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# A new method for pedicel/peduncle detection and size assessment of grapevine berries and other fruits by image analysis

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## Abstract

The berry size of wine-grapes has often been considered to influence wine composition and quality, as it is related to the skin-to-pulp ratio of the berry and the concentration of skin-located compounds that play a key role in the wine quality. The size and weight of wine-grapes are usually measured by hand, making it a slow, tedious and inaccurate process. This paper focuses on two main objectives aimed at automating this process using image analysis: 1) to develop a fast and accurate method for detecting and removing the pedicel in images of berries, and 2) to accurately determine the size and weight of the berry. A method to detect the peduncle of fruits is presented based on a novel signature of the contour. This method has been developed specifically for grapevine berries, and later extended and tested with an independent set of other fruits with different shapes and sizes such as peppers, pears, apples or mandarins. Using this approach, the system has been capable of correctly estimating the berry weight ( $R^2 > 0.96$ ) and size ( $R^2 > 0.97$ ) of wine-grapes and of assessing the size of other fruits like mandarins, apples, pears and red peppers ( $R^2 > 0.93$ ). The proven performance of the image analysis

26 methodology developed may be easily implemented in automated inspection systems to accurately  
27 estimate the weight of a wide range of fruits including wine-grapes. In this case, the implementation of  
28 this system on sorting tables after de-stemming may provide the winemaker with very useful  
29 information about the potential quality of the wine.

30

31 **Keywords:** Image analysis; Contour function; Pedicel detection; Grape berries, Size and weight  
32 estimation

33

### 34 **1. Introduction**

35 Machine vision systems are being used to automate inspection tasks in agriculture and food  
36 processing. Apart from its use in defect detection or colour estimation, image analysis is also an  
37 objective and reliable tool for examining other features such as shape and size (Cubero et al., 2011;  
38 Lorente et al., 2012).

39 Berry size and weight are two key parameters in the quality of table and wine-grapes. Berry size and  
40 weight parameters not only have an impact on the cluster architecture and compactness (leading to  
41 looser or tighter clusters), thereby influencing the cluster health status (Tardaguila et al., 2010), but are  
42 also considered indicators of grape and wine quality. In fact, berry weight and size, and their  
43 implications in grape and wine quality, have been extensively studied worldwide (Roby et al., 2004;  
44 Walker et al., 2005) and recently reviewed by Matthews and Nuzzo (2007). Most of the key  
45 compounds for wine quality, such as aromas and phenols, are located in the skin (Kennedy, 2010).  
46 Therefore, it is widely assumed that better wines are made from smaller berries, which have higher  
47 skin-to-pulp ratios (Barbagallo et al., 2011). Berry weight and size are common parameters for  
48 assessing wine-grapes' ripening from veraison to harvest (Iland et al., 2004) and quality features in  
49 table grapes. Their assessment – usually performed in the laboratory – often requires the removal of  
50 the berry pedicel, which is time and labour consuming.

51 Image analysis has recently been used outdoors to characterise several grapevine features, such as leaf  
52 area and yield (Diago et al., 2012). An important step forward would be the capacity to estimate berry  
53 size and weight from the analysis of images taken in the field, i.e. of the clusters hanging on the vines.  
54 This would allow close non-destructive monitoring of berry size throughout the ripening period of the  
55 actual clusters. In this respect, the detection of berry pedicels would be an even more critical step to  
56 avoid confounding effects.

57 The automatic detection of the pedicel in berries, or peduncle in other fruits (pedicel is normally used  
58 in the case of grain fruits that are joined together in a bunch and peduncle is more common for fruits  
59 joined directly to the branch of the plant), is still a challenge. Kapach et al. (2012) offered an extensive  
60 description of the computer vision techniques that can be used for fruit-harvesting robots, concluding  
61 that the automation of some specific tasks is especially difficult, such as the detection of the peduncle  
62 in the grasping and picking operations carried out by the robot.

63 In some fruit, like oranges, the presence of large peduncles can damage other fruits during storage but  
64 their absence is considered a loss of quality. Sometimes it is important to detect the peduncle clearly in  
65 order to avoid confounding effects between the presence of the peduncle and external damage in  
66 automated quality inspection systems. If the peduncle is visibly different from the fruit, strategies  
67 based on colour information can be applied to locate it. Laykin et al. (2002) used colour information to  
68 discriminate between the peduncle on tomatoes and bruises with a success rate of 100%. However, in  
69 other cases the difference between the peduncle and other defects is not so apparent. In these  
70 situations, Blasco et al. (2007) used visible images complemented by a multispectral system to  
71 discriminate among the peduncle and various defects in citrus fruits, achieving a peduncle  
72 identification rate of 67%.

73 Peduncle detection is also needed when information regarding the orientation of the fruit is required.  
74 Bennedsen and Peterson (2005) developed a computer vision system to detect defects in apples that  
75 had previously been oriented towards preventing the peduncles from appearing in the image. For the  
76 orientation process, these authors used a prototype developed by Throop et al. (2003), who oriented  
77 the apples with the peduncle on one side. In another work, Lu and Peng (2006) needed the fruit to be

78 oriented with the end of the peduncle horizontal in order to obtain scattering measures in peaches. A  
79 similar idea was used by Blasco et al. (2003), who acquired four images of apples from different views  
80 in order to estimate the size of the fruit in the image based on the equatorial diameter. For this  
81 purpose, the more perpendicular and centred the peduncle was, the better.

82 Harvesting robotics may also require peduncle detection systems to be implemented in order to collect  
83 the fruit properly. In this regard, Van Henten et al. (2006) presented a robotic system for de-leafing  
84 cucumber plants. To perform its tasks, the robot identified the pedicel of each leaf using two images at  
85 wavelengths of 850 nm and 970 nm, which can potentially be exported for use in actual harvesting  
86 robots. Hayashi et al. (2010 and 2011) used a machine vision unit based on three cameras installed on  
87 a robotic harvesting system to detect the position of strawberries and the orientation of the peduncle,  
88 thereby allowing accurate guidance of the robotic arm.

