

## Surface Defect Detection and Grading of Apples

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**Abstract--** This paper presents a novel method to detect surface defects of an apple using RGB images and apples are graded based on these identified defects. We only consider the outer surface to grade the apples. The method starts with background removal and region of interest (ROI) selection using grow-cut method; this is followed by multi-threshold segmentation. We fuse the results of grow-cut and multi-threshold segmentation to detect the defects of an apple. In order to represent the defected area, we extract color statistical, color texture features in addition to shape features, which are further used for apple grading. Sequential Forward Selection algorithm is used for selecting useful discriminant features. Based on the selected features, we grade the apples into different grades using K-Nearest Neighbor (K-NN) classifier. The experimental results show that our technique achieves highest accuracy..

**Index Terms—** Grow-cut segmentation, Defect detection, Thresholding, Statistical features, Textural features, Shape features, Stepwise discriminant analysis.

### I. INTRODUCTION

Defect detection for inspection of quality of apples has been gaining importance all over. The uniformity in size, shape and other quality parameters of apples are required for deciding the overall acceptance quality for customers. In many industries, at present, grading of apples is performed by hand, and this is a very labor-intensive. Labor shortages and a lack of overall consistency to the process resulted in a search for automated solutions. Color, size and amount of defects are important aspects for inspection and grading of fresh apples; many machines have been built for the same.

The study of apples using computer vision has been used for tasks such as shape classification, defect detection, and quality grading. Surface defects are of great concern to producers to grade the apples. The grading system utilizes computer vision techniques to detect the defects on the surface of apples. After identifying the surface defects of apples, the system grade the apples based upon this criterion. The defect or damage is usually occurred in apples due to various factors. Apples with rot, bruising, scab, fungal growth, injury, disease and other defects must be removed to prevent cross-contamination and reduce subsequent processing cost. The researchers have adopted image processing and computer vision based techniques to detect the surface defects and graded the apples based on identified defects using either RGB images or multispectral images. There are two important stages involved in grading the apples such as surface defect detection and grading the apples based on identified defects. Some researchers have developed techniques for defect detection only and both the steps such as surface defect detection and grading the apples based on identified defects are carried out in some papers. The proper identification of defects is a very important step in order to grade the apples accurately. The difficulty in detecting the defects in apples is that while identifying the defects, stem-calyxes are identified as defects; because after applying image processing techniques, they are similar to defective spots on the image and this reduces the grading accuracy. Some of

the papers deal with defect detection of the surface of an apple considered this challenge and proposed techniques to differentiate the actual defects and stem-calyx.

B.S Bennedsen et al., [2] proposed an approach to detect the defects in multispectral images; flat-field correction is used for brightness correction. Multi-threshold segmentation is used to detect the defects. J.A Throop et al., [5] proposed quality evaluation of apples based on surface defects in the multispectral images. The apple height is calculated using area of ellipse, and the major axis is determined. Flat-field correction is used for uniform distribution of light. The success rate is greater than 97.6%. The researchers have developed apple grading techniques using RGB or monochrome digital images. Unlike the MIR camera, digital cameras are inexpensive and easy to afford. Another advantage of digital data is that they can be readily processed using digital computers. Qingzhong Li et al., [4] proposed an approach to detect the defects in the surface of an apple. Background removal is done by image subtraction. For this, local adaptive threshold segmentation is employed to detect the defects. Stem-calyx has been identified using fractal features and ANN. A feed-forward back-propagation (BP) NN algorithm was used to classify stem-calyx from true defect areas. The algorithm was used to detect defects and stem-calyx areas in 40 samples of Fuji apples. Accuracy of the network classifier was over 93%. The main drawback of this paper is that processing time is very high, and they considered fractal features to classify the stem-calyx part assuming that concave surface. But this is not true in case where apples are oriented along in any direction and the concave surface may not exist.

