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Semiautomatic tree ring segmentation using Active Contours and an optimised gradient operator

Poloautomatizovaná segmentácia ročných radiálnych kruhov stromov s využitím metódy „Active Contours“ a optimalizovaného gradientového operátora

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Abstract
This paper presents an easy and effective method to extract tree rings completely from images of tree discs independent of their source. The method uses Active Contours, often used in medical image processing to detect organs, in combination with an optimised image filter based on the Sobel operator to automatically outline the tree rings. Special attention is given to eliminate critical physical irregularities caused by branches, cracks or colourisations. The work resulted in the implementation of a platform independent, free and open source software solution for semiautomatic tree ring segmentation. Comparison to manual measurements shows that the system is dependable and the results are reproducible. The system has been applied to several conifer species.
Keywords: stem disc analysis; filter optimisation; segmentation tool; image analysis

Abstrakt
Článok prezentuje jednoduchú a efektívnu metódu pre extrakciu radiálnych ročných prírastkov z obrázkov získaných skenovaním diskov odobratých zo stromov. Metóda využíva techniku „Active Countours“, ktorá je často používaná pri spracovaní obrazu pre detekciu orgánov, v kombinácii s optimalizovaným obrazovým filtrom založeným na „Sobel“ operátore pre automatizované zvýraznenie ročných kruhov. Špeciálna pozornosť sa venuje eliminácii kritických fyzikálnych nepravidelností spôsobených vetvami, puklinami alebo zafarbením. Výsledkom práce je voľne dostupný softvér pre poloautomatizovanú segmentáciu ročných radiálnych prírastkov na odobratých diskoch. Porovnanie s manuálnym meraním ukázalo, že systém je spoľahlivý a výsledky sú reprodukovateľné. Systém bol preskúšaný na niekoľkých ihličnatých drevinách.
Keywords: analýza kmeňových diskov; filtrová optimalizácia; nástroj pre segmentáciu; analýza obrazu

1. Introduction

Tree rings can tell us a lot about climate variations over the last several thousand years. Generally, the precise determination of tree rings of a tree disc is an arduous and time-expensive matter. Therefore, one is in most cases satisfied with measuring the radii of the annual rings along single rays, e.g. obtained by a core sample. This is often done in a computer-assisted way and with the aid of a macroscope (Taube & Sloboda 1992). Other external systems like measuring stages, encoders, and readout units enable linear encoding of measurements. Such systems provided, e.g., by Metronics, Boecker boxes, Acu-Rite or Measucron are directly supported by commercial software systems like MeasureJ2X. For a great number of applications this restriction can lead to acceptable solutions, for example in the case of dendrochronological investigations where a destructive treatment of historical samples has to be avoided as far as possible. Later developments can process high-resolution images of tree discs or core samples. Commonly used, commercial representatives are WinDENDRO (Guay 2012) and LIGNOVISION™ (RINNTECH e.K.).

However, if one is interested in precise statements about stem growth, e.g., to explore how a predominating wind direction affects the stem or how a slope situation is balanced by asymmetric growth, a complete extraction of all tree rings can hardly be avoided. Therefore, digitizing and processing of whole tree discs are required. Image analysis techniques have been applied already in several systems like TRESS (Conner 1999, Gopalan 2000). A watershed based transformation in combination with other morphological operations for measuring the areas of annual tree rings was introduced by Soille and Mission (2001). Zhou et al. (2012) presented another method based on watershed segmentation to detect and count tree rings. Norell (2011) used image filter based methods to analyse wood quality by counting the number of annual rings.

Since stem positions are fixed to the ground, asymmetric tree growth is an adaption in response to environmental conditions, e.g., plant density what influences light conditions or topo-graphical site conditions. The question of which influencing factor most prominently define such differences in growth is not trivial. Field experiments were already done by Gaffrey (2004) to investigate how influences of the elastomechanical behaviour of the stem, as well as the distribution of the assimilate crown production will affect the growth behaviour. The aim was to analyse, and then describe and model the expected resulting change in stem growth. In

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functional-structural plant modelling of trees the focus also lies to physiological processes, because they are the driving force that determine growth and shape development of the stem in order to guarantee both mechanical stability and sufficient water supply to the foliage.

