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A Self-developed System for Visual Detection of Vegetable Seed Vigor Index

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Abstract

Conventional detection ways of seed vigor cannot meet currently development demands of automation and efficient breeding because of its subjectivity, high-cost and complicated operations. In the study, a visual detection system of vegetable seed vigor was developed, to calculate the seed vigor index (SVI) through image feature extraction, the aim to explore new method for detecting automatically vegetable seed vigor. The detection system was composed of four platforms including image acquisition, image processing, germination index computing and seed vigor index calculating. Vegetable seeds, cucumber, chilli, tomato, and aubergine were chosen to evaluate the capacity of detection system. Via experimental tests between manual and self-developed SVI system, the latter shown higher recognition accuracy through comparative analysis of four vegetable seeds, as well as deviations were respectively 4.32, 4.90, 5.95 and 3.22% and within acceptable limit. Thus, this work provides a reliable reference and research foundation for streamline detection of vegetable seed quality.

Keywords: Vegetable seeds; Breeding; Seed vigor index; Detection system; Accuracy

Introduction

Seed vigor is different from seed viability. According to International Seed Testing Association, seed vigor is a vitally important indicator for seed quality, which generally determines the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field condition (AOSA, 1983). This is one of the significant indexes for detecting and improving seed quality, ensuring the high efficiency and yield of agricultural production. Therefore, it is important to detect the seed vigor. The seed vigor index (SVI) is a comprehensive indicator, which includes the capability for seed germination and seedling growth. It has been a research hotspot because it provides lots of valuable information for seed quality assessment (Chen *et al.*, 2010; Ma *et al.*, 2010).

Currently, seed vigor detection based on image processing technology has been mainly applied in the fields of grain and vegetables (Tohidloo and Kruse, 2009). Although some researches have been reported, the defects cannot also be ignored. For example, McCormac *et al*. (1990) and McDonald *et al*. (2001) successfully developed a kind of lettuce seed vigor evaluation system. However, this evaluation method is only suitable for seeds whose hypocotyl can be clearly distinguished from the radicle and the results with a bigger system error for seeds without a clearly distinguished hypocotyl and radicle. Hoffmaster *et al.* (2003) designed an evaluation system of soybean SVI based on the image processing technology. The system algorithm defined the growth speed as the ratio of the seed actual length to the maximum, which was an experience value and differed among varying seed-growing environments. Thus it would bring much uncertainty to the evaluating system of seed vigor. In China, the study of seed vigor started in the early twenty-first century, and many research achievements have also been obtained (Yu *et al.*, 2005; Zhang, 2007; Sun *et al.*, 2012). At the present, the technologies of near-infrared spectral analysis and laser detection have been reported by Yu *et al.* (2012), but these new techniques were used to detect seed vigor limited in the lab's qualitative analysis and there is huge distance for industrial streamline production. Moreover, Deng *et al.* (2012) estimated seed vigor of Chinese fir and Masson's pine using image-based analysis technology, but they could only calculate and process a single seed image each time. In addition, Jilin Agricultural University utilized image recognition with the tetrazolium staining method to detect the seed vigor (Zhao *et al.*, 2004). In their experiment, the embryo of the seed needed to be exposed by impaling and incising seeds in order to improve the dyeing; this greatly influenced the seed

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vigor. Meanwhile, when the image of the dyed seed was transformed into gray-scale type, the calculation of the seed vigor was affected.

In conclusion, above-mentioned literature mostly focused on vigor assessment of crop and plant seed using machine vision technology. However, a fewer studies paid attention to vigor detection of vegetable seed. Generally the seed type of bigger size was chosen as observation objective owing to be recognize easily based on regular image. With the shortage of labor force and demand of industrial breeding in China, how to improve breeding effective by image processing technology, it needs urgently researchers to explore new method and develop reliable system to accomplish. Based on this objective, a visual detection system for seed vigor index in this study was developed using imagery processing technology, different types of seeds like as cucumber, chilli, tomato and aubergine were selected to evaluate the capacity of detection system.

Materials and Methods

The Visual Detection System

The visual detection system of the seed vigor index composed of the following hardware: a Point Grey camera (FLEA3 FL3-U3-13S2C-CS), host adapter card (U3-PCIE2-2P01), a Point Grey lens (TV Lens 12mm 1:1.4), an industrial controllable computer (Nuvo-2030+), a monitor (Dell), a thermostat (GHP-2000), an energy saver (Midea 22W), and culture dishes (10 cm × 10 cm), as shown in Fig. 1.

