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Design, development and evaluation of an online grading system for peeled pistachios equipped with machine vision technology and support vector machine

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ABSTRACT

In this study, an intelligent system based on combined machine vision (MV) and Support Vector Machine (SVM) was developed for sorting of peeled pistachio kernels and shells. The system was composed of conveyor belt, lighting box, camera, processing unit and sorting unit. A color CCD camera was used to capture images. The images were digitalized by a capture card and transferred to a personal computer for further analysis. Initially, images were converted from RGB color space to HSV color ones. For segmentation of the acquired images, H-component in the HSV color space and Otsu thresholding method were applied. A feature vector containing 30 color features was extracted from the captured images. A feature selection method based on sensitivity analysis was carried out to select superior features. The selected features were presented to SVM classifier. Various SVM models having a different kernel function were developed and tested. The SVM model having cubic polynomial kernel function and 38 support vectors achieved the best accuracy (99.17%) and then was selected to use in online decision-making unit of the system. By launching the online system, it was found that limiting factors of the system capacity were related to the hardware parts of the system (conveyor belt and pneumatic valves used in the sorting unit). The limiting factors led to a distance of 8 mm between the samples. The overall accuracy and capacity of the sorter were obtained 94.33% and 22.74 kg/h, respectively.

1. Introduction

Pistachio nut is the top non- petroleum export of Iran that accounted up to 60% of global pistachio market. It has an important role in Iran's exports and economy as a non- petroleum good [1]. Due to drawbacks of manual grading such as subjectivity, tediousness, labor requirements, availability, cost and inconsistency, an automated grading system needs to be developed. Recently, several researchers have conducted their efforts on developing the grading system. The methods extend from manual-machine grading, where the features are determined manually, under laboratory conditions to

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machine vision systems for automated high-speed fruit sorting [2]. It is clear that mechanized grading of pistachio nut reveals many advantages including elimination of wages behalf of manual grading, more uniformity and more hygienic product compared to manual methods. Therefore, design of full-automatic sorting machines can attract more customers and supports to Iran's position in export of this worthwhile produce. Among many available methods for quality evaluation of the crops, machine vision (MV) systems have proven to be the most powerful [3,4]. A MV system consists of two main parts: hardware and software parts. These systems like the human eye are strongly influenced by lighting system. This part has a significant effect on the quality and resolution of the captured images and also considerably affects overall performance and efficiency of the MV system [5,6].

Computer-generated artificial classifiers that are intended to mimic human decision making for product quality have recently been studied, intensively [7]. Omid et al. [8] designed and evaluated an intelligent sorting system for open and closed-shell pistachio nuts. The system included a feeder, an acoustical part, an electronic control unit, a pneumatic air-rejection mechanism and ANN classifier. The recognition was based on combined PCA of impact acoustics and ANN classifier. To generate useful features, both time and frequency-domain analysis of recorded sound signals were performed. In a recent study, a new method based on MV system was developed for egg volume prediction [9]. Two methods of egg size modeling (i) a mathematical model based on Pappus theorem, and (ii) an ANN model were developed and validated. Mollazade et al. [10] applied MV and various artificial classifiers for grading raisins into four classes. To provide uniform lighting and to eliminate the environmental noises, they used two fluorescent tube lightings above the samples and put a black cover on the imaging set. There is no doubt that purity of the agricultural products from unwanted materials is one of the requirements and it is an important task at post-harvesting industries of most crops [5]. A full-automatic system has been developed to remove the unwanted materials from pomegranate seeds and classify the seeds into four classes [11]. Another research proposed an algorithm based on image processing for grading chestnuts. The algorithm was successfully applied on the online sorting systems [12]. Mustafa et al. [2] developed a sorting and grading system based on image processing and Support Vector Machine (SVM). The developed system captured fruit's image using a regular digital camera. Then, the image was transmitted to the processing level where feature extraction, classification and grading was done using MATLAB. The fruit was classified using SVM. ElMasry et al. [13] developed a fast and accurate computer-based machine vision system for detecting irregular potatoes in real-time. Supported algorithms were specifically developed and programmed for image acquisition and processing, controlling the whole process, saving the classification results and monitoring the progress of all operations. The experiments showed that the success of in-line classification of moving potatoes was 96.2%. Kaur and Singh [14] developed machine vision system to grade the rice kernels using Multi-Class SVM. Multi-Class SVM classified the rice kernel by examining the shape, chalkiness and percentage of broken kernels. They concluded that the system was enough to use for classifying and grading the different varieties of rice grains based on their interior and exterior quality. Teimouri et al. [15] combined artificial neural network with machine vision to identify five classes of almond according to visual features. The images of five classes of almond including normal almond, broken almond, double almond, wrinkled almond and shell of almond were acquired, segmented by Otsu's thresholding method and classified by ANN. Olgun et al. [16] developed wheat grain classification system by machine vision and SVM classifier.

