# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

Inspection for quality is an important procedure for marketing, storing and processing of fruits. Size, shape, colour and defects are some of the significant properties related to the quality of fruits. Evaluation of these quality parameters and removing any defective fruits from processing line is an important aspect of quality control in industry. Also, such inspection results in fruits having a better appearance and improved consumer acceptance.

Traditionally, the fruits are inspected for quality by human inspectors. Manual inspection of large quantities of fruits is a tedious and labour-intensive task. Human inspectors view the fruits and assign quality scores depending on fruit quality for suitable grading. Although human vision is best at analysing very complex scenes, it looses its precision for carrying out a repeated task like the inspection of fruits.

Application of machine vision for quality inspection of fruits can solve many of the limitations related to the manual inspection. This has great potential for supplementing human labour for the visually intensive inspection work. Machine vision inspection involves determining the fruit quality by analysing the images of the fruits. Machine vision based sorting system consists of a computer and video cameras to perceive fruit images, process their images, and make suitable inspection decisions. Grading decisions required in many agricultural processes, which are otherwise difficult, can be taken up by machine vision. Machine vision can also be far more cost effective and sometimes is the only viable solution for higher throughput and/or hazardous conditions.

The machine vision inspection system essentially involves three main processes namely image acquisition, image processing and decision making. Image acquisition is carried out by cameras under appropriate lighting conditions and by converting the visual information into analogue or digital images. The acquired images are analysed by image processing hardware and/or software to extract the required object features and quality parameters. Based on these results, a decision on the fruit quality is taken by software considering the end user's requirements.

A machine vision based fruits sorting system essentially consists of a mechanical conveying system, an illumination system, an imaging system, suitable image analysis software and mechanical separator. The mechanical conveyor system physically transports the fruits along the process line for imaging, sorting, grading and packing either manually or automatically. This system carries out singulation, orientation, rotation and transport of fruits along the process line without causing any damage. The illumination system provides suitable lighting to the fruits. This system provides a diffused, uniform illumination while avoiding specular reflections and shadows. The imaging system acquires the images of the fruits. It is capable of acquiring multiple images of the fruit's surface for proper quality evaluation as the fruits pass on conveyor system. The image analysis software analyses the acquired images to extract various features relevant to the quality of the fruits. The quality parameters may include size, shape, colour etc. Based on these results, the software assigns a grade number to each fruit. The mechanical separator unit directs the fruits in to different bins based on the grade number.

Each of the above described subsystems of a fruit sorting system plays an important role in influencing the overall performance of the on-line sorter. Parameters like size, shape and colour are the most significant criteria related to fruit quality and decide many commercial factors like pricing, variety identification, grade, etc.

Size and shape are features easily comprehended by humans but difficult to quantify or define for analysis by computers. The biological products like fruits tend to have great variability in shape and size. Damage during harvesting and handling adds more kinds of shapes. Thus fruits may have infinite number of possible shapes. Size and shape of fruits is usually judged manually according to how well they conform to the characteristic shape of the fruit variety. Colour is one of the most significant inspection criteria related to fruit quality. Colour is a parameter, which influences the visual appearance of the fruits and their consumer acceptability. Also, the surface colour indicates maturity and defects. The biological products will create difficulties for the measurement or even assessment, due to the lack of homogeneity in colour distribution. Thus, it is hard to provide precise guidelines for appearance using colour discrimination. The colour of an object is determined by wavelength of light reflected from its surface. These spectral variations provide a unique key to machine vision and image analysis.

Most of the image processing applications for parameter extraction deals with huge amount of data. So the image processing algorithms should be efficient and be optimised for speed to achieve the required throughput. The diversity and variation in characteristics of biological materials create large variations in measurements. This variation complicates the vision inspection algorithm and measurement accuracy of the vision system. These variations must be considered while developing an effective vision inspection system for fruits.

A typical on-line sorter system for fruits contains a conveyer system, illumination system, imaging system, computer system for analysis as shown in Figure 1.1.