Calculations of ring area and the annual increment and furthermore estimations of volume and volume increment, what is possible when several sample disks are taken at different sections of the tree, are important information not only from a modelling or forest economic point of view.

2. Material and methods

The method which will be presented here and which was implemented in a software tool enables the complete extraction of tree ring information on the basis of images of tree discs. Data can be retrieved step by step from the disc to determine the precise dimensions of the annual rings.

In order to extract the tree rings from image data, well-known methods from image processing are used. First, the image will be improved qualitatively, then the proper extraction of the rings is carried out by means of Active Contours (Kass & Witkin & Terzopoulos 1987). This image processing method of course gives the best results if the tree rings are already well visible and distinguishable in the original sample. A (preferentially sharp) colour gradient between subsequent rings, however, does not occur in all tree species. In fact, in most deciduous tree species there is frequently the situation that some tree rings can hardly be identified. Thus our method is preferentially to be used for conifer species.

2.1. Description of the procedure

The primal material for our system are pictures of cross sections of a tree, in short tree discs, independent of which source they are origin, e.g., X-ray, photographs or scanned. The surface of the disc should be smooth and free of unevenness. Therefore, the discs should be planed or sanded using a grid 200 or higher in order to remove the damages caused by sawing. For pictures taken by a camera you need to make sure that the object plane is parallel to the camera in order to obtain an undistorted image.

Preparation of the base material is as important as image pre-processing including blurring and noise reduction can be to produce better results. A set of basic operations are also implemented for this reason in our software.

Besides quality of the image material, resolution of the image (dot density: number of individual dots per inch – dpi) plays a major role. This density directly limits the amount of informations that can be stored within an inch of an image and so it limits the number of rings and the minimal ring width that can be resolved. In order to distinguish more rings per inch a high resolution is recommended. At a density of 300 dots per inch 1 millimetre corresponds to 11.81 pixels.

A further problem that cannot be solved in such a simple way is a too weak contrast between early and late wood, which occurs frequently in some tree species. If there is the possibility before the images are taken, it is recommended to pre-apply colouring to the tree discs with specialised indicator colours, e.g., with a solution of hydrochloric acid and phloroglucinol, which colourises latewood darker than earlywood because of the higher concentration of Lignin. For coloured images it can be an advantage to split the original image into RGB channels and to use only the channel with the highest contrast for further analysis. Likewise, wood discolorations caused by fungal infection, e.g., by the Blue Stain, can cause errors in ring boundary detection. Besides colour and contrast problems, physical irregularities like branches or cracks in the wood represent further challenges. Another nontrivial problem comes from rings that are located so narrowly next to each other that with unaided eye their course is hardly tractable. In order to get as few problems as possible and thus to avoid time-expensive manual post-processing of the images, already in the phase of sample selection there should be paid attention to choose discs as immaculate as possible.

The described problems require new procedures for the semi-automatic tree ring extraction which exceed the standard image processing operations since the latter fail in difficult situations.

For the improvement of picture quality it is absolutely helpful to enhance the images using appropriate software in order to improve contrast or brightness before the extraction is carried out.

The extraction is based on the so-called edge image which is generated by means of gradient operators. This edge image serves as the basis for the segmentation by Active Contours.

The process of tree ring extraction can thus be split in the following steps: preparation of the disc → digitization → image pre-processing → edge recognition → segmentation → data post-processing.

2.2. Tree ring extraction = edge recognition

In order to identify a tree ring in a picture of a tree disc in a computer-assisted way, the here presented procedure uses the difference in colour or brightness, respectively, that occurs between the darker late wood and the brighter early wood. In the field of image processing, such an abrupt change is called an edge.

