XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

ANALYSIS OF THE MOVEMENT OF FRUITS DURING MECHANICAL HARVESTING WITH SHAKERS USING COMPUTER VISION AND A SLOW MOTION CAMERA

J. BLASCO[1], A. TORREGROSA[2], N. ALEIXOS[3], C. ORTIZ2, S. CUBERO[1], F. JUSTE[1], E. MOLTÓ[1]

[1]Centro de Agroingeniería. Instituto Valenciano de Investigaciones Agrarias (IVIA),
Ctra. Moncada-Náquera km 5. 46113 Moncada (Valencia), Spain, blasco_josiva@gva.es
[2]Dpto. de Ingeniería Rural y Agroalimentaria. Universidad Politécnica de Valencia,
Camino de Vera s/n, 46022 Valencia, Spain
[3]Instituto en Bioingeniería y Tecnología Orientada al Ser Humano.
Universidad Politécnica de Valencia. Camino de Vera s/n, 46022 Valencia, Spain.

CSBE100602 – Presented at Section VI: Postharvest Technology, Food and Process Engineering Conference

ABSTRACT Mechanization of citrus harvesting drastically reduces production costs. Shaking machines are commonly used for this operation in USA and are starting to be used in Spain, yielding around 70% of total fruit to be harvested. However, it is necessary to optimize such machines in order to increase their rates of fruit detachment, reduce the damage to the bark of the trees and preserve the quality of the fruit. Computer vision systems can help in this task by registering video sequences of the vibrating motion produced by the shakers on individual fruit in the canopy until they fall down. A slow motion camera is used in this work to register video sequences. All the images that compose each sequence are segmented and processed using high speed techniques. In each of the images, the contour of the main object (fruit) is deducted and the point of the insertion of the stem detected. The XY coordinates of the fruit centroid and the angle between the vertical and the stem-centroid axis is also calculated. These parameters are the basis of a study to understand how the fruit is really affected by the shaking produced by the machine.

Keywords: pixel classification, fruit inspection, video analysis

INTRODUCTION The automatic inspection for fruit classification is being increasingly used to determine parameters such as size, shape, colour, etc. However, nowadays there exists a demand for more complex inspection capable of automatically detecting external defects in fruit. In scientific literature one can find numerous examples of computer vision techniques applied in this area (Chen et al., 2002; Zheng et al., 2006). The presence of irregular fruits or pieces is detected by means of relationships (ratios) between measures of length, width, perimeter, area, moments of inertia, etc. (Lootens et al., 2007; Koc, 2007). In scientific literature it can be found examples of the application of various techniques of image analysis to find defects or the presence of foreign objects in fruit (Blasco et al., 2007, López-García et al., 2010). Its application is especially important in automatic inspection where the solution usually adopted to inspect the fruit is made by bi-conical rollers (Bennedsen et al., 2005) but current technology allows to implement applications in the orchards under field conditions, such as the detection of fruit in trees (Okamoto et al., 2009).

This work uses machine vision to study the performance of mechanized harvesting by automatic shakers by analysing the movement of the fruit in the tree before falling to the ground. The centroid and the stem of the fruits are detected in the images to determine the angle between the stem axis-centroid and the vertical line. When the fruit breaks down from the branch, it can conserve the stem or not. Fruits without stem cannot be considered with good quality and their economical value is reduced. On the other hand, fruits with large stems can damage other fruits when they are transported or stored. It is very important to study the influence of the shaking parameters in order to maximice the performance (percentage of collected fruits) and to ensure that the fruits are collected in good conditions and minimizing the damages. A way to perform these studies is by means the computer vision. Using a slow motion camera, it is possible to capture the complete shaking sequence of the fruits till they fall down, which allows studding this phenomenon and establishing the appropriate parameters. This work analyses all the video frames to study the specific movement, segmenting each image and extracting features as the stem position, the centroid, or some marks that indicate the torsion of fruit. The algorithms have been implemented in an application that performs the analysis of, approximately, 700 images per minute.