89 As can be seen, the detection of fruit peduncles is an important issue to be taken into account in the  
90 design of a computer vision system for estimating the quality features of fruit or vegetables. Several  
91 solutions have been proposed to determine the peduncle position, such as: the use of structured  
92 lighting to detect concavities in apples (Yang, 1993); colour segmentation techniques to differentiate  
93 the calyx and peduncle in citrus fruits (Ruiz et al., 1996); or the study of light reflection in apples  
94 (Penman, 2002). In some of these works, the use of a spectral imaging system to locate the peduncle  
95 and discriminate it from other damage was required. Thus, the peduncles of some fruits present  
96 different reflectance values in the NIR region in relation to the skin of the fruit at certain wavelengths.  
97 Xing et al. (2007) used the texture of multispectral images to discriminate between smooth faces and  
98 those presenting peduncles in apples of different colours. A similar approach was taken by Nanyam et  
99 al. (2012) to detect and discriminate the peduncle and leaves from defects in strawberries.

100 The main objective of this work was to develop an effective new method using image analysis and  
101 based on contour signatures to detect and remove the pedicel in images of grapevine berries using  
102 machine vision, and thus accurately determine the weight and size (diameter) of grape berries. The  
103 algorithm was also tested with other fruits like mandarins, apples, pears, and so on to validate it.

104 This paper is organised as follows. In section 2 we present the materials and methods, including a  
105 description of the plant material, the vision system, the segmentation process and a detailed  
106 description of the peduncle/pedicel location algorithm. In section 3 we present the results obtained for  
107 the size and weight of grape berries, including the results for other fruits to validate the algorithm, as  
108 well as some discussion of the results. Finally, section 4 offers some conclusions from this work.

109

## 110 **2. Materials and methods**

111 The algorithms were developed and tuned using different images of 20 wine-grape berries of several  
112 colours and sizes, and captured with the pedicel at various random orientations. They were validated  
113 using another independent set of 100 single berries of different sizes and colours belonging to two  
114 grapevine (*Vitis vinifera* L.) cultivars (50 samples of Grenache and 50 of Tempranillo). The berries  
115 were placed on a white background inside a chamber equipped with a still camera (EOS 550D, Canon  
116 Inc, Japan) and four lamps each containing two fluorescent tubes (Osram L 18W/965 BIOLUX) with a  
117 colour temperature of 6500 °K. The angle between the axis of the lens and the sources of illumination  
118 was approximately 45°, the insides of the inspection chamber were coated with anti-reflective material,  
119 and cross-polarisation was achieved by placing polarising filters in front of the lamps and in the  
120 camera lenses to minimise the impact of specular reflections produced on spherical fruits. The berries  
121 were oriented with the pedicel facing upwards and downwards interchangeably and the images were  
122 obtained with a size of 2592 x 1944 pixels and a resolution of 0.11 mm/pixel. The berries in the  
123 images included the pedicel, which makes it necessary to detect the insertion point between the fruit  
124 and the pedicel in order to obtain accurate measurements of the berry parameters. Two algorithms  
125 based on the radius function (Kunttu and Lepisto, 2007) and arc-length versus the turning angle graph  
126 (Wolfson, 1990) of the contour were developed to detect these points in the contour of the objects  
127 found in the images. In addition, a new algorithm based on a signature derived from these previous  
128 functions is proposed to improve the performance and robustness of a potential automatic system. To  
129 make the algorithm more robust and potentially general, the algorithms were also tested in other fruits

130 like mandarins, pears, apples and peppers representing bigger spherical fruits, non-spherical fruits and  
131 irregular fruits with different types of peduncles and with randomly oriented peduncles.

132 For the manual assessment of grape berry size and weight, all imaged grape berries were individually  
133 labelled and weighed (XR205SM-DR, Precisa Instruments Ltd., Switzerland), and their size was  
134 measured manually using an electronic calliper (Digital, TESA SA, Switzerland) to determine the  
135 peduncle/pedicel-calyx (stem-calyx) axis and equatorial diameters. The resolution used for the size  
136 measurements was 0.01 mm. For the rest of the fruits tested to validate the peduncle/pedicel location  
137 algorithm, all the manual measurements for determining the stem-calyx axis and the equatorial  
138 diameters were carried out using the same electronic calliper.

### 139 2.1. Segmentation and contour detection processes

140 Prior to the segmentation of images, an off-line process is carried out. This process consists in  
141 generating a look-up table (LUT) that is later used to segment the images of the fruit. This process is  
142 performed using a computer application specially developed for this purpose that allows an operator to  
143 select different windows in the images representing the background and peel/stem classes. The RGB  
144 values of the training windows selected are used as input in a Bayesian discriminant model (Harrel,  
145 1991), the independent variables of the model thus being the grey levels of the RGB bands. Finally,  
146 the model is stored in an LUT which contains the classes of the model, and thus the segmented image  
147 contains the classes that each pixel belongs to. After image segmentation, a binary image showing the  
148 fruit in white and the background in black was obtained. The next step was to apply an algorithm  
149 which extracted the eight-connected contour by means of the chain code described by Freeman (1961).

### 150 2.2. Peduncle/pedicel location algorithm

151 One of the key points of the methodology presented here was the algorithm proposed to detect the  
152 connecting points between the peduncle and the fruit by analysing the contour of the fruit. Several  
153 approaches to analysing the contour of the objects have already been proposed for different purposes,  
154 like the analysis of the shape. Many of them propose the use of signatures, which are methods that  
155 represent a contour using a one-dimensional function. The best known is probably the radius signature

156 (Blasco et al., 2009; ElMasry et al., 2012), which can yield a useful description of the shape of regular  
157 or manufactured objects with a known shape, but could fail when it is applied to biological objects  
158 with irregular or different shapes. Signatures are invariant against size or orientation, which makes  
159 them particularly interesting in cases where the size or the orientation of the object is unknown.  
160 Applied to peduncle detection, the main problem appears in irregular fruits, which present large  
161 variations in their signatures that make them unsuitable to identify the peduncle properly. Even in  
162 regular-shaped fruits this signature is sometimes not robust enough to ensure good results. A different  
163 descriptor of the perimeter is the curvature signature, although it has not been used frequently for food  
164 analysis but is common in other fields (Gulato et al., 2008). Both of them have been tested in this  
165 work. The approach proposed in the present study was to obtain a new signature derived from the  
166 radius signature. This new signature analyses the changes in the direction of the curvature of the radius  
167 function. In regular fruits, these changes are supposed to be very smooth except when peduncle exists.  
168 In the berries, the detection of the pedicel was carried out by an algorithm that consists in the  
169 following steps:

- 170 1. The centre of mass of the berry was calculated as the average coordinates of the pixels  
171 belonging to the fruit. A faster method that could be used instead when the processing time is  
172 a constraint would involve using only the information about the boundary to estimate the  
173 centroid of the fruit. But in this case, the centroid could be too biased towards the  
174 pedicel/peduncle location if it is too long, and the performance of the method could decrease.
- 175 2. The radius function (Rubine, 1991) of the berry contour was calculated as a one-dimensional  
176 function in which each item of data was the Euclidean distance between the centroid and each  
177 of the points on the contour. This is represented in Figure 1, where Figure 1a shows a sample  
178 of the original image of a berry and the contour extracted with its centroid position. The radius  
179 function is shown in Figure 1b. In this function it is supposed that the farthest point from the  
180 centroid corresponds to the top of the pedicel/peduncle and therefore the two local minima  
181 around this point are selected as the connecting points between the pedicel/peduncle and the



182 fruit. The maximum value of the radius signature for the end of the pedicel/peduncle (1) and  
 183 the two contact points of the pedicel/peduncle with the berry (2), (3) can also be observed.

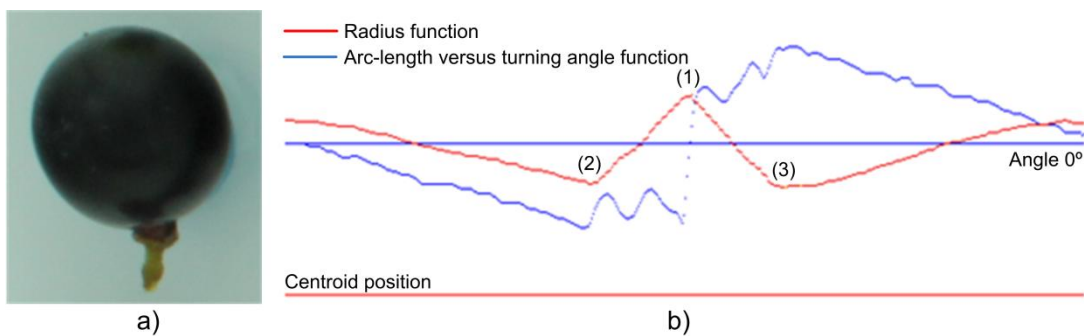
184 3. The second function calculated was based on the arc-length versus the turning angle graph of  
 185 the curvature (Kalvin et al., 1986). In essence, the curvature consists in the rate of change of  $\theta$ ,  
 186 the angle between the tangent vector to the curvature, and the horizontal axis for each point in  
 187 the contour. The present work made use of the turning angle function (also called direction  
 188 function), which consists in the graph showing the difference in  $\theta$  at equally spaced points in  
 189 the contour  $S_i$  ( $i=1..n$ ), the difference being computed as reflected in equation (1) (Shih,  
 190 2010):

$$\Delta\theta(S_i) = \theta(S_{i+\Delta S}) - \theta(S_i) \quad (1)$$

192 In this work  $\Delta S$  was set to 4, which was enough to capture changes in the direction of the  
 193 contour. Therefore, the equation (1) was modified as follows:

$$\Delta\theta(S_i) = \theta(S_{i-2}) - \theta(S_{i+2}) \quad (2)$$

195 For regular curves or shapes, the arc-length versus turning angle graph should be a monotonic  
 196 decreasing function with values in the interval  $[-\pi, +\pi]$  radians. When changes in the contour  
 197 are encountered due to irregular shapes or the presence of pedicel/peduncle, these are reflected  
 198 on the graph of the function and can therefore be detected and analysed. An example of this  
 199 signature is also shown in Figure 1b for a berry with the pedicel oriented downwards.

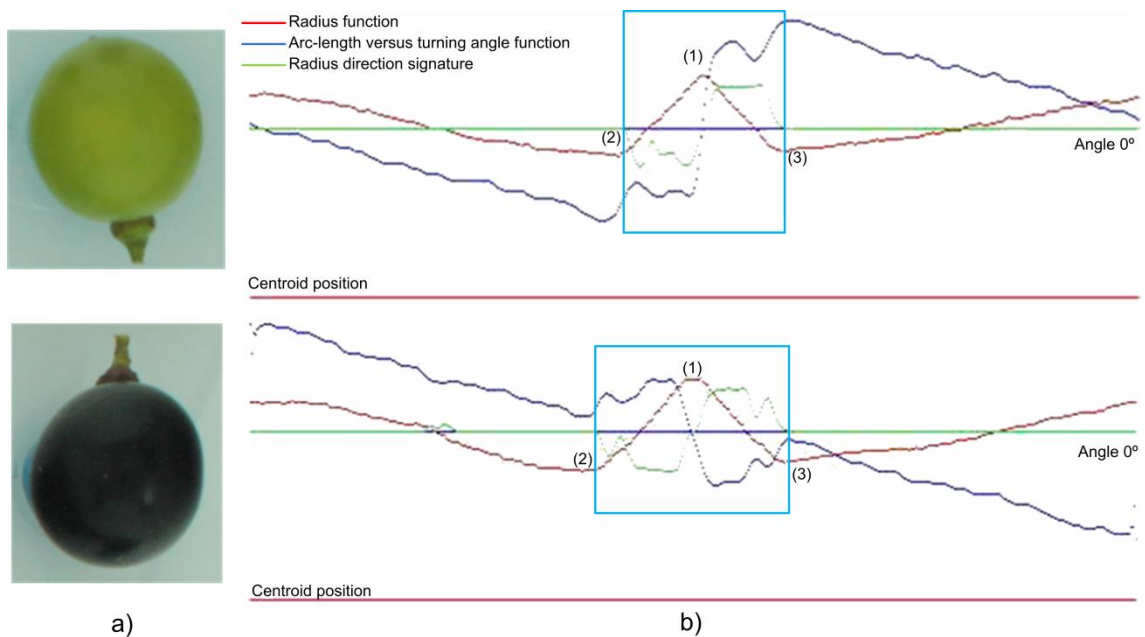


200 a) Original image and contour of a grape berry with pedicel; and b) its corresponding  
 201 radius function and arc-length versus turning angle function  
 202

203

204 4. Finally, both functions were mixed to obtain a new one derived from the radius function that  
205 was thereafter called the radius direction signature. The new function was then obtained by  
206 applying the arc-length versus turning angle using the radius function as input instead of the  
207 fruit contour, which allows drastic changes in the outline of the fruits to be detected. This new  
208 function took values close to zero when the radius signature presented small changes, and  
209 different from zero otherwise.

