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Automatic detection of orientation and diseases in blueberries using image analysis to improve their postharvest storage quality

Gabriel A. Leiva-Valenzuela*, José Miguel Aguilera

Department of Chemical and Bioprocess Engineering, Pontificia Universidad Católica de Chile, Avenida Vicuña Mackenna 4860, Macul, Santiago, Chile

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ABSTRACT

The production of the South American blueberry has increased by over 40% in the last decade. However, during storage and shipping, several problems can lead to rejections. This work proposes a pattern recognition method to automatically distinguish stem and calyx ends and detect damaged berries. First, blueberries were imaged under standard conditions to extract color and geometrical features. Second, five algorithms were tested to select the best features to be used in the subsequent evaluation of classification algorithms and cross-validation. The blueberries classes were control, fungally decayed, shriveled, and mechanically damaged. The original 951 features extracted were reduced to 20 or fewer with sequential forward selection. The best classifiers were Support Vector Machine and Linear Discriminant Analysis. Using these classifiers made it possible to successfully distinguish the blueberries' orientation in 96.8% of the cases. By evaluating damages to fungally decayed, shriveled, and mechanically damaged blueberries, the average performances of the classifiers were above 97%, 93.3%, and 86% respectively. All of the experiments were evaluated using external images with 95% confidence – 10-fold cross-validation. These results are promising because they will allow for the increase in export quality when implemented in production lines.

1. Introduction

The blueberry is an important fruit worldwide whose consumption has increased in recent years due to its good flavor and high antioxidant capacity, which is good for anti-aging. The United States of America is the leading blueberry exporter and consumer (FAO, 2009). However, in recent years, countries in the southern hemisphere (e.g., Argentina, Chile, New Zealand and South Africa) have increased fruit export to the northern hemisphere. However, long-distance shipping requires delivering higher-quality and more consistently fresh blueberries to meet quality standards upon arrival.

The accurate determination of blueberry quality is challenging because individual fruits are small, dark in color, and vary greatly in external and internal quality characteristics. Traditionally, blueberry quality was inspected by hand in sorting lines in the fruit's place of origin for color, size, and the absence of defects and foreign materials. However, in blueberry quality assessment, sorting by hand is inefficient and unreliable, making the implementation of automatic systems necessary. Previous studies have shown that applications of computer vision in quality control in food are more accurate, safe and quicker than human sight (Aguilera, 2005).

Detailed information about statistical pattern recognition may be reviewed in the work of Jain (Jain, Duin, & Jianchang, 2000), Duda (Duda, Hart, & Stork, 2000), and Bishop (Bishop, 2007). Previously, (Leiva-Valenzuela, Lu, & Aguilera, 2013) incorporated image processing techniques into a push broom hyperspectral reflectance system to select areas and extract using the mean intensity of individual blueberries to predict internal attributes (i.e., solid soluble content and firmness). (Leiva, Mondragón, Mery, & Aguilera, 2011) used visible and external features to sort fungally diseased blueberries and were able to recognize more than 95% diseased units using linear discriminant analysis and 10-fold cross validation.

Computer vision, as an objective, consistent, rapid, and economical technology, offers an automated alternative to visual inspection and is currently being used in various food and agricultural sorting systems (Brosnan & Sun, 2002; Kumar-Patel, Kar, Jha, & Khan, 2012). Specifically, color computer vision has been used to effectively assess quality in strawberries (*Fragaria* spp.) (Bato, Nagata, Cao, Hiyoshi, & Kitahara, 2000), pistachios (*Pistacia*

Abbreviations: BMP, Bit Mapped Picture; CCD, Charge-coupled-device; FOSMOD, Forward orthogonal search algorithm maximizing the overall dependency; n-KNN, K-neareast neighbor with n neighbors; LBP(o,q), Local binary patterns; LDA, Linear discriminant analysis; MAH, Mahalanobis distance; MDI, Minimal distance; PNN, Probabilistic neural network; QDA, Quadratic discriminant analysis; RANKFS, Rank key features by class sorting criteria; ROC, Relative operating characteristic curve; SFS, Sequential forward selection; SVM, Support vector machine.

* Corresponding author. Tel.: +56 2 354 5481.
E-mail addresses: gmleiva@uc.cl, gabriellv@gmail.com (G.A. Leiva-Valenzuela).

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vera) (Pearson & Toyofuku, 2000), fungally decayed sliced chestnuts (Donis-González, Guyer, Leiva-Valenzuela, & Burns, 2013), olives (Riquelme, Barreiro, Ruiz-Altisent, & Valero, 2008; Wang et al., 2011), apple (De Belie, Tu, Jancsók, & De Baerdemaeker, 1999; Xing, Van Linden, Vanzeebroeck, & De Baerdemaeker, 2005) and bayberries (Lu, Zheng, Hu, Lou, & Kong, 2010). Thorough reviews of non-destructive inspection technology for postharvest fruit were performed by Brosnan and Sun (2004) and Studman (2001).

