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AUTOMATIC GRADING OF ANTHURIUM CUT FLOWERS USING 3D COMPUTER VISION

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ABSTRACT Anthurium flowers, also known as “flamingo flowers”, exist in a wide range of colors, forms and sizes on the cut flower market. Nowadays each flower is graded manually which requires a high amount of manual labour and special expertise. Typically Anthurium flowers are classified according to the diameter of the spathe, the hood-like bract found along with the spadix. To be able to automate this sorting process the possibilities of computer vision were studied. Because of the cup shaped nature of the spathe it is impossible to determine the diameter accurately by means of a 2 dimensional camera image. Using stereo vision techniques three dimensional (3D) images of the flowers were recorded. Flowers passed the vision system with an arbitrary orientation and with some variation of the distance to the cameras. An algorithm was developed to determine the orientation of the flower in the image and the position where the diameter is measured. This algorithm needed to cope with the extreme high variability in color and shape of the different types of Anthurium. Shape based templates were used to analyze the 3D image and to measure the diameter of the spathe at the determined position. The results of these measurements showed good correlation with the manual measurements.

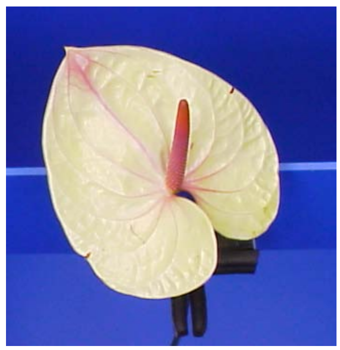
Keywords: Computer vision; stereo vision; Anthurium; cut flowers; grading; sorting

INTRODUCTION In the last decade, the use of computer vision techniques has found its way to the greenhouse industry. Vision systems for inspecting trays of seedlings, grading young plants and pot plants are tasks performed daily in horticultural practice. A number of scientific publications about this subject appeared in the past (Timmermans and Hulzebosch, 1996, Brons et al., 1993) whereas sorting machine producers often prefer not to publish about the used algorithms. Nowadays, also cut flowers as e.g. gerbera and roses are commonly classified by means of computer vision (e.g. Steinmetz et al., 1994 or Miao et al. 2006). Anthurium flowers, also known as “flamingo flowers”, exist in an extremely wide range of colors, forms and sizes on the cut flower market. Nowadays each single flower is graded manually on size which requires a high amount of manual labour and special expertise. However, humans can not grade objectively nor can they grade consistently. Accuracy and speed of the grading operation largely depends on the experience and condition of the grader (Dijkstra et al., 1997). In line with the plant grading standard available from the auctions, Anthurium flowers are classified according to the flattened (unfolded) diameter of the spathe. The spathe is the hood-like bract found along with the spadix. Because of the cup shaped nature and the more or less arbitrary position of the spathe it is impossible to determine the diameter accurately by means of a 2d image from a camera mounted on a fixed position. To simplify further reading, the Anthurium spathe together with the spadix is called ‘flower’ in the remaining text.

MATERIAL

Plant Material For this study 121 single Anthurium flowers of different varieties were used. The flowers originated from a commercial Anthurium grower of The Netherlands. The major part consisted out of 3 common varieties: the small sized, red coloured African King, the medium sized rose coloured Anastasia and the large sized yellow coloured Marysia. Moreover a compilation of different coloured flowers (black, green, pink, orange, bi-coloured) and different shaped flowers (heart-shaped, ellipse shaped) were used. Figure 1 shows some example images of the flowers used and table 2 the mean values of the flower diameter.


African King


Anastasia


Marysia


Black Queen


Red Heart


Nunzia

Figure 1. Example photos of different Anthurium flower varieties

Test set-up Two 1/2’’ charged coupled device (CCD) colour camera’s (Sony DFW-X700, IEEE 1394) were used to set-up a binocular stereo vision system. The two cameras were mounted parallel to each other with a baseline distance of 55 mm. Two identical lenses with 8 mm focal length were used. For the analysis images with a resolution of 1024x768 pixels were grabbed using a personal computer. The camera to object distance was in the range of 650-750 mm. To illuminate the scene fluorescent tubes with a diffuser were mounted behind the camera head. Diffuse illumination was necessary to minimize specular reflections which will occur easily due to the wax layer of the flower spathe. A bracket for holding a single flower was mounted in front of a blue coloured background.

