Segmentation of partly occluded plant leaves

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Abstract

When using image processing to identify crops and weed, the plants first need to be separated from the soil and from each other. When segmenting the plants from the soil, the plants are not often segmented as one object per plant. The plant leaves can be segmented as single leaves, or be connected with other leaves. Crop plants are also likely to be occluded by weed plants.

To disconnect the weed from the crops all leaf objects can be divided into single leaves which then can be grouped as one plant. This paper shows the result of segmenting single leaves when using different segmentation methods. Segmentation methods such as watershed and erosion have been tested and compared to a new method for how to separate plant leaves. The new method gives segments that in average match the crop leaves with 80%, while the segments from the other tested methods match the crop leaves with up to 66%.

1. Introduction

When using image processing to classify crops and weeds, one of the first steps is to separate the plants from the soil and to define what objects belongs to what plant. The binarization, which separates plant material pixels from background pixels, followed by a connected component labeling results in an image with a lot of objects, see figure 1. These objects sometimes contain single leaves, but they often contain more than one leaf. The leaves in multi leaf objects are not always belonging to the same plant. To build objects that only contain single plants, the leaves in multi leaf objects has to be separated and then put together with leaves from the same plant.

Different segmentation methods can be used to split objects into single leaves. Lee et al. [1] used watershed. To reduce the number of oversegmented leaves modifications were made to how many starting positions

Figure 1: (a) RGB image of a sugar beet occluded by weed. (b) Binarized image showing multiple leaf object and single leaf object.

the watershed segmentation used. Hemming [2] used a number of consecutive erosions to separate the leaves. To regain the shape of the leaves, the eroded leaves were dilated and then combined with the original shape. Mahn et al. [3] looked for leaf tips and then tried to fit a deformable template to the leaf.

In this paper a new method for leaf segmentation of partly occluded crop leaves is presented. The method aims at cutting the leaves where they meet. Where to cut the leaves is found by looking at the area between the leaves. The starting point of the cut is where this area is the broadest and the direction is perpendicular to the base of this area.

2. Method

All segmentation methods are tested on images taken on a sugar beet field. The set contains 199 RGB images in total and 49 of these contain sugar beets occluded by weed. For evaluation of the segmentation methods these 49 images are used. The images are converted to greyscale by 2G-R-B and to binary by a threshold.

To define the correct segmentation, the leaves of interest are marked manually in the test images. The leaves of interest are every sugar beet leaf and the weed leaves connected to sugar beet leaves, see figure 2. The total number of marked leaves is 278 crop leaves and 157 weed leaves.

2.1. Watershed

The watershed algorithm [4] is based on how water that is poured into neighbouring valleys rises in the valleys and finally meets. A greyscale image over the object to segment makes a topographic map where the dark areas are valleys and the bright areas are hills. When water is flooding the object, the object will be split into segments where the water from different valleys meets.

In these tests the distance transformation of the object was used as greyscale. The distance transform gives higher values the further away from the edge, therefore and inverted distance transform, 256 – distance, was used

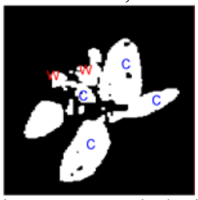

Figure 2: Leaves of interest are marked with C for crop leaves and W for weed leaves. The left most leaf is not marked as weed since this weed leaf is not connected to any crop leaf.

as topography.
When using watershed for segmenting the leaves each local minimum in the inverted distance transform gives a segment in the segmented object. This often causes the objects to be oversegmented. One of the methods used in [1] to decrease the number of segments is pre-flooding. Pre-flooding means that the valleys are pre-filled up to a certain level. This causes some valleys to be combined into one valley, thus rendering fewer segments from the watershed segmentation.

2.2. Merging segments

Another way to reduce the number of segments after the segmentation is to merge some segments into one segment. Two segments are merged if predefined criteria are fulfilled. In these tests two merging methods with different criteria were used.

2.2.1. Merging method 1

Jain [5] describes the merge criteria that were used in merge method 1. Two segments will be merged if

$$\frac{W}{P_m} > \Theta_1 \qquad (1)$$

where:
P_m = Perimeter of the segment with the shortest perimeter.
W = The number of weak boundary locations. A weak boundary location is a location between the two segments where the grey intensity on either side of the location differ less than a factor σ.
Θ_1 = A factor controlling the amount of weak locations needed to merge the two segments.

2.2.2. Merging method 2

Merging method 2 is developed to improve the result of the cutting method.
Segment A is merged with segment B if:

$$\frac{f}{P} < \Theta_2 \qquad (2)$$

where:
f = Number of free perimeter pixels of segment A. The free perimeter pixels are pixels having background as neighbour before the object is segmented.
P = Perimeter of segment A.
Segment B is the segment to which segment A has the most number of border pixels. During segmentation, when an object is split into segments the pixels separating the segments are the border pixels.