According to performed studies on production and processing steps of pistachio kernels (PK), after cracking of close pistachios some cracked pistachio shells (PS) remain. The purpose of this study was to develop an automated system for sorting of PKs from unwanted PSs by using MV technique and SVM classifier.

2. Material and methods

Fig. 1 shows a schematic of the developed automated system for sorting PKs from the PSs. The MATLAB software (version R2012a) [17] was used to integrate all algorithms.

2.1. System components

The sorter consists of five main parts including a conveyor belt, images acquisition unit, pneumatic components, electronic unit and a personal computer. The conveyor was used to transfer pistachios into the range of view of the camera. Samples were carried by a PVC infinite conveyor belt with size of 25×180 cm and thickness of 1 mm. The conveyor was driven by an AC one phase electric motor with power of 60 W. In order to control the conveyor speed, a gearbox with ratio of 50 was used which reduced the speed of the motor to about 25 rpm of driver roller of the conveyor. To capture images without any noise and having a uniform light, a lighting chamber made of fabric was used. Two fluorescent tube lamps and a CCD color video camera were installed inside the lighting box. The lamps were installed about 25 cm above the conveyor belt to capture uniform images without shadow. Illuminating tubes were used together with high frequency electronic ballast to avoid the flicker effect. ElMasry et al. [13] also used a cubic chamber for imaging system in sorting potatoes. In that system, fluorescent tube lamps were used as lighting unit. The used camera (Proline, Model 565S, UK) was equipped with a CS lens mount (3.5–8 mm focal length, 480 vertical TV lines resolution). The acquired images were digitalized by a capture card and were transferred to a personal computer for further analysis. Pneumatic method was used to sort and separate the samples. The main components of the pneumatic unit were a laboratory air compressor with a cylindrical container of 15 liter and working pressure of 7 bar, hoses and 7 solenoid-pneumatic valves, 24Vdc. The pneumatic valves were installed under the tail end of the conveyor (Fig. 1). An electronic device was designed and fabricated as an interface between the computer and the pneumatic system. The ATMEGA16 microcontroller was the main component of the electronic system.

