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Best Paper Award

Whole-surface round object imaging method using line-scan hyperspectral imaging system

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ABSTRACT

To achieve comprehensive online quality and safety inspection of fruits, whole-surface sample presentation and imaging regimes must be considered. Specifically, sample presentation method for round objects is under development to achieve effective whole-surface sample evaluation based on the use of a single hyperspectral line-scan imaging device. In this paper, a whole-surface round-object imaging method using hyperspectral line-scan imaging techniques is presented.

Keywords: hyperspectral, multispectral, line-scan imaging, online inspection, safety and quality

1. INTRODUCTION

For over a decade, implementation of machine vision techniques has become more prevalent for non-destructive inspection tasks in the handling and processing of agricultural products. Conventional color-based machine vision methods for fresh produce are typically limited to online sorting for basic physical qualities and morphological properties of fruits and vegetables, such as size, shape, and color [8, 11]. Additional chemical and biological properties of agro-foods have been assessed by spectroscopic techniques. However, spectroscopic techniques are generally inadeaute for use as comprehensive inspection tools owing to their lack of spatial information.

Since the late 1990s, hyperspectral imaging has played an important role in the development of nondestructive methods to assess the safety and quality of agro-foods for human consumption [2, 5, 6, 10, 12, 13]. Hyperspectral imaging combines the advantages of both spectroscopy and imaging. However, myriads of hyperspectral imaging studies have paid attention to finding optimal spectral imaging approaches suitable for potential online implementation to evaluate produce. The full-spectrum hyperspectral images (i.e., image cubes) contain large amounts of redundant data that, if processed and analyzed in whole, would require lengthy processing times inappropriate for near real-time online applications. These studies are restricted to imaging processing methods, which are still far from perfect for online sorting systems.

Agricultural products are diverse in size and shape. Because of morphological differences, many various sample presentation/processing regimes for imaging have been considered to achieve whole-surface sample evaluations. Specifically, the entire surfaces of round fruits such as oranges and apples are difficult for most online-based imaging systems to inspect. Until now, existing inspection methods of rotating a fruit for imaging still fails to capture a portion of rotating axis regions using a single camera system, while use of multiple imaging devices for whole-surface imaging may not be economical and can add complexity for online processing/inspection when dealing with dynamic sample shapes and sizes. The modeling of whole-surface imaging of apples using multiple mirrors below a wire-suspended fruit has also been investigated [14]. However, because of the size variations of fruits, producing a whole-surface image was not straightforward, and the method was inefficient for online applications for whole-surface imaging [9]. Currently, no rapid spectral imaging-based whole-surface screening methods are used online for rapid and comprehensive safety inspection of fresh produce. The need for such risk reduction technologies has clearly been illustrated by various outbreaks of illness associated with consumption of produce in recent years. The development of methods to image the whole surface of a round fruit is essential to successful implementation of line-scan imaging technologies on processing

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lines for produce safety and quality inspection. In this paper, a whole-surface round object imaging method using hyperspectral line-scan imaging techniques is presented.

2. MATERIALS AND METHODS

2.1 Line-scan hyperspectral imaging system

A schematic of the hyperspectral imaging platform used to acquire line-scan images of rotating round fruits is shown in figure 1. The hyperspectral line-scan imaging system consists of an electron-multiplying charge-coupled device (EMCCD) camera (EMCCD: Luca R DL-604M, 14-bit, Andor Technology, South Windsor, CT, USA), a C-mount objective lens (F1.9 35-mm compact lens, Schneider Optics, Hauppauge, NY, USA), and VNIR (visible and near-infrared) imaging spectrograph (Headwall photonics, Fitchburg, MA, USA). The round object is positioned on four truncated-cone rollers that allow the round object to rotate in place. While rotating the round object via stepping motor control of the rollers, line-scan hyperspectral images are captured through the center reflectors angled at 90°. The computer program was developed using Visual Basic 6 on a Windows platform to control the system and acquire image data. In this investigation, the imaging system was configured for line-scan imaging at two selected wavelength bands, since two-waveband ratio algorithms have been shown to mitigate heterogeneous spectral responses resulting from natural sample variations, and to enhance spectral differences between the background and the contaminants or defects of interest [3, 4]. Moreover, ratio algorithms, in conjunction with image processing methods including fuzzy logic, histogram thresholding, and spatial filters such as edge detection and erosion, have been used to enhance the ratio images and to detect the defects and contaminants present on produce [1, 7].

