Thresholding of Images in Combination with "Improved Max-Min Filters"

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Abstract

In the framework of the EC-funded AIR-project "Objective plant quality measurement by digital image processing" taking images each three weeks during more than nine months follows the development of *Ficus benjamina* plants. From these images a large number of features is extracted and a relation is laid between these features and the external quality by using neural networks.

A segmentation procedure for classifying the pixels into object pixel (plant) and non-object pixels (background) has to be used before feature extraction. Segmentation procedures based on thresholding depend on the specific threshold that is used, especially when the transition between object and background follows a ramp instead of a step and/or the intensity of the object and/or background is not constant for the whole image.

Improved versions of MAX-MIN filters for edge enhancement are less noise sensitive than other filters for edge enhancement as for example a Laplace operator. The same feature extraction procedures are applied to images with different illumination levels and that have or have not been enhanced by "improved MAX-MIN filtering". The influence of image enhancement by "improved MAX-MIN-filtering" on the segmentation of images and consequently on the feature values will be discussed.

INTRODUCTION

In the framework of the EC funded AIR project "Objective plant quality measurement by image processing" (AIR3-CT94-1072) several growth experiments with *Ficus benjamina* have been executed. The growth of the plants is followed by taking colour images (24 bit) of four different views (45° difference between the successive images) every three weeks with a CCD camera (Sony 930DXC-P) from almost seedling stage to marketable plant. All images are stored on CD and processed afterwards to determine different features of the plants. The features represent characteristics of the plants and the values of the different features are used as input for a decision system for grading the *Ficus benjamina* at different stages during the growth and at the end when a relation with quality is laid. An important step in the image processing is the segmentation of the image into background and plant. The segmentation of the image is based on thresholding with respect to the colour values for Red, Green, and Blue or a value that is a function of Red, Green, and/or Blue.

The *Ficus benjamina* plants are placed in a special almost dark chamber with a distinct red background. The plants are illuminated from the front side with three incandescent light tubes. Influences of daylight and other external light sources are excluded as much as possible. Many measures are taken to achieve an equal exposure of the plants at the different measuring moments. However it is not possible to obtain exact the same exposure of the plants. An important reason is that the CCD camera has a limited exposure range (between one and two diaphragm stops). A small rotation of the diaphragm ring results in an intensity change of 5 to 10%. A second reason is that the plants grow. The front level is coming closer to the light sources, resulting in a higher exposure level at the plant (a lighter plant) and at the same time the plant takes away more light resulting in a darker background. Further the older leafs are dark green whilst the younger leafs are light green.

These varying exposure conditions between the different measurements require that much attention is paid to the segmentation and hence to the threshold. A too low threshold results in that too many pixels are classified as object pixels and a too high threshold results in that too many pixels are classified as background (assuming that the object has a higher intensity than the background). The use of “improved MAX-MIN filters” can contribute to a more consistent separation between object and background by means of thresholding.

This paper will first discuss the background of the “improved MAX-MIN filters” to clarify the principle of the filter. Then the application of the technique in relation to the thresholding based segmentation of *Ficus benjamina* images is described and discussed.

MATERIALS AND METHODS

Image Processing

The images of the *Ficus benjamina* plants (1200 per measurement (300 plants and four images per plant)) are stored on CD’s and processed afterwards. The first step in post-processing is removing artefacts (if they are there) from the image. The stick for supporting the plant is also considered as an artefact. The second step is thresholding the image to make a separation between background and object. This results in a binary image. After this segmentation the different features as object area, object width, object height, filling grade of the object, etc. are determined for each of the plants and stored in a file for further processing.