Technically seen, the problem of tree ring extraction can thus be reduced to that of edge recognition. If a grey-level gradient from black to white (Fig. 1a) is considered and the corresponding brightness values are plotted in a diagram where the value 0 is assigned to black and 1 to white, one receives Figure 1b. An edge can thus in the continuous case be defined by using the derivative of the brightness (or colour) function. The location at which the first derivative is maximal while the second derivative is zero defines the edge, see Figure 1.

From image processing a number of methods are known that approximate the derivative of an image, the so-called gradient procedures. Corresponding to the possibility to define an edge by primarily using the first or the second derivative, some gradient procedures approximate the first and some the second derivative.

In most procedures, one or several matrices, so-called convolution kernels, are shifted step by step over the initial

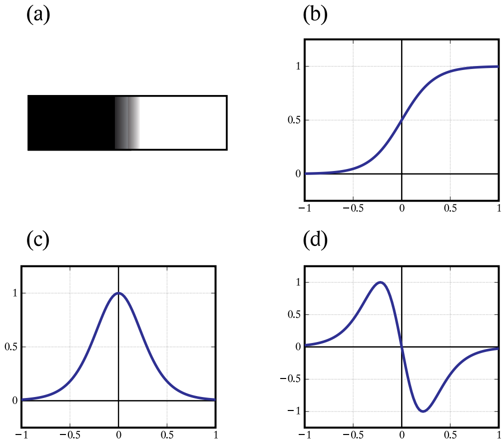

Fig. 1. Definition of an edge using derivatives. (a) Brightness gradient, (b) Brightness gradient in the diagram, (c) First derivative, (d) Second derivative.

image, and in each step a new pixel of the edge image is generated. A higher brightness value in the obtained edge image corresponds to a stronger gradient in the initial image. The edge (or gradient) image thus shows the positions and, via brightnesses, the strengths of the edges which occur in the initial image.

A simple but effective representative of such a discrete differentiation operator which approximates the first derivative is the Sobel operator method (Gonzalet & Woods 1992). In this case two convolution kernels are used, one (G_h) for the detection of horizontal edges and one (G_v) for vertical edges. In our implementation we use 3×3 kernels:

$$G_h = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}, \quad G_v = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad [1]$$

The two values are afterwards combined using one of the two variants in equation 2 in order to calculate the actual value.

$$|G| = \sqrt{G_h^2 + G_v^2}, \quad \textit{accurate}$$
$$|G| = |G_h| + |G_v|, \quad \textit{approximation} \qquad [2]$$

The application of the Sobel operator for example to the picture of a coast fir disc (*Abies grandis*) (Fig. 2a) yields the corresponding edge picture (Fig. 2b).

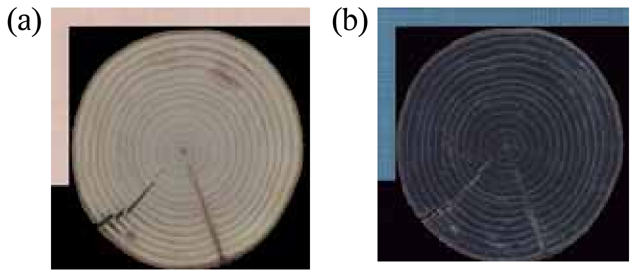

Fig. 2. Sobel operator applied to the picture of a coast fir disc: (a) Original disc, (b) Result of the application of the standard Sobel operator.

A more precise look at the edge image, however, reveals several unpleasant features which render the image almost useless for automatic edge detection. On the one hand every edge in the initial image is emphasized, including those generated by possibly existing branches or cracks in the wood (Fig. 2a). On the other hand sometimes double edges are generated (Fig. 3): This happens if the late wood appears only as a thin line that is enclosed by the brighter early wood. So the application of the Sobel operator gives two edges when the late wood is approached, one when coming from the centre and one when coming from outside.

