CONCEPTS FOR INTERNAL AND EXTERNAL EVALUATION OF AUTOMATICALLY DELINEATED TREE TOPS

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ABSTRACT:
This paper contains two parts: a short description of our tree finder, and a concept for the automatic evaluation of the results. The basic idea of our delineation approach is, that the coarse structure of the crown can be approximated with the help of a sphere or an ellipsoid. This assumption is true, if the fine structure of the crown is ignored and the coarse structure is revealed in an appropriate level of the multi-scale representation of the surface model. However, this scale level is unknown, because it is correlated with the unknown diameter of the crown. The proposed solution for this chicken-and-egg problem is to investigate a wide range of scale levels, and to subsequently select the best hypothesis for a crown from all these scale levels. This selection must be based on an internal evaluation of the obtained results.
The evaluation concept is based on the classification of the topological relations between the crown's projection from different data sets onto the ground level. In general, eight different topological relations exist in 2D space: *disjoint*, *touch*, *overlap*, *covers*, *contains*, *contained by*, *covers*, and *covered by*. These topological relations can be subdivided into two clusters *C1* and *C2*, where the *C1* cluster includes the relations *disjoint*, *touch* and *C2* the other ones apart from the *overlap* relation. The *overlap* relation is between these two clusters, it can be divided into *weak-overlap* (*C1*) and *strong-overlap* (*C2*). The motivation behind this partitioning is that the relations in *C1* are similar to *disjoint*, and in C2 to *equal*. In our approach the type of the relation cluster is used in the internal evaluation to decide whether hypotheses from different scale levels are identical. In the external evaluation, we use the relation cluster to decide which trees from a reference data set are identical to automatically extracted trees.

1. INTRODUCTION

In this paper we give an overview on our work on automatic delineation of trees from height data. In the first part we shortly summarize our approach. In the second part a concept for the comparison of compact regions from two different data sets is proposed, which can be used for the external evaluation of the tree hypotheses.

It is often difficult to compare the results of different approaches for object extraction. On the one hand there is the problem, that usually the scenes under investigation are quite different regarding the scene content (species, time of image acquisition) but also regarding the used raster data (height data, optical data, both). On the other hand the used method for performance evaluation are sometimes rather ad hoc. Furthermore, different assumptions are often used in the different methods for object extraction which render a comparison very difficult. As a first step, a qualitative comparison between the approaches of (ANDERSEN ET AL. 2001) (ANDERSEN ET AL. 2002) (BRANDTBERG 1999) (PERSSON ET AL. 2002) (SCHARDT ET AL. 2002) (POLLOCK 1996) can be found in (STRAUB 2003A).

The proposed method can be used as a basis for a generally accepted performance evaluation tool. It is easy to implement, theoretically well founded, and leads to "natural" results regarding the association of the individual objects, which is the basis for the computation of the success rate of an approach.

2. STRATEGY FOR EXTRACTING TREE TOPS FROM HEIGHT DATA

The idea of our strategy for extraction of trees from height data is to create a multi-scale representation of the surface model similar to (PERSSON ET AL. 2002). The difference to the approach of Persson et al. is that in our approach the scale level is not assumed to be known. A search of the best tree hypothesis in multiple scales is performed in order to overcome the chicken-and-egg problem that the size and spatial structure of the tree tops – which is not known in advance - defines the optimal scale-level.

Technically we use the Linear Scale Space theory as basis for our approach, as it was proposed e. g. in (BRANDTBERG & WALTER 1998) for the extraction of individual trees. A basic idea of the Linear Scale Space is to construct a multi-scale representation of an image, which only depends on one parameter and has the property of *causality*: Features in a coarse scale must have a cause in fine scale. The scale space transformation itself may not lead to new features. One can show that a multi-scale representation based on a Gaussian function as low pass filter fulfils this requirement. In practice, the original signal $f(\vec{x})$ is convolved with a Gaussian kernel with different scale parameter σ, the result of the convolution operation is assigned as $f(\vec{x},\sigma)$. Small values of σ correspond to a fine scale, large values to a coarse scale. An extensive investigation and mathematical reasoning including technical instructions can be found in (LINDEBERG 1994).

