Application of spectral imaging for safety inspection of fresh cut vegetables

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Abstract. Food safety remains a critical issue and receiving increasing attention in both developed and developing countries. Fresh-cut vegetables may contain foreign objects such as small plastic pieces or biological contaminants (bugs and worms). In order to comply with requirements for product safety and maintain consumer confidence, there is a need for high-throughput, non-invasive technique for foreign objects detection in and real-time sorting of fresh-cuts. In this work, a liquid crystal tunable filter (LCTF) based spectral imaging system in the spectral range from 420 nm to 730 nm has developed and integrated with a conveyor unit. A software-interface was developed to collect the selected band images of moving samples and real time image processing for potential foreign materials detection on fresh cut vegetables. Spectral images throughout the whole spectral region were first collected for both fresh-cuts and foreign materials. The optimal wavebands for discriminating between foreign materials contaminated and sound fresh-cut were investigated. The optimal wavebands for each fresh-cut were selected and thus the developed system was used in multispectral imaging mode. Image processing algorithms were developed for detection of all potential foreign materials in fresh cut processing. The obtained results demonstrate that several kinds of foreign materials can be detected effectively despite being similar in color or nearly transparent. The ultimate advantage of a developed system is that it can be used either as in fluorescence mode or for collection of multispectral images in visible regions.

1. Introduction
The consumption of fresh-cut vegetables has been increasing recently so the quality control of fresh-cuts became a very important issue [1]. Even though there are quality control and processing procedures, but small amount of foreign materials often remains with the packaged fresh-cut. Foreign materials in fresh-cut are the biggest single source of consumer complaints [2][3]. Sometimes some malicious consumers take photos of foreign materials, even a small amount of foreign materials, in their food and just spread it through social media. It may cause a bad image for the company or industry since it is a big issue. In addition, physical hazardous foreign materials may cause traumatic injury like damages to the mouth, tongue, or throat [2]. There are some major contamination events such as in 2018 Belgium recalled leafy green because plastic contaminants in fresh-cut vegetables. In 2018, German companies recalled processed spinach contaminated with foreign materials and frozen spinach contaminated with plastics.
There are many kinds of foreign materials such as metal, plastic, glass, peels, wood, and insects [3]. Currently, to detect those foreign materials, conventional detection techniques have been used such as X-ray, magnetic resonance imaging (MRI), and ultrasonic[4][5]. X-ray is the common technique for detecting foreign materials which has good performance in terms of fast measurement and gives more thorough information [6]. However, it is only feasible for high density materials and very difficult to be used for soft materials. MRI is a very precise system but very expensive and not feasible for high-throughput screening because the measurement speed is relatively slow. Ultrasound is not feasible for uneven surfaces, only for even surface materials. Therefore, the current methods are considered to have limitations.

Another candidate for detecting foreign materials is spectral imaging. Spectral images are images of multiple wavebands across the magnetic spectrum[7]. To acquire spectral images, light sources and detectors are required. Usually spectral images are acquired line-by-line which can give hyperspectral images or multispectral images. Spectral imaging is simple, relatively cheap, feasible for high-throughput screening, and very fast measurement.

Spectral images can be acquired usually by line-scanning, but there is another method i.e. area scanning spectral images. Spectral images can be acquired by liquid crystal tunable filter (LCTF) which is a spectral tunable filter but controlled electronically. By using LCTF, 2D images for single wavelength can be acquired at a time [8]. Other advantages of area-scanning over line-scanning hyperspectral imaging system (HSI) are it does not induce sample motion related artifacts because there is no moving part and imaging parameters can be adjusted over each band, which make it easy to acquire certain desired wavelengths. Therefore, the area-scan HSI system is flexible, fast, and relatively cheap[9].

The objectives of this study are to develop a LCTF-based spectral imaging system at 420-730 nm, with unique advantages over line-scan HSI system, to calibrate and test for detection of foreign substances in fresh-cut vegetables, and to integrate a programmable motion controller based conveyor unit for real-time and on-line applications.

2. Materials and Methods

Figure 1 shows instrumental design of LCTF system covered field of view (FOV) was 23x23 cm. In order to get enough FOV, 2 relay lenses were used. The spectral imaging system consisted of an LCTF system with a CMOS camera, 2 relay lenses, and illumination source in reflectance and fluorescence modes. For reflectance mode, white LEDs were used, while for fluorescence mode, ultraviolet LEDs were used.

![Figure 1](image_url)

*Figure 1. Photo image of (a) developed spectral imaging system which shows (b) LCTF system and (c) LCTF schematic arrangement*

For foreign materials detection, a custom-built software was developed using LabVIEW. The software was focused on focus alignment, data collection, data correction, and real-time data analysis.
The software was also able to control LCTF parameters and to acquire hyperspectral and multispectral images or single waveband images.

For proper spectral imaging, a system calibration was required in terms of spectral and spatial calibration. A white board was used for flat field correction to remove vignette effects in the image. Spectral calibration was done by using 9-bands multispectral images of colour charts with 12 patches (Colorchecker® classic). Those 9-bands were 450, 489, 520, 555, 590, 625, 660, 695, and 720 nm. Acquired colour values were compared to standard colour values followed by correcting raw images with standard images.

Experiments of detecting foreign materials were conducted by using fresh-cut vegetables of green onion, zucchini, onion, garlic, and carrot which are popularly used for making instant vegetable soups, curry, and rice. Foreign substances studied were commonly found in real processing facilities. Those substances were peel residues of dry skin of vegetables, bugs, as well as soft (mostly films) and hard plastics. Several kinds of plastics used were acrylonitrile butadiene styrene (ABS), polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), and nylon. To cover a wide range of potential foreign materials, different shaped, sized, and coloured foreign materials were used. Figure 2 shows an example of image acquisition using fluorescence mode.

