Developments in computer vision system, focusing on its applications in quality inspection of fruits and vegetables - A review

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ABSTRACT
Quality inspection of food is a tedious and labor intensive process. Ever-increasing population, losses in handling and processing and the increased expectation of food products of high quality and safety standards has raised the need for accurate, fast and objective quality determination methods. Manual quality inspection is a slow, costly, unreliable process and suffers from poor repeatability. Computer vision provides one alternative for an automated, non-destructive and cost-effective technique to accomplish these requirements. Computer vision is a rapid, economic, consistent, objective inspection and evaluation technique. Computer vision has been successfully adopted for the quality analysis of meat and fish, fruits, vegetables and bread with applications ranging from routine inspection to the complex vision guided robotic control. The paper presents the recent developments in computer vision technology along with important aspects of image processing techniques coupled with application of computer vision technology in quality inspection of fruits and vegetables.

Key words: Computer vision, Fruit, Quality inspection, Vegetable.

In modern food industry, high quality product is the only basis of success. Quality of any product determines its sale value in the market (Vijayarekha, 2012). Today’s consumer demands quality food which are safe in every aspect, this has raised the need for enhanced quality monitoring. Quality is the sum of all those attributes which can lead to the production of products acceptable to the consumer when they are combined (Brosnan & Sun, 2004). Generally, food quality is evaluated from its sensory attributes which involves comparison of attributes such flavour, smell, texture, colour and appearance by trained judges. Human inspection is a slow process, has poor repeatability and result varies from person to person which have emphasize the demand of objective system for evaluation of food quality. Further, automatic evaluation of food quality results in increased production rate and efficiency and reduction in the production cost. This has necessitated the introduction of computer-based image processing techniques. Computer vision technology aims to simulate the effect of human vision electronically by acquiring and understanding an image and it constitutes the expression and relevant descriptions of physical objects from images (Singh et al., 2013). Computer vision based image processing techniques can quantitatively characterize complex size, shape, color and texture properties of foods.

Being rapid, economic, consistent and accurate, use of computer vision systems for quality evaluation has been increasing in the food industry (Gumus et al., 2011). This technology has been developed in recent past and its origin can be traced back to the 1960s with an exponential growth in research and development during 1980s (Singh et al., 2013). It is an engineering technology that integrates mechanics, optical instrumentation, electromagnetic sensing, digital video and image processing technology. It has found applications in many areas such as medical diagnostics, automated manufacturing, aerial surveillance, remote sensing and very recently in the agricultural and food sector. Table 1 enlists the application of computer vision in different areas (Kodagali & Balaji, 2012). The working of computer vision system consists of capturing, processing and analyzing images, facilitating the nondestructive assessment of various quality characteristics in food products (Narendra & Hareesh, 2010). The utilization of computer vision system in food industry is increasing day by day and now it ranks among top ten industries using this technology (Brosnan & Sun, 2004). Over the past few years, it has developed significantly because of the explosive growth in both computer hardware and software. Currently, computer vision systems are being developed as a vital part of food processing plants for online, real-time quality evaluation and quality control. This paper reviews the fundamental elements of computer vision system and application of computer vision technology in evaluation of food quality with special emphasis on fruits and vegetables.

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Table 1: Summary of different areas for computer vision application

<table>
<thead>
<tr>
<th>Application Area</th>
<th>Purpose</th>
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<tbody>
<tr>
<td>Industrial automation and image</td>
<td>Process control, quality control, geometrical measurement, barcode and package label reading, object sorting, parts identification on assembly lines, defect and fault inspection, inspection of printed circuit boards and integrated circuits</td>
</tr>
<tr>
<td>Medical image analysis</td>
<td>Tumor detection, measurement of size and shape of internal organs, blood cell count, x-ray inspection</td>
</tr>
<tr>
<td>Robotics</td>
<td>Obstacle avoidance by recognition and interpretation of objects in a scene collision avoidance, machining monitoring, hazard determination</td>
</tr>
<tr>
<td>Radar imaging</td>
<td>Target detection and identification, guidance of helicopters and aircrafts in landing, guidance of remote piloted vehicles (RPV), guiding missiles and satellites from visual cues</td>
</tr>
<tr>
<td>Food industry</td>
<td>Sorting of vegetables and fruits, location of defects e.g. location of dark contaminants and insects in cereals</td>
</tr>
<tr>
<td>Document analysis</td>
<td>Handwritten character recognition, layout recognition, graphics recognition</td>
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ELEMENTS OF COMPUTER VISION SYSTEM

A typical computer vision system consists of illumination, a camera, an image capture board (frame grabber or digitizer), computer hardware and software as shown in the figure 1 (Swami & Swami, 2010). However, some unique modifications are made in design of computer vision system to suit the inspection of a particular product.