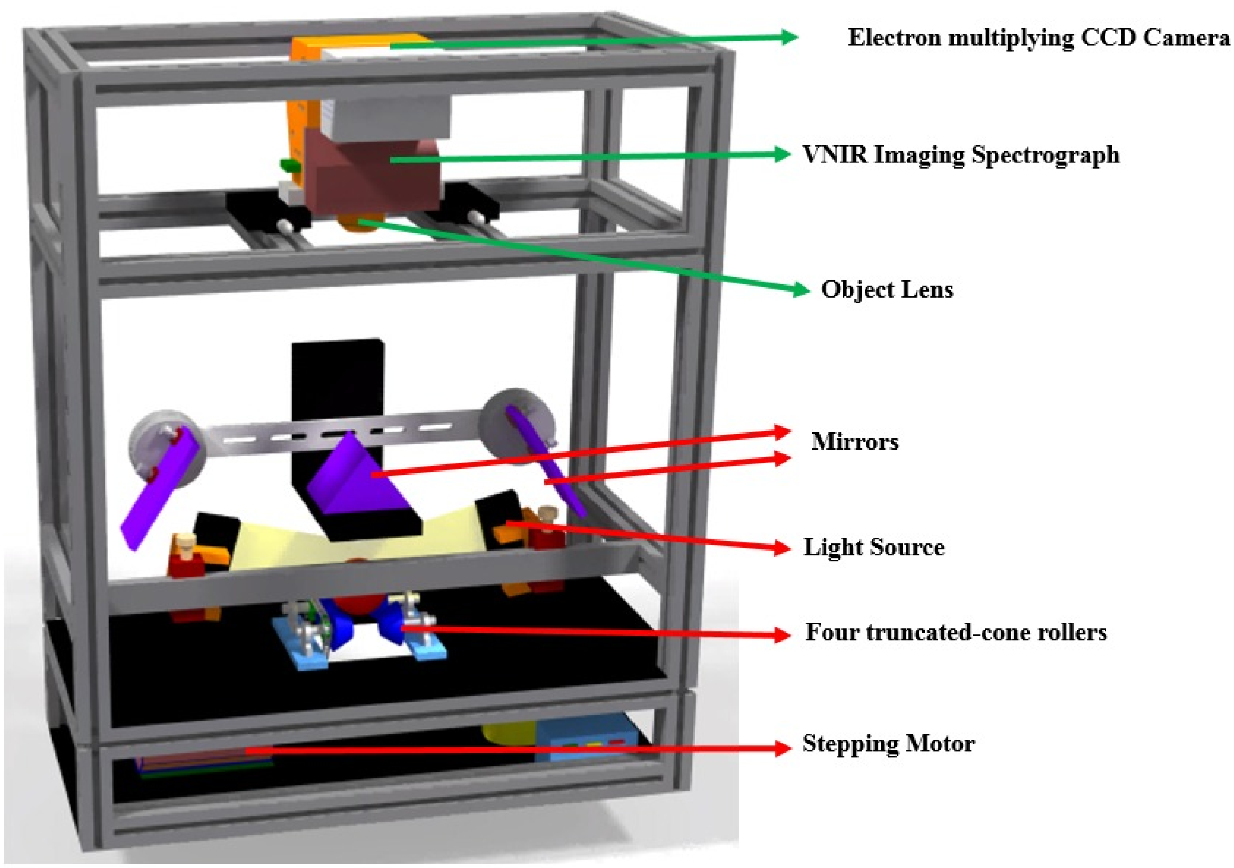


Figure 1. Schematic of hyperspectral imaging-based round-object imaging platform.

2.2 Round object image acquisition method

The whole-surface round-object imaging/inspection prototype platform includes two-view-angle optics that projects two side-views of a round object to the common aperture of the line-scan hyperspectral imaging camera (figure 2). Distances from the center and incline angles (α) of the mirrors that create two side-views of the round object can be adjusted to capture images of the object areas around the poles that would normally be hidden from the view of a single overhead camera. The images of the side-views are projected to the common aperture of the imaging system by the center reflectors angled at 90° as illustrated in figure 2.

