A statistical study on precision of ultraviolet (UV) image processing in detecting and measuring apple bruises

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Abstract

Apple grading is always performed to increase its market appeal and competitiveness in international markets. The mechanized grading of horticulture products, including apples, is essential for simpler pricing, handling and storage. Machine vision and image processing systems are novel methods with various applications in the agricultural sector. The machine vision is used for grading different products. The objective of this study was to detect bruises in apple fruits using the UV image processing technique as a means for grading. In doing so, a full machine vision set – including lighting at the UV-A wavelength, a UV camera equipped with UV-passing filter at 395nm spectrum, and a computer – was prepared. A number of 100 Red Delicious apples with different bruising levels were randomly selected. The samples were imaged under UV lighting, and the images were then processed in MATLAB. By binarizing the captured images and counting the bruised area pixels, the data from measuring the bruised area by the image processing method, along with the data from the measurements by a meshed transparent panel, were imported to SPSS for statistical analysis. The following statistical values were obtained: \( R^2 = 0.964 \), \( \text{RMSE} = 1.731 \) and Sum of Squares for Errors (SSE) = 299.63. These results indicate that there is a high coefficient of determination between the bruised area data from both methods (UV image processing and meshed transparent panel). The results showed that the grading performed by UV imaging is highly precise.

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Introduction

Historically, apple is among the first known fruits by men since prehistoric times and the start of cultivation. Annually, a large percentage of horticulture products, including apples, are removed from the supply chain and become unmarketable due to mechanical damages. The small share of apples in exports is because they fail to comply with the standards of target markets. During its production cycle, apple undergoes different practices such as harvesting, packaging, storage, and transport. During these stages, numerous static and dynamic loads are imposed on each of the fruits, leading to bruises and damages. In this regard, dynamic loads can produce much larger bruises. Impact is a dynamic load created during falling and collision with other apple fruits (Pourdarbani et al., 2009). Bruising is a damage to the apple's tissue, which changes its physical and physiological structures and finally leads to discoloration. It usually causes no cut in apple skins.

During the past four decades, a large body of research has studied the impact-induced bruises, which is due to the complicated nature of this phenomenon (Shekarbeigi et al., 2011). Besides the quality loss and the decline in the market appeal of unprocessed fruits, bruises can also reduce the quality of final processed products such as compotes. Moreover, since most compote manufacturers have no qualitative grading systems within their production lines, most bruises are visible in final products (Nikbakht et al., 2008). Because of the defects and limitations of manual and mechanical grading methods, imaging technologies at different wavelengths are widely used today to determine the product quality, including detecting bruises. The following is a review of the literature in this regard, plus their advantages and disadvantages.

Li et al. (2002) developed a system based on machine vision and visible-spectrum lighting. Their system, including a conveyor, uniform spacing unit and a machine vision system, was designed to detect damages on apple surface. This system was highly accurate in measuring apple diameters, and therefore facilitated their quantitative grading. However, on the other hand, it was impossible to measure damages under the skin since visible wavelengths were used. This affected its efficiency. Within the same wavelength, Mizushima and Lu (2011) used machine vision to evaluate four different apple cultivars in term of size and position direction. Results of their study showed that machine vision’s error is lower than previous mechanical methods, and it is more cost-efficient and more successful. Furthermore, the feasibility of using this method for qualitatively grading apples based on their surface damages was studied by Pourdarbani et al. (2009). They used a machine vision system comprised of a lighting chamber, a camera and a computer. Captured images were processed in MATLAB, and the threshold of the desired color spectrum was defined by trial and error, as a criterion to decide whether an apple is tact or intact. This threshold can was a reference for grading apples. This study also reported that peduncles were mistaken for damaged areas. This error was, however, fixed by comparing the length to thickness ratio. Nonetheless, the common disadvantage of machine vision studies using the visible spectrum is their failure to detect under-skin damages.