Illumination/Lightening: Illumination is the critical component of computer vision system, must be properly selected and designed. Similar to human eye, vision systems are affected by the level and quality of illumination. The performance of the illumination system critically influences the quality of image and plays an important role in the overall efficiency and accuracy of the system. Good lightening decreases the processing time by reducing the reflection, shadow and some noise (Panigrahi & Gunasekaran, 2001). Image analysis can be improved by enhancing image contrast through a well-designed illumination system. Clear image of the object can be obtained through proper selection of lightening source, lightening arrangements and light geometry. The lightening source used include incandescent lamps, fluorescent lamps, halogen, X-ray tube, infra-red light, Xenon and LED (Patel et al., 2011).

In general, lighting arrangements are grouped as front and back lighting (Gunasekaran S., 2001). Front lighting i.e. electron projection lithography or reflective illumination is used for surface feature extraction, for example defect detection in apples while back lighting i.e. transmitted illumination is used for generating a silhouette image for critical edge dimensioning or for sub-surface feature analysis as in the size inspection of chicken pieces (Brosnan & Sun, 2004).

Image Acquisition: Image acquisition involves capturing a real image and transforming it into a digital image with the help of cameras, scanners, videos, etc. A digital image is numerical representation of an image that can be computationally processed (Rafiq et al., 2013). On the basis
of characteristics determined from digital image, products can be classified or inspected for rejection. Sensors such as ultrasound, X-ray and near infrared spectroscopy can be used to generate an image. Further, displacement devices and documents scanners can also be used to obtain images (Brosnan & Sun, 2004). Camera generates electronic signal on receiving light received from the scene/object. Generally, industrial cameras are based on CCD, which consist of a series of sensors (pixels), each of which is composed of a photocell and a capacitor (Saldana, Siche, & Lujan, 2013). A typical system for generating digital images consists of a high-pixel resolution CCD (charge coupled device) chip and associated hardware. Generally two types of cameras i.e. array (area) and line scan are used to obtain accurate and complete image of the object. Array type camera consist of a matrix of minute photosensitive elements called photosites while line scan camera use a single line of photosites which can repeatedly scan up to 2000 times per minute (Hahn & Sanchez, 2000).

Digitization: Digitization is the process of conversion of pictorial image into numerical form with the help of a vision processor board called digitizer or frame grabber. In this process, an image is divided into a two dimensional grid of small regions containing picture elements defined as pixels. Numerous types of analog to digital converters (ADC) are available but for real time analysis a flash ADC is required. It takes only nanoseconds to produce 50–200 mega samples processed per second. Selection of the frame grabber depends on the camera output, spatial and grey level resolutions and the processing capability of the processor board.

Image processing and image analysis: The image processing and image analysis are recognized as being the core of computer vision (Krutz et al., 2000). Image processing involves removal of defects such as geometric distortion, improper focus, repetitive noise, non-uniform lighting and camera motion to produce quality images while image analysis produces quantitative information by distinguishing the objects (regions of interest) from the background and the generated information is used for subsequent control systems for decision making. As shown in the figure 2 image processing/analysis consists of different stages which can be broadly divided into three levels: low level processing (image acquisition and pre-processing), intermediate level processing (image segmentation and image representation and description) and high level processing (recognition and interpretation) (Sun, 2000).

Low level processing: It includes image acquisition and image preprocessing. Image acquisition is the transformation of electronic signal received from the sensing device into a numeric/digit form while image pre-processing is the removal of faults like geometric distortion, noise, blurring of image, grey level correction etc. to enhance and improve the acquired image for further analysis (Patel et al., 2011).
Averaging and Gaussian filters are often used for noise reduction with their operation causing smoothing in the image but having the effect of blurring edges.

