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Title:

Fruit Size Determination by a New Optical Sensor

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Summary:

A ring sensor system is being used to calibrate different kinds of fruit. The system consists of a feeding device –aligner- with two conveyor belts that convey the fruits to the optical sensor. The fruits are put on the aligner, and when they leave it, they cross the ring, which scans them, measuring length, volume and four diameters. Until now, the analysed parameter has been the maximum diameter of the largest cross section.

In trials with models it has been proved that speed has no influence on that parameter. It has also been showed that the centered passing through the ring is not always the best option, but it depends on the object's size.

At fruit tests, it has been demonstrated that the best orientation is that carrying the fruits with their polar axis parallel to the line direction.

Excellent results have been obtained at 'Navelina' orange -average coefficient of variation CV= 0.9% and average absolute error taken in absolute value |Ea|= 1.37 mm- and 'Primafiori' lemon -average CV= 1.5% and average |Ea|= 1.12 mm-. Values not so good, although similar to those coming from a last generation computer vision system have been obtained on 'Salustiana' orange. Results with apples and tangerines are still pending to be analysed.

The next step is to improve the feeding system, achieving a totally automated one with the fruits self-orientating, for commercial application.

1. Introduction

Nowadays, different calibration systems are used at the sorting facilities of the fruit packing lines in order to classify fruits and vegetables, either by size or by weight. Thus, for weight calibration there are electronic weight sizers on one hand, and mechanical weight sizers on the other, although the second are deprecated. Concerning to size, there is the mechanical calibration, consisting sometimes of variable gap rollers, and, as the most modern option, the computer vision systems. The last ones allow colour sorting as well as sizing.

The previous classification refers to direct measurements. Indirectly we could make weight calibration with a machine vision equipment, by estimating a density according to the kind of fruit. Similarly, we could calibrate by diameter from a weight value supplied by an electronic weight sizer, applying a function according to species and variety.

(Gall, 1997; Fleming et al., 1998) developed a new optical sensor – they called it ring sensor- to calibrate irregular shaped objects, as agricultural products, having being used until now on potato. The LPF of the Rural Engineering Department from the Polytechnic University of Madrid, agreed with the company Argus Electronic –which manufactures the ring sensor- to study one of these sensors, with the purpose of testing it for the calibration of several fruits and vegetables different from potato; such as apple, pear, citrics, peach, apricot, plum, kiwifruit, cucumber, etc.

In this paper we are presenting the results obtained until now with this new sensor.

2. Materials and methods

2.1. Description of the testing machine

For undertaking the different tests, a machine has been used, made up by a ring sensor at the beginning followed in the line by a standard computer vision system (*fig. 4*). It was designed like this for comparing the results obtained – in sizing- with both systems. Immediately we describe briefly the ring sensor. The detailed description and the mathematical basis are at (Gall, 1997; Fleming et al., 1998).

The measuring device or ring sensor consists of a circular hoop, throughout it the object to calibrate must fly. All around the perimeter are arranged infrared emitters and receivers, drawing chords which wrap the object's cross-section. The need of 'flying', this is, crossing the ring without resting on a surface, is because the infrared curtain must be clear, i.e., it cannot have another thing different from the passing fruit in its plane. In figure 1, a mounting scheme of the sensor and its feeding device is presented.

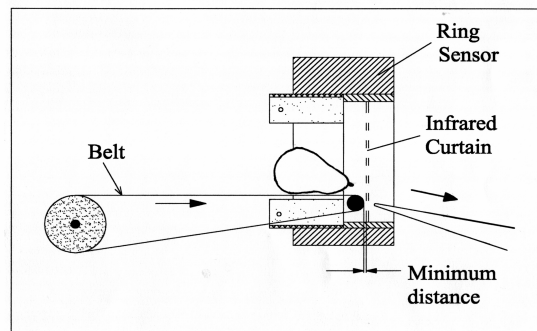


Fig. 1. Setting up scheme of the aligner and the ring sensor

The elements to measure the fruit in the two systems (sensors) are:

- Ring: a double belt- single row aligner (being each belt of 'duck bill' type) with the next features:
 - Length: 0.5 m.
 - Angle of the V-plate supporting the conveyor belts: 129°.
 - Velocity: the same for the two belts, having been tested the speeds: 0.6 m/s; 0.8 m/s; 1m/s; 1.2 m/s and 1.4 m/s.
- Video-Camera: a bicones conveyor, with the following features:
 - Distance to the camera's objective: 0.6 m aprox.
 - Distance between bicones shafts: 95 mm.

