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152 Riley-Robb Hall
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APPLE SHAPE INSPECTION WITH COMPUTER VISION

Leemans V., M. Sc.
Department of Agricultural Engineering,
Faculté des Sciences Agronomiques de Gembloux (Belgium)

Magein H., PhD.
Department of Horticulture,
Faculté des Sciences Agronomiques de Gembloux (Belgium)

Destain M.-F., PhD., A.S.A.E. Member Engineer
Department of Agricultural Engineering,
Faculté des Sciences Agronomiques de Gembloux (Belgium)

ABSTRACT

Two shape separation methods were compared for shape grading of 'Golden Delicious' apples using machine vision. The first one was based on moments and other geometric parameters while the second implied the computation of Fourier descriptors. Both methods required that one stem view and six cheek views of the fruit were presented to the camera. The Fourier descriptors were found the most efficient method since they allowed an accuracy in classification reaching 96 % and can be made invariant to translation, rotation and scale. Furthermore, they are obtained from boundary information and do not need to examine the whole area of the apple. They permit the reconstruction of the apple shape from the harmonics.

Key-words

Apple, shape grading, machine vision, Fourier descriptors, moments

INTRODUCTION

Among other characteristics, such as colour, size, defects, ..., shape determines the overall quality of fruit. The European Union has edicted standards describing the characteristics of fruit aimed for exportation within its borders. For apples, the standards specify that the fruit belonging to "Extra" grade must conform to the characteristic shape of the variety (Journal Officiel des Communautés Européennes, 1989). Some misshapeness is tolerated under grade A and the tolerances increase in grade B.

Apple shapes vary with species and cultivar. According to an early study (Childers, 1949 quoted by Kuhn et al., 1982), the shape of 'Delicious' apples is characterised as being "conic with 5 more or less distinct ribs and 5 crowns on the shoulders at the calyx end". The apple shape is influenced by the growing environment. For example, the dose and time of application of gibberellins may influence the ratio of longitudinal to transversal diameter (Eccher and Boffeli, 1981).

Up to now in Europe, automated sorting machines are available to perform sorting operations of apples on basis of size and colour. Nevertheless, the grading process of apples on the basis of shape and defects continues to be a manual effort. In fact, shape is difficult to appreciate by a simple visual impression and, in certain circumstances, it may be that the attention of the operators would be more focused on the possible presence of severe defects such as scab than on misshapeness. It would thus be interesting to use machine vision as part of an automated shape inspection system in order to have a fair and impartial evaluation of apple shape.

Developing adequate algorithms to describe the shape of apples is complicated because of the high natural variability of these products, implying that the machine vision must be trained by a great number of samples to ensure its reliability. The main techniques used for shape description of food material may be summarised as follows. Sakar and Wolfe (1985), who develop algorithms for feature extraction of tomatoes, compute the curvature of chain-coded boundaries (8-neighbour chain). Van de Vooren et al. (1992) use image analysis for variety testing of mushrooms and measure morphological characters such as circularity, bending energy, sphericity, eccentricity, ... Singh and Delwiche (1994) study the performance of machine vision at detecting defects in stone fruit and quantify the shape by the ratio « maximum dimension » to « minimum dimension ». Ding and Gunasekaran (1994) develop food shape feature extractors based on the comparison of the object to be tested with an average reference undamaged object. Heinemann et al. (1995) define a shape separator based on third-order moments to form a basis for grading 'Golden Delicious' apples. Tao et al. (1995) develop a Fourier-based shape separation method for shape grading of potatoes.

The objective of this study was to develop an effective shape separation method for the grading of 'Golden Delicious' apples using machine vision. Two methods of feature extraction were compared. The first one is based on moments and other geometric parameters while the second implies the computation of Fourier descriptors. In order to judge the fairest method, the following technical specifications are considered:
- the classification accuracy;

- the invariance to translation, rotation and scale;
- the speed of the computation.

