Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Journal of Food Engineering 78 (2007) 597–605
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Stem and calyx recognition on 'Jonagold' apples by pattern recognition

D. Unay *, B. Gosselin

TCTS Labs., Faculté Polytechnique de Mons, Multitel Building, Avenue Copernic 1, Parc Initialis, B-7000 Mons, Belgium

Received 20 February 2005; accepted 28 October 2005
Available online 10 January 2006

Abstract

In this paper, a novel method to recognize stem or calyx regions of 'Jonagold' apples by pattern recognition is proposed. The method starts with background removal and object segmentation by thresholding. Statistical, textural and shape features are extracted from each segmented object and these features are introduced to several supervised classification algorithms. Linear discriminant, nearest neighbor, fuzzy nearest neighbor, support vector machines classifiers and adaboost are the ones tested. Relevant features are selected by floating forward feature selection algorithm. Support vector machines, which is found to be the best among all classification algorithms tested, correctly recognized 99% of the stems and 100% of the calyxes using selected feature subset. These results exhibit considerable improvement relative to the ones introduced in the literature.

Keywords: Apple; Stem; Calyx; Machine vision; Quality sorting; Classification

1. Introduction

Tons of apples are produced, harvested and consumed throughout the world each year. Visual inspection of these apples are traditionally done by human experts. Even so, automatization of this process is necessary to increase speed of inspection as well as to eliminate human error and variation introduced by experts. In recent years machine vision systems have been widely applied to evaluate external quality of apples. However, these systems cannot provide robust and accurate results yet, because high variability of defect types and skin color as well as presence of stem/calyx (SC) areas increase complexity of the problem. Computer vision systems are mostly confused in discriminating SC ends from true defects due to their similarity in appearance. Hence, accuracy of apple sorting is diminished by false identification of SC ends.

Several approaches have been introduced to recognize SC's using mechanical or computer vision systems. Mechanical approaches include systems in which orientation of fruits, therefore positions of SC's are known. However, in reality, adjusting and preserving orientation of fruit reliably while acquiring images of whole apple surface is problematic. Moreover, in the image acquisition system used in this research as well as in most other systems introduced by other researchers, orientations of apples while imaging are not known. Hence, mechanical solutions are not considered in this paper.

Yang (1996) introduced an image analysis technique to identify SC's on 'Golden Delicious' and 'Granny Smith' apples. Assuming stems and calyxes appear as dark patches, first these areas are segmented by flooding algorithm from images under diffuse light. Then, 3D surfaces of patches are reconstructed from structural light projected image. Patches are classified as SC or patchlike defect by back-propagation neural network using features extracted from both images. Average recognition rate achieved was 95%, however, proposed method is tested only on monocolored apples. Crowe and Delwiche (1996a, 1996b) used structural illumination to detect apple defects, where concave dark spots were considered to be SC. Unfortunately, no numerical result was provided by the authors for

* Corresponding author. Tel.: +32 65 374745; fax: +32 65 374729.
E-mail address: unay@tcts.fpms.ac.be (D. Unay).
URL: http://www.tcts.fpms.ac.be (D. Unay).

0260-8774/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2005.10.038

identification of SC's. Wen and Tao (1999) developed a rules-based NIR system and used histogram densities to discriminate SC's of 'Red Delicious' apples from defected areas. Recognition rates of stems and calyxes were 81.4% and 87.9%, respectively. Their system was less reliable when SC's appeared closer to the edge of fruit. In their later work, Wen and Tao (2000) used an NIR and a middle-infrared (MIR) camera for apple fruit inspection, where image from the latter was used to segment SC's and about 99% of them were correctly recognized. However, cost of cameras, which is not discussed by the authors, is an important issue for practical implementation of this approach. Penman (2001) illuminated four different varieties of apples with blue linear light and used reflection patterns of the fruit acquired by a ccd-camera to locate SC's as well as blemishes. Accuracy of the algorithm was inversely proportional with the location of SC's relative to fruit center. Moreover, the author mentioned about neither presence of defects nor their effect on recognition. Li, Wang, and Gu (2002) assumed that SC areas were concave and defected ones lost their concavity. So, fractal analysis with an artificial neural network is used to discriminate SC areas from defected ones in 'San Fuji' apples. Tests were done on a small database and it was reported that highly rotten areas were misclassified because their surfaces were concave. Cheng, Tao, Chen, and Luo (2003) proposed to use MIR camera with segmentation based on gray-level similarity of pixels to detect SC's on 'Red Delicious' apples. Euclidean distance was used to evaluate similarity. Recognition rates achieved for stems and calyxes were 94% and 92%, respectively. Kleynen, Leemans, and Destain (2005) utilized correlation-based pattern matching technique to detect SC's of 'Jonagold' apples in a multispectral vision system. Recognition rates for stems and calyxes were 91% and 92%, respectively. And 17% of defects were misclassified as SC's. Pattern matching method has been widely applied for object recognition, but its main disadvantage is its high dependency on the pattern (template) used. Recently, Bennedsen and Peterson (2004) used unsupervised feature extraction and neural networks to discriminate apple images including SC's from those that do not. Recognition rate achieved was 98%, however, their approach was not able to discriminate between true defects and stems or calyxes.

Above literature review reveals that SC identification is a necessary task for an accurate fruit sorting system, but it is not so easy to accomplish. Mechanical methods are simply not reliable enough. Computer vision-based methods introduced by other researchers cover wide range of materials and techniques, however, the quest for a general, accurate and cheap solution is still open. Pattern recognition on computer images is typically composed of object segmentation, features extraction, features selection and classification steps. And performance of overall system depends on individual accuracies of these subsequent steps. For example, a suitable feature selection process can improve performance by increasing recognition, removing irrelevant features or both. Similarly, certain classification algorithms can be more efficient in certain tasks than others. Hence, aim of this paper is to introduce a novel pattern recognition method for recognizing SC regions in 'Jonagold' apples images with special emphasis on feature selection step and effect of using different classification algorithms. 'Jonagold' variety is chosen due to their bi-colored skin, which increases the difficulty of the recognition problem.

2. Materials and methods

2.1. Image acquisition and database

Image acquisition device used for this research is simply composed of a high resolution (1280×1024 pixels) monochrome digital camera, four interference band-pass filters, a frame grabber, a diffusely illuminated tunnel with two different light sources (fluorescent tubes and incandescent spots), and a conveyor belt on which fruits are placed. The filters are centered at 450, 500, 750, and 800 nm with respective bandwidths of 80, 40, 80, and 50 nm. This device is capable of acquiring only one-view images of fruits. Each of these one-view images were composed of four filter images, which had to be separated by alignment based on pattern matching. Then, *flat field correction* is applied to remove vignetting on filter images. Finally, each filter image is composed of 430×560 pixels with 8 bits-per-pixel resolution (Fig. 1).

Database consists of images of 819 'Jonagold' variety apples, which are manually placed in the view of camera (Table 1). 280 of the images contain only healthy skin in view. 293 images are of stems or calyxes with various orientations with respect to the camera view. The rest of the images (246) have defects of various size and kind (russet, recent bruises of 1–2 h old, rot, scald, hail damage with and without perforation, scar tissue, limb rubs,...). Bruises are produced by dropping the fruit from 30 cm height onto a steel plate. 'Jonagold' variety is selected, instead of mono-colored ones, because it has a bi-colored skin

Fig. 1. Filter images of a fruit. Left to right: 450, 500, 750, and 800 nm filters.