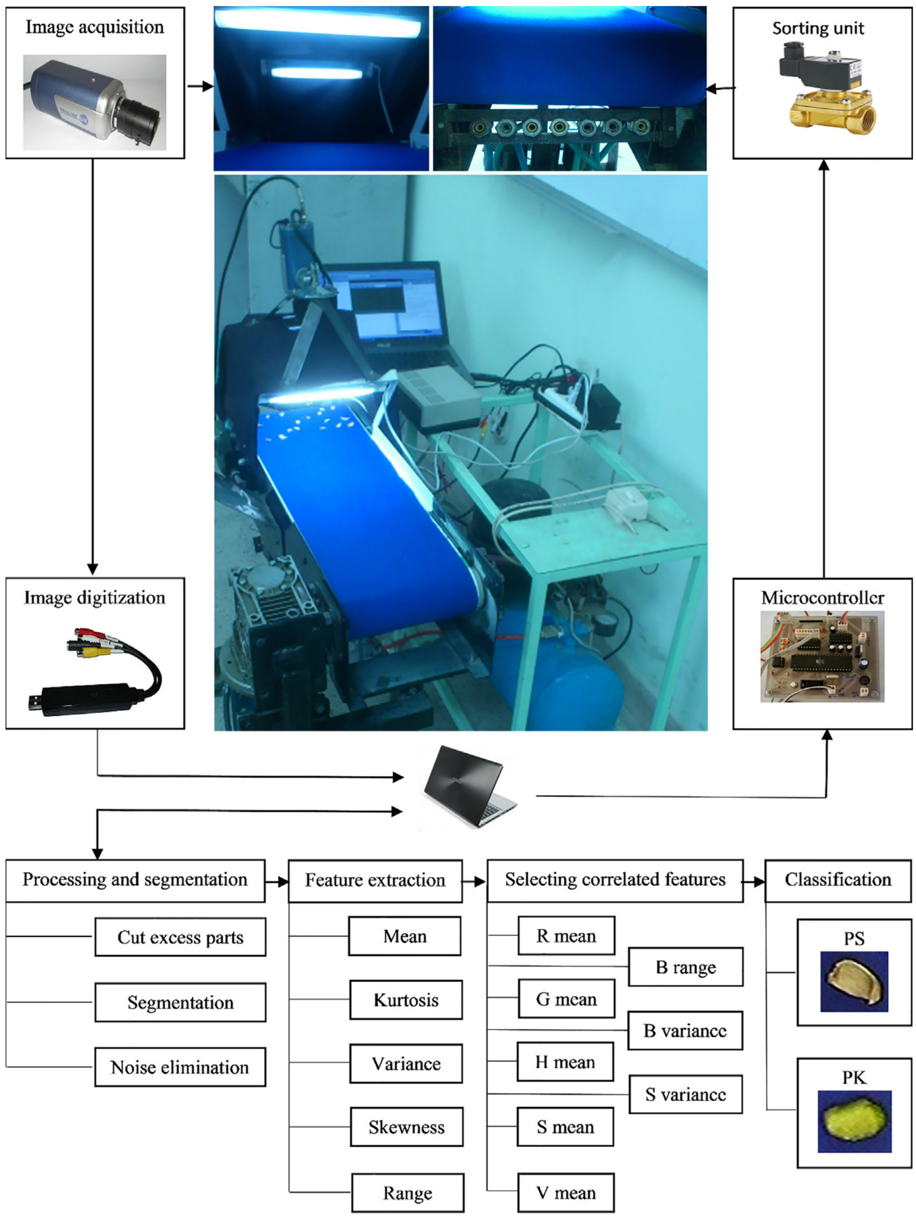

Fig. 1 – The framework of the system for separating pistachio kernels and shells.

2.2. *Image segmentation*

Segmentation is the primary stage of image processing tasks. Segmentation strongly affects accuracy of image processing that so should be carefully implemented. Thresholding is an essential and important method for image segmentation [18]. One of the widely used methods thresholding is Otsu's technique [19]. In this research we also used Otsu method to separate the pistachio kernel from background. Primary tests indicated that the best color component for segmentation purpose was H-component of the images in HSV color space that successfully separated objects from background. However, if this component was directly used for the segmentation, some parts of the samples (see Fig. 2(b)) were also considered as background. So it was necessary to perform histogram processing. Accordingly, as shown in Fig. 3, pixels values above 0.85 were replaced with zero. After that, the H-component was suitable for the segmentation. In Preliminary tests, we found that after segmentation, objects with less than 400 pixels in the segmented images were noises. Therefore, these objects were eliminated.

2.3. *Feature extraction*

Color, texture, size and shape are the most important visual features of an object in the image. [18]. As shown in Fig. 2 (a), there is a suitable contrast between the two classes, PK and PS, in terms of color. Logically, it is better to use only superior features for classification in the online systems to decrease processing time and speed up the system. The advantage of color space is clear distinction that is set in the relevant parameters of color between classes. This clear distinction can play a vital role in pistachio sorting, accurately. To verify the differences between PKs and PSs in differ-