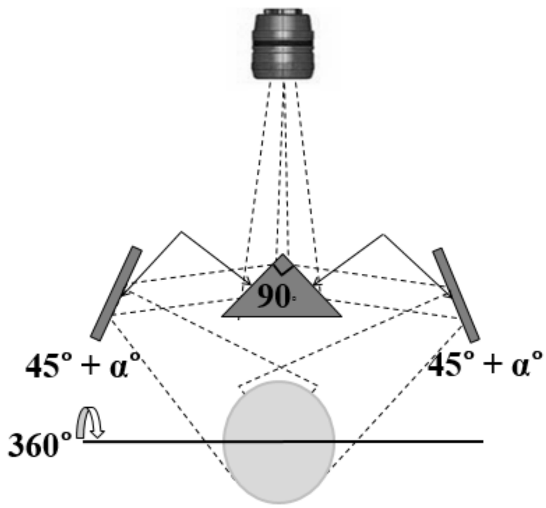


Figure 2. Schematic of the method for simultaneously capturing two side-view line-scan images of a round object

For this preliminary investigation to determine the efficacy of the whole-surface imaging method, we used a miniature basketball with 8cm diameter, which is approximately the size of a medium apple. In addition to the logo, trademark, and outlined basketball lines already printed on the surface, we wrote "5" and "4" on the polar regions as shown in the figure 3 photos.

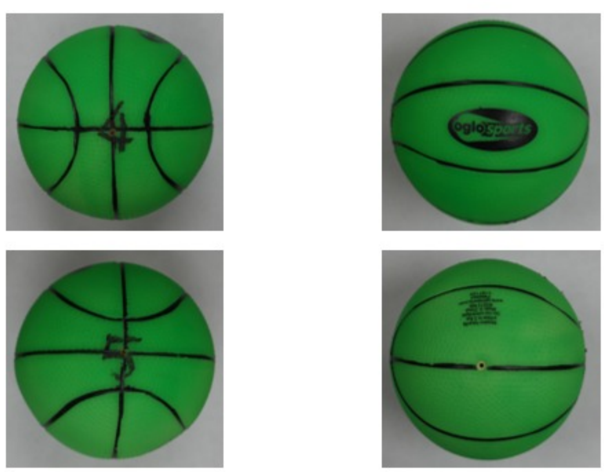


Figure 3. Photos of a miniature basketball used to evaluate the whole-surface imaging method.

3. RESULT AND DISCUSSION

The prototype system produces an image representation of the entire surface of the round object as a rectangular-shaped projection, unlike conventional imaging of round objects that produces hemispherical views as circular projections. Figure 4 (upper image) shows an unsegmented two-view-angle (side views) image of the ball acquired at a line-scan imaging speed of 570 lines per second while the ball rotated at 3 rotations per second on the truncated-cone rollers. The two-side-view images, shown using reflectance ratio 680 nm / 750 nm, were captured from inclined mirrors in real-time during testing of the whole-surface inspection platform system. The first image processing procedure performed is to determine the diameter of the ball. The ball diameter was estimated from one side image by calculating the number of vertical image pixels (excluding the background area). Following the removal of the overlapping sample regions in the two side-view images, the circumference or the number of line-scans needed to cover 360° in rotation is estimated (figure 4, lower image). Figure 5(a) shows the resultant whole-surface representation of the basketball in line-scan imaging mode. The rectangular line-scan image of the basketball can be transformed to project onto a sphere (3-D projection) as illustrated in figure 5(b).

