Spectral line-scan imaging system for high-speed non-destructive wholesomeness inspection of broilers

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A spectral line-scan imaging system was developed for automated online wholesomeness inspection of broilers and evaluated in a commercial chicken processing plant. Real-time online hyperspectral images acquired by the system on a 140 bird-per-minute processing line were analyzed to optimize Region of Interest (ROI) size and location and to determine key wavebands by which to implement online high-speed multispectral inspection. Multispectral imaging algorithms were implemented to automatically recognize individual carcasses entering and exiting the field of view, to locate the ROI on the bird, and to determine the condition for each carcass as being wholesome or unwholesome. The high accuracy obtained from the in-plant evaluation results showed that the system can effectively perform food safety inspection tasks on high-speed processing lines. The system is being adapted for commercial use in pre-sorting chicken during initial processing operations, to help poultry processors improve production efficiency and satisfy increasing consumer demand for poultry products.

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Introduction

Hyperspectral imaging is one of the most exciting technologies that have been developed for non-destructive quality and safety inspection in the area of food processing. The technology goes beyond and above machine vision and spectroscopy, two technologies that have already been widely adopted in the food and agricultural industries. Machine vision imaging is commonly used to detect surface features (color, size/shape, surface texture, or defects) in food inspection, but is unable to identify or detect chemical, biological, or material properties or characteristics from the product. Spectroscopy, on the other hand, is useful for evaluating these properties and characteristics, but does not provide the spatial information that is often critical in food inspection. Hyperspectral imaging integrates the main features of imaging and spectroscopy to simultaneously acquire both spectral and spatial information from a product item. As a result, the technology provides us with unprecedented detection capabilities, which otherwise cannot be achieved with either imaging or spectroscopy alone. Hyperspectral imaging technology has demonstrated superiority in its unique capabilities as an analytical tool for developing methods of automated multispectral inspection (Lu & Chen, 1998). One major limiting factor hindering direct commercial application of hyperspectral technology for online use was the speed needed for rapid acquisition and processing of hyperspectral image data (Gowen, O’Donnell, Cullen, Downey, & Frias, 2007). However, advances in computers and optical sensing technologies are gradually overcoming this problem, as demonstrated by the recent development of online hyperspectral detection systems for wholesomeness and fecal contaminants on poultry carcasses and fresh produce (Chao, Yang, Chen, Kim, & Chan, 2007; Heitschmidt, Park, Lawrence, Windham, & Smith, 2007; Kim, Lee, et al., 2008), and for automated sorting and grading of fruits for internal quality (Lu, 2007). In particular, the application of line-scan imaging technology has demonstrated significant advantages for the direct implementation of hyperspectral imaging for rapid and non-destructive food quality and safety inspection. This has opened a new horizon for the technology in the food processing industry.

The major challenge for industrial adaptations of line-scan based imaging in the hyperspectral/multispectral domain has been the number of line-scan images an imaging device can acquire within a given time, as directly...
related to the spatial resolution of the system. The idea of streamlining the number of spectral bands for applications in processing plants has emerged in an effort to reduce data transfer volumes and increase acquisition speed, thus allowing sufficient spatial resolution for hyperspectral line-scan image-based inspection such as that demonstrated in recent years in the development of a reflectance-based imaging system for inspection of chicken carcass wholesomeness on high-speed processing lines and a fluorescence-based imaging system for contamination detection on fruit and vegetable processing lines (Chao, Yang, Kim, & Chan, 2008; Kim, Chen, et al., 2008). Improvements in detector sensitivity for low-light detection at very short exposure times were critical to these systems, and were made possible by the development of electron-multiplying charge-coupled-device technology (EMCCD). Following the preliminary acquisition of hyperspectral reflectance images on a 70 bird-per-minute (bpm) poultry processing line, spectral analysis methods were then modified for real-time online image processing. With these algorithms, the line-scan imaging system demonstrated effective real-time automated online inspection of birds on the 70 bpm processing line (Chao et al., 2008).