IMAGE PROCESSING SYSTEM

The shape investigation is a part of a whole study, including colour information. In this aim, the image processing system comprises a Sony XC-003p 3-CCD camera, a Imascan Chroma colour image frame grabber, a Compaq 80586/133MHz computer equipped with a CD-ROM writer to store the images. The frame grabber captured 768 x 576 pixels images from the camera with eight-bit resolution per colour channel. With a lens of 16 mm focal length, the viewing frame was approximately 140 mm x 90 mm at a camera-to-object distance of 400 mm. The Image Pro plus software (2.0, 1993) containing basic functions for image acquisition and processing was used. The C++ (Microsoft, 2.0, 1994) programming language was used for the development of the algorithms.

Images were acquired under diffuse illumination provided by two fluorescent tubes, 20 W, positioned in the lower part of a horizontal reflector cylinder (500 mm in diameter). The interior surface of the cylinder was painted flat white. A window at the top of the cylindrical chamber was made so that the camera can acquire an image of the upper part of the fruit. A dark conveyor belt was chosen to provide a high contrast between the fruit and the background.

METHODS

Two methods were used and compared to define the apple shape. On the basis of the classification given by Sonka et al. (1995), the first method is "region-based" information while the second is based on apple "boundary" information.

Region-based information

Simple region-based parameters can describe an object shape. The *circularity* is one of the simplest parameters of this kind (Fig. 1). It is defined as:

$$c = \frac{p^2}{4\pi A}$$

with p the perimeter and A the area. The circularity is a dimensionless number with a minimum value of 1 for circles. The circularity is 1.27 for a square and shows high values for elongated objects. It does not depend on the orientation of the objects on the image plane.

The *rectangularity* r is the ratio of apple area and the area of a bounding rectangle having an imposed direction (Fig. 1). Rectangularity assumes values comprised between 0 and 1 with 1 representing a perfect rectangle. L/D gives the ratio of the side lengths of the rectangle (Fig. 1).

The *moments* are well known in statistics, where they are used to characterise data and probability density functions, as well as in mechanics where they are associated with rotating bodies problems. The central moments of order p, q are invariant to translation and are given by:

$$\mu_{pq} = \sum_{i=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} (i - x_c)^p (j - y_c)^q f(i,j)$$

where i, j, x_C, y_C are respectively the co-ordinates of the pixels and of the centroid of the apple. The function f(i,j) is a binary, 2-dimensional function with level "1" within the apple and level "0" elsewhere.

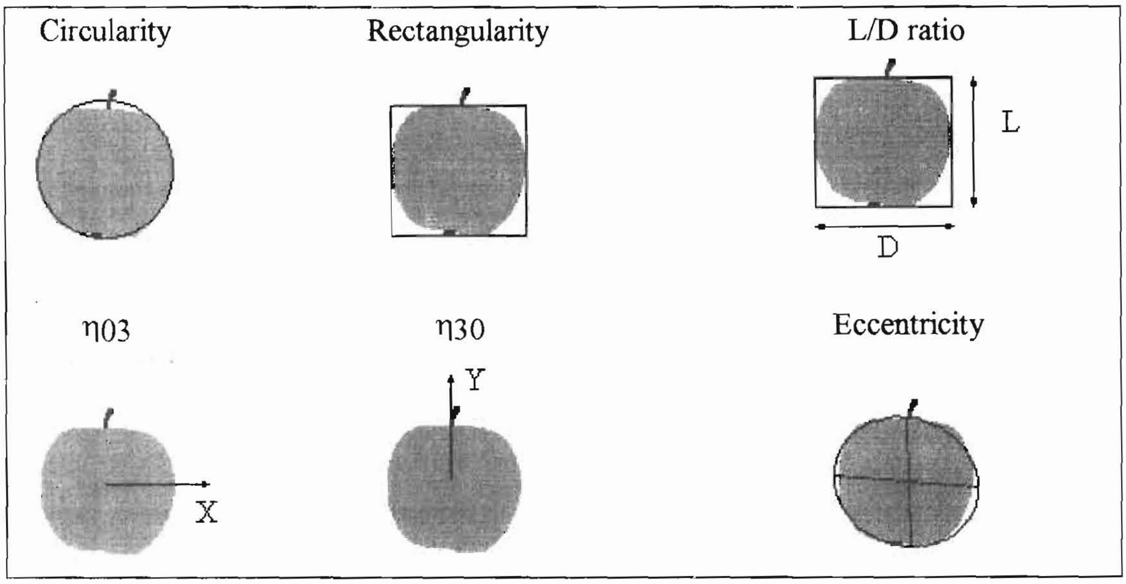


Figure 1 : Region-based parameters.

