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An entire fruit surface imaging system with the support of a mirror system and a flipping mechanism

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ABSTRACT

Computer vision is considered a useful tool for evaluating the external quality of fruits. Some solutions for capturing the entire surface image of fruits have been implemented, but they still have limitations, such as not being able to guarantee capturing the entire surface, bulky, or expensive. In this study, a two-shot and simple system for capturing the entire surface image of fruits was proposed. With the support of a mirror system, the top and lateral surfaces of the fruits were captured. To capture the bottom surface of the fruits, a flip mechanism has been integrated into the system. Testing results with pomelo and mango showed that the entire surface of the fruits was fully observed with two shots. This shows that the proposed system has great potential for imaging the entire surface of fruits. Besides, this solution can also be easily integrated into automatic inspection applications to evaluate the quality of agricultural and other products.

1. INTRODUCTION

Quality indicators of agricultural products are often divided into two groups - internal quality and external quality. Internal quality indicators such as sweetness, acidity, nutritional content, and internal damage, are often evaluated by destructive methods with specialized measuring equipment. Meanwhile, external quality such as size, shape, color, and surface damage, is often easily assessed with the naked eye and will directly affect the first impression as well as the purchasing decision of the customer. Therefore, evaluating and classifying agricultural products based on external quality criteria is often prioritized before selling them on the market. Although external quality indicators can be easily evaluated manually, it is time-consuming, expensive, and often difficult to ensure consistency between evaluation results. Therefore, the application of modern technologies in assessing the external quality of agricultural products is of interest in research, and computer vision is considered a very effective assessment technology (Alfatni et al., 2011; Cubero et al., 2011; Zhang et al., 2014). In computer vision evaluation technology, images of the entire surface of agricultural products need to be captured to then process, analyze and provide evaluation results.

Taking images of the entire surface of a product is very important and there are three main solutions for this task: (1) using multiple cameras to take images in many different directions, (2) using a camera combined with a roller mechanism on the conveyor belt, and (3) using a camera and supporting mirror system (Zhang et al., 2018).

The use of multiple cameras to take multiple images of products from many angles has been used in many fields, including agricultural product quality assessment. In the study by Kurita et al. (2006), a system was designed to evaluate the external quality of tomato fruit. This system utilized six cameras to capture images of the tomatoes, including views from the top, bottom, and lateral surfaces. This setup ensured 100% capture of the product's surface images, allowing for a comprehensive evaluation of the tomatoes' external quality. However, due to the use of multiple cameras, this is quite an expensive solution.

The solution of using a camera and roller system to capture images of the entire product surface is also quite popular. For example, Loc et al. (2022) designed a system to capture the images of the four main sides (top, bottom, left, and right) of a mango using one camera and a roller system on a conveyor belt. Sofu et al. (2016) designed an apple classification system based on information about color, size, and weight. With this system, the rollers on the conveyor belt rotated the apple so that the camera could take images of the entire surface of the apple. However, the limitation of this solution is that it cannot ensure that the entire product surface is recorded during the rotation process with the rollers, especially in the area at the two ends of the rotation shaft because of its variation in size and shape.

Taking images with the support of a mirror system has also been proposed to take images of the entire product surface with just one camera. Reese et al. (2007, 2009) tested this solution to image the entire surface of an apple. In that study, the authors tested several configurations of the supporting mirror systems with flat and curved mirrors. That study concluded that a mirror system consisting of four or six mirrors can capture 100% of the surface of the apple. However, in that study, the apple needed to be hung on small strings and the apple also needed to be arranged in a suitable direction for rolling on the strings.

A combination of these solutions has also been done by several research groups. Li et al. combined the use of a mirror system with one camera placed on top and another camera placed on the bottom to take images of the apple's surface (Li et al., 2002). However, this solution still cannot guarantee to take the entire apple surface because the apple needs to be placed on a bottomless glass. The solution of using a camera combined with a mirror and roller system has also been proposed by Baek et al. (Baek et al., 2019). In that proposal, the mirror system included two mirrors placed above to capture the image of the entire upper half of the product and a roller system used to rotate the product. However, this solution still faces difficulties when the products are not uniform in size and shape.

