manageable risk—from the production line to everyday meals.

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