![Figure 2. Image acquisition using fluorescence illumination mode](image)

3. Results and Discussion
Two spectral imaging modes used i.e. fluorescence and reflectance modes. To acquire fluorescence imaging mode, a UV-A illumination at 365 nm was used, while to obtain reflectance imaging mode, white LEDs illumination were used. Examples of zucchini images taken by using fluorescence and reflectance illumination is presented in Figure 3.

![Figure 3. Images of zucchini in (a) fluorescence and (b) reflectance mode](image)

Figure 3 shows spectra of fresh-cut samples illuminated using short wavelength light i.e. UV-light. Fluorescence emission can be observed at longer wavelengths. In the case of zucchini and green onion,
fluorescence peaks can be observed at 680 nm due to chlorophyll. On the other hand, for garlic, carrot, and onion, the fluorescence intensity are very low, thus cannot be considered for fluorescence imaging. It means that for zucchini and green onion, fluorescence imaging are quite effective, while for garlic, carrot, and onion, reflectance imaging are better than fluorescence imaging.

Figure 4. Fluorescence intensity of fresh-cut vegetable samples in (a) fluorescence and (b) reflectance mode

The advantages of fluorescence over reflectance imaging are it is not sensitive to colour, has unique fluorescence peak, effective for fluorescence sensitive transparent plastics, and can classify foreign materials of same colour with fresh cuts. Figure 5 is a comparison of reflectance and fluorescence images of plastic placed on zucchini in which transparent and similar colour plastics are not able to be detected using reflectance mode.

Figure 5. Images of zucchini covered with plastics obtained using reflectance and fluorescence modes.

3.1. Fluorescence imaging
The performance of fluorescence imaging for detecting foreign materials is shown in Figure 6. Different kinds of foreign substances such as materials having small sizes, transparent, and identical with sample and conveyor belt colour are used and spread on the samples.

![Figure 6. Example of several foreign materials placed on the surface of fresh-cut vegetables for evaluating fluorescence mode performance.](image1)

The image processing algorithm is developed for detecting foreign materials using hyperspectral fluorescence images. Three band images were selected i.e. 460, 615, and 680 nm were used for bright objects which means high fluorescence materials, residual, and dark objects detection which means low fluorescence materials, respectively. Image thresholding are done by using an image ratio of 680:615 nm to remove the background which were then used for dark foreign object detection images. Image thresholding is also done for bright objects. Next, by combining two images from two previous image thresholding processes, final images are produced as shown in Figure 7.

![Figure 7. (a) Binary images of bright objects, (b) ratio image of 680/615 nm, and (c) final image which shows visualization of foreign materials.](image2)

Figure 8 shows examples of fluorescence imaging experiments on zucchini and green onion. In general, most foreign materials can be detected very well but some false negatives and false positives appear. For zucchini, false negatives come from non-fluorescent plastic and objects which have pixel intensity similar to sample edges. While false positives come from low fluorescence intensity at sample edges. So, the errors mostly come from sample edges. Possible solution recommended is since a single light source at 30 causes shadow, it is better to use two light sources side-by-side to mitigate the edge effect. Moreover, in case of green onion experiment, although the resultant images can be detected very well but several false negative and positive are also found. The source of false negatives is resulted from non-fluorescence plastics, objects having pixel intensity similar to a conveyor unit (background), and very tiny size plant residuals which have very low fluorescence intensity. False positives come from low fluorescence intensity of sample edges. Possible solutions to overcome the problems can be done by using a different background material and using two light source side-by-side.
3.2. Reflectance imaging

Besides fluorescence imaging, reflectance mode is also used to obtain reflectance imaging. A colour camera is used to acquire images using three wavelengths i.e. Red (R, at 620 nm), Green (G, at 525 nm), and Blue (B, at 450 nm) images using white LEDs instead of UV-A light. Garlic, onion, and carrot cuts are used to evaluate the performance. To detect foreign materials using reflectance imaging, two band ratio and image summation algorithms are used. For detecting low and high intensity foreign materials, a Red band and Red+Green band threshold are used. For detecting red and brown objects, blue objects, and green and yellow objects, two band ratios of Red/Blue, Blue/Green, and Green/Blue band thresholds are used. By combining all the detected images, the resultant image can be constructed. The image processing algorithm used includes edge correction, image thresholding, and small objects (noise) removal. Figure 9 shows the process of detecting foreign materials in reflectance mode.

Figure 8. Results of fluorescence imaging experiments using (a) zucchini and (b) green onion

Figure 9. Image processing of foreign materials detection in garlic. (a) Original image, (b) image thresholding using several selected bands, and (c) final image.

The results of reflectance imaging for foreign detection in garlic, carrot, and onion are shown in Figure 10. False negatives are from transparent plastic objects which are partially detected due to shining surface, foreign materials of similar colour to sample, and similar colour with conveyor belt, while false positives are from low intensity at sample edges. False positive pixels can be reduced to zero by using...
two light sources located side-by-side. In general, most of foreign materials were detected successfully, however there are few false positive pixels at the edges of the samples.

![Image of reflectance imaging experiments using garlic, carrot, and onion](image)

**Figure 10.** Results of reflectance imaging experiments using (a) garlic, (b) carrot, and (c) onion

4. Conclusion
The developed spectral imaging system facilitates both reflectance and fluorescence imaging for real-time foreign object detection. The research shows good performance with accuracy of 90-97% using only a few wavebands to detect different kinds of foreign materials. To reduce false negative detections, combination of fluorescence and reflectance modes simultaneously are required to increase the performance of detection accuracy up to 95-100%.

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