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Automatic Detection of Kiwifruit Defects Based on Near-Infrared Light Source

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Abstract. A mathematical model that expresses the relationship between Near-infrared light intensity and automatic threshold for automatic kiwifruit surface defect detection was established. By applying different levels of Near-infrared light intensity to machine vision system, 268 images were collected. Then the images were processed with MATLAB using the method to detect kiwifruit defects based on Near-infrared light source. The obtained 268 sets of data on Automatic Threshold T_0 and Manual Threshold T_1 were divided into 19 groups according to different aperture and light intensity. After processing data, a series of linear equations about the relationship between Near-infrared light intensity and Automatic Threshold T_0 , with function fitting coefficient of $R^2 > 95\%$ was obtained. Finally, relationship between T_0 and T_1 was analyzed according to the effectiveness of image processing results and constant P was introduced to revise Automatic Threshold T_0 . Thus, a mathematical model needed to gain kiwifruit defects detection threshold, namely Model Threshold T , was established.

Keywords: Image processing, Near-infrared light intensity, Automatic threshold, Manual threshold, Model threshold, Linear relationship

1 Introduction

The kiwifruit, or often shortened to kiwi in many parts of the world, is the edible berry of a cultivar group of the woody vine *Actinidia deliciosa* and hybrids between this and other species in the genus *Actinidia*. It's nutritious and has high medicinal value [1]. China is one of the major areas in producing kiwi. Currently, kiwifruit postharvest sorting processing is still performed manually and its surface defects judgment depends on human completely. Standard Sphere Method [2-5] which uses machine vision technology to separate the fruit surface defects has achieved good

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results. However, with the traditional RGB [6][7], CCD imaging systems [8-11], the angle between the camera and edge light reflection direction of sphere and ellipsoid fruits remains very large. According to Lambertian light laws of reflection, the fruit edge and surface defects both have lower gray level. Therefore it is difficult to detect and distinguish the defect. In addition, there is a challenge in uniform illumination with the RGB and CCD systems. To overcome these difficulties, near-infrared hyper spectral is used by many research institutes to test external qualities of agriculture products such as maturity of strawberry [12], bruises of strawberry [13] [14], apple [15] and chestnut [16] defects etc.

There are two assumptions in Standard Sphere Method. First assumption is that the shape of fruit is either standard sphere or ellipsoid. Second assumption is that light illumination in machine vision field is uniform. Under these conditions, optical system consisting of lens and camera can be a linear system [17]. In the case of kiwifruit, its shape is quasi-ellipsoid. With the Near-infrared light source, the issue of fruit surface reflective area can be overcome as it plays the role of uniform illumination according to preliminary studies [18][19]. This paper aims at collecting images of defective kiwifruit with different light intensity by adjusting the Near-infrared light intensity, then processing images by detection methods for kiwifruit surface defects grading, and finally analyzing the relationship between binarization threshold of kiwifruit defects and Near-infrared light intensity, to establish a mathematical model.

2 Material and Method

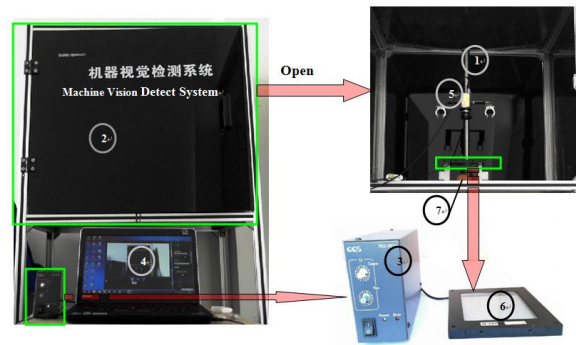
2.1 Test Materials and Equipment

Test kiwifruit samples were “Qin Mei” cultivars. They were bought from Xizhai Village, Qinghua Country, Mei County, Shaanxi Province. All of the fruits (total 182 samples) were picked up on site and kept in cartons. Weight of a single fruit ranged from 69.6g to 224.0g. Tests were carried out at College of Mechanical and Electronic Engineering, Northwest A&F University.

Firstly the fruits were classified; according to the type of defects such as sunburn, parasitic spot. Then intact fruits were scratched to make them defective.

In terms of equipment, lamp house was made of black organic plastic material to avoid external light interference. The camera used was DALSA CCD camera (matching dedicated image acquisition and debugging software Spera Cam Expert) and the lens was Camera FUJINON HF16HA-1B (aperture range 1.4~16.0). PC used to save data after image processing was Lenovo ThinkPad E420. LFX2-100IR850 Near-infrared light source and dedicated power supply PD-3024-K1320-014 with Light source extension line (1m, 24V) also consisted the test equipment. As a background a white soleplate was provided to enhance the contrast of the background and kiwifruit. The distance between camera FUJINON HF16HA-1B and kiwifruit was 370mm and distance between Near-infrared light source and kiwifruit was 110mm, as shown in Fig. 1.