These mentioned solutions have their own limitations, so finding a better solution is still being paid attention to and researched. In this study, a low-cost and simple system for imaging the entire fruit surface was proposed. With the support of the mirror system and flip mechanism, the entire surface of the fruit will be fully captured in just 2 shots without regard to the direction of the fruit. The proposed system was evaluated through imaging of a pomelo and a mango, representing fruit objects of different sizes and shapes.

2. MATERIALS AND METHOD

2.1. System overview

The proposed system included three main components: supporting mirror system, image capturing system, and flipping mechanism. Figure 1 shows the layout of the main components of the proposed system. In this study, a fruit will be placed into the clamping arm of the flipping mechanism. The flip mechanism was responsible for keeping the fruit during imaging and flipping the fruit in a fixed position. The supporting mirror system was placed above the flip mechanism to assist in taking images of the top and lateral surfaces of the fruit. On top of the proposed system was a camera used to capture images of the product surface reflected through the supporting mirror system. These components were arranged coaxially and installed into an iron frame. The overall dimensions of the proposed system were 1.0 x 1.0 x 2.0 m.

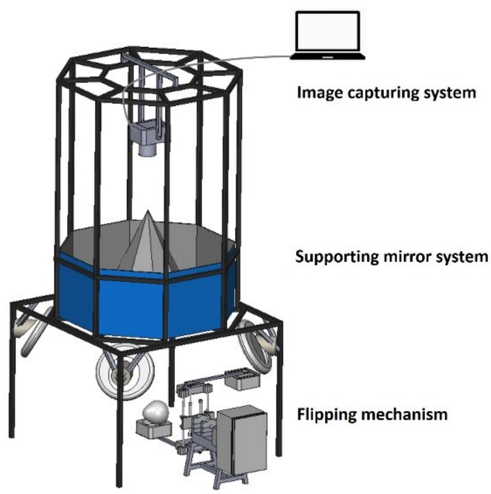


Figure 1. The overview of the proposed imaging system

2.2. Supporting mirror system

The supporting mirror system was a key component, which helped to take images of the top and lateral surfaces of the fruits with one camera in one shot. To capture the top and lateral surfaces, the proposed mirror system consisted of a pyramid mirror and a tube mirror.

The size of the mirrors was calculated based on the maximum diameter of the fruit to be captured. In this study, the maximum diameter of the fruits was designed to be 20 cm so that the system can capture images of large-sized agricultural products, such as large commercial Da Xanh pomelo with an average diameter of about 17 cm (Nguyen et al., 2021). Figure 2 shows the dimensions and arrangement of the proposed pyramid and tube mirrors. Figure 2a was a top view of the mirrors. Accordingly, the pyramid mirror was made from 8 triangular flat mirrors and the tube mirror was made from 8 rectangular flat mirrors. The heights of the pyramid and tube mirrors were 60 cm and 35 cm, respectively. Figure 2b shows a side view of the mirror system with the pyramid mirror placed inside and about 17.5 cm higher than the tube mirror.