AIM The objective of this work is to set up algorithms and procedures to capture and process video sequences of the movement of a fruit while is forcing to vibrate until they fall down from the tree. The shaking motion needs to be studied to better knowing how the fruit moves in the branch and the mechanism of stem breakdown with the goal of optimising this mechanical way to harvest the fruit, avoiding unnecessary damages to the tree and the fruit. The parameters to be studied are the angle of the fruit forced by the movement, the centroid displacement, the rotation of the fruit during the sequence and the moment of stem breakdown. An application has to be developed to process quickly the video sequences since it will be used to study later videos of different fruits in laboratory and field conditions.

ACQUISITION OF VIDEOS The videos were acquired using a camera Casio EX-F1 at a rate of 300 images per second with a size of 584 x 312 pixels and a resolution of 3.65 mm/pixel. In order to perform the tests, there were used fruits with approximately a stem of 7 cm long. The stem was held on a support connected with an engine that shakes it laterally, simulating a shaking motion. Two frequencies of 19 Hz and 14.5 Hz were tested because they are the frequencies in which shakers should work in the real world. In Europe, the trunks of citrus trees are about 500 mm tall, and it is not possible to apply large displacements, on the order of 10 cm, as applied in USA (Salyani et al, 2002), which would be very effective for pulling down the fruit because it would cause damages to the trees. So, the displacements have been limited on the order of 20-30 mm, that combined with frequencies round 14-20 Hz produce the best percentages of success in pulling down fruit minimizing the loosening of leaves.

A total of 10 oranges with uniform orange colour and 10 yellow lemons were used in the experiments. The main difference between both fruits is the geometry of the shape.

Oranges are spherical with a round projection in the images, while lemons are like ellipsoids, having a well defined main axe. Ten videos of each fruit were recorded. The fruit was placed over a black background. The complete video sequences have a length between approximately 3 and 5 seconds until the fruit is pulling down because the bleakness of the stem. Additionally, the fruit presents three coloured marks, one placed in the frontal part respect to de camera, and other two placed in both sides and perpendicular to de camera. The objective of these marks is to calculate the rotation suffered by the fruit during the shaking. Each frame has been recorded in a bitmap format and analysed with an application developed for this purpose. The details of this application are explained in subsequent points. A computer based on Intel Core2 QUAD processor (2.66 MHz) was used for the tests.

IMAGE SEGMENTATION A video sequence is composed of hundreds of images that have to be independently processed to obtain a common result. Lots of videos have to be processed. An important requirement is the performance of the image analysis, which restricts the range of the segmentation techniques that can be used. Techniques based on the analysis of areas, like region growing or other iterative methods can obtain good segmentations but have great time requirements. For this reason, a simpler technique, oriented to pixel segmentation has been chosen with the idea of relating each of the possible colour arrays of a pixel (the red, green and blue values, RGB) with one of the predefined classes. This relationship can be stored in the memory of the computer using a look up table (LUT) in such a way that each pixel in the image can be segmented simply by searching by its colour entry in the LUT. This process is time effective but needs a previous training to establish the relationships between the RGB values and the predefined classes. To perform this task, a specific windows based application has been developed. This application allows loading different images, selecting rectangular areas and assigning each area to one of the pre-programmed classes. The possibility of making a zoom in the image and preview the result of the segmentation allow obtaining a representative and accurate set of pixel values. The LUT is obtained by performing further statistical processing of this values using Bayesian discriminant analysis.

The probability of a vector RGB to be identified as a particular class is estimated through the Bayes theorem, which allows to estimate the a posteriori probability P(wi|x), of a pattern x formed by a set of j features (x1...xj) to belong to any of the N classes wi, from the a priory P(wi) and the conditional P(x|wi) probabilities. In our particular case, the set of features j are the R,G and B values of each pixel, which are the independent variables in the statistical analysis to classify pixels as one of the predefined classes. A standard non-linear Bayesian discriminatory analysis was used to determine the classification functions. Thus, a classification function was obtained for each class which maximizes its value when a pixel value is assigned to its corresponding class.

