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Automatical Extraction of the Forest Inventory Parameters on Laser Scanning Data using Mathematical Methods

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Abstract

This paper gives some mathematical methods for the automatic analysis and determination of forest management parameters in particular for the measurements of geometrical sizes on terrestrial scanning laser data using segmentation with iterative contrast enhancement, skeletonization, local digital geometry and topology (LDGT) and numerical methods for the determination of the fractal dimension and for the circle fitting.

1. Introduction

The geometrical parameters and structure features of the tree stems, tree crowns such as stem position, high, length, diameter of the stem, size/volume of the leaf area etc. play a very important role in the forest management. An automatic or computer based extraction of these parameters is from great relevance for the forest inventory.

Figure 1: The Riegl laser scanner in forest measurement in Freising, Germany

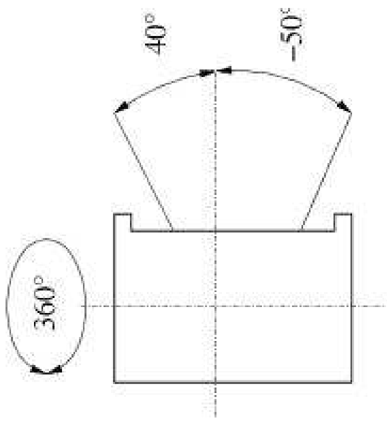

Figure 2: The horizontal and vertical scanning range of Riegl laser scanner.

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For the data acquisition was used the Riegl LMS-Z360 terrestrial laser scanner (see Figure 1). The Riegl scanner provide 2D, 3D data and true colour information (separate digital camera) about the 3D scene. The laser scanner measures the distance and the intensity to the nearest object point in a [0..360] and [-50..40] grad polar-system (see Figure 2), which can be converted into an intensity 2D panorama picture, as well. For the automatic extraction and analysis of the forest management parameters will be used both the 2D intensity image and the 3D raw data set, but currently without the combination with the colour informations.

The data was recorded in the Bavarian forest - Böhm forest in Germany and Czech Republic. From an inventory point 3-5 measurements including the central point were made. In this work we will use only the data set from the central acquisition.

In our paper we will focus on the mathematical methods to extract and to measure forest relevant features from the panorama pictures (2D) with the help of the 3D data sets. Our approach is based on the segmentation and skeletonization of the 2D panorama pictures using common image processing algorithms for the picture analyze. For the measurement on the segmented digital pictures with the help of the skeletonized image the local digital geometry and topology and numerical methods were used.

2. Image Processing of the Laser Data

For the image processing task the 2D panorama pictures (see Figure 3 /a/) will be used. In the first step the panorama image is filtered with a Gaussian filter in order to remove and reduce the noisy artifacts. After that the image is binarized and segmented. The segmentation is based on an iterative contrast enhancement method (Pál et al., 1996) which extract the thin line-like (1-2 pixel wide) structures using a mask. The result is shown on the Figure 3 (b). The characteristic of this segmentation method and comparisation with another line segmentations and how it works on noisy images were shown in (Pál, 2002). If the intensity Information gives not enough information and quality or some trees are faulty segmented, also the 3D information, the distances to the projection plane to correct this can be used.

For the geometrical measurement on the 2D digital images also the middle lines of the segmented trees/objects are needed. The extraction of the tree, banches or object middle lines can be done with thinning or skeletonization. The segmented pictures with the skeleton images perhaps with another masks or pictures allow us the exact measurement in the digital space. To extract the skeletons of the tree structures the Zhou's algorithm (Zhou, Quek and Ng, 1995) with a modification (Pál, 2003) was used. The Zhou's algorithm is a sequential process to eliminate the boundary pixels which satisfy some topological conditions. These topological conditions ensure that a connected object stay connected and the object is not broken in two or more parts. The modification of the topological conditions in the Zhou's algorithm makes it possible to reduce the so called (2×2)-Structures (approx. 25% see Pál, 2003), which give a better calculation of the length of the skeleton e.g. the tree length. Furthermore the modification gives better application for the local digital geometry and topology approaches, in particular the determination of the orthogonal at a pixel to the middle line of the tree-trunk (see the next section).