From the second order central moments, it is possible to compute the *principal axes* of the apple and the *principal moments*. These are respectively the eigenvectors and the eigenvalues of the following matrix :

$$\begin{bmatrix} \mu_{20} & \mu_{11} \\ \mu_{11} & \mu_{02} \end{bmatrix}$$

The *eccentricity* ε can be defined as the ratio between square roots of the two principal moments (Fig. 1). This parameter ranges from 1 to ∞. It is one for a circular object and high for a line-shaped object. It depends solely on the shape, not on size and orientation.

The third order central moments $\mu 03$ and $\mu 30$ are useful because they indicate the fruit imbalance with respect respectively to x and y axes (Fig. 1). They are computed using the following relationships:

$$\mu_{30} = \sum_{i=-\infty}^{\infty} (i - x_c)^3 \qquad \mu_{03} = \sum_{j=-\infty}^{\infty} (j - y_c)^3$$

In order to arrive at a size independent description, $\mu 03$ and $\mu 30$ can be normalised using following expressions:

$$\eta_{30} = \frac{\mu_{30}}{\mu_{00}^{\alpha}} \qquad \eta_{03} = \frac{\mu_{03}}{\mu_{00}^{\alpha}}$$

with $\alpha = 2.5$ and μ_{00} is the area of the object.

Moment invariants $\phi 1$ and $\phi 2$, defined by Hu (1982) and quoted by Jähne (1995), depend neither on position, nor size, nor orientation and are given by:

$$\phi_1 = \eta_{20} + \eta_{02} \,,$$

$$\phi_2 = (\eta_{20} - \eta_{02})^2 + 4(\eta_{11})^2 \,,$$

where $\eta 11$, $\eta 20$ and $\eta 02$ are the second order normalised central moments. A disadvantage of the moment invariants is that it is difficult to give them a geometric interpretation.

Boundary information

The Fourier descriptors use only the boundary of the object and consider it as a pair of cyclic waveforms which provides a parametric description of the boundary trace. Let θ be the angle between the radius drawn from the centroid to a point on the boundary and the x-axis for example. By travelling along the boundary curve, one describes the apple *radius* r(k) as a function of this angle. Boundary signature r(k) is one-dimensional and translated to Fourier domain by:

$$F(h) = \frac{1}{N} \sum_{k=1}^{N} r(k) \exp\left(\frac{-j2\pi hk}{N}\right)$$

where N is the number of equiangular samples to describe the boundary, F(h) is the complex magnitude at harmonic h, with h = 0,1,2 .... N/2-1. The Fourier descriptors give a complete description of an object which can be made translation, rotation and scale invariant. If an object is rotated by an angle γ, the Fourier descriptors are multiplied by a phase factor. If an object is scaled by a factor of α, the Fourier descriptors are multiplied by the same factor.

Algorithms

Firstly, the RGB colour information issued from the camera was transformed to a 8-bits grey level. To extract the binary apple from image data, images were threshold at a 50 level. A succession of erosion, dilatation and erosion operators was then applied to remove the stem from the image without altering the apple shape. Before computing the Fourier descriptors, an edge detection was performed on the image. The harmonic components were computed thanks to a Fourier transform (FFT).

RESULTS AND DISCUSSION

Two samples of 20 apples 'Golden Delicious' were taken at random in grades A and B established by professional inspectors. 14 misshapen apples were selected within the rejected products. Whatever the chosen method for feature extraction, two particular fruit orientations were chosen. Firstly, the stem-calyx axis was placed perpendicular to the camera optical axis. Six images of the fruit cheeks were acquired at 60° rotation increments, around the stem-calyx axis. Secondly, the fruit was placed with the calix end on the conveyor. In this latter case, one view was acquired of the stem pole.

Region-based information

Circularity c, rectangularity r, eccentricity ε, third order central normalised moments η_{03}, η_{30} and invariants moments ϕ_1, ϕ_2 were computed for the views from the stem end. Mean, maximum and minimum values of the same parameters were computed for the six views of the cheek apples.