A region merging procedure is needed before following with the next step. Because it is difficult to obtain a uniform background, it appears in black and white colours. Moreover, the slow motion cameras need a high intensity of illumination that causes bright spots and shadows in the surface of the fruit. Bright spots can be removed using cross polarisation (Blasco et al., 2009) but they cannot be used for this appliance because it absorbs a high amount of the light, preventing the fruit to be properly lighted. To solve this problem, two different classes were used to segment the background. In the case of the fruit, they were necessary three classes for bright, medium and dark skin. Additionally, other two classes were needed for segmenting the rotational marks. After the segmentation, all the classes belonging to the same region of interest were joined and labelled as a unique class resulting finally the image segmented in four regions of interest, background, peel, and rotational marks.

A drawback associated to this technique is the presence of noise in the image. Since this technique is pixel oriented, isolated pixels after segmentation can be considered as belonging to a different class to the one they actually should belong to. On the other hand, the colour gradient produced by the spherical geometry of the fruit causes undefined contours, appearing zones with diffusion between the background and the peel. So the contour will contain aliasing instead of being uniform. In order to reduce the impact of these problems and to speed up further processes, a mode filter is passed through the segmented image. This filter has been chosen because it reduces noisy pixels and slightly smoothes the contours what can speed up further processes.

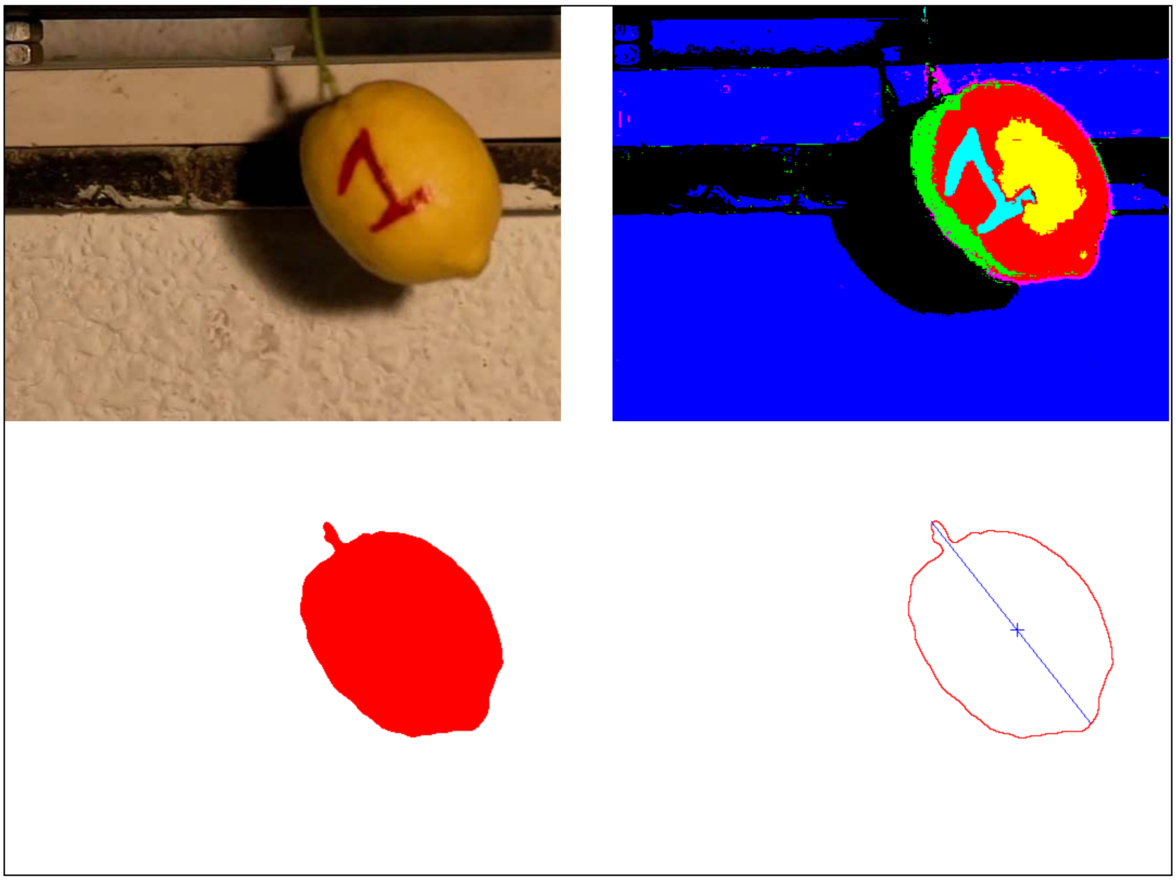


Figure 1. Scene showing the original image (top-left), segmented image (top-right), merged and filtered image (bottom-left) and feature extraction (bottom-right).

FEATURE EXTRACTION Once the fruit has been segmented, some features are extracted, as the angle formed between the axis stem-centroid and the vertical line, which gives the fruit orientation. The coordinates of the centroid of the fruit allow knowing the lateral displacements and generating a chart to show them in a graphical way. Besides, it is important to detect the coloured marks on the fruit and their position in the scene to perform an estimation of the fruit rotation and relate it with the stem-break moment. Moreover, it is important to determine the first frame in which the fruit starts to move and the frame that contains the precise stem-break moment, in order to calculate the time between both events.