Another machine-vision-related technology is hyperspectral imaging. In this method, halogen lamps provide the required lighting at 400 to 1000 nm wavelengths. In order to perform spectrometric studies using spectrograph, images are captured at different wavelengths within the mentioned range (which also includes infra-red wavelengths). The images are then analyzed and the wavelength that produces the sharpest images of the studied qualitative parameter is also introduced.

Moreover, given that IR spectrum is also within this range, it is feasible to isolate the studied wavelengths using their specific filter, without any spectrograph, and to capture images with a regular camera equipped with this filter mounted on it lens. The following is a brief description of such studies:

Mendoza et al. (2011) used a combination of spectral analysis and spectral imaging methods to estimate the
stiffness and Total Soluble Solids (TSS) of apples. This study reported acceptable results (about 90% precision) in estimating the mentioned properties. A similar study was conducted by Peng and Lu (2008) who reported the 675nm wavelength as the best for evaluating the stiffness and TSS of apples. The coefficient of correlation from this method for TSS and stiffness were 0.883 and 0.894, respectively. Luo et al. (2012) determined the suitable wavelength for bruise detection in apples within visible and IR spectra. Using the information from the output spectrum, they reported that the suitable wavelength for detecting bruises in four apple varieties was 700nm. The application of hyper-spectral machine vision at 450, 500, 750 and 800nm wavelengths proved that this system can detect surface bruises with a 93.5% accuracy (Unay et al., 2011). The hyper-spectral imaging system was also employed by Elmasry et al. (2008) to detect bruises at 75, 820 and 960nm wavelengths. The indicated that this system has an acceptable accuracy in detecting apple bruises. Huang and Lu. (2010) used hyper-spectral imaging technique to study the abnormal mealiness and intracellular fluids of apples. Their results showed that if an apple texture is severely damaged by both defects, this method can separate intact from damaged apple samples with a more than 92% accuracy. However, this method performed poorly in detecting damages with low severity. Another study on hyper-spectral imaging was performed by Elmasry et al. (2009) to detect chilling injury in red apples. Their results showed that intact apples can be separated from samples with chilling injury with a 92% accuracy when using an Artificial Neural Network (ANN). Baranowski et al. (2012) also used hybrid hyperspectral- thermal imaging for early detection of bruises in apple fruits. This study, which studied the three ranges of 400-1000, 1000-2500 and 3500-5000, indicated that the thermal imaging produced the sharpest images at the 3000 to 5000 range for the early detection of bruises in apples. This method can be an option for separation and grading processes.

Studies on hyper-spectral images show that this technique is a research method in order to find the best wavelength for detecting defects and injuries in different products. However, since images at different wavelengths are first separated by a spectrograph and then it would be possible to capture images by a camera, using this method is highly time-taking; from the stage where images are separated at the required wavelength by a spectrograph to the image processing stage and triggering the command circuits. Despite its high accuracy, the application of this method to online grading lines is limited due to its time losses, and, therefore, it is most used in research and offline applications. For this purpose, special filters at different wavelengths were used. These filters, which are made to isolate different wavelengths from optic spectra, allow taking images at the required wavelength once they are mounted on lenses of regular or specialized cameras. This brings about faster performance in qualitative separation lines of agricultural product. Charge-coupled devices (CCDs) of camera play an important role in the quality and brightness of captured images; however, the CCDs of regular cameras are designed and developed to take images within the visible wavelengths. As a result, images captured by this method using regular cameras at UV or IR wavelengths lack quality and proper sharpness, leading to decline in accuracy.

Moreover, there are reports of using X-ray (used in CT-Scan devices) and gamma ray for imaging. Both rays are suitable for measuring those qualitative parameters that are a function of mass variations, because their penetration rate depends on density and absorption coefficient. The most important disadvantage of both methods is their ray generation limitations and their negative impact on consumer health. Besides their expensive and complex equipment, using high radiation intensity ionizes molecules of agricultural produce, resulting in complications in both operators and consumers in the long run. The Magnetic Resonance Imaging (MRI) method is also expensive, slow and not economically justified and requires complicated hardware. The application of these methods is limited since they have no economic justification and are not
competitive (Nikbakht, 2008).