These disadvantages make an optimisation of the filter necessary.

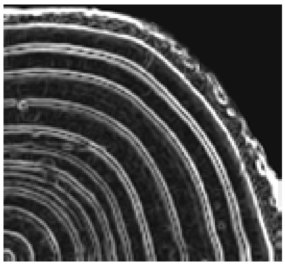

Fig. 3. Magnification of detail: A spruce disc after application of the standard Sobel operator illustrates double edges which can occur with wide late wood parts.

2.3. Filter optimisation

Purpose of the optimisation is to emphasize only the desired edges, in this case those corresponding to annual rings, and to weaken or to delete all other edges. Furthermore, the double edges should be reduced to a single edge. The basic idea of our filter optimisation is to consider the angles of the detected edges and to emphasize only those edges which are orthogonal to a ray through the marrow of the tree disc, taking a certain tolerance zone into account (Fig. 4). This condition is based on the property that tree rings expand in a more or less circular way around the pith and thus have tangents orthogonal to a ray through the centre.

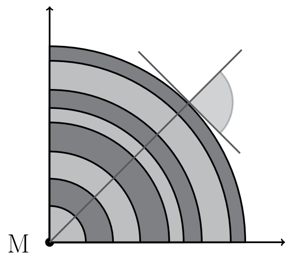

Fig. 4. Edge orthogonal to the ray through the centre.

As the basis of the filter optimisation the Sobel operator is used. While the convolution kernels are applied to the initial image step by step, in each pixel the angle between the tangent in this pixel and the ray through the centre is calculated according to equation 3.

$$\theta = \begin{cases} \arctan\left(G_h/G_v\right), & G_v \neq 0 \\ 0°, & G_v = 0, G_h = 0 \\ 90°, & G_v = 0, G_h \neq 0 \end{cases} \qquad [3]$$

If the angle between the tangent and the ray to the centre lies now in a tolerance zone of up to five or ten degrees, the point will be intensified by 20 percent, otherwise the point is not included in the edge image. The reverse orientation of the dark and bright side of a “false” edge has the desired consequence that these false edges are refused by the modified operator. Thus the artefact of “double edges” (as in Fig. 3) is automatically avoided. Figure 5 shows the result of the optimization, applied to the example shown in Figure 2.

Precondition for the method is that the centre of the tree disc, more precisely: the position of the pith, is known. The exclusive strengthening of those edges which follow a nearly circular course around a centre has led us to the name "circular Sobel operator" for the optimized operator.

In the process of extraction of tree rings, the next step is the segmentation, i.e., the assignment of the detected edges to single tree rings and the extraction of their coordinates. The procedure which we have applied here is known under the name "Active Contours".

Fig. 5. Application of the circular Sobel operator to the tree disc of Fig. 2. Problematic edges caused by cracks and branches as well as noise are removed.

2.4. Active Contours

The concept of Active Contours, also known as Snakes, was introduced by Kass (1987). A lot of optimizations and derived methods were subsequently developed, and their applications are today widespread. Basically the aim is to determine the contour of an object. A special feature of the method is its robustness against disturbances and noise in the initial image. Hence it is possible to identify even objects with very weak contours. This feature has led to a particularly widespread usage of the method in medical image processing where objects like organs or venation are to be identified in CT or MRT images. The method is also widely used in computer-aided object tracking and in face recognition.

The method makes use of a parametric curve, which is in most cases initialized manually. The slope of this curve is controlled by so-called internal and external energies. The internal energies are calculated solely from the form of the contour. They determine the tension and thus the tendency to the formation of loops, as well as the stiffness of the curve, or, expressed in a positive sense, its ability to adapt itself to fine details of the contour. The initial image determines the external energy via the edge (or gradient) image. An iterative optimization, which seeks to minimize the sum of the energies, deforms the contour until a stable state is obtained. The Snake curve thus seeks in the gradient image for maximal brightness values and adapts itself to their locations in the best possible way, taking the internal energies into account.