Thresholding

The purpose of thresholding is to classify pixels on the basis of colour or a local property (for example a function of the colour value(s)). There does not exist one specific defined procedure for thresholding that results under all conditions in a correct classified image. Most of the techniques are based on the histogram of the pixel values (colour or another local property). In case of a bimodal histogram the threshold is chosen somewhere in the valley between the peaks. This can be the minimum between the two peaks or can be based on probability densities of the two subpopulations. These procedures however only give a good result when there is a significant valley between the peaks. When there is no such significant valley other approaches have to be used and most them are more or less based trial and error. This means that the thresholded image is judged whether it has a desired property or not. If not, the thresholding procedure has to be adjusted until the desired property is reached.

Images with an uneven exposure may also cause problems when only one threshold value is used. For these type of images it may be more appropriate to divide the image in subimages and determine a pixel value histogram for each subimage. Each subimage is then segmented individually.

The problem of uneven exposure in colour images can be handled by normalising the image:

$$R_n = R \times 255 / (R + G + B)$$
$$G_n = G \times 255 / (R + G + B)$$
$$B_n = B \times 255 / (R + G + B)$$

In this procedure the same colours (i.e. the same ratio between Red, Green, and Blue but with a different intensity) are projected on one new colour (R_n, G_n, B_n). For example, all grey values (including white and black) are projected on one grey value.

The factor 255 (in case of 8 bit colour values) is used to rescale the image. Thresholding then has to be performed on one or more colour bands or on the values of a function of R_n, G_n or B_n.

Thresholding of images can be improved when the images are processed in such a way that the valley between the peaks becomes more clear. The application of “Improved MAX-MIN filters” is a procedure that contributes to this. The edges become sharper and consequently the number of pixels in the valley decreases in favour of the number of pixels in the peaks.

“Improved MAX-MIN filters”

1. Theory Maximum and minimum filters are used in image processing for several purposes: contrast enhancement, texture description, edge detection and also thresholding. Maximum and minimum filters assign to each pixel in an image a new value equal to the minimum or maximum value of the neighbourhood; the neighbourhood also stands for the shape of the filter and is not necessarily a square. (Verbeek et al., (1988) setup a systematic framework that accommodated existing max-min filter methods and they also suggested some new ones.

The five basic operations that can be applied to an image are:

ORI	:	Identity operation
MAX	:	Local maximum (grey dilation)
MIN	:	Local minimum (grey erosion)
UPP=MIN (MAX)	:	Upper envelope (grey closing)
LOW=MAX (MIN)	:	Lower envelope (grey opening)

With these five basic operations the following primitives can be derived:

DY+ = MAX - ORI >0
TE+ = UPP - ORI >0

RA+ = MAX - UPP >0
DY- = ORI - MIN >0
TE- = ORI - LOW >0

RA- = LOW - MIN >0

For ramp edge and texture edge detection (Verbeek et al., 1988) proposed to replace ORI in the Lee edge detector by UPP and LOW. The Lee edge detector is defined as a pre-smoothing followed by the point minimum:

DYL = pmin (MAX - ORI, ORI - MIN) (“Lee edge detector)

The envelopes UPP and LOW follow ORI at a ramp but follow MAX and MIN at a non-ramp edge. The Lee edge detector then becomes:

RAL = pmin (MAX - UPP, LOW - MIN) (“ramp Lee”)

and expressed in the primitives the detectors become:DYL = pmin (DY+, DY-)
RAL = pmin (RA+, RA-)

The Lee edge detector yields a result similar to the modulus of the linear Laplace operator. The non-linear operator that yields the Lee edge is:

DYS = smin (DY+, DY-) smin = signed minimum>0 if DY+ < DY-

The ramp analogue is:

RAS = smin (RA+, RA-) smin = signed minimum> 0 if RA+ < RA-

Adding these to the original image:

DYF = ORI + DYS
RAF = ORI + RAS

results in steep fronts (DYF and RAF) at edge positions. These steep fronts make that it becomes more easier to find proper threshold values. The ramp based version RAF is less noisy than the general one DYF.

In the research work presented in this paper DYF is used because it requires less computational efforts than RAF does. Further MAX and MIN are based on a 5×5 neighbourhood.