Cucumber, chilli, tomato, and aubergine seeds were soaked for 3 h at a 30°C temperature (Egli and Rucker, 2012; Li *et al.*, 2012) and sprouted after about 35 h. Then the seeds were put on culture dishes with black flannelette (10 cm × 10 cm) at an angle of 85° from the horizontal. To enhance the hygroscopicity, two pieces of white filter paper were placed under the black flannelette, and supplemental water was added in a timely fashion during seed germination. Thirty-six vegetable seeds were placed neatly on each culture dish and the temperature was controlled at 30°C using a thermostat. The original seed images are shown in Fig. 2.

Through a series of experiments, it was found that the vegetable seeds clearly germinated every 10 h. So a growth cycle was defined as 10 h. The seed images of 848 × 848 pixels resolution were acquired by the camera fixed at a height of 38.5 cm above the seed culture dishes. The status of seed germination was recorded after 10, 20, 30, 40 and 50 h when the seeds were put on the culture dish.

The software for the visual detection of the seed vigor index was programmed based on Visual Studio 2010 (Microsoft Corporation) and OpenCV in an industrial controllable computer with Windows XP system installed. The software was composed of four platforms, image acquisition, image processing, germination index computing, and a vigor index computing platform. The pictures of various seed growth periods were processed by the software system, and then the seed germination index and average radicle length were obtained by the special method presented in this paper. These data were used to calculate the seed vigor index according to the system algorithm.

Image Processing

Three focusing steps were used to process the seed images as follows:

(1) Gray threshold transformation was performed (Ruan and Ruan, 2009; Ekstrom, 2012; Zuo, 2014). To separate seeds from the background, the seed images must be transformed into binary figures of black and white, which were acquired by equation 1:

$$y = \begin{cases} 0 & x < T \\ 255 & x \geq T \end{cases} \qquad (1)$$

T represents the threshold value. After the seed image was processed by this system, if the gray value of pixels was bigger than T, it was considered as the seed color and the value of the pixel was set as 255. If not, the value of the pixel was considered as background and set as 0. Because images were acquired with a fixed energy saver under stable conditions, a constant threshold was used. From many tests, the threshold value was set to 40, which was able to produce better results.

(2) The noise of binary figures was removed by open operation in image morphology processing (Ruan and Ruan, 2009; Ekstrom, 2012; Zuo, 2014). In corrosion processing, if the pixel neighborhood has a pixel value of 0, the gray value of the center pixel is set as 0. After many measurements, this paper determined a 3 × 3 sampling window to process the seed images. In dilation processing, if the pixel neighborhood has a pixel value of 255, the gray value of the center pixel is set as 255. The method could not only remove noise, but also protected seed size from the effect of removing the noise.

(3) The arithmetic cvFloodFill was used to separate the seeds in the seed image; it could choose a connected domain of every seed and fill in a different color value for every seed (Ruan and Ruan, 2009; Ekstrom, 2012; Zuo, 2014).

An example shows the result of image processing of the cucumber seed in Fig. 3. Fig. 3b was obtained based on processing of Fig. 3a by the arithmetic cvFloodFill, where the seeds were filled with different red values from 5 to 180, the interval value was 5.

Calculation of the Seed Germination Index

The seed germination index (GI) was considered as the statistical data of the mean germination rate of seeds. It could be obtained by referring the equation 2 (Liu *et al.*,

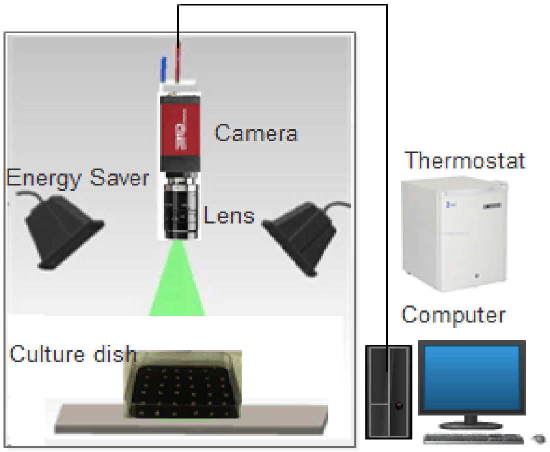
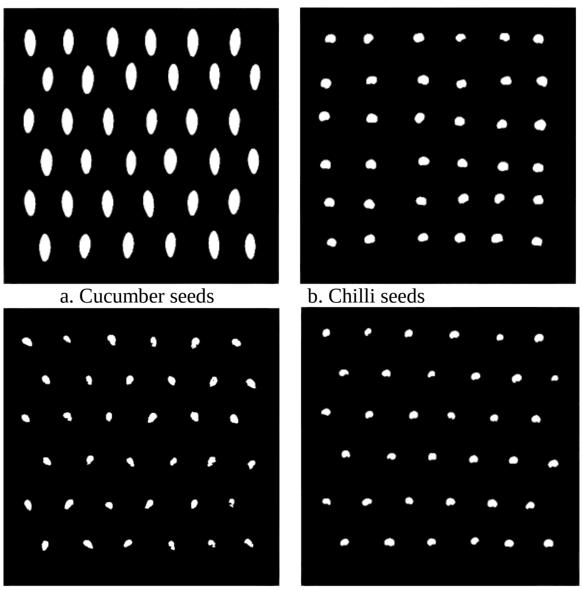


