DEVELOPMENT AND EXPERIMENT ON AUTOMATIC GRADING EQUIPMENT FOR KIWI /
猕猴桃自动分级设备的研制与试验

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Abstract: *There is little equipment specially developed for grading kiwi fruit in both China and foreign countries. While the full automatic grading equipment often has complex mechanical structure and costs highly, it always grades kiwi fruit on the basis of singular feature such as size, weight, shape, color and surface defect such that it is hard for them to promote kiwi fruit's market competitiveness. Therefore, this paper developed a set of practical automatic kiwi fruit grading equipment basing on technologies of mechanical separation and conveyance, image capture and processing as well as intelligent control. This set of equipment mainly consists of material storage bin, single-line positioning system, image capture system and grading executive system. And it also has programs of image capture, image processing, grade determination and human-machine interaction for the host computer as well as control programs for the slave computer. Its operating principle is that: firstly put a small amount of kiwi fruits or slowly put kiwi fruits into the storage bin and switch on, and then the host computer sends the startup command to the slave computer. Upon receiving such command, the slave computer starts grading equipment and initializes the camera. The camera will then get into the image capture state. Kiwi fruits are conveyed to the image capture system by the single-line positioning system in single row. Upon the slave computer receives the signal that kiwi-fruits are on position sent by the position sensor of the image capture system, it will immediately send such signal to the host computer. Then the host computer will store the images from the camera at this time and discard the images captured at other time. After the host computer carries out relevant operations such as image processing and grade determination to moving images, it will send grading results to the slave computer. At this time, the kiwi fruits will have been conveyed to the grading implementation area and the slave computer will control the implementation system at all levels to perform grading. Each kiwi fruit will be graded through the same grading flow. By testing, this equipment is capable of grading by three features of size, shape and surface defect and their grading accuracy can reach to 88.9%, 91% and 94% respectively. And the accuracy of integrated grading can reach to 86%. The output of this equipment can reach to 1.22kg/min which is much more than the efficiency of manual grading. With simple mechanical structure and low cost, this equipment reduces the processing cost of kiwi fruit and is suitable to vast middle and small users.*

Keywords: *kiwi, grading equipment, image processing, BP network*

摘要：*很少有专用设备在中国和国外的分级猕猴桃开发。而全自动分级设备往往具有复杂的机械结构和成本高，它总是成绩猕猴桃的奇异特征如大小，重量，形状的基础上，颜色和表面缺陷等，来促进猕猴桃的市场竞争力是很困难的。因此，本文开发了一套实用的自动猕猴桃分级机械分离和输送技术的基础设备，图像采集和处理以及智能控制。这套设备由储料桶，单线定位系统，图像采集系统、分级执行系统。它还具有图像采集，图像处理程序，等级的确定和人机交互的上位机以及下位机控制程序。其工作原理是：首先把少量的猕猴桃猕猴桃果实或慢慢放进储存仓和开关，然后主机发送给从计算机启动命令。接到命令，从计算机开始分级设备和初始化相机。相机将进入摄像状态。猕猴桃被传送到图像采集系统由单线定位系统在单排。在下位机接收信号，奇异果，在位置的图像采集系统的位置传感器发送，它将立即向主机发出这样的信号。然后，主机将存储的图像从摄像机在这个时候放弃在其他时间拍摄的图像。计算机主机后进行如图像处理和等级确定运动图像的相关操作，它将发送到下位机分级结果。在这个时候，猕猴桃将被输送到分级实施地区和下位机控制各级实施系统进行分级。每个猕猴桃将分级通过相同的分级流。通过测试，该设备可由大小三功能分级，形状和表面缺陷及其分级准确率可以达到88.9%，分别为91%和94%。和综合评分达到86%的精度。该设备的输出可以达到1.22kg/min远远超过手工分级效率。机械结构简单，成本低，该设备减少了猕猴桃加工成本，适合广大中小用户。*

关键词: *猕猴桃，分级设备，图像处理，神经网络*

INTRODUCTION

Grading is a very important link before kiwi fruits come into the market, and is concerned with subsequent packaging, transport, storage and sales of kiwi fruits. Because of low technical level of post-pick grading and other factors, Chinese kiwi fruits are not competitive in the international market although China is country of origin and world first largest country of production of kiwi fruits.

引言

猕猴桃分级是其进入市场前一个非常重要的环节，直接关系到猕猴桃的包装、运输、贮藏和销售。由于采后分级技术水平低等因素，作为猕猴桃的原产国及世界第一生产大国，我国出口的猕猴桃在国际市场缺乏竞争力，2007年我国猕猴桃出口仅占全球的 2%，出口价格仅为进口价格

For example, in 2007, Chinese kiwi fruit export volume accounted for only 2% of global kiwi fruit export volume, and export price was only one fourth (1/4) of import price, and kiwi fruit imports and exports were embarrassed by “widely different positions at home and abroad” [1].

At present, kiwi fruits are graded in artificial or semi-mechanical way at home and abroad. Artificial grading fully depends on experience, time-consuming, strenuous and low-accuracy. Semi-mechanical grading focuses on a single characteristic such as size, weight, shape or color, and grading kiwi fruits only as a single characteristic can hardly improve market competitiveness of kiwi fruit. Given this, in the paper, a practical automatic grading method is designed. The method can integrate the characteristics of size, shape and surface defect in grading, and make good effect of grading.

