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Systematic approach for using hyperspectral imaging data to develop multispectral imagining systems: Detection of feces on apples

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Abstract

The large size of data sets generated using hyperspectral imaging techniques significantly increases both the capability and difficulty of designing detection and classification systems. Of particular interest is the confluence with increasing use of multispectral imaging in machine vision, particularly in the area of food safety inspection. The purpose of this study was to develop a robust method for selecting one or two wavelengths for multispectral detection systems using hyperspectral data. The actual performance of detection algorithms in terms of true positives and false positives was used as optimization criteria. Detection of fecal contamination on apples is an important health safety issue. Prior observations suggest reflectance or fluorescence imaging in the visible to near-infrared can be used to detect such contamination. For this study, 1:2, 1:20, and 1:200 dilutions of dairy feces were applied to 100 Golden and 100 Red Delicious apples. Apples were imaged using a hyperspectral system, and a uniform power transformation was used to reduce inter-apple intensity variability. Detection was accomplished by applying a binary threshold to transformed single wavelength images and images construct using ratios or differences of images at two different wavelengths. Optimization criteria allowed for a maximum of three false positives. For reflectance imaging, maximum detection rates for 1:20 dilution spots on Golden and Red Delicious apples images were 100% and 62.5% using $R816 - R697$ and $R784 - R738$, respectively. For fluorescence imaging, maximum detection rates for 1:200 dilution spots on Golden and Red Delicious apples were 97.9% and 58.3% using $F665/F602$ and $F647/F482$, respectively. In all case, more concentrated dilution spots were detected at 100%. Maximum detection rates for Red Delicious apples required use of a Prewitt edge-detection filter. In comparison, tests of wavelengths and algorithms identified in previous studies using statistical methods such as principal component analysis produced lower detection rates, mainly due to problems with false positives. The procedures used for developing detection algorithms are not specific to detecting feces on apples, and it is theoretically easy to extend the results to detection schemes involving many wavelengths. The problem is the classical dilemma of rapidly increasing computational time. Still, given the costs of thoroughly testing a candidate detection algorithm, the time maybe warranted. Furthermore, as machine vision systems are often limited to one or two wavelengths due to practical considerations including cost, exhaustive search algorithms based-on optimizing the output of candidate detection algorithms should be cost-effective.
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1. Introduction

Hyperspectral imaging techniques allow collection of data sets that include spectral information for each spatial pixel location. Often, such hyperspectral data are used to identify a limited number of wavelengths to be used in practical, real-time, multispectral detection systems (Shaw and Manolakis, 2002; Cheng et al., 2004). In the area of food safety, a specific example is efforts to use hyperspectral reflectance or fluorescence data in the visible and near-infrared (NIR) regions to select appropriate wavelengths for detection of feces on apples (Kim et al., 2002a,b; Liu et al., in press) or cantaloupes (Vargas et al., 2005). Generally, selection of wavelengths was done by looking at characteristics of the data sets to select wavelengths and image transformations that enhanced the visible contrast in resulting images between contamination sites and uncontaminated surface areas. Only limited attempts have made to consider the actual percentage of contamination sites that could be detected, particularly in relation to false-positive rates (Lefcourt et al., 2003, 2005). The purpose of this study was to develop a robust method for selecting one or two wavelengths for a multispectral detection system using hyperspectral data, and to use actual detection performance to optimize the selection process. A secondary purpose was to directly compare the efficacy of using reflectance or fluorescence imaging for detection using the same samples imagined in exactly the same positions.

Detection of fecal contamination on apples is a critical health safety issue as feces can be the source of a number of human pathogens (Armstrong et al., 1996; Blackburn and McClure, 2002; Hui, 2001; Mead et al., 1999). The FDA has solicited development of systems to detect contaminated apples (FDA, 2001). The efficacy of algorithms to detect feces on apples has been examined using more restricted data sets generated using laser-induced fluorescence imaging (Lefcourt et al., 2003, 2005). These data sets were limited to images acquired at four wavelengths. Effective detection algorithms were found that utilized both single-band images and ratios of images at two wavelengths. Effectiveness was evaluated by considering the acceptable number of false positives. Contamination sites were detected using a binary threshold after the images had been suitably transformed. The best detection was obtained by subjecting images to a universal power transformation followed by edge detection (Lefcourt et al., 2005). The universal power transformation reduces normal apple-to-apple intensity variation and enhances the contrast between contamination sites and uncontaminated surface areas (Lefcourt and Kim, 2006). For this study, single-band images, and ratios or differences of two single-band images were examined. Two classes of detection schemes were proposed based-on use of the uniform power transformation with and without the addition of edge detection. As the proposed detection schemes are complex and non-linear, optimization required use of an exhaustive search routine. To test the validity of the optimization methods, detection algorithms were developed using one-half of the apples and then applied to the remaining apples.

2. Methods

Golden Delicious and Red Delicious apples were artificially contaminated with titrations of dairy feces using a standardized laboratory protocol and subsequently scanned using a hyperspectral imaging system for reflectance responses to white light and fluorescence responses to UV-A excitation. For each apple variety, one-half of the apples were used to identify single- and two-band detection algorithms. For validation, the most promising algorithms were applied to the remaining apples.

2.1. Apples and feces application

Apples were handpicked from crates of early or mid-season, tree-run, apples at the Rice Fruit Co. (Gardners, PA) and stored at 3 °C. Fresh cow feces were collected at the Beltsville Agricultural Research Center dairy, diluted 1:2, 1:20, and 1:200 by weight with de-ionized water, and a single 30 μl drop of each of the three dilutions was immediately applied to each apple (Fig. 1). Drops were applied using a pipette with disposable plastics tips; about 2 mm was cut-off each tip with a razor blade to allow passage of particulates. Apples were then returned to the storage refrigerator to allow applications to dry overnight. Dry matter content of undiluted feces was about 16%. Feces were applied to 100 apples of each variety. Only 96 apples for each variety were used for analyses, the remainder were used to substitute for problem apples, e.g. where the application ran.