**Intermediate level processing:** It includes image segmentation and image representation and description. Image segmentation consists of segmenting a composite image into component parts or objects that have a strong correlation with objects or areas of interest using the principle of matrix analysis. It is critical process as subsequent extracted data are highly dependent on the accuracy of this operation (Brosnan & Sun, 2004). Segmented image data is nothing but the raw pixel data of the image boundary or a region of interest in the image. Segmentation can be achieved by the following techniques: thresholding, edge based and region based. Thresholding involves characterization of image regions on the basis of constant reflectivity or light absorption of their surface. It is used in application involving sorting based on colour (maturity) and feature (defect and damages detection) (Kodagali & Balaji, 2012). Edge detection is the process of making edges more visible by locating edge pixels and increasing the contrast between the edges and the background (i.e. edge enhancement). In image processing, the boundary between an object and its background is known as edge. It represents the frontier for single objects. Edge detection technique can be used to locate the object and in calculation of their properties such as area, perimeter, shape, etc. In addition, edge tracing is another terminology used by researcher which consist of the process of following the edges, usually collecting the edge pixels into a list (Parker, 2010). The commonly used edge detectors are the Sobel, Prewitt, Roberts, canny and Kirsch detectors. Canny edge detection is a multi-stage algorithm which is the ideal and most broadly used algorithm for edge detection. Canny edge detection is robust compared to other edge detection methods such as Roberts and Sobel and is used in the food industry for boundary extraction of food products. Region based segmentation involves the grouping together pixels which are neighbours and have similar values, extraction of these to form regions representing single objects within the image. In this segmentation, the other regions (dissimilar pixels) are deleted leaving only the feature of interest (Kodagali & Balaji, 2012).

The segmented image may then be represented as a region or a boundary. Region representation is used in the evaluation of image texture and defects while boundary representation is suitable for analysis of size and shape features. The image representation as either a boundary or a region should be selected based on the intended application. Image description is also known as image measurement, uses various algorithms for the extraction of quantitative information from the previously segmented image regions. During this process various features such morphological, textural, and photometric are quantified so that subsequent object recognition and classifications may be performed (Singh, Chatli, Singh, & Kumar, 2013).

**High level processing:** High level processing involves application of statistical and multilayer neural networks/techniques to the data for recognition, interpretation of images and to distinguish elements of the image. Desired information is extracted from processed image through application of various operations and techniques. Extracted information is provided to the process/ machine control for quality sorting and grading. Operation and techniques applied to images includes object recognition, feature extraction, analysis of position, size, orientation etc (Patel, Kar, Jha, & Khan, 2011).

**Knowledge database:** Knowledge database is an integral part of image processing process and it is integrated with all the processes for effective and more precise decision making. The knowledge database required for the operation of intelligent decision making is incorporated into the computer. The knowledge bases are nothing but algorithms such as neural networks, fuzzy logic, statistical learning and genetic algorithm which have image understanding and decision making capacity thus providing system control capabilities. In food industry, computer vision is being used successfully to implement neural network, decision tree and fuzzy logic (Ying et al., 2003). Shahin et al., (2001) developed a fuzzy logic and neural network classifier for sorting apples based on watercore severity using selected features. Similarly, based on feature selection seed species were discriminated by artificial vision using a genetic algorithm while decision tree has been applied to problems such as predicting meat yield and meat quality grade (Song et al., 2002), and segmenting the colour images of chicory (Zhang, De Baerdemaecker, & Schrevens, 2003).

**APPLICATIONS**

Computer vision is non-destructive and cost effective technique that offers the potential to automate manual grading practices thus standardizing sorting techniques and eliminating monotonous human inspection tasks. It has proven successful for the objective and online measurement of several food products with applications ranging from routine inspection processes to the complex vision guided robotic control. This section of the paper focuses on the application of computer vision technology in the inspection and sorting of fruits and vegetables with respect specific feature.