的 1/4，猕猴桃进出口贸易呈现出“国内国外两重天”的尴尬境地 [1]。

目前，国内外猕猴桃分级普遍采用手工分级和半机械分级，前者完全依靠经验，费时费力且分级精度低；后者偏重大小、重量、形状或颜色，表面缺陷等单一特征对猕猴桃品质进行分级，仅凭单一特征对猕猴桃进行等级划分，难以提高猕猴桃的市场竞争力。对此，本文设计了一种实用的猕猴桃自动分级方法，能融合大小、形状、表面缺陷 3 种特征进行分级，分级效果良好。

MATERIALS AND METHOD

Image Acquisition System

As shown in Fig.1, the system comprises a closed box, camera, position sensor and upper computer. Image acquisition is carried out in closed image acquisition box. Learned from multiple tests, moving image extracted at white background facilitates subsequent grading. The box is equipped with GS-500C1/2’’ CCD camera with high frame rate, fixed-focus lens (8mm) and 5,000,000 pixels, directly supported with USB. Its light source is white-light energy-saving lamp with hood, 220V in rated voltage and 9W in power. The box is 250×480×500(mm) and equipped with 9W white-light energy-saving lamp at 8 corners. Such lamp is provided with hood to stabilize and even light and stabilize each collected image of kiwi fruit. In center of the bottom of the box, 2 cameras are provided. Transparent conveyor belt facilitates image acquisition at two sides simultaneously and makes collected image clear and complete.

材料与方法

图像采集系统

图像采集系统如图 1 所示，由封闭箱、摄像头、位置传感器、上位机等组成。图像采集在封闭的图像采集箱中进行，经多次试验获知在白色的背景下提取到的运动图像便于后续分级处理。本设备选用高帧率 GS-500C1/2 英寸 CCD 摄像头，焦距为 8mm 的定焦距镜头，500 万像素，USB 直接供电。光源采用额定电压为 220V、功率为 9W 的白光节能灯并附灯罩。采集箱尺寸为 250×480×500(mm)。采集箱的 8 个箱角安装 9W 的白光节能灯并附灯罩使光照稳定且均匀，使每次采集到的猕猴桃图像质量稳定。2 个摄像头位于箱体上下面的中央位置，透明传送带是便于同时双面采集图像，使采集到的图像清晰、完整。

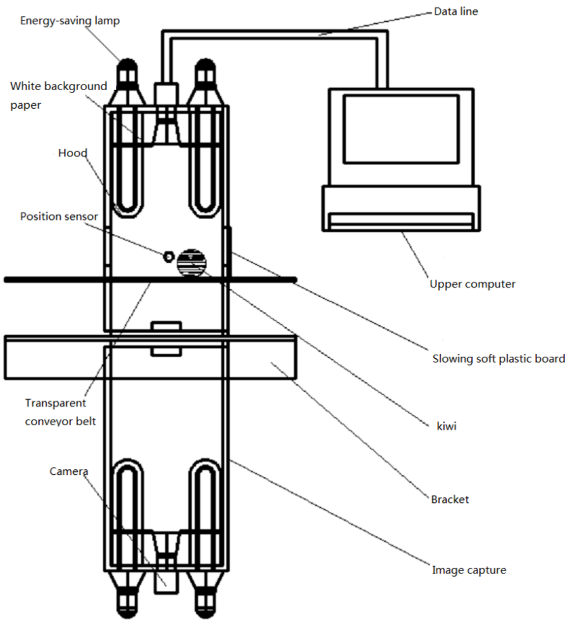


Fig. 1 - Image capture system / *图像采集系统图*

Grading Execution System

As shown in Fig.2, grading execution system is made up of transparent conveyor belt, baffle, push-pull electromagnet and grading frame.

Upper computer processes and grades kiwi fruit image, and sends result of grading to lower computer. After receiving the signal, lower computer connects power supply of push-pull electromagnet, and maintains the power supply for 1s. Within time of connection of the power supply,upon effect of movement of conveyor belt, a

分级执行系统

分级执行系统俯视图如图 2 所示，由分级透明传送带、分级挡板、推拉式电磁铁、分级框等组成。

上位机对获得的猕猴桃图像经过图像处理、分级判断后，将分级结果传送到下位机。下位机接收到此信号后，就接通推拉式电磁铁的电源并维持 1s。通电时间内猕猴桃在传

kiwi fruit falls along direction of baffle to grading frame of its grade. When the power supply is disconnected, battle will be automatically lifted. If the kiwi fruit is at the lowest grade, it will be directly baffled to the final grading frame upon movement of conveyor belt. Electromagnet is not needed for the final baffle. Push-pull electromagnet responds quickly to rapidly move baffle, structurally simple and sensitive.

