Scientific Papers. Series B, Horticulture. Vol. LXIV, No. 1, 2020
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

AUTOMATIC SORTING OF POTATOES ACCORDING TO THEIR DEFECTS

Rodica SOBOLU, Mirela CORDEA*, Ioana POP, Luisa ANDRONIE, Dana PUSTA

University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Mănăştur Street, 400372, Cluj-Napoca, Romania

*Corresponding author email: mcordea@usamvcluj.ro

Abstract

In this work we proposed an automatic sorting algorithm for potatoes based on computer vision techniques. We performed two types of sorting: one depending on the potatoes size and the other one depending on their quality. We proceeded with the segmentation of the defected areas through global thresholding methods. Then, we extracted some morphological and statistical features from the segmented areas. These features were chosen as inputs for classification algorithms. We trained the SVM, Tree and LDA classification learners implemented in MATLAB Classification Toolbox and evaluated their performance. We concluded that the SVM has classified the potatoes according to their size with a higher success rate. In the case of quality sorting, the LDA method is recommended.

Key words: *image processing, grading, potatoes.*

INTRODUCTION

Potato culture is of great importance worldwide, both from a nutritional point of view and as a raw material in food industry. This aspect is supported by the composition of its nutrients which classifies it as a strategic product for the food industry. Due to the large-scale consumption of this product, precise control of it is recommended.

In Romania, the production of autumn potatoes was about 2 million tonnes, as it was recorded in 2019 (agrotrends.ro).

At present, the inspection and analysis of the quality of food products using techniques based on image processing and computer vision has taken a wide development due to the low cost, and also because it is sustainable and efficient. Plenty of scientific work in the field of image processing provides significant results in terms of inspection and quality analysis of fruits, vegetables, cereals or seeds (Feng et al., 2019; Gursoi 2020; Lurstwut et al, 2017). Image processing in agricultural applications comprises three stages: image enhancement, image feature extraction and image feature classification (Mahendran et al., 2011).

At present, it is necessary to replace the manual sorting with the automated one which is characterized by speed, accuracy and easy to use.

Potato sorting is an essential factor in the context of marketing process, helping to establish a fair price and providing quality products. Also, the sorting process for sprouted potatoes is essential because they generate a high level of solanine, becoming toxic. Potato grading is an important step, both in the harvesting stage and also in post-harvesting operations. Potatoes can be sorted according to several criteria: morphological features (size and volume), variety (colour features), quality (healthy potatoes, unsound potatoes, sprouted potatoes or damaged potatoes).

Computer vision is a complex process that applies a number of steps for the automatic inspection of some images. These steps are intended to extract significant data to control a process or a certain activity. Computer vision has been applied for several goals as: shape classification, defect detection, quality classification and variety identification. Size, which represents the first parameter associated with the quality of a product, can be estimated with computer vision technology starting from the measurements like: area, minor axis length, major axis, diameter, perimeter. Machine vision method applied in works based on size

related feature have been developed by many researchers, such as: Yongsheng et al., 2017; Lopez et al., 2018; Geng et al., 2019; Moallem et al., 2013.
The grading procedure implemented in this work, based on computer vision technique, has as input data images of potatoes of different sizes, belonging to two varieties, both damaged and healthy. The result of processing will classify the potatoes according to their size and their quality.
The colour represents also a good quality indicator of fruits and vegetables.
Image texture reveals information about the intensity of the colours and the spatial arrangement of them within an image. Statistical features are considered to analyse an image texture. Skewness indicator provides information about image surfaces. Glossy and darker surfaces appear to be more positively skewed than lighter and matte surfaces. Kurtosis indicator quantifies the sparsity of data. It establishes if a distribution is peaked or flat.
A lot of current studies have approached the advanced technology of digital image processing in order to indicate the degree of damage attack on some crops, such as: potatoes (Geng et al., 2019; Lopez et al., 2018), cucumbers (Wei et al., 2018), roses (Tuba et al., 2017), oranges (Fouda et al., 2013), apples, grapes and mango fruits disease detection (Sandesh et al., 2017), sugarcane (Prajakta et. al, 2016), cotton (Naik et al., 2015).
Diagnosis of healthy and defected potato images based on image processing and computer's vision recognition can be implemented on a large scale, because it requires a reduced amount of time, lower costs and identifies different classes in which potatoes can be integrated, it is fast and accurate compared to visual observation performed by farmers.
This article aims to classify the potatoes into classes delimited by their size or their degree of quality, i.e. potatoes with certain skin defects or potatoes with intact and healthy skin.