**FRUITS**

In case of fruit, external quality is of importance and consumer judges the internal quality features from the external appearance of fruits only. The degree of acceptability of fruits is primarily affected appearance i.e. size, shape, colour and presence of blemishes. To meet the quality...
requirements of consumer, computer vision system is being employed in automatic inspection and grading of the fruits. In case of apple handling and processing, computer vision has been used for such tasks as shape classification, defect detection, quality wise grading and variety classification. Yang (1993) considered three major surface features to study the machine vision based classification of apples using neural network. The system gave an average accuracy of 96.6% for the separation of defective samples. Further, Yang (1994) used flooding algorithm to segment patch-like defects viz. russet patch, bruise, and also stalk or calyx area. This technique was further improved by Yang and Marchant (1995), who used a ‘snake’ algorithm to closely surround the defects. A discriminant analysis technique was applied for the classification of Golden Delicious apples on the basis of mean hue. The systems achieved over 82.5% accuracy which is poor with reference to European standards (Heinemann, Varghese, Morrow, Sommer, & Crassweller, 1995). Tao et al. (1995) achieved accuracy of over 90% in color based (yellow or green) classification of ‘Golden Delicious’ apples using HSI (hue, saturation and intensity) colour system method. Leemans et al., (1998) studied the defect segmentation of ‘Golden Delicious’ apples using machine vision and found that proposed algorithm is effective in detecting various defects such as bruises, russet, scab, fungi or wounds. Steinmetz et al. (1999) tried the combination of image analysis and near-infrared spectrophotometric sensors to predict the sugar content in apples. Proposed system gave an accuracy of 78% for the prediction of sugar content with a processing time of 3.5 s per fruit. Paulus and Schrevens (1999) performed that shape profile analysis of apples using a Fourier expansion procedure. These results were then compared to Fourier coefficients of profiles from an existing shape descriptor list. The first and second components were found to explain 92% of the total variance in the fruit. Experimentation by Paulus et al. (1997) also used Fourier analysis of apple peripheries as a quality inspection/classification technique. Kim and Schatzki (2000) classified apples based on features extracted from X-ray scanned apple images. 2-D X-ray imaging was used to detect internal water core damage in apples. Apples were classified into clean and severe categories with 5–8% false positive and negative ratios. Dubey et al. (2016) investigated an image processing based approach for the apple disease classification using color, texture and shape based features. The approach is composed of four steps i.e. 1. Extraction of region of interest by K- means based defect segmentation method, 2. Drawing state-of-the-art color, texture and shape based features from the segmented apple diseases, 3. Formation of more distinctive feature by combining the different features and 4. Training and classification by Multi-class Support Vector Machine. They concluded that the proposed approach is better as compared to the individual features.

Nielsen et al. (1998) applied fuzzy sets to correlate the inner quality of the tomato samples with the attributes of size, colour, shape and abnormalities, obtained from tomato images. Laykin et al. (1999) performed quality sorting of tomatoes based on a two-sensor system, one for vision and the other for impact. The combined sensor system yielded 88% exact classification with 95% of the fruit correctly classified. Morimoto et al., (2000) applied chaos theory to evaluate tomato fruit shape quantitatively using an attractor, fractal dimension and neural networks. The study showed that a combination of these three elements offers more reliable and sophisticated classification. Arjenaki et al. (2013) developed a online tomato sorting system based on shape, maturity, size, and surface defects using machine vision.

In case of citrus fruits, color and size are considered to be the most important features for accurate classification and sorting (Khojastehnazhand et al., 2009). Further, the reflectance properties of citrus fruit are also considered as the basis for image analysis for citrus inspection. Ruiz et al., (1996) used image analysis techniques such as colour segmentation, contour curvature analysis and a thinning process for the location and characterisation of stem calyx area on mechanically harvested oranges. These techniques have yielded accuracies of 93%, 90% and 98% respectively, for stem absence or presence. Cerruto et al. (1996), proposed a technique to segment blemishes in oranges using histograms of the three components of the pixel in HIS (Hue, Saturation, Intensity) color space. Ying et al. (2004) estimated the maturity of citrus using a dynamic threshold in the blue component to segment between fruit and background. In this study, neural network is used to distinguish between mature and immature fruit. Kondo et al., (2000) evaluated Iyokan orange fruit for its sugar content and acid content using a machine vision system. A colour TV camera was used for obtaining images to extract features representing fruit colour, shape and roughness of fruit surface. The correlation coefficient between measured sugar content values and predicted sugar content values was 0.84 while the correlation coefficients between measured pH values and predicted pH values was 0.83 for the developed system.