With current commercial processing lines operating at speeds as high as 140 bpm, there remains a need to develop automated food safety inspection systems that can inspect chickens for wholesomeness at those higher speeds. In 2007, the U.S. poultry processing plants processed over 8.9 billion broilers, more than any other country and valued at over $31 billion (USDA, 2008). In recent years, broiler production has increased dramatically to meet rising market demand. The U.S. domestic per capita consumption of broilers increased from 59.5 pounds in 1990 to 76.9 pounds in 2004, and reached 87 pounds in 2006. The 1957 Poultry Product Inspection Act mandated postmortem inspection of every bird carcass processed by a commercial facility. Since then, U.S. Department of Agriculture (USDA) inspectors have conducted on-site organoleptic inspection of all chickens processed at U.S. poultry plants for indications of diseases or defects. Inspectors of the USDA Food Safety and Inspection Service (FSIS) examine by sight and by touch the body, the inner body cavity surfaces, and the internal organs of every chicken carcass. With the 1996 final rule on Pathogen Reduction and Hazard Analysis and Critical Control Point (HACCP) systems (USDA, 1996), FSIS implemented the HACCP and Pathogen Reduction programs in meat and poultry processing plants throughout the country to prevent food safety hazards. More recently, FSIS has also been testing the HACCP-Based Inspection Models Project (HIMP) in a small number of volunteer plants (USDA, 1997). HIMP requirements include zero tolerance for unwholesome chickens exhibiting symptoms of “septoX” — a condition of either septicemia or toxemia, which are systemic conditions characterized by pathogenic microorganisms or toxins in the bloodstream.

USDA inspectors currently remove birds that exhibit signs of septox from the processing lines during bird-by-bird inspections conducted at a maximum speed of 35 bpm for each individual inspector. Subject to human variability, the inspection process makes inspectors prone to fatigue and repetitive injuries, and the inspectors’ speed also limits the maximum possible output for the processing plants. The need to increase production throughput to satisfy increasing chicken consumption and demand places additional pressure on both chicken producers/processors and the U.S. food safety inspection program. Automated line-scan imaging inspection systems can help alleviate this pressure as well as provide further improvements to food safety and quality inspection. This paper presents the current development of a line-scan imaging system for high-speed wholesomeness inspection of chickens on a 140 bpm commercial processing line.

**Spectral line-scan imaging system**

The spectral line-scan imaging system consists of an Electron-Multiplying Charge-Coupled-Device (EMCCD) camera, an imaging spectrograph, a C-mount lens, and two pairs of high power, broad-spectrum white light-emitting diode (LED) line lights. The EMCCD camera (Photometric Instruments Corp.) has 512 × 512 pixels and is thermoelectrically cooled to approximately −70 °C (via a three-stage Peltier device). An imaging spectrograph (ImSpec/Spec-Tral Imaging Ltd., Oulu, Finland), and a C-mount lens (Rainbow CCTV S6 × 11, International Space Optics, S.A., Irvine, CA) are attached to the EMCCD imaging device. The 50 micron aperture slit of the spectrograph limits the instantaneous field of view (IFOV) of the imaging system to a thin line for line-scan imaging. Light from the IFOV is dispersed by a prism-grating prism-line-scan spectrograph and projected onto the EMCCD imaging device. The spectrograph creates a two-dimensional (spatial and spectral) image for each line-scan, with the spatial dimension along the horizontal axis and the spectral dimension along the vertical axis of the EMCCD imaging device. Thus, for hyperspectral imaging, a full spectrum is acquired for every pixel in each line scan. The spectral distribution of useful wavelengths and the size of the spatial image features to be processed determine the parameters for image binning, which reduces the number of image pixels and increases the signal-to-noise ratio by adding together photons from adjacent pixels in the detector array. For this study, the original hyperspectral line-scan image size (512 × 512 pixels) was reduced by 1 × 4 binning to result in line-scan images with a spectral resolution of 128 pixels (512 divided by 4) in the spectral dimension. Then, because the useful spectrum of light did not span the entire width of the EMCCD detector, the first 20 and last 53 spectral bands were discarded, resulting in a final hyperspectral line-scan image size of 512 × 55 pixels, with the 55 spectral channels spanning 389 nm to 744 nm.
The spectral line-scan imaging system can function in two imaging modes, hyperspectral imaging and multispectral imaging. For conventional development of multispectral inspection methods for online applications, specific spectral parameters would be determined first using a hyperspectral imaging system or spectroscopy-based methods, and subsequently implemented for use in a separate multispectral imaging system. The conversion and implementation of parameters from one system to the other would usually involve time-consuming cross-system calibration. The capability of a single system to operate in either hyperspectral or multispectral imaging mode can eliminate the need for cross-system calibration and ensure accurate performance. This approach is taken with the line-scan imaging system used in this study. In hyperspectral imaging mode, a 55-band spectrum was acquired for each of the 512 spatial pixels in every hyperspectral line-scan image, as described above. After hyperspectral analysis to select specific wavebands for multispectral inspection of chicken carcasses, the same line-scan imaging system was operated in multispectral imaging mode to use only the selected wavebands for real-time inspection. Thus, there remained 512 pixels in the spatial dimension of the image but the pixels in the spectral dimension were further reduced from 55 to only 2 or 3 wavebands, with even faster imaging speed enabled by the elimination of unnecessary waveband data. The ability of the spectral line-scan imaging system’s EMCCD camera to use a very short integration time (0.1 ms) with a high gain setting, and to select a limited number of pixels in the spectral dimension of the line-scan images, were vital to the system’s successful online operation in multispectral imaging mode for differentiating wholesome and systemically diseased chickens. These factors enabled the system to effectively image birds on a high-speed processing line operating at a speed of 140 bpm.