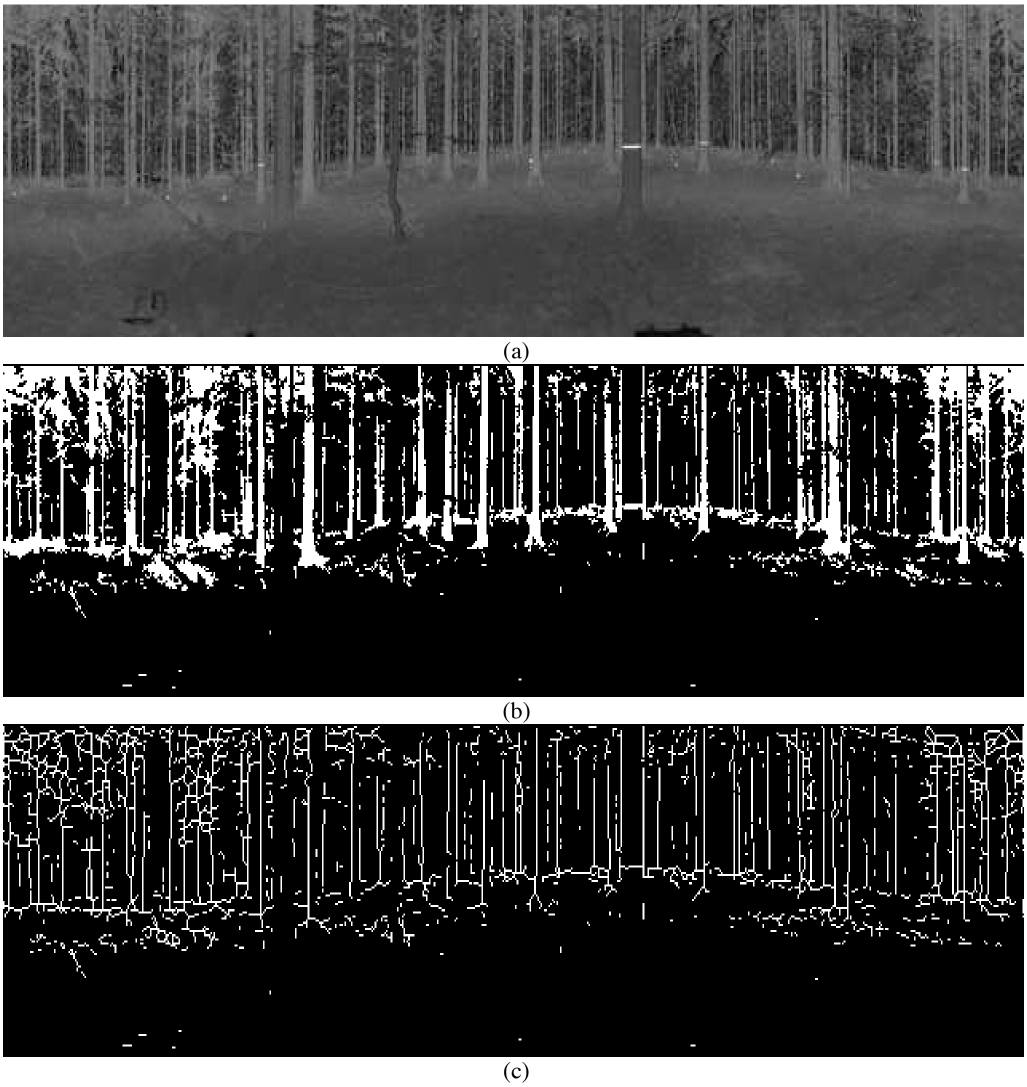
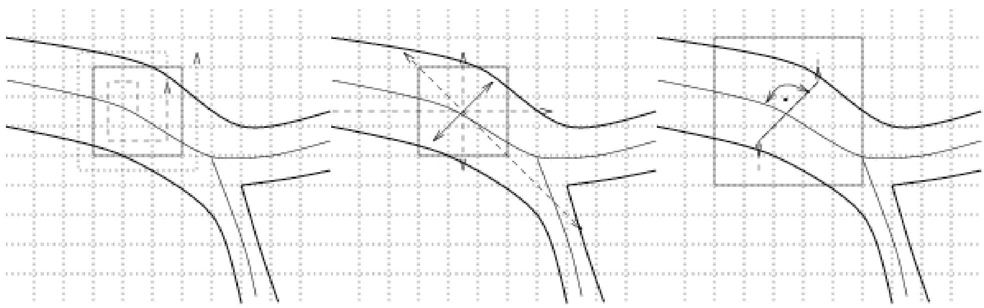