2.5. Tree Ring Segmentation Tool – TriST

As a basis for the implementation of our software we have used the Java Extensible Snake System, JESS for short, which has been developed by Tim McInerney and his team at Ryerson University, Toronto (McInerney & Sharif & Pashotanizadeh 2005). It offers a hierarchically designed structure with various Snake implementations and a simple graphical user interface. Furthermore, the system allows an interactive manipulation of form and parameters while the Snake curve is optimized. To control the course of the curve, additionally so-called magnets can be defined which have impact on the form of the curve independently from the edge image and from the parameters.

We have extended JESS by the circular Sobel filter and by the necessary infrastructure for tree ring extraction. This includes all functionality that is used for processing the recognized rings, for automatic initialization of the new curve in relation to the recognized ring, and, ultimately, for storage of the recognized rings. Additionally, a toolbox of standard image processing routines for pre-processing of the scanned rings was implemented, which will not be discussed further here.

For standard image manipulation the free Java Advanced Imaging Library – JAI (version 1.1.3, Oracle Corporation) was used. Therefore, all common image formats, e.g., TIFF and PNG, are supported by our software. Our tool is platform independent and as open source software it is free of charge, available upon request by the first author.

3. Results

3.1. Tree Ring Segmentation

The process of tree ring extraction is started by the initialization of the first curve outside the innermost ring and by the definition of the centre. During the process of adaption of the curve the user can interact and manipulate the pathway of the curve at any time by simple pressing the mouse at one point where the curve should cross. When the first ring is seized correctly by the curve, the user gives a confirmation. Subsequently, the recognized ring is stored and a new curve, positioned in relation to the old one, is initialized. In addition approximations of average radius, circumference and the area enclosed are calculated (Fig. 6). So each ring, successively from the innermost to the outermost one, is processed until the bark is reached. Finally, the data can be saved in different plain text formats (e.g. coordinate based and polar coordinates). Images can be archived with or without their analysis.

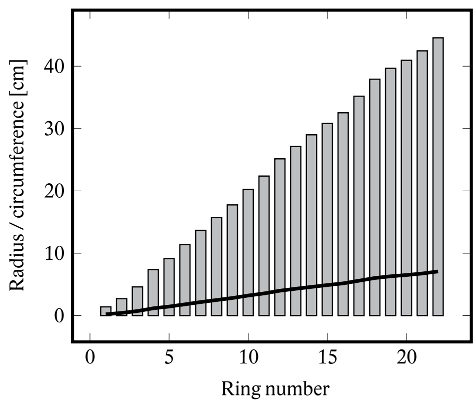

Fig. 6. Approximation of average radii (line) and circumference (bars) of a spruce disc with 22 rings (Fig. 8).

Branch scars, injuries or contaminations, e.g., caused by fungal infestation, are a common problems which usually causes trouble and requires manual intrusions during the extraction of tree rings. Figure 7a shows a disc from a coast fir with a branch scar and a crack at the bottom. It is clearly visible how the curves (highlighted in blue) have adapted to the courses of the tree rings, without having been significantly influenced by the branch scar or the crack.

The following example (Fig. 7c–d) of a spruce disc with 22 rings shows in a direct comparison the original disc and the extracted tree rings.

It is also possible to extract the rings from discs with a diameter of 50 centimetres and more with the here presented software TRiST. The problem in this case rather lies in the process of digitizing, which is restricted by the size of the maximal scanning area. A solution is offered by scanning in several steps with subsequent joining, the so-called stitching, of the partial images to a complete image, which then serves as the basis for tree ring extraction as described.

The largest tree disc which we have processed until now originated from a 21 years old coast fir (*Abies grandis*). It had dimensions of 45 to 38 centimetres and had to be scanned in four steps. Figure 7b shows the original disc as well as the extracted tree rings.

