VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

BRNO UNIVERSITY OF TECHNOLOGY

FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

ÚSTAV JAZYKŮ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

DEPARTEMNT OF LANGUAGES

EMERGING TRENDS IN DENDROCHRONOLOGY

BAKALÁŘSKÁ PRÁCE

BACHELOR THESIS

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SUPERVISOR

BRNO, 2015

VYSOKÉ UČENÍ
TECHNICKÉ V BRNĚ

Fakulta elektrotechniky
a komunikačních technologií

Ústav jazyků

Bakalářská práce

bakalářský studijní obor
Angličtina v elektrotechnice a informatice

Student: Tomáš Horáček ***ID:*** 159163
Ročník: 3 ***Akademický rok:*** 2014/2015

NÁZEV TÉMATU:

Nové trendy v oblasti dendrochronologie

POKYNY PRO VYPRACOVÁNÍ:

Sledujte aktuální vývoj v oblasti dendrochronologie. Proveďte průzkum hardwarových a softwarových nástrojů pro určování stáří dřeva a porovnejte výhody a nevýhody jednotlivých řešení. Součástí bude literární rešerše v této oblasti.

DOPORUČENÁ LITERATURA:

[1] Speer, J.H. Fundamentals of Tree Ring Research, The University of Arizona Press, 368 s., ISBN 978-0-8165-2685-7.
[2] Cook, E.R., Kairiustis, L.A., Methods of Dendrochronology, 1990, 394 s. ISBN 978-94-015-7879-0.

Termín zadání: 9.2.2015 ***Termín odevzdání:*** 22.5.2015

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Předseda oborové rady

ABSTRAKT

Tato práce se zabývá popisem současných a experimentálních metod odběru vzorků pomocí presslerova nebozezu, výřezů z kmene, fotografie, rentgenu, počítačové tomografie a magnetické rezonance na poli dendrochronologického výzkumu. V práci jsou rozebírány destruktivní a nedesktruktivní metody odběru vzorků. Je také kladen důraz na původ vzorků: zdali je možno využít destruktivní metody nebo zdali je to nemožné jako v případě vzácných archeologických objektů. Dále popisuje standardní optometrickou metody a další experimentální metody fungujicí na principu kontranstního zpracování obrazu za účelem rozeznání letokruhů. V práci jsou také popsány různé druhy metod softwarového zpracovnání kde jako vstup slouží buď série dat nebo obraz letokruhů. Další rozdíly tvoří vymezené spektrum uvedených prací, některé práce se zaměřují na zpracování obrazu od píky tedy od pořízené fotografie až po hotové datovaní, některé však zajímá pouze úzký sektor dendrochronologie jako jsou například vady či špatně rozeznatelné letokruhy.

KLÍČOVÁ SLOVA

Dendrochonologie, letokruhy, rentgen, počítačová tomografie, magnetická rezonance, zpracování obrazu

ABSTRACT

This thesis deals with a description of current and experimental methods of sample extraction with the increment borer, cuts from sawn logs, photos, X-rays, computed tomography and magnetic resonance in the field of dendrochronology. This work deals with destructive and non-destructive sample acquisition methods. Difference between the possibilities of usage of these methods is also emphasized: whether or not is it possible to use destructive methods - especially the case of the rare archaeological objects. Along with the description of current optometric method other methods of image processing based on contrast recognition for the purpose of the tree ring recognition are given. Description of different software methods are given with the respect to the data input (image or data series). Other differences are in the spectre of interest of presented programs, some of them are programed to analyse the rings from input image whereas some deal only with narrow spectre of dendrochronology such as faults in tree ring formation or poorly recognizable rings.

KEYWORDS

Dendrochronology, tree rings, X-rays, computed tomography, magnetic resonance, image processing

HORÁČEK, T. Nové trendy v oblasti dendrochronologie. Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav jazyků, 2015. 40 s., 5 s. příloh. Bakalářská práce. Vedoucí práce: Ing. Jan Mikulka, Ph.D.

PROHLÁŠENÍ

Prohlašuji, že svou bakalářskou práci na téma Emerging trends in dendrochronology jsem vypracoval samostatně pod vedením vedoucího bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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V Brně dne .... (podpis autora)

PODĚKOVÁNÍ

Zde bych chtěl poděkovat vedoucímu mé práce Ing. Janu Mikulkovi, Ph.D. za směrodatné vedení mé práce a M. A. Kennethu Froehlingovi za podmětné vedení jazykové stránky.