The most significant parameters were found by performing an analysis of variance to compare the apple populations graded in class A, B and within the rejected fruit. It appears that for the stem view, the value of parameters c, ε and ϕ_1 were significantly different. For the cheek views, r_{max}, ε_{max}, c_{max}, η_{03min} and η_{30max}, ϕ_{1max} and ϕ_{2max} were different between the grades and were considered as good indicators of apple shape. On the basis of the numerical values of these parameters, it may be confirmed that commonly accepted 'Golden Delicious' has a conic shape and is almost symmetric with regard to stem - calyx axis (Kuhn et al., 1982). The mean values of these parameters corresponding to apples belonging to categories A and B are given in Table 1.

Table 1. Mean values of shape parameters for apples belonging to grades A and B - measurements on cheeks

Parameters	Values
Circularity c	1.17
Rectangularity r	0.82
Eccentricity ε	1.05
η_{03}	8.79 E-04
η_{30}	5 00 E-04
ϕ_1	0 1603
ϕ_2	7.83 E-05

Linear and quadratic discriminant functions were developed using the most significant parameters and including either the third order central normalised moments η_{03}, η_{30} or the moment invariants ϕ_1, ϕ_2.

When using the third order central normalised moments and taking into account two grades (accepted: A+B; rejected), the classification accuracy reached about 90 %, provided that parameters related to both the cheeks and the stem views were introduced. The best set of two parameters included $(\eta_{30max})_{cheek}$, and $(\varepsilon \quad)_{stem}$. The accuracy in the discrimination was not really improved when three or four parameters were used. On the other hand, it decreases dramatically when performing computations only on the basis of the cheek views or when less than 6 cheek views were taken into account. Furthermore, results were quite similar whatever the kind of discriminant function, linear or quadratic. When considering 3 grades (A, B, rejected), the accuracy of the classification was smaller. This resulted probably from the fact that the manual inspection considered as reference is not perfect: grading on the basis of the shape is not easy to perform manually and, in some cases, does not appear as primordial in the mind of the inspectors.

Even if the classification was quite satisfactory by using the third order central normalised moments, it suffered from the fact that results depended on the apple orientation. To overcome this problem, the moments were taken about the principal axes which are an inherent shape characteristic. Unfortunately, the orientation of these latter were found to vary widely from the position of the stem-calyx axis, from one apple to another, and hence this technique was not adequate to characterise the symmetry or the conic shape of the fruit.

When using the moment invariants as basis for the classification, the error reached more than 20 % whatever the kind of discriminating function (linear or quadratic).

Boundary information

In a first stage, the Fourier descriptors were computed by taking N = 256 (Fig. 2). The magnitude of the harmonics F(h) were normalised by dividing each of them by F(0) which is the mean apple radius. It was found that the amplitude of the harmonics becomes negligible when h increases and, consequently, the number of samples N to describe the boundary was limited to 32 ($=2^5$).