## 1.2 BRIEF REVIEW OF LITERATURE

In literature, considerable research work has been reported regarding development of different sub-systems of a machine vision based on-line fruits sorter.

The conveyor system transports large quantities of fruits at constant speed along the process line for quality inspection. (J.A. Throop and G.E.Rehkugler 1986, M.Recce, et al., 1998, H.K.Purwadari and I. W. Budiastra 1997). In machine vision based systems, the conveyor is additionally required to fully expose the fruits for imaging over their surface area. Also, the orientation of the fruit becomes important as it controls the portions of the fruit available for imaging. For many fruits, the stem portion may be mistaken for bruises (J.A. Throop et al 1997, J.A., Throop et al.,1995). The orientation mechanism orients the fruits to their stem and calyx

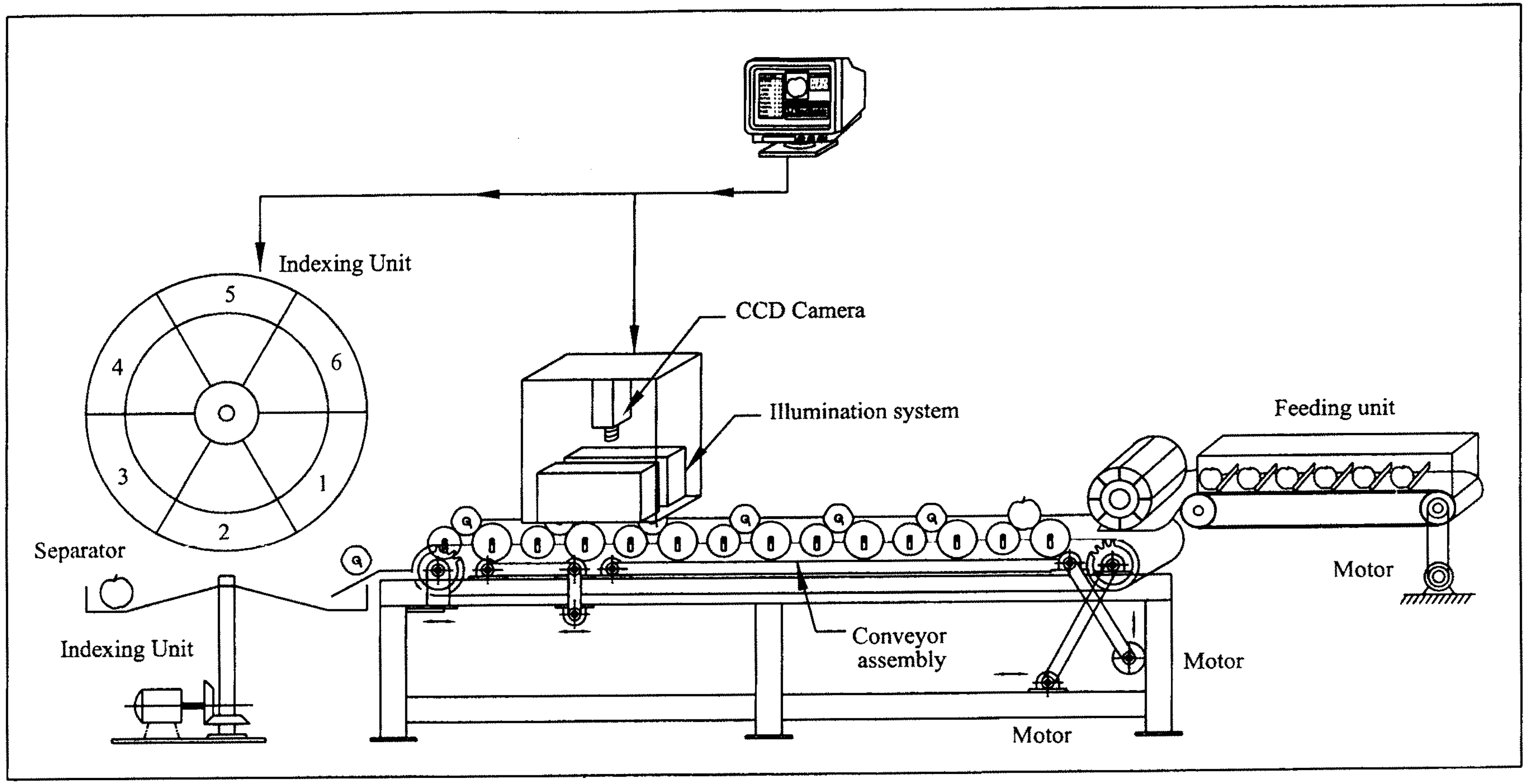


Figure 1.1 Line diagram of a Machine vision system for sorting and grading of fruits

axis from any random orientation. The fruit is rotated around the stem-calyx axis and multiple images are collected for evaluation. Under this condition, the stem portions will only appear at either the stem or calyx ends of fruit's image. Hence, it becomes easier to detect and eliminate the stem portion by suitable software algorithms (E.Molto et al.1996).

The image of an object is a function of the spectral properties of its surface, the spectral distribution of illumination source and the camera's spectral response. The spectral response may be known for a camera chosen for an application. However, illumination may vary over time in both intensity and colour due to lamp deterioration or changes in supply voltage and ambient temperature. As a result, images of an object taken at different times may appear differently, making analysis of images difficult, especially when colour or reflectance information are involved in the analysis. (M.R.Paulsen and W.F.Mcclure 1996, Brainard, D.H. and M.B.Wandell 1990, Gershon R and A.P.Jepson 1989, Hetzroni A and G.E.Miles 1994). As the colour inspection and classification system is expected to match the judgement of human graders, the illumination source should provide light in the visible spectrum i.e. 400nm to 700nm (J.A..Throop and G.E.Rehkugler, 1988).

