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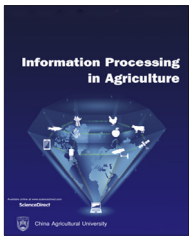

Computer vision-based apple grading for golden delicious apples based on surface features

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ABSTRACT

In this paper, a computer vision-based algorithm for golden delicious apple grading is proposed which works in six steps. Non-apple pixels as background are firstly removed from input images. Then, stem end is detected by combination of morphological methods and Mahalanobis distant classifier. Calyx region is also detected by applying K-means clustering on the Cb component in YCbCr color space. After that, defects segmentation is achieved using Multi-Layer Perceptron (MLP) neural network. In the next step, stem end and calyx regions are removed from defected regions to refine and improve apple grading process. Then, statistical, textural and geometric features from refined defected regions are extracted. Finally, for apple grading, a comparison between performance of Support Vector Machine (SVM), MLP and K-Nearest Neighbor (KNN) classifiers is done. Classification is done in two manners which in the first one, an input apple is classified into two categories of healthy and defected. In the second manner, the input apple is classified into three categories of first rank, second rank and rejected ones. In both grading steps, SVM classifier works as the best one with recognition rate of 92.5% and 89.2% for two categories (healthy and defected) and three quality categories (first rank, second rank and rejected ones), among 120 different golden delicious apple images, respectively, considering K-folding with K = 5. Moreover, the accuracy of the proposed segmentation algorithms including stem end detection and calyx detection are evaluated for two different apple image databases.

1. Introduction

Computer vision-based systems as a developing technology find many applications in agricultural and food industries, especially in domain of quality control and classification of products [1–3]. Quality control in apple-based industries and marketing plays an important role to produce high quality products. Traditionally, apple quality inspection is performed by human experts. Apple grading is problematic due to variety of defects in type and shape. Apple fruit can be divided into two types of mono-colored (like golden delicious) and bi-colored (like jonagold).

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Most of works done in this domain can be categorized into two main groups: in the first one, the researches apply special equipment in non-visible band to assist grading, while in the second one they use ordinary machine vision systems with imaging in visible band. The X-ray imaging [4], thermal cameras [5], near infrared imaging [6], multi spectral imaging [7] and hyper spectral imaging [8], are special some equipment in the first group.

For ordinary machine vision systems, the computer vision algorithms used for apple grading are important. Among the researches that use ordinary machine vision system, Wen and Tao [9] introduced a rule based system to grade 960 red delicious apples (bi-colored) into two groups of healthy and defected. Results showed that their system was confused by stem-calyx areas and achieved 85–90% accuracy. Leemans et al. [10] presented a system equipped with a color camera to grade golden delicious and jonagold apples into 4 quality groups in a six-step process. They used a quadratic discriminant classifier (QDC) and a multi-layer perceptron (MLP) for grading and achieved 78% accuracy for golden delicious apples and 72% accuracy for jonagold apples. Blasco et al. [11] introduced a system with a color camera to grade golden delicious apples into 3 quality groups by thresholding on size of defects and achieved 86% accuracy. Leemans and Destain [12] employed a QDC classifier and graded jonagold apples into two quality groups and achieved 73% accuracy.

Unaya and Gosselin [13] introduced a system that used different classifiers. They employed an artificial neural network (ANN) to segment apple defects and then tested and compared five supervised classifiers. The results showed that the Adaboost and support vector machine (SVM) were the best ones with about 90% accuracy. Zou et al. [14] introduced a system that used multiple color cameras to scan apples surface. They classified apples into groups of healthy and defected by thresholding and achieved 96% accuracy.

In this paper we introduce an apple grading computer vision algorithm that can be used in an ordinary machine vision system. This algorithm firstly detects stem and calyx areas and removes them from defective regions and then it classifies apples into corresponding quality categories by statistical, textural and geometric features. Classification is first done into two categories of healthy and defected, and then a more realistic classification is achieved by multi-category grading. The remainder of this paper is organized as follows: In Section 2, the proposed method is explained in detail. The performance of the proposed method is evaluated among 120 different golden delicious apple images in Section 3, and finally, the paper ends with a section on conclusion.

2. Proposed computer vision algorithm

An overview of our proposed computer vision algorithm for quality control of apple fruits is shown in Fig. 1. In the first step, several segmentation algorithms are applied consequently on the input apple image which includes background removal, stem end detection, calyx detection, primary defect segmentation, and refinement of defect regions. The second step extracts proper statistical, textural and geometric features from the refined defected regions, which is the output

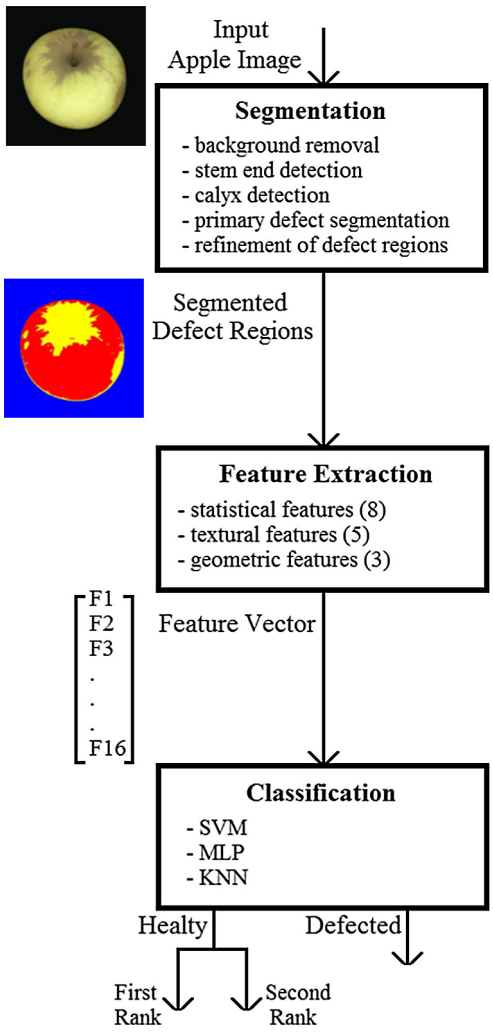

Fig. 1 – Overview of our proposed computer vision algorithm for apple quality control.

of the first step. The third step classifies and ranks the input image by SVM, MLP and K-Nearest Neighbor (KNN) classifiers. The second and third steps are recognized as apple grading stage. The details of each steps are presented in the following sub-sections.

2.1. *Background removal*

In a machine vision-based apple grading system, the lighting and background of apple image is fully controlled. Usually, a dark background is used to simply separate from apple image. Our apple image database also involves dark background apples images. Hence, background pixels have low values and easily can be removed by applying the heuristic threshold value, μ_{Thr}, which is calculated by following relationship [15],

$$\mu_{Thr} = \frac{\mu_{MaxRep} + \mu_{Median}}{2} \quad (1)$$

where μ_{Median} is the median of the image gray level distribution and μ_{MaxRep} is the gray level which has maximum repetition in input image. In fact, this threshold which is automatically determined separately for each image by

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