A Survey on Fresh Produce Grading Algorithms Using Machine Learning And Image Processing Techniques

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Abstract. Agriculture has been the backbone of the Indian economy. Automation in the agriculture field helps to improve productivity and economic growth. The export market for fresh produce requires fast and reliable fruit and vegetable quality detection techniques. The traditional manual system of quality assessment is a time consuming and tedious task which is more prone to error. The goal of supply-chain management is to add product value by maintaining quality, reduce wastage of fresh produce, retain consumers by keeping customer satisfaction, and increase the profitability. Researches are going on in various domain to develop a fast and reliable automated fruit quality grading system which helps to meet the food value goals of supply-chain. This paper focuses on a detailed survey of the researches being carried out on various techniques used in post-harvest grading of fresh produces using computer vision, image processing and machine learning techniques. Few papers have been reviewed and discussed here pertaining to the above techniques. The advantages and shortcomings of various methods are also mentioned. This comprehensive paper will give researchers a deeper insight to the state of the art technologies in fresh produce grading system.

1. Introduction
In the modern world, people are more health-conscious and in a way try to eat healthy and fresh and are pretty much concerned to include all the nutritional food in their diet. Fruits and vegetables are the primary sources of dietary nutrients. Unfortunately, nowadays fruits and vegetables available in markets are not at its peak freshness as it is at the time of harvest. This may lead to the loss of nutritional values of fresh produces. According to the Food and Agricultural Organization (FAO) of the United Nations, every year around 1.7 billion tonnes, or almost one-third of food produced for human consumption are lost or wasted globally. Among them, fruits and vegetables are the ones that are being wasted on a large scale at all stages namely post-harvest and processing levels as well as the retail and consumer levels. The wastage at the retail level is mainly due to the quality standards of the
produces that over reflects on its appearance. The wastage and losses that happen at the early stages of the food chain are mainly due to the inefficiency and lack of financial and technical methodologies applied in harvest, storage, and cooling mechanisms. In medium and high-income countries fresh produce is wasted and lost at the later stages in the supply chain. Adopting and implementing the appropriate strategies can help in the reduction of food wastage globally at production, retail, and consumer level. A huge reduction in the amount of fresh produce wastage can be attained in the farming industry by mechanizing and automating each stage from harvest to the food storage, packaging and shipping. To ensure the best quality, freshness, and sensory characteristics of produces before being sold to the end-users, it should be sorted into various grades. Since price depends on quality, products can be sold for reasonably good prices by attaining customer satisfaction. Also, the consumption of microbially contaminated fruits may cause a severe threat to human life. Therefore, this vital issue strongly demands the need for the integration of innovative and feasible technological solutions to ensure the mechanism for best quality fruit detection system. The conventional method for grading fruits based on its visual appearance and freshness is done manually which is an inconsistent, fickle, time-consuming, and subjective task. It is more prone to errors as different inspectors give a different opinion on the same batch of produces which also depends on the surroundings and lighting. This leads to a great demand for automation of the fruit grading techniques. Much researches are being carried out using computer vision and image processing techniques in fruit grading based on its external appearances. Machine learning techniques are also a major domain where researches are being done on various fruits. This paper focuses on a survey of various automation techniques in fruit sorting using computer vision, image processing, and machine learning techniques. Using these technologies, digital images and videos are being studied and analysed using computers for the various features of fruits and the algorithms can decide on whether the produces are good or rotten. The effect of human vision is duplicated electronically by perceiving, understanding, and classifying images acquired from the real world. We have reviewed and briefed a few papers which explain the techniques used in the sorting of fresh produces based on their features analysed and the shortcomings of a few of the methods have also been discussed.