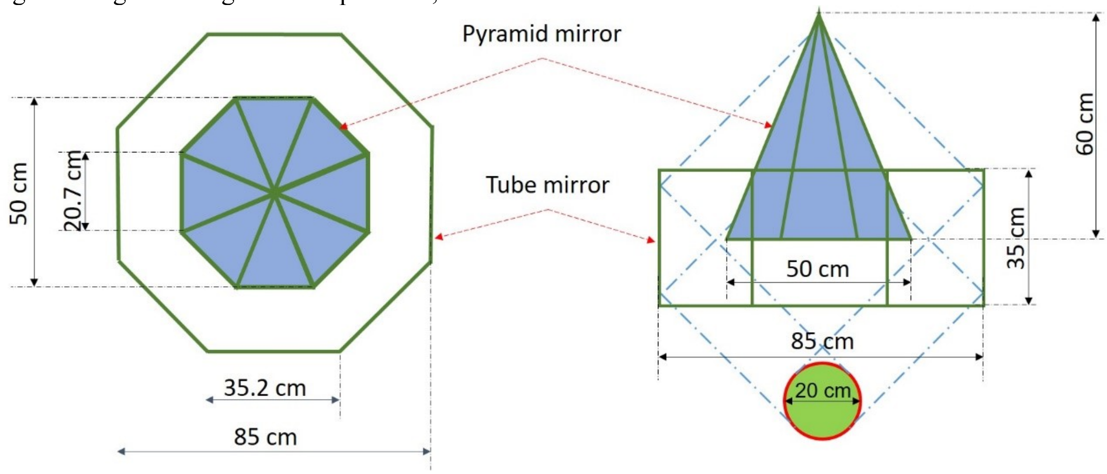


Figure 2. The dimensions and arrangement of the proposed pyramid and tube mirrors: (a) top view and (b) side view

2.3. Image capturing system

In this study, a Nikon D3300 digital camera coupled with a standard lens (AF-S DX NIKKOR 18-55mm f/3.5-5.6G VR II) was used to take images of the fruit surfaces. Some key parameters of the camera are presented in Table 1 (Nikon, 2014).

The Nikon D3300 camera was connected to a laptop via a USB interface. A free, open-source software digiCamControl (https://digicamcontrol.com/) was installed on the laptop to control the camera's parameters and to take images remotely. Figure 3 shows the main window of the digiCamControl application when connected to the Nikon D3300 camera. At this window, most camera settings can be adjusted such as shooting mode, light sensitivity, shutter speed, aperture, white balance, and exposure compensation. In addition, at this main window, users can control how to take images, open preview window, and many other useful features.

Table 1. The key parameters of the Nikon D3300 camera

Parameter	Value
Image sensor	- Type: CMOS - Size: 23.5 x 15.6 mm - Total Pixels: 24.7 million
Shutter speed	1/4000 to 30 second
ISO sensitivity	ISO 100 – 12,800
Focus	Autofocus or manual
Interface	Audio input, HDMI output, Hi-speed USB
Dimensions	124 x 98 x 75.5 mm
Weight	460 g

To support taking images clearly, a light source with a strong intensity and uniform distribution needs to be equipped. In this study, four 50 W LED bulbs with integrated light-scattering surfaces were used. These lights were arranged around the fruit and were placed below the bottom of the mirror system.