D. Unay et al., [6] proposed an approach to recognize stem and calyx on apples using monochrome images. Flat-field correction is used to remove vignetting on filter images. Fruit area is separated from background using threshold. After background removal, fruit area is eroded by rectangular structuring element of size adaptive to fruit size. Features are extracted using statistical, shape and texture methods. They conclude that SVM classifier gives best performance. This paper focus only on stem-calyx recognition and grading are not carried out. Zou Xiao-bo et al., [10] proposed an approach for defect detection using three-color cameras. The apple image is segmented from the black background by multi-threshold method; flooding algorithm and snake algorithm is used for image segmentation. The disadvantage of this method is that it could not differentiate defects and stem-calyx. V. Leemans et al., [3] developed an on-line fruit grading according to their external quality using machine vision. Golden Delicious and Jonagold apples; two varieties were selected. The first step is color grading; this is done by Fisher's linear discriminant analysis, and the fruits are classified into four classes from far green to yellow. Then stem and calyx recognition is done by using correlation pattern recognition technique; this is followed by image segmentation. The defects characterization is done for segmented images using the color, geometrical, texture parameters and the parameters related to the calyx and stem ends. Two grading methods were compared, first is quadratic discriminant analysis preceded by the computation of the first principal components, another one is neural network, with a multi-layer perceptron with one hidden layer. The proposed method for apple external quality grading showed correct classification rates of 78 and 72%, for Golden Delicious and Jonagold apples, respectively.

Xianfeng Li et al., [7] developed an apple Grading Method Based on Features Fusion of size, shape and color. A multi-feature information fusion method based on BP neural network and Dempster-Shafer evidential theory is used in this study to improve the accuracy of apple grading. The size, shape and color features of apples are used and defects are not considered to grade the apples. Akira Mizushima et al., [1] developed an image segmentation method for apple sorting and grading using support vector machine and Otsu's method. This paper gives the development of an automatic adjustable algorithm for segmentation of color images, using linear support vector machine (SVM) and Otsu's thresholding method. The segmentation error varied from 3% to 25% for the fixed SVM, while the adjustable SVM achieved best results for training set with the segmentation error of less than 2%. The main drawback of this paper is that the training images are captured in such a way that stem-calyx part is either any one side, or it does not appear to the camera. Therefore, there is no need of differentiating the actual defects and stem-calyx. However, this is impossible in real time.

In this paper, we proposed an approach to detect the surface defects and apples are graded based upon this criterion. The main contribution to this paper compared to other papers is that after detecting the defects, in order to represent the defected area, we extract color statistical, color texture features in addition to shape features, which are further used for apple grading. The literature survey reveals that color features improve the grading accuracy compared to gray level image. The method starts with background removal and region of interest (ROI) selection using grow-cut method; this is followed by multi-threshold segmentation. We fuse the results of grow-cut and multi-threshold segmentation to detect the defects of an apple. Sequential Forward

Selection algorithm is used for selecting useful discriminant features. Based on the selected features, we grade the apples into different grades using K-Nearest Neighbor (K-NN) classifier.

The organization of the paper is as follows: In section II, The proposed approach for defects detection is discussed. The section III describes apple grading procedure. The experimental results are demonstrated in Section IV. Finally, Section V draws the conclusion.

## II. DEFECTS DETECTION

In this section, an approach to estimate the defects in the surface of an apple using grow-cut and multi-threshold based segmentation technique is presented.

### A. Image pre-processing

In order to improve the quality of an image, operations need to be performed on it to remove or decrease degradations suffered by the image during its acquisition. The captured images are suffering from illumination variations, due to specular reflection. The reflected parts become full white and also the shadows; these are the main challenges in defect detection.

We employ median filtering to normalize the uneven distribution of light and to suppress noise. The median is much less sensitive than the mean to extreme values (called outliers). Median filtering is therefore better able to remove these outliers without reducing the sharpness of the image. The median filter technique allowed the edges to be preserved while filtering out the peak noise. For this reason, the median filter is often used before applying defect detection technique to preserve the main apple defect as much as possible.

### B. Background Subtraction

For background subtraction, we used grow-cut approach; it removes background and gives fruit part separately. Vladimir Vezhnevets and Vadim Konouchine from the Media Laboratory at Moscow State University first came up with this algorithm in 2005. The unique feature of the grow cut algorithm is in its ability to incorporate both “Von Neumann neighborhood” theory and the “region growing/region merging” technique. The algorithm executes as follows:

1. Using the "user input seed points", the algorithm automatically computes a region of interest that encompasses the seed points.
2. Next, the algorithm iteratively tries to label all the pixels from the image using the label of pixels in the user seeded portions of the image.
3. The algorithm converges when all the pixels in the ROI are labeled, and no pixel can change its label any more.
4. Individual pixels are labeled by computing a weighted similarity metric of a pixel with all its neighbors, where the weights correspond to the neighboring pixel's strength. The neighbor who results in the largest weight greater than the given pixel's strength confers its label to the given pixel.