2. Review On the Previous Methods Employed in Fresh Produce Grading Using Machine Vision and Machine Learning Techniques

2.1. Mechanized Quality Evaluation system for Tomatoes using Computer Vision

Megha P Arakeri and Lakshmana had proposed an automated system for tomato quality evaluation with the aid of computer vision and image processing algorithm [1]. Both software and hardware systems were involved. The hardware part consisted of cameras, conveyor belts, lights, 8051 microcontrollers, DC gear motor, LM293 D motor driver, UART bridge, computer, and bins for segregating tomatoes based on its quality. The images after the acquisition were inputted to an image processing system, which analysed the tomato pictures to determine if they were defective or not and also to determine its ripeness. The dataset contained a collection of as many as 520 pictures of a variety of tomatoes piled from agricultural science universities, Bangalore, and other gardens. The computer vision-based image processing system consisted of a DC gear motor attached to the conveyor belt so that the tomatoes which were laid on the belt could be moved and stopped at the position of the fixed camera to acquire the images which are then transferred to the processor via the serial port. Further analysis of the acquired image is done by the image processing module which is the software part. Once the classification is completed using image processing techniques, the tomatoes were segregated to their respective bins.

In the pre-processing step, the image was filtered using a nonlinear filter to suppress the reflections and noise that appeared during the acquisition of the image. The tomato regions were segmented from its background by using Otsu’s method. If the defects on the tomatoes had similar intensity values as that of the background it appeared to look like holes. The hole that appears due to the defect on the tomatoes was filled with pixel value 1 to get the complete region of tomatoes. The next step which was feature extraction and selection, the color statistical features like color mean, standard deviation
and skewness, and color texture features like contrast, correlation, energy, and homogeneity for individual R, G, B channels were extracted. As the color feature is more likely used to determine the ripeness, color mean was calculated for each channel. This value was compared with the experimentally determined threshold value and the decision was made to be ripe if the calculated color mean value was greater than the threshold. A total of 21 features were extracted from the three channels which included 9 color statistical features and 12 color texture features.

To improve the accuracy, the Sequential forward selection (SFS) method was used to determine the optimal features and thus the dimension was reduced to 13 features. Then for the classification of tomatoes to defective or not, features extracted were given to a three-layer feed-forward neural network that used weight adjustments using a backpropagation procedure. LOO method was used for training and testing the dataset using a classifier. Validation consisted of n iterations where for each time, n-1 samples were considered for training the classifier and the left out one sample for testing. Thus the average accuracy of n iterations helped to estimate the overall accuracy. With the help of confusion matrices, the performance of the classifier was measured. The combination of color and textural features together gave a better performance in categorizing the tomatoes into defective/non-defective than using the features individually.

Further, the system could classify the non-defective tomatoes as ripe or unripe using R, G, B values of the image. Most of the research work carried out in the fruit grading system focuses on the color or texture of the fruit in deciding the quality of the fruit. This system which comprised of a combination of hardware and software modules was able to classify the tomato as defective/non-defective with 100% accuracy and as ripe or not with an accuracy of 96.47% respectively. The grading system had a capacity of 300 fruits per hour. The drawback mentioned is that images with high specular reflection were unable to give a good performance and the system speed and classification accuracy need further improvements in real-time.

2.2. Feature-Based Comparative Study for Strawberry Classification using SVM Classifier

In this paper, Oka Mahendra, Hilman F. Pardede, Rika Sustika, and R. BudiarientoSuryoKusumo have done a detailed study in quality-based strawberry sorting algorithm, which was implemented using several attributes extracted via image processing techniques and by measuring and comparing the performance of SVM classifier to each extracted feature inputs [2]. SVM prediction accuracy has been compared by giving seven different image processed features as input to determine the quality of strawberries. This research was aimed at finding the feature that best describes the quality of strawberries with high accuracy and to study if the accuracy in classification can further be improved by inputting a combination of several features to SVM. Good and bad strawberries were determined using binary class labels. Dataset was created by acquiring images of strawberries using a webcam where 382 of the image data were of good quality and 350 of damaged strawberries. The dataset was also given to the public so that researchers could access for further research.

Pre-processing steps like segmentation, resizing and padding were done on these acquired images before feature extraction. These features were given as input to the SVM classifier, and cross-validation steps were performed. Accuracies were computed for different features. The following features were extracted for classification and then compared on which features gave more classification accuracy.

a) Basic RGB, HSV and 3D (RGB) Histogram
b) Scale-Invariant Feature Transform (SIFT)
c) Speeded-Up Robust Features(SURF)
d) Oriented FAST and Rotated BRIEF (ORB) and
e) Histogram of Oriented Gradients (HoG).