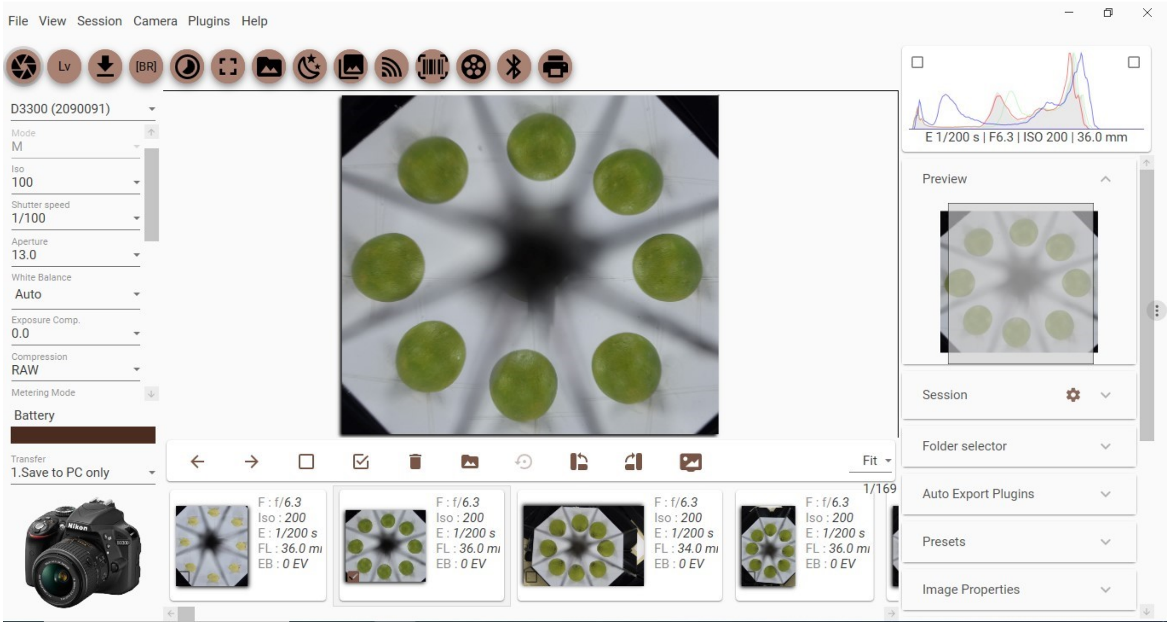


Figure 3. The main window of the digiCamControl application

2.4. Flipping system

With the support of the mirror system, only the top and lateral surfaces of the fruit are captured by a camera placed above, and the bottom surface of the fruit is still unrecorded. Therefore, a flipping mechanism was added to the system to ensure that the entire fruit surface was captured with two shots. In this study, because the position of the supporting mirror system and the image capturing system was fixed, the position of the fruit after flipping needed to be kept in a fixed position in all x, y, and z directions. In addition, the flipping mechanism is needed to meet the requirements of the size and weight of the fruits.

To fulfill these requirements, the flipping mechanism was designed and manufactured with three main components including clamping mechanism (clamping arms and linear cylinder), 90-degree rotary cylinder, and 180-degree rotary cylinder, as presented in Figure 4. In this study, pneumatic cylinders in types of straight, 90-degree rotation, and 180-degree rotation were used to allow the flipping system to operate quickly and accurately.

The operation of the flipping mechanism was divided into 3 steps, shown in Figure 5.

Step 1: Clamping arm 2 (red) rotates 90 degrees and waits for the fruit to be placed in clamping arm 1 (green). When the fruit is in the clamping arm 2, the image capturing system will be activated and take the first image.

Step 2: Clamping arm 2 rotates to 0 degrees and combines with the clamping arm 1 to clamp the fruit. After clamping and keeping the fruit, the clamping mechanism and the fruit will be rotated 180 degrees (flipping).

Step 3: After flipping, the clamping mechanism will be opened, clamping arm 1 will rotate 90 degrees, the image capturing system will be activated and take the second image.