The first step is to extract the contour of the objects presents in the scene. This process is performed scanning the whole image and considering that all object labelled pixels that have at least a 4-connected background neighbour belong to the contour. In this way we obtain an 8-connected contour. Scanning the image from left top corner, the first object labelled pixel found will be considered as belonging to the contour. From this first pixel, the object is followed in a clockwise direction using a chain code to store the contour points (Freeman, 1961). While the contour is being extracted, other features as the centroid, curvature or perimeter length are being calculated. The perimeter length is needed to establish a lowest threshold below which all the objects will be considered as noise. Ideally, the image should contain one object (the fruit), so it is enough a threshold with the value of the half of the perimeter corresponding to the smallest fruit used in the tests. The centroid is calculated as the average of the coordinates X and Y from the all contour points. Moreover, the rotational marks are also detected in the image and their position estimated. Figure 1 shows the steps of the processing of an image from the original RGB image to the last step showing the main axe and the centroid.

These algorithms have been implemented in a second application which loads and processes all the images belonging to the video sequence. This application loads each image, extracts all the features and stores them to be lately analysed. The left and right point for each shaking movement, the time elapsed between consecutive vibrations, the maximum and minimum height that reach the fruit during its movement and the rotation of the fruit are stored and analysed.

For the last image, it is important to detect the point of rupture of the stem, which is done by analysing its length. If the breakdown occurs in the calyx, there will be no stem in the fruit. However, if the breakdown happens in the stem, part of it will remain in the fruit as a fringe.

Since the standard timer of windows has not resolution enough to measure the performance of the algorithms, it was used an oscilloscope connected to the parallel port of the computer. Each operation was repeated 1000 times in different images and start-end signals were sent to the oscilloscope for measuring each operation separately.