Various techniques were suggested for estimating the size of the objects. Boundary encoding such as chain coding (H Freeman 1961), was adopted for size evaluation. Curvature, compactness, bending energy, and maximum-minimum diameters were used for size /shape description (K.S.R. Fu et al 1987, M Barnsley 1988 and S Marshals 1989). Different wheat varieties were distinguished using algorithms that compared kernel dimensions and shape characteristics (Jayas et al 1982,1985,1986 and Lai et al 1986)

Fast Fourier Transform analysis for size inspection of potatoes based on elongation ratio was derived from Fourier harmonics (Y. Tao et al 1990). Size and shape features such as kernel length, width, projected area, and aspect ratio were used to classify cereal grains (H. D Sapirstein 1987). Size and shape algorithms were described for evaluating potatoes (J.E McClure 1988). Size, shape and colour evaluation of apples and potatoes was described (Y. Tao et al 1995a and Y. Tao et al 1995b). A computer vision based multi-index active food shape feature extractor was developed (S. Gunasekaran and K. Ding 1994).

Fourier descriptor technique (T Jiang 1988 and Gonzalez 1988) of using boundary radius and its Fourier transform was studied for size/shape description. Boundary coding methods were found not useful for quantifying size because of the stem on some apples (H. Heinemann et al 1996). Size was estimated from area measurements in certain variety of apples (Varghese et al 1991 and N.K. Okarmra 1991). In certain fruits like tomatoes, the size was estimated based on perimeter and diameter. Measurement of size was done based on the ratio of major and minor axes of fruits (E. Molto et al 1996).

Usually the shape of a fruit is determined by judging how well it conforms to the characteristic shape of the fruit variety. Various techniques (M.K. Hu 1962, M.R Teague 1980, Jayas et al 1982,1985,1986, Ding et al 1990, Kass et al 1988, K Liao 1992, M. Shah and D.J William 1992) were reported for shape identification and grading. They may be categorized as boundary encoding technique (H Freeman 1961) for finding shape number, statistical analysis using moments (Varghese et al 1991 and N.K. Okarmra 1991), bending energy, radius variation, structure analysis from geometry (J.E McClure 1988 and spectrum analysis (T Jiang 1988 and Gonzalez 1988).