Our strategy is based on differential geometric properties of the tree tops. In the following we use a profile along four synthetic tree tops to study the properties of the surface model if the trees stand close together, which is the normal case - free-standing trees constitute exceptions. The synthetic tree tops for this study were computed using the generalized ellipsoid of revolution as it was introduced in (POLLOCK 1994) for the mathematical description of a crown. In the left part of Figure 1 four of these “Pollock-Trees” computed with a=6 [m], b=2 [m], and n=2.0 (1 m is equivalent to 10 pixels respectively grey values) are depicted.

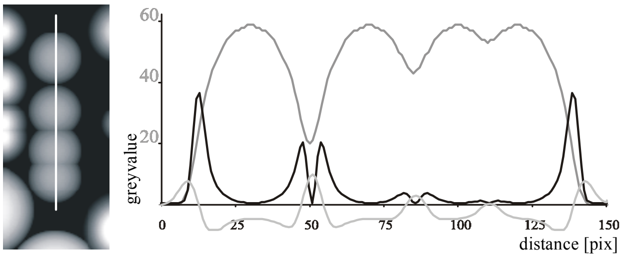

Figure 1: Profile of the surface model of four Pollock-Trees, the location of the profile is depicted in the upper left corner.

The profile along the white line (left part of Figure 1) is plotted in dark grey in the right part of Figure 1: One can see that the “valley” between the trees decreases from the left to the right. The absolute value of the gradient $\left|\nabla H\left(\vec{x}\right)\right|$ (black line in Figure 1) decreases also. Obviously, this is a consequence of the decreasing distance between the trees, and of the crown’s shape. The surface at the tree tops has a convex shape in both directions, along and across the profile. Therefore the sum of the second partial derivations is always negative for the whole crown (refer to the light grey line in Figure 1).

$$\frac{\partial H^2\left(\vec{x}\right)}{\partial x^2} < 0 \vee \frac{\partial H^2\left(\vec{x}\right)}{\partial y^2} < 0 \;\Rightarrow\; \Delta H\left(\vec{x}\right) < 0 \qquad (1)$$

At a point on the profile between two trees the second derivative along the profile is smaller than zero, but the second derivative across the profile is larger than zero. Therefore, the Laplacian of the surface model $\Delta H\left(\vec{x}\right)$ at these points is larger than at points on the crown. These characteristics lead to local maxima in $\Delta H\left(\vec{x}\right)$ as points separating the crowns.

In the case of real data this model is only valid in the correct scale level. A height profile from real data is used to explain the term “correct” in this context. Two different Scale Space representations of the surface model $H\left(\vec{x}\right)$ are depicted in Figure 2, according to the used σ of the Gaussian they are assigned as $H\left(\vec{x},\sigma\right)$ with σ values 0.5 m and 8 m. One can see that more and more of the fine structure disappears and the coarse structure is revealed with the increase of the scale parameter σ.

The height profile along the tree tops is measured along the dotted line which is superimposed to the surface model in Figure 2. The left height profile which is measured in the original surface model is noisy compared to the profile of the synthetic trees. As a result of this noise the Laplacian oscillates close to zero. In the “correct” scale level for this small group of trees the assumptions regarding the Laplacian are fulfilled quite well. Similar to the profile of the synthetic Pollock-Trees (Figure 1) the Laplacian is negative for trees and positive for the valleys between them. The coarse structure of the crown is enhanced, and as a result the properties of the Pollock-Model are valid also for the real trees in this scale level.

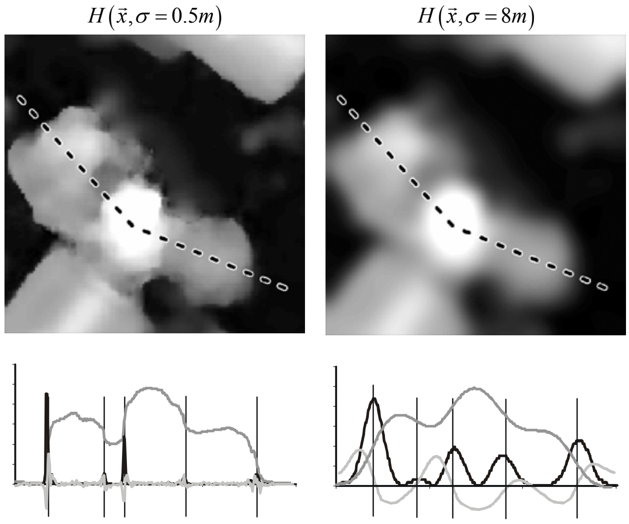

Figure 2: Representation of the surface model $H\left(\vec{x}\right)$ at two different scale levels (above). The height profiles below are measured along the dotted line in the images.

