Computers and Electronics in Agriculture 130 (2016) 38–47

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Review

A hyperspectral imaging based control system for quality assessment of dried figs

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ARTICLE INFO

Article history:
Received 24 March 2016
Received in revised form 26 September 2016
Accepted 1 October 2016

Keywords:
Hyperspectral imaging system
Food quality control
Dried fig
Black mold
Reflectance
Transmittance

ABSTRACT

Computer vision based systems address the need for fast, reliable and non-destructive methods for food quality assessment which is traditionally done by manual inspection techniques that are costly, time-consuming, and high labor intensive. A recent advancement in these systems is the use of hyperspectral imaging (HSI) which can exploit reflectance or transmittance characteristics in a wide range with narrow bands, to achieve improved classification for accurate quality control. In this study, a HSI based computer vision system based on reflectance characteristics is proposed for assessment of dried figs which are economically important for rural development and yet prone to mold infection. By extracting the features as the average intensity of the fig regions at each spectral band, the proposed HSI system employs sequential floating forward selection with commonly used classifiers (support vector machines and Bayes classifiers), to precisely find contaminated dried figs for their pneumatic removal from the production line. The proposed HSI system can achieve an accuracy of 99.3% based on the most discriminative twenty-seven spectral bands. It also produces an acceptable accuracy of 93% by using only four bands. A preliminary lab-based prototype can control the figs and then pneumatically remove the detected contaminated ones. The throughput of this prototype is seven figs per minute when the full spectrum of 784 bands is evaluated by a single processing line. When only the most discriminative four bands are considered, the throughput improves to seven figs per second using four processing lines on the conveyor belt, which makes it promising for an operational detection system. In addition to reflectance mode, it is shown by an experimental setting that the transmittance characteristics can help identify dried figs with internal contamination when the contamination have no detectable affect on the outer fig surface.

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http://dx.doi.org/10.1016/j.compag.2016.10.001
0168-1699/

1. Introduction

The quality control for agricultural and food products has been important in recent decades due to increased contamination and negative effects of bio-industrial production. The desired quality standards are generally assessed by manual inspection techniques which can often be time-consuming with high labor costs, destructive and tedious. In addition, manual assessment may cause inconsistent subjective evaluation results. To address these challenges, computer vision based machine learning systems have been popular by providing fast, effective, reliable and non-destructive evaluations with reduced operational cost (Brosnan and Sun, 2004; Rong et al., 2011). These systems not only reduce required human interaction but also classify faster (and often better) than human beings (Al-Marakeby et al., 2013). They evaluate visible characteristics for food quality assessment by capturing, processing and analyzing images using single or multiple cameras (Huang et al., 2014).

The machine vision based systems using grayscale or color images are often successful for visual evaluation of foods depending on their texture or color. Yet, they are inefficient to obtain detailed spectral characteristics required for precise discrimination of food quality in some particular applications. To address this critical need for agricultural and food products, hyperspectral imaging (HSI) systems have been developed to obtain spectral and spatial information, simultaneously. The HSI systems provide numerous spatial image planes of the same object at different wavelengths (narrow spectral bands) by hyperspectral sensors (operated either in reflectance or transmittance modes) to create a three-dimensional data cube (hypercube) representing the detailed spectral signatures of the corresponding products (Huang et al., 2014). These HSI systems hence provide measurements beyond the visible spectrum of human perception. Thanks to these advantages, they have increasingly become popular in many applications for quality assessment.

In this study, a HSI system is proposed based on reflectance properties to assess the quality of dried figs. Dried figs, one of the widely produced agricultural products in the world (Curzi et al., 2014), are often sorted with manual techniques and their recent computer vision based automatic control methods are limited to color and size based sorting (Baigvand et al., 2015; Benalia et al., 2016). Being the first HSI based prototype system for their assessment, the proposed approach automatically detects dried figs with contamination (either external or internal) and removes the contaminated ones from the conveyor belt by a pneumatic system. Contrary to existing HSI systems for food quality assessment, which mainly use feature transformation (such as partial least squares or principal components), the proposed approach uses a sequential feature selection method to select the most effective bands for an online operational system, based on reflectance characteristics. In addition to the proposed HSI system based on reflectance, an experimental setting, based on transmittance, is also established to show that the transmittance characteristics can aid significantly if imaging can be performed precisely.