2. Example To visualize the result of the "improved MAX-MIN filter" filter an artificial image has been created. In this image there are two areas, one with a low value of the pixels (for example background) and one with a high value of the pixels (for example object). Noise (normally distributed with mean 0 and standard deviation 2) is added to each individual pixel. The low level had a constant pixel value of 60 and the high level pixel value varied from 90 to 180 in steps of 30. The transition from background to object has been varied between zero pixels (steep) and three pixels (ramp). For one line in this image the resulting values after application of the "improved MAX-MIN filter" to the source image with different pixel values for the object and different transition widths are presented in the Figures 1.a to 1.d.

The figures show that regardless the pixel values, the transitions become steep and are located at the same position. This means with respect to thresholding that the separation between object and background will always take place at the same position and does not depend on the pixel values of the object (or background), i.e. the exposure of the object. Between which two positions the transition takes place depends on the slope of the transition and the noise. In the situation of no noise, all transitions take place at the same position (between 6 and 7) regardless the slope. When noise is introduced the transition will take place between either the pixels 5 and 6 or the pixels 6 and 7 (in the situation discussed in this paper). This depends on the noise levels in the 5? 5 neighbourhood. Considering a whole image with many transitions and noise that is more or less normally distributed the distribution over the pixels where the transitions take place may be assumed equal.

RESULTS

Histogram Based Thresholding

In the *Ficus benjamina* experiments thresholding was first based on a histogram of the Green Red ratio of each pixel (Figure 2). Thresholding based on the Green value only is not possible because the green value of the background is in the same range as the green value of the dark green leafs.

The highest peak (PV_{max}) in the histogram of Green/Red-values corresponded with the object. Further the positions left (PV_{max-50}) and right (PV_{max+50}) of this peak where the values were equal to 50% of the peak value were determined. The threshold (TH) has been set to:

$$TH = PV_{max} + 4.0 \times (PV_{max+50} - PV_{max-50})$$

This resulted at some moments in problems when there was a (small) over exposure of the background (Red and Green became both 255 and hence the ratio 1.0). This also resulted in a peak in the histogram at 200 (all ratios are multiplied by 200) and a not correct segmentation of the image. This was the reason to compensate for the exposure level of the image by normalising the image. As mentioned earlier it is almost impossible to realise an equal exposure during a series of measurements with a growing object. At the same the moment the thresholding is improved by applying the "improved MAX-MIN filter" too.

1. Normalizing and "Improved MAX-MIN Filter" The pixel values of the Green colour band after normalising of an image line are shown in Figure 5. The original image is shown in Figure 3 and the original Red, Green and Blue values are shown in Figure 4. Figure 5 shows that the green value for the background is in the range 42 to 51. The pixels for which green is larger than 80 are object pixels and the pixel values between 52 and 80 are in the transition range. The figure also shows that the transitions between object and background are not steep but follow more or less a ramp. When to the same image the "improved MAX-MIN filter" is applied after the normalisation, the transitions become steep. This is also shown in Figure 5.

2. Feature Values To analyse the influence of the application of the "improved MAX-MIN filter" in relation to the threshold, a series of 42 images is processed without and with application of the "improved MAX-MIN filter" and with thresholds between 56 and 80. The influence of the threshold on the feature value for the features 'object area' and 'area within convex hull' are shown in Figure 6 and 7. These figures very clearly show that the value of 'object area' much depends on the threshold when the MAX-MIN filter is not applied. The range (maximum min minimum) is 25.2% of the average. When the "improved MAX-MIN filter" is applied the range is much smaller and 9.4% of the average. The value of 'area within convex hull' is much less affected because this feature depends on the position with respect to each other of a limited number of object points. Increasing the threshold when the "improved MAX- MIN filter" is not applied results in that these points shift over maximal the width of the transition. The maximum decrease expressed in pixels will be six to ten times the height of the plant; assuming a width of the transition between 3 and 5 pixels.