MATERIALS AND METHODS

The main purpose of this work is to classify potatoes according to their size and to identify imperfections on the potato surface (mechanical damage potatoes or sprouted potatoes).
The experiments comprise a lot of 206 potatoes, belonging to two varieties: 65 potatoes of yellow skin variety and 141 potatoes of red skin variety. The samples were selected from the experimental fields UASVM Cluj-Napoca. The potato samples were analysed three months after the storage under favourable conditions of temperature and humidity.
The colour images of potatoes are captured using a mobile phone camera. Images are stored in jpg format and were processed with MATLAB 2018b application. The images quality was improved in the preprocessing step, using some routines implemented in MATLAB. Preprocessing means adjusting the quality of the images for accurate processing of them. We opted for a method based on the direct manipulation of the pixels in the image. We chose a 5x5 median filter to eliminate the noise spots. Median filter is a nonlinear filter that replaces the value of the central pixel by the median of the grey values of neighbouring pixels. The pattern of neighbours is called the "window", which slides, pixel by pixel over the entire image. This type of filtering involves arranging pixels values in ascending order, then calculating the median value and finally assigning the median value to the window central pixel.
MATLAB is highly-performant software for technical computing that integrates computation, visualization and programming in an easy-to-use environment. MATLAB stores images as matrices and each element of the matrix represents a pixel of the image.
In MATLAB, a grayscale image is represented by a matrix of the $m \times n$ type, where m is the number of lines (the number of pixels of the image wide) and n is the number of columns (the number of pixels for the image length).

$$I(m,n) = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix},$$

where each element of the image matrix has range values 0 to 255, 0 is the code for black colour and 255 corresponds to white colour. In the concept of image processing, the colour is a powerful descriptor that often facilitates the identification and extraction of objects from a scene.

The RGB images are represented in MATLAB as a three-dimensional matrix *m x n x p*, where *m* and *n* values were defined for the grayscale images and *p* parameter denotes the plane which can be 1 for the red colour, 2 for green colour and 3 for the blue one.

$$I_R(m,n,1) = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix},$$

$$I_G(m,n,2) = \begin{bmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & \ddots & \vdots \\ g_{m1} & \cdots & g_{mn} \end{bmatrix},$$

$$I_B(m,n,3) = \begin{bmatrix} b_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b \end{bmatrix}.$$

If we intend to process a pixel of a colour image it is necessary to assign a value to each plane.

A binary image represents an image in which each pixel can have a value of 0 or a value of 1. A quick method for generating binary images is the threshold technique. It follows the steps: setting a threshold value, assigning a value of 1 to all pixels with a value greater than the threshold and encoding with a value of zero all the pixels having values smaller than the threshold. Regarding the binary images, their structural characteristics can be easily distinguished.

The features are morphological or quantitative descriptors extracted from an image or from an object image. A pattern is a way of arranging descriptors.

In computer vision technology, the determination of morphological features such as: area, perimeter, Minor Axis Length, Major Axis Length is of particular importance.

Potatoes Classification

Creating a predictive model based on a training data set involves the passing through the following stages: collection of individual data records, records description using their attributes, placing attributes in a lot of classes and, finally the assignment of each record to a class.

In this paper we tested the following supervised classifiers: SVMs (Support Vector Machines), Tree and LDA (Linear Discriminant Analysis).

SVMs is a successfully method applied in the data classification process. A classification task usually involves separating data into training and testing sets. Each instance of the training set contains one target value (i.e. the class label) and some attributes (i.e. features). The purpose of this method is to generate a model, starting from the training data which predicts the target values of the test data given only the test data attributes. The SVMs algorithm output is an optimal hyperplane which categorizes new examples. It can be synthesized in this way: given a training set of instance-label pairs $(x_i, y_i), i = 1, \dots, l$ where $x_i \in \mathbb{R}^n$ and $y \in \{1, -1\}^l$, the SVMs algorithm aims to determine the solution of the optimization problem:

$$\min_{w,b,\zeta} \frac{1}{2} w^t w + C \sum_{i=1}^{l} \zeta_i$$

subject to $y_i(w^t \phi(x_i) + b) \geq 1 - \zeta_i,\ \zeta_i \geq 0.$

The training vectors x_i are mapped into higher dimensional space by the function ϕ. SVMs find a linear separating hyperplane with the marginal margins in the higher dimensional space. $C > 0$ is the penalty parameter of the error term and $K(x_i, y_i) \equiv \phi(x_i)^T \phi(x_j)$ is called the kernels function. The following basic kernels can be considered: linear kernels, polynomial kernels, radial basis function, sigmoid kernels, gaussian kernels (Hsu et al., 2011). Gaussian kernel depends on the Euclidean distance between x_i and y_i and is based on the assumption that the similar points are close one to each other in the features space, in terms of Euclidean distance.

