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Embedded vision detection of defective orange by fast adaptive lightness correction algorithm

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ABSTRACT

Automatic detection of defective fruit by computer vision system still faces challenge due to the uneven lightness distribution on the surface. A fast adaptive lightness correction algorithm implementation which is simpler and easier in real-time approach is proposed to overcome interferences from non-uniform reflectance intensity distribution on moving fruit surface and avoids error detection. The algorithm is tested by on-line and static defective orange images in the different lighting conditions. This study also compares other lightness correction algorithm implementations for defect detection. Recently, embedded vision systems are more and more popular because of low-cost, compact size and stability. A low-cost embedded vision system based on an industry gigabit ethernet camera and embedded Linux system in an arm processor with limited computing power compared with high-performance major PC is also originally developed to test and prove the performance of fast adaptive lightness correction algorithm using the most common surface defect of Navel orange in China. The time consumption of adaptive lightness correction algorithm of an image is below 6 ms. The processing time of an orange image is below 30 ms.

1. Introduction

Automatic detection of defective fruit by computer vision system still faces challenge due to the uneven lightness distribution on the surface. Orange grading is done by hand in many developing countries of orange-producing. The machine vision and image techniques have been used to inspect the quality of food (Li et al., 2002; Blasco et al., 2007a; Cubero et al., 2011, 2014a, 2014b; Lorente et al., 2012, 2013a, 2013b; Li et al., 2011, 2012; Okamoto and Lee, 2009; Obenland et al., 2010; Ogawa et al., 2011). Common surface defects on fruit are complex and irregular, defect detection is not an easy task. Recently, some articles are concerned with the detection methods of common surface defects on orange using high-performance major PC-based vision system with RGB image sensor. The multispectral imaging was firstly used to detect defects in citrus fruits by Aleixos et al. (2002). A region-oriented segmentation algorithm for detecting citrus peel defects was proposed by Blasco et al. (2007b). The spectral and morphological information to distinguish between some serious damages and other cosmetic defects was introduced by Blasco et al. (2009). A multivariate image analysis and principal component analysis strategy was introduced by Fernando et al. (2010). The color segmentation technique was used to detect defects in citrus fruits by Vijayarekha (2012). Li et al. (2013) proposed a combined lighting transform and image ratio methods to detect the common defect on oranges.

Illumination is one of factors that most seriously affect detection performance. These bright spots can affect the estimation of defects that are important to detect. The problem grows because of the spherical shape of the fruit. Cubero et al. (2016) and Gómez-Sanchis et al. (2008) created an elevation model from the circumference of the oranges, assuming them to be perfectly spherical with a Lambert surface. Zhang et al. (2014) used Lambertian model to analyze uneven distribution of lightness and use the annulus area of the static fruit to finish lightness correction. However, the distribution of lightness in the annulus area of on-line fruit is still uneven so that the lightness correction effect is not good using easy averaging method when the position of moving fruit on the grading line is not in the center of camera optical axis or the fruit shape is not a perfect sphere fruit. Li et al. (2013) used digital signal processing and Butterworth filter to complete lightness correction because of non-uniform reflectance intensity distribution on fruit surface, but it is not proper for on-line detection because of time consuming computation. And the most optimal cutoff frequency D_0 of Butterworth filter is uncertain and still needed to choose by hand in the different lighting condition. The edges can be removed simply from the analysis using morphological operations by Niphadkar et al. (2013), but it is time

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consuming and computationally expensive. And the morphological operations cost more time using higher resolution images.

The high-performance major PC-based vision system is of a large size, which limits its applications on compact machine systems. Recently, the embedded systems are being rapidly developed, which are widely applied in the fields of industrial control, automobile and robotics (Blanza and Holland, 2012; Chen et al., 2012; Frontoni et al., 2015; Pedre et al., 2016). With the help of the embedded systems, many kinds of application-specified embedded vision systems with limited computing power compared with major traditional PC has been developed. The embedded machine vision system loads the image processing algorithms into the specific hardware including power supply module, I/O module, memory control module, image sensor module and data processing module. These modules are combined to achieve an integrative design of embedded systems, which endows the embedded machine vision system with the features of low-cost, easy-to-install, stability (Zou et al., 2009).