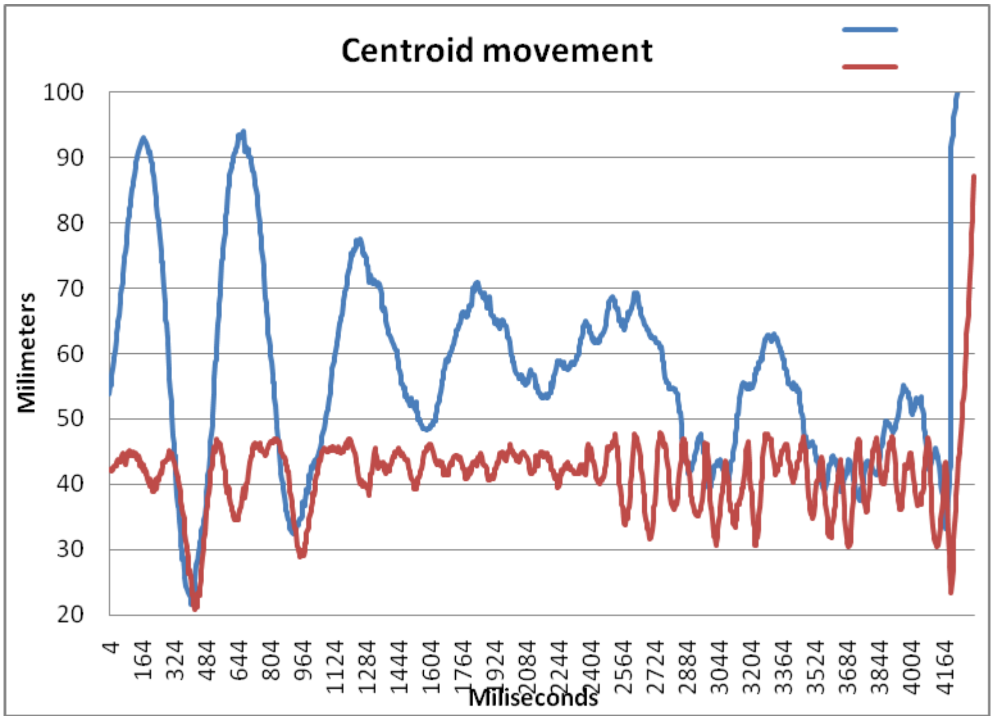
RESULTS A main result is the high performance of the algorithms developed. Each image was loaded by the application from the hard disk of the computer and processed in about 75 ms which allowed analysing each second of video (300 images) in less than 25 seconds. Table 1 shows the performance for each step involved in the analysis.

The accuracy in pixel classification of the segmentation technique used could not be measured because the background was not uniform, which introduced noise that difficult this task, but, in general, the visual inspection of the results showed a good segmentation after the region merging and the filtering of the noise which allowed the accurate extraction of features. The data extracted from the estimated parameters of the fruit reveal a uniform and logical motion which leads to think that the algorithms implemented are not only fast, but also accurate in their task. At this moment we are developing an improved system for the better acquisition of the videos.

Table 1. Confusion matrix

Category	Time (ms)
Image loading	26
Segmentation	17
Mode filtering	4
Contour extraction	2
Feature extraction	9
Data recording	13
Total	75

The study of the sequence of the centroid coordinates shows that the movement is slow during first two seconds when the fruit reach the major frequency. From this point, the fruits are shaken sharply in periods of half second until the stem breaks. This movement is shown in the figure 2 (top). This trend is followed by the changes in the angle (figure 2 bottom), which shows that between the periods between sharply shakes, the fruit is pulled up instead of moved probably because the run length of the fruit is larger than the shaking displacements.