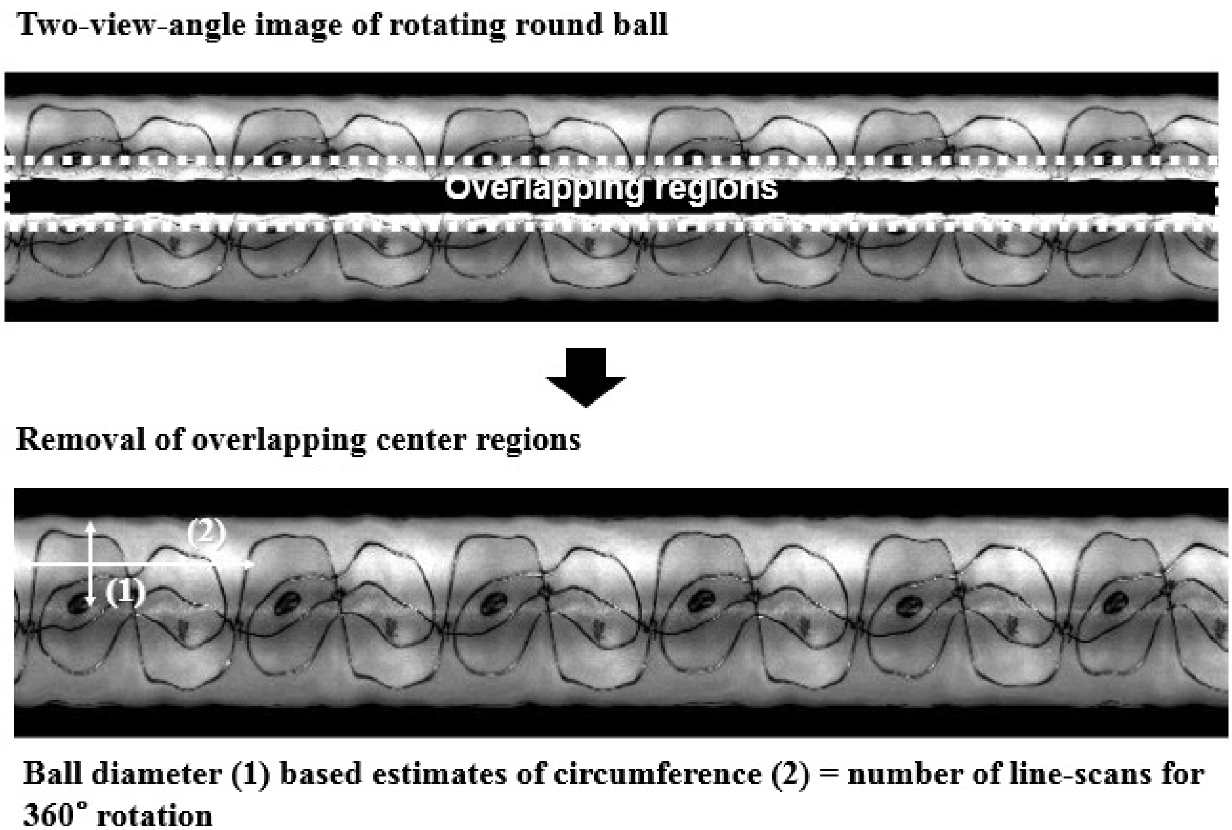
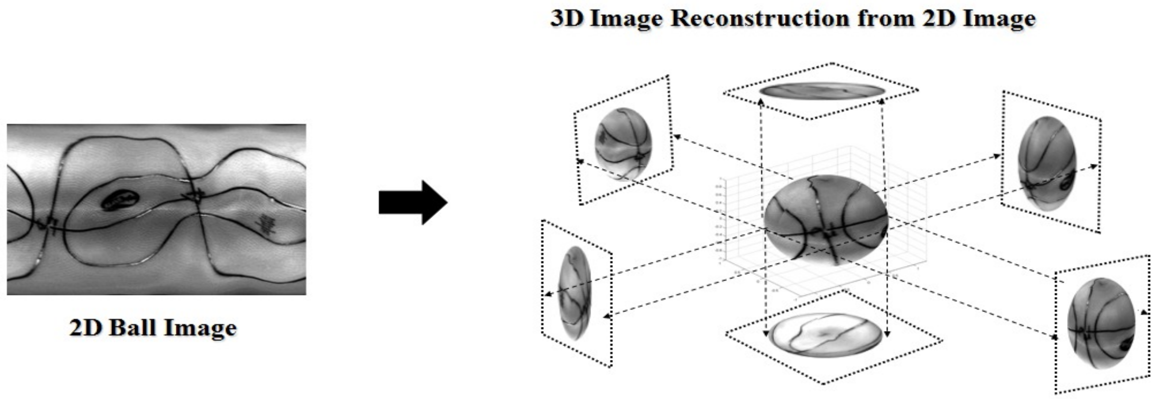


Figure 4. Upper image shows the two-side-view images of the basketball acquired using the two-view-angle optics. The lower image shows the result of removing the overlapping regions from the two-side-view images to produce the whole-surface representation of the basketball.