送带的运动作用下随挡板方向下落至对应等级的分级框，通电结束后挡板会在弹簧力的作用下自动提升。若该猕猴桃属于最差等级，猕猴桃随分级透明传送带的运动直接被挡落到最后一个分级框，最后一个挡板无需推拉式电磁铁。推拉式电磁铁响应快，使挡板移动迅速，结构简单且灵敏。

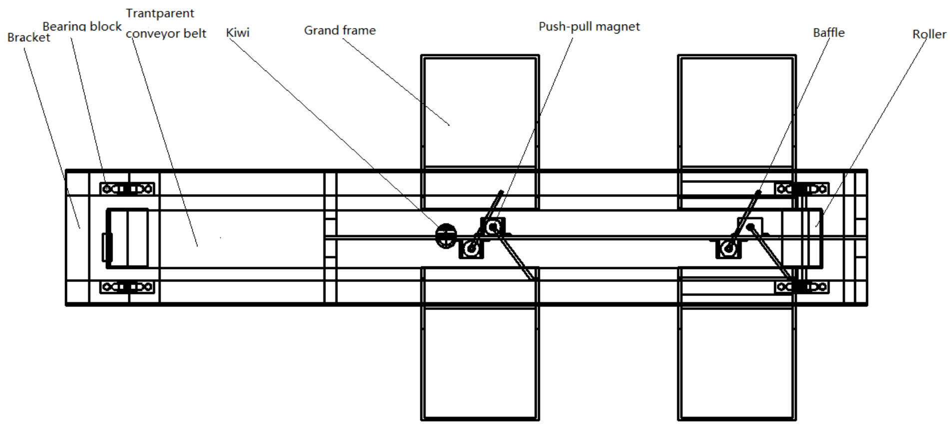


Fig. 2 -Vertical view of grading executive system / *分级执行系统俯视图*

Image Processing

In the system, the software MATLAB is adopted to write image processing and grading program in upper computer. Image processing is divided into 3 steps (image pre-processing, characteristic extraction, integration grading), as shown in Fig. 3.

图像处理

本系统中采用 MATLAB 软件编写上位机中的图像处理及分级判断程序。图像处理分为图像预处理、特征提取和融合分级 3 个步骤，如图 3 所示。

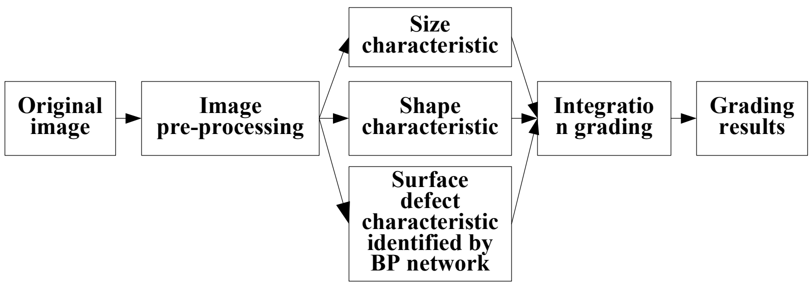


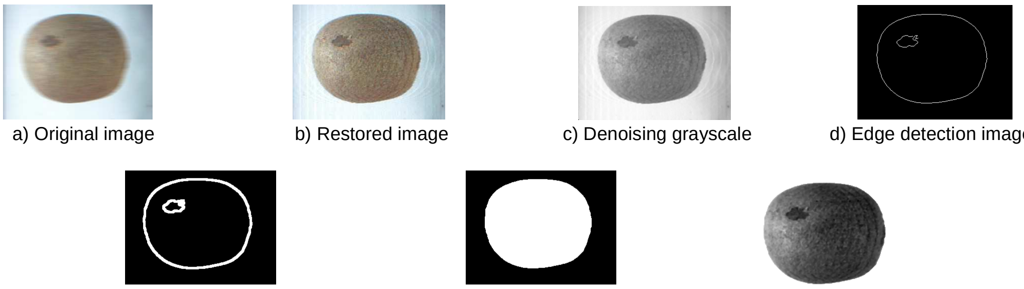
Fig. 3 - Image processing / *图像处理过程*

Image pre-processing

In practical application, kiwi fruit grading is finished with uniform linear motion of conveyor belt. Due to this, motion blur may occur in image taken during grading, as shown Fig. 4a. If PSF (point-spread function) and movement direction of kiwi fruit are known, the closest PSF can be estimated based on blurring image analysis and treatment in multiple tests. On the basis, restoration model can be structured for deblurring. The system restores image by means of Wiener filtering [2]. The restored image is shown in Fig. 4b. Restored image is converted to gray level image, which is denoised by means of median filtering. The denoised image is shown in Fig. 4c. Its edges are detected by means of Canny. Result of such detection is shown in Fig. 4d, Fig. 4e is the result of expanding Fig. 4d. Regional image of kiwi fruit is obtained by filling, corrosion, opening operation and redundant pixel deletion, as shown in Fig. 4f. Gray level image of kiwi fruit is separated from background with Fig. 4f involved as template, by AND operation [3] with Fig. 4c. A large area of white background in the image is cut out[4] to bring pre-processed image shown in Fig. 4g.