The primary color values of each pixel were obtained from the acquired images in a simple RGB model using the webcam. This pixel’s independent values which will be R, G, and B can be transformed to the HSV model in which Hue (H) dimension represents the actual colors, the intensity of purity of Hue represents Saturation (S) and the relative degree of black or white mixed with Hue
gives the Value(V) dimension. RGB, HSV, and 3D histograms (obtained by combining R, G, B planes) color features were used in this work in the sense that these features can differentiate images based on colors, and thus they could give better performance measures.

Using Scale-Invariant Feature Transform (SIFT), scale-invariant key-points (highly distinctive locations in an image) were extracted which involved the steps like Scale-space extrema detection, Key-point localization, Orientation assignment, and Key-Point Descriptor Generation. Thus using OpenCV 3.4.1 and Python 3.6, Key-Points were generated from the strawberry images using the SIFT technique. The next feature used in this work is Speeded-Up Robust Features (SURF) which produces key points for detecting blobs in images. Processes like Object recognition, classification, etc. was made possible by using this local feature descriptor. In this, blob-like structures are used to locate the key points wherever the elements of the Hessian Matrix (square matrix used for determination of local maxima and minima) is found maximal. Feature orientation was calculated using HAAR feature responses. The SURF generated blob-like key-point detectors are very effective in detecting blobs.

Another feature called the Oriented FAST and Rotated BRIEF (ORB) algorithm was created from the Features Accelerated Segment Test (FAST) algorithm and the Binary Robust Independent Elementary Features (BRIEF) descriptor. The key-points were determined using FAST and the Peak-N points were in turn determined by applying the Harris corner measure. Also, multiscale features were produced using pyramid representation. Vector direction from the corner point to the intensity centroid determined the orientation of key points. The BRIEF descriptors steer BRIEF features in the orientation of key-points. ORB can be used for the detection of angles from the damaged strawberry image as it can detect the key points. The Histogram of Gradient algorithm was the next feature used for the detection of objects. Contour and a few texture details were extracted from the first-order image gradients; which converts region-wise gradient information from the pixels into an orientation histogram with a few bins for which normalization is performed.

After the collection of all the above-mentioned image features, experiments were conducted by inputting those features to SVM Classifier and comparing the results in classifying the strawberries based on its quality. Training and testing were done using the extracted feature data. k-fold cross-validation method with k set to 5 was done for training and testing processes. Five groups of data samples were considered with four groups dedicated to training and the remaining group was for testing by alternating the test group for each iteration. The average of the five test results was found to get the final result and it was observed that among all the above features SURF features gave better performance accuracy. The testing of each image-based feature on SVM was done using linear, radial basis function and polynomial kernels of degrees 2, 3 and 4. The C parameters were chosen to be 0.1, 0.5, and 1.0. For all kernels and C values, the SURF feature gave the highest classification accuracy of 90.73%, the 2nd best accuracy was obtained by using ORB (83.45%). Classification accuracies obtained by using the remaining feature sets are as shown, SIFT gave 67.42%, HSV gave an accuracy of 58.77%, RGB Histogram gave 56.50%, RGB gave 55.05%, and HoG 53.61% accuracies. SURF gave the highest predictive accuracy and as the number of key-points generated is not uniform in all samples; a minimum amount of key-points is necessary and others are ignored. Only valid samples that satisfy this requirement are considered for processing. It was observed that an increase in the minimum number of key-points resulted in increased accuracy which was because the information obtained from the image was more. It was found that if the rate of minimum key-point used is less, then there is a possibility of losing important image information.

Thus in the classification process by using various features, it was proven that the SURF feature gave the best experimental results with SVM. This good performance of SURF shows that blob-like features can be used to detect the rotten areas of strawberries accurately. Although the SURF feature showed good performance, the disadvantage of this feature is that, only a minimum amount of key-points after omitting the remaining may result in loss of important information from the image. This research was focused on determining the best image processing based feature which gave superior accuracy in classifying strawberries into good and bad. It also helped in analysing the performance achieved by using various features for the SVM classifier. The minimum accuracy obtained while detecting the damaged strawberry image area by using RGB, HSV, and RGB histogram features have
proven that it was not adequate to detect the damage. HoG feature gave the least classification accuracy.