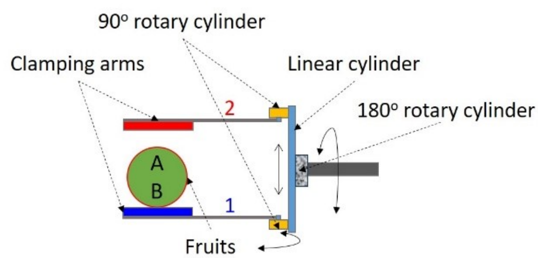


Figure 4. Three main components of the flipping mechanism

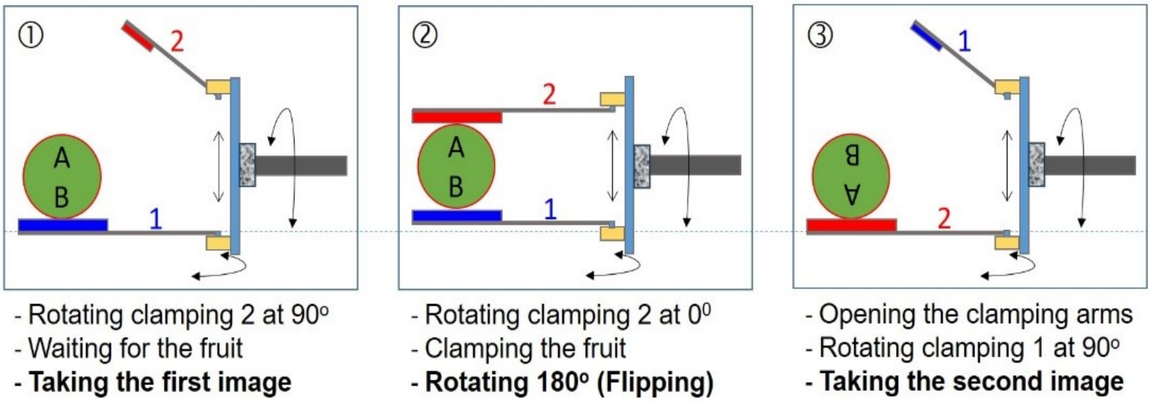


Figure 5. The operation of the flipping mechanism

3. RESULTS AND DISCUSSION

3.1. Testing the operation of the flipping mechanism

To test the operation of the flipping mechanism, a commercial pomelo and a commercial mango with markings on the surface were used. Figure 6 shows the three-step operation of the flipping mechanism applied to the pomelo (Figure 6a, b, and c) and the mango (Figure 6d, e, and f). The results in Figure 6 show that the flipping mechanism worked correctly and satisfied the requirements for the size and weight of pomelos and mangoes.

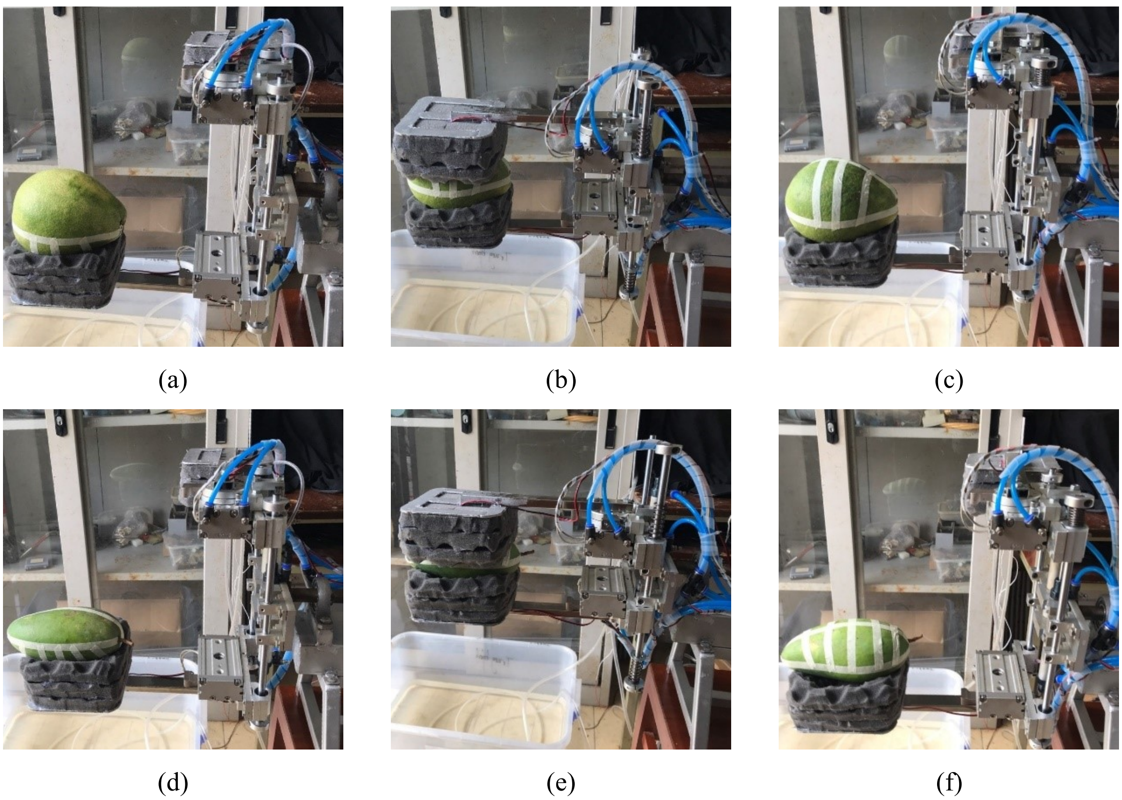
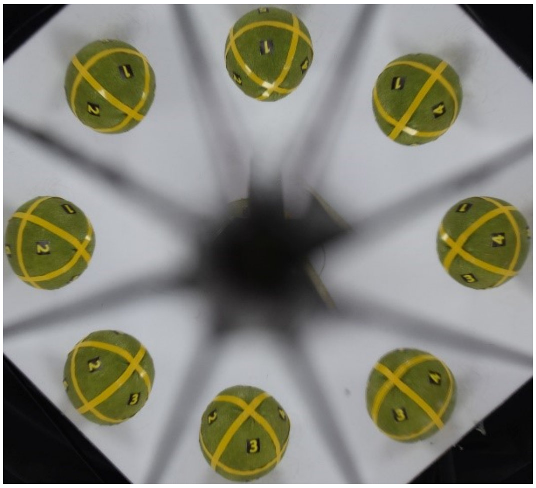


