Line-scan imaging for high-speed food safety inspection

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New spectral-imaging technologies can deliver online safety and quality inspection of food and agricultural products on high-throughput processing lines.

Concerns about food safety and quality are rising with every new outbreak of foodborne illness in the US and worldwide. Recent incidents include bacterial contamination of spinach, peppers, and peanuts. Chemical and biological food properties can often be assessed by spectroscopic methods, while machine vision is already regularly used for sorting by physical attributes. However, high speeds and large product volumes present significant challenges to improving real-time online inspection across the food and agricultural industries. When online inspection is not otherwise mandated by law, routine offline random sampling offline is common.

New spectral-imaging techniques combine the advantages of spectroscopy and machine vision in addressing food quality and safety problems. For example, hyperspectral imaging methods provide full-spectrum data (often hundreds of spectral data points) for every pixel in food-product images, enabling spectral and spatial analysis for correlation to composition, contaminants, and physical attributes (such as size and shape). Because of its speed restrictions, hyperspectral imaging has been used primarily as a research tool to develop rapid online inspection methods based on only a few spectral data points. To address high-speed inspection requirements, we developed a line-scan hyperspectral-imaging platform for commercial processing lines that can simultaneously perform multiple inspection algorithms to target different safety and quality problems.

As objects cross a linear field of view, line-scan imaging rapidly acquires a series of narrow images (of only one pixel wide) that can then be analyzed. Full-spectrum hyperspectral data can then be selectively processed using multispectral algorithms for specific tasks in contaminant detection, disease identification, or size grading. Our platform was developed to simultaneously accommodate both hyperspectral fluorescence imaging using high-intensity UV (UV-A) excitation and visible/near-IR (Vis/NIR) hyperspectral reflectance imaging. Multispectral algorithms can be implemented by the same system without any changes to the optical sensing components, eliminating the need for conversion/calibration of a separate imaging system. The associated software can perform real-time hypercube image visualization and hyperspectral image analysis to help select the optimal wavelengths.

Figure 1 shows the critical components of our line-scan imaging platform. The imaging spectrograph disperses incoming light into a continuous spectrum across the electron-multiplying CCD (EMCCD) camera. The EMCCD camera is suitable for imaging with very short exposure times, while its hardware
performs image binning, waveband selection, and fast pixel readout. These features are critical to the system’s processing speed and flexibility for both hyperspectral and multispectral imaging.

Our line-scan imaging platform was used to develop a multitask inspection system for apples. First, we developed algorithms to detect and differentiate individual apples on a commercial sorter operating at three to four apples per second. Samples included uncontaminated normal Red and Golden Delicious apples, uncontaminated apples exhibiting surface defects, and normal and defective apples contaminated with smears of fecal matter, both visible and visually indistinguishable. Reflectance images at 750 and 800nm identified defects such as bruises while fluorescence images at 530 and 665nm detected contamination and differentiated it from surface defects. Simultaneous visible fluorescence images and NIR reflectance images used a NIR long-wavelength-pass filter (750nm) to eliminate reflectance in the visible spectrum and a long-pass filter (450nm) over the C-mount lens to remove second-order effects of the UV light. Results showed that the system could perform high-speed safety and quality-inspection tasks.

Our research also led to a line-scan imaging inspection system for freshly slaughtered chickens that was tested on processing lines in commercial poultry plants. Wavebands at 580 and 620nm were selected after the software analyzed 55-band hyperspectral images. Multispectral algorithms used these wavebands to detect and classify individual birds as either wholesome or unwholesome. Online multispectral inspection of more than 100,000 chickens at 140 birds per minute during two eight-hour shifts demonstrated better than 99% accuracy in identifying unwholesome birds. These results show that a line-scan inspection system could significantly increase efficiency, reduce labor costs, and improve inspection programs for poultry processors. Efforts to commercialize the system are underway.

We continue to research and develop inspection systems suitable for commercial processing of other fresh produce, such as leafy greens. Effective detection of contamination by fecal matter and bacterial biofilms, for example, is important because of their association with common bacterial causes of foodborne illness.

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References