Figure 3: (a) Original polar picture by the Riegl scanner (size 750×3000 pixels), (b) segmented picture, (c) skeletonized picture

3. Mathematical Models

3.1 Calculation of the Tree Diameter using LDGT

Local digital geometry and topology (LDGT) (Pál, 2004a) is used for the measurements and extraction of the forest relevant features in particular of the tree-trunk diameter on the binary images, which are obtained after the segmentation and skeletonization of the 2D panorama pictures. For the exact measurement on the 2D images a correction must be applied, to eliminate the perspective distortion and to get a real size of the objects. The perspective correction or the real distance between two pixels on the 2D pictures is calculated from its 3D coordinates using the known vector geometrical formulas.



(a) (b) (c)

Figure 4: diameter (a) with square filling (b) with directions (c) with orthogonals

The diameter can be determined on the segmented picture by its different geometrical definition. A possible procedure for the diameter determination is the square filling out (the algorithm is described in Pál, 2004b) with the help of the skeleton picture, which is a cover of the tree branches with squares in the tree-emphasized binarized picture (see Figure 4/a/). In the skeleton picture a value to each pixel of the center line of the tree (similar to Pál, 2004b) can be assigned, to which the diameter of cover square corresponds.
An another algorithm of the diameter determination is based on the following definition (see also to picture 4 /b/).

Definition 1
The diameter of the tree-trunk in a given position (tree-trunk center) is the minimum distance to the edges of the tree-trunk, which results from the intersections of a digital line segment over the given reference pixel position and of the edges of the tree-trunk.

The determination of the intersection with the edges of the tree-trunk or tree branches is possible with the help of an edge-segmented picture or with the increasing of the digital line segments in both directions, until all pixels of the digital lines are still tree pixels.

A further possibility of the diameter determination is based on an another geometrical definition of the diameter (see also Figure 4 /c/)

Definition 2
The diameter of a tree-trunk in a given position (tree-trunk center) is the distance, which results from the intersections of the perpendicular digital line segment to the center line (skeleton) in the given reference pixel position and of the edges of the tree-trunk.

In order to carry out algorithmically the above two definitions of the tree-trunk diameters calculation the digital line segment (Klette and Zamperoni, 1995) will be used. The digital line segments in a $(n \times n)$-window are uniquely represented by a natural number $l \in [1,...,2n-2]$. So in a $(n \times n)$-window are $2n$-2 different digital line segments, which are going across the middle or reference pixel of the window, and each rows and columns contain only one pixel. Because the number of the pixels on the boundary of the

($n \times n$)-window, which are $4n$-4, the modulo ($2n$-2) was used for the mapping of the representation number of a digital line number to range ($2n$-2). The calculation of the digital line segment coordinates in the ($n \times n$)-window are also in (Klette and Zamperoni, 1995) described.

The skeleton of the tree-trunk is a digital curve or straight line area, which is on a discrete lattice a group of pixels, whose pixels all belong also to the outline of the group, thus in the (3×3)-neighborhood of the pixel no object pixel exists (Pavlidis, 1990). The connectivity number $C_4^{(n)}$ is used for the determination about a pixel if it belongs to a crossing or bifurcation, to a normal line structure or an end pixel structure in a ($n \times n$)-window with the 4th-neighborhood. The definition for the special case n=3 can be found in Ernst (1991) and see also Figure 5. With the help of the perpendicular digital line segment l_p to a given digital line segment l in a ($n \times n$)-window and the bisector digital line segment l_{wh} of two digital line segments the perpendicular digital line segment to the digital curve can be obtained.