Hyperspectral imaging analysis

Hyperspectral analysis of images of chicken carcasses, compiled from hyperspectral line-scans acquired on a 140 bpm commercial chicken processing line, was performed using MATLAB software (MathWorks, Natick, MA) to determine specific Region of Interest (ROI) parameters and to select wavebands useful for online wholesomeness inspection. The image background was first removed using a 0.1 relative reflectance threshold value for the 620 nm waveband. For any pixel in a hyperspectral line-scan, if its reflectance at 620 nm was below the threshold value, then that pixel was identified as background and its value at all wavebands was re-assigned to zero. The background-removed line-scan images were compiled to form images of chicken carcasses for a set of wholesome birds and a set of unwholesome birds. These images were analyzed to determine the parameters for an optimized ROI for use in differentiating wholesome and unwholesome birds. Within each bird image (Fig. 1), the potential ROI area spanned an area from an upper border across the body of the bird to a lower border at the lowest non-background spatial pixel in each line scan, or to the last (512th) spatial pixel of the line-scan if there were no background pixels present at the lower edge. For each potential ROI, the average relative reflectance spectrum was calculated across all ROI pixels from all wholesome chicken images, and the average relative reflectance spectrum was also calculated across all ROI pixels from all unwholesome chicken images. The difference spectrum between the wholesome and unwholesome average spectra was calculated. This calculation was performed for all potential

![Fig. 1. Contour images of two chicken carcasses marked with example locations of the SP, EP, m, and n parameters used for locating the region of interest.](image-url)
ROIs evaluated, which varied in size and were defined by the number of ROI pixels and their vertical coordinate locations within each line-scan. The optimized ROI was identified as being that which provided the greatest spectral difference between averaged wholesome pixels and averaged unwholesome pixels across all 55 wavebands.

Using the optimized ROI, a key waveband was identified as being the waveband corresponding to the greatest spectral difference between averaged wholesome chicken pixels and averaged unwholesome chicken pixels, for differentiating wholesome and unwholesome chicken carcasses by relative reflectance intensity. Again using the optimized ROI, the average wholesome and average unwholesome spectra were examined for wavebands at which local maxima and minima occurred, to identify wavebands that might be used in two-waveband ratios for differentiating wholesome and unwholesome birds. The value of each potential band ratio was calculated for the average wholesome chicken pixels and for the average unwholesome chicken pixels. The two-waveband ratio showing the greatest difference in ratio value between average wholesome and average unwholesome chicken pixels was selected. Thus, multispectral imaging inspection used the selected key wavelength and the two-waveband ratio to differentiate between wholesome and unwholesome chicken carcasses.

Online multispectral inspection

The capability to detect individual bird carcasses, classify the carcass condition, and generate a corresponding output useful for process control, all at speeds compatible with online operations, is required for effective multispectral imaging inspection for wholesomeness of chicken carcasses on a commercial processing line. LabVIEW 8.0 (National Instruments Corp., Austin, TX) software was used to develop in-house inspection modules to control the spectral imaging system for performing these tasks in real-time. The following algorithm, based on the imaging system’s line-by-line mode of operation, was developed to detect the entry of a bird carcass into the IFOV and classify the carcass as either wholesome or unwholesome using real-time multispectral inspection on a processing line.