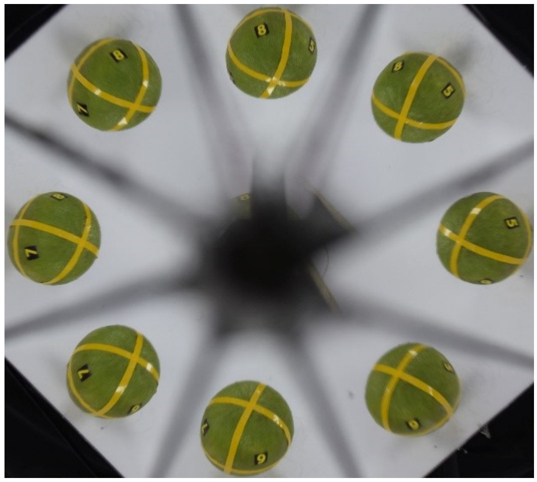
Figure 6. Testing the operation of the flipping mechanism with the pomelo (a, b, and c) and the mango (d, e, and f)

3.2. Testing on commercial pomelos

To test the ability to image the entire surface of fruits with the proposed imaging system, a large commercial Da Xanh pomelo with a weight of 1.6 kg and a diameter of 18 cm was used. The entire surface of the pomelo was divided into 8 parts with sequential numbers pasted on the surface. Images of the pomelo taken from the proposed system with two shots are shown in Figure 7. In the first shot (Figure 7a), the surface of the pomelo with the numbers from 1 to 4 was clearly shown. The remaining surface parts (the numbers from 5 to 8) were captured the second time after the pomelo was flipped (Figure 7b). The results in Figure 7 show that the proposed imaging system captured the entire surface of the pomelo with two shots.



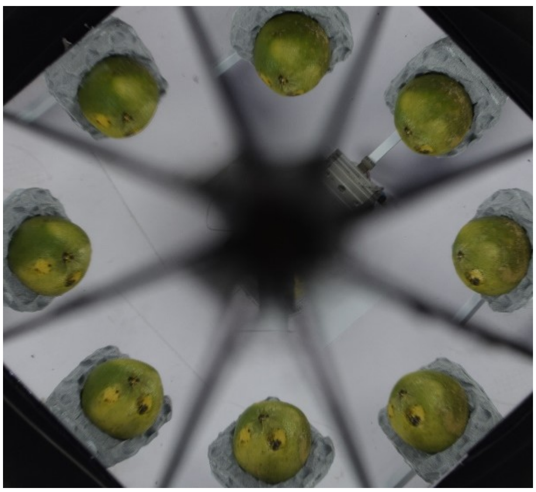
(a)