Fig. 1: Demonstration diagram of the self-developed system



a. Cucumber seeds b. Chilli seeds c. Tomato seeds d. Aubergine seeds

Fig. 2: Original images of vegetable seeds

2007):

$$GI = \sum Gt / Dt \qquad (2)$$

Dt is defined as the seed growth cycle (where a growth cycle occurs every 10 h), and Gt represents the number of seeds that germinated in every seed growth cycle.

In order to calculate the seed germination index, the seed germination number of every seed growth cycle must be acquired. For instance, the original seed image and the seed growth image after 10 h were all processed by the system software. Then the pixel numbers of every seed in two processed seed images were calculated by the software. Then we analyzed the pixel numbers in the vertical direction and found that germinated seeds after 10 h growth had more pixels than original those, and so as to avoid over-counting, seed gray values in the original seed image were set as 0. The cucumber seed image is displayed as an example to present the calculation of the seed germination index (Fig. 4).

Fig. 4a is the original image of the cucumber seed, and Fig. 4b is the image obtained at first growth cycle (after 10 h growth). Fig. 4c was obtained after Fig. 4a and 4b were processed by the SVI system software. The germinated seeds' gray values were set to 0 in Fig. 4c.

The seed germination images of the first, second, third, fourth and fifth growth cycle was input into the SVI system software successively. After the system calculation, Dt (the seed growth cycle) and Gt (the seed germination number in every seed growth cycle) was recorded on a text file by the system software. Finally, the software was able to use the statistical data to calculate GI .

Calculation of the Average Seed Radicle Length

The average seed radicle length was the key to calculating the seed vigor index. If we directly measure the number of objective pixels, it would result in a system error because the object was not placed in the image as an upright and standard way. So the SVI system used a circle image to calibrate the length of pixel. The length of the pixel was calculated by equation 3:

$$xl = d / n \qquad (3)$$

xl represents the length of a pixel in the images. d is defined as the diameter of the circle (Fig. 5), which is 90.0 mm. n is the number of pixels in the circle diameter, which is 756 according to the calculation of the SVI system.

From the above processing and calculation, xl (the length of a pixel in the images) was determined as 0.1190 mm.

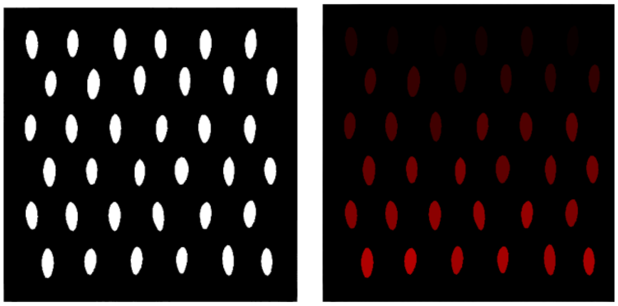
The original images and their corresponding seed images after 50 h were all processed by the SVI system. The cucumber seed image is presented as an example to show the calculation of the average seed radicle length (Fig. 6).

The pixels number of every seed in the vertical direction was obtained from the images shown in Fig. 6. The results were combined into an average seed radicle length referring equation 4 and 5:

$$Nxl = (\sum_{i=0}^{35} (S_{2i} - S_{1i})) / 36 \qquad (4)$$

$$S = Nxl \times xl \qquad (5)$$

S_{1i} is the pixels number of a certain seed on upright in the original image, and S_{2i} is the pixels number of a certain seed on upright in the image after 50 h. Nxl is the number of pixels in the average length of a seed radicle. S represents the average seed radicle length.



a. The original image b. The post-processing image

Fig. 3: Contrast results of image processing

a. Original image of cucumber seed b. The image of first growth cycle c. The system-based processed imag