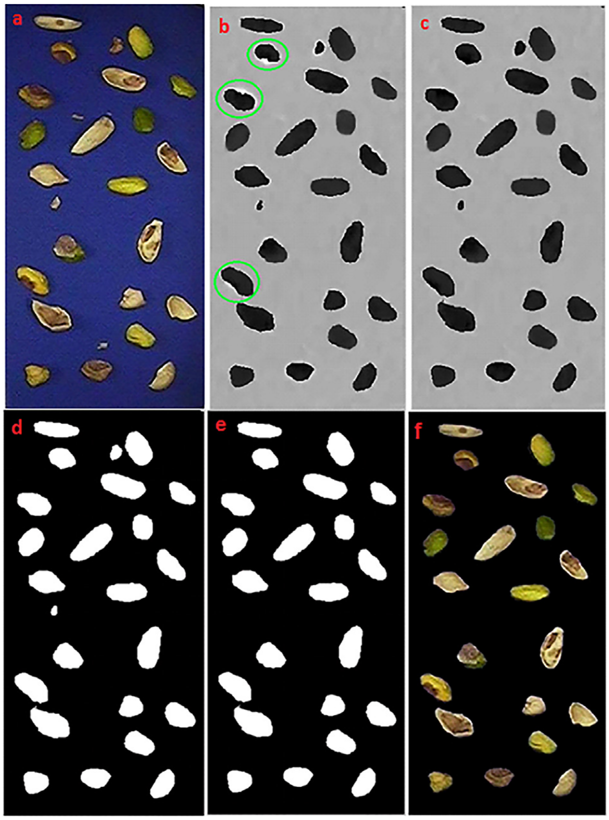

Fig. 2 – Segmentation steps. (a) The RGB image, (b) The H-component of the HSV color space (problematic samples marked with a green circle), (c) The improved H-component (pixels values which are above 0.85 were replaced by zero), (d) The binary image with noise, (e) The final binary image, and (f) The image obtained by multiplication of binary image and RGB image.

ent color spaces, various color descriptors were applied. So, color as one of the most important indicators was used to create the feature vector. Indicators usually are used to extract the color features are mean, variance, skewness, kurtosis and range [15,18,20] that the formula of the mentioned features are presented in Table 1. For this purpose, the five indices for each sample in the images were extracted from the components of RGB and HSV color spaces. Accordingly, a total of 30 features were obtained for each sample. To improve the performance and speed of the sorter, it was necessary to choose the features that were more effective in determining the correct output. The best feature selection would speed up the system decision making task which results an increased performance of the sorter. A good feature has the property that it is similar among the same class of objects and dissimilar among different classes of objects [21]. Different feature selection techniques and classification methods have been developed and introduced by researchers who work in the field of artificial intelligence. Some of feature selection methods are Forward Feature Selection, Backward Feature Selection, PCA, Genetic Algorithm, etc. [22]. Also different classifiers have been invented including Support Vector Machine (SVM), Neural Network, Decision Tree, Random Forest and Bayesian Network, etc. In this paper, SVM was chosen for shape sorting based on the results obtained by Mustafa et al. [2] and Cristianini and Taylor [23] and their recommendation to use this technique as a applicable method for grading and sorting of agricultural produces.

The Sensitivity Analysis (SA) is one of the popular methods for feature selection [15,24,25]. SA is studying impact of input variables (independent variables) to output variables (dependent variables) of a statistical model and how much changes in those variables will change the independent variable. To perform SA, at the first step, the dependent variable should be identified as well as many of the independent variables that might impact the dependent variable. By using SA technique, 8 superior features with the highest impact were selected among 30 extracted features as the input vector of the classifier system.

2.4. Classification with support vector machines (SVMs)

The SVM is a supervised learning method that is widely used for classification. Although initially designed for binary classification, the basic SVM approach can be extended for the multi-class classification task [26].

A detailed mathematical explanation of SVM can be found in Vapnik's paper [27,28]. Here, only some of the main features are presented. A SVM performs classification by mapping input vectors into a higher-dimensional space and constructing a hyper-plane that optimally separates the data in the higher-dimensional space. Given a training set of instance-label pairs (x_i, y_i), in the classification type of SVM, the training involves the following optimization problem [27,28]:

$$Min_{\omega,b,\xi}\frac{1}{2}\omega^T\omega + C\sum_{i=1}^{n}\xi_i \tag{1}$$

Subject to:

$$y_i(\omega^T\varphi(x_i) + b) \geqslant 1 - \xi_i \text{ and } \xi_i \geqslant 0,\ i = 1, \ldots, n \tag{2}$$

where $x_i = (x_1, x_2, \ldots, x_n)$, and $y_i = 1$ if x_i is in class 1, and $y_i = -1$ if x_i is in class 2. $C > 0$ is the penalty parameter of the error term., ω is the vector of coefficients, b is a constant and ξ_i is a parameter for handling non-separable data (inputs). In Eq. (2), x_i is mapped to a higher dimensional space by the function $K(x_i, x_j) = \phi(x_i)^T\phi(x_j)$ is called the kernel function [27]. The kernel is a function that simulates the projection of the initial data in a feature space with higher dimension Φ: $Kn \rightarrow H$ [29] (see Fig. 4).

In the new space the data are considered as linearly separable. There are several different kernel functions used in constructing SVM models. In this study, various kernel function such as linear, polynomial, and radial basis function (RBF) kernels were examined.

