J Bangladesh Agril Univ 19(4): 528–532, 2021 https://doi.org/10.5455/JBAU.123862

ISSN 1810-3030 (Print) 2408-8684 (Online)

Journal of Bangladesh Agricultural University

Journal home page: http://baures.bau.edu.bd/jbau

Research Article

Potato Grading Based on Size Features by Machine Vision Technique

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ARTICLE INFO

Article history
Received: Sep 13, 2021
Accepted: Nov 19, 2021
Published: 31 Dec 2021

Keywords
Potato grading,
Machine vision,
Image processing,
Size features,
Multivariate Analysis

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ABSTRACT

In this study, a method was established to grade the potato based on size features using a machine vision technique with image processing and multivariate analysis method. The image of individual potato was captured using a color camera sensor with white LED lighting conditions in the laboratory. An image processing algorithm was developed for extracting the size (major, minor, and surface area) features from 57 potato images. Using these extracted feature data, the potatoes were classified using the partial least squares-discriminant analysis (PLS-DA) algorithm, and the overall accuracy was achieved at 86%. Finally, it was stated that the PLS-DA classification algorithm with size features could be used for grading the potato in Bangladesh.

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Introduction

Potato (*Solanum tuberosum*) is an annual herbaceous that ranks as the world's fourth most important food crop, cultivated as a major food resource in some countries with a moderate climate like in Bangladesh (Zaheer and Akhtar, 2016). In 2000, potato production was 2.93 million tonnes in Bangladesh, whereas the production reached 9.74 million tonnes in 2018 (BBS, 2020). In Bangladesh, the grading of potatoes is done by hand, especially for seed, which is very time-consuming and is not cost-effective because potatoes vary tremendously in size, shape, and regularity (Ghanbarian et al., 2010). A product with a good appearance, size, and uniform shape will always be preferable to most consumers and will have a better sales appeal. Therefore, grading and sorting processes will ensure that the products meet sellers' defined grade and quality requirements and provide an expected level of quality for buyers (Pedreschi et al., 2016).

Moreover, potatoes with abnormalities in appearance do not meet quality requirements for export. Even though Bangladesh produces a substantial quantity of potatoes, and overseas demand is steadily increasing, current post-harvest processing, which is still predominantly performed manually, cannot meet international quality requirements. Therefore, a simple, reliable, and computer-assisted potato grading system would greatly benefit the potato growers in Bangladesh.

Machine vision with image processing is a typical important field of information science and technology. Nowadays, it is being improved as a key technology in quality control, especially for object shape, size, and appearance-related feature analyzing and grading (Su et al., 2018). Several researchers have previously designed algorithms and machine vision systems for automatic potato inspection (Tao et al., 1995; Zhou et al., 1998; Rios-Cabrera et al., 2008; Hasankhani and Navid, 2012; Rady and Guyer, 2015; Pedreschi et al., 2016; Su et al.,

Cite This Article

Islam, M.H., Rahman, A., Rana, M.S., 2021. Potato Grading Based on Size Features by Machine Vision Technique. *Journal of Bangladesh Agricultural University*, 19(4): 528–532. https://doi.org/10.5455/JBAU.123862

2018). However, the development and deployment of machine vision systems for potato grading are still in their infancy (Rady and Guyer, 2015). Some systems have expensive mechanical hardware or are challenging to maintain color camera technology, limiting their affordability, portability, consistency, reproducibility between systems and not applicable in Bangladesh standard. So, it demands a simple, rapid, and cost-effective method capable of predicting grades in Bangladesh standards that would be very useful to both the potato growers and buyers. Therefore, the objective of this study was to develop a potato grading system based on machine vision techniques.

Materials and Methods

Potato sample

The experimental potato samples (Diamond variety) with different sizes were bought from the local market at a scale of 10 kg. Then, the sample was stored based on major axis lengths, such as Big (>55 mm), Medium (40-55 mm), and Small (<40 mm), and free from all kinds of injury, diseases, etc. After that, the potato samples were washed with plenty of clean water for cleaning the soil and other dirt and wiped using soft tissue. The experiment was conducted at Precision Agriculture Lab, Department of Farm Power and Machinery, Faculty of Agricultural Engineering and Technology, Bangladesh Agricultural University (BAU), Mymensingh.

Image acquisition system

The image acquisition system consists of a charge-coupled device (CCD) camera (DFK 42AU02, Imaging source, Germany), four light-emitting diodes (29.5 cm long, 6W, 4000K, Jiangsu ChuangXu Optoelectronics Technology Co., Ltd, Jiangsu, China) as light source, and a desktop personal computer. In this study, the LED light sources were placed at the lateral position in the image acquisition chamber following Ansari et al. (2021). The camera was placed into the image acquisition chamber using an adjustable scale to eliminate the ambient light effects. A CS-mount lens was used in this study, whose focal length was 6 mm. To avoid the reflection of light from the object, a polarizing filter (PL) was used in the front of the lens.