(a) (b)

Figure 5. (a) Whole-surface representation of the basketball in line-scan imaging mode. (b) Illustration of 3D spherical image transformation/reconstruction.

Figure 6 compares photos of features on each of four sides of the basketball (logo, trademark, and written numbers "4" and "5") with the 3D reconstruction of each side from the two-view-angle line-scan imaging of the basketball. The resultant 3D spherical projection of the line-scan image exhibits the individual features examined in this study. The shapes of the basketball lines and the features are distorted due to bouncing of the ball while being rapidly rotated during line-scan imaging. However, for inspection of agricultural products for contaminant and defect, precise shapes are non-critical. This preliminary evaluation of the whole-surface imaging platform demonstrate that the presented method can provide means to achieve whole-surface-based safety and quality inspection of round-shape fruits such as apples and oranges.

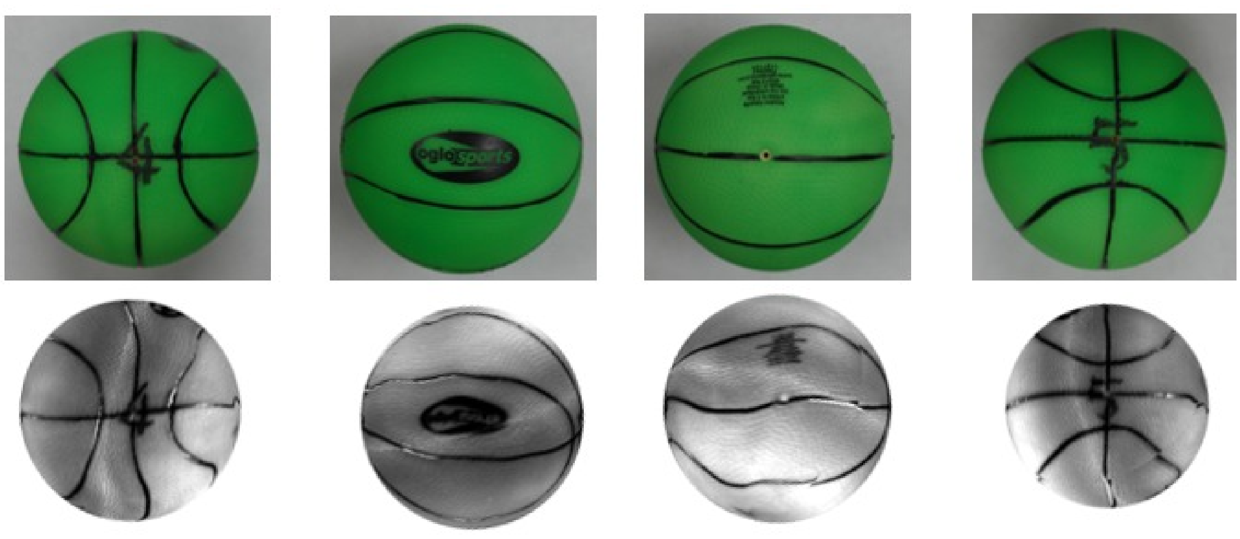


Figure 6. Comparisons of the sample photos and with resultant 3D spherical projection images obtained by the whole-surface line-scan imaging method.

4. CONCLUSION

As illustrated in this preliminary investigation, whole-surface imaging of a quasi-round object in a processing line is feasible. The on-line inspection methods/systems under development now are targeting cost-effective post-harvest processing of fresh fruits on commercial processing lines by enabling single-instrument-based whole-surface inspection. The round fruit inspection system will complement current automated screening and sorting based on quality attributes by the addition of safety inspection. However, this study is only the initial step for a whole-surface inspection system; further research is required to develop real-time image processing/segmentation methods and to validate the prototype system with samples of varying size and shape.

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