图像预处理

通常实际应用中的猕猴桃分级是在随传送带做匀速直线运动的过程中完成，故分级过程中所拍摄的图像会出现运动模糊，如图 4a 所示。假设系统的点扩散函数 PSF（point-spread function）为已知，经多次试验在对已模糊图像分析和处理的基础上估计最逼近的 PSF，且猕猴桃的运动方向已知，这样即可构造出复原模型来实现猕猴桃运动模糊图像的去模糊。本系统采用维纳滤波[2]实现图像复原，复原图像如图 4b 所示。将复原后的图像转换为灰度图，并采用中值滤波对此灰度图进行去噪处理，去噪后的图像如图 4c 所示。对图 4c 采用 Canny 法进行边缘检测，结果如图 4d 所示。对图 4d 进行膨胀处理得图 4e，继而对图 4e 进行填充、腐蚀、开运算和删除冗余像素等操作，获得猕猴桃的区域图像如图 4f 所示。将图 4f 作为模板，与图 4c 的图像进行与运算，得到从背景中分割出来的猕猴桃灰度图像[3]，并将此图像中的大量白色背景裁掉[4]，得到预处理后的图像如图 4g 所示。



a) Original image b) Restored image c) Denoising grayscale d) Edge detection image

e) Expansion processing image f) Regional image g) Preprocessed image

Fig. 4 - Image preprocessing / *图像预处理*

Size characteristic

Mean pixel of images taken by upper camera and lower camera after pre-processing is taken as the parameter for size grading [6, 7, 8, 9]. 20 regular kiwi fruits of the same type with different sizes are selected from the same batch as samples to fit relation between the mean pixel and actual weight. Approximate relation between mean pixel point Y (Unit:piece) and actual weight *W* (Unit: g) concluded in test is,

大小特征

上下 2 个摄像头拍摄的图像经过预处理，然后将预处理后的 2 幅图像投影的平均像素量作为大小分级参数[6,7,8,9]，并选取 20 个大小不一且形状较规则的同品种同批次的猕猴桃作为样本，拟合猕猴桃平均像素量与其实际质量的关系。经试验得出猕猴桃图像的平均像素点 Y（个）与其实际质量 W（g）之间的近似关系为

$$Y = 798W + 34081 \tag{1}$$

Size of kiwi fruit is divided into 3 gradesas formula (1) in reference to kiwi fruit grade standard [5]. Pixel threshold of each grade is shown in table 1.

参照猕猴桃等级规格标准[5]，并结合式（1）得出猕猴桃大小分成 3 等时各等级像素阈值如表 1 所示。

Table1 / *表 1*

Size specifications of kiwi and its pixel thresholds / *猕猴桃大小标准及像素阈值*

***Quality / 质量* [g]**	***Standard / 规格***	***Pixel / 像素阈值***
<80	Small / *小*	<97921
≥80~100	Middle / *中*	97921 ~ 113881
>100	Large / *大*	>113881

Shape characteristic

Shape of kiwi fruit is described with Fourier descriptor [6,7]. Pre-processed image is binarized to new regional image of kiwi fruit. The 1st non-zero pixel point of the 1st line Q_0 is taken as start point to track edges of the new image and conclude edge sequence point $V_0, V_1, \cdots, V_{n-1}$ (*n*: number of sequence point). Coordinate of each edge sequence point is $(x_k, y_k)(k = 0,1,\cdots,n-1)$. Coordinate of center point of the new image (x_c, y_c) is concluded by means of double integral. Thereafter, radius sequence is calculated and normalized to conclude $r_k(k=0,1,\cdots,n-1)$:

形状特征

采用傅里叶描述子[6,7]对猕猴桃形状进行描述。预处理后的图像经二值化处理后作为新的猕猴桃区域图像，以此图像第 1 行中第 1 个非 0 像素点 Q_0 作为起始点对该区域图像进行边界跟踪，得到边界序列点 $V_0, V_1, \cdots, V_{n-1}$（$n$ 为序列点个数）。各边界序列点的坐标为 $(x_k, y_k)(k = 0,1,\cdots,n-1)$。通过二重积分求取区域图像的中心点坐标 (x_c, y_c)，继而计算半径序列并归一化处理，得到 $r_k(k = 0,1,\cdots,n-1)$:

$$r_k = \frac{\left[(x_k - x_c)^2 + (y_k - y_c)^2\right]^{1/2}}{r_{\max}} \tag{2}$$

In the formula (2), $r_k(k = 0,1,\cdots,n-1)$ is post-normalization radius sequence, and $r_{\max}$ is pre-normalization maximum of radius sequence.