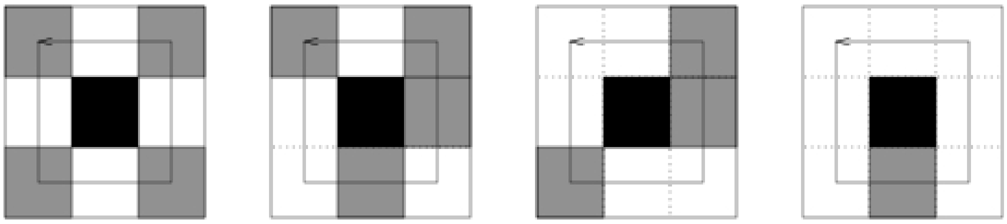


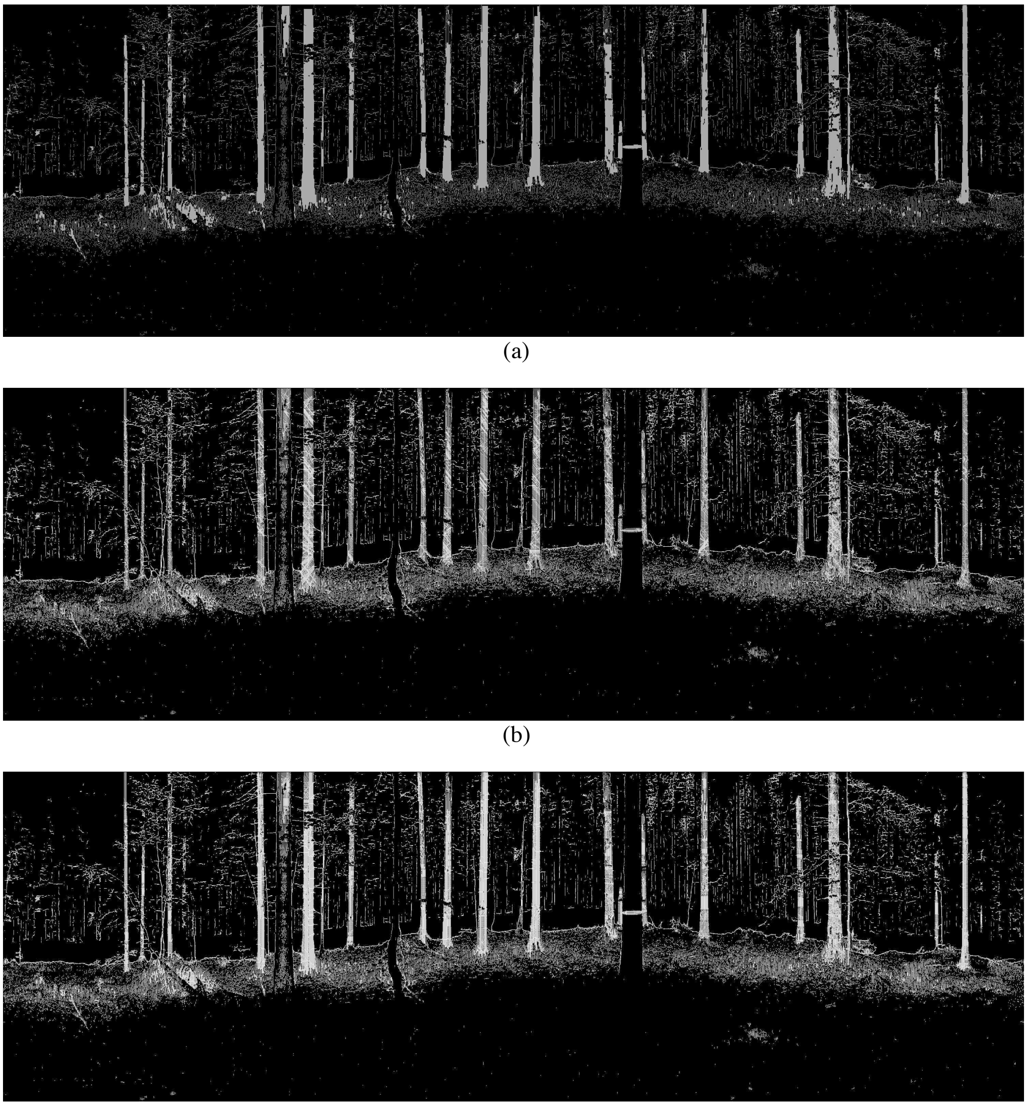
Figure 5: Connectivity number in a (3×3)-window, $C_4^{(3)}$=4 crossing, $C_4^{(3)}$=3 bifurcation, $C_4^{(3)}$=2 normal line and $C_4^{(3)}$=1 an end pixel structure

On the basis of the above mathematical descriptions the tree-trunk diameters can be determined in each skeleton pixel according to the Def. 3.2. The measurement of the tree-trunk diameters by square filling out is very well suitable for a reconstruction (see Figure 6) of the tree-trunk from the diameters. The other two procedures (Def. **3.1**, Def. **3.2**) supply against it a more exact diameter, but it can be well determined only outside of the branch bifurcations. On the basis of the diameter the separate representation of the branches and the thicker trunk is possible, as well.