2.3. Erode/dilate

Hamming [2] used a method based on erosion and dilation to separate the leaves. First all black and white holes with area less than A_{fill} are filled. Next a number of erosions are made in order to know where to separate the leaves. To regain the original shape of the leaves, dilation is made 1.5 times the number of erosions. Objects split

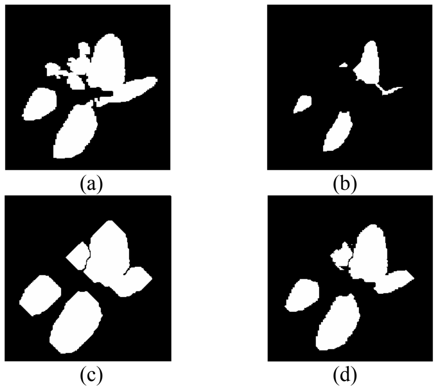

Figure 3: Erode/dilate method (a) Objects after black and white holes are filled. (b) Objects after erosion. (c) Objects after dilation. (d) Objects after logical AND of dilated image and original image.

by erosion shall not be connected during the dilations. At last, the original binary image and the dilation image are combined with logical AND. Figure 3 shows the different steps of this method.

2.4. New method, cutting

The idea of this segmentation method is to cut the leaves where they meet. To find where to cut the leaves, extract the area between the leaves, the broadest point of this area becomes the start point of the cut. The direction of the cut is perpendicular to the base of the area between the leaves. The base is the line between the tips of the leaves.
The method steps are:

1. Label all objects in the binary image (figure 4 a).
2. For objects with an area larger than a threshold, T_{area}, calculate the objects between the leaves (figure 4 d) by subtracting the object area (figure 4 b) from the convex area (figure 4 c) of the object.
3. For each object between the leaves with an area larger than a threshold, $T_{between\ area}$, draw a line to cut the original object. The line is drawn perpendicular to the base of the area between the leaves (marked in figure 4 d) and through the point within this area that is the furthest away from the base (marked with circles in figure 4 d). Figure 4 e shows the cut lines with their corresponding areas.
4. When all cut lines are drawn, one for each object between the leaves, merge the segments. Figure 4 f shows the objects after the cut and figure 4 g shows the objects after the merge.

When calculating the objects between the leaves some objects might sometimes consist of areas corresponding to more than two leaves. See figure 5. This gives that not all leaves are separated after applying the segmentation method only once. Applying the segmentation method twice reduces this problem.

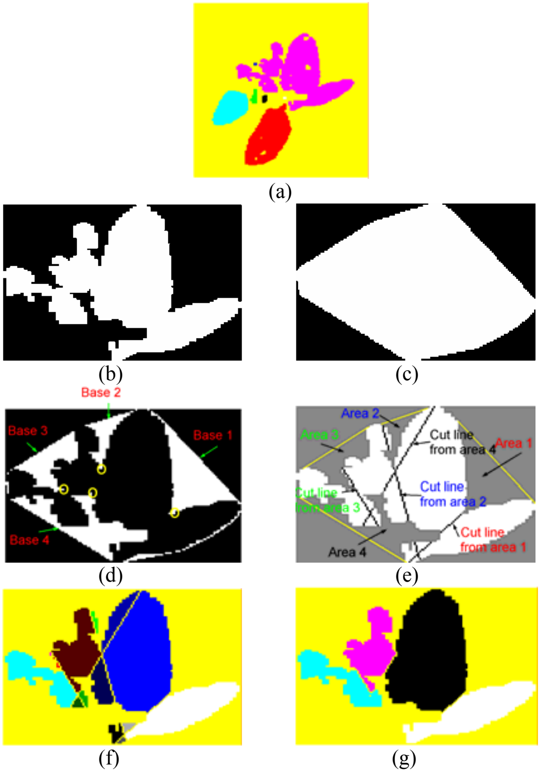

Figure 4: The different steps of the cutting method. (a) Connected component labelled image of a sugar beet with some occluding weed. Each label has its own colour. (b) Original binary object to cut, (correspond to upper label in (a)). (c) Convex area. (d) Area between leaves. (e) The cut lines with corresponding area between the leaves. (f) Segmented objects before merge. (g) Segmented objects after merge. The segments are from left to right: weed occluding crop, weed, crop and crop.

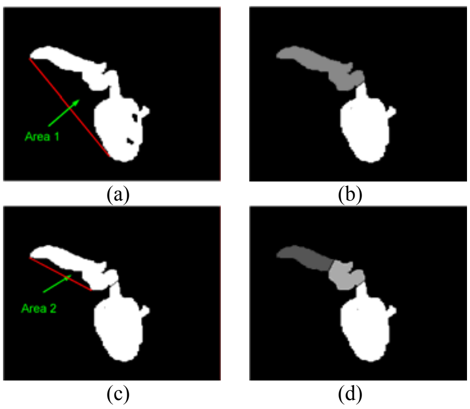

Figure 5: *First run* - (a) Area 1 contains areas between three leaves. (b) Area 1 results in one leaf separated from the other leaves. *Second run* - (c) Area 2 marks the area between the two remaining leaves (d) All three leaves are separated after the second segmentation.

