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Design of an automatic apple sorting system using machine vision

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ABSTRACT

This study proposes an automatic apple sorting and quality inspection system, which is based on real-time processing. Golden and Starking Delicious, and Granny Smith apple cultivars are sorted into different classes by their colour, size and weight. It also detects apples affected by scab, stain and rot.

The proposed system consists of a roller, transporter and class conveyors combined with an enclosed cabin with machine vision, load cell and control panel units. The roller and transporter conveyors have two channels.

In order to analyze the visual properties of apples, two identical industrial colour cameras are set on the roller conveyor. Four images of any apple rolling on the conveyor can be captured and processed using image processing software in 0.52 s. As a result, the proposed machine can sorted averagely 15 apples in per second using two channels, in real time.

In the experimental studies, the system design was tested using three different conveyor band velocities and three apple cultivars to sort and inspect 183 samples with an average sorting accuracy rate of 73–96%.

1. Introduction

Nowadays, the fruits must be of a certain standard in order to be efficiently offered to better quality markets. Various automatic classification machines are used to ensure these standards are met. Especially apple fruit harvested with high tonnage, are needed for automatic classification machine with the aim of increasing the economic value. The apple fruit, in particular, has a very wide range of cultivars. Therefore, apples have different colours and dimensions, must be classified in order to be sold to the market as a better quality product. The quality of the apples is determined according to the colour, weight, dimension and their defects.

In any automatic apple sorting system mainly consists of machine vision, conveyor band, separator, and classifier. So, it has mechanical, electrical, electronics and software parts. The first processing about apple is done on machine vision section. Generally, the systems used for apple classification do not operate in real-time, take an image of a single apple under the camera (Sabliov et al., 2002; Nicolai et al., 2006). The apparatus used in real-time image processing studies obtain faster and more effective classification results (Fattal et al., 2008).

There are many studies about apple sorting using colour, size and stain features. The most important characteristic affecting the quality of the apple classification is stain and decay. Most studies performed are concerned with this area (Du and Sun, 2004). One of the reasons for the low percentage of accurate classifications of decayed and stained apples is that the natural geometry of the calyx and stem parts of the apples are perceived as being decayed or stained (Penman, 2001). Li et al. (2002) used neural networks (NNs) to solve this problem. However, their proposed system processed the apples with low tonnage capacity in real-time sorting because of their cumbersome structure. Pla et al. (2001) performed a classification in their study with a colour map created by using a colour classification in a classification mechanism working in real-time that is known as a Look up Table (LUT).

In many simple colour classification studies, as in the study carried out by Yam and Papadakis, 2004, the classification is made by using different colour spaces. In the prospective classification studies on the fruits, near infrared (NIR) or mid-infrared (MIR) hyperspectral imaging techniques and hardware were also used. This hardware and these techniques offer information about the aroma, sugar, juiciness ratio and internal structure disorders of the apples (Nicolai et al., 2006; Baranowski et al., 2013).

To distinguish the apples from the background is a very important problem due to non-uniform lighting of apple surfaces. Mizushima and Lu (2013) solved this problem using support vector

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machines and a proposed adaptive segmentation is employed using the Otsu algorithm. Zhang et al. (2015) used automatic light correction for detection of defects. The other most widely used classification criteria is the size. In theory, apples are classified as Class I, Class II and extra as determined in European standards (Anonymous, 1989). But these standards could be changed according to costumer demands.

There are different classification methods for apple sorting such as neural network (Unay and Gosselin, 2002; Li et al., 2002; Bhatt and Pant, 2015), support vector machines (Mizushima and Lu, 2013), decision tree (Kavdir and Guyer, 2008), rule based (Wen and Tao, 1999) and statistical based tree (Kavdir and Guyer, 2008) methods.

In this study, the automatic apple sorting system was designed and then implemented in hardware and software. Performance of the developed system was tested by using a total of 183 samples of Golden and Starking Delicious, and Granny Smith cultivar apples with different geometries and colour, and the results were published. Apples was classified by stain, colour, weight and size characteristics to the duration of the experiment.

2. Materials and methods

The apparatus used in general fruit classification is made by simple image processing equipment (Chen et al., 2002). In this study, the mechanical and conveyor parts were designed and realized by Gençgüçsan firm. Then we set up machine vision system on the main conveyor and we coded programs to control the systems and to process the images at CAD-CAM Research & Application Center of Suleyman Demirel University. The machine is over a formal ground, and in a closed area. Therefore, daylight and humidity are not affected to machine. Although, the enclosed cabin is decreased the environmental negativities.