The following steps were implemented for selecting the most optimum SVM model:

(1) Dividing data: 240 samples for training and validation and 120 samples for testing.

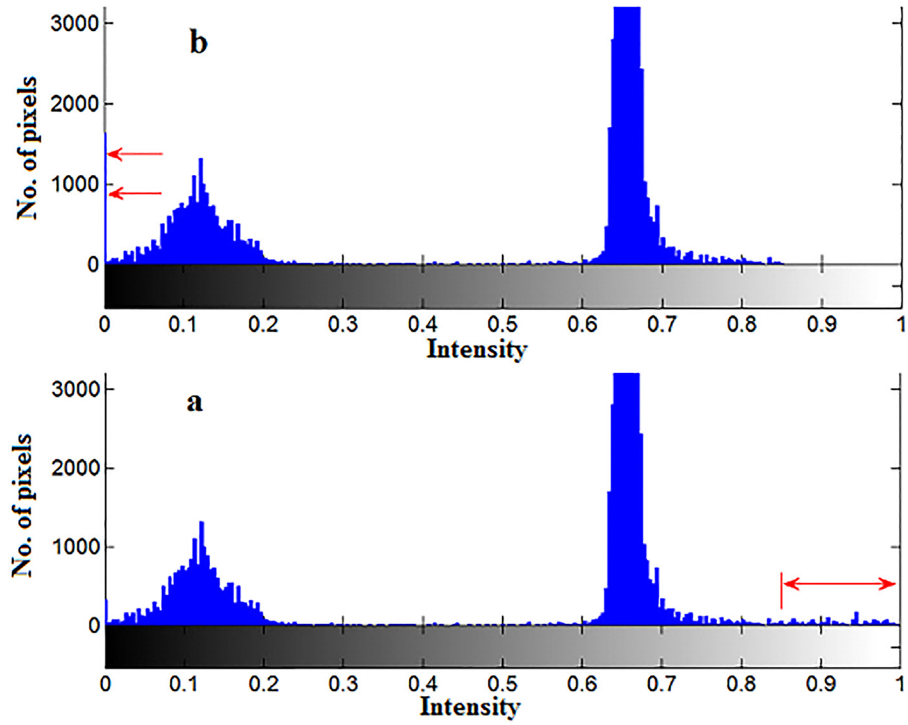

Fig. 3 – (a) Histogram of H-component of HSV color space, (b) improved histogram (pixels values which are above 0.85 were replaced with zero).

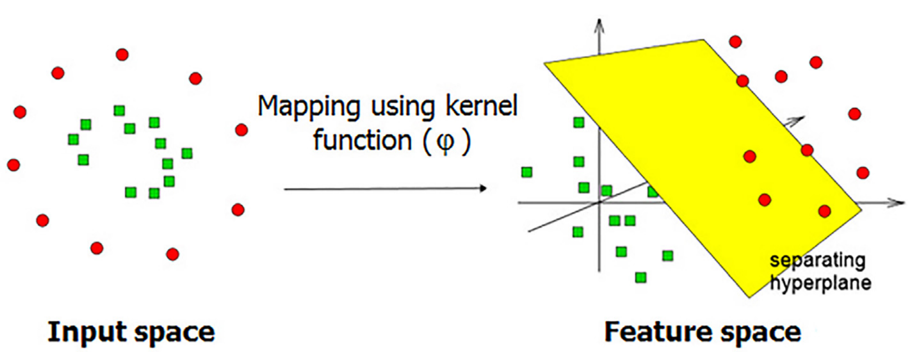

Fig. 4 – Principle of Support Vector Machine (SVM).

Table 1 – The used statistical indexes for features extraction.

Feature	Formula[a]
Mean	$\frac{1}{n}\sum_{i=1}^{n} x_i$
Variance	$\frac{1}{n}\sum_{i=1}^{n} (x_i - \mu)$
Skewness	$\frac{\frac{1}{n}\sum_{i=1}^{n} (x_i-\mu)^3}{(\sqrt{Var})^3}$
Range	$\max(x_i) - \min(x_i) i = 1:n$
Kurtosis	$\frac{\frac{1}{n}\sum_{i=1}^{n} (x_i-\mu)^4}{(\sqrt{Var})^4}$

[a] In this table, n, x, μ are the number of sample pixels in the image, the value of the pixels and mean, respectively.