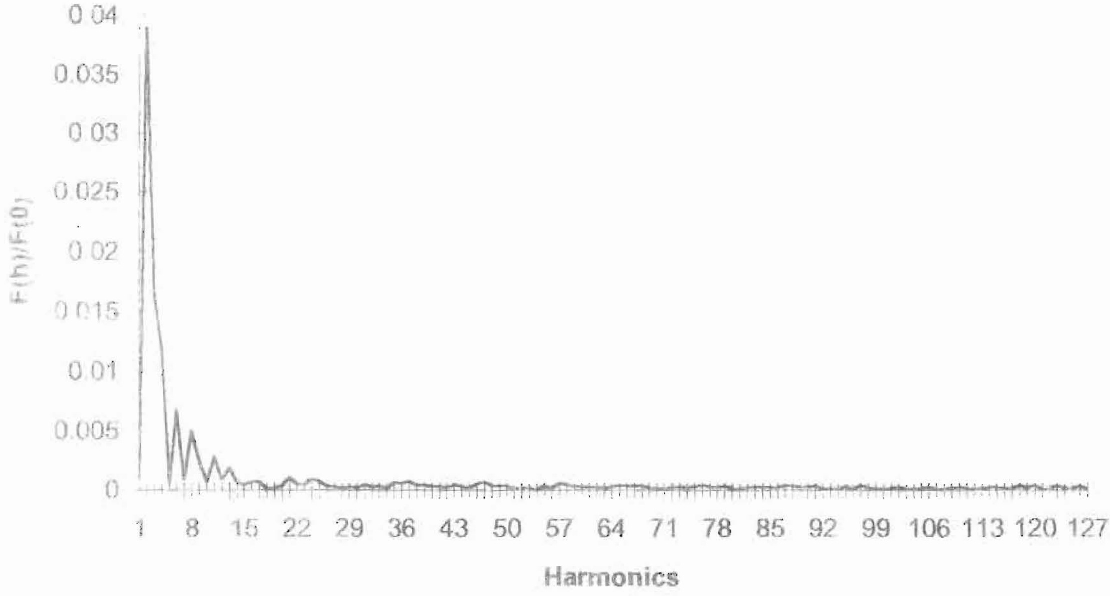


Figure 2 : Fourier transform of the radius r(k).

The ability of the method in shape reconstruction was tested by computing the Fourier inverse. Results were compared when taking into