A Decision Tree is a predictive method based on a branching series of Boolean tests that uses specific facts to make more generalized conclusions.

This method can be compared to a tree where each node represents a feature (attribute), each link (branch) describes a decision rule and each leaf shows an outcome. The idea of this method is to generate a tree for the entire data and process a single outcome at every leaf. Decision algorithms aim to separate the attributes to be tested at the level of each node and to determine when the separation is best in the individual classes (Patel et al., 2018). There are several variants of this method. In this article we have choose the Fine Tree method.

Linear Discrimination Analysis (LDA) is a supervised technique applied in the pattern classification and machine learning applications. The purpose of this method is to project a data set onto a lower-dimensional space with good class separability in order to remove overfitting and to reduce the computational costs (Li et al., 2005). LDA computes the directions that will represent the axis that maximize the separation between multiple classes.

The classification process was evaluated by K-fold cross-validation, k = 5, implemented in MATLAB environment.

Experiments were conducted on potatoes data set comprising two different classes, depending on the size specific features, such as: area, perimeter, major axis length, minor axis length. The first class includes samples with small dimensions: area less than 12,500 pixels, perimeter less than 400 pixels and the other class contains samples with area larger than 12,500 pixels and perimeter larger than 400 pixels. Samples of this class are considered to be of normal size

The Gaussian SVMs algorithm, Fine Tree algorithm and Linear Discriminant Analysis was trained with a sample of 147 potatoes in order to obtain a classification model. Three different predicted models were generated by these three algorithms.

At this stage, we have prepared the test features data file. It contains 59 samples belonging to the two size categories.

Potatoes included in the test file were pre-sorted by experts starting from quantitative and qualitative factors in order to later verify the accuracy of computer sorting.

The samples data set has been uploaded into MATLAB *Classification Learner Apps,* as input data.

Then, we have performed the classification task on the test data started with the three generated predicted model. The first classification has been made by SVMs algorithm and then Fine Tree and LDA algorithms were applied.

Finally, the accuracy of total sorting was established comparing pre-graded values and Computer Vision Grading. We have quantified the accuracy of classification process as the ratio of correctly recognized sample images to the total number of sample images.

$$Percentage\ accuracy\ (\%) =$$

$$= \frac{correctly\ recognized\ sample\ images}{total\ number\ of\ test\ sample\ images}\ x\ 100.$$

The performance of the proposed algorithms can be quantified using the FAR indicator (False Acceptance Rate) that represents the percentage in which false acceptance occurs.

Defect Classification

We also have applied computer vision technique in order to identify potato defects.

Many of the defects of the potatoes are identified by colours features. These features allow the classification of image pixels into homogeneous regions which are useful in the image segmentation process.

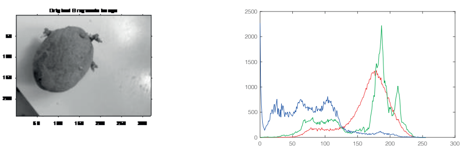
Two different main colour classes are identified: one that corresponds to undamaged potatoes and one that includes potatoes with various defects. These classes are divided into two sub classes according to potato variety: red skin potatoes variety respectively yellow skin potatoes variety. Thus, the sorting process targets to place the samples in four classes: healthy yellow skin potatoes, unhealthy yellow skin potatoes, healthy red skin potatoes and unhealthy red skin potatoes.

The defects of two potato cultivars are identified starting from colour features included into a training set respectively into a test set. The training set comprises 147 samples belonging to four qualitatively different classes. In the test set we included 59 potatoes, also selected from the four quality classes

Feature selection is an essential step in computer vision context. It contributes to reducing the size of the input vector removing features with insignificant information involved in the process of pattern recognition or classification.

Image texture provides information regarding the spatial arrangement of colours within an image. The computer vision technology can identify a wide range of colour spectrum compared to human vision.