This background was made from foamed plastic sheets which do not show specular reflections. The bracket was designed as a part of a future sorting machine for Anthurium flowers. Figure 2 shows a photo of the test set-up.

The image acquisition and analysis software was programmed in C# language with Microsoft Visual Studio 2008 and the machine vision software package Halcon 9.0 (MVTec, 2010).

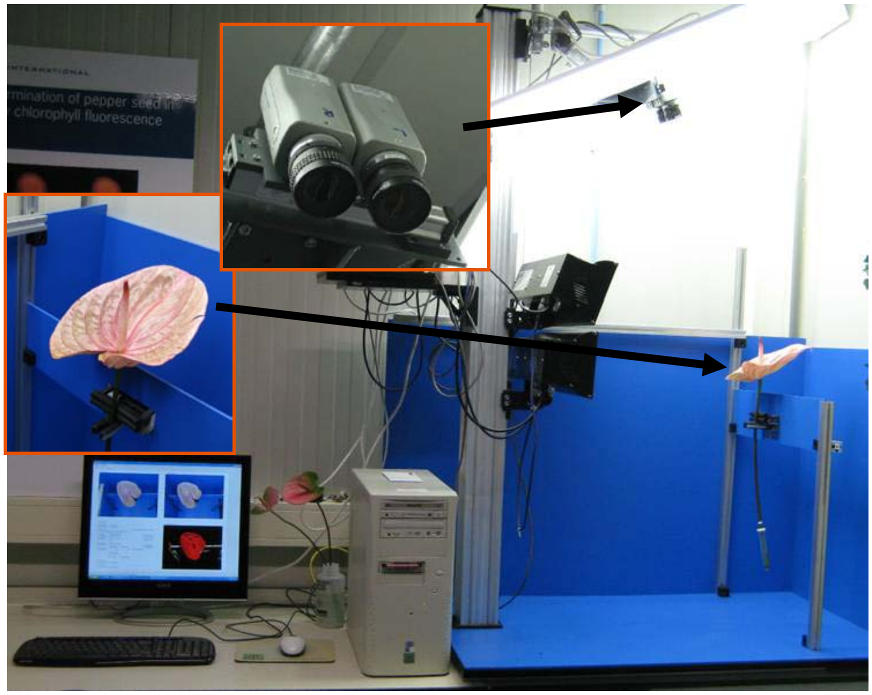


Figure 2. Test set-up in the laboratory. The two inlays show the stereo-camera head and a flower in the bracket.

METHODS

Manual diameter measurement The flattened and not flattened diameter of each flower was measured by means of a ruler. To measure the flattened diameter the cup-shaped flower was carefully pressed down on a table with help of the ruler. To be able to trace back the position of the manual measurement in the camera images the edges of the flower (most left and most right point) were marked with a marker pen on the spathe. These marks can be e.g. seen in figure 1 on the Anastasisa flower image.

Automatic diameter measurement All flowers were manually inserted in the bracket and recorded and analysed with the image processing system. The flowers were inserted at an arbitrary orientation with a limit of +/- 60° from the 0° orientation. A projected line from edge to edge of the flower, called scan line, was used to determine as well the flattened and not flattened diameter. The position of the scan line was determined in two different ways. In the first case the begin and the end position of the scan line was set manually in the image by using the two marks visible. In the second case the position and orientation of scan line was determined fully automatically by the image analysis software as described below.

Camera calibration The color and white balance of the cameras were adjusted to enable a good color based segmentation of flower and background. To be able to perform real world measurements the system was calibrated with the help of a set of images acquired of a calibration board (with printed marks) placed in several orientations in front of the camera system. Applying the binocular calibration functions from Halcon (MVTec, 2010) the internal camera parameters (focal length, lens distortion parameters) describing the underlying projective camera model and the external camera parameters (relative pose of the left camera in relation to the right camera) were obtained. The images were corrected for their geometrical distortions (rectified).