DFT $F(\omega)$ of the radius sequence $r_k(k = 0,1,\cdots,n-1)$ is,

式(2)中，$r_k(k = 0,1,\cdots,n-1)$ 为归一化后的半径序列，$r_{\max}$ 为归一化前半径序列的最大值。

半径序列 $r_k(k = 0,1,\cdots,n-1)$ 的离散傅里叶变换 $F(\omega)$ 为

$$F(\omega)=\frac{1}{n}\sum_{k=0}^{n-1}r_k\exp(-j\frac{2\pi k\omega}{n})=A(\omega)+jB(\omega)(\omega=0,1,\cdots,n-1) \quad (3)$$

In the formula (3), $\exp()$ is DFT function. Then, Fourier descriptor $|F(\omega)|$ is,

式(3)中，$\exp()$ 为傅里叶变换函数。
则傅里叶描述子$|F(\omega)|$为

$$|F(\omega)|=\left[A^2(\omega)+B^2(\omega)\right]^{1/2} \quad (4)$$

Learned from analysis on $|F(\omega)|$ of image, with increase in frequency ω, Fourier descriptor of each shape quickly decreases (if $\omega>7$, $|F(\omega)|\to 0$). For the purpose of easy calculation and completeness of overall shape information, edge information of kiwi fruit is described with the first 15 components of DFT. As derived, *m*-order derivative of r_k is,

随着频率 ω 的增加，每种形状的傅里叶描述子$|F(\omega)|$均迅速下降，当 $\omega>7$ 时，$|F(\omega)|\to 0$，为计算简便同时保证图像总体形状信息完整，用离散傅里叶变换的前 15 项分量描述猕猴桃的边界信息。经推导可求得 r_k 的 m 阶导数为

$$\left|\frac{d^m}{dk}r(k)\right|\Leftrightarrow 2\pi\omega^m|F(\omega)| \quad (5)$$

Learned from formula (5), derivative of the radius sequence $r_k(k=0,1,\cdots,n-1)$ can be indicated as the product of $|F(\omega)|$ and ω. More irregular shape brings more significant change in radius sequence, higher m-order derivative and higher $\omega^m|F(\omega)|$. Given this, $\omega^m|F(\omega)|$ can be involved as the basis for determining regularity of radius.

To identify kiwi fruit shapes with different positions of zoom, rotation, translation and start point, $|F(\omega)|$ is normalized as,

从式(5)可知，半径序列$r_k(k=0,1,\cdots,n-1)$的导数可以用$|F(\omega)|$与 ω 的乘积表示，形状越不规则，半径序列的变化越剧烈，其 m 阶导数就越大，$\omega^m|F(\omega)|$ 也就越大，故 $\omega^m|F(\omega)|$ 可作为半径规则程度的判定依据。

为了能够识别具有缩放、旋转、平移、起始点位置不同的猕猴桃形状，将$|F(\omega)|$进行归一化处理：

$$D(\omega)=\frac{|F(\omega)|}{|F(1)|}(\omega=0,1,\cdots,n-1) \quad (6)$$

In the formula (6), $D_{(\omega)}$ -normalized Fourier descriptor.

The first-order derivative of the radius sequence $r_k(k=0,1,\cdots,n-1)$ is enough to indicate change in the radius sequence. Therefore, *m* in formula (5) is let as 1. Shape classifier X is defined as,

式(6)中，$D_{(\omega)}$ 为归一化后的傅里叶描述子。

用半径序列 $r_k(k=0,1,\cdots,n-1)$ 的一阶导数即足以表征其变化程度，故令式（5）中的 $m=1$。定义形状分类器 X 为

$$X=\sum_{\omega=0}^{14}\omega D(\omega) \quad (7)$$

Analyzed from the above, higher X brings more significant change in the radius sequence $r_k(k=0,1,\cdots,n-1)$ and more irregular shape. For analysis on many experiments, set shape irregularity threshold as 1.85 (If $X>1.85$, shape will included in poor grade; if X < 1.85, shape will be included in good grade).

由前述分析可知，X 越大，半径序列 $r_k(k=0,1,\cdots,n-1)$ 变化越剧烈，形状就越不规则。对多个试验数据进行分析，可设形状的不规则度描述阈值为 1.85，当 $X>1.85$，形状等级为差，反之形状等级为好。

Surface defect characteristic

Common surface defects of kiwi fruit are surface bruise, scratch, bumping, etc. Pre-processed gray level image is compressed to 100×100 dimension matrix. Statistical eigenvector $H=(H_1,H_2,H_3,H_4)$ is extracted from the matrix. H_1, H_2, H_3 and H_4 are median, maximum, minimum and maximum-minimum difference of the matrix. Normalized H is taken as characteristic sample, and BP network is taken as identifier [8,9] to identify surface defect of kiwi fruit.

表面缺陷特征

猕猴桃常见表面缺陷有表皮擦伤、刮伤、碰伤等。将预处理后的灰度图像压缩成 100×100 维的矩阵，从该矩阵中提取出统计特征向量 $H=(H_1,H_2,H_3,H_4)$，其中 H_1、H_2、H_3 和 H_4 分别是该矩阵的中值、最大值、最小值、最大值与最小值之差。将 H 归一化后作为特征样本， 以 BP 网络作为识别器[8,9]，对猕猴桃进行表面缺陷的识别。

Integration grading

Learned from the above, kiwi fruits are divided into large type, medium type and small type by size, good type and poor type by shape, and defective type and non-defective type by surface. Based on grade and specification of kiwi fruit[10] and consumer's fondness, integration standard is prepared, as shown in table 2. In the paper, size, shape and surface defect are integrated as table 2, and kiwi fruits are divided into 4 grades. Learned from table 2, any kiwi fruit with surface defect is included in grade 4.