210 Under the premise that the contour moves away from the centroid in the pedicel/peduncle part  
211 (the distance between the contour and the centroid increases), this new signature attempted to  
212 detect the points where these changes in the direction happened. In the case of spherical fruits,  
213 the distance from the contour to the centroid should be very similar for all points on the  
214 contour and therefore the function should present small changes. In a similar way, in the case  
215 of elliptical or other regular-shaped fruits, the changes should be smooth and constant. Figure  
216 2 shows several samples of berries with different orientations of the pedicel (Figure 2a) and  
217 their corresponding signatures (Figure 2b). The local maximums have been centred in the  
218 graphs to make them easier to understand.



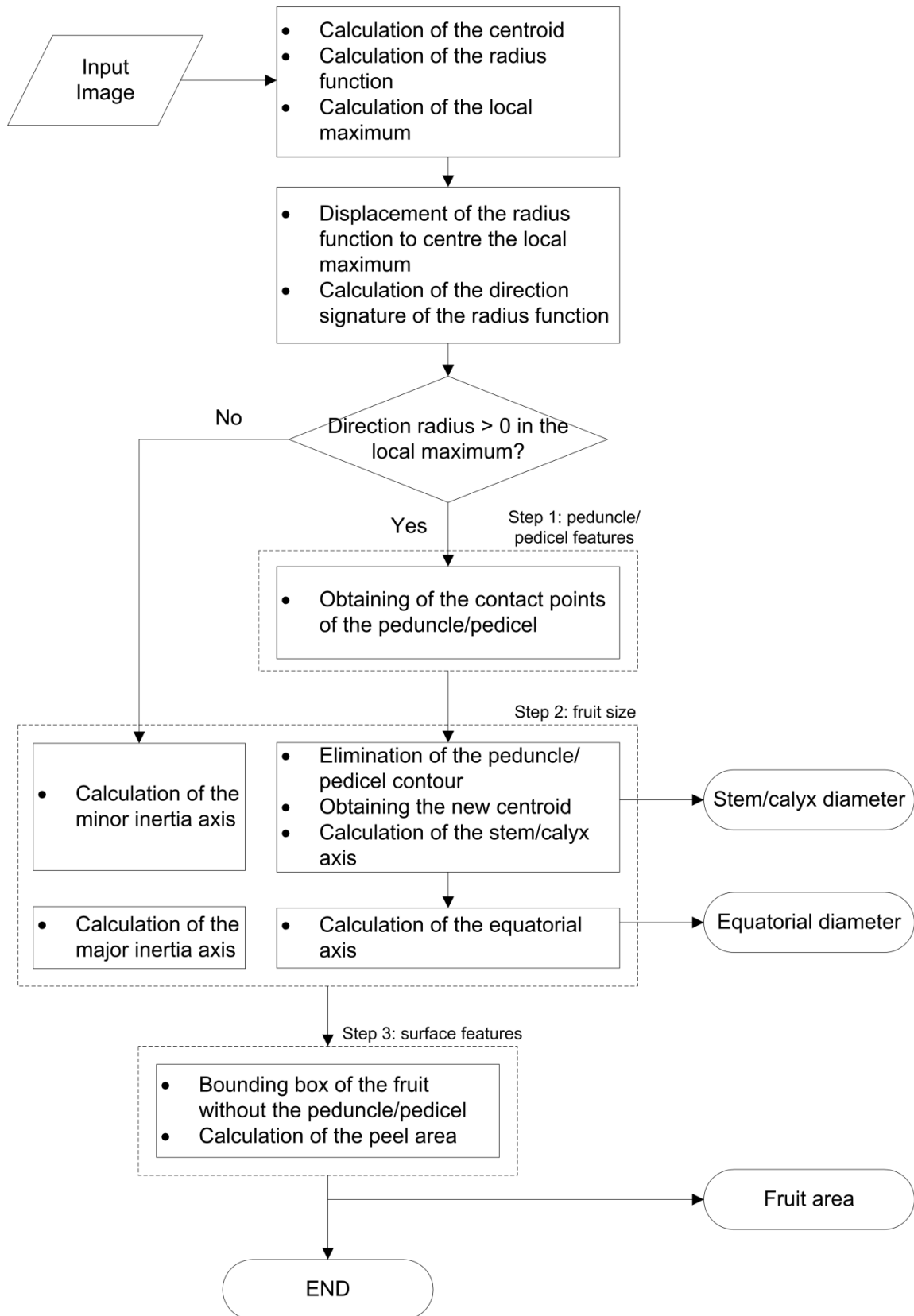
219

220 FIGURE 2. a) Two samples of grape berries; and b) their corresponding radius and arc-length versus  
221 turning angle function and radius direction signature

222

223 2.3. Validation process in grape berries

224 To estimate berry size, each individual berry was first located in the image and then the pedicel was  
225 detected following the algorithm described above. The two points identified as the connecting points  
226 between the pedicel and the fruit were joined to close the fruit contour while excluding the pedicel.  
227 Then, the centroid was calculated again without the influence of the pedicel and the size was estimated  
228 by means of the peduncle/pedicel axis and the diameter crossing the centroid, which was  
229 perpendicular to the previous peduncle/pedicel axis (equatorial diameter). The area of each berry was  
230 also estimated as the number of pixels belonging to the fruit excluding the pedicel. The information  
231 about the area was used to predict the weight of each individual berry. The flowchart of the features  
232 extraction algorithm can be found in Figure 3 and the pseudo-code of the main algorithm is presented  
233 in Figure 4.