The process is iterated on, in the same manner as general data clustering algorithms. It performs well with respect to noise.

### C. Multi-Threshold Segmentation

After extracting the apple fruit part from the image, we partition an apple fruit image into defected part and non defected part using multi-threshold segmentation. In multi-threshold segmentation, the images were segmented several times at different threshold levels i.e., the thresholds are 20, 45 and 85 for different defects on the basis of distinctive defects are having different threshold levels based on our visual observation. The resulting binary images were added to form a so called multi layer image. This in turn was then subjected to threshold segmentation. This segmentation aimed at identifying the darkest areas in the original image. The resulting, binary image was referred to as a marker image. The final step consists in constructing a binary image, based on the marker image and the multi-layer image. With the position of the defects identified, a simple thresholding routine i.e. a gradient segmentation is employed to determine the area of these defects. The results obtained from the background subtraction and multi-threshold segmentation methods are overlapped to each other. In the resultant image, we observe that the actual defected parts are appeared on the surface of the apples.

### D. Stem-Calyx Identification

During the defect inspection process, it is difficult to distinguish the stem and calyx from the true defects, because they are similar to defective spots on the image.

We have adopted the technique proposed by Qingzhong Li et al.[4], which is based on fractal features and feed-forward back-propagation (BP) Neural Networks algorithm.

### III. APPLE GRADING

The color features give detailed features compared to gray level features. After detecting actual defected part in the apple images, in order to represent defected area, we extract color statistical and color texture features for individual Red (R), Green (G) and Blue (B) channels. The shape features are extracted for Red channel. The discriminant features are selected using sequential forward selection method. The apples are graded using k-NN classifier with Euclidean distance.

#### A. Feature Extraction

For each fruit sample, the extracted 37 feature set is the collection of 12 texture (4 for each channel), 21 statistical (7 for each channel) and 4 shape features (only for red channel).

*Color Statistical Features:-* The seven statistical features on each color channel are extracted (21 features in total):

$$\text{Color mean } (\mu) = \frac{1}{N} \sum_{i=1}^N P_i \quad (1)$$

$$\text{Standard Deviation } (\sigma) = \left( \frac{1}{N-1} \sum_{i=1}^N (p_i - \mu)^2 \right)^{1/2} \quad (2)$$

$$\text{Minimum (min)} = \min(p_i) \text{ for } i=1, \dots, N \quad (3)$$

$$\text{Maximum (max)} = \max(p_i) \text{ for } i=1, \dots, N \quad (4)$$

$$\text{Gradient (grad)} = \text{max} - \text{min} \quad (5)$$

$$\text{Skewness (skew)} = \frac{\sum_{i=1}^N (p_i - \mu)^3}{N\sigma^3} \quad (6)$$

$$\text{Kurtosis (kurt)} = \frac{\sum_{i=1}^N (p_i - \mu)^4}{N\sigma^4} \quad (7)$$

*Shape Features:-* The 4 shape features for red channel are extracted:

$$\text{Area (S)} = N \quad (8)$$

$$\text{Perimeter (P)} = N_p \quad (9)$$

$$\text{Euler number (E}_N\text{)} = O - H \quad (10)$$

where, O is Number of objects, H is Number of holes.

$$\text{Eccentricity (E)} = \frac{c}{a} \quad (11)$$

where, c - is the distance from the center to the focus of the ellipse, a - is the distance from the center to a vertex.

*Color Texture Features:-* The four texture features on each color channel are extracted (12 features in total): The GLCM is a statistical method of examining the texture features that consider the spatial relationship of pixels.

*Contrast:* Returns a measure of the intensity contrast between a pixel and its neighbor over the whole image.

$$\sum_{i,j} |i - j|^2 p(i, j) \quad (12)$$

*Correlation:* Returns a measure of how correlated a pixel is to its neighbor over the whole image.

$$\sum_{i,j} \frac{(i - \mu_i)(j - \mu_j)p(i, j)}{\sigma_i \sigma_j} \quad (13)$$

Energy: Returns the sum of squared elements in the GLCM.

$$\sum_{i,j} p(i,j)^2 \quad (14)$$

Homogeneity: Returns a value that measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal.

$$\sum_{i,j} \frac{p(i,j)}{1 + |i - j|} \quad (15)$$

### B. Feature Selection

Feature selection algorithm search for the best feature subset that reduces the feature space dimensionality with the smallest loss in classification accuracy. Sequential forward selection (SFS) is a greedy search algorithm that determines an “optimal” set of features for extraction by starting from an empty set and sequentially adding a single feature in the superset to the subset if it increases the value of the chosen objective function.