2.2 Parameters supplied by the ring sensor

There are 7:

- Length (L): it is the passing object's length, measured in the motion direction.
- Volume: it is the volume of the object.
- DM1: It is the diameter or major axis at the middle slice ($=L/2$).
- DM2: It is the diameter or minor axis at the middle slice ($=L/2$).
- DL1: It is the diameter or major axis at the largest slice. This slice is the one which has the greatest area among all the cross-sections analysed by the sensor.
- DL2: it is the minor axis at the largest slice.
- Pos Max: it is the distance from the 'top' –or part of the object first crossing the infrared curtain- to the largest slice.

In figure 2 some of these dimensions are shown:

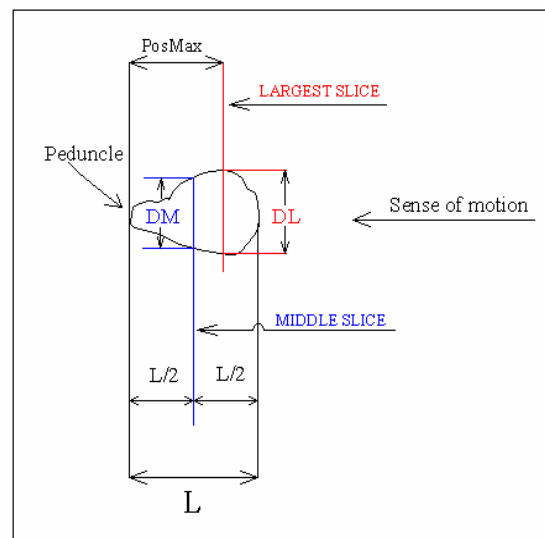


Fig. 2. Measurements made by the ring sensor.

2.3 Studied variable

From among the 7 parameters provided by the ring sensor, the one that has been studied for the time being is DL1. We decided to start with this variable because it's the one that represents the maximum diameter of the equatorial section, for fruits oriented with their polar axis parallel to the movement –or line- direction. This maximum diameter of the equatorial section is the calibration parameter for most products, according to the European Marketing Standards for Fresh Fruit and Vegetables.

2.4. Trials programming

Before starting to work with fruit, it was decided to make some preliminary tests with calibrated models, in order to analyse the behaviour of the ring sensor, as well as the effect of different levels of 4 treatments or factors.

The models used have a special shape, coming from cork spheres with weights inside, turned in the lathe and filed to obtain 2 flat and 2 curved faces in the cross section.

2.5. Test with models

The following factors or sources of variation have been analysed:

1. Position (p): it refers to the vertical distance between the ring's center and the aligner's vertex (fig. 3). This is directly related with the object's crossing zone, more or less centered. Number of levels tested: Three: p1, p2 and p3, with a 15 mm distance between one and the next.

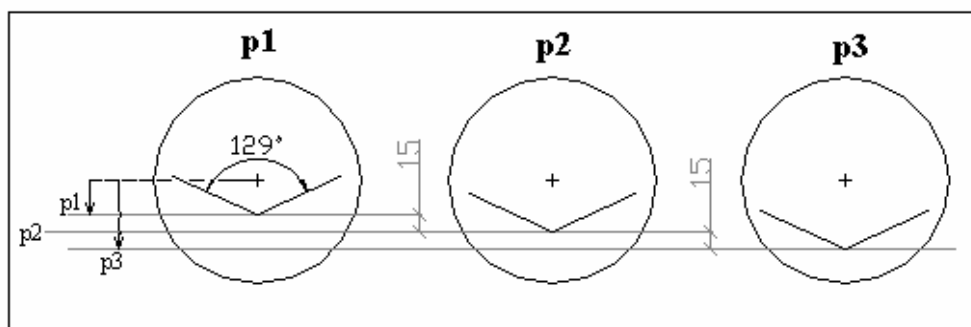


Fig. 3. Scheme of the 3 tested positions (dimensions in mm)

2. Speed (v): it makes reference to the model passing speed. Five levels were tried: v1 (0.6 m/s); v2 (0.8 m/s); v3 (1m/s); v4 (1.2 m/s) and v5 (1.4 m/s).
3. Location (C): it refers to the object's orientation on the aligner. Two levels were tested: C1 (Model resting on a flat face) and C2 (Model resting on a curved face).
4. Model size. Three objects: NTG, NTM and NTP with the dimensions:

Model	Length	DL1	DL2
NTG	92 mm	81.5 mm	70.5 mm
NTM	70.5 mm	61.5 mm	54.5 mm
NTP	61 mm	54.5 mm	45.8 mm

Table 1. Dimensions of the 3 models

The trial method followed was: the 3 positions (p1, p2 and p3) were tested. For each one, the 5 five levels of speed, the two locations and the three sizes were tried. The number of repetitions was 50 for each factors combination. Therefore the total number of measurements was:

$$3 \times 5 \times 2 \times 3 \times 50 = 4500 \text{ measurements.}$$

The statistical analysis method has been based on an objectivist approach, also known as frequencialist. It consists of resembling each value's frequency to its probability. In order to decide if a result has been good or not, the absolute error has been studied. It is defined as the difference between the mean value- of 50 repetitions- measured by the sensor and the actual value attained with the reference instrument. That is to say:
 $E_a = (\text{sensor's estimated measure}) - (\text{measure obtained with the reference instrument}).$

2.6. Reference instrument

As a reference to compare the measurements provided by the ring sensor as well as the computer vision equipment, a high quality special vernier calipers has been used, with the jaws a bit longer than standard. This is useful to measure properly the fruit diameters, avoiding the calipers' bar nuisance.

2.7. Tests with fruit

In fruit, the tested locations have been (fig. 4):

- c1: Peduncle upwards.
- c2: Peduncle forwards.
- c3: Peduncle backwards.
- c4: Peduncle towards the machine's control board.
- c5: Peduncle opposite to the control board.

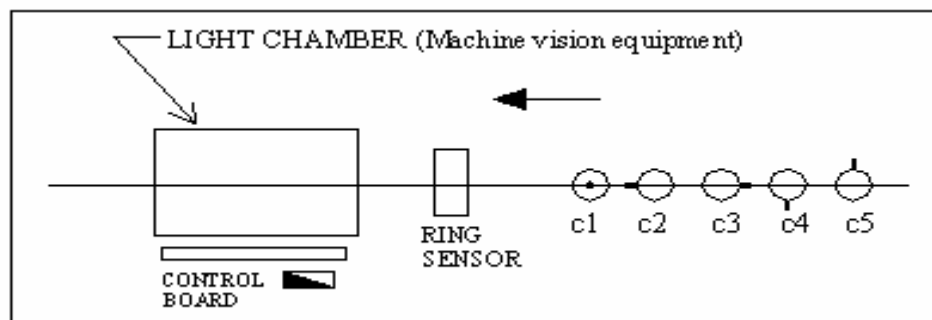


Fig. 4. Machine's overall scheme, featuring the line direction, and fruit orientation

2.7.1. Trial with 'Navelina' orange

This test was made for assessing the ring sensor's behaviour at the calibration of this product, as well as to find out which location - orientation- was the optimal.

Data of this test:

- Number of samples: 30.
- Number of positions: 1: p3.
- Number of speeds: 1: $v_3 = 1\text{m/s}$.
- Number of locations: 5: c1, c2, c3, c4 and c5.
- Number of repetitions by fruit and orientation: 10.

Total number of measurements: $30 \times 1 \times 1 \times 5 \times 10 = 1500$ measurements.

2.7.2. Trial with 'Salustiana' orange.

This trial was made to compare a last generation machine vision system (at the factory Maxfrut) with the ring sensor, as well as with the LPF testing machine's computer vision system. Fruit material employed: 20 'Salustiana' oranges with maximum equatorial diameters between 50 mm and 104 mm. So we have:

- On one side the measurements of the 20 oranges with the reference instrument.
- On other side the measurements of the same oranges estimated by the last generation computer vision system.
- The measurements of the 20 oranges estimated by the ring sensor.
- The measurements estimated by our machine's computer vision system.

2.7.3. Trial of 'Primafori' lemon

This test was made to assess the ring's results at the calibration of this product.

Data of this trial:

- Number of individuals: 30.
- Number of positions: 3: p1, p2, p3.
- Number of speeds: 5: v1, v2, v3, v4 and v5.
- Number of locations: 1: c2 or c3.
- Number of repetitions: 10.
- Total measurements: $30 \times 3 \times 5 \times 1 \times 10 = 4500$.

3. Results and discussion

3.1. Results with models

- Position: in most of the cases the best position is p3, while the worst is p1 (fig. 5). Position p2 is intermediate.