Stereo vision The reconstruction of a 3d point from the corresponding images is specified by the internal and external camera parameters. Hence, given a pixel in the rectified reference image (left image) the homologous pixel in the right image is selected by searching along the corresponding row in the rectified second image and matching a local neighbourhood within a rectangular window of a certain size using correlation techniques. In the experiments described here a window size of 11 by 11 pixels was used. The pixel correspondences are returned in a so called disparity image which specifies for each pixel of the reference image a suitable matching pixel in the second image. Thereafter, the 3d information can be determined as the distance of the object surface from the stereo camera system for each image pixel (real world x, y and z co-ordinates).

Image segmentation

To segment the flower object from the blue background the red, green, blue (RGB) images were transformed to the hue, saturation, intensity (HSI) color space. Empirical determined fixed thresholds for the levels of all three channels were applied to segment the flower object in a binary image. To remove noise pixels a morphological opening operation was applied and following the largest blob (the blob with the highest number of pixels) was selected as target object.

Determination of flower orientation using region contour

The first step to determine the flower orientation was to calculate the center of mass of the binary input region. The region center was calculated as the mean value of the line or column co-ordinates, respectively, of all pixels. Then the contour of a region was extracted. A contour is the result of line and column coordinates describing the boundary of the region. Holes of the region are ignored. The first contour point is the topmost point of the region and the contour is followed clockwise. Next the Euclidean distances from the object center to all contour points were calculated. The region point with the smallest distance was finally defined as base point of the flower $P(x, y)_{base}$ according to:

$$P(x, y)_{base} = \min_{i=1}^{n}\left(\sqrt{\left(\left|x_c - x_i\right|\right)^2 + \left(\left|y_c - y_i\right|\right)^2}\right) \qquad (1)$$

x_c and y_c the row and column pixel co-ordinates of the center of mass

x_i and y_i the row and column pixel co-ordinate of a region contour point

n the number of region contour pixels

After calculating the distances from the base point to all contour points were calculated. The region point with the maximum distance was defined as the tip of the flower $P(x,y)_{tip}$ according to:

$$P(x,y)_{tip} = \max_{i=1}^{n}\left(\sqrt{(|x_b - x_i|)^2 + (|y_b - y_i|)^2}\right) \tag{2}$$

x_b and y_b the row and column pixel co-ordinates of the base point

x_i and y_i the row and column pixel co-ordinates of a region contour point

n the number of region contour pixels

The orientation of the flower was finally defined as the direction of the virtual line object center to object tip. Figure 3 and Figure 4 illustrate this approach.

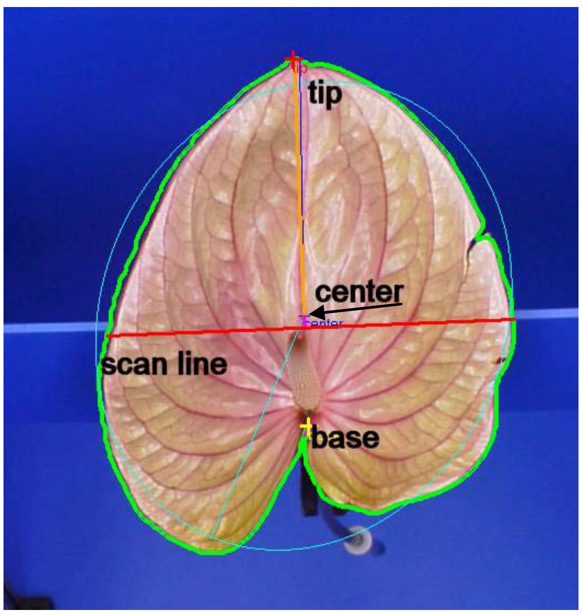


Figure 3. Example image of a flower with calculated center point, base point, tip point, scan line and region contour. Also displayed is the ellipse having the same orientation and the same side relation as the input region.

