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Automatic detection of defective apples using NIR coded structured light and fast lightness correction

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A B S T R A C T

The automated detection of defective apples with a machine vision system is difficult because of the non-uniform intensity distribution on the apple images and the visual similarity between the stem-ends/calyx and the defects. This paper presents a novel method to recognise defective apples by using a machine vision system that combines near-infrared(NIR) coded spot-array structured light and fast lightness correction. By analysing the imaging principle of the spots projected onto the surface of a spherical object, we regard the change in the position of the spots as a coded primitive. A binary-encoded *M-array* is designed by using primitives as the pattern of the NIR structured light. The stem-ends/calyxes can be identified by analysing a difference matrix from the NIR apple image captured with a multi-spectral camera. Fast lightness correction is performed to convert the uneven lightness distribution on the apple surface into a uniform lightness distribution over the whole fruit surface. The candidate defective regions segmented and extracted from the RGB apple image captured with the same multi-spectral camera are classified as the true defects or the stem-ends/calyxes by using the result of the stem-end/calyx identification in the NIR image. The apples are finally classified into sound and defective classes according to the existence or absence of defects respectively. The online experimental result with an average overall recognition accuracy of 90.2% for three apple varieties indicates that the proposed method is effective and suitable for defective apple detection.

1. Introduction

An automatic fruit sorting system based on machine vision can classify fruits into different quality grades according to their size, colour, shape and defect. The automatic inspection technology has been commercialised in apple pack industries to sort apples according to their colour, shape and size. Nevertheless, detecting true defects and distinguishing them from stem-ends/calyxes are still challenging tasks for online apple inspection because stem-ends/calyxes exhibit patterns and intensity values that are similar to the defects in apple images and the uneven distribution of lightness on apple surfaces.

To distinguish true defects from apple stem-ends/calyxes, many scholars have explored the application of mechanical and machine vision technology. Throop et al. (2005) employed mechanical systems to control the orientation of apples. The mechanical method prevents stem-ends/calyxes from showing in the field of view of cameras. The method needs a special length of mechanical conveyor for apple orientation. Zou et al. (2010) proposed a three colored CCD camera classification system to detect apple defects. As this method cannot identify stem-end/calyx regions, it cannot detect the size and position of defective region on an apple surface, although it can identify the presence of a defective region in an apple image. Many attempts have been made to identify stem-ends/calyxes by using pattern recognition methods (Leemans and Destain, 2004; Bennedsen and Peterson, 2005; Unay and Gosselin, 2007; Song et al., 2012; Zhang et al., 2013, 2015a). However, the recognition accuracy of such methods is highly dependent on the features selected and extracted. The specific features that are good for one variety of apples may do poorly for others. New features must be proposed for new apple varieties, and grading parameters must be tuned for new apple varieties. The process also requires extensive training before classifiers are used in practical applications. At the same time, human experts are needed to select

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image samples that are used in the training process. Hyperspectral imaging methods (Lu, 2003; Huang et al., 2013) are proposed to recognise defects on apples. As a result of their long acquisition time and high cost, hyperspectral imaging methods cannot be applied to the online detection of defects on apples. Zhu et al., (2007); Jiang et al., (2009) introduced a three-dimensional (3D) reconstruction approach based on the shape from shading for identifying stem-ends/calyxes. The accuracy of the 3D reconstruction method is easily influenced by changes in lighting conditions. Zhang et al. (2015b) proposed a 3D reconstruction method to identify stem-ends/calyxes by using NIR line structured light. However, the effectiveness of the 3D reconstruction depends greatly on the accuracy of the structured light system, and the online detection results should still be verified. A group of line structured lights (Yang, 1996; Crowe and Delwiche, 1996; Penman, 2001; Cheng et al., 2003a) is used to identify stem-ends/calyxes. Given that the encoding method is not used in these methods, the accuracy of recognition fails to meet the requirements of practical applications. Zhang et al. (2012, 2015c) introduced a stem-end/calyx identification method based on NIR speckle-array structured light. Cheng et al. (2003b) also built a dual-camera imaging system, which incorporates a NIR camera and an expensive mid-infrared (MIR) camera, to identify apple stem-ends/calyxes. Although this method is currently the most effective method in terms of detecting apple defects, the high cost of the MIR camera may limit the practical application of the approach.