234

235

FIGURE 3. Flowchart for peduncle/pedicle detection and features extraction

```

main () {
    Calculate the Radius_function of the contour;
    Search for the Maximum value in the Radius_function;
    Shift the contour so that the element corresponding to the Maximum in
        the Radius_function is centred;

    Calculate the Radius_function_new of the shifted contour;

    Calculate the Direction_function as the Arc-length versus the turning
        angle graph of the curvature;

    Calculate the Direction_Radius_function as the Arc-length versus the
        turning angle graph of the Direction_function;

    peduncle = false;
    for (i=0; i<total_points_contour; i++)
        if (Radius_Direction_function[i] != 0.0) {
            peduncle = true;
            break;
        }
    if (peduncle) {
        Search for the Local_minimum_1:
        for (i=0; i<total_points_contour/2; i++)
            if (Radius_Direction_function[i] != 0.0) {
                Local_minimum_1 = i; break;
            }
        Search for the Local_minimum_2:
        for (i=total_points_contour; i>total_points_contour/2; i--)
            if (Radius_Direction_function[i] != 0.0) {
                Local_minimum_2 = i; break;
            }
        Recalculate centroid without peduncle contour points;
        Remove peduncle contour points from original contour;
        fruit_size:
            Calculate stem/calyx diameter;
            Calculate equatorial diameter;
        fruit_weight = Calculate fruit_area;

    }
    else {
        fruit_size = Calculate inertia axes;
        fruit_weight = Calculate total_area;
    }
}

```

236  
237

FIGURE 4. Pseudo-code of the algorithm for peduncle/pedicel detection

238

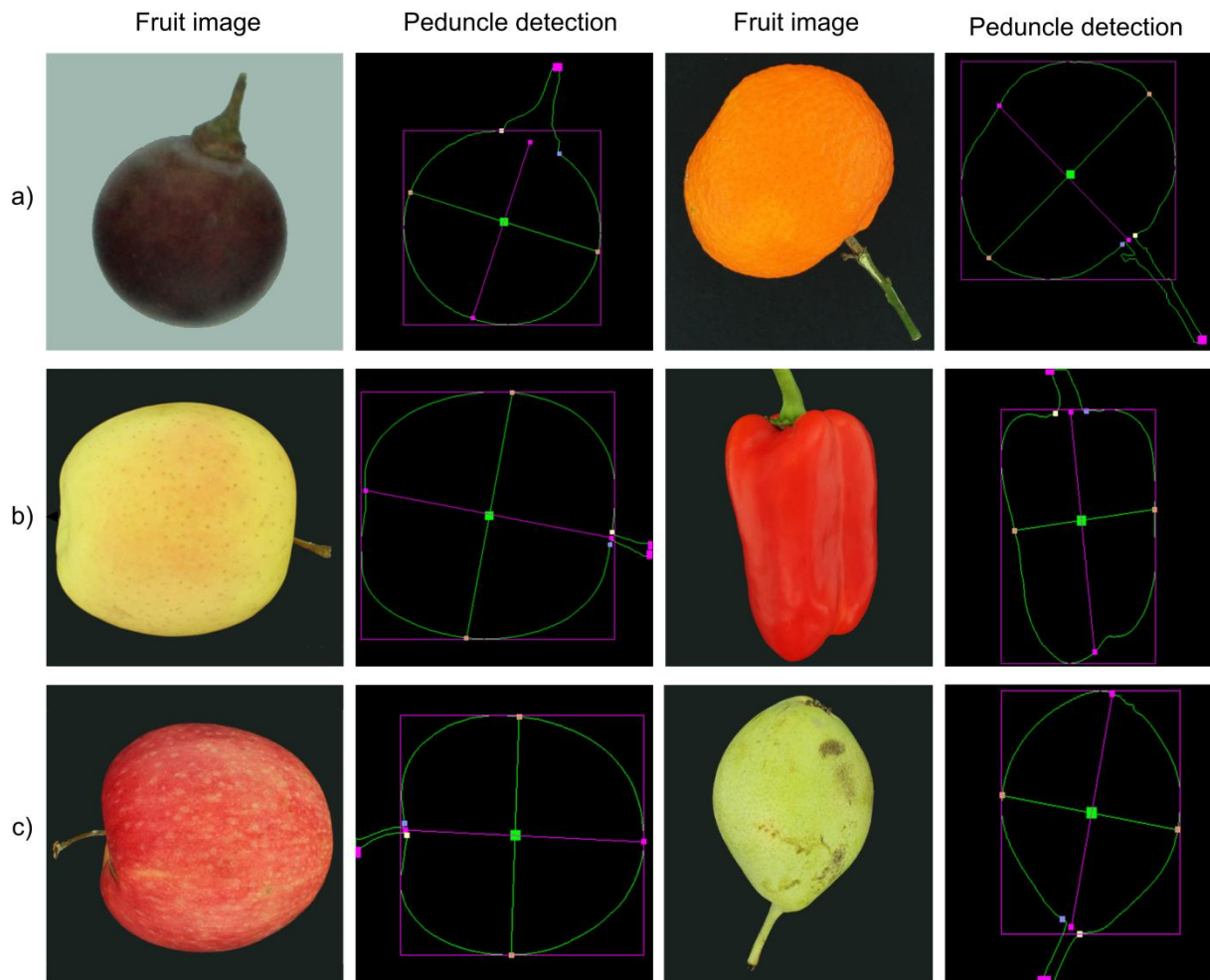
239 In order to assess the performance of the imaging system developed to predict the size (polar diameter)  
240 and weight of the berries in images including the pedicels, a regression model was built on a training  
241 set of 66 of the 100 berries. The remaining 34 berries were later used for validation.