融合分级

依据前述可知，猕猴桃的大小规格分为大、中和小 3 个档次，其形状分为好与差 2 个档次，其表面分为有缺陷和无缺陷 2 个档次。以猕猴桃等级规格[10]为依据，并结合消费者的喜好制定了如表 2 所示的融合标准。本文以表 2 为标准对大小、形状、表面缺陷 3 个特征进行融合，将猕猴桃分成 4 个等级。由表 2 可知，只要表面有缺陷的猕猴桃都被分为 4 等品。

Table 2 / *表 2*

Four grades of kiwi / *猕猴桃等级划分*

Grade / 等级	***Size / 大小***	***Shape / 形状***	***With or without surface defect / (有/无)表面缺陷***
The first grade / *一等品*	Large / *大*	Good / *好*	Without / *无*
The second grade / *二等品*	Middle / *中*	Good / *好*	Without / *无*
The third grade / *三等品*	Small / *小*	Good / *好*	Without / *无*
	Large / *大*	Poor / *差*	Without / *无*
	Middle / *中*	Poor / *差*	Without / *无*
The fourth grade / *四等品*	Small / *小*	Poor / *差*	Without / *无*
	Large / *大*	Good / *好*	With / *有*
	Large / *大*	Poor / *差*	With / *有*
	Middle / *中*	Good / *好*	With / *有*
	Middle / *中*	Poor / *差*	With / *有*
	Small / *小*	Good / *好*	With / *有*
	Small / *小*	Poor / *差*	With / *有*

Design of Control System

Control system is made up of upper computer program and lower computer program. Written with the software labVIEW8.6 [10], it supports image storage, called image processing, grade judgment, communication between upper computer and lower computer and human-computer interaction. With STC89C52 (SCM) involved as core, lower computer receives command from upper computer, controls motor and push-pull magnet, and transmits kiwi fruit state parameter measured by sensor to upper computer.

控制系统的设计

控制系统主要分为上位机程序与下位机程序。上位机程序使用 labVIEW8.6 软件[10]编写，以完成图像存储、调用图像处理及分级判断程序、上位机与下位机之间的通信以及人机交互等功能。下位机以单片机 STC89C52 为核心，接受上位机指令并实时完成对电机、推拉式电磁铁等的控制，且将传感器检测的猕猴桃状态参数传输至上位机。

Upper computer monitoring

After initializing camera, upper computer calls image acquisition program to drive 2 cameras to continuously acquire and send image to upper computer [11]. When receiving kiwi fruit in-position signal from lower computer, upper computer can immediately store the image acquired at the time, and call image processing and grade judgment program to grade the image[12], followed by sending of processing result to upper computer via serial port. A user can send command on start, pause and stop on upper computer. Such command will be immediately sent to lower computer via serial port, and lower computer will act correspondingly to control equipment operation [13,14]. Parameters of serial port are set as 9600bps, 8 in data bit and 0 in check bit.

上位机的监控

上位机对摄像头进行初始化后，调用图像采集程序驱动 2 个摄像头持续地采集图像并传至上位机[11]。当上位机接收到下位机发送的猕猴桃就位信号后，随即存储此时摄像头采集的图像，继而调用图像处理及分级判断程序对此图像进行分级处理[12]，然后通过串口将处理结果传输至下位机。用户在上位机上可以对设备发送启动、暂停以及停止等命令，这些命令会立即通过串口传至下位机，下位机做出相应的动作以控制设备的运行[13,14]。串口参数设置为 9600bps、8 数据位和 0 校验位。

Lower computer controlling

Lower computer (i.e. STC89C52) and its peripheral circuit control motor driving module (motor, push-pull electromagnet, etc.) and collects and transmits equipment operation state. Control program is made up of main program and sub-programs. The main program functions to initiate system and call subprogram. The sub-programs

下位机的控制

下位机（即 STC89C52）及其外围电路用于完成对电机驱动模块（如电机、推拉式电磁铁等）的控制以及对设备运行状态的采集与传输等。控制程序由主程序及各子程序组成。主程序主要完成系统初始化、子程序调用等，子

are position sensor inspection program, serial port communication program, serial port interruption service and motor driving program.

When receiving start command from upper computer, lower computer will initiate itself, and implement communication with upper computer through serial port. Lower computer controls motor driving program to start motor of transparent conveyor belt. When a kiwi fruit reaches image acquisition box, sensor installed there will send kiwi fruit in-position signal to lower computer via external interrupter 1, and subsequently lower computer will send the signal to upper computer. When receiving the signal, upper computer will immediately finish image storage, processing and grade judgment, and transmit result of grading to lower computer via serial port. Lower computer controls motor driving program as result of grading to activate corresponding grading baffle, send kiwi fruit to corresponding grading frame thus implement kiwi fruit grading.

Meanings of signal codes defined for communication between upper computer and lower computer are shown in table 3.