The developed system was tested by using a total of 183 samples of Golden and Starking Delicious, and Granny Smith cultivar apples. The apples are processed in this apparatus by two cameras across two channels. The captured images were processed and the apples distinguished from the background using the K-means algorithm. The stain, defects, scab, stem and calyx were detected from the binary apple image. The apples could be classified as small, normal and large according to size and weight, or classified as light and dark according to colour. We also sorted apples as defective and non-defective. The C4.5 algorithm was preferred as the common classifier due to its simplicity and rule-based structure. What's new in this study, the two classification requirement at the same time as the software is able to do online. Stain classification feature can work together with the colour and size of the property.

2.1. Hardware

The proposed automatic apple sorting system is shown in Fig. 1. There are two different conveyors. The first is used for recognition of the apples. For this, a machine vision system was set up in an enclosed cabin. Two Charge-Coupled Device (CCD) cameras and lighting system were also positioned in the cabin.

The first conveyor rotates and shifts the apples along the two channels as in Fig. 2. In this way, all sides of the apple can be monitored.

The classified apples are transferred to the transporter conveyor using a brush. In the transporter conveyor, the apples are located in special bowls in order to maintain the location of the classified apples. At the beginning of the transporter conveyor, two load cells are placed under the apple bowls to measure the apple weights. When the apple bowls arrive at the classification slides, the bowls are open and the apples are slowly dropped into these slides. The classification slides, which are five conveyors, are also driven by motors. The motors, bowl opening and closing magnets, counting, triggering and load cell sensors are controlled by a Programmable Logic Controller (PLC). The PLC also communicates with a personal computer (PC).

The PC is also used for image capturing, acquisition and software processing. Software flow diagram is shown in Fig. 3.

The classification data of the apples is sent to the PLC via a parallel port. The properties of the machine vision and control elements are shown in Table 1.

After the machine vision system reaches the decision about the apple classification, the apples are transferred to the transporter conveyor. At this time, the PC sends the classification data of the apples to the PLC via a parallel port without losing the apple location. The PLC also uses the load cell information, and then opens the bowls according to the class of the apple as in Fig. 4.

The bowl system allows the apples to be sorted into the classes by opening them using the trigger information sent by the PLC to 48v electromagnets.

2.2. Image acquisition

The main problem in apple sorting is to achieve the synchronization of the camera and conveyor. The other problem is to capture four images of each apple in the enclosed cabin. Therefore, an encoder is used to trigger the camera. The camera and PC easily communicate via a USB 2.0 port. A MATLAB Image Acquisition Toolbox is used to acquire the video signal of the camera. In this way, use of a frame grabber is unnecessary. The captured images are shown in Fig. 5.

Deciding the apple classification is made after the processing of the fourth image. In this time, eight apples can be processed within the two channels. The processed images and apple features are buffered in memory.

The position of apples under the camera with different processing times can be demonstrated in a matrix form $\mathbf{R}$ as,

$$\mathbf{R} = \begin{bmatrix} \mathbf{D}_{t+3} & \mathbf{C}_{t+2} & \mathbf{B}_{t+1} & \mathbf{A}_{t} \\ \mathbf{E}_{t+3} & \mathbf{D}_{t+2} & \mathbf{C}_{t+1} & \mathbf{B}_{t} \\ \mathbf{F}_{t+3} & \mathbf{E}_{t+2} & \mathbf{D}_{t+1} & \mathbf{C}_{t} \\ \mathbf{G}_{t+3} & \mathbf{F}_{t+2} & \mathbf{E}_{t+1} & \mathbf{D}_{t} \end{bmatrix}, \quad (1)$$

where $\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{D}, \mathbf{E}, \mathbf{F}, \mathbf{G}$ denote the different apples. The subscript t denotes the processing time. In this way, all apples have four successive pictures.

Image extraction is completed in three steps. The camera shoots sixteen photographs in a second on the real-time working conveyor band.

The first step is triggering. A triggering solution is created to always keep the apples in the same position and to use the memory efficiently. Triggering catches the proper photograph from the sixteen pictures taken per second using a token with any conveyor band velocity. The chain connection located on the band is painted with a white colour in front of the camera for this reason.

The second step is the apple extraction from the captured image. In this way, all the surface of the apple is processed.

The third step is labelling each apple in the image. In addition, it is controlled to allow for an apple image to be present or not. The labelled apple with t index is processed by the software and its information, including the four surfaces, is stored in a matrix. The colour, detecting the maximum size, and the number and size of defective regions from the images are the main information used to classify the apples. At the end, the load cell and image information are combined to give a decision about specific apples.