Image acquisition procedure

At first, the camera was connected to a computer with a USB 2.0 interface data cable. Then, white balancing was done by adjusting different parameters like gain, gamma corrections, iris, lens, and shutter speed. For white balance, a perfect white color checkerboard was used. Upon completion of white balance, the potato image was captured manually and distance between the camera and the sample was kept 25 cm. The captured images were saved on the hard disk in BMP format for further analysis. After the image acquisition, the size of the potato (major and minor axis) was measured manually using a marked ruler and the data was recorded. Finally, the potato's surface area was manually calculated using the ellipsoid equation according to Tabatabaeefar (2002).

Data analysis

Image processing

Image processing includes – image pre-processing, color space conversion, background segmentation, and feature extraction. An individual RGB image of the potato sample must be separated from the background. The potato sample segmentation was performed on RGB images to separate the potato image from the background using Color Thresholder App within MATLAB® computational environment. First, the RGB image was converted to HSV color space and defines the threshold value based on the channel histogram. Then, a masked image was created based on the chosen histograms threshold setting and applied *imfill* and *bwareaopen* operation to eliminate tiny (pixel <100) artifacts that may appear during the data collections. Finally, the masked output image was used to obtain the segmented potato sample image. These procedures were repeated for all potato sample images. Then, the feature extraction algorithm was then run to collect the minor axis, major axis, and surface area for further classification model development.

Multivariate classification model

Partial least squares regression (PLS-R) is an important methodology to solve both regression and classification problems. In this study, partial least squares discriminant analysis (PLS-DA) was utilized for grading the potato samples. The response variable Y of PLS-DA is a set of binary variables related to the sample's categories or class. PLS-R or PLS-DA is expressed as follows:

$$Y = Xb + E$$

where X is an n × p matrix that holds the image feature of each class, b is the regression coefficient, and E is the error term. In this study, for the construction of the PLS-DA model, the class of potato value expressed as given below:

Y= {1=small size of potato, 2= medium size of potato, 3= large size of potato}

Furthermore, the whole dataset for each size was divided into a calibration (65% of the sample) set and a validation (35% of the sample) set. A baseline was selected as <1.5 and >2.5 for the small and big groups, respectively. Samples within the baseline ranges were considered as classified in that group. The MATLAB

software was used for image analysis, feature extraction, and model development in this study. A flow diagram of the multivariate classification model is shown in Figure 1.

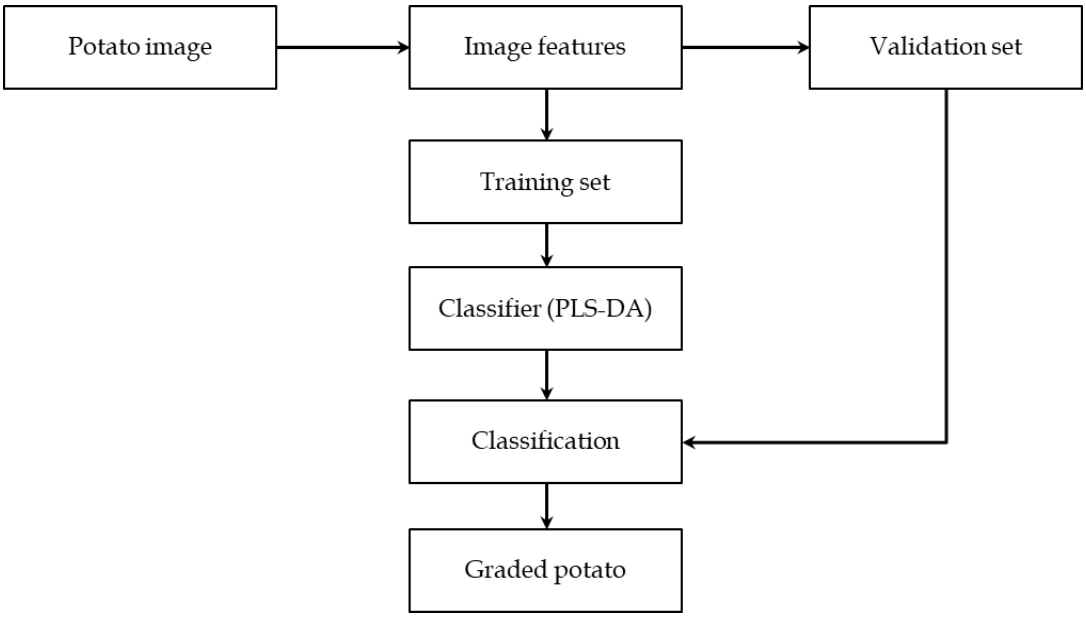
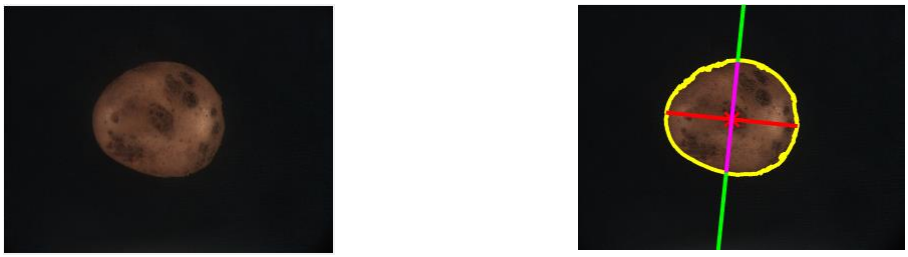