LFX2-100IR850 Near-infrared light source needed to be attached to the light source dedicated power supply CCS PD-3024- K1320-014 with a light source extension line (1m, 24V). There are 16 brightness coarse adjustment gears and 16 fine adjustment gears respectively. Fig.1 shows pictures of Near-infrared plane illuminator LFX2-100IR850 and light source dedicated power supply CCS PD-3024- K1320-014. The light source needed to be warmed up for 30 minutes before usage.



1. Lifting frame
2. Lamp house
3. Light intensity regulator
4. PC
5. CCD Camera
6. Near-infrared light source
7. Kiwifruit

Fig.1 Kiwifruit Machine Vision Detect System

2.2 Research Program

As shown in Fig.2, the left dotted line box shows the image processing of kiwifruit defects detection [18]. Although this method is able to extract the fruit surface defects, there are two problems exist:

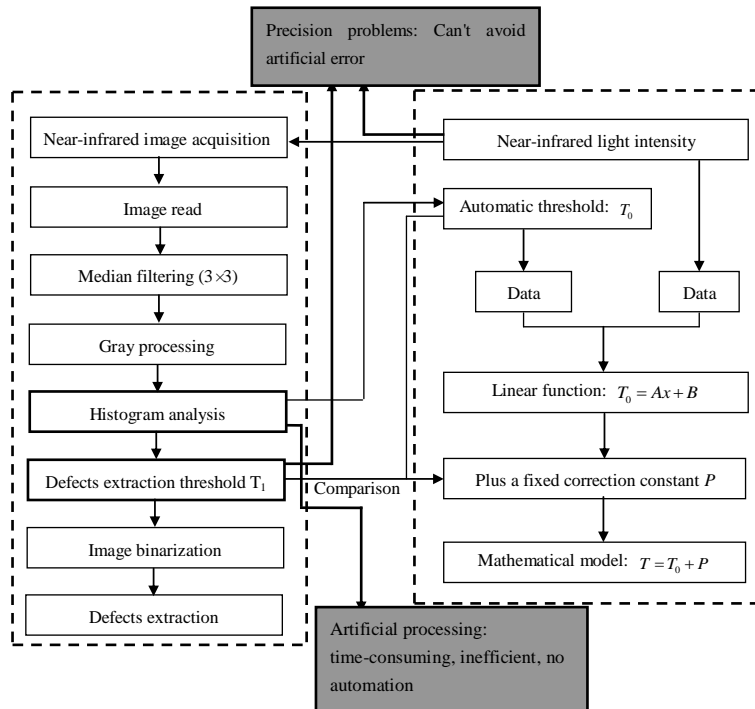


Fig.2 The Block Diagram of Research

Problem 1: It's time-consuming to extract the image parameters of fruit surface defects manually and the automatic detection of fruit defects is a mainstream in the development of nondestructive testing of the fruits.

Problem 2: As shown in Fig.2, the automatic deflection threshold T_0 will produce error and it will influence the accuracy of fruit deflection.

To extract the fruit defects threshold automatically, this paper proposed a method based on Near-infrared light intensity with Automatic Threshold T_0 and thus established a mathematical model. The dotted line box on the right is the solution diagram. As T_1 obtained by manual analysis will produce error. Therefore, Automatic Threshold T_0 was introduced to solve the problem, where T_0 is automatically generated by the image processing program and it reduces the systematic errors effectively. T_0 cannot be used to detect defect directly. After comparing T_1 with T_0 , a correction constant P was introduced to revise T , as $T = T_0 + P$.

2.3 Test Methods and Procedures

Scratch wound is one of kiwifruit surface defects which is the most difficult defect to be extracted. So we took kiwifruit with scratch wound as objects to establish the relationship between Near-infrared light intensity and scratch defects and to determine the automatic threshold of surface defects.