(2) Designing and developing various SVM models with different kernel functions (linear, quadratic, polynomial, and radial basis).
(3) Selecting the best model based on the highest accuracy (AC) at the testing stage and the minimum number of support vectors, since by selecting SVM with minimum number of support vectors, the processing speed would be increased and makes the algorithm more appropriate to use in the online system.

2.5. Online performance evaluation

After pistachios were transferred by the conveyor and located under the camera lens in the light chamber, the images were captured. Next, instead of processing the entire image, only a narrow strip was selected and processed. This strip was selected where the product was fell from the conveyor (camera was exactly placed above the edge of belt near the seven valves, so each strip was contains the seven samples). In this way, the possibility of error for the online system is minimized compared to status that the chamber is installed in the middle of conveyor or processing of the whole the image. After classifying the samples by SVM and identifying shells, their centroid were obtained to locate each PS on the conveyor. The center of gravity of shells were needed to be used for automatic sorting and rejection. By using the data, each pneumatic valve timely operated and thus undesired materials (PS) were rejected by sending a command signal by PC to open the related valve through the microcontroller. The sorting unit is a pneumatic type, consisting of an electronic circuitry, an air compressor and 7 valves which separate undesired materials from PKs by injecting compressed air.

2.6. Performance analysis

To examine performance of the online system, two statistical indices including correct classification rate (CCR) and accuracy (AC) were used [10,16]:

$$AC = \frac{TP + TN}{TP + TN + FP + FN} \tag{3}$$

$$CCR = \frac{N_{Right}}{N_C} \tag{4}$$

where TP, TN, FP and FN are the numbers of true positives, true negatives, false positives and false negatives, respectively. For example, for PK class, TP is the number of samples in PK class when they actually are PK class, and TN is the number of samples in PS class when they are actually related to this class. Similarly, FP is the number of samples in PS class when they are actually related to PK class, and FN is the number of samples in PS class when they are actually related to PK class. In Eq. (4), N_{Right} and N_C refer to the number of samples correctly classified and total number of samples in that class, respectively.

3. Results and discussion

Fig. 5 shows results of SA on the 30 color features. 8 features that had the highest effect on identifying the output classes were selected for further analysis. The selected features were highlighted (bold) in Fig. 5.

Different models of SVM were developed, the best results for each model are presented in Table 2. The best kernel function was found to be the polynomial with order of 3 and 38 support vectors.

The confusion matrix for cubic polynomial kernel function and the values for AC and CCR of classes are presented in Table 3. The excellent results were obtained for offline classification, i.e., the accuracy for training and validation data set and testing data set were 99.58% and 99.17%, respectively. Therefore, this kernel function was identified to be appropriate to use for the online system.

3.1. Online sorting and performance evaluation

The software system performs processing of 28 images per second (196 samples per second) and computes gravity center coordinates of the inappropriate samples. To pass the sam-

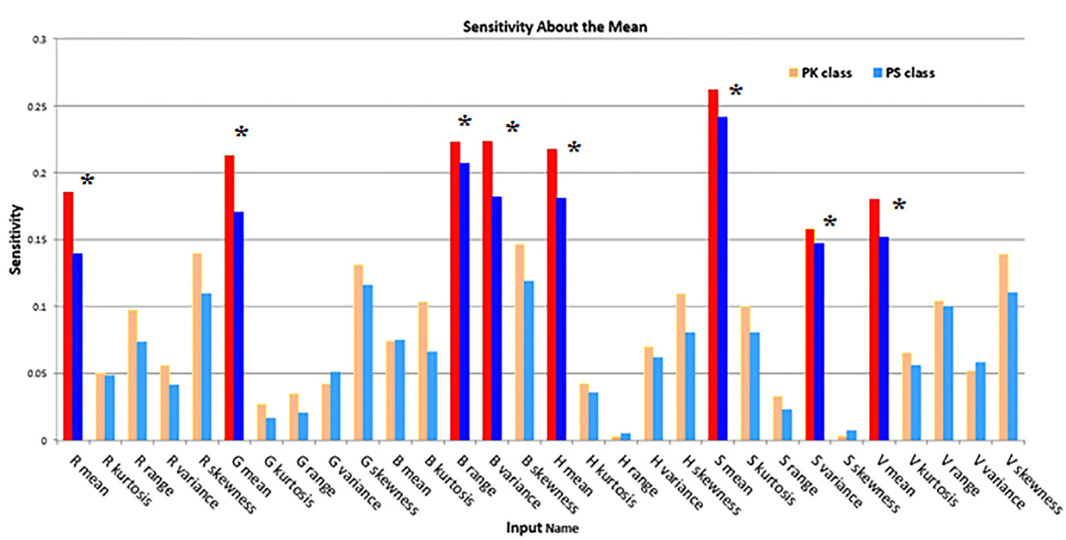

Fig. 5 – The eight superior features selected by sensitivity analysis (marked by *).