These observations have lead to the following strategy for the automatic extraction of trees from height data: First we generate a multi-scale representation of the height data which is segmented using the watershed transformation with the gradient of the height data as segmentation function. The resulting segments are evaluated using the Laplacian of the height data, the size and the roundness of the region. The approach was tested in different environments, urban as well as forests, and lead usually to a success rate of more than 70% compared with a manually captured reference data set. A detailed description of the approach is given in (STRAUB 2003B), an overview can be found in (STRAUB 2003C).

3. INTERNAL AND EXTERNAL EVALUATION

Internal and external evaluation has many aspects. One important and non-trivial problem is the definition of identity between different entities in two data sets. For the internal as well as for the external evaluation one has to decide if two hypotheses are identical. In Figure 3 one can see a typical situation. The white circles are associated with the results of our automatic approach for the extraction of trees as it was described above, and the black ones correspond to manually captured reference data. The two sets of circles are not identical, of course, and the question is, how a 1-to-1 relation between the two sets can be defined.

The problem of overlap is sketched in Figure 5, a circle and a square overlap each other. We assume, that the circle is a hypothesis from one data set and the square comes from another data set, and we want to know if these two hypotheses are – from a spatial point of view – identical. There exist 8 different topological relations between two regions in $\Re^2$, 5 of them are depicted in Figure 4.

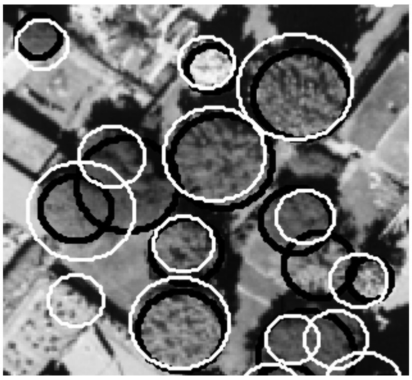

Figure 3: Example for two different data sets: background image shows some trees, black and white circle are different hypotheses of trees.

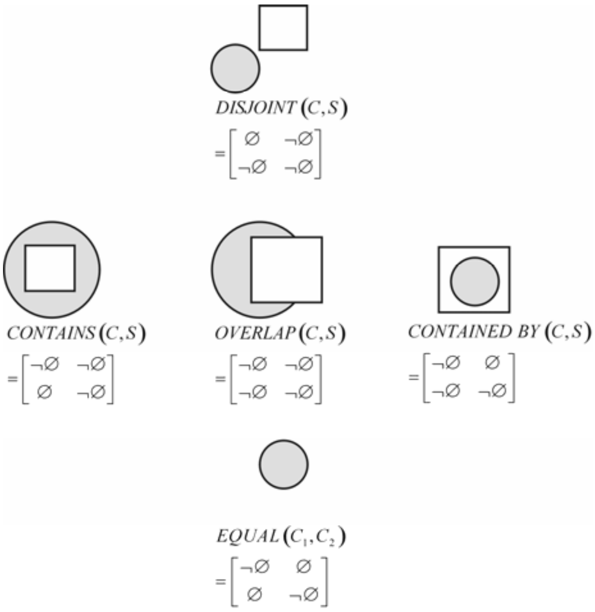

Figure 4: Five different topological relations between two regions (circle C and square S) and the associated 4-Intersections.