The influence of threshold in combination with "improved MAX-MIN filtering" is also determined for some other features. The results are summarised in Table 1. The data in this table show that the features 'object width', 'object height', 'convex perimeter', 'optical centre horizontal direction, and 'optical centre vertical direction' are almost not affected by both threshold and application of "improved MAX-MIN filter". Features as 'object area' and 'convex hull area' are very much affected. The relative size of range of the feature 'object perimeter' is not much affected. An increase in threshold shows an increase of the object perimeter and application of the "improved MAX-MIN filter" shows also an increase of the object perimeter. This is related to that the position of the transition depends on the slope of the ramp and the neighbourhood as is already discussed in Section 2. Example.

DISCUSSION

The analysis of the "improved MAX-MIN filter" shows that application of the filter to image results in steep transitions between object and background. It has to be mentioned that transitions only become steep when the transition takes place within the neighbourhood. When the neighbourhood is 3×3 only transitions of three pixels or less (including one object and one background pixel) become steep and with a 5×5 neighbourhood the maximum width is five. On the other hand, an increase of the neighbourhood results in loss of detail. So the size of the neighbourhood will always be a compromise. Also wider transitions become more steep after application of the improved MAX-MIN filter but they will maintain a ramp shape but with a larger slope.

Because of the steeper transitions between object and background the threshold has less effect on the segmentation of the image and the resulting features. An increase of the threshold from 56 to 80 resulted for the feature 'object area' in a decrease of 25.2% (relative to the average) when the "improved MAX-MIN filter" was not applied and after application it reduced to 9.4% (relative to the average). This is still a relatively large percentage. However, one has to realise that in a *Ficus benjamina* image, as shown in for example in Figure 3, there are about 6000 transitions between object and background.

For a good segmentation of images it is necessary to create steep transitions between background and object before the segmentation takes place. If this is not realised the segmentation results are affected by the threshold. Consequently the feature values are affected too. Especially when images made at different moments with different exposure levels are compared in some way, it is important that the edges are steep to reduce the influence of the threshold. This becomes even much more important when there are a large number of transitions in the image, as is the case with the images of the *Ficus benjamina*. For these images it is very important that much attention is paid to the exposure of the object and background and the choice of the threshold.

Literature Cited

Verbeek P.W., Vrooman, H.A. and vanVliet, L.J. 1988. Low-level image processing by max-min filters. Signal Processing 15:249-258.

Tables

Table 1. Influence of "improved MAX-MIN" on feature values

	with “improved MAX-MIN"					” with “improved MAX-MIN"					
Threshold	Object height	Object width	Object perimeter	Convex perimeter	Opt X	Object height	Object width	Object perimeter	Convex perimet -er	Opt X	Opt Y
56	431	340	5736	1257	223	276	338	6814	1256	223	277
58	431	339	5848	1254	223	276	338	7020	1255	223	278
60	430	338	5973	1252	223	277	338	7149	1253	223	278
62	430	337	6078	1250	223	277	337	7252	1252	223	278
64	430	336	6144	1247	224	277	337	7348	1251	223	278
66	430	335	6214	1245	224	277	336	7460	1249	223	278
68	430	335	6260	1243	224	277	336	7507	1248	223	278
70	430	334	6190	1241	224	277	336	7442	1246	223	278
72	430	333	6259	1240	224	277	335	7423	1245	223	278
74	430	333	6257	1238	224	277	335	7340	1244	223	278
76	430	332	6331	1237	224	277	335	7316	1243	223	278
78	430	331	6340	1235	224	277	334	7219	1242	223	278
80	429	331	6310	1233	224	277	334	7149	1241	223	278
Minimum	429	331	5736	1233	223	276	334	6814	1241	223	277
Maximum	431	340	6340	1257	224	277	338	7507	1256	223	278
Range	2	9	604	24	1	1	4	693	15	0	1
Average	430	335	6149	1244	224	277	336	7264	1248	223	278
Range 0.5%	2.7%	9.8%	1.9%	0.4%	0.4%	0.0%	1.2%	9.5%	1.2%	0.0%	0.4%