Dále bych chtěl poděkovat Tomáši Kolářovi a Michalu Rybníčkovi z Ústavu nauky o dřevě Mendelovy Univerzity v Brně. Radku Tichavskému a Matěji Horáčkovi z Přírodovědecké fakulty Ostravské Univerzity.

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Introduction

In this thesis, I deal with technologies used in the field of dendrochronology. Dendrochronology is a branch of science where researchers deal with physical properties of trees, namely the age and width of springwood and summerwood. The output is not only an increment of the tree growth phases but, it may also indicate different biological, climate or chemical changes that occurred during that time, similar to the research of ice crust on the Earth poles these changes presents certain difficulties in image processing techniques.

The currently used method is an optic with direct measurement done by researchers, where a small sample must be obtained, polished and measured under a microscope. Such a method is not only highly time-consuming, but also difficult and sometimes almost impossible since the quality of samples may vary. The usage of this method for living trees is also quite dangerous since an untreated drill hole can cause various problems.

One of the proposed methods also depends on optic and optical instruments but without using the most imprecise element in measuring which is the human one. The other ones, image processing, encounters a lack of sufficiently advanced screening technology and ring recognition software, however it brings a completely non-invasive way on how to acquire a sample.

The two most significant branches proposed encounter different difficulties depending on the method used in identifying the cross-section or getting an appropriate sample.

The aim of this work is to summarize the methods proposed by researchers, identify the most significant difficulties and suggest the most valuable method for different samples, conditions and environments under which the dendrochronology is conducted.

1. Dendrochronology

The term Dendrochronology is a compound from three Latin words: ology = the study of, chronos = time – events/processes in past, dendros = using trees – here growth rings.

The exact definition is some publications over half a page long (Conner et al), however the core of most of the publications is the same, the dendrochronology is supposed to be a tree dating science (Oxford dictionary, Grissino-Mayer), yet there is even more than that behind the dendrochronology.

Taking samples in the field conditions can point at this fact directly; a sample from a 50-year-old pine might have the same cross-section length as a sample from a 100-year-old pine from a different location. This may be caused by many different factors such as altitude, climate conditions, chemical composition of the soil and even the bedrock. The research in dendrochronology may present surprising results at places where an orogeny process took place, or where variance of the bedrock is not expected to be. It means a different chemical composition of the soil occurred due to dissolution of unusual bedrock composition caused by perturbation by the tree roots or by any other means.

We can also deduct the origins of a tree, due to the tree ring patterns, which bear similarities between trees from the same area. There is one prerequisite: we need to have a set of previously examined samples of the same species from the given location.

These pointers tell us that many other branches of science are involved in dendrochronological research. Climatology, dendrogeomorfology are important parts in nature sciences, because of them we can successfully date historical events such as short summers and long winters via the dendrochronology.

1.1. Origin of the tree rings

The difference between speed of growth, caused by climate and the chemical factors such as the temperature, an access to nutrients and the water causes trees to grow wood with a different density creating the tree ring. Even wind causes slight differences in tree rings. One of the reasons for inability to provide the dendrochronological research worldwide is the absence of seasonal changes.

The springwood has a brighter color caused by faster growing Vascular cambium because of the favorable conditions. In the Czech Republic, we can describe the conditions as milder temperature, plenty of water and organic material rotted under the snow cover, which penetrates the earth's crust in the spring due to the melting.

The summerwood has a darker color usually caused by dry summers and a slower intake of solutes. This also causes thinner and denser summerwood rings in comparison to the springwood ones.

2. Sample and sample extraction

The samples are taken in a perpendicular way to the aim of the growth in the part of an object, which contains most of the tree rings from the core to the edge of a log, joist, statue, furniture, etc… We need to choose a point where the tree rings are not damaged or disrupted by a twig. It is important to choose a point where there is ring right under the bark (in vascular cambium), which tells us when the tree was cut or when it died in the case of a standing tree.

I want to note that *object* is a very general word; I use it in the introduction of this chapter since the sample is taken from various things such as joist, furniture, statues, sculptures, standing living or dead trees, logs, carbonized parts and soggy parts.
The width of the rings varies from 10-µm to several millimeters.