Tab.1 Test conditions and image collection

Aperture (1.4~16.0)	Coarse adjustment (1~16)	Fine adjustment (1~16)	Image quantity
1.4	1	3~11	9
3.7	2、3	1~16	32
4.0	3、4	1~16	32
6.0	5~10	1~16	96
8.0	5	1~16	16
8.0	6~16	1、9、16	33
12.0	6~16	1、9、16	32
16.0	8~16	1、16	18
Total			268

Test procedures:

- (1) Put the scratch kiwifruits into lamp house; adjust the camera aperture according to Tab.1. Adjust the brightness coarse adjustment gears and fine adjustment gears in accordance with Tab.1. Finally collect images using supporting software Sopera Cam Expert and adjust R, G, B to 0 dB.
- (2) Number the collected images and light intensity record mode. E.g. coarse adjustment gear 1 and fine adjustment 1~16 are recorded as 101,102,103, 104...116, while coarse adjustment gear 1~16 and fine adjustment 1 are recorded as 1601, 1602, 1603, 1604...1616.
- (3) Process the numbered images using the method described in [18], and record T_0 , T_I and image processing results.Tab.2 is part of the test data records.
- (4) Change the Near-infrared light intensity from 103 to 111, gain T_0 using the method as mentioned in Step (3), and adjust the threshold interval to gain T_I . It is obtained by adding a constant P to T_0 , as shown in Tab.4.
- (5) Finally, analyze and process the data with Microsoft Excel. Although the final threshold used in image processing is defect detection threshold, the mathematic model expresses the relationship between T_0 and Near-infrared intensity. The reason is that T_I is a manual selected threshold according to the effectiveness of image processing results. If T_I is selected to analyze data, it will increase the error. Thus T_0 obtained by MATLAB is used to establish the exact relationship between threshold and light intensity. Then analyze the relationship between T_I and T_0 . Finally introduce a correction constant P to revise T_0 .

Tab.2 Part of the test data

No.	Aperture	Light intensity	Automatic Threshold T_0	Manual Threshold T_I
001	1.4	103	0.0941	0.1400
002	1.4	104	0.1333	0.2400
003	1.4	105	0.1686	0.2590
004	1.4	106	0.2039	0.3590
005	1.4	107	0.2353	0.4000
006	1.4	108	0.2706	0.4400
007	1.4	109	0.3020	0.5300
008	1.4	110	0.3333	0.5533
009	1.4	111	0.3686	0.6700

3 Results and Discussion

3.1 Mathematical Model

The data were analyzed using Microsoft Excel, and the data in Tab.2 were used to produce the function graph in Fig.3. The intensity of Near-infrared was from 103 to 111, and the automatic threshold interval was from 0.0900 to 0.4000. Fig.3-a is the linear diagram of T_0 and light intensity, in Tab.3, we established the equation $T_0=0.0339x-3.3884$, $R^2=0.9992$. Fig.3-b is the linear diagram of T_l and the light intensity and we can find out the equation $T_l=0.0614x-6.1688$, $R^2=0.9844$.

The function fitting degree in Fig.3-a is higher than that in Fig.3-b. This is because the T_0 is free from the human error of T_l .

Similarly, we processed the 19 groups' data and the results were recorded in Tab.3.

As a result, the function relation graphs between Near-infrared intensity and T_0 was gained. It was linear. All of the 268 groups of data were processed by this method, the results were shown in Tab.3, with $R^2 > 95\%$. Thus the relation between Near-infrared intensity and T_0 can be defined as follows:

$$T_0 = Ax + B. \quad (1)$$

Where: T_0 , x , A , B stand for automatic threshold, Near-infrared intensity, light intensity coefficient, Near- infrared fine adjustment influence coefficient, respectively.

- (1) In Tab.3, the functions from 01 to 11 were gained under the same aperture and light intensity with both brightness coarse and variable fine adjustment. They showed linear relationship. In addition, value A and B are variables. Value A increased as the light intensity enhanced, while value B had the opposite trend.
- (1) The functions from 12 to 19 were gained under the same aperture and light intensity with brightness fine adjustment and variable coarse adjustment. They also showed linear relationship. In addition, value A didn't change as the light intensity enhanced, while value B increased with light intensity enhancing.
- (2) Considering that T_0 was not used to detect the fruit surface defects directly, it was necessary to define the correction constant P value. The relationship between Near-infrared intensity and defection threshold was defined as follows:

$$T = T_0 + P. \quad (2)$$

This is because the T_0 is free from the human error of T_l .

Where: T , T_0 , P stand for defects threshold, automatic threshold, threshold correct constant, respectively.