Fig. 4: The system-based processed images of germinating number for cucumber seeds at first growth cycle

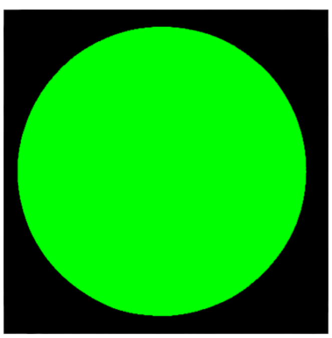
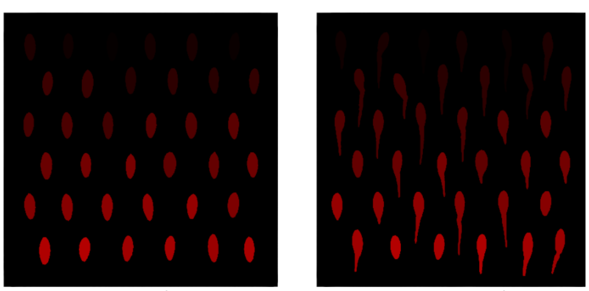


Fig. 5: The circle image of pixel length calibration



a. The original image of cucumber seeds b. The seeds image after 50 h

Fig. 6: Cucumber seed images at different growth time

Finally, GI (The seed germination index) and S (the average length of a seed radicle) were all used to calculate the vigor index by equation 6 (Liu *et al.*, 2007):

$$Vigor = S \times GI \qquad (6)$$

$Vigor$ is used to assess the vegetable seed vigor.

Results

The system for visual detection of the seed vigor index was used to numerically evaluate sample seeds of four different vegetables (Fig. 7): cucumber, chilli, tomato and aubergine. Values of manual detection and SVI automated assessment were shown in Table 1. The deviation of the system was tested by comparing the vigor indexes between manual accounting and self-developed system which was calculated according to the formula: deviation= (SVI-Manual)/Manual (Fig. 8).

Via many experiments, we found, under the same test condition, the vigor of tomato seed was stronger; the SVIs were 92.83% and 98.35% for manual and the SVI system, respectively (Table 1). Duo to the germination rate of aubergine seed was only 75% and germination index was also low. Thus, its SVIs were the worst, being about 33.89% (manual) and 34.98% (the system).

For seed germination index and average seed radical length, the largest percentage difference between manual and the SVI system was 3.74% and 7.97% (Fig. 8). In the worst case, the SVI percentage difference between manual and the SVI system was only 5.95%. Due to smaller size and irregularity in seed types, the deviations could be acceptable. Moreover, the percentage difference between manual and system determinations of the aubergine SVI was only 3.22%. The main reason was the germination rate of sample aubergine seed was about 75% and seed vigor was relatively low. The SVI of dead seeds was 0, the corresponding percentage difference of seed vigor between manual and system determinations also displayed as 0. The detection accuracy of the SVI system was higher than 94%, thus, it could provide reliable research foundation for vegetable seed assessment.

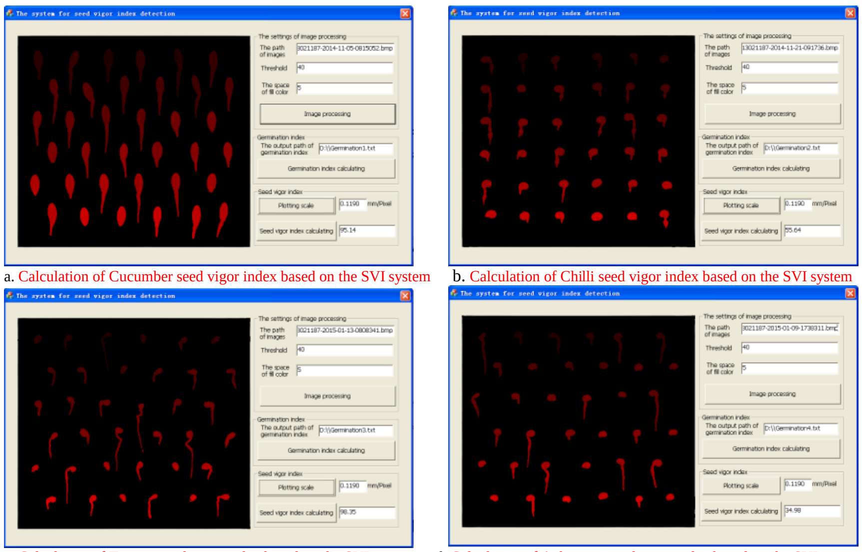
The results of manual measurement and the SVI system assessment were not completely consistent because of limitations of the measuring tools and human subjectivity. Before using the system to assess seed vigor, it is necessary to calibrate the length of pixel in the seed images. The actual length of a pixel found by the SVI system calculating is 0.1190 mm. However, the average seed radicle length must be a multiple of the scale (0.1190 mm). Thus, the test result is quantization error. If we want to increase the resolution of seed images to reduce the quantization error, the amount of system calculation will greatly increase; the system might become slow or crash. Therefore, the utilization of system algorithm could reduce the influence of quantization error, but deviations still exist.