242

#### 243 2.4. Validation process in other fruits

244 To test the performance and robustness of the algorithm as well as its capability to be generalised to  
245 other fruits, a number of types of fruit with different shapes, sizes and colours were imaged in a  
246 variety of orientations and the images were processed to find the peduncles and size using the  
247 proposed approach. Particularly, a total of 30 pieces of each of these sets of fruits were used: pears cv.  
248 ‘Blanquilla’, apples cv. ‘Golden Delicious’ and cv. ‘Royal Gala’, red bell peppers cv. ‘Lamuyo’, and  
249 mandarins cv. ‘Nova’. For each set of different fruits, the peduncle was visible in the image for a total  
250 of 25 out of 30 fruits. The rest of the fruit had no peduncle or it was located inside the projected area  
251 of the fruit. In the case of red peppers, all the samples contained peduncle. The size of this set was  
252 measured manually along the peduncle axis using a digital calliper and the measurements were  
253 recorded. The size of all the fruits was also estimated as the peduncle diameter from the closed contour  
254 of the fruit, excluding the peduncle.

255 Some of the results of the peduncle location algorithm for the fruits tested in this work are shown in  
256 Figure 5. The points of contact between the peduncle and the fruit are depicted by small yellow and  
257 blue key points (small squares), and the base point of the peduncle is the midpoint in-between (pink  
258 key point). The distance between the base point of the peduncle and its opposite key point represents  
259 the diameter of the peduncle/pedicel, and the other two points on both sides of the centroid determine  
260 the length of the equatorial axis, both of which later correlated with the calliper measurements.



261

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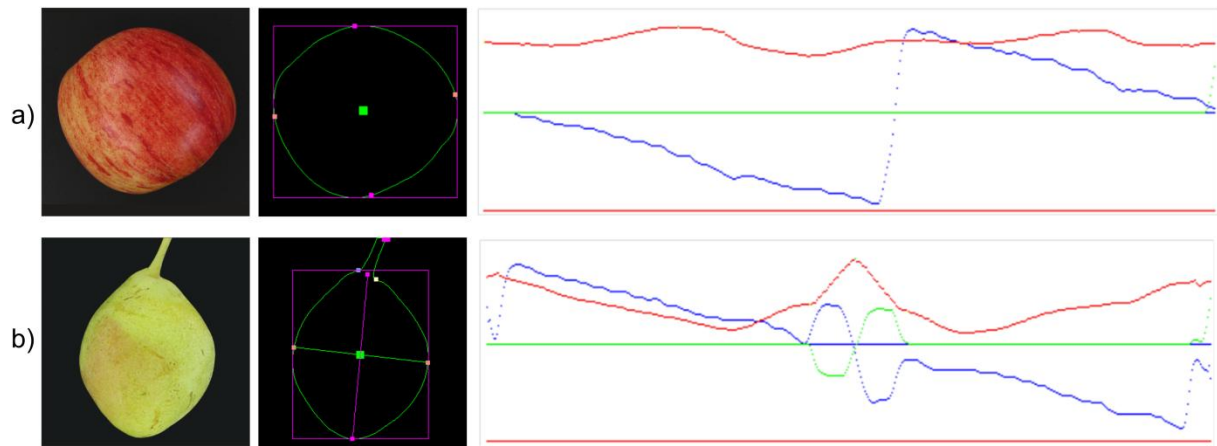
267

268

269

FIGURE 5. Results of peduncle detection and size estimation for some fruits tested with a random position of the peduncle: a) for grape berry and mandarin, b) for apple ('Golden Delicious') and red pepper, and c) for apple ('Royal Gala') and pear

When no peduncle was present, the direction radius signature did not vary from zero since changes in the direction of the radius signature were very smooth, and both axes of inertia were calculated from the contour to obtain the size features. Figure 6 shows the differences in the signals calculated in images with and without peduncle.



270

271 FIGURE 6. Example of results when (a) no peduncle was present in a ‘Royal Gala’ apple, compared  
 272 to (b) a result with peduncle detected in a pear

273

### 274 3. Results and discussion

#### 275 3.1. Assessment of grape berry size and weight by image analysis

276 Table 1 shows the statistical parameters for the regression model for the size estimation in ‘Grenache’  
 277 and ‘Tempranillo’ grape berries. The adjusted  $R^2$  value obtained for the two grape varieties (0.97)  
 278 confirmed the goodness of the linear regression found between the real and the estimated size values,  
 279 the two coefficients being statistically significant (Table 1).

280

281 TABLE 1. Regression analyses for the estimation of the size of ‘Grenache’ and ‘Tempranillo’ grape  
 282 berries

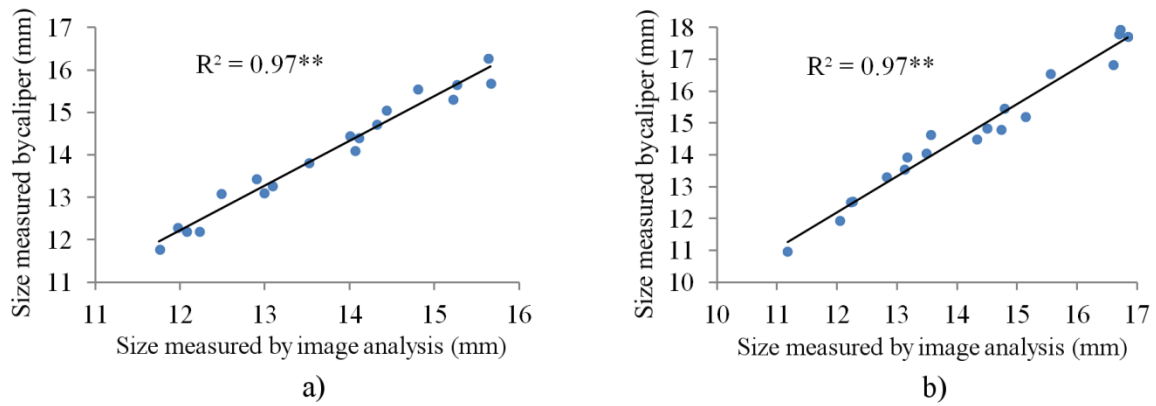
Grape variety	Parameter	Estimation	Std. error	T Statistic	P-Value
Grenache	Constant	1.0436	0.2735	3.81	<0.001
	Polar Diameter	0.9045	0.0198	45.76	<0.001
Tempranillo	Constant	0.8156	0.3350	2.44	<0.019
	Polar Diameter	0.9086	0.0237	38.32	<0.001

283

284 In order to validate the models properly, the next step was to use the regression models to predict the  
 285 berry size values of the validation set. Figure 7 shows the validation results for both grapevine  
 286 varieties. The validated  $R^2$  values remained almost the same (a little bit lower, as expected for very



287 high  $R^2$  values), which finally gave rise to a reliable predictive model. This result indicates that the  
 288 vision system developed for the estimation of the size of grape berries with pedicel was completely  
 289 reliable and could be used as a useful laboratory tool replacing the very slow and tedious manual  
 290 methods that are currently employed.