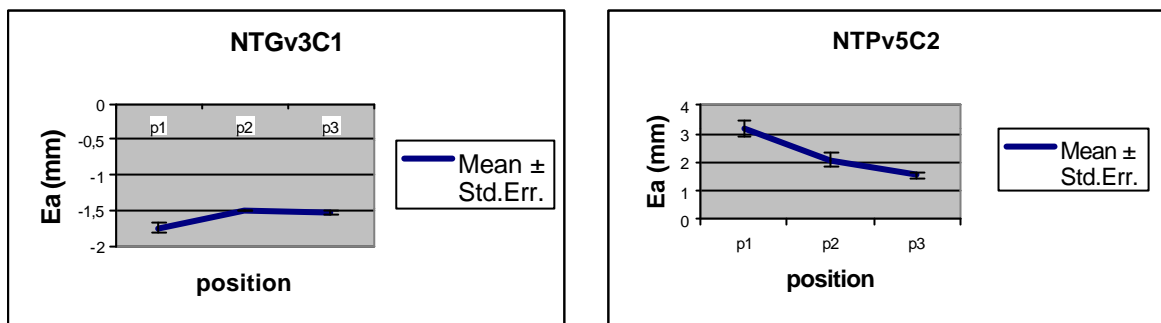


Fig. 5: Variation of the absolute error (E_a) with the position.

- Speed: It almost hasn't got any effect, in what concerns to the analysed variable (DL1).
- Location: For the models, the effect of the tested locations is negligible.
- Size: The ring tends to measure the greater models (NTG) by default ($E_a < 0$), and the smaller ones (NTM and NTP) by excess ($E_a > 0$), (fig. 5). On the other hand, the maximum absolute error in absolute value is 2.5 mm for NTG and 3.5 mm for NTM and NTP.
- Combined effect position-object's size: the centered crossing of the ring is not always the best option. This is shown in fig. 6: For the model NTP with the location C2 the centered passing corresponds to position p1 but this is not however the best position, since it has an absolute error of 3 mm versus 1 mm at p3.

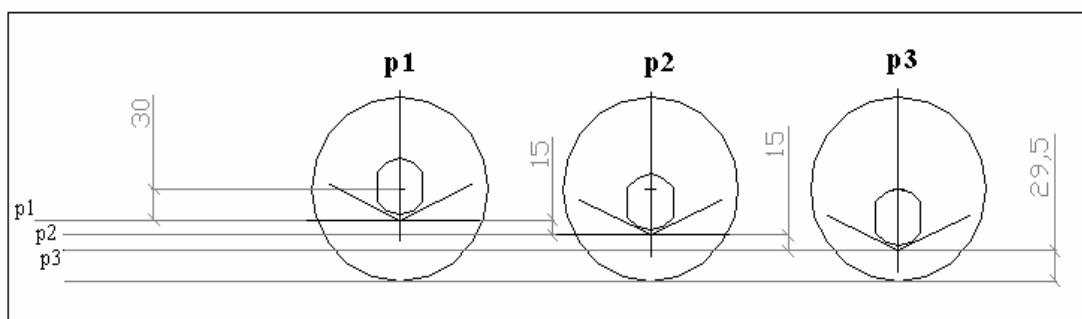


Fig. 6. Model NTP in the 3 tested positions, for location C2 (dimensions in mm).

This is probably because -as described in (Gall, 1997; Fleming et al., 1998)- the zone of less chords intersections corresponds to the ring center, increasing their concentration at circular crowns further from the center. An extreme case could be a cherry: if it crosses totally centered, we would have a rather worse result than if it crosses by a circular crown near to the perimeter of the ring.

Comparing NTG and NTP, both for location C2, the difference of the best position can be noted. Thus, for NTG the position that implies a centered passing is optimal, as its contour occupies an imaginary circumference in which the chord intersections density is rather high. Nevertheless, for NTP the position that makes it centered crossing (p1) is not optimum, as its contour only reaches zones nearby the ring center, where the chords intersections density is not so high.

3.2. Results with fruit.

3.2.1. Trial of 'Navelina' orange.

It was showed that the best locations were c2 and c3, this is, polar axis parallel to the line direction. The following metrological parameters were obtained for location c2:

- Average absolute error in absolute value: 1.37 mm.
- Average standard deviation: 0.73 mm.
- Average standard error 0.23 mm.
- Average coefficient of variation: 0.9%.