3. Result

The evaluation of the result from the segmentation methods is based on three measures

1. Classification of segments. Is the segment a crop, weed or combined segment?
2. How well does the segment fit the leaf?
3. How much weed is removed from the plant after segmenting the objects?

3.1. Measure 1

Measure 1 was measured by taking all segments that is part of a marked crop or weed and calculate the amount of pixels belonging to weed and crop respectively. Depending on how many pixels belong to crop or weed respectively, the segments were divided into three groups:

1. Crop segment $$\frac{\text{num crop pixels}}{\text{tot num of pixels}} \geq 90\% \qquad (3)$$
2. Weed segment $$\frac{\text{num weed pixels}}{\text{tot num of pixels}} \geq 90\% \qquad (4)$$
3. Combined segment otherwhise

3.2. Measure 2

How well the segment fits the leaf was measured by calculating an area ratio [6] of how much area the leaf and the segment have in common. This area ratio will tend to one if the marked leaf and the segment cover the same area, and the more different areas the marked leaf and the segment cover the more the area ratio will tend to zero. The area ratio is calculated as

$$\text{area ratio} = \frac{\text{Num pixels covered by segment AND leaf}}{\text{Num pixels covered by segment OR leaf}} \qquad (5)$$

3.3. Measure 3

How much weed that is removed from the plant is calculated from the number of weed pixels in the segments classified as combined segments in measure 1 and the number of weed pixels before the segmentation.

$$W_{removed} = 1 - \frac{W_{comb}}{W_0} \qquad (6)$$

$W_{removed}$ = how much weed that is removed compared to how much weed was occluding the plant before the objects were segmented.
W_{comb} = number of weed pixels in the combined segments.
W_0 = number of weed pixels before objects are segmented.

3.4. Test of segmentation methods

All the tested segmentation methods are depending on a set of parameters. Different combinations of parameters have been tested to find the best parameter set. The parameter set that gives the highest area ratio for the crops are considered the best set, since this gives the segmentation that best matches the marked leaves.

The tested segmentation methods are:

1. Watershed + merge method 1
2. Watershed + pre-flooding
3. Erode/dilate
4. Cutting + merge method 1
5. Cutting + merge method 2
6. Before any segmentation method is applied, i.e. only connected component labelling

3.4.1. Result measure 1 and 3

Table 1 shows the result of measure 1 and measure 3 for the tested segmentation methods. Column 2-4 shows the total amount of crop, weed and combined segments found in the 49 test images (measure 1). The last column shows how much weed area that has been removed compared to before the objects are segmented (measure 3).

All tested segmentation methods reduces the amount of occluding weed. Segmentation method 3 gives the lowest weed reduction (31%) while segmentation method 1 gives the highest weed reduction (66%). Segmentation method 1 results in 625 segments, 44 percent more than the number of marked leaves (435). This means that to be able to benefit from the high weed reduction the segments need to be merged once again to be able to form segments that match the marked leaves. Both method 4 and 5 have lower weed reduction than method 1, but they result in fewer segments. Method 4 gives 19% more segments than marked leaves and method 5 gives 6% fewer segments.

3.4.2. Result measure 2

Table 2 shows the result of measure 2, area ratio for crop and weed leaves, for the tested segmentation methods.

Segmentation method 4 and 5, both using the cutting method, are the algorithms that give the highest area ratio for both crop and weed leaves. This means that these are the methods that give single segments that match the marked crop and weed leaves best.

4. Conclusion and outlook

Which method is the best one? The watershed together with merge method 1 is the segmentation method that manages best to reduce the amount of weed occluding the crop. The disadvantage of this method is that it gives more than one segment per leaf, resulting in that more merges are needed to give a segment that matches the leaf. When classifying crops from weed it is preferable to get one good segment that matches the crop leaf, which then puts the cutting method in a good position. The cutting method with merge method 1 or 2 gives a higher area ratio and less number of segments per leaf, i.e. a better fit of the segments to the leaves, even though there is more weed attached to the crop segments.

The separation of plants into single leaves opens up opportunities. The single leaves can be used in a leaf classifier to distinguish crops from weeds, but they can also be put together to a plant and be used in a plant classifier. Future work is needed on how to find the leaves belonging to the same plant.

Table 1: Test result for measure 1 and 3. All numbers are a total for the 49 test images.

	Measure 1			Measure 3
Segm method	Num crop segm	Num weed segm	Num comb segm	Percentage weed area removed from crop
1.	400	168	57	66%
2.	591	207	78	56%
3.	261	50	46	31%
4.	386	74	58	51%
5.	302	58	51	57%
6.	99	25	52	0%
Ideal segm	278	157	0	100%

Table 2: Test result for measure 2. For weeds, area ratio is averaged over 157 weed leaves. For crops, area ratio is averaged over 278 crop leaves.

Segm method	Mean area ratio crops	Mean area ratio weeds
1.	0,64	0,29
2.	0,64	0,27
3.	0,64	0,20
4.	0,78	0,31
5.	0,80	0,34
6.	0,46	0,26
Ideal segm	1	1

5. Acknowledgements

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