Nagata et al. (1997) developed a computer vision sorting system to sort fresh strawberries based on size and shape. The developed system had an accuracy of 94–98%. However, another automatic strawberry sorting system was developed by Bato et al. (2000), had average shape and size accuracies of 98 and 100%, respectively. Feng et al. (2009) developed a color space based image segmentation algorithm. They developed a strawberry harvesting robot which uses a global camera and a local camera for imaging. From the binary image, the robot finalizes the location of the fruit. The color space based fruit ripeness judgment method guided the robot to pick the fruit according to its
A machine vision system was developed for the detection of early split lesion on the hull of pistachio nuts (Pearson & Slaughter, 1996). Grey scale intensity profiles across the width of the pistachio nuts were used for the detection of early split. The developed system classified early split nuts with 100% success and normal nuts with 99% accuracy. Ghazanfari et al., (1996) developed a multi-structure neural network classifier for classification of four varieties (classes) of pistachio nuts.

Pearson and Toyofuku (2000) developed an automated machine vision system to identify and remove pistachio nuts with closed shells from processing streams. The system uses line scan cameras for classifying the open and closed shell nuts. The classification accuracy of the system was approximately 95%, similar to mechanical devices. A system having X-ray imaging integrated with machine vision was used to detect pinhole damage in almonds (Kim & Schatzki, 2001). For online system, the computation rate was estimated to be 66 nuts per second.

For detecting and identifying major defects in stone fruit, a monochromatic camera with a near infrared band pass filter was used (Singh & Delwiche, 1994). The values of correlation coefficients between the machine predicted and manually measured defects areas were 0.75 and 0.72 for bruise and scar, respectively. Zhang et al. (1999) applied computer vision technology in detection of pear bruising and confirmed that bruised areas can be precisely perceived with most relative errors controlled to within 10%. Silvia (2011) assessed quality blueberries while Sadegaonkar (2013) evaluated the quality Inspection and grading of mangoes by computer vision & image analysis. Nandi et al. (2012) developed a computer vision based automatic based system for automatic grading and sorting of mango (Magnifera indica L.) based on maturity level. The automated system collect video image from the CCD camera placed on the top of a conveyor belt carrying mangoes, then it process the images in order to collects several relevant features which are sensitive to the maturity level of the mango. Finally the parameters of the individual classes are estimated using Gaussian Mixture Model for automatic grading and sorting.

Patel et al. (2011) developed an efficient fruit detection system using multiple feature based algorithm. They analyzed multiple features like intensity, color, edge and orientation. The system computes the feature map for different type of feature points and according to the feature map the fruit regions are extracted. The developed method can be used for all kind of images provided that there are at least one or more meaningful fruit regions.

Savakar et al. (2012) used a Back Propagation Neural Network (BPNN) to classify and recognize the bulk fruit image samples, using three different types of feature sets, viz, color, texture, combination of both color and texture features. The study revealed that the combination of color and texture features are out performed the individual color and texture features in identification and classification of different bulk fruit image samples.

**VEGETABLES**

Consumer demand for quality vegetables has resulted in the greater need for improved and more accurate grading and sorting practices. Computer vision has shown to be a viable approach of meeting these requirements for the vegetable industry (Shearer & Payne, 1990).

Batchelor and Searcy (1989) developed two algorithms for analysing digital binary images and estimating the location of stem root joints in processing carrots. Developed algorithms had potential of estimating the root location with standard deviation of 5 mm. For classifying broccoli heads from assessment of its maturity from the analysis of line scan images, the discrete Fourier transform was developed. An accuracy of 85% was achieved for multiple cultivars.