In what concerns to the absolute error (E_a) sign, it is prevalingly negative. This looks reasonable if we realize that the average maximum equatorial diameter of the 30 oranges is 79.8 mm, this is, very close to the NTG's one (81.5mm).

A distribution graph of the absolute error $|E_a|$ for 300 observations –corresponding to location c2- is shown in figure 7.

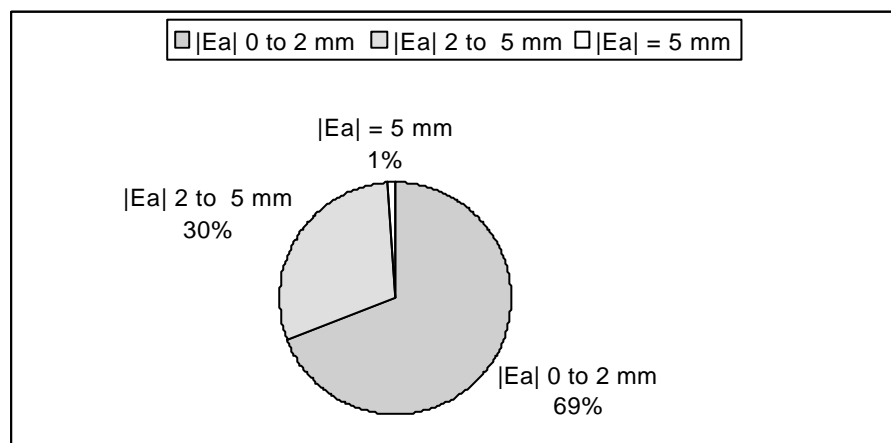


Fig. 7. 'Navelina' orange. Cases belonging to 3 ranges of absolute error in absolute value $|E_a|$

To sum up, we are talking of very good results for this test.

3.2.2. Trial with 'Salustiana' orange

The following results (Table 2) were obtained for the absolute error in absolute value $|E_a|$:

Measure equipment	From 0 to 2 mm	From 2 to 5 mm	From 5 to 7 mm
Ring sensor	51 %	43%	6%
Last generation computer vision system	53 %	44%	3%
Computer vision system in LPF	25 %	62%	13%

Table 2. 'Salustiana' orange. Cases belonging to 3 ranges of $|Ea|$, for every equipment tested.

As shown in Table 2, the ring and the last generation computer vision system provide very similar results. On the contrary, the testing machine's computer vision system supplies rather worse results. This is because it only acquires one image per fruit, and, moreover, it uses an absolute coordinate system, this is, machine referred, instead of a fruit referred coordinate system, giving errors in the estimation of diameters as the fruit rotate.

3.2.3. 'Primaflori' lemon trial.

The following metrological parameters were obtained:

- Position p1 and speed v3.
 - Average absolute error in absolute value: 1.41 mm.
 - Average coefficient of variation: 1.3 %.
 - Average standard deviation: 0.84 mm.
 - Average standard error: 0.26 mm.
- Position p3 and speed v3.
 - Average absolute error in absolute value: 1.12 mm.
 - Average coefficient of variation: 1.5 %.
 - Average standard deviation: 0.95 mm.
 - Average standard error: 0.30 mm.

Comparing both positions, it can be said, yet being the difference small, that the results are a little better for p3 than for p1.

4. Conclusions

- It has been showed that the centered passing through the ring sensor is not always the best option, but it depends on the fruit size.
- It has been obtained that the ring sensor tends to default measure the bigger objects and surplus measure the smaller ones, regardless the position and the speed.
- It has been showed that for models speed has no influence on DL1. Therefore it is so accurate to work at 1m/s as at 1.4 m/s. For fruits, nevertheless the errors might increase a little at the highest speed, due to their irregular shape combined with a greater aligner vibration.
- It has been proved that for fruit the orientation has a big influence on the final results. The best locations are those carrying the polar axis parallel to the line direction, since in this way it does not appear in the cross sections.
- Excellent results have been obtained on 'Navelina' orange and 'Primaflori' lemon.
- Similar results have been attained for 'Salustiana' oranges with the ring sensor and the last generation computer vision system.
- The results of the ring with 'Navelina' oranges (fig.7) are better than with 'Salustiana' (Table 2), because for the optimal location (i.e. c2 and also c3) the first ones, due to their shape, scarcely tilt during its approaching to the ring, while the

second ones do; they tend to lift up at the end of the aligner, just before crossing the ring.