Fig. 2 shows a flowchart describing the line-by-line algorithm for multispectral inspection. First, a line-scan image was acquired that contains only raw reflectance values at the two key wavebands needed for intensity and ratio differentiation; this raw reflectance data was converted into relative reflectance data and background pixels were removed from the image (Fig. 2, Box 2.1). The line-scan image was checked for the presence of the Starting Point (SP) of a new bird (Fig. 2, Box 2.2); if no SP was present, no further analysis was performed for this line-scan image and a new line-scan image was acquired. If the line-scan was found to contain an SP, then the ROI pixels were located (Fig. 2, Box 2.3) and the decision output value of \( D_n \) was calculated for each ROI pixel in the line-scan image (Fig. 2, Box 2.4), before a new line-scan image was acquired. With each new line-scan image acquired (Fig. 2, Box 2.5), the ROI pixels were located, and the decision output value of \( D_n \) was calculated for each pixel, until the Ending Point (EP) of that bird was detected (Fig. 2, Box 2.6), indicating no additional line-scan images to be analyzed for that carcass. The average \( D_n \) value for the bird was calculated across all its ROI pixels (Fig. 2, Box 2.9) and then compared to the threshold value (Fig. 2, Box 2.10) for the final determination of wholesomeness or unwholesomeness for the bird carcass (Fig. 2, Boxes 2.11 and 2.12). The decision output \( D_n \) calculation was based on fuzzy inference classifiers (Chao et al., 2008) developed using mean and standard deviation values for ROI reflectance at the key wavebands during hyperspectral analysis of the wholesome and unwholesome sets of chicken images.

The imaging system is suitable for online multispectral inspection on high-speed chicken processing lines because of the capacity for short-exposure low-light imaging provided by the EMCCD detector. Pixels from the detector are binned by the high-speed shift register (which is built into the camera hardware) and transferred to the 16-bit digitizer, which has a rapid pixel-readout rate of approximately 10 MHz. The digitizer performs rapid analog-to-digital conversion of the image data for each line-scan image. The random track operation mode of the camera allows for selection of specific spectral channels to be acquired during multispectral imaging—although all detector pixels are available, the camera hardware transfers only the selected spectral channels as set by the user through software control. The rapid multispectral image acquisition is followed by computer image analysis for real-time classification of wholesome and unwholesome pixels in the line-scan images of the chicken carcasses.

Implementation and evaluation

Key waveband selection by hyperspectral analysis

The hyperspectral images were analyzed to optimize ROI size and location and to select the wavebands for differentiation of wholesome and unwholesome birds by reflectance intensity and by waveband ratio as calculated for the ROI pixels for each bird. A contour image of two example birds is shown in Fig. 1, with the SP and EP marked on each. Within each line-scan, possible ROI pixels begin at the SP-EP line and extend to the furthest non-background pixel below the SP-EP line, which in some cases coincides with the pixel at the far edge of the line-scan image. Parameters \( m \) and \( n \) indicate, as percentages of the pixel length between the SP-EP line and the furthest non-background pixel within each line-scan image, the location of the upper and lower ROI boundaries for ROIs under consideration. To optimize the ROI size and location, combinations of \( m \) and \( n \) were evaluated with values of \( m \) between 10% and 40% and values of \( n \) between 60% and 90%.
For each possible ROI, the average spectrum was calculated across all ROI pixels from the 5549 wholesome chicken carcasses, and the average spectrum was calculated across all ROI pixels from the 93 unwholesome chicken carcasses. The difference between the average wholesome and average unwholesome value at each of the 55 wavebands was calculated. Fig. 3 shows the range of these 55 values for each possible ROI. Across all the possible ROIs, wavebands near 580 nm showed the highest difference between the average wholesome and average unwholesome spectra, and wavebands near 400 nm showed the lowest difference values. Because the 40%–60% ROI showed the highest difference values overall (with the highest value occurring of 0.212 at 580 nm), this ROI was used in the waveband selection process. Fig. 4 shows the average spectra for pixels within this optimized ROI from all line-scan images in the wholesome data set and in the unwholesome data set. Because the 580 nm band showed the greatest difference between the average wholesome and the average unwholesome spectra, this band was selected as the key waveband to be used for intensity-based differentiation of wholesome and unwholesome chicken carcasses.