account 15 harmonics, which is the maximum number available when N=32, and smaller numbers such as 2 and 4.

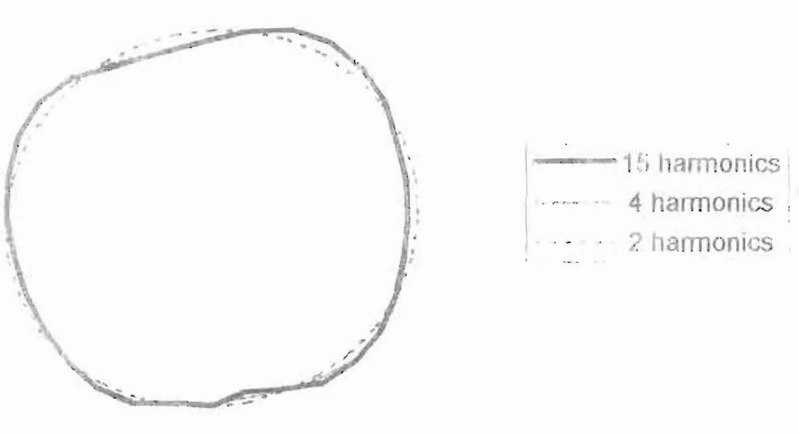
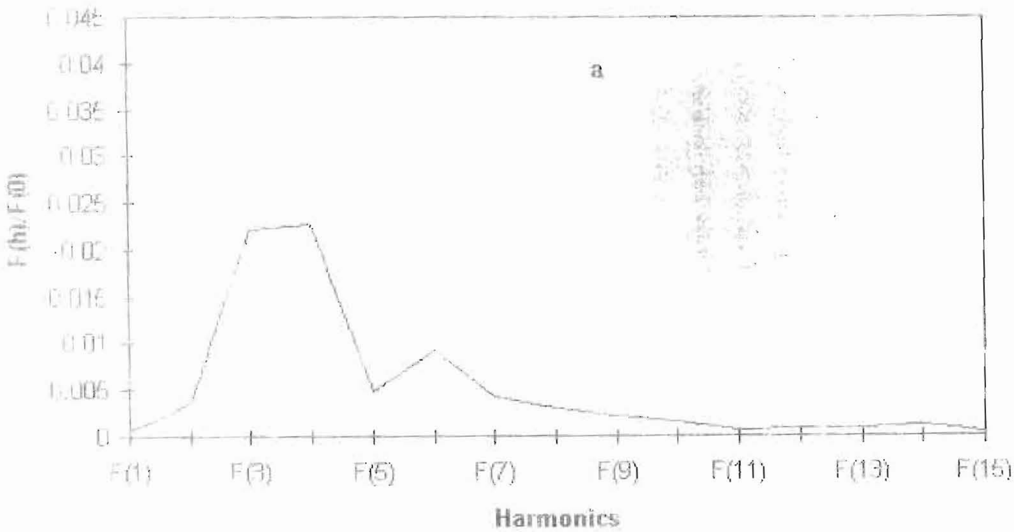
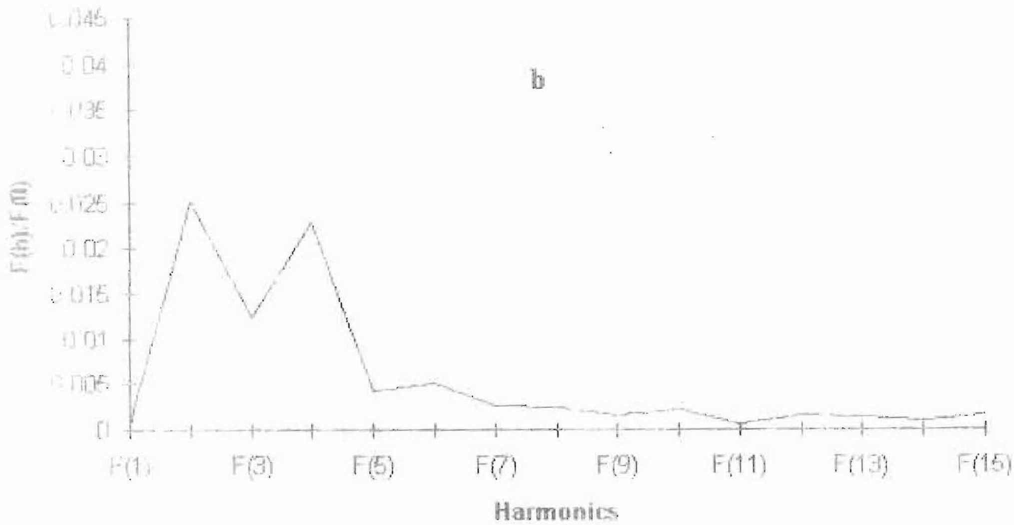