The colours feature of the sample images are analysed to separate defected area from the healthy ones. The colour information in RGB space were extracted from the acquired images. We considered the red (R), green (G) and the blue (B) one component of potato images, then we calculated twelve statistical features of these components in RGB space using a routine written in MATLAB. We calculated the next features: Mean(R), Mean(G), Mean(B), Standard Deviation(R), Standard Deviation(G), Standard Deviation(B), Skewness(R), Skewness(G), Skewness(B), Kurtosis(R), Kurtosis(G), Kurtosis(B). Thus, each potato is represented by twelve features analysed in order to determine its quality.
The extracted statistical features are used as inputs for the SVMs, Tree and LDA, supervised classification routines. These algorithms, implemented into *MATLAB Classification Learner Apps*, were trained on features data file to obtain predictive models for classifying potatoes according to their quality.
The obtained models are then checked starting on a test file containing 59 samples. The output file contains a string that represents the index of the class in which each sample was placed.
We have done defect detection by calculating a threshold value to highlight pixels belonging to the affected regions. We have got the threshold value as the local minimum. The histogram shows how many times a certain intensity occurs in an image (Figure 1.b). The histogram was generated in the MATLAB environment using *imhist* function.



a) b)

Figure 1. Grayscale image (a) and image histogram (b)

In order to separate and evaluate the defected area we applied image segmentation by using *Colour Thresholding* tool implemented in *Matlab2018b Apps*. Figure 2 shows the segmentation results applied for the aim to isolate defected areas.

RESULTS AND DISCUSSIONS

In this article, we processed colour images using the *Colour Thresholder* tool implemented into *Image Processing and Computer Vision Apps* of the MATLAB application. This tool contains a collection of algorithms created for the purpose of binary image processing, image segmentation, colour and morphology manipulation or structure recognition.
Image segmentation is a procedure that partitions an image into independent components that are similar according to a set of predefined criteria, in order to identify objects of interest within it. Due to the high degree of variation of the defects, we tested various global threshold techniques on filtered images. Finally, we chose the one that provided optimal damage detection.
The experimental results of the thresholding image segmentation technique applied in the *RGB* space are shown in Figure 2.

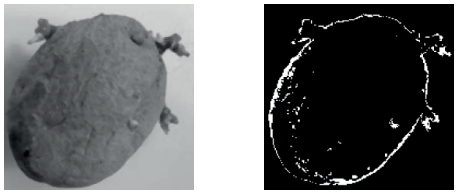


Figure 2. Filtered red skin potato compare to segmentation of defected areas

The statistical features are calculated over the segmented area of each potato tuber.
The next supervised classifiers are tested in this work: SVMs, Tree and LDA.
A comparison between the performance of considered classification methods has been done in terms of accuracy. The Table 1 shows the classification accuracy based on size features and the execution time corresponding to each chosen algorithm.

Table 1. Accuracy of classification process according to size and execution time

	SVMs	Fine Tree	Linear Discriminant
Overall Classification Rate	92%	90%	86%
Execution Time (seconds)	1.86	1.80	0.80

Analyzing the accuracy of the classification results obtained after the application of algorithms dedicated to grading process, we highlight the fact that the SVM algorithm is recommended in the classification according to size. From the point of view of the working speed, the LDA algorithm is distinguished. The FAR indicator for SVMs algorithm is 8.47%.
In order to choose the best algorithm, indicated for quality assessment, we evaluated the accuracy of each implemented method. The results, expressed as accuracy rate are displayed in Table 2. It also contains the time required for the classification process.

Table 2. Accuracy of classification process according to quality and execution time

	SVMs	Fine Tree	Linear Discriminant
Overall Classification Rate	46%	41%	72%
Execution Time (seconds)	1.84	0.97	0.78

The evaluation of the classification according to quality shows that the LDA method is more efficient compared to SVMs and Fine Tree. We conclude that the LDA method provides better detection performances with lowest execution time.
The accuracy of the classification starting from the quality indicator can be improved by cumulating other texture features in the input data file. For example we can choose the features like uniformity, entropy and smoothness.
Overall, in terms of processing time, the LDA algorithm is distinguished by speed. We also remark that the Fine Tree method is faster than the SVM method.
If we aim to simultaneously classify a potato sample both according to the size and from a qualitative point of view, we can combine the morphological features with the statistical ones. Thus, we will integrate the input data into eight distinct classes. The sample data considered into the test file will also be distributed in eight different classes.
Choosing as many attributes as possible, of different types, can considerably improve the quality of the potato tuber classification algorithm. In Europe, agricultural products must respect UNECE (United Nations Economic Commission for Europe) standards in order to be marketed in stores. The standards are set according to precise criteria: quality, color, size, shape, these contributing to the pricing of products. So it is necessary to verify these standards on a large scale in order to sell potatoes.
In conclusion, this type of approach applied to grading potato tubers has provided useful results to develop an automatic system to monitor the quality of potatoes. Computer vision and image processing techniques have been extended on a large scale in the context of artificial intelligence, being able to capture, quickly and precisely, complex features. These features allow a sufficiently accurate, non-destructive evaluation of products, which tends to replace manual checking (inspection) trained by farmers/humans.