Two regions A and B can be *disjoint*, they can *touch* each other or they can *overlap*. Region A can *cover* region B, or A can be *covered by* B, A can *contain* B or can be *contained by* B, and they can be *equal*. In (EGENHOFER & HERRING 1991) it was shown that these topological relations can be differentiated using the so called 9-Intersection, a 3*3 matrix of intersections between the regions itself, their margins and their complements. These topological relations can be subdivided into two clusters *C1* and *C2*, where the *C1* cluster includes the relations *disjoint*, *touch* and *C2* the other ones apart from the overlap relation. The *overlap* relation lies between these two clusters, it can be divided into *weak-overlap* (*C1*) and *strong-overlap* (*C2*) (WINTER 1996). The motivation behind this partitioning is that the relations in *C1* are similar to *disjoint*, and in C2 to *equal*.

The relations *touch*, *covers, covered by, contained* and *contained by* are associated with the margins of the two regions. If the margin is not defined, for example if the regions consist of particular pixels, then the mentioned relations are no longer relevant and one can reduce the 9-Intersection to a 4-Intersection (see figure 4), which includes only regions A respectively B itself and their complements $\overline{A}$ and $\overline{B}$:

$$R(A,B) = \begin{bmatrix} A \cap B & A \cap \overline{B} \\ \overline{A} \cap B & \overline{A} \cap \overline{B} \end{bmatrix} \qquad (2)$$

The matrix of 4-Intersection and the associated topological relations between a circle and a square are also depicted in Figure 4. With the help of this matrix the type of the topological relation can be differentiated by analysing four different intersections between the two regions in question (Equation 2). From a topological point of view the relations are non-ambiguous, but for a natural evaluation it is useful to define a weak transition between overlap and disjoint (refer Figure 5).

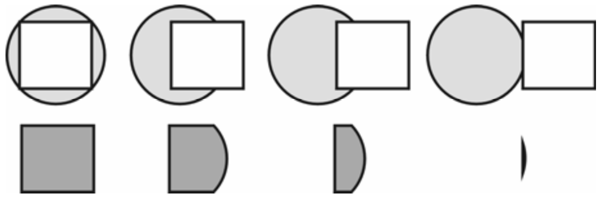

Figure 5: Different types of overlap relations. The situation is drawn in the upper part of the figure, under it the intersection $C \cap S$ between the circle S and the square C is depicted.

The overlap relation can be looked upon as a transition between equal and disjoint. This is depicted in Figure 5, the situation at the left side as close to equal and on the right side the circle and the square are nearly disjoint. This transition can be described with the so called overlap factor, as introduced in (WINTER 1996):

$$OF_{A,B} = \frac{A \cap B}{\min\left(|A|, |B|\right)} \qquad (3)$$

An overlap factor $OF_{A,B}$ between A and B (Equation 3) smaller than 0.5 hints to a *weak overlap* situation, which is more or less close to *disjoint* and therefore a part of *C2*, and values greater than 0.5 show, that the two regions are more or less equal – *strong overlap* and part of *C2*.

In (STRAUB 2003A) it was proposed two use the topological relation and the overlap factor in the internal as well as in the external evaluation in order to decide if two hypotheses for trees cover the same region of the scene. We define: A relation from the *C2* cluster between a tree T_{REF} from the reference data set and an automatically extracted tree T_{EXT} means, that T_{REF} and T_{EXT} are identical. Using this definition one can automatically and objectively decide if an extraction result is identical with a reference data set. In the internal evaluation, the classification of the topological relation is used for the detection of other valid hypotheses which are or could be identical with the actual hypotheses. Experience in our experiments has shown, that the identity problem can be solved very reasonable using the described approach.

4. SUMMARY AND OUTLOOK

The strategy and the mathematical basics of a multi-scale approach for the automatic extraction of trees was described shortly in the first part of this paper. In the second part we introduce a method which can be used to decide if two different regions in $\Re^2$ are identical. The method is based on the investigation of the topological relation between the two regions and a weak transition between *disjoint* and *equal*. The proposed method can be used to render the evaluation of extraction results more objective: different approaches become more comparable, if such a method is used for the external evaluation of the results.

For the internal evaluation of the results the type of topological relation can be used for the further investigation of hypotheses themselves. For example, an extracted crown in a coarse scale can consist of two or more crowns in finer scale levels, which are *contained by* the larger crown. This information can be used for a more detailed description of the extracted tree. Future work will be directed towards a detailed investigation of sub-structures of the crown on the basis of the described formalism.

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