Currently, several types of commercial sorting systems are available, (e.g., the "*Berrytek*" sorting system from Woodside Electronics Corp., CA, USA, and "*Color Sorta*" from BBC Technologies Ltd., Ohaupo, New Zealand). These commercial systems allow for high-speed sorting (up of 2 tons h^{-1}) and are able to reject up to 95% of out-of-range fruit (http://bbctechnologies.com/en_US/colorsorta.htm). However, these sorters are based on the overall detection of berry color, reducing their ability to recognize specific defects over fruit surfaces such us fungal decay and shriveling. Therefore, using pattern recognition algorithms is necessary to improve the ability to separate the most diseased fruits in only one step using the simplest systems available. This paper proposes a pattern recognition methodology to extract and select visible features from images to sort blueberries into four classes—control (good blueberries), shriveled, fungally decayed, and mechanically damaged blueberries—and two fruit orientations—stem end and calyx end. Thus, this report will facilitate the development of automatic sorters that can separate fruits exhibiting visible disease in only one step.

2. Materials and methods

Experiments were carried out in the Biomaterials Laboratory of the Department of Chemistry and Bioprocess Engineering at Pontificia Universidad Católica de Chile (PUC) in Santiago, Chile between August 2009 and February 2010. Image processing was carried out using Matlab R2007a and its image processing toolbox (The Mathworks, Inc., Natick, MA, USA).

2.1. Samples

"Highbush" blueberries, (*Vaccinium corymbosum* var. 'Star') were acquired from cultivars in the central region of Chile. Before experimentation, blueberries were stored at 0 °C for 8 weeks to induce different levels of postharvest damage. Before image acquisition, samples were visually inspected to divide them into four classes based on appearance and surface defects (Fig. 1). *Control blueberries* were defined as well-colored, spherical fruits free of irregularities such as spots, hairlines, impacts, compression, wrinkles, and the present of mold. Fruits with wrinkles over their surfaces were defined as *shriveled blueberries*. In most of the cases, wrinkles appeared as concentric curves close to the stem end. Fungally decayed *blueberries* were defined as fruits with at least one isolated mold spot over their surfaces or a characteristic purple color and a relatively softer texture around the pedicel than that of the rest of the fruit. The threshold area used to distinguish decayed from non-decayed fruits was approximately 1/50 of each overall image. Finally, *mechanically damaged* blueberries were defined as berries with visible changes in their external geometry as a result of compression or impact caused by transportation or storage.

2.2. Image acquisition, segmentation and color transformation

Images were acquired under standard conditions using a DVS-lab colorimeter (Digital Vision Solutions, www.divisol.cl). Each fruit was imaged along two orientations, the calyx end and stem end, for each class in groups of 15 berries (480 × 640 pixels color image). Images were stored in the bitmap picture (BMP) format.

Image segmentation was implemented in two steps. The first step consisted in the recognition of single berries by cropping the original image in pre-defined regions. The second step consisted in building a binary mask to recognize the fruit from the background using threshold segmentation and morphologic color image operations. Those morphologic operations included the elimination of small, isolated groups of pixels, the slight erosion of blueberry

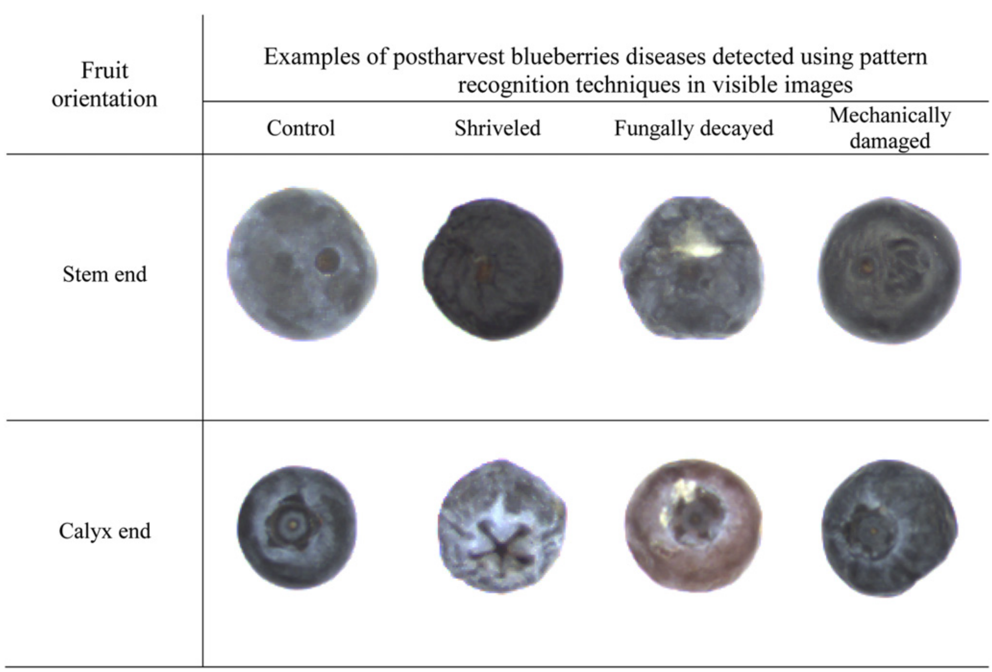

Fig. 1. Examples of dual-orientation blueberry classes after segmentation. Control blueberries were defined as well-colored, spherical fruits free of irregularities. Fruits with wrinkles over their surfaces were defined as shriveled blueberries. Decayed blueberries were fruits with at least one mold spot over their surfaces or a characteristic purple color and a relatively softer texture around the pedicel than that of the rest of the fruit. Finally, mechanically damaged blueberries were defined as berries with visible changes in their external geometry as a result of compression or impact. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)