Table 2 – Results of pistachio classification by SVMs using different kernel functions.

Kernel function	SVs	AC (%)
Linear	47	95.83
Polynomial (degree = 2)	39	96.67
Polynomial (degree = 3)	38	99.17
Radial basis (Sigma = 0.4)	210	96.67

Accuracy (AC) are obtained from the confusion matrix during testing phase, and SVs are the number of support vectors.

Table 3 – The confusion matrix obtained from the SVMs with the linear kernel function and performance evaluation by Accuracy and CCR.

Desired				
	Training and validation		Testing	
Predicted	PK	PS	PK	PS
PK	**120**	1	**59**	0
PS	0	**119**	1	**60**
CCR (%)	100	99.17	98.33	100
Accuracy (%)	99.58		99.17	

Table 4 – The confusion matrix obtained from the online system evaluation.

	Desired	
Sorted	PK	PS
PK	108	13
PS	4	175
CCR (%)	96.43	93.09
Accuracy (%)	94.33%	

ples in front of the camera, it was required to have a high speed conveyor. But, increasing speed of the conveyor belt led to vibration and even displacement of the samples on the conveyor. Also the pneumatic valves made further limitation due to their response time and therefore we had to increase the distance between produces on the conveyor, for following reasons:

(1) Needing to sufficient time to create effective magnetic field in the solenoids for mechanical parts triggering of the pneumatic valves.
(2) Inertia of the mechanical components in the valves and their friction that prevents immediate reaction of the valves.
(3) The inertia of the compressed air in the valves, the distance between the valves and the falling location of the product which prevented timely reaching of the compressed air flow.

Due to the aforementioned drawbacks, we found the limiting factors that affected the system's performance were related to the system hardware parts (conveyor and valves). In development of a machine for the automatic sorting of pomegranate seeds based on computer vision, Blasco et al. [11] confronted to a similar limitation. To find appropriate distance between the products and the time required for the valves to stay open, we performed trials and errors. In this study, the optimal distance between the products was found 8 mm, the time necessary for valves to stay open was found 75 ms and the conveyor speed was fixed on 88 mm/s.

Table 4 shows the results of the online system evaluation for 112 samples of PK and 188 samples of PS (number of total samples = 300). The accuracy of both classes is equal because we only have two classes. By comparing the results with offline mode, we found that the accuracy was reduced, due to the following reasons:

(1) If sampling time is too short, valves may seize correct alignment with samples to be rejected.
(2) If for any reason distance between samples is less than 8 mm or samples are in contact with together, there is a possibility of misclassification between them.

The capacity of the developed sorter was obtained 22.74 kg/h. This was achieved under the following conditions: conveyor speed = 88 mm/s, distance between the samples = 8 mm, average length of samples = 7 mm, product weight = 650 samples per 100 g and number of valves = 7.

The obtained results are in agreement with results of other researchers. Teimouri et al. reported that the developed system for grading of almond nuts into five classes had the accuracy value of 97.84%. They used SA and PCA techniques to reduce dimension of the feature vector [15]. Ghezelbash et al. developed an intelligent system for pistachio sorting using computer vision. The system used a combination of two flat mirrors and a camera to detect closed-shell nuts. They reported 92.7 and 86.7% average removal accuracy, respectively for open and closed shell pistachio nuts [30]. The developed system by Olgun et al. [16] had accuracy rate of 88.33% for wheat grain classification based on MV and SVM.

4. Conclusion

This work described an engineering solution for automatic sorting of the pistachio kernels from the unwanted shells. Superior features were extracted by means of SA method. Results of offline classification showed that SVM classifier with the cubic polynomial kernel function was accurate and efficient to be used for the online system. It was found that the capacity of the sorter was limited by the hardware parts of the system. This was mainly due to the distance between samples on the conveyor belt to reach 8 mm apart and pneumatic valves response time. The sorter has the capacity of 22.74 kg/h with the accuracy of 94.33%.

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