3.2. Accuracy of measurement and expenditure

For verifying the accuracy of measurement, a tree disc was measured exemplarily by hand and the results were compared with the data obtained from computer-assisted extraction. The object for this test was a disc from an approximately 25 years old coast fir (*Abies grandis*), taken from a height of 9.5 meters, with 9 tree rings. Starting with a fixed direction, at intervals of 10 degrees the radii of all tree rings in relation to the pith were determined.

The sample thus included a total of 324 measuring points (36 directions, each with 9 measurements). To check the quality of extraction, the differences between the manually measured points and the points obtained from computer-assisted extraction were calculated and plotted in Figure 8. The average deviation is about −0.184 mm and shows a systematic error, which was probably caused by the conservative measuring by hand. The obtained errors are in an interval between −0.99 and 0.95 millimetres. Altogether, 86% all of all differences are within a deviation of 0.5 millimetres or less around the mean.

Several test runs gave an average extraction time per ring of 60 seconds, with the required time increasing with larger radius. This results from the increase in perimeter and the resulting longer control time. For the complete analysis of a disc with 20 tree rings we got an average processing time of approximately 20 minutes.

4. Discussion

The key issue for successful, accurate and reliable measurements of whole tree rings with our system depend mainly on the quality and type of input material. As discussed above, the quality and success of extraction are proportional to the visibility of each ring within the image, consequently species where early- and latewood are clearly distinguishable