In mushroom, discoloration is undesirable as it reduces the market value. Heinemann et al. (1994) utilized image analysis technique for automated inspection and grading of mushrooms (Agaricus bisporus). The features considered automatic grading includes colour, shape, stem cut and cap veil opening. Misclassification of the vision system averaged 20% and compared well with the analysis of two human inspectors. Reed et al (1995) used camera vision technology to select mushroom by size for picking by a mushroom harvester. Van Loon (1996) studied the objective measurement of the developmental stage of mushrooms using computer vision system. The study revealed that the developmental stage of mushrooms and cap opening of mushrooms are correlated the best with the except for tightly closed mushrooms. Another study by Williams and Heinemann (1998), described the development of computer vision techniques for the detection, selection, and tracking of mushrooms prior to harvest. Vizhanyo and Tillett (1998) applied vision technology for distinguishing mechanical damage from diseases in mushrooms for optimizing the handling practices so as to maintain maximum quality. On the same line, Vizhaanyo & Felfoldi, (2000) used machine vision system to recognise and identify discoloration caused by bacterial disease. Intensity normalisation and image transformation techniques were applied in order to enhance colour differences in true-colour images of diseased mushrooms.

Shape, size, colour, blemishes and diseases are the important characteristics which are considered while grading...
and inspecting potatoes. As per the market need potatoes are required to be classified in various shape, as potatoes have many possible shapes, this has created difficulties for shape separation. Tao et al. (1995a) investigated the use of a Fourier based automatic separation technique for shape grading potatoes and defined a shape separator based on harmonics of the transform, resulting in 89% agreement between the vision system and human assessment. Guizard et al. (1998) developed an automatic potato sorting method based on two colour components related to tuber brightness and blemishes. The developed system had an 80% success rate when validated against human expertise. Wooten et al. (2000) developed an image acquisition system for mounting on a sweet potato harvester for the purpose of yield and grade monitoring. Classification rates as high as 84% were recorded for the separation of culls from saleable produce. Machine vision system consisting of an accelerator system based on Pneumatic control valves and air pressure was developed for online sorting of potato (Golmohammadi, 2013). The developed system had an accuracy of 97.4% with the speed of two potatoes per second.

Machine vision has also been used in a variety of other quality assessment applications in the vegetable industry. Hayashi et al. (1998) developed three image processing algorithms to recognise cabbage head and to estimate head size for the construction of a selective harvester. With developed algorithms, the projected area the head size could be estimated in a processing time of 2.2 s with an error of between 8.6 and 17.9 mm.

Tollner et al. (1999) used X-ray imaging technology for line-scanning the sweet onions for estimating the internal defects. The study indicated that a Neural classifier was better than a Bayesian, in terms of sorting onions into two classes.

Chilli is consumed in the various parts of the world. It has a high processing demand and proper sorting is required before filling or canning. Hahn and Sanchez (2000) developed a chilli classifier that classifies chilli by three different width sizes, by means of a photodiode scanner. Classifier had accuracy on the necrosis detection and width classification as 96.3 and 87%, respectively.

Gracia et al. (2011) developed a new vision system to characterize the position of flowers/fruits/vegetables in complex images. The retrieved information was used for several types of agricultural tasks, such as recollection, cutting, packaging, classification, fumigation, etc.

Dubey et al. (2013) developed a framework operating in three phases, image segmentation, feature extraction and training and classification. The experimental results suggested that the developed method is able to support the accurate classification of fruits and vegetables from the images. The proposed feature is validated for the fruit and vegetable recognition problem and shows fairly more accurate results compared to other features.

CONCLUSION

This review presents the basic concepts and recent developments in computer vision technology coupled with its application in quality evaluation of fruits and vegetables. The adoption of this emerging technology in sorting and grading of fruits and vegetables will be of immense benefit as it improve productivity of industry and will also help to provide better quality fruits and vegetables to consumers. The objectives of the typical applications of such systems include the classification, quality estimation according to the internal and external characteristics, supervision of fruit and vegetable processes during storage or the evaluation of experimental treatments. The online sorting system allows one to inspect large quantities of fruits or vegetables individually and provide statistics on the batch inspected. The use of computer vision technology can be as simple as producing an inspection quality report or as complex as total process automation. As our understanding of learning algorithms continues to mature, it seems inevitable that machine learning will play an increasingly important role in computer vision for food quality evaluation.

REFERENCE