程序包括位置传感器检测程序、串口通信程序、串口中断服务程序以及电机驱动程序等。

当下位机接收到上位机发送的启动指令后，自行完成自身的初始化，并通过串口与上位机实现通信。下位机控制电机驱动模块以启动分级透明传送带的电机。若有猕猴桃到达图像采集箱时，安装于此处的位置传感器通过外部中断 1 将猕猴桃就位信号传输至下位机，随即下位机将此信号发送至上位机。上位机接收到该信号后，随即完成图像存储、处理以及分级判断等操作，并经串口将分级结果传输至下位机。下位机根据此分级结果来控制电机驱动模块使相应的分级挡板动作，将猕猴桃送入对应的分级框，从而实现猕猴桃的分级。

上位机与下位机进行通信所定义的信号代码含义如表 3 所示。

Table3/ *表 3*

Signal connection between PC and lower computer / *上位机与下位机的信号连接*

Signal / 信号	*The sending code / 发送代码*
Kiwi in place / *猕猴桃就位*	0X55
The first grade / *一等品猕猴桃*	0X31
The second grade / *二等品猕猴桃*	0X32
The third grade / *三等品猕猴桃*	0X33
The fourth grade / *四等品猕猴桃*	0X34
Start / *开始*	0X30
Pause / *暂停*	0X35
Stop / *停止*	0X36

RESULTS

Grading test

Size grading test

90 regular kiwi fruits of the same type with different sizes from the same batch are subject to online size grading test as large type, medium type and small type. Result of the test is shown in table 4. Learned from data in the table, mean accuracy of size grading by the equipment is 88.9%.

实验结论

分级试验

大小分级试验

将 90 个大小不一且形状较规则的同品种同批次的猕猴桃按大小分为大、中、小 3 等，进行在线大小分级试验，试验结果如表 4 所示。由表中数据可知该设备大小分级的平均准确率为 88.9%。

Table 4 / *表 4*

Grated results based on the size of kiwi / *大小分级结果*

Number of test samples / 测试样本个数		*Number of right classification / 分级正确个数*	*Accuracy rate / 准确率[%]*	*Average accuracy rate / 平均准确率[%]*
Large / 大	27	24	88.9%	88.9%
Middle / 中	34	30	88.2%	
Small / 小	29	26	89.7%	

Shape grading test

47 kiwi fruits with good shape and 53 with poor shape are selected artificially. The 100 kiwi fruits are put into the *X* above for automatic classification. Result of the test is shown in table 5. Learned from data in the table, mean accuracy of shape grading by the equipment can be as high as 91%.

形状分级试验

人工选择形状好的猕猴桃 47 个、形状差的猕猴桃 53 个作为试验样本，以前述的 *X* 作为分类器，将此 100 个猕猴桃放入分级设备进行自动分级，试验结果如表 5 所示。由表中数据可知该设备形状分级的平均准确率可达 91%。

Table 5 / 表5

Grated results based on the shape of kiwi / 形状分级结果形状分级结果

Number of test samples / 测试样本个数		*Number of right classification / 分级正确个数*	*Accuracy rate / 准确率[%]*	*Average accuracy rate / 平均准确率[%]*
Good shape / 形状好	47	42	89.4%	91%
Poor shape / 形状差	53	49	92.5%	

Surface defect grading test

The 100 kiwi fruit images taken in advance are taken as training sample after extraction of statistical eigenvector and normalization. The 100 kiwi fruit images taken in actual running of the equipment are taken as test sample after extraction of statistical eigenvector as the same method and normalization.

With BP network involved as identifier, surface defect of kiwi fruit is identified. Result of the test is shown in table 6. Learned from the table, mean accuracy of BP network grading can be as high as 94%.

表面缺陷分级试验

对预先拍摄的 100 幅猕猴桃图像提取其统计特征向量并归一化处理后作为训练样本，对设备实际运行中拍摄的 100 幅猕猴桃图像以相同方法提取统计特征向量并经归一化处理后作为测试样本，以 BP 网络作为识别器，对猕猴桃进行表面缺陷的识别，试验结果如表 6 所示。由该表可知，BP 网络分级的平均准确率可达 94%。

Table 6 / 表6

Grated results based on the surface defect of kiwi / 表面缺陷分级结果

Number of test samples / 测试样本个数		*Number of right classification / 分级正确个数*	*Accuracy rate / 准确率[%]*	*Average accuracy rate / 平均准确率[%]*
With surface defect / 有缺陷	50	48	96%	94%
Without surface defect / 无缺陷	50	46	92%	

Integration grading test

The equipment is subject to 7 automatic integration grading tests. Quantity of sample is higher in latter test. After each automatic integration grading test, kiwi fruit of each level is re-inspected with result of manual inspection involved as reference value, followed by number of kiwi fruit mis-graded at each grade. The accuracy rate (%) is calculated as formula (8).

融合分级试验

对设备进行 7 次自动融合分级试验，每次试验的猕猴桃样本数量递增，每次自动分级试验后对各个等级的猕猴桃再进行检验，以人工检验的结果作为参考值，统计每个等级中被错误分级的个数。利用公式（8）计算准确率（%）：

$$\eta = 1 - \frac{|\Delta A| + |\Delta B| + |\Delta C| + |\Delta D|}{N} \quad (8)$$

In formula (8), ΔA, ΔB, ΔC and ΔD are numbers of kiwi fruit mis-graded at grade 1, 2, 3 and 4, respectively. N is number of sample. η is accuracy rate. Integration grading result and artificial grading result are compared in table 7. A, B, C and D are numbers of kiwi fruit at grade 1, 2, 3 and 4, respectively.