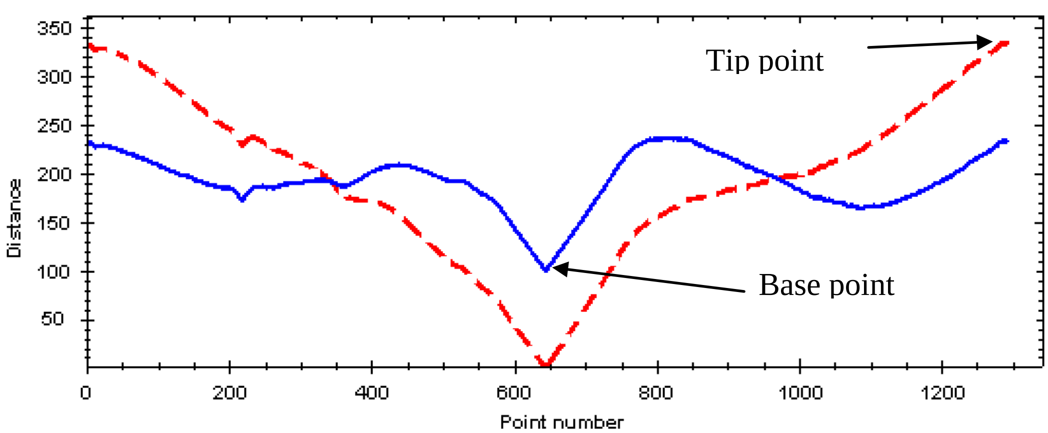


Figure 4. Distance graph for the distance center point to each contour point (blue solid

line) and the distance base point to each contour point (red dashed line) of the flower shown in figure 3. Distances are displayed in number of image pixels.

Determination of flower orientation using a fitted ellipse Preliminary experiments revealed that for some flower varieties the determination of the flower orientation based on the above described method was faulty in a large number of cases. Main reason for this was the more or less absence of an indentation at the lower part of the spathe. In this situation it was difficult for the algorithm to determine the base point of the flower. Therefore for the varieties Marysia and Nunzia a different approach was chosen to determine the orientation. With the operator "elliptic axis" (for calculation see user manual of Halcon, MVTec, 2010) the orientation of the ellipse having the same orientation and the same side relation as the input region was calculated. The orientation of the main axis of the ellipse was taken as flower orientation. Figure 3 shows a flower with such an overlaid fitted ellipse.

Determination of scan line position The position to measure the flattened and not flattened diameter on the flower (scan line) was calculated as follows:

1. The orientation of the scan line was rotated 90° with respect to the flower orientation.
2. The vertical position of the scan line was on 10% below the center point of the length of a virtual line between the center point and the base point.

Determination of flower diameter Two kinds of diameters were calculated, the flattened and the not flattened diameter. The not flattened diameter d_u was computed by calculating the Euclidean distance in between the furthest left and furthest right point on the scan line. Therefore the real world x, y and z co-ordinates of theses points were obtained from the 3d stereo image and processed with:

$$d_u = \sqrt{\left(\left|x_r - x_l\right|\right)^2 + \left(\left|y_r - y_l\right|\right)^2 + \left(\left|z_r - z_l\right|\right)^2} \quad (3)$$

where x, y and z are the 3d real world co-ordinates of the furthest left and furthest right point relative to the left stereo camera co-ordinate system.

