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Journal of Food Engineering 69 (2005) 225–234
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Development of multispectral image processing algorithms for identification of wholesome, septicemic, and inflammatory process chickens ☆

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Received 3 November 2003; revised 23 June 2004; accepted 16 July 2004

Abstract

A multispectral imaging system and image processing algorithms for food safety inspection of poultry carcasses were demonstrated. Three key wavelengths of 460, 540, and 700 nm, previously identified using a visible/near-infrared spectrophotometer, were implemented in a common-aperture multispectral imaging system, and images were collected for 174 wholesome, 75 inflammatory process, and 170 septicemic chickens. Principal component analysis was used to develop an algorithm for separating septicemic chickens from wholesome and IP chickens based on average intensity of first component images. A threshold value of 105 was able to correctly separate 95.6% of septicemic chickens. To differentiate inflammatory process chickens, a region of interest was defined from which spectral features were determined. The algorithm was able to correctly identify 100% of inflammatory process chickens by detecting pixels that satisfied the spectral feature conditions. A decision tree model was created to classify the three chicken conditions using inputs from the two image processing algorithms. The results showed that 89.6% of wholesome, 92.3% of inflammatory process, and 94.4% of septicemic chickens were correctly classified.
Published by Elsevier Ltd.

Keywords: Food safety; Machine vision; Poultry

1. Introduction

The Poultry Products Inspection Act (PPIA) requires Food Safety and Inspection Service (FSIS) inspectors of the United States Department of Agriculture (USDA) to conduct post-mortem inspection for wholesomeness of all chickens intended for sale to US consumers (USDA, 1984). Poultry inspection is a complex process. FSIS inspectors are trained to recognize infectious condition and avian diseases, dressing defects, fecal and digestive content contamination, and conditions that are related to many other consumer protection concerns. FSIS has just completed a three-year transformation of its traditional inspection system to a Hazard-Analysis-and-Critical-Control-Point (HACCP) inspection system. Under this new system, FSIS inspectors still do a bird-by-bird organoleptic examination, but FSIS personnel also monitor a producer-run HACCP plan, which is developed by each plant and approved by FSIS. Under HACCP, increasing consumer demand and line speeds will continue to increase the need for and pressure on inspectors. Thus, to address food safety concerns and meet growing consumer demand, there is an urgent need to develop automated inspection systems that can

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0260-8774/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.jfoodeng.2004.07.021

operate on-line in real-time in the slaughter plant environment. These systems should be able to accurately detect and identify carcasses with infectious condition, particularly septicemia/toxemia. They should also detect avian diseases, particularly airsacculitis, ascites, and inflammatory process (IP).

Machine vision is a non-invasive technology that provides automated production processes with vision capabilities when the majority of inspection tasks are highly repetitive, and their effectiveness depends on the efficiency of the human inspectors. A number of investigators have demonstrated various applications using machine vision techniques for agricultural and food industries, particularly in grading and inspection (Miller & Delwiche, 1989; Precetti & Krutz, 1993; Sakar & Wolfe, 1985; Tao, Morrow, Heinemann, & Sommer, 1990). Although implementations of machine vision technologies have generally concentrated on quality assessments, interest in addressing food safety issues has been steadily increasing in recent years. The broadband spectral characteristics of color machine vision techniques traditionally used in systems for quality assessments have been found less effective for some food safety issues compared to some more recently developed techniques such as multispectral imaging systems (Chen, Chao, & Kim, 2002).

A multiwavelength imaging system could be implemented in several ways: using a filter wheel, a liquid crystal tunable filter (LCTF), several cameras with filters, or a single camera with beamsplitter. A critical issue that should be considered in real-time operations of these devices is the amount of time between sequentially acquired images at different wavelengths. This is a function of both the image capturing speed and band switch speed. Electromechanical filter wheels have limitations in the speed of wavelength switching. Improvement in LCTF technology makes a LCTF system superior to electromechanical filter wheels in both speed and flexibility of spectral selection (Evans, Thai, & Grant, 1997). The time required for the LCTF to switch between wavelengths is approximately 50ms (Mao & Heitschmidt, 1998). However, this still makes the system unsuitable for synchronization with moving objects during high-speed inspection. Recent advances in optical design make common aperture systems, which allow multispectral (two to four spectral bands) imaging of samples with a single acquisition, promising for real-time operation.

In developing such vision inspection systems it is essential to first identify key wavelengths, then develop algorithms based on those wavelengths, and finally implement them for on-line applications. For example, Windham, Lawrence, Park, and Buhr (2003) and Park, Lawrence, Windham, and Buhr (2002) have used a visible/near-infrared (Vis/NIR) monochromator to identify wavelengths associated with fecal absorption bands, and then, using hyperspectral imaging, evaluated those wavelengths and developed image-processing algorithms. For food safety inspection of poultry carcasses, wavelengths associated with infection conditions have been identified using a visible/near-infrared spectrophotometer (Chao, Chen, & Chan, 2003).

The main objective of this study was to develop multispectral image processing algorithms for the detection of infectious poultry conditions. An imaging system was designed using a multispectral common-aperture camera with three interference filters in the visible wavelength range. Two image-processing algorithms were developed for the specific identification of septicemic and inflammatory process chickens. A decision tree model was constructed for the classification of wholesome, septicemic, and inflammatory process chickens.

2. Materials and methods

2.1. Sample collection

Eviscerated chicken carcasses were identified and collected by USDA FSIS veterinarians from Allen Family Foods (Cordova, MD, USA). A total of 245 unwholesome carcasses (170 septicemia and 75 inflammatory process) and 174 inspected and passed wholesome carcasses were collected over a three-month period in 2003. Septicemia is a systemic disease caused by pathogenic microorganisms in the blood, and its symptoms are visible on the exterior of the carcass. Inflammatory process (IP) is a physiologic condition when the yolk sac was not completely absorbed after hatching and has progressed into a pathological inflammatory process. The IP lesions are normally observed between the skin and the ventral abdominal muscle tissue in the perineal area after the vent is opened and the eviscerator has drawn out the internal visceral organs.

Chicken carcasses were identified according to the condemnation conditions and placed in plastic bags to minimize dehydration. The bags were then placed in coolers, covered with ice, and transported to the Instrumentation and Sensing Laboratory (ISL) located in Beltsville, MD, USA, within 2h for the experiments.

2.2. Multispectral imaging system

The multispectral imaging system consists of a three-channel common aperture camera (MS2100, DuncanTech, Auburn, CA, USA), a frame grabber (PCI-1428, National Instruments, Austin, TX, USA), an industrial computer (BSI, City of Industry, CA, USA), and eight 100-W tungsten halogen lights. The three-channel common aperture camera utilizes a color-separating prism to split broadband light entering the camera through the lens into three optical channels. An interference filter