式(8)中，ΔA、 ΔB、 ΔC、ΔD 分别代表 1、2、3、4 等品中错误分级的猕猴桃个数，N 为样本数量，个；η 为准确率，%。融合分级的试验结果与人工分级结果的对比如表 7 所示，其中 A、B、C、D 分别代表 1、2、3 和 4 等品的分级个数。

Table7 / 表7

Comparison of automatic grated results and artificial grated results / 自动分级结果与人工分级结果的对比

Test number / 试验次数	*Number of test samples / 试验样本个数*	*Automatic grated results / 自动分级结果*				*Artificial grated results / 人工分级结果*			
		A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
1	50	11	15	16	8	12	17	15	6
2	80	17	26	24	13	20	28	20	12
3	100	24	30	31	15	27	34	26	13
4	150	36	44	47	23	41	48	43	18
5	200	46	61	62	31	53	67	57	23
6	250	56	77	79	38	64	85	69	32
7	300	68	94	93	45	77	104	82	37

Upon data comparison in table 7, numbers of kiwi fruit mis-graded at grade 1, 2, 3 and 4 and grading accuracy rate are shown in table 8.

通过表 8 中的数据对比，统计出一、二、三和四等品中错误分级的猕猴桃个数和分级准确率如表 8 所示。

Table8 / *表 8*

Fusion grated results / *融合分级结果*

Test number / 试验次数	*Number of samples / 样本数*	*Number of error classification / 错误分级数*				*Accuracy rate / 准确率[%]*
		$\|\Delta A\|$	$\|\Delta B\|$	$\|\Delta C\|$	$\|\Delta D\|$	
1	50	1	2	1	2	88%
2	80	3	2	4	1	87.5%
3	100	3	4	5	2	86%
4	150	5	4	4	5	88%
5	200	7	6	5	8	87%
6	250	8	8	10	6	87.2%
7	300	9	10	11	8	87.3%

Learned from table 8, accuracy rate of integration grading is 86%. Learned from comprehensive analysis on test results of table 5~8,, accuracy rates of grading as characteristic of size, shape and surface defect are 88.9%, 91% and 94%, respectively. Upon comparison, accuracy rate of integration grading gets lower. Such lowering is due to: (1) superposition of error in grading as each individual characteristic; (2) Artificial grading is involved as reference standard. However, artificial grading is subjective and naturally has error. (3) error caused by image processing and grading algorithm (For example, there's error in fitting function relation between mean pixel point and actual weight, shape irregularity threshold, subjective grading as well as surface defect grading through BP network.)

Learned from result of kiwi fruit grading test, with the method, kiwi fruit with surface defect is included only at grade 4. This avoids impact on storage of other kiwi fruits (Kiwi fruit with surface defect often shortens storage time of other kiwi fruits). Comprehensively, although lower in accuracy rate, integration grading is more reasonable.

由表 8 可知：融合分级的准确率达 86%。综合分析表 5～表 7 中的试验结果可知，以单个特征即分别按大小、形状、表面缺陷特征分级的准确率分别达 88.9%、91%、94%。对比可知，融合分级准确率有所降低，分析有以下 3 个方面的原因：（1）各单个特征的分级误差叠加；（2）以人工分级作为参考标准，而人工分级含有较强的主观性，本身就有一定的误差；（3）由图像处理与分级算法而引起的误差。如以平均像素点与实际质量的拟合函数关系存在误差、形状的不规则度阈值与主观分级时存在误差、BP 网络在表面缺陷分级时也存在误差，等等。

通过猕猴桃的分级试验结果分析还可知，该方法把有表面缺陷的猕猴桃分至 4 等品，而不会分至其它类别，这样就不会影响到其他猕猴桃的贮藏，因为表面有缺陷的猕猴桃常会缩短其他猕猴桃的贮藏时间。综述可知，虽然融合分级的准确率略有降低，但其分级结果是更合理的综合评价。

CONCLUSIONS

Given artificial grading of kiwi fruit is time-consuming and strenuous and popularity of automatic grading is low due to high cost, a method for automatic grading of kiwi fruit is designed. Transparent conveyor belt and closed image acquisition environment implement complete and stable image acquisition. Programs are designed for integration grading as size, shape and surface defect of kiwi fruit. Grading parameters (e.g. number of graded kiwi fruit) can be learned through upper computer. Indicated in test result, accuracy rates of grading as characteristic of size, shape and surface defect are 88.9%, 91% and 94%, respectively. Accuracy rate of integration grading is as high as 86%.

结论

针对目前猕猴桃人工分级费时费力、自动分级成本高导致普及程度低的问题，设计了一种猕猴桃自动分级方法。采用透明传送带和封闭的图像采集环境，实现了完整与稳定的图像采集；设计了大小、形状和猕猴桃表面缺陷的融合分级程序，经上位机可以获知已分级猕猴桃的个数等分级过程中的参数。试验结果表明：以单个特征即分别按大小、形状、表面缺陷特征分级的准确率分别达 88.9%、91%和 94%，而融合分级的准确率可达 86%以上。

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