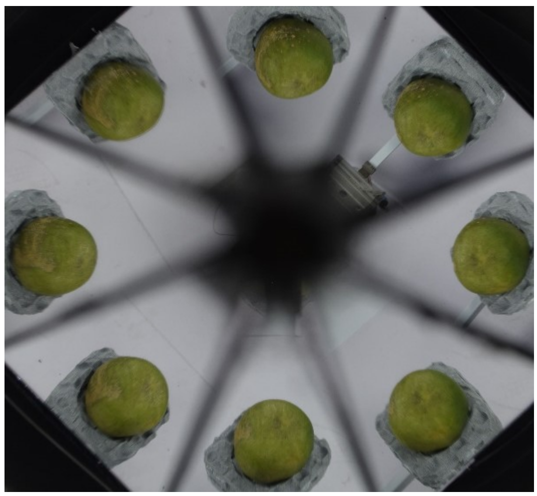
(b)

Figure 7. The images of the pomelo captured in the first shot (a) and the second shot (b)

Furthermore, to evaluate the potential of the proposed system in automatically evaluating the external quality of pomelos using computer vision, another pomelo with defects appearing at several locations on the surface was tested and the result is presented in Figure 8. After two shots with the proposed system, the entire pomelo surface was recorded and the defects on the pomelo surface were clearly observed.



(a)

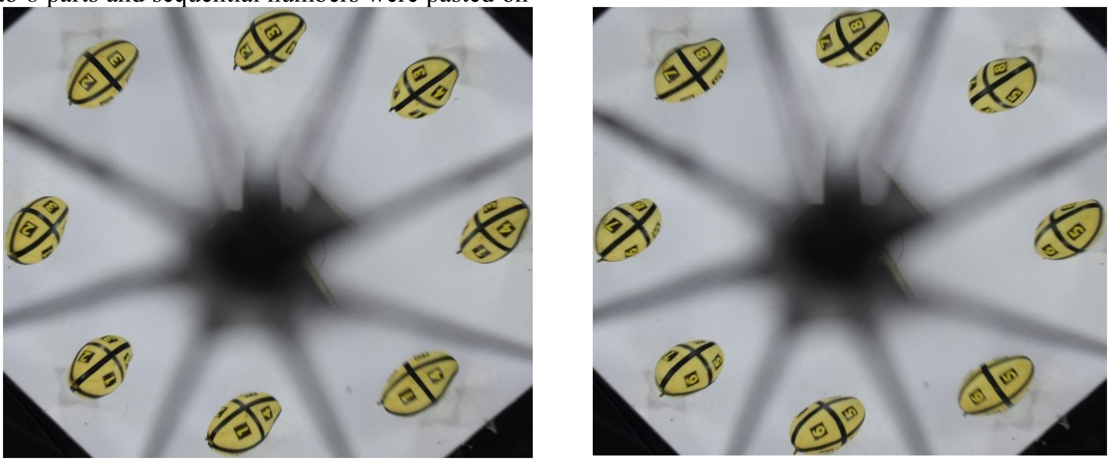


(b)

Figure 8. The images of the pomelo with defects captured in the first shot (a) and the second shot (b)