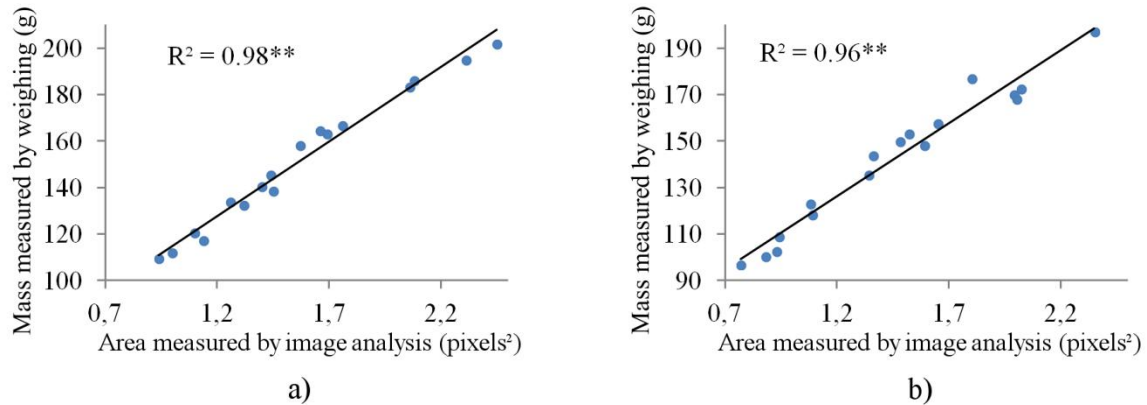
291 a) b)  
 292 FIGURE 7. Adjustment to the linear model for the diameter of the berries from a) ‘Grenache’, and b)  
 293 ‘Tempranillo’. Statistical significance at  $p < 0.01$  is represented by (\*\*)

294  
 295 Similar analyses were performed to assess the goodness of the system at predicting the weight of  
 296 individual berries obtaining a  $R^2=0.98$  for cv. ‘Grenache’ and  $R^2=0.96$  for the cv. ‘Tempranillo’  
 297 (Table 2) with  $P\text{-value} < 0.01$  for both cultivars. To obtain more precise values of the weight, the  
 298 pedicel was previously removed from the grape berries.

299  
 300 TABLE 2. Regression analyses for the estimation of the weight of ‘Grenache’ and ‘Tempranillo’  
 301 berries

Variety	Parameter	Estimation	Std. error	T Statistic	P-Value
Grenache	Constant	-0.6737	0.0566	-11.91	<0.001
	Weight-Area	0.0148	0.0004	38.88	<0.001
Tempranillo	Constant	-0.6593	0.0524	-12.59	<0.001
	Weight-Area	0.0149	0.0004	44.42	<0.001

303 To validate the models, the regression models were used to predict the weight values of the validation  
304 set. Figure 8 shows the validation results for both varieties. These results indicated that the vision  
305 system developed was also reliable for estimating the weight of grape berries of both cultivars.



306

307 FIGURE 8. Adjustment to the linear model for the estimation of the weight of berries a) ‘Grenache’,  
308 and b) ‘Tempranillo’. Statistical significance at  $p < 0.01$  is represented by (\*\*)

309

310 Berry size and weight are common parameters for monitoring grape maturity before harvest in the  
311 wine industry (Iland et al., 2004). Nevertheless, berry weight and size determination is conducted  
312 manually in the winery laboratory, and is therefore a tedious and time-consuming task. Cluster  
313 compactness, berry colour and health grape status are properties that are strongly influenced by berry  
314 weight (Tardaguila et al., 2010) and size.

315 On the other hand, berry size is also related to the skin-to-pulp ratio, which is widely assumed to be a  
316 grape and wine quality factor. Since the most decisive compounds for berry and wine quality, such as  
317 aromas and phenols, are located in the skin, the larger the skin-to-pulp ratio is, the higher the potential  
318 quality of the final wine will be (Barbagallo et al., 2011). Hence, smaller berries are often considered  
319 to yield better wines and are highly appreciated by winemakers, who usually include a grape berry  
320 separation step based on their size carried out on a sorting table when the intention is to produce high-  
321 quality wines.

322 The methodology developed for berry weight assessment, using image analysis, is a new, fast and  
323 inexpensive tool for the wine industry to monitor berry ripening and to evaluate potential grape and

324 wine quality. This method could also be implemented as an inspection module on the sorting belts and  
 325 tables of wineries producing high quality ultra-premium wines, thereby replacing the manual  
 326 separation based on berry size that is currently performed after the de-stemming process.

327

### 328 3.2. Detection of peduncle in other fruits

329 As stated in section 2, the algorithm developed was also tested on other fruits, such as apples, pears,  
 330 mandarins and peppers so as to be able to generalise it. The two functions and the signature described  
 331 in section 2.3 were used to detect the peduncle, and the best results were obtained for the new radius  
 332 direction signature (Table 3), which includes the correct determination of all fruits without peduncle.  
 333 The main drawback of using the radius signature was that minimum values did not always match the  
 334 contact points of the peduncle with the fruit when this was non-spherical (because there were points  
 335 closer to the centroid than the peduncle points). Furthermore, in irregular fruits the arc-length versus  
 336 turning angle function showed sudden changes in different parts of the signal, which caused confusion  
 337 with the peduncle.

338 Regarding the estimation of the fruit size, the peduncle/pedicel axis was compared to the manual  
 339 calliper measurement, an adjusted  $R^2 > 0.93$  being obtained for all types of fruit. This result confirmed  
 340 the goodness of the regression, since  $P\text{-value} < 0.01$  in all cases, thus demonstrating the reliability of  
 341 the algorithms that were developed.