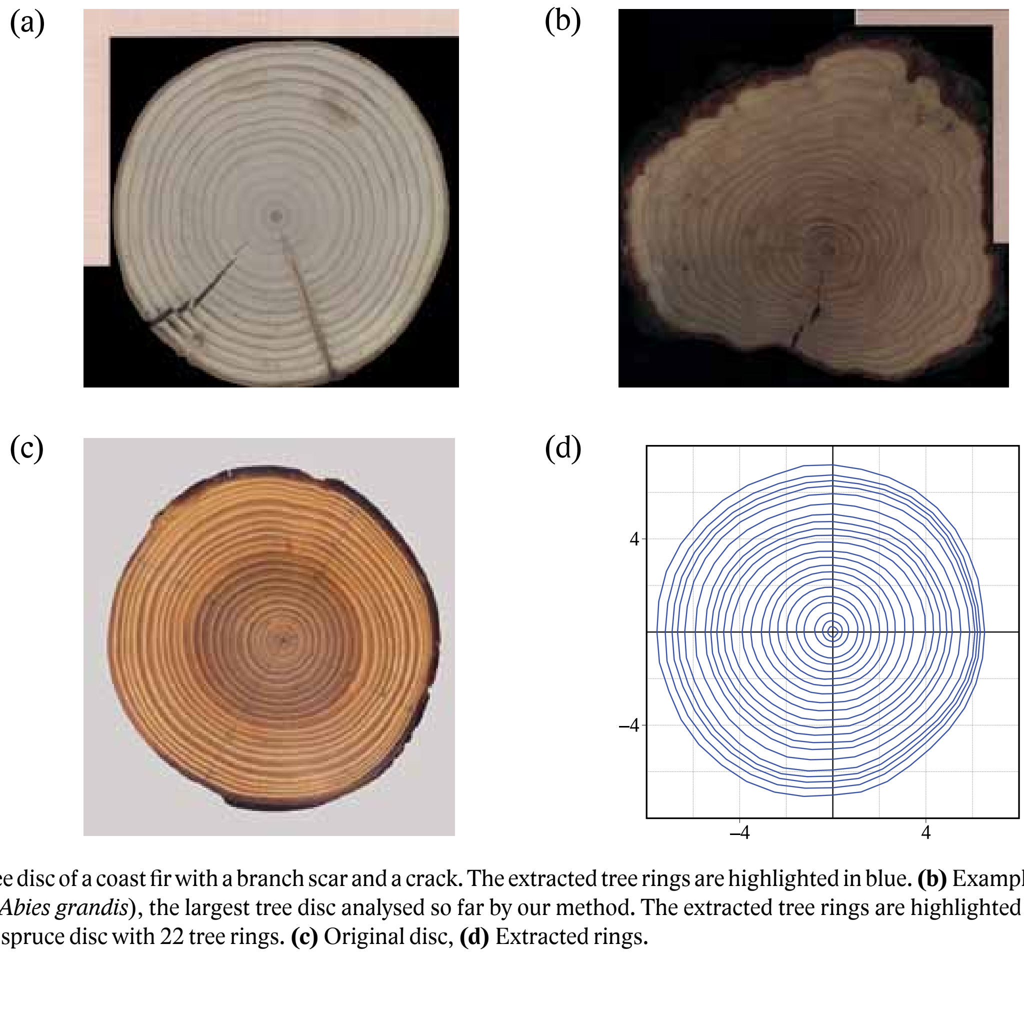

Fig. 7. (a) Tree disc of a coast fir with a branch scar and a crack. The extracted tree rings are highlighted in blue. **(b)** Example of a 21 years old coast fir (*Abies grandis*), the largest tree disc analysed so far by our method. The extracted tree rings are highlighted in blue. (c–d) Example of a spruce disc with 22 tree rings. **(c)** Original disc, **(d)** Extracted rings.

are preferred. In order to reduce false detections during the segmentation process caused by traces of the cutting process, e.g. sawing scratches, precedent preparations of the tree disc itself are advisable before scanning. During image processing common strategies to eliminate noise and enhance the contrast can be applied by the system if required. For our purpose, we can conclude that the technique of Active Contours produce reproducible and reasonable results.

The reliability of our system was evaluated by comparison with manually measurements performed on 324 measuring points (36 directions, each with 9 measurements). From Figure 8 we can see that the errors does not follow any pattern, while with increased ring number the variation are larger. The overall accuracy of measurement of our system might be low compared with touchstones applied in dendrochronology. While systems used in dendrochronology normally using light microscopes and consider only radial ring-width measurements, our system is designed to extract whole tree rings, what can compensate the errors to a certain extent. For deducing growth behaviour, the difference has no significant consequences.

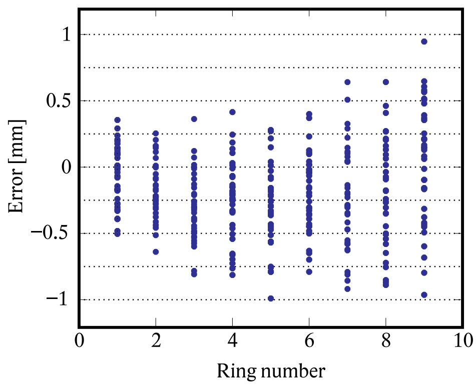

Fig. 8. Differences between the manually measured points and the points received from computer-assisted ring recognition. Mean = −0.184 mm, standard deviation = 0.336 mm.

While for common edge detection operators applied to wide latewood parts double edges, so called pseudo rings, are produced, it is found that our optimised Sobel operator does not face this problem. Cracks as well as branches can be nearly eliminate in the same way.

Our system reaches his limits when the contrast between early- and latewood is to low and following no edge can be identified. The same applies when a gradient instead of a sharp switch in colour is given. Very thin rings, low ring width and large image noise can lead to more user interaction and so increase the time for extraction.

5. Conclusions

A new software tool for the semiautomatic tree ring extraction by using Active Contours was developed. In order to enhance the tree ring recognition a new filter was designed and integrated into the software. The system is suitable for all kind of input images that fulfils a minimum requirement of a certain contrast, while the size of tree disks is only limited by the used recording equipment. To improve the accuracy of the interactive measurement process and to reduce its complexity, some exemplary studies have been conducted which gave promising results. The system provides an efficient, time-saving way for tree ring extraction. The resulting data can deliver plenty of information on how trees adapt growth to environmental conditions that further can be used to analyse wood quality or to describe and model changes in stem growth.

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