In this paper, a fast adaptive lightness correction algorithm implementation which is simpler and easier in real-time approach is proposed to overcome interferences from non-uniform reflectance intensity distribution on fruit surface and avoid error detection. The algorithm is tested by on-line and static defective orange images in the different lighting conditions. This paper also compares other lightness correction algorithm implementations from the recent published research papers for fruit defect detection. A low-cost embedded vision based on embedded Linux system with limited computing power compared with high-performance major PC is also originally developed to test and prove the adaptive lightness correction algorithm performance using the most common surface defects of Navel orange in China.

2. Materials and methods

2.1. Materials

The sound and defective orange (Jiangxi Navel Orange in China) samples were obtained from the commercial orchard in Jiangxi province in December 2015. The defective samples consist of the six types of the most common defective Navel oranges (wind scarring, thrips scarring, scale infestation, canker spot, dehiscent fruit, copper burn) with light black or dark black or brown peel defects and various numbers of defects in different sizes.

2.2. Hardware and image acquisition

The lighting and embedded image acquisition system was designed to be adapted on a mechanical machine with a single detection channel (Non-commercial teaching prototype version from Zhejiang Univ., China). Six LED lighting tubes (10 W, 2700–4500 K, type YJ-T8CA144WW from AGLARE. China) were placed at the inner side of a lighting box to decrease shadow being cast. The diffuse reflection plate was placed in front of each fluorescent tube in order to reduce the bright spots of the scene. An industry color gigabit ethernet camera with 1288 $\times$ 964 resolutions (BFLY-PGE-13S2C from Point Grey Inc., Canada. The price is 280 dollars) connected with embedded Tegra K1 circuit board was above the grading line with an optical axis in a plane perpendicular to the orange movement direction in the lighting box, as shown in Fig. 1. The lighting box was 1000 mm in length, 1000 mm in width and 1500 mm in height. The distance between orange and camera was 1100 mm, and the resolution was 0.5 mm per pixel in the view field of the camera with four oranges. The system guarantees each image with a resolution of 0.5 mm/pixel. The images were captured using Gigabit Ethernet port connected with an embedded processor Tegra K1 (quad-core 32-bit ARM Cortex-A15 with 192-coreKepler GPU) released from NVIDIA Semiconductor Inc. in the latter half of 2014 year (NVIDIA, 2014). The price of embedded Tegra K1 circuit board is 198 dollars, as shown in Fig. 2. The embedded image algorithm software was designed using C/C++ language, shell script, Linux GTK program and free OpenCV4Tegra. The friction between rollers and the belt on the grading line make oranges rotate and move through the field-of-view of the cameras. The grading speed can be adjusted by the stepping motor at 10–15 oranges per second.

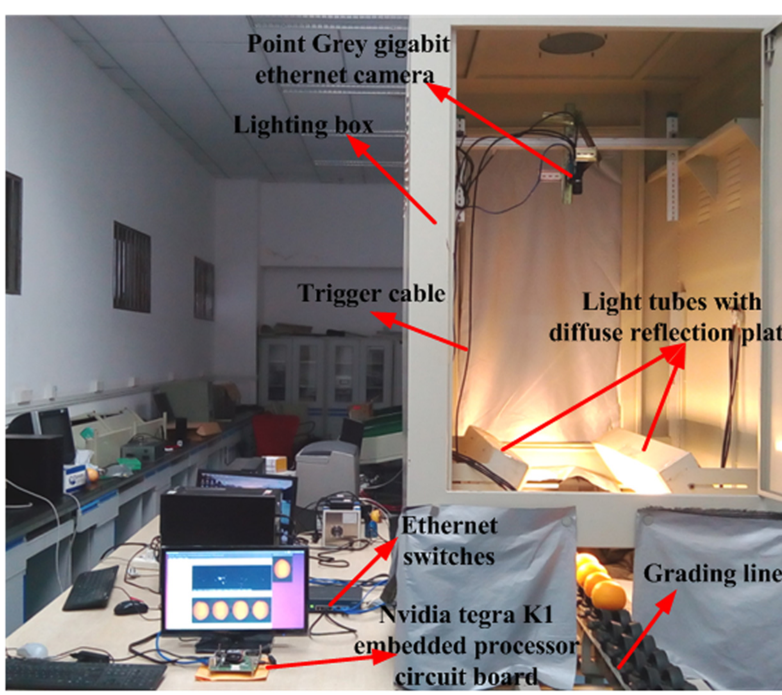

Fig. 1. Hardware system.