Six wavebands were investigated for differentiation of wholesome and unwholesome chicken carcasses by a two-waveband ratio, these are marked on Fig. 4. Because visual examination showed noticeable differences between the average wholesome and average unwholesome spectral slopes in the three areas corresponding to 440–460 nm, 500–540 nm, and 580–620 nm, two-band ratios were investigated using these particular pairings. Two-band ratios for these pairings were calculated using the average wholesome reflectance W and average unwholesome reflectance

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**Fig. 2.** A flowchart of the line-by-line algorithm for online wholesomeness inspection by the multispectral line-scan imaging system.
U values. The differences in ratio value between wholesome and unwholesome were then calculated:

\[ \frac{W_{440}}{W_{460}} \frac{U_{440}}{U_{460}} = 0.003461 \]
\[ \frac{W_{500}}{W_{540}} \frac{U_{500}}{U_{540}} = 0.038602 \]
\[ \frac{W_{580}}{W_{620}} \frac{U_{580}}{U_{620}} = 0.115535 \]

The last ratio, using the 580 nm and 620 nm wavebands, showed the greatest difference between the average wholesome and average unwholesome chicken spectra and was thus selected for use in differentiation by two-waveband ratio.

Real-time online multispectral inspection

In-plant hyperspectral line-scan images of chickens were acquired on a 140 bpm commercial processing line in March 2007. A total of 5549 wholesome and 93 unwholesome chickens were imaged, with their conditions identified by an FSIS veterinary medical officer who observed the birds as they approached the illuminated IFOV of the imaging system. The 55-band hyperspectral data for the chicken carcasses were analyzed for Region of Interest (ROI) optimization and for selection of one key wavelength and two ratio wavebands, based on average spectral differences between wholesome and unwholesome birds.

Fig. 3. Plot of the range of difference values between average wholesome and average unwholesome chicken spectra for ROIs evaluated during hyperspectral analysis to optimize the ROI for multispectral inspection of chickens.

Fig. 4. The average ROI pixel spectra for wholesome chickens and the average ROI pixel spectral for unwholesome chickens, used to select wavebands for intensity- and ratio-based differentiation.
Multispectral imaging for online high-speed inspection in real time used only the key wavelength and ratio wavebands. LabView-based software modules were developed for detecting each bird and for implementing the online inspection algorithms. The imaging system performed online multispectral inspection for over 100,000 birds on a commercial processing line during two 8-h shifts in July 2007. To verify system performance, an FSIS veterinary medical officer identified wholesome and unwholesome conditions of birds immediately before they entered theIFOV of the imaging system, during several 30–40 min periods, for direct comparison with the classification results produced by the multispectral imaging system.

The optimized ROI and key wavebands determined from the hyperspectral data analysis were used for online multispectral inspection of over 100,000 chickens on a 140 bpm processing line at a commercial poultry plant. The top row in Fig. 5 shows nine examples of chicken images acquired online, with the ROI pixels highlighted in red on each bird. During online operation, the inspection program automatically located the 40%–60% ROI with the acquisition of each line-scan image. As shown, the ROI location was clearly affected by the size and position of the bird and thus varied for different birds. For a bird whose body extended past the lower edge of the image, such as the first bird in the row, the ROI encompassed a rectangular area. In contrast, an irregularly shaped ROI resulted for birds positioned such that background pixels were present at the lower edge of the image.

The middle row in Fig. 5 shows a masked image of the nine birds above, highlighting all the ROI pixels for each bird. Using fuzzy inference classifiers (Chao et al., 2007), two $D_o$ values were calculated (ranging between 0 and 1) for each pixel in the ROI, one for the key waveband and one for the two-waveband ratio. Online multispectral inspection averaged the $D_o$ values for all ROI pixels for each bird, in order to classify the bird by comparison to the threshold value of 0.6. For illustration purposes, the bottom row in Fig. 5 highlights the classification results of classifying each individual pixel in the ROIs, instead of classifying whole birds. For each ROI pixel in the top row image, the two $D_o$ values were averaged and the average value was compared with the 0.6 threshold value. In this illustrative example, the fourth chicken from the left is an unwholesome bird and all of its ROI pixels were individually identified as unwholesome, consequently not appearing in the bottom-row image.