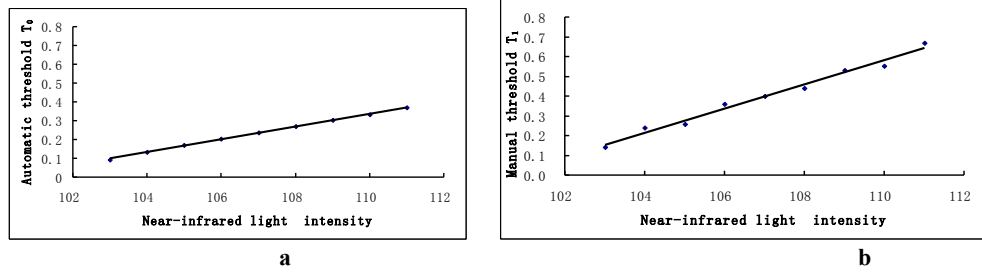


Fig.3 The relation between light intensity and T_0 , T_1 (Data in Tab. 2)

Tab.3 The relation between light intensity and automatic threshold

No.	Aperture	Coarse adjustment	Fine adjustment	Function ($T_0=Ax+B$)	R^2
01	1.4	1	3~11	$T_0=0.0339x - 3.3884$	0.9992
02	3.7	2	1~16	$T_0= 0.0057x - 1.0295$	0.9975
03	3.7	3	1~16	$T_0= 0.0063x - 1.7055$	0.9985
03	4.0	3	1~16	$T_0=0.0050 x - 1.3321$	0.9976
04	4.0	4	1~16	$T_0=0.0052 x - 1.8516$	0.9935
05	6.0	5	1~16	$T_0= 0.0027x - 1.1500$	0.9882
06	6.0	6	1~16	$T_0= 0.0026x - 1.3268$	0.9893
07	6.0	7	1~16	$T_0= 0.0027x - 1.6486$	0.9865
08	6.0	8	1~16	$T_0= 0.0028x - 1.9274$	0.9927
09	6.0	9	1~16	$T_0= 0.0029x - 2.2458$	0.9930
10	6.0	10	1~16	$T_0= 0.0027x - 2.2822$	0.9808
11	8.0	5	1~16	$T_0= 0.0011x - 0.4516$	0.9545
12	8.0	6~16	1	$T_0= 0.0002x - 0.0209$	0.9995
13	8.0	6~16	9	$T_0= 0.0002x - 0.0109$	0.9987
14	8.0	6~16	16	$T_0= 0.0002x - 0.0029$	0.9993
15	12.0	6~16	1	$T_0= 0.0001x +0.0099$	0.9980
16	12.0	6~16	9	$T_0=0.0001x + 0.0129$	0.9981

17	12.0	6~16	16	$T_\theta=0.0001x + 0.0077$	0.9929
18	16.0	8~16	1	$T_\theta=0.00003x+0.0210$	0.9634
19	16.0	8~16	16	$T_\theta=0.00003x+0.0291$	0.9867

Tab.4 The correction constant P for surface defects extraction threshold

T_θ	$T_\theta < 0.1$	$0.1 \leq T_\theta < 0.2$	$0.2 \leq T_\theta < 0.3$	$0.3 \leq T_\theta < 0.4$	$T_\theta \geq 0.4$
P	0.0400	0.1000	0.1600	0.2200	0.2800

3.2 Results and Discussion

T_θ was obtained by processing the 268 images and divided into five intervals. One image was selected from each interval for the manual threshold, and the results are shown in Fig.4. Fig.4-a is a Near-infrared original image, Fig.4-b is a threshold binary image of T_θ and Fig.4-c is the binary image of T_l , Fig.4-d is the binary image of Model Threshold T .

- (1) The image processing results are shown in Fig.4 which mainly include flaws and scratch. This processing the reflection of light effectively and simplify the image processing based on Near-infrared light to detect surface defects of kiwifruit. Using P and interval of T_θ could detect the defects of fruit. There was some difference in the extent of noise influence. Results showed that interval of T_θ value from 0.1 to 0.2 had better effects than those of other intervals. Thus mathematical morphological operation was used to remove the noises.
- (2) Using T_θ alone does not detect the surface defects for kiwifruit from Near-infrared image; however, it provided the precondition to quantify the standard of image segmentation reasonably, which meant that we could process different brightness images under the same standard. In Fig.5, for example, the binary images of T_θ were almost the same though different intervals were selected.
- (3) Compared with the results of image processing in [18], the results in this paper were much better as it overcame the influence of fruit calyx.

- (4) Fig.4-a is Near-infrared original image. Fig.4-d is binary image of T . Fig.4-c is binary image of T_I . When two images were compared, both detected the fruit surface defects. Therefore to make further comparison, the pixel values of the two binary images were calculated. As for Tab.5, Where: p_{i1} is pixel value of Fig.4-d and p_{i2} is pixel value of Fig.4-c.