Figures

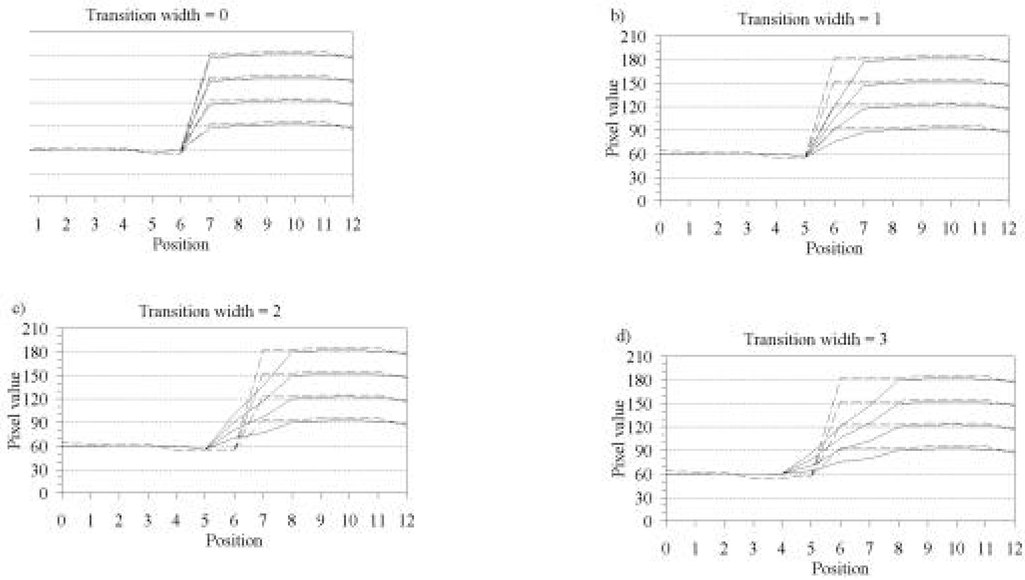

Fig. 1. Result after application of an “improved MAX-MIN filter for four different transition widths and four differences in level between background and object. (solid line = original; dashed line = result after “improved MAX-MIN filter”).

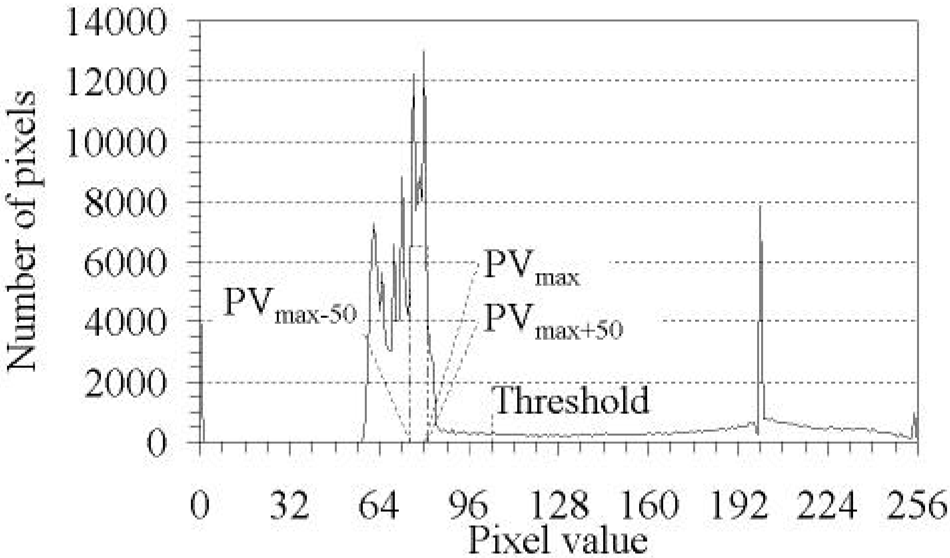

Fig. 2. Histogram of the Green Red ratio of an image. All ratios are multiplied by 200.