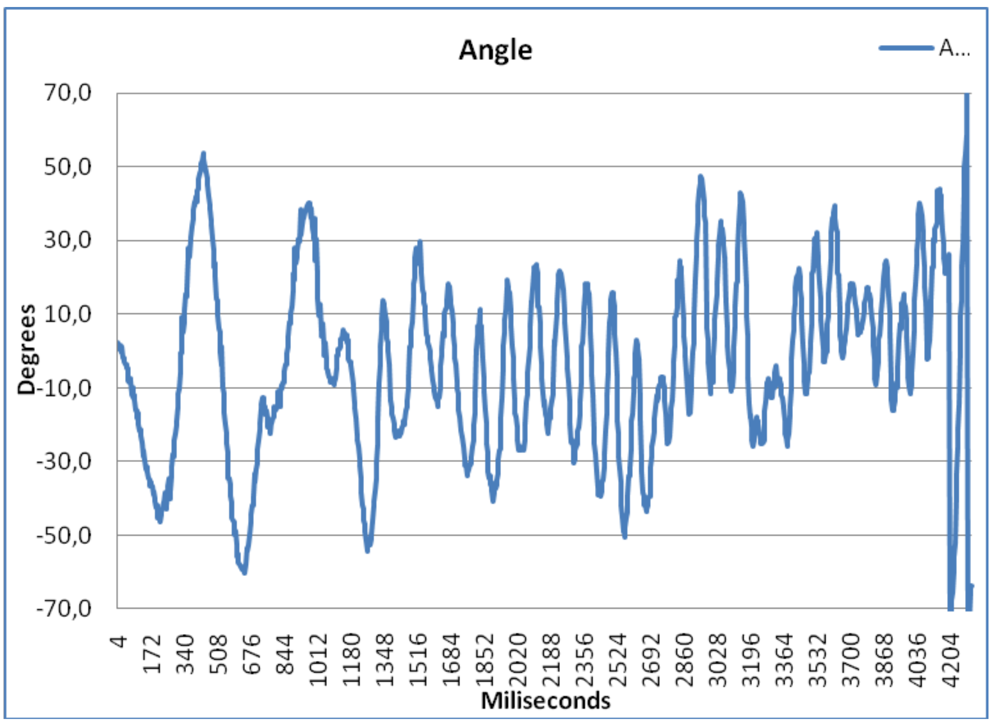


Figure 2. Top) Sequence of XY coordinates showing the true frequency of the shaking movement. Bottom) Sequence angles between the vertical line and the main axe of a lemon

CONCLUSION

The high-speed artificial vision is a valuable technique for studying the movement of the fruit on the tree before removing the branch and fall to the ground in mechanized harvesting systems using vibrators. Parameters extracted from the image analysis allow to obtain the actual frequency of vibration and analyze the type of movement that makes the fruit before breaking and falling to the ground, which can help improve the efficiency of the equipment.

Acknowledgements. This work was partially funded by the Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria de España (INIA) and by European FEDER funds, through projects RTA2009-00118-C01 and RTA2009-00118-C02

REFERENCES

Bennedsen, B.S., Peterson, D.L., Tabb, A. 2005. Identifying defects in images of rotating apples. Computers and Electronics in Agriculture 48, 92–102.

Blasco, J., Aleixos, N., Moltó, E. 2007. Computer vision detection of peel defects in citrus by means of a region oriented segmentation algorithm. J. Food Eng 81, 535–543.

Blasco, J., Cubero, S., Gómez-Sanchís, J., Mira, P., Moltó, E. 2009. Development of a machine for the automatic sorting of pomegranate (*Punica granatum*) arils based on computer vision. Journal of Food Engineering 90 (1), 27-34.

Chen, Y.R., Chao, K., Kim, M.S. 2002. Machine vision technology for agricultural applications. Computers and Electronics in Agriculture 36, 173-191.

Freeman, H. 1961. On the encoding of arbitrary geometric configurations. IEEE Trans. Elect. Computers EC-10, 260-268.

Koc, A.B. 2007. Determination of watermelon volume using ellipsoid approximation and image processing. Postharvest Biology and Technology 45(3), 366-371.

Lefebvre, M., Zimmerman, T., Baur, C., Gugerli, P., Pun, T. 1994. Potato operation: automatic detection of potato diseases. Proceedings of SPIE 2345, 2-9.

Lootens P., Van Waes, J., Carlier, L. 2007. Description of the morphology of roots of Chicorium intybus L. partim by means of image analysis: comparison of elliptic Fourier descriptors classical parameters. Comput. Electr. Agr. 58(2), 164-173.

López-García F., Andreu-García G., Blasco J., Aleixos N., Valiente J.M. 2010. Automatic detection of skin defects in citrus fruits using a multivariate image analysis approach Comput. Electr. Agr. 71, 189–197.

Okamoto H., Leeb W.S. 2009. Green citrus detection using hyperspectral imaging. Comput. Electr. Agr. 66, 201–208

Zheng, C., Sun, D.W., Zheng, L. 2006. Recent developments and applications of image features for food quality evaluation and inspection –a review. Trends in Food Science & Technology 17, 642-655.