A total of 37 features is extracted from each fruit sample, the extracted 37 feature set is the collection of 12 texture features (4 for each channel), 21 statistical features (7 for each channel) for RGB color channels and 4 shape features are used to grade the apples based on the extracted features. All features of each fruit do not give the discriminant features, so it includes some redundant or irrelevant features, it does not differentiate the normal apple skin with the defected parts of the apple surface. In our work, only 23 discriminating features are selected from the features set, they are area and perimeter from the shape features set, mean, standard deviation, max and gradient are from the statistical features set and finally, the contrast, homogeneity and energy are from the texture features set.

### C. Classification using K-NN

Classification stage is applied to grade the apples based on the defects presented on the surface. This method is applied to differentiate the apples into three different categories, i.e., grade-A, grade-B and grade-C. We have used K-nearest neighbor algorithm (k-NN) with Euclidean distance for classification.

## IV. EXPERIMENTAL RESULTS

We have conducted experiments on 180 apple image samples, which are captured in controlled environment and manually graded into 3 grades. We select 120 apple images (40 images for each grade) for training purpose and remaining 60 apple images (20 images for each grade) as testing samples. The result of grow-cut for background subtraction is shown in Fig. 1. The segmentation result using proposed multi-threshold technique is shown in Fig. 2. Since there is no ground truth data is available for our sample images, the segmentation result of our approach is compared visually with results of Hill-climbed segmentation and color-based segmentation technique. The visual comparison shows that our segmentation technique extracts defected part accurately compared to others.

After segmented the defected part accurately, the result of background subtraction and segmentation is fused to identify the defects. To distinguish the stem and calyx from the true defects, we have adopted the technique proposed by Qingzhong Li et al. [4], which is based on fractal features and feed-forward back-propagation (BP) Neural Networks algorithm. The color features are extracted as explained in section III. The discriminant features are selected using SFS.

The 23 features values extracted for each apple by using criteria i.e. if the apple having more than one defects, then the features are averaged for all defected parts; if the apple having one defected area, then the features are from that defected area otherwise the features are extracted for whole fruit. The feature values for healthy apple and defected apple are shown in Table I and II.

In Table I, 23 selected features are shown i.e., 2 shape features, 12 statistical features for RGB channels (4 for each channel) and 9 texture features for RGB channels (3 for each channel). The apples are graded into three classes such as grade-A (very good) i.e., the apples without defects, grade-B (good) i.e., the apples those having 1 to 3 defects with very small size, and finally, the apples those having more defects and with large size are belonged to grade-C (poor).



Figure 1. Results of background subtraction of the test

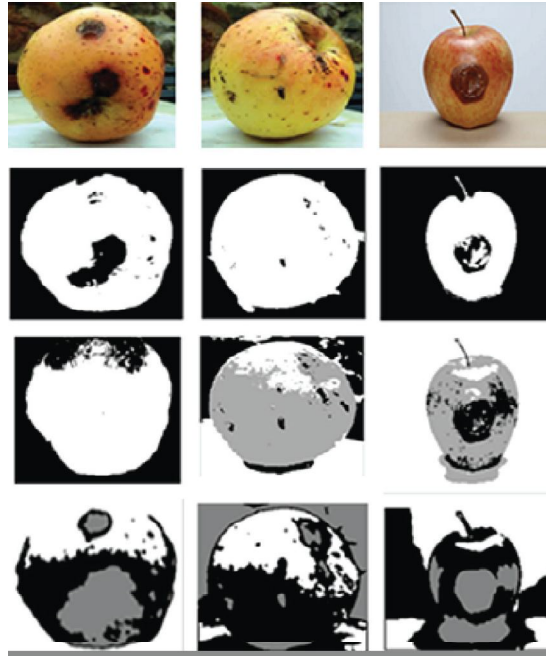


Figure 2. First row: test images of apples; second row: result of defect detection of proposed method; third row: result of Hill-climbed method and fourth row: result of color based segmentation method