Although many general shape analysis techniques were reported, the natural variability and diversity of biological materials create difficult and practical problems for shape analysis (S.Gunasekaran and K.Ding 1994). In general, two approaches (Leemans et al 1997) namely, region based information and boundary information were adopted for shape extraction of fruits. The first approach was based on geometric parameters while the second approach involves computation of Fourier descriptors. Shape was evaluated (P. Heinemann et al 1995) by comparing the fruit perimeter, the area enclosed by the perimeter, the convex hull of the perimeter and the area enclosed by the convex hull. The Fourier descriptors of an image were calculated by taking the FFT for the sequence considering sample points on the image contour. In general, an image that possesses uniform harmonic values and also containing minimum number of harmonics is highly regular in shape and can be reconstructed easily using lesser number of samples (Y. Tao et al 1995a, 1995b and Leemans et al 1997). The inverse Fourier transform helps in reconstruction of the object based on the contour value of the Fourier descriptors. In general, global shape or the approximate shape of an object can be obtained back using minimum number of harmonics (Leemans et al 1997), but higher harmonics contribute to finer details pertaining to sharp transitions. Using these harmonics data a 'shape number' was defined, which can be used for comparing the shapes.

The colour of an object is determined by wavelengths of light reflected from its surface. RGB colour space was used for colour classification of apples (W.V. Thomas and C. Connoly 1986). Usage of HSI colour space for colour classification of apples was suggested (S.A Shearer and F.A Payne 1990). Entropy and probability methods were adopted for colour analysis (R.K.

McConnell et al 1991). The colour classification of apples was carried out based on histogram comparison (Y.Tao et al 1995). Researchers (E. Ding et al 1990, P. Heinemann et al 1994, 1995 and Robinson 1998) experimentally found that HSI model is most suitable for carrying out colour classification. Linear discriminant analysis (M.G. Kendall and Stuart 1979, D.F. Morrision 1990) was used as a tool to sort apples based on colour. Researchers (E. Ding et al 1990, P. Heinemann et al 1994, 1995 and Robinson 1998) experimentally found that HSI model is suitable for finding out the ripeness of fruits and colour matching.

Although machine vision has been used for varied applications, the vision and image processing methods are largely problem dependent. The power of a machine vision system is a function of computer speed, effectiveness of image processing algorithms, lighting design for feature extraction and speed of the imaging devices. Machine vision techniques have been developing for over three decades, however there is no simple or universal machine vision technique or algorithm that can solve every problem. Based on current technology in computer vision, an efficient and effective method for each particular application can only be achieved through analysing the problem in that domain and developing specific methods for particular applications.

Most of the published literature deals with image analysis independent to the machine vision system. Even couple of papers published around the machine vision system do not deal with more than one parameter based sorting. The machine vision system should deal with more than one parameter that suits on-line applications keeping the throughput requirements as also one of the goals. Hence it is required to develop and analyse suitable algorithms for efficient performance and demanded throughput.

## 1.3 OBJECTIVES

The objectives of the present study are

a) to develop a conveyor system that simultaneously rotates fruits like apples about their stem and calyx axis for alignment
b) to develop an illumination system that provides nearly uniform white light for sorting fruits based on colour, external and internal defects
c) to develop machine vision techniques and algorithms to measure parameters including size, shape and colour

## 1.4 OUTLINE OF THESIS

Present study involved development of an improved conveyor system, illumination and imaging system and new software algorithms for analysis of size, shape and colour. The developed subsystems and software modules are evaluated individually and integrated into a prototype on-line fruit sorter.

The thesis is organized into eight chapters. The chapter wise summary of the thesis stating the developments reported therein and the obtained results are presented here below.