For calculating the flattened diameter it was necessary to measure the length of the cup-shaped scan line in the 3 dimensional space. The position of the spadix of the flower is not well defined and depending on the position of the scan line might even not be visible in the 3d profile. The raw real world distance data for each point on the scan line where stored in an array. Figure 5 shows an exemplary graph of these distances. The peak caused by the spadix and eventually other noise from the signal had to be removed. For this purpose a shape template was created. A parabola simplifies the geometrical representation of the cup-shaped flower we have to deal with. With the first and the last point in the array and with the point with the maximum distance a parabolic curve ($y = ax^2$) was established using these parameters (see dashed line in figure 5). To remove the peak, all points in the array were cleared which were above 20% of the total modelled parabola height. Doing so, the spadix peak could be removed from the signal in a very robust manner. In the next step the remaining data points in the array were smoothed heavily with a moving average filter. The size of the moving average filter was ¼ of the number of points in the array. The smoothing operation removed the ripples from the shape. Even though these ripples are actually visible on the leaf they must not be used to measure the length of the diameter. Also the human graders of the flowers do not flatten these small ripples. Finally the flattened diameter d_f was calculated as follows:

$$d_f = \sum_{i=1}^{n-1} \sqrt{(|x_i - x_{i+1}|)^2 + (|y_i - y_{i+1}|)^2 + (|z_i - z_{i+1}|)^2} \text{, where} \quad (4)$$

n is the number of points and

x_i, y_i, z_i are the real world x, y and z co-ordinates of scan line point at index i

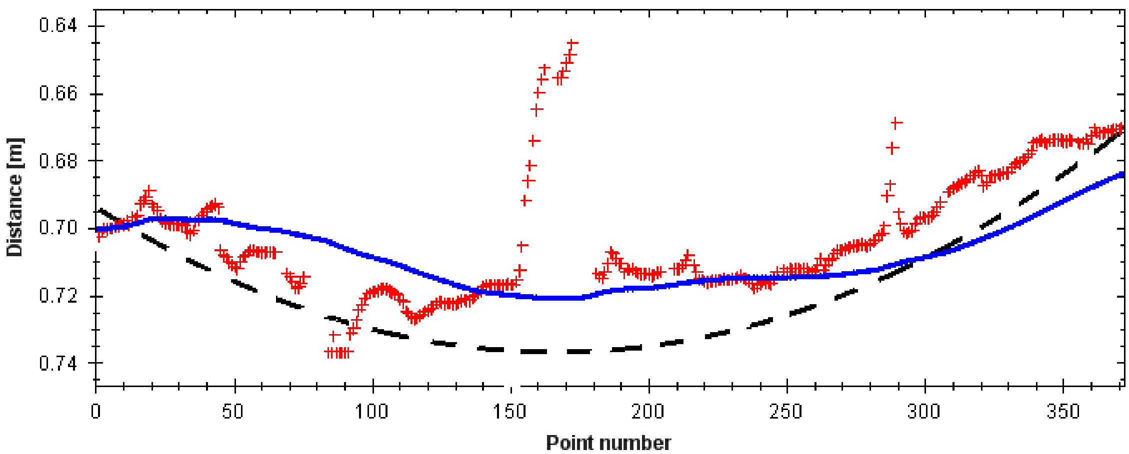
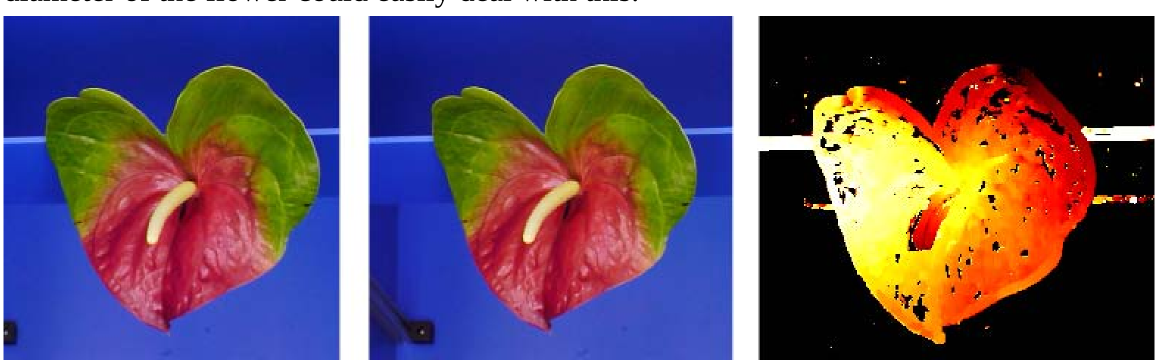