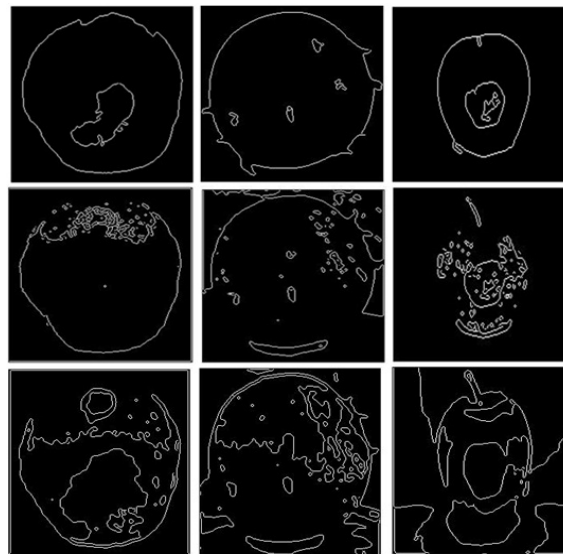


Figure 3. First row: results of labeled image of proposed method; second row: result of labeled image of Hill-climbed method and third row: result of labeled image of color based segmentation method

TABLE I. SELECTED FEATURES OF HEALTHY SKIN OF OUR TEST IMAGES

Features		Fruit Part		
		Red	Green	Blue
Shape	Area	344	344	344
	Perimeter	376.2914	376.2914	376.2914
Statistical	Mean	161.7842	114.1503	83.0805
	Standard Deviation	11.4232	8.9117	12.5565
	Max	251	235	244
	Gradient	235	235	244
Texture	Contrast	1.873e+03	1.918e+03	1.961e+03
	Energy	1.513e-04	1.103e-04	1.475e-04
	Homogeneity	0.0736	0.0725	0.0695

TABLE II. SELECTED FEATURES OF DEFECTED SKIN OF OUR TEST IMAGES

Features		Defected Part		
		Red	Green	Blue
Shape	Area	121	121	121
	Perimeter	138.4680	138.4680	138.4680
Statistical	Mean	103.1665	49.7594	29.0739
	Standard Deviation	4.5726	4.9703	5.8209
	Max	165	136	126
	Gradient	105	124	126
Texture	Contrast	216.176	218.268	210.204
	Energy	5.856e-04	6.988e-04	7.890e-04
	Homogeneity	0.1654	0.1705	0.1772

TABLE III. GRADING RESULTS OF APPLES USING OUR APPROACH

Grade	Accurate Results	Statistical	Shape	Texture	Features Fusion
A	20	28	20	30	20
B	20	20	26	13	21
C	20	12	14	17	17
Correct rate of grading		60.00%	70.00%	75.00%	85.00%

TABLE IV. COMPARISON OF CLASSIFICATION ACCURACY OF K-NN CLASSIFIER WITH OTHER CLASSIFIERS

Classifier	Classification accuracy (%)
K-NN	85.00
LDC	75.00
AdaBoost	70.00
SVM	80.00

The results are shown in Table III. The classification is carried out using K-NN with Euclidean distance and results are compared with other classifiers such as Linear Discriminant Classifier (LDC), AdaBoost and Support Vector Machine (SVM). The classification results are shown in Table IV. Table III shows the results of human expert and our approach, the feature level fusion gives the more correct rate of grading compared to individual feature set. Table III shows the features are fused at the score level. From Table III, it is observed that, the proposed method can achieve a much higher accuracy in grading the apples using fused features, which are color statistical, color texture and shape features compared to individual features. This is due to the fact that we have extracted color features, which improves the performance of our approach compared to gray level image based features. The different classifiers are compared with K-NN approach, which is used in our approach and classification accuracy is given in Table IV. It is observed that, the K-NN classifier with the value K=5 yields highest classification accuracy 85.00% compared to other classifiers.

## V. CONCLUSION

In this paper, we proposed an approach to estimate the defects on the surface of an apple and apples are graded using this criterion. The grow-cut and multi-threshold techniques results are combined to identify the defects. The stem-calyx regions are recognized and removed in order to detect the actual defects. It is observed that the proposed method effectively estimates the defects on the surface of apples compared with hill-climbed and color based segmentation techniques. Finally, the selected features are extracted, and fusion is carried out in order to improve the performance. The apples are graded using K-NN classifier with Euclidean distance. The experimental results show that our approach effectively identifies the defects and grade the apples accurately. The grading results evaluated with human grading. It is observed that our approach performs nearer to human grading. The color features improve the performance of grading by machine.

The system has the advantage of being able to inspect defects on the surface of the apple, shows how many defects are present in the apple. Proposed approach does not effectively work on apple image with high specular reflection and apple fruits occluded with other objects or apples, which is the objective of further research.

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