3.3. Testing on commercial mangoes

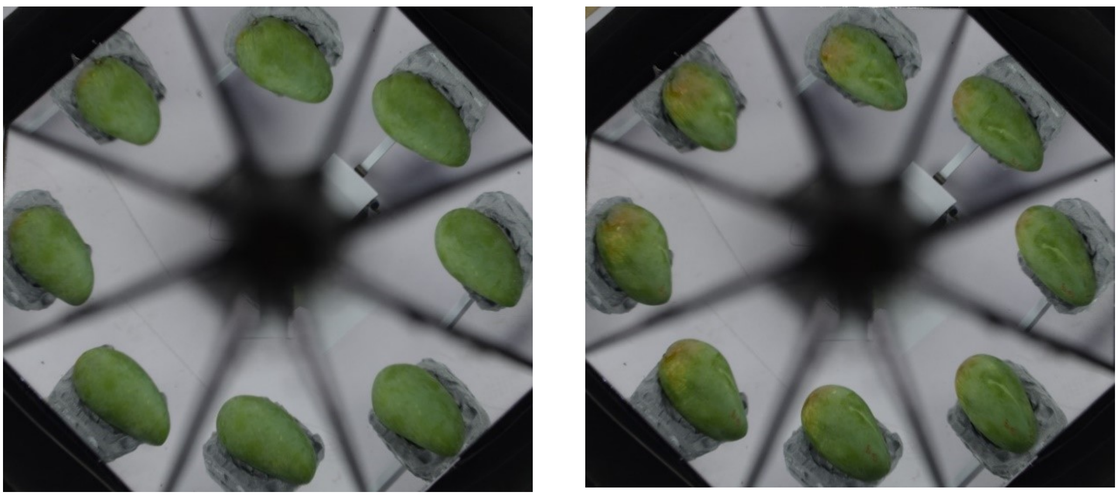
Besides spherical fruits such as Da Xanh pomelos, cylindrical fruits are also quite popular such as mango, papaya, and dragon fruit. In this study, mangoes were chosen to represent cylindrical fruits. The surface of a commercial mango was divided into 8 parts and sequential numbers were pasted on the surface. With the first shot (Figure 9a), the surface parts with the numbers from 1 to 4 were fully observed. The second shot is depicted in Figure 9b, showing the remaining surface parts of the mango. The results from Figure 9 show that the entire mango surface was also observed with two shots using the proposed system.



(a) (b)

Figure 9. The images of the mango captured with the first shot (a) and the second shot (b)

Figure 10 shows the captured images of a defective mango with two shots using the proposed imaging system. Figure 10b reveals that the defects on the mango surface were observed. In addition, the stem area of the mango can be observed clearly with the captured images.



(a) (b)

Figure 10. The images of the mango with defects captured in the first shot (a) and the second shot (b)

3.4. Discussion

By combining the supporting mirror system and the flipping mechanism, the proposed imaging system can completely capture the entire surface of the fruit with two shots using only one camera. Because the proposed imaging system only uses one camera and a simple supporting solution, the investment cost of the system is relatively low compared to other solutions such as using multiple cameras or using a robot arm to pick and flip the fruit at a fixed location. In addition, with the arrangement of the supporting mirror and image-capturing systems above the fruit, the proposed system can be easily integrated into the visual inspection process of fruit quality assessment and classification.

Although the proposed imaging system achieved its goal of being able to image the entire fruit surface with two shots, several issues need to be considered and further developed:

– Flipping and imaging speed: This study only proves the feasibility of the solution for capturing images of the entire surface with the support of the mirror system and flipping mechanism without considering flipping speed and capture time of the system. Therefore, this issue needs to be further considered and improved so that the proposed system can soon be deployed in practice.

– Integrating image processing and analysis: Capturing images is the initial step in applying computer vision to automatically assess the external quality of fruits. Therefore, integrating the ability to process and analyze captured images will help create a complete system for assessing the external quality of fruits using computer vision.

– Expanded to other applications: With the ability to image the entire product surface with two shots, the proposed system in this study can also be applied to many other fields such as surface inspection of machine parts after processing, checking product packaging, checking product labels, etc.

4. CONCLUSIONS

In this study, a system for capturing the entire fruit surface images with the support of a mirror system and a flipping mechanism was proposed and tested. The proposed system was evaluated through surface image capturing of pomelo and mango fruits. Evaluation results show that all parts of the fruit surface were fully observed with two shots. The results of this study show that the proposed imaging system has great potential in capturing the entire surface images of fruits at low cost and can be easily integrated into the automatic inspection process to evaluate the quality of agricultural products and other extended applications.

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