As shown in the literature review, all the reviewed methods have limitations in aspects such as using the proper wavelength for injury detection, accuracy and grading speed. In most cases, focusing more on one of these parameters, would reduce accuracy and speed, making it impossible to be implemented in online applications. Against this background, this study intended to correct the mentioned methods and develop a device capable of detecting bruises and grading apples with high accuracy, speed, and at the proper wavelength. In addition to examining the spectral response of apple bruises at the UV wavelength, a study is developed in this study to detect and separate intact apples from those with bruising injuries. This device may outperform previous prototypes in terms of accuracy and image brightness thanks to the selected wavelength and using a camera with UV-sensitive CCD.

Materials and method
A total of 100 Red Delicious apple samples with bruising injury were exposed to UV lamps in a trapezoid lighting chamber under 45° angle (ElMasry et al., 2009). For imaging purposes, an Ultrak UV camera equipped with 395nm-passing filter was used. After mounting the filter on the lens, images were captured at the 395nm wavelength and were transferred to and saved in a computer via an A/D capture card in 480×640 resolution (Figure 1). Images were monochrome and bruises were clearly brighter than intact areas. This was the basis for developing the image processing algorithm. The procedure was as follows: images were exported to MATLAB for processing and binarization. Then, using a proper algorithm and image processing-related codes, the images were binarized, and the apple outline was separated from the background. In this stage, the bruising area was clearly representing in white (Gonzalez, 2008).

In the next stage, in order to separate the bruised area, the whole binarized image was turned to black except for the bruised area. Then the white pixels (bruised area) were counted using MATLAB’s pixel count codes. The area was calculated in mm² by scaling the images and the pixels related to this area were counted. This way it was found that how many pixels equal one mm² of apple surface. A transparent panel marked with 1-mm² meshes was used to measure and compare the real bruised area with the area determined by the image processing method. To do so, the apples were peeled with a blade at the bruised section, and its area was measured using the transparent panel in mm². The results were recorded and compared to those from the image processing method (Pourdarbani et al., 2009). The findings were used for statistically studying the accuracy of UV imaging in detecting apple bruises. Data from both methods were analyzed by SPSS.

Results and discussion
According to the statistical analysis of data from comparing UV imaging measurements (using a UV camera with 395nm-passing filter equipped with UV-sensitive CCD) with measurements by the meshed transparent panel, results showed a good accuracy in detecting bruises on Red Delicious apples. Therefore, this study can be the cornerstone for designing and developing a device, which can separate and grade intact from bruised apples with high accuracy based on the injury severity, using UV imaging and processing. The following statistical values were obtained: $R^2 = 0.964$, RMSE = 1.731 and Sum of Squares for Errors (SSE) = 299.63. These results indicate that there is a high coefficient of determination between the bruised area data from both methods (UV image processing and meshed transparent panel).

![Fig. 1. The actual UV imaging system including a lighting chamber, a UV camera, and a computer with a capture card.](image-url)
Figure 2 presents the correlation’s diagram. Moreover, the study data suggest that the larger the bruising area, the bigger the difference between the values from both methods. This difference is caused by refraction and reflection of light around the bruised area, which cause an error in measuring this area using image processing. Therefore, the area measured by the image processing technique is slightly larger than that measured by the meshed panel. In fact, a major source of variation for this error is a sample’s orientation. Accordingly, the more perpendicular to the camera axis the bruised area is, the smaller the error would be, resulting in more accurate image processing. Another source of error can be the lighting method of the system, in that, more indirect lighting would decrease refraction and reflection on the sample’s surface, leading to a lower error value. In such experiments, it is would be better to direct light through a medium in order to obtain more spread and non-concentrated lighting on the sample. Factors such as the quality of the wavelength separation filter, using lenses specific to UV-imaging, using high-end cameras and state-of-the-art technologies and also higher resolutions coupled with upgraded computer systems (capture card and cables) can play a significant role in removing potential noises and consequently reducing the system’s error. The research findings will be used to design and develop an apple grading apparatus using the UV imaging technique.

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