2.3. Automated Sorting of Matured Cherry Tomatoes Using Machine Vision Technique.

A quality grading algorithm of matured cherry tomatoes using a machine vision technique was proposed by V Pavithra, R Pounroja, and Dr. B Satyabama [4]. Grading was done in two phases: grading based on maturity and grading matured ones based on their quality. The first step was to acquire images of cherry tomatoes and classify them into matured and immatures. A maturity algorithm based on color was proposed as the color changes during the stages of ripening. That is, if redness on the tomato surface is above 60% then it falls under stage 5 which will be ripe and mature, and if it is above 90%, then it falls under stage 6 which is over-ripened and mature. Below 60% indicates the unripe and immature ones which can be from stage 1 to 4 depending on its unripe color. Evaluation was done as described below. Once the tomato is separated from its background, the total area of the tomato is evaluated. Then by calculating the ratio of the surface area with red pixel to the total area of the tomato, if the value is greater than 0.6, it falls under matured ones; else immature.

Once tomatoes are identified based on its maturity, in phase II, the matured ones are again classified in terms of its quality into I, II, and III categories. The ripe ones which fall under stage 5 will belong to category I, the overripe ones which fall under stage 6 will be in category II and the damaged or rotten ones will be in category III. For this classification, features corresponding to outer and inner attributes like texture, color, and shape were educed as these features change for different maturity levels and it affects the quality. Initially, to separate the tomato from its background, a color image segmentation method based on Euclidean distance was proposed. The Euclidean distance of every image pixel with agent pixels was calculated, giving the distances dr, dg, and db. If the distance 'dr' (representing red color) was greater in a pixel, then that is considered as tomato pixel, else background. Thus segmentation was done which was followed by feature extraction.

The texture attribute gives information about the structural organization of the tomato surface. Entropy, Angular Second Moment (ASM), Inverse Difference Moment (IDM), and Variance were the educed texture features. Grey Level Co-occurrence Matrix (GLCM) was found and the features were extracted from it. In image processing, GLCM depicts the frequency of appearance of grey level combinations co-occurring in an image. The external color features like ASM and color inverse difference moment (IDM) of cherry tomatoes were educed from the color level co-occurrence matrix (CLCM). Since RED is the dominant color in mature tomatoes, CLCM is computed only for the red band. The color distribution of tomato is uniform over the surface in class I and II, whereas damaged or defected ones in class III fruit will be heterogeneous. Therefore, for class I and II, the color ASM feature value was higher whereas class III had a higher value for color IDM.

To best describe the shape of tomatoes, characteristics like area, perimeter, circularity, and aspect ratio were educed. As the rotten or deformed tomatoes will be over soft and shape will be deformed; good quality tomatoes will be in good shape and aspect ratios will be approximately equal to one.

After extraction of all the features (texture, color, and shape), these were given to k-NN based SVM classifier, which classifies the fully grown fruit based on its quality and categorizes them into Ist, IInd and IIIrd categories. The 3-dimensional plots of GLCM and CLCM were plotted for all the matured tomatoes and observed that the number of large peaks were less for good quality tomatoes in comparison to the damaged/rotten ones. Also for good quality tomatoes, the surface is homogeneous and uniform. k-NN classifier had a good computation time but SVM was more efficient in classification. Thus as the terms, accuracy, and computation time is considered, k-NN based SVM classifier outperformed each classifier individually.

2.4. Sorting of Thompson Oranges using Non-Intrusive Image Processing Methods.

Based on the fact that the computer vision technology can be effectively utilized to come up with an innovative fruit sorting and classification algorithm for the export industry, SajadSabzi, Yousef
Abbaspour-Gilandeh, and Juan Ignacio Arribas did a study on the grading of Thompson Orange fruit using non-intrusive image processing techniques [5]. In this work, programs were coded using Matlab for preparing and studying the captured digital images of oranges. Parameters like; area, length, eccentricity, perimeter, the ratio of length to the area, B_average, G_average, R_average, width, contrast, texture, the ratio of width to the area, the ratio of width to length, and roughness were extracted from the Thompson orange. 100 data samples were randomly selected and its volume was determined using the water displacement method (WDM). Images of oranges were captured using a digital camera with a resolution of 352*288 pixels with proper lighting arrangements and from an equal distance. For analysis purposes, the captured images from fruit samples were digitized and stored in RGB color coordinates. The orange images were separated from the background using the image segmentation method and histograms were plotted. From the histograms of RGB color space, it was observed that image with red components was most approving for the fruit segmentation process. Noise removal was done by Canny and Laplacian filters. Canny edge detection uses a derivative of the Gaussian filter for the calculation of gradients and identifies edges using the local maximum gradient. Two different level threshold values were used to identify strong and weak edges. After applying the Gaussian filter on the image, the edges were identified using the Laplacian filter.