During the first shift of online multispectral inspection, the imaging inspection system inspected 45,593 birds in total, of which it identified 45,305 (99.4%) as wholesome and 288 (0.6%) as unwholesome. During this same shift, human line inspectors examined 53,647 birds in total, of which 53,563 (99.8%) they identified as wholesome and 84 (0.2%) as unwholesome, according to numbers drawn from FSIS tally sheets. During the second shift of online inspection, the imaging inspection system inspected 61,020 birds in total, of which it identified 60,922 (99.8%) as wholesome and 98 (0.2%) as unwholesome. During this

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**Fig. 5.** Nine chicken images chickens with ROI pixels highlighted in red (top row). Identification and masking for pixels in the 40%–60% ROI for each bird (middle row). Identification of wholesome ROI pixels after threshold-based classification of each individual pixel (bottom row).
same second shift, human line inspectors examined 65,043 birds in total, of which 64,972 (99.9%) they identified as wholesome and 71 (0.1%) as unwholesome. Although direct bird-to-bird comparison between the imaging inspection system and the inspectors was not feasible, the percentages indicate that the relative numbers of wholesome and unwholesome birds identified by the imaging inspection system and by the processing line inspectors were not significantly different. Slightly fewer birds were inspected by the imaging inspection system than by the human inspectors during each shift due to logistical arrangements with the processing plant regarding the operation of the imaging system.

System verification was also performed by an FSIS veterinary medical officer for several 30–40 min periods within the inspection shifts. This consisted of bird-by-bird observation of chicken carcasses on the processing line immediately before they entered the IFOV of the imaging system; the imaging system output was compared with the veterinary medical officer’s identifications. Over four verification periods during inspection shift 1, the imaging system correctly identified 99.3% of wholesome birds (16,056 of 16,174) and 95.4% of unwholesome birds (41 of 43). Over six verification periods during inspection shift 2, the imaging system correctly identified 99.8% of wholesome birds (27,580 of 27,626) and 97.1% of unwholesome birds (34 of 35). These verification period results, together with the whole-shift comparison results against the FSIS tally sheets, demonstrates that the imaging inspection system can perform effectively on a 140 bpm high-speed commercial poultry processing line.

**Industry application: online pre-sorting of broilers**

The spectral resolution (full width at half maximum) of the imaging system was approximately 7 nm after calibration of the binned spectral data. On the 140 bpm processing line in this study, the imaging system was able to acquire in real-time approximately 50 hyperspectral (55-waveband) line-scan images per bird, for a spatial resolution of 0.35 mm in the hyperspectral images that were analyzed for waveband selection, with the ROI of any given bird spanning approximately 20–30 of those 50 line-scans. During multispectral online inspection, the ROI per bird spanned approximately 40 multispectral (2-waveband) line-scan images, depending on the bird size. With about 4000 pixels in the ROI to analyze for multispectral classification of a bird, the spatial resolution of the system is more than adequate for accurate and effective detection of unwholesome chickens at a speed of 140 bpm. For operation at speeds as high as 200 bpm, the system can acquire 20–25 multispectral (2-waveband) line-scan images for ROI analysis per bird.

Automated online pre-sorting of broilers is an ideal application for this spectral line-scan imaging system. By detecting and diverting unwholesome birds exhibiting symptoms of systemic disease earlier on the processing line, production and efficiency can be improved - fewer unwholesome birds will be presented for inspection by human inspectors and fewer empty shackles (nearer 100% operating capacity) will occur during downstream processing. By diverting most unwholesome birds earlier, the reduced inspection workload for human inspectors can provide the opportunity for inspectors to address additional tasks beyond direct carcass inspection. The rejected birds are detected and diverted while still on the high-speed kill line, prior to automatic rehanging on the evisceration line, which helps to reduce food safety risks from possible cross-contamination. For the small number of wholesome birds that might occur as false positives for the automated inspection system, a processing plant can opt to re-inspect diverted birds and manually transfer any wholesome birds to the evisceration line.

For the purpose of pre-sorting young chickens on commercial processing lines, the spectral line-scan imaging technology has been recently reviewed and approved by the USDA-FSIS Risk and Innovations Management Division. Commercialization of this system for industry use will be the first application of spectral line-scan imaging technology for a food safety inspection task.

**Conclusions**

A spectral line-scan imaging system was developed for real-time online imaging of chickens on commercial processing lines. The system is particularly well suited for pre-sorting poultry carcasses on high-speed processing lines by removing systemically diseased birds prior to the inspection stations. This system can increase efficiency and reduce cross-contamination risks by minimizing the presence and unnecessary processing of unwholesome birds on the processing line. Real-time detection and prompt removal of unwholesome poultry carcasses can enhance the production throughput of processing plants and help to ensure the safety of poultry products. Commercialization for industry use will provide food processors with a tool to help improve operations and increase production to meet consumer demand. The spectral imaging methodology of this system also has the potential for adaptation to other high-speed processing tasks relevant to food quality and safety inspection.

**References**