Figure 3 : Reconstruction of the apple shape, by considering 2, 4, 15 harmonics

It appeared that a low number of harmonics were sufficient for representing the shape of an apple without loosing essential information (Fig. 3). For example, in Fig. 3, the global shape is given by 4 harmonics, more accuracy in the reconstruction, especially at the calyx pole, is obtained with 15 harmonics.

The Fourier descriptors carry information about the boundary shape. As mentioned above, F(0) is the mean object radius, F(1) represents the bending of an object, F(2) corresponds to elongated objects, F(3) is significant in presence of triangular objects, F(4) can be pointed out when the objects are squared, etc... Since the apple shape approaches a circular form, as indicated namely by the geometric parameters computed above, the numerical value of F(0) is high. The effect of the apple shape on F(1), F(2), ...is shown at Fig. 4.





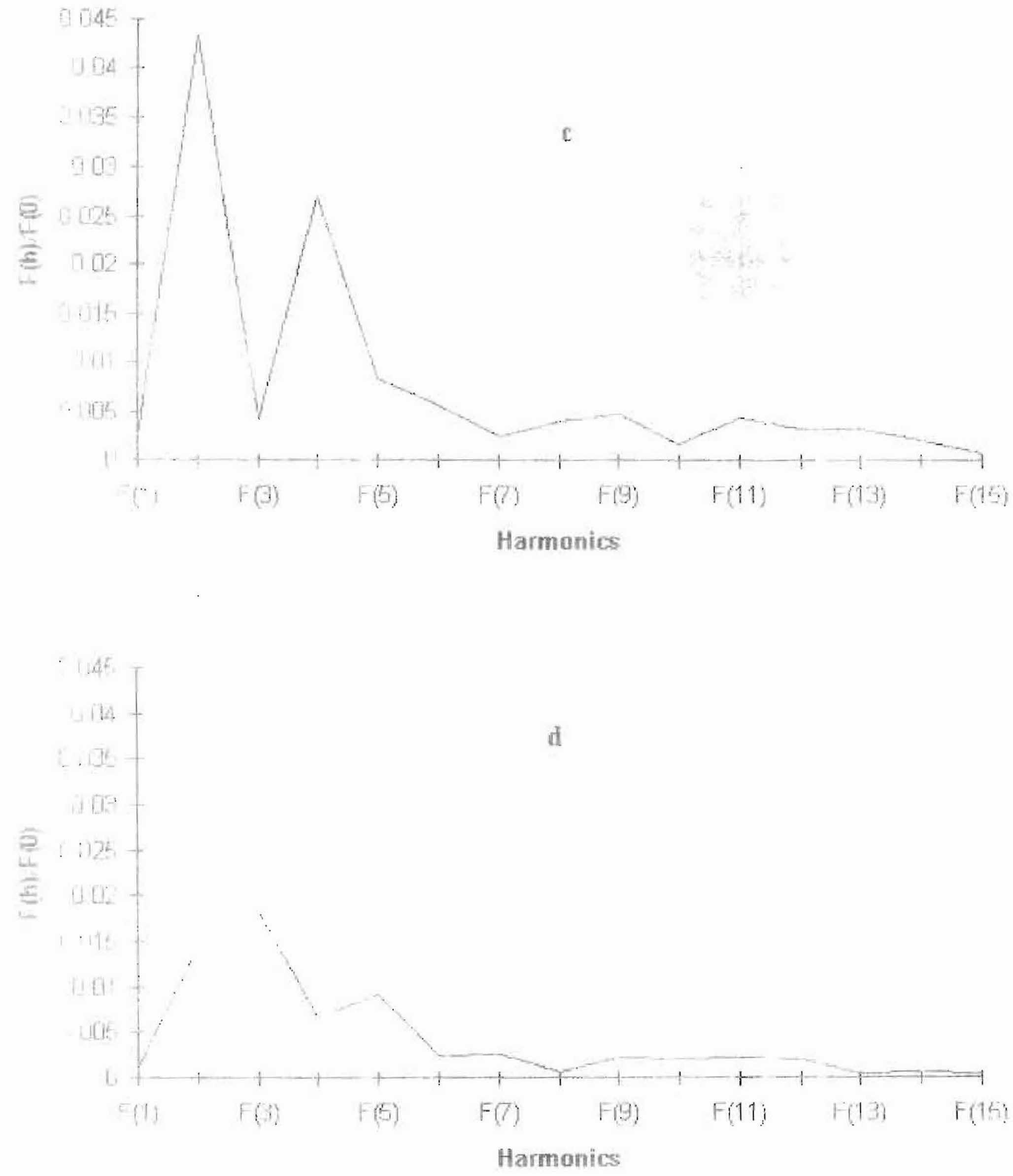


Figure 4 Apple Shape and magnitude of harmonics

Apples **a** and **b** belonged to grade A, their spectrum indicated peaks corresponding respectively to F(3), F(4) and F(2), F(4).

The shape of both fruit could be related to a square, but apple **a** was more "triangular" than apple **b** which is more elongated. Apples **c** and **d** were rejected by the inspectors because of their inadmissible shape. Apple **c** was characterised by a too high amplitude of F(2) and a very low F(3) one, when **d** exhibited a too low F(4) values.

Discriminant analysis was used to allocate the apples into 3 grades (A;B; rejected). The eight first harmonics were considered as well for the cheek views as for the stem view. The examples given above showed that the extremum values of the cheek views were particularly significant to describe the apple shape. Consequently, the maximum and minimum values of the eight first harmonics were introduced into the linear discriminant analysis. With this method, 94 % of apples were correctly graded. With quadratic discriminant analysis, and when choosing special harmonics, namely F(2), F(3), F(4) for the cheek views and F(1), F(3), F(9) for the stem view, the accuracy classification reached 96 %. The badly sorted apples belonged generally to intermediate grade B and it was noticed that it is generally easier to separate fruits between A, B in one hand and reject category in the other hand than within A and B.

CONCLUSION

The Fourier descriptors are a powerful tool which ensures a better accuracy in apple classification than region-based parameters. By taking six views of the cheeks spaced of 60° and one view of the stem and extracting extremum values of particular harmonics, accuracy in classification reaches 96 %. Furthermore, the Fourier descriptors can be made invariant to translation, rotation and scale; this feature is important to point out for "on-line" grading objectives. They are obtained from boundary information and do not need to examine the whole area of the apple; in that way, they can ensure a reduction of memory storage when compared to region-based parameters such as the moments. At least, they allow the reconstruction of the apple shape.

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