Discussion

Currently, studies mainly focused on vigor assessment of crop grain and plant seed using machine vision technology (Hoffmaster *et al.*, 2003; Ma *et al.*, 2010; Deng *et al.*, 2012; Egli and Rucker, 2012), only a few researchers paid attention to vigor detection of vegetable seed, owing to the

Table 1: Statistic results of seed germination index, the average seed radicle lengths and seed vigor index for four vegetable seeds between manual and SVI-based system

Crops	Seed germination index		Average seed radicle length (mm)		Seed vigor index	
	Manual	SVI	Manual	SVI	Manual	SVI
Cucumber	14.25	14.20	6.40 ± 0.15	6.70	91.20	95.14
Chilli	10.40	10.40	5.10 ± 0.18	5.35	53.04	55.64
Tomato	11.75	11.53	7.90 ± 0.20	8.53	92.83	98.35
Aubergine	7.21	6.94	4.70 ± 0.31	5.04	33.89	34.98



a. Calculation of Cucumber seed vigor index based on the SVI system
b. Calculation of Chilli seed vigor index based on the SVI system
c. Calculation of Tomato seed vigor index based on the SVI system
d. Calculation of Aubergine seed vigor index based on the SVI system

Fig. 7: Calculation of seed vigor index for four different vegetables based on the SVI system

seed type of bigger size was easy to be detected based on regular image, such as the seeds of lettuce and cucumber (McDonald *et al.*, 2001; Hoffmaster *et al.*, 2003). In this study, a detection system of seed vigor index was developed, to explore new method for improving breeding effective of vegetable seed by image processing technology. Compared with previous seed vigor evaluation systems, which assesses lettuce seed quality through calculating the lettuce SVI (McCormac *et al.*, 1990; McDonald *et al.*, 2001), the self-developed SVI system had the better universality (four vegetable seeds of different size). Meanwhile, the SVI system has huge potential value for implementing streamline production in the factory. Although the results showed that the detection accuracy of the SVI system was high, surpassing 94%, in order to make the system to be more rapid, general and useful, further studies need to do: not only reducing the quantization error through increasing the resolution of seed images, but also lowering the amount of system calculation to save the computing time. The method of image processing also need to optimize and extension of feature extraction for vegetable seeds will be necessary. A multi-index seed vigor assessment is more beneficial for evaluating seed vigor.

In conclusion, for assessing seed vigor, the seed germination index, the average length of seed radicle and the seed vigor index were simultaneously obtained through

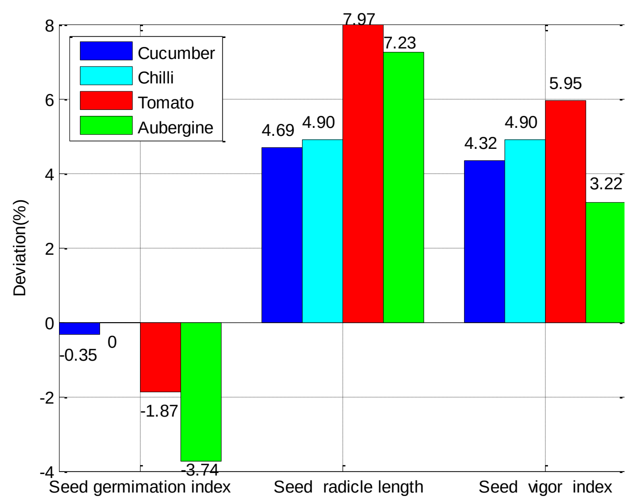


Fig. 8: The detection deviations of four vegetable seeds based on the SVI system

calculation of the SVI system. Via comparative analysis of four vegetable seeds between manual and self-developed system, The SVIs of the system had higher detection accuracy, as well as lower deviations were 4.32%, 4.90%, 5.95% and 3.22%, respectively. Therefore, the calculation accuracy more than 94% was acceptable and the study will provide a research conference for streamline detection of vegetable seed quality.

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