Fig. 3. Example of a *Ficus benjamina* image.

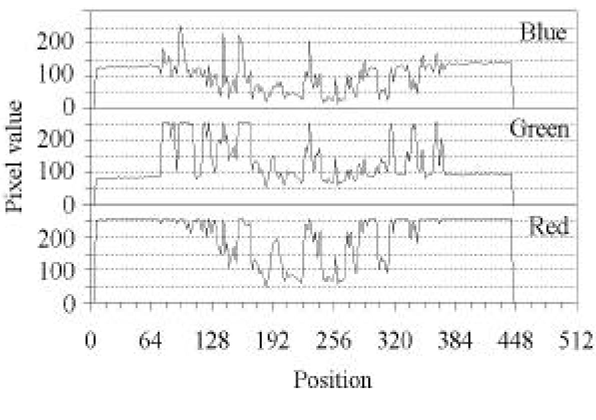

Fig. 4. Values of red, green, and blue of an image line (310) of a *Ficus benjamina* image.

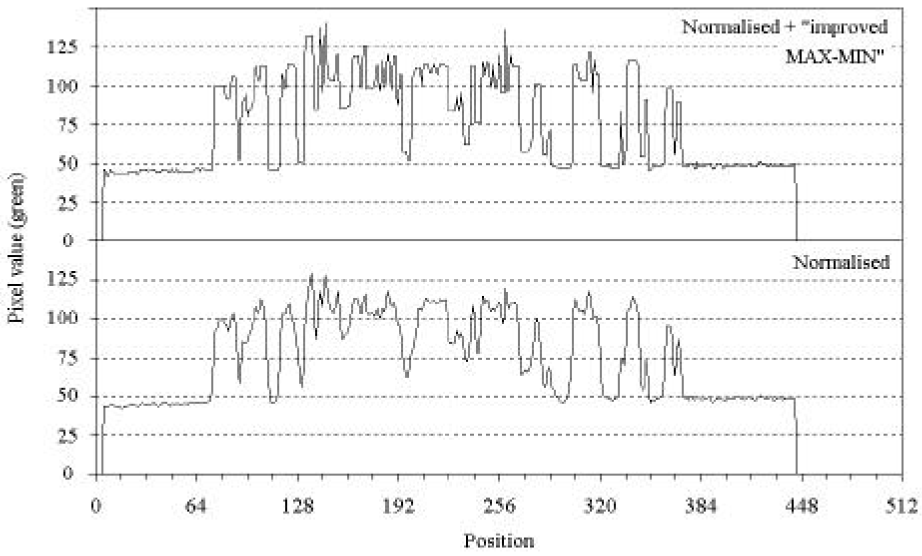

Fig. 5. Values of Green after normalising and application of the "improved MAX-MIN filter".

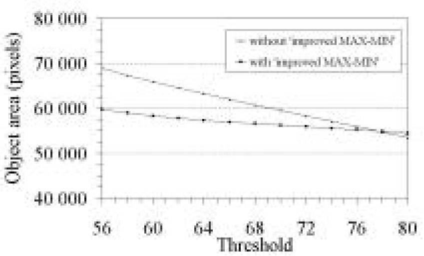

Fig. 6 Influence of "improved MAX-MIN" on the feature 'object area'.

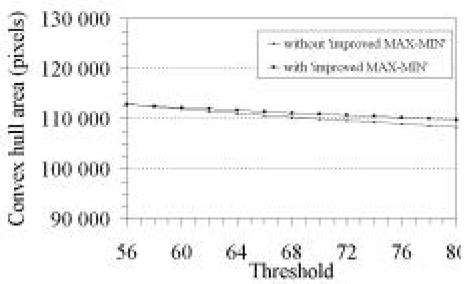

Fig. 7 Influence of "improved MAX-MIN" on the feature 'area convex hull'.