- Although there have been obtained very good results with the ring sensor for the present, it is necessary to implement an automatic feeding system, with the fruit orientating by itself, for application in the industry.

Acknowledgements

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Purpose

The aim of this work is to assess the applicability of an optical ring sensor system (Gall, 1997; Fleming *et al.*, 1998), which has been already applied in calibration of potatoes, at the calibration of several fruits and vegetables, such as oranges, lemons, apples, pears, peaches, kiwis, cucumbers, etc.

Method

A testing machine was designed, consisting of the ring sensor system followed by a machine vision equipment; the reason of this design is to be able to compare the results obtained with both systems.

The ring sensor feeding device is a modified 'aligner'. Usually, at the fruit sorting machinery sector, an aligner consists of a V-plate with two belts running at different speed, but in this case the speed of the two belts is the same.

The object to be measured passes through the ring sensor (Fig. 1), and it is scanned by infrared chords, giving a three dimensional enveloping spiral of the object.

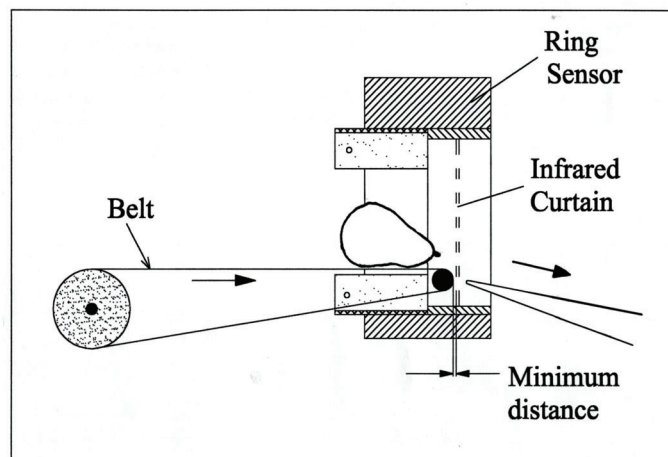


Fig. 1: Setting up scheme of the ring sensor

First of all, it was considered necessary to characterize the metrology of the ring sensor by measuring some models. These models have a special shape, coming from cork spheres with weights inside, turned in the lathe and filed to obtain 2 flat and 2 curved faces in the cross section. Four sources of variation were analysed. They are:

- Position: Refers to the vertical distance between the centre of the ring and the edge of the aligner. This factor corresponds to the object's entering zone –more or less centered-. Three levels of position were tested.
- Speed: It is the speed of the object that passes through the ring. Five levels of speed were tested, ranging from 0,6 m/s to 1,4 m/s.
- Arrangement: It means the orientation of the fruit upon the aligner. For the trials with models, 2 levels were used, and for trials with fruit, 5 levels have been tested, distinguishing ones from the others by the orientation of the peduncle.
- Size: It is the size of the model or fruit. Three levels of this factor were tested.

After the trials with the models, tests with fruit followed. The first fruit tested was 'Red Chief' apple. The aim of this trial was to decide which of the 5 arrangements was/were the best. The next trials were: 'Navelina' orange, 'Salustiana' orange (this test to compare the ring sensor with a last generation computer vision system) and 'Primaflori' lemon.

The ring sensor supplies 7 parameters. The only one that has been analysed for the moment is 'DL1', which for the suitable orientation becomes the maximum diameter of the 'equatorial' section. This parameter is the most common calibration one in the European Union Normative of Fresh Fruit and Vegetables.

Results and Conclusions

- It has been showed that the centered passing position through the ring is not always the best option, but it depends on the object size.
- It has been obtained that speed has not any effect on the parameter DL1. Nevertheless, it is expected to be quite important at volume and length.
- It has been showed that the ring sensor system tends to default-measure the bigger objects and to an excess-measure for the smaller ones, regardless of the position and speed. Moreover, the maximum absolute error, E_a , is -2,5 mm for the bigger model and +3,5 mm for the two smaller ones.
- Excellent results have been achieved with 'Navelina' oranges and 'Primaflori' lemons.
- There have been obtained very similar results with the ring sensor and with the last generation computer vision system.
- It has been concluded that for fruits, the best orientation is the one in which their polar axe is parallel to the direction of motion–or line direction-.
- Although there have been obtained very good results with the ring sensor for the present, it is necessary to implement an automatic feeding system, with the fruit orientating by itself, for application in the industry.

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