Figure 5. Real world distances camera – flower along the scan line. Raw data (red crosses); filtered and smoothed data (blue solid line) and fitted parabola (black dashed line)

RESULTS

Stereo match Figure 6 shows an example stereo image from the left and the right camera and the resulting disparity image. Despite the glossy surface of the flowers, the stereo matching algorithm was able to produce a dense disparity image with only a few gaps in most cases. The raised spadix of the flower is also clearly visible. Also the distance graph along a scan line as shown in figure 5 confirms that the 3d information which can be revealed from the disparity image matches closely the real shape of the flower. Some gaps and missing points did not cause problems because the method to calculate the diameter of the flower could easily deal with this.



(a) (b) (c)

Figure 6. Stereo image from the left (a) and right (b) camera and resulting disparity map (c). Darker (more orange) colors represent closer distances to the camera in the disparity map.

Flower orientation The accuracy of the flower orientation was analyzed by comparing the orientation of the scan line manually drawn between the two marker points (see chapter manual diameter measurement) and the orientation of the scan line determined fully automatically by the algorithm.

Table 1 shows the result for the different Anthurium varieties. For the common varieties the mean error did not exceed 20°. In the special sets of heart shaped or extreme shaped flowers this raised up to more than 70°. Whereas the mean error looks acceptable in most varieties the maximum error for single flowers reached even for the common varieties almost 90°. The correct determination of the orientation is the precondition for an accurate diameter determination and thus a critical step in the method.

Table 1. Errors in determination of the orientation with different flower varieties.

Variety	Mean error in determination of orientation (degrees)	Maximum error in determination of orientation (degrees)
African King	8.5	55.3
Anastasia	17.4	82.2
Marysia	15.2	87.6
Black Queen	5.1	15.2
Red Heart	21.7	86.9
Salmon Queen	32.4	85.0
Rose	5.7	27.4
Nunzia	39.9	75.0
Special	71.3	100.8

Flower diameter Table 2 lists the mean values of the manually measured flower diameters of different varieties. It is noticeable, that the difference between the not flattened and flattened diameter is only a few percent in most cases. Table 3 lists the mean values of the measurements based on the developed computer vision system.

Table 4 summarizes the results of the diameter measurements of the flattened and the not flattened diameter. Displayed are the absolute mean differences between measuring the flower diameter by hand and by the computer vision system. Also displayed are the standard deviation of the differences and the maximum differences. The position of the scan line was defined manually based on the visible marker positions in the images. For the common varieties the mean difference stays below the desired 5 mm for the not flattened diameter and is also not much higher for the flattened diameter. However the maximum difference between manual measurement and machine vision measurement exceeds in all cases 10 mm but sometimes even 40 mm.

Table 5 also compares manual and machine vision measurement but with the automatically calculated scan line position. In that case the scan line did not always correspond well with the manual determined scan line position and therefore the results show increased differences For the common varieties African King, Anastasia and

Marysia the mean difference between manually and automatically measured diameter does not exceed 10 mm, but the maximum differences exceed in some cases even 40 mm.

Table 2. Mean manually measured flower diameters of different varieties.

Variety	n	Not flattened diameter (mm)	Flattened diameter (mm)	difference (%)
African King	25	97	99	1
Anastasia	26	120	124	3
Marysia	24	141	144	2
Black Queen	8	125	130	4
Red heart	9	182	186	2
Salmon queen	8	174	183	5
Rose	9	142	151	6
Nunzia	6	125	137	10
Special	6	138	197	38

Table 3. Mean computer vision based measured flower diameters of different varieties.