The following orange image features were used. The total no: of pels in a region gives the area. The no: of pels around the boundary of each region defines the Perimeter. Length is the no: of pels that exist in the major axis of the ellipse that has the same normalized second central moments as the region. The no: of pels that exist in the minor axis of the ellipse that has the same normalized second central moments as the region gives the Width. The ratio of the distance from the ellipse center to the length of the main axis defines Eccentricity. Variations of intensity values or grey levels in the region define Roughness. The local variations of grey values give Contrast. The measure of randomness of texture is known as Entropy. The total number of red, green, and blue pixels existing in a region is indicated by Red, Green, and Blue value.

After the computation of the above features, Pearson’s correlation method was found out for each extracted feature. To compute the volume of orange using an image processing algorithm, several statistical models like ANFIS (Adaptive Neuro-Fuzzy Inference System), linear and non-linear regression statistical models were leveraged. It was observed that the ANFIS method outperformed linear and non-linear regression statistical techniques. Mean squared error (MSE), Sum Squared Error (SSE), and coefficient of determination (R2) which gives the performance evaluation measures were computed for the three models and found that ANFIS was the best fit model. Also, the results of regression analysis (estimated orange mass versus experimental true orange mass) for ANFIS and linear regression were plotted and the plot proves that ANFIS method was the best model. It is suggested that this work can be implemented and launched for sorting oranges based on its volume into small, medium, and large in the relevant food packaging industries and thereby drastically improve the sorting speed, accuracy and reduce cost through automation.

3. Conclusion
Here, a few papers were discussed which detailed the sorting and grading of different varieties of fruits using machine vision, image processing and machine learning techniques. In the first paper, a tomato grading system using computer vision for quality evaluation was discussed. Although this system was able to classify the tomato as defective/non-defective with maximum accuracy and as ripe or not with high accuracy, high specular reflection in the images was an obstacle for good performance of the system and needed improvements in terms of speed and accuracy while implementing in real-time. The second paper focuses on a comparative study on the performance of the SVM classifier. Using this technique, strawberries were classified on its quality using different attributes extracted via image processing techniques. In this, various features were extracted for classification and then compared on which feature gave more classification accuracy. The color only attributes were not enough to identify the rotten surface of the strawberry and gave lower precision. SURF feature gave the highest classification accuracy and the HoG feature gave the least. The third
paper under discussion focused on an algorithm for Date recognition using certain features and deep learning techniques. The framework was effective in classifying the Dates based on its color, size, and shape features extracted from its images. It is said that additional features like texture can be included and also different varieties of Dates may be added as a future work for improved results. The next paper reviewed focused on the machine vision-based grading algorithm of cherry tomatoes. In this work, grading was done in two phases: grading based on maturity and further grading of the matured ones based on their quality. Certain features that changes with the growth stages were extracted and K-NN based SVM classifier was used and it was found that it outperformed the performance of each classifier individually in terms of accuracy and computation time. The next paper discussed was a non-intrusive image processing based grading method applied to Thompson oranges. In this, fourteen parameters; area, length, eccentricity, perimeter, the ratio of length to the area, B_average, G_average, R_average, width, contrast, texture, the ratio of width to the area, the ratio of width to length, and roughness were extracted from the Thompson oranges. This was followed by Pearson’s correlation calculation for each extracted characteristics. To get the volume of oranges several statistical models like ANFIS, linear, and non-linear regression statistical models were used. By applying various performance measuring techniques, it was found that ANFIS method was proved to be the best model. Many of these techniques can be employed in future researches, several features like texture and more, and also various types of fruits can be added to develop a more efficient and powerful application of recognition and classification algorithms.

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