Figure 1. Block diagram of the multivariate classification model

Results and Discussion

Performance evaluation of the developed algorithm

During the experiment, a total of 57 potato images were used to evaluate the performance of the developed image processing algorithm for the major axis, minor axis, and surface area of a potato. The acquired and processed images of the small, medium, and large potatoes with the boundaries major and minor axes are shown in Figure 2.



(a) Small

(b) Medium

(c) Big

Figure 2. Orignal and processed potato images with boundaries of major and minor axes (a) Small size, (b) Medium size, and (c) Big size

The surface area of the potato measured by the image processing technique was compared with manually measured data. A comparison between the calculated and measured areas is shown in Figure 3. From the figure, it is observed that there is no significant difference between the calculated and measured surface areas of potatoes.

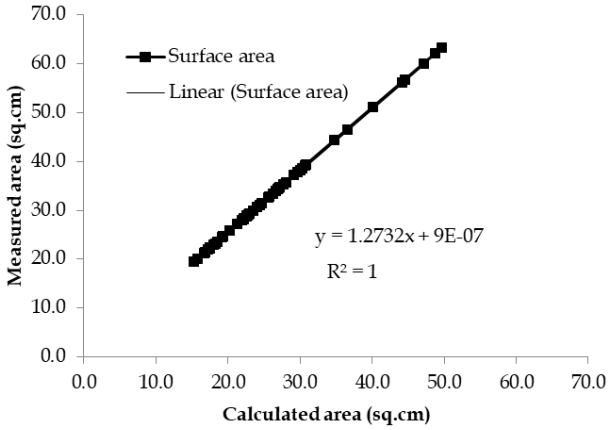


Figure 3. A comparison between calculated and measured surface areas

Performance evaluation of PLS-DA calibration model

For the classification of different-sized potatoes, a PLS-DA model was developed using major and minor axes and surface area data obtained by the image processing method. At first PLS-DA model was developed using a calibration sample set, then the model was tested with a validation sample set. Therefore, a total of three PLS-DA models have developed all varieties of potato samples. The result obtained from the multivariate classification model is shown in Figure 4. From the figure, it is observed that small-sized potato is staying below the line of 1.5, the medium potato is staying in the range of (1.5– 2.5), and the large potato is staying above the line of 2.5. Moreover, it is observed that some samples remained outside of the baseline, indicating that they were not correctly classified. Furthermore, the performance of the model is shown in Table 1.

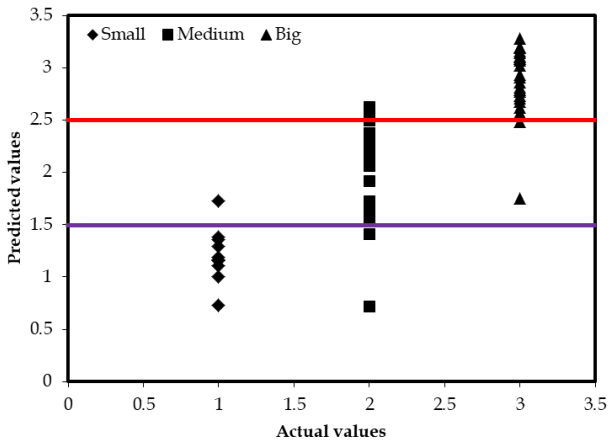


Figure 4. Classification of different sized potato by PLS-DA method

Table 1. Classification of the PLS-DA model for potato samples

Sample	Total potato	Truly classified	False classified	Truly classified (%)	False classified (%)	Accuracy (%)
Small	10	9	1	90	10	86
Medium	22	17	5	77	23	
Large	25	23	2	92	8	

The present study demonstrates the feasibility of grading the three different potato sizes (small, medium, and large). This method was satisfactory for grading the potato samples. However, slight false classification was also observed due to the irregular shape of the potato. The classification accuracy of the PLS-DA model was achieved for both calibration and validation sets for all three sizes of potato. The true classification accuracy

for small, medium and large potatoes was 90%, 77%, and 92%, respectively, whereas the false classification accuracy was 10%, 23%, and 8%, respectively. The overall accuracy was 86% with PLS-DA model.

Conclusion

The results obtained from the research work showed that the machine vision system and the PLS-DA model could measure potato size with an adequate level of reliability and classify the potato. The PLS-DA model can grade the potato into three sizes with an accuracy of 86%. The developed complete machine vision system with appropriate image processing and multivariate classification method can serve as the front-end decision support for the grading process. It can be seen as the first stage of mechanizing the potato grading operation in developing countries such as Bangladesh.

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