The rest of the paper is outlined as follows: Section 2 describes existing HSI systems for food quality assessment, Section 3 explains quality assessment of dried figs, the proposed HSI system based on reflectance and the experimental setup based on transmittance characteristics. Section 4 provides promising experimental results for an operational system and Section 5 concludes the paper with possible future directions.

2. Related work

Hyperspectral imaging (HSI) has been recently used in the agricultural and food industry as a novel non-destructive assessment method, mainly based on reflectance characteristics. Xiong et al. (2015b) investigated the convenience of HSI for quantitative determination of total pigments in red meats, based on a visible and near infrared (VIS/NIR) HSI system covering the spectral range of 400–1000 nm. They determined the optimal features from the reflectance values by a partial least squares regression (PLSR) model. After the band selection, they established a simplified successive projections algorithm (SPA) and regression coefficients (RC) for PLSR, leading to SPA-PLSR and RC-PLSR models, to generate distribution maps representing the samples. Their promising results showed that HSI can be used instead of time-consuming and destructive mechanical methods to measure total pigments in red meats. Similarly, Xiong et al. (2015a) developed a non-destructive technique for prediction of thiobarbituricacid reactive substances (TBARS) in chicken meat in the reflectance mode with the range of 400–1000 nm. They also implemented PLSR to establish the spectral models. The performance of their models proved that HSI could be an alternative non-destructive method to determine frozen meat quality without thawing. Additionally, Cheng et al. (2015) investigated the feasibility of VIS/NIR HSI system to evaluate microbial spoilage of fish in the range of 400–1000 nm. Their models showed good performance using both full wavelengths and selected wavelengths, to indicate HSI is a useful tool to evaluate the freshness loss and microbial spoilage of grass carp fillets.

In another study, Ravikanth et al. (2015) developed an automatic method by using NIR hyperspectral imaging for classification of contaminants from wheat. The NIR reflectance spectra with the range of 1000–1600 nm were used to acquire sample images. The data was classified by using support vector machines (SVM), naive Bayes (NB), and k-nearest neighbors (KNNC) classifiers, among which the KNNC was the best performing classifier. Ariana et al. (2006) provided a NIR HSI system to detect hidden internal damage in pickling cucumbers using the spectral region of 900–1700 nm, using the principal component analysis (PCA), band ratio, and band difference. Their results indicated that the band ratio and difference methods were better than the PCA. Xing et al. (2005) developed another HSI system with the region between 400 and 1000 nm to detect bruises on "golden delicious" apples, based on the PCA of the multi-spectral images. Zhang et al. (2015) attempted to develop a non-destructive method for internal quality assessment of eggs. They applied successive projections algorithm (SPA) combined with support vector regression for detection model. Their findings suggested that hyperspectral imaging may be useful for assessment of internal quality of eggs. Barbin et al. (2013) evaluated chemical composition of intact and minced pork in the range of between 900 and 1700 nm, using the PLSR to predict fat, moisture and protein contents. Nicolaï et al. (2006) developed a hyperspectral NIR spectra system to identify bitter pit lesions on apples based on a discriminant PLS calibration model with the range of 900–1700 nm. The calibration model successfully identified pit lesions except corky tissue. Rodríguez-Pulido et al. (2014) studied on flavanols in grape seed to detect red and white grapes, using also a PLSR based model. Moscetti et al. (2014) provided a detection system for hidden insect damage in chestnuts by NIR spectroscopy and a genetic algorithm for feature selection in combination with a linear discriminant analysis. Kalkan et al. (2011) developed a local discriminant bases algorithm to detect contaminated hazelnut kernels and red chili peppers by using a multispectral imaging system. They achieved classification accuracies of 92.3% and 80% for aflatoxin-contaminated and uncontaminated hazelnuts and red chilli peppers, respectively.

While reflectance images have been used to evaluate external quality, several studies have detected internal quality of fruits by using transmittance characteristics. Teerachaichayut et al. (2011) developed a non-invasive technique to determine a hardening