In general, the shape of an apple is approximately spherical. An apple can be approximately considered as a Lambertian object. Hence, the central part of such object is brighter than its edge. The uneven distribution of lightness on the surface of apples hinders the identification of defects from the area of sound peel at the darken edges. To reduce the negative influence of lighting systems, many studies have attempted to correct the uneven lightness on apple surfaces. Blasco and Moltó (2002) used a local threshold method to classify different regions of interest. However, with the number of classes increasing, the classification accuracy declined. Gómez-Sanchis et al. (2008) proposed a method for correcting the unevenly distributed lightness on spherical objects. This method requires the construction of 3D models for each individual fruit. However, in practical implementation, an image frame may include several fruits, and several fruit images must be corrected at the same time. Hence, the algorithm is time consuming. Although existing methods (Zhang et al., 2015b; Tao and Wen, 1999) can extract defects, they require long processing periods. Li et al. (2013) proposed a lightness transform method for detecting common defects on orange surfaces. However, the online detection period still needs to be verified because the lightness transform is based on Fourier transform and Butterworth filter.

In this paper, a method is proposed for detection of the defective apples in real time. To identify defective apples, stem-ends/calyxes are recognised by analysing the change of every NIR spot between on the apple surface and on the reference plane. Then a lightness correction method is used to obtain a uniform intensity distribution over the apple surface. The low intensity regions can be extracted from the corrected apple image as the candidate defective regions. Finally, the candidate defective regions can be classified as true defects or the stem-ends/calyxes by using the results of stem-end/calyx identification. The defect identification method proposed in this study is not disturbed by the colour variations on apple surface, and it does not require complicated training for different apple varieties. Thus, this method is suitable for apple sorting and grading in high-speed dynamic applications.

2. Materials and methods

2.1. Fruit sorting system

The research platform is a 4-lane fruit sorting system (Fig. 1). The machine vision system in the lighting chamber consists of a 2CCD camera (AD-080 GE, JAI Ltd., Yokohama, Japan) with the same resolution for RGB and NIR images (1024 × 768 pixels), a lighting system comprising four pairs of 72 W visible LED light source, a NIR structured light projector, a PLC control unit and an industrial computer applied in industrial automation. The AD-080 GE camera, which comprises a 3CCD C-mount lens with a 6 mm focal length, is connected to the industrial computer through a dual Ethernet card. This camera can simultaneously acquire RGB and NIR images for the same scene. The lighting system is equipped with a brightness regulation device for regulating brightness of the visible light source according to the specified requirements. A conveyor comprising black rubber rollers is built to separate apples and rotate each one freely so as to make every side available to the

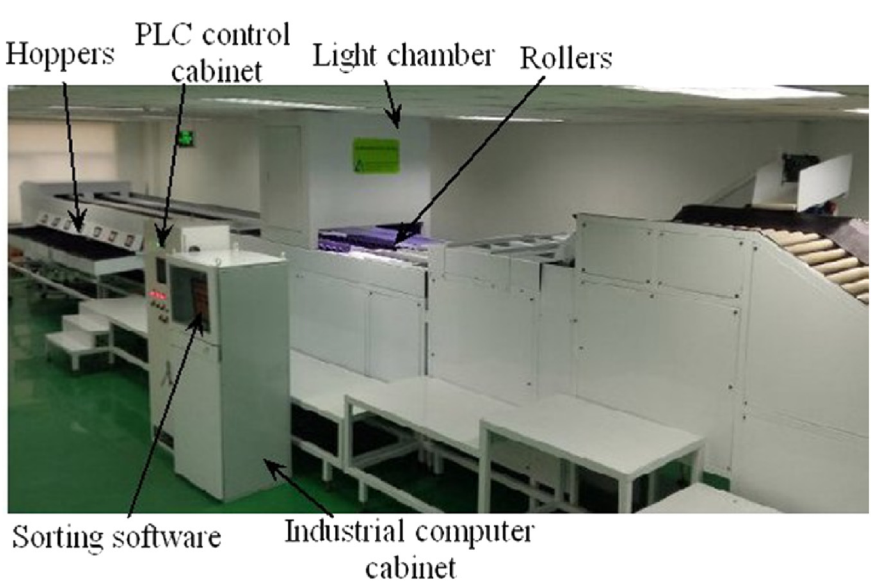

Fig. 1. Fruit sorting line based on machine vision.