Variety	Not flattened diameter, scan line manually (mm)	Flattened diameter, scan line manually (mm)	Not flattened diameter, scan line automatically (mm)	Flattened diameter, scan line automatically (mm)
African King	94	98	93	97
Anastasia	117	123	111	120
Marysia	137	149	138	150
Black Queen	122	127	115	120
Red heart	173	186	165	192
Salmon Qeen	166	183	136	150
Rose	140	152	139	151
Nunzia	123	143	115	159
Specials	155	181	152	177

Table 4. Mean absolute differences between measuring the flower diameter by hand and by the computer vision system. Position of the scan line is defined manually.

Variety	Not flattened diameter (mm)	Standard deviation (mm)	Max. differ-ence (mm)	Flattened diameter (mm)	Standard deviation (mm)	Max. differ-ence (mm)
African K.	4.5	4.8	16.5	4.3	4.8	16.6
Anastasia	4.7	5.2	20.6	4.1	3.5	11.2
Marysia	4.2	3.5	11.9	5.9	5.2	19.3
Black Q.	3.5	3.3	10.3	3.8	3.6	11.5
Red Heart	9.2	8.8	21.4	6.4	4.7	16.9
Salmon Q.	13.8	17.9	55.0	13.1	13.5	41.1
Rose	3.2	2.4	7.6	6.0	3.5	12.6
Nunzia	2.5	2.4	6.1	7.7	8.4	25.1
Special	14.1	36.9	111.3	9.8	16.0	45.8

Table 5. Mean absolute differences between measuring the flower diameter by hand and by the computer vision system. Position of the scan line is calculated automatically.

Variety	Not flattened diameter (mm)	Standard deviation (mm)	Max. differ-ence (mm)	Flattened diameter (mm)	Standard deviation (mm)	Max. differ-ence (mm)
African K.	5.7	7.9	36.6	5.6	5.9	27.3
Anastasia	10.2	16.5	59.2	7.9	10.0	43.2
Marysia	4.3	4.0	14.4	6.8	8.1	35.9
Black Q.	10.7	11.6	40.6	10.4	13.4	43.7
Red Heart	27.3	46.3	148.9	12.7	7.3	22.2
Salmon Q.	45.2	45.3	148.3	42.1	44.9	136.8
Rose	3.3	3.7	11.5	6.2	4.0	14.7
Nunzia	11.8	13.0	37.6	23.6	24.8	76.2
Special	16.4	32.6	110.1	12.8	16.2	48.4

Processing time When a computer vision system is used in a sorting machine, process time is an important factor. With the algorithms described here one set of stereo images could be processed within 300 milliseconds (CPU Intel Core2 Duo 2.53 Ghz). It is expected that comparable results can be achieved with images of much lower resolution resulting in a throughput of more than 10 flowers per seconds.

DISCUSSION AND CONCLUSION The on the first view relatively simple looking question to measure the diameter of a flower by means of computer vision turned out to be very complex. The flamingo flowers are such different in color and shape that it is impossible to process them with one generic algorithm. The use of 2d images only will not yield in useful measurements.

Stereo vision techniques are capable to produce a high quality 3d images of the flowers which can be used for further analysis. Nowadays, the needed processing time and computing power of such algorithms play only a minor role. The real world diameter (length along a scan line) of such a cup-shaped flower can be determined precisely from the 3d image. Filter and smoothing techniques are necessary to eliminate e.g. the spadix or to bridge gaps in an incomplete 3d image. Crucial for accurate diameter measurements is the correct determination of the flower orientation in the camera image. Only then the diameter can be measured at the correct position on the flower. Because the spathe and the spadix are variable situated (tilted) on the flower stem and they are also variable in size they are quite often sub-optimal imaged and therefore the determination of the orientation from the 2d image becomes inaccurate. Subsequent all following calculations are questionable.

Whereas for the major part of the flowers the manual and automatic measurements correspond well there are some extreme outliers. In most of theses cases the orientation of the flower was miscalculated due to the fact that the surface of the flower was tilted on the flower stem. The orientation algorithm which is based on a 2d image failed and this implicated the faulty measurement of the diameter.

The mean accuracy achieved with the algorithms presented here is acceptable for use in a sorting machine. However the relatively high number of outliers is not. Therefore, further research is needed, especially on the aspect of the flower orientation.

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