The second chapter describes the development of an improved conveyor system, particularly the singulation unit, the drive system, an improved fruit orientation mechanism, which are critical to its performance. The orientation mechanism automatically aligns a fruit to its stem and calyx axis in a horizontal position. Two orientation mechanisms namely, vertical and horizontal orientation systems are developed, evaluated and the results are presented. After carefully analysing the system requirements, the horizontal orientation mechanism is integrated into the on-line sorter.

The third chapter describes the illumination system developed for use with the on-line sorter system. Various illumination sources, various forms of lighting systems and their suitability for on-line sorting are discussed. Details of newly developed parallel illumination system, procedure for evaluation and obtained results are presented. A novel combination of compact fluorescent lamps (CFL) and incandescent lamps is utilised to obtain illumination with improved primary colour component balance. The illumination system utilised the reflectance standards to calibrate the camera. Study of the uniformity of light distribution in the field of view is carried out using opaque acrylic sheet and delrin ball and the results are presented. 3D graphical representations of colour components distribution over the field of view are also presented.

The fourth chapter describes the development and evaluation of imaging system, which is integrated in to an on-line sorter system. Consideration in the selection of a CCD camera and the optical characteristics of the chosen camera are presented. Various defects in the lenses and details regarding the selection of a suitable lens for this application are discussed. Technical details of frame grabber card used to interface the camera with computer are discussed. This chapter further describes the calculation of focal length and field of view. A novel method adopted for synchronizing image capture with the fruit movement is described. The synchronisation is verified experimentally using a delrin ball. A novel method of colouring the background mechanical parts of the conveyer is described for easy extraction of apple images from the overall image captured by the camera is presented.

The application software of the on-line sorter analyses the captured fruit images to decide on the quality of fruits. The software analyses the size, shape and colour for assigning the grade. Keeping the above in view, new and improved algorithms are developed for analysis of size, shape and colour for quality evaluation of fruits.

Chapter five describes four new analytical methods namely circle method, parabola method, ellipse method, principal axis method and three statistical methods namely, co-efficient of variation, radius signature and area signature for determining the size of fruits. The circle method approximates the fruit image contour with a circle and utilises this circle diameter as a measure of fruit size. The parabola method approximates the fruit image contour with parabola and utilises the length of its latus rectum as a measure of fruit size. The ellipse method approximates the fruit image contour with an ellipse and utilises the eccentricity of the ellipse as a measure of fruit size. Principal axis method quantifies the size of a fruit based on the asymmetry of the contour about its principal axis. Sizes of apples are compared using coefficient of variation, radius and area signatures. All the above methods are evaluated using typical images of apple fruits as an example. As the appearance of the fruit depends on its posture, the analysis utilises six images of each fruit taken in different postures. The methods are evaluated using a large number of fruits and a few sample results are presented.

The sixth chapter describes three different techniques, namely radius signature method, area signature method and boundary vectors methods, to analyse the shape of a fruit. The signatures data provided by the above methods are analysed using statistical methods namely coefficient of variation and Fast Fourier Transform (FFT). For each method, important frequency components generated by FFT analysis are used to derive a shape number, which is useful for grading the fruits. As the appearance of the fruit depends on its posture, the analysis utilises six images of each fruit taken in different postures. Numerical results as well as graphical representation of radius and area signatures are also presented. The newly suggested contour vectors method measures the incremental changes in phase angle between two consecutive vectors on the contour. FFT analysis of these phase angle changes that contain the shape information is used to derive a shape number. The above methods are evaluated using large number of fruits and a few sample results are presented.

The seventh chapter describes two new methods namely hue histogram comparison and linear discriminant analysis developed for colour analysis of fruits. Various colour models are briefly described while highlighting the advantages of HSI colour model for colour classification. Histogram comparison method compares two histograms corresponding to the same colour attribute of the test and the sample fruits. The method makes use of probability density as the information per hue histogram. Linear discriminant method categorises apples based on Mahalanobis distance.

In the concluding eighth chapter, the significant contributions of the present study are summarised and future scope for further work is discussed.