Tab.5 The pixel values p_{ij} for surface defects extract threshold

T_0	$T (T=T_0+P)$	T_I	p_{i1}	p_{i2}
0.0784	0.1184	0.1180	2789	2789
0.1490	0.2490	0.2450	1458	2214
0.2745	0.4345	0.4305	7275	5521
0.3765	0.5965	0.6050	7022	8459
0.4039	0.6839	0.7000	3716	5450

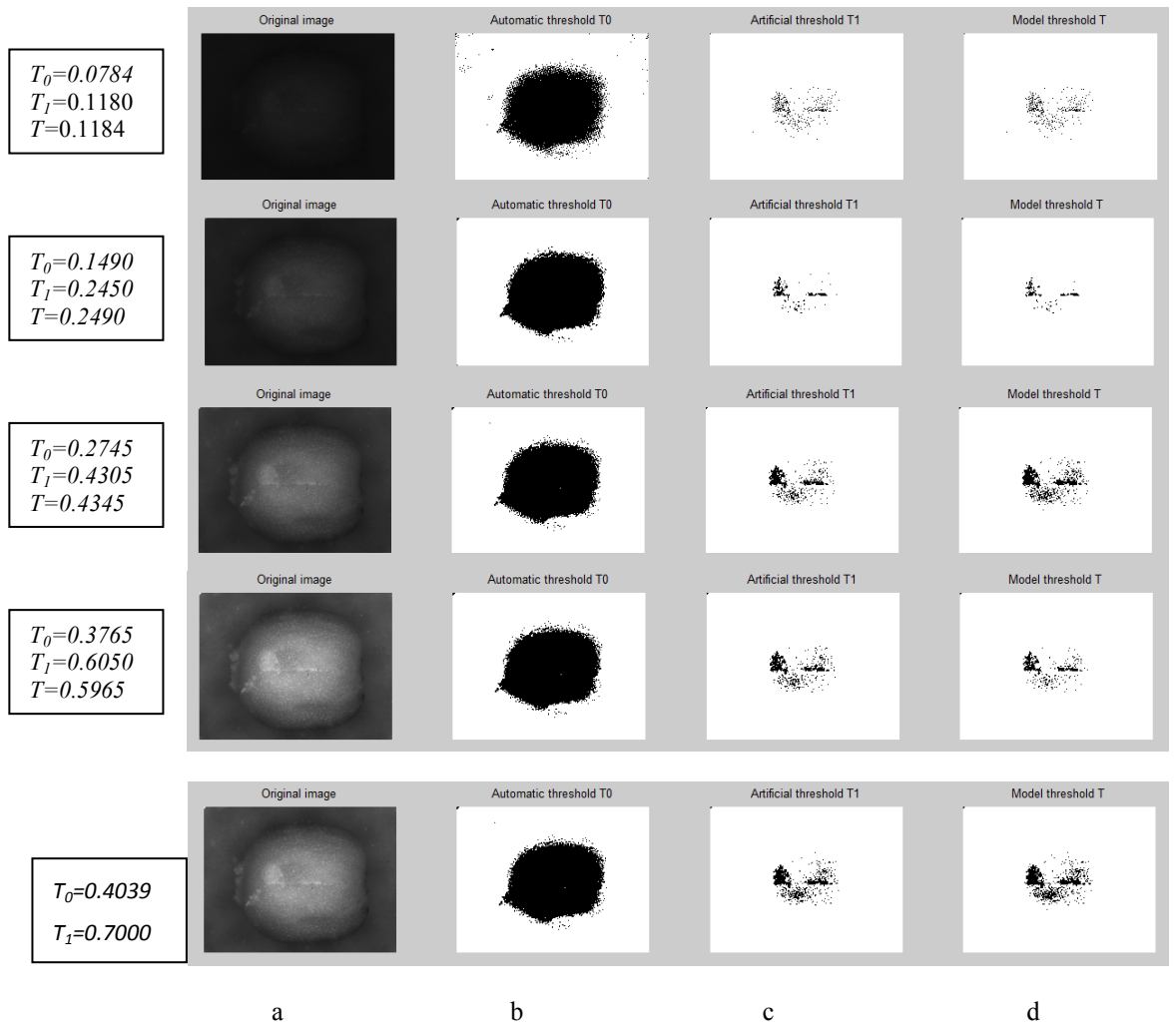


Fig.4 Five image processing results

4 Conclusion

The function of Near-infrared light intensity and automatic threshold showed obvious linear relationship, with function fitting coefficient of $R^2 > 95\%$. A linear mathematical model was developed to detect threshold of kiwifruit surface defects automatically.

In the five intervals of T_0 , the Near-infrared image processing excluded the interference of the fruit calyx and therefore this method was more effective to detect fruit defects of surface flaws and scratches, especially with T_0 range of 0.1 to 0.2.

Overall our data provide a promising tool for automatic defects detection in the fruit grading system.

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