342

343 TABLE 3. Percentage of pedicel (grape berries) and peduncle (other fruits) detection using different  
 344 signatures. For the coefficient of determination,  $R^2$  was tested at  $p < 0.01$

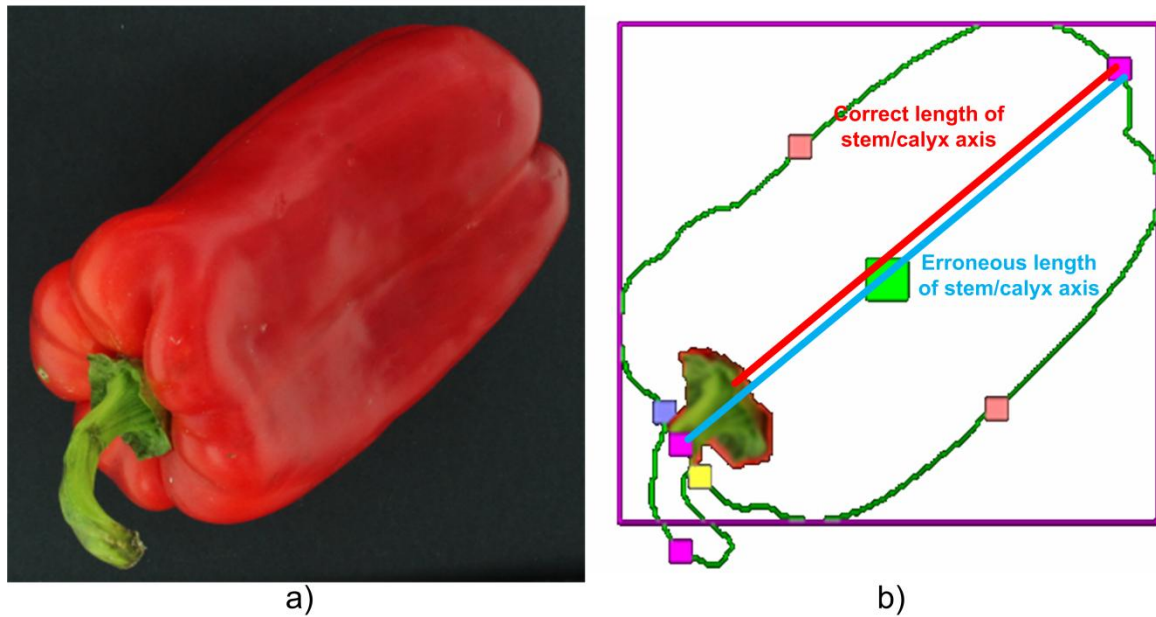
Fruit	Radius function	Arc-length vs. turning angle function	Radius direction signature	Size ( $R^2$ )
Grape berry	57.0%	72.0%	100%	0.97
Mandarin	60.0%	76.7%	100%	0.97
Apple Golden Delicious	50.0%	63.3%	96.7%	0.96
Apple Royal Gala	40.0%	60.0%	96.7%	0.96
Pear	16.7%	60.0%	96.7%	0.96

Red pepper	20.0%	30.0%	90.0%	0.93
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345

346 The limitations of the method mainly concerned the shape of the object, since the algorithm was able  
 347 to determine the presence of the peduncle in regular and more or less rounded or compact fruits very  
 348 well, but was not able to determine the presence or absence of the peduncle in fruits that were either  
 349 elongated or that had irregular shapes, like the green peppers. This occurred because this method is  
 350 based on the radius signature calculated as the distance of the contour points from the centre of mass.  
 351 Therefore, although this centre was calculated from the area and not only from the contour, in  
 352 elongated objects the centre of mass was biased to the peduncle (and sometimes outside the object  
 353 surface), causing the local maximum of the polar signature to not always match the position of the end  
 354 of the peduncle.

355 Another limitation concerns the requirement that the peduncle had to stand out from the contour of the  
 356 object, which meant that the fruit or vegetable had to be oriented in order to image its profile,  
 357 otherwise the peduncle could be detected, but not the correct size parameters. This can be observed in  
 358 Figure 9, where the detection of the peduncle is performed correctly (Figure 9a), but the parameter of  
 359 size is not (Figure 9b). In contrast, the method performed well for regular-shaped fruits. This is  
 360 important since it could potentially be applied in industrial imaging vision systems. For instance,  
 361 Lefcourt et al. (2009) found that under particular loading conditions in industrial systems, rotating  
 362 apples generally moved to an orientation where the peduncle/pedicle axis was parallel to the plane of  
 363 the track and perpendicular to the direction of travel. This orientation would allow this algorithm to  
 364 detect the peduncle location properly and to measure the size of the fruits accurately in real time, since  
 365 the processing time needed to analyse one image is less than 40 ms. On the other hand, it could also be  
 366 implemented in harvesting robots to orient or guide the robotic hand, but in this case other problems  
 367 related with the image segmentation could appear.



368

a)

b)

369 FIGURE 9. Example of result when the fruit was not well oriented on its profile and its impact on  
 370 the size parameters

371

#### 372 4. Conclusions

373 This work has presented a new, fast and inexpensive method to accurately assess the berry size and  
 374 weight of wine-grapes, thus providing the wine industry with a cheap useful tool to monitor berry  
 375 ripening and to evaluate potential grape and wine quality.

376 Moreover, a new effective method was developed to detect and remove the part of the  
 377 peduncle/pedicel that protrudes from the fruit in the images taken by computer vision systems. The  
 378 algorithm developed here could be applied to locate the peduncle/pedicel in order to have the fruit  
 379 oriented or to avoid misclassification between the peduncle and defects, to accurately estimate the size  
 380 while avoiding the effect of the peduncle, or also to measure the length of the peduncle. The new  
 381 method does not require the segmentation of the peduncle and/or fruit defects in different regions,  
 382 thereby allowing faster processing and can be used on standard images taken in the visible region of  
 383 the spectrum. These two advantages make the proposed methodology faster and cheaper than other  
 384 image vision methods that implement slow complex algorithms or require more expensive spectral

385 computer vision equipment. The methodology developed here may be implemented in automated  
386 inspection systems and robots for multiple purposes such as sorting or harvesting tasks.

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