CONCLUSIONS

The external quality of agricultural products is a main attribute that contributes to the classification process. It can be quantified in colour, size, shape, texture, visual defects, features that can be extracted directly from images and automatically monitored with computer vision technique.
Therefore, the images taken from the potato tubers provide useful information in identifying their quality. The algorithms applied in the classification process can be basic elements that, integrated in automatic classification systems can bring benefits in the potato industry. Automatic systems significantly reduce the large volume of work done on farms, require a short time, are sufficiently accurate and eliminate the human error involved in the classification process.

ACKNOWLEDGEMENTS

This research work is funded by the Ministry of Research and Innovation of Romania, Projects for Financing the Excellence in CDI, Contract no. 37PFE/06.11.2018.

REFERENCES

Ebrahimi, E., Mollazade, K., Arefi, A. (2012). An Expert System for Classification of Potato Tubers using Image Processing and Artificial Neural Networks, *International Journal of Food Engineering*, 8(4), Article 9, DOI: 10.1515/1556-3758.2656.

Feng, J., Zeng, L., He, L. (2019). Apple Fruit Recognition Algorithm Based on Multi-Spectral Dynamic Image Analysis, *Sensors*, 19(949), doi:10.3390/s19040949.

Fouda T., Derbala A., Elmetwalli E., Salah, S. (2013). Detection of orange color using imaging analysis. *AgroLife Scientific Journal*, 2, 181-184.

Geng, J., Xiao, L., Gao, Y., Rao, X. (2019). Separating clods and stones from potato tubers based on color and shape. *Journal of Food Measurement and Characterization*, 13, 287-295.

Gonzalez, R.C., Woods, R.E., Eddins, S.L. (2009). Digital Image Processing Using MATLAB, Gatesmark Publishing.

Gursoi, S. (2010). Determination of Lentil Seed Size and Shape Properties by Using Image Analysis Techniques, Turkish Journal of Agriculture, 96-100, ISSN: 2148-127X.

Hsu, C.W., Chang, C.C., Lin, C.J. (2011). A Practical Guide to Support Vector Classification.

Li, M. (2005). 2D - LDA: A statistical linear discriminat analysis for image matrix, *Pattern Recognition Letters*, 26(5), 527-532.

Lopez-Juarez, I., Rios-Cabrera, R., Hsieh, S., Howarth, M. (2018). A hybrid non-invasive method for internal/external quality assessment of potatoes. *Eur Food Res Technol*, 244, 161-174.

Lurstwut, B., Pornpanomchai, C. (2017). Image analysis based on color, shape and texture for rice seed (*Oryza sativa* L.) germination evaluation, *Agriculture and natural Resources*, 51(5), 383-389.

Mahendran, R., Jayashree, G.C., Alagusundaram, K. (2011). Application of Computer Vision Technique on Sorting and Grading of Fruits and Vegetables, *J. Food Process Technol* S1-001. doi:10.4172/2157-7110.S1-001.

Moallem, P., Razmjooy, N., & Ashourian, M. (2013). Computer vision-based potato defect detection using neural networks and support vector machine. *International Journal of Robotics and Automation*, 28(2), 137-145.

Si, Y.S., Sankaran, S., Knowles, N.R., Pavek, M.J. (2018). Image-based automated potato tuber shape evaluation. *Journal of Food Measurement and Characterization*, 12, 702-709.

Su, Q.H., Kondo, N., Li, M.Z., Sun, H., Al Riza, D.F., Habaragamuwa, H. (2018). Potato quality grading based on machine vision and 3D shape analysis. *Computers and Electronics in Agriculture*, 152, 261-268.

Naik, D.M., Vyavahare, A.J., (2015), Disease Detection of Cotton crop using Image Processing Technique: A Survey, *IJRASET*, 3(6), 204-210.

Patel, H.H., Prajapati, P., (2018), Study and Analysis of Decision Tree Based Classification Algorithms, *JCSE*, 6(10), 74-78.

Prajakta, M., Priyanka, P., Mira, N., Priyanka, B., Mira, P., Priti, N. (2016). Leaf Disease Detection and Prevention Using Image Processing in Matlab, *IJRTER*, 2(2), 26-30.

Sandesh, R., Amit, F. (2017). Plant Disease Detection in Image Processing Using MATLAB, *IJIRSET*, 6(6), 10373-10381.

Wei, Y., Chang, R., Wang, Y., Liu, H., Du, Y. (2012). A Study of Image Processing on Cucumber Disease, *Springer, IFIP Advances in Information and Communication Technology*, AICT-370, 201-209.

*** https://www.mathworks.com