The LDGT can be used not only for the tree-trunk diameter determination, but also for further characteristics of the tree-trunk, like the angle of the branch-bifurcations, the curvature of the tree-trunk and branches etc.

3.3 Fractal Dimension

In numerous investigations for the measurement of biological forms the fractal dimension is used. Accordingly it can be used also for the study of the leaf area. The leaf density is an important characteristic, which can be used for the estimation of the light absorption of the biomass. For the calculation of the leaf density with fractal dimension can be used the panorama picture, the segmented panorama picture and also the 3D data set, where in each pixel of the polar image (R,θ) in place of the intensity the distances of the pixels to the projection plane are used, which is obtained by the formula $d_{pixel} = R \cdot \sin(\theta)$.



(a)

(b)

(c)

Figure 6: The reconstructed tree structures (a) by square filling, (b) by directions and (c) by orthogonals

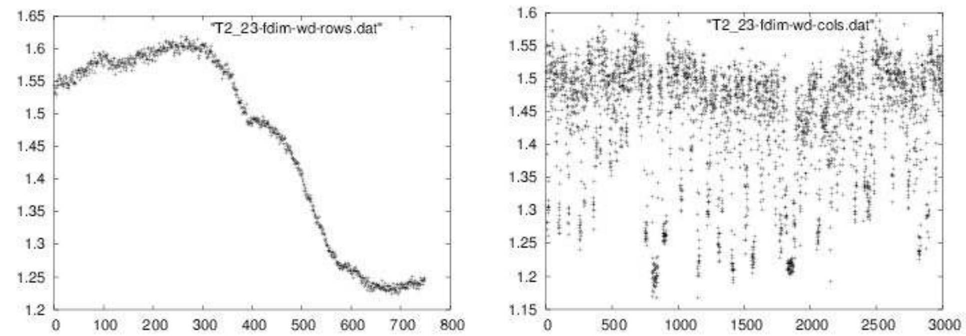
For the calculation of the fractal dimension on binary pictures can be used the box- or mass-radius dimension, where the numbers of object pixel in an always smaller and smaller grid structure are calculated and put into a logarithmic coordinate system. The tangent of the fitting straight line is computed, which the fractal dimension indicates.

The box and mass radius dimension can be used also for a 3D surfaces, like 'grey value mountains' of the pictures (Chaudhuri and Sarkar, 1992). Here instead of the 2D small boxes 3D cubes are used accordingly, which are determined by the grey values of the picture.

The disadvantage of the above calculations of the fractal dimension is that the pictures must be binarized or segmented. An another method for getting of the fractal dimension is the walking divider method introduced by Shelberg [Tuner, Blackledge and Andrews, 1998 p.41]. This method uses a chord length (StepLength) and measures the number of chord lengths (NumLength) needed to cover the fractal curve. The technique is based on the principle of taking smaller and smaller rules of size StepLength to cover the curve and computing the number of rules 'NumLength' required in each case.

The calculations algorithm of the fractal dimension is based on the following relationship: NumLength $=c\cdot\text{StepLength}^{\beta}$ and $\log(\text{NumLength})=\log(c)+\beta\cdot\log(\text{StepLength})$.

The least squares fit to the bilogarithmic plot of 'NumLength' and 'StepLength' gives



(a) (b)

Figure 7: The walking divider fractal dimension (a) on rows and (b) on columns calculated on the Figure 3 (a)

the slope β where the fractal dimension $D = -\beta$.

On the Figure 7 is shown the fractal dimension using the walking divider method by Shelberg for each row (a) and for each column (b). The tree crown and stem structure have higher fractal dimension as the ground area.

3.4 Circle/Ellipse Detecting and Fitting

The detecting of circles and ellipses such as the tree-trunk slice in the 3D scene e.g with Hough transformation is a very time-consuming task (searching in the 3-5 dimensional space). Using the LDGT on the 2D panorama pictures with the help of the 3D-coordinates it is possible to reduce the circle/ellipse detection time. On the segmented 2D panorama pictures and with the help of LDGT and of the 3D geometry the 3D points near to an orthogonal plane in a tree trunk position can be extracted, which points belong to the stem boundary. After the projection of these points to the orthogonal plane to the tree-trunk can be used any regression approach to determinate the stem border and the stem diameter at this position. For the circle/ellipse fitting was used its algebraic equation wiht the least squares method to determinate the circle middle position and radius.

4. Results and Discussion

In this work there were shown algorithms and mathematical methods for the segmentation, skeletonization and digital measurements. The purposed approach makes possible the automatic and computer based measurements on digital pictures and terrestrial laser data. The extraction of forest relevant parameters are based on the using of pictures as digital masks (segmented and skeletonized pictures) and on calculating the distances, lengths along the line structures and n-connected digital pixel structures (digital curves) in a local area which are determinated by LDGT.

5. Conclusions and Future Work

The quality of the segmentation influences mainly the skeletonization and also the digital measurements using LDGT. In the ideal case the exact object sizes can be determinated, but the intensity values of the laser data are not always enough to detect all tree structures. Because of it the segmentation on 2D panorama pictures should be extended for the 3D data set to get better preprocessing result. The colour information and its projection to the 3D data set are also necessary for the separation of the crown and leaf structures from the tree stem and branches and from the ground area.

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Bibliography

Chaudhuri, B.B., Sarkar, N. (1992): An efficient approach to compute fractal dimension in texture image. In Computer Vision and Applications, Proceedings of the 11th Int. Conf. on Pattern Recognition, International Association for Pattern Recognition(IAPR), IEEE Computer Society Press, Hague, Netherland, volume 1., pp. 358–361, Aug. 30.-Sep. 3.

Ernst, H. (1991): Einführung in die digitale Bildverarbeitung: Grundlagen und industrieller Einsatz mit zahlreichen Beispielen. Franzis–Verlag GmbH, München.

Klette, R., Zamperoni, P. (1995): Handbuch der Operatoren für die Bildbearbeitung. Vieweg Verlag, Braunschweig, 2. üb.

Pál, I. (1996): Michelson G, Niemann H, Welzenbach J: Erkennung von Mikrozirkulationsstörungen der Netzhaut mittels "Scanning Laser Doppler Flowmetrie". In: Lehmann T, Scholl I, Spitzer K, editors, Bildverarbeitung für die Medizin: Algorithmen–Systeme–Anwendungen Proceedings des Aachener Workshops, Verlag der Augustinus Buchh., Aachen, pp. 89–94, Nov. 8.-9.

Pál, I. (2002): Ein Vergleich der Gefäßsegmentierungsverfahren auf SLDF-Perfusionsbildern. In: Meiler M, Saupe D, Kruggel F, Handels H, Lehmann T, Eds., Bildverarbeitung für die Medizin 2002: Algorithmen–Systeme–Anwendungen Proceedings des Workshops in Leipzig, Springer–Verlag, Berlin, Informatik aktuell, pp. 378–381, Mar. 10.-12.

Pál, I. (2003): Ein Skelettierungsalgorithmus für die Berechnung der Gefäßlänge. In Wittenberg T, Hastreiter P, Hoppe U, Handels H, Horsch A, H.-P. Meinzer, Eds. Bildverarbeitung für die Medizin 2003: Algorithmen–Systeme–Anwendungen Proceedings des Workshops in Leipzig, Springer–Verlag, Berlin, Informatik aktuell, pp. 71-75, Mar. 9.-11.

Pál, I. (2004a): Computerunterstützte Analyse der retinalen Zirkulationsstörungen, insbesondere des Glaukoms auf Scanning Laser Doppler Flowmetrie Aufnahmen. Logos Verlag, Berlin, ISBN: 3-8325-0490-7.

Pál I. (2004b): Zeitbedarf des Algorithmus für die Berechnung des gefäßfreien Gebietes. In: Bildverarbeitung für die Medizin 2004: Algorithmen–Systeme–Anwendungen Proceedings des Workshops in Leipzig, Springer–Verlag, Berlin, Informatik aktuell, pp. 115-119, Mar. 29.-30

Pavlidis, T. (1990): Algorithmen zur Graphik und Bildverarbeitung. Heinz Heise Verlag, Hannover

Turner, M.J, Blackledge, J.M, Andrews, P.R. (1998): Fractal Geometry in Digital Imaging. Academic Press, San Diego, Kalifornia