2.1. Drilling

The less destructive sample acquirement is drilling with hollow drill – increment borer. Such a method provides us with 1 – 2.5cm thick sample with variable length according to the diameter of the researched object. In order to get the sample, an increment borer or a cordless drill are used, however using the increment borer requires experience. [1]

2.2. Cross-section

The cross-section of an object is the more destructive way. We need to acquire a sample with visible rings under the bark. This may prove to be difficult if the object is damaged joist, has an archeological value or is infected with the Old-house borer (*Hylotrupes bajulus*) in such cases a sample more than 5 cm is needed to be taken which has proven difficult especially with object with an archeological value since they cannot be damaged by taking a sample.
Procedure with a soggy object is similar to cross-section only with exception that we must prevent it from drying since some negative effects (sample disintegration) can occur. Also, a certain grade of prudence must be present so the sample is not devalued by the procedure. [1]

2.3. Carbonized samples

Obtaining a sample from carbonized objects is the most difficult of the direct approach methods. Not only can careless handling destroy the sample, but also transportation of the sample is difficult. To prevent disintegration it is recommended to wrap the sample in a plastic foil and secure it with a string. It should be noted that the carbonized samples must not be exposed to sunlight. Wet samples must not be wrapped in water absorbent material since drying can cause disintegration. [1]

2.4. Photo

Using a cross-section photo is also a possibility with joists. The faces of the joists must be sometimes adjusted in order to respond to the required quality of a sample; however, this method is the least invasive compared to those mentioned above. A greyscale photo with photosensitivity 100 is used and certain light conditions must be met. [1]

2.5. X-ray

Parker

In 1970 Parker described a method using wedge–shaped slabs of wood (stump V–cuts) for X–ray exposure and following preparation steps for samples:

1) Flat surface parallel to long axis of longitudinal tracheids is chiseled along one edge of the V–cut slab

2) 1/2 inch (≈1.3 cm) thick mounting board is glued to chiseled surface

3) specimen is 'squared off' by making 90° saw cuts along the top of the slab, along the outer edge of the side opposing the first mounting board and along of the specimen

4) second mounting board is glued to the plane surface opposite the first mounting board

5) 3/32 inch (≈0.24 cm) thick traverse cross section of the tree ring specimen are produced by making saw cuts along the axis of mounting board [2]

In order to process samples from very large tree stumps, a block containing entire tree–ring series is cut and mounted in a similar manner

The information is more relevant if intra–annual ring density data are used. Parker also described new problems that occurred with the use of the X–ray or/and densitometric techniques: tree–ring characteristics such as false rings, frost rings, faint latewood, microscopic rings, locally absent rings, partially formed rings and compressed wood can be presented graphically and quantitatively. [2]

The x-ray used apparatus is Picker portable instrument with a 50 kilovolt (maximum) capacity, 1.5 mm focal spot, 0.5 mm beryllium window and self-rectifying circuit. [2]

Parker described stationary and in–motion techniques:

1) stationary: sample is placed on single emulsion of radiographic film and subjected to X–radiation from a distance of 48 inches (≈122 cm) and 90° angle. Exposure is 2 minutes long at 22kV and 5mA [2]

2) in–motion: Parker noted that a proper definition of annual ring density (density is main factor causing difference in contrast) is obtained only if X–rays penetrate the sample at an angle parallel to long axis of the longitudinal tracheids. In this case X–radiation is transmitted through a 1 mm wide slit from a stationary source 10 inches (≈25.4 cm) from the tree–ring specimen positioned on the film. Specimen and film are supported by a carriage and move at a slow and uniform speed 3/8 inch (≈0.95 cm) beneath the slit. Experiments have been conducted with the speed of carriage of 2 inches per minute (≈ 5.08cm/m) at 22kV and 6.5mA. [2]

Experiments with mixed results were conducted with double emulsion radiographic film and photographic film. It was stated that fine grain photographic film provided good results.

Parker mentioned that unlike the photographic equipment, the X–ray technique is not influenced by color distortions such as stains, heartwood and sapwood differences [2] (as the output is black and white).

On the other hand there were many factors affecting quality: condition of specimens (angle of extraction, preservation, foreign matter – sand and glue, moisture, cracks, branch distortion, thickness, ring boundary alignment, xylem cells alignment), method of preparation, X-ray and film developing. [2]

2.6. CT (computed tomography) scan

In order to obtain this sample from living tree, the tree must be cut down or drilled. Some smaller samples can be scanned without the need of an extraction of a smaller piece. Grabner et al described that the ring borders which are needed to precisely measure the width are not distinct in diffuse porous hardwoods such as European beech (Fagus sylvatica) and the vessel can be 85 to 8 µm wide. [3] They also mention that for accurate species determination resolution of 20 µm needs to be achieved [3], which for some thicker samples proves to be difficult.

Onoe, Tsao, Yamada, Nakamura, Kogue, Kawamura, Yoshimatsu

In 1983 Onoe et al described a portable CT machine capable of taking scans on standing trees without any verifiable damage.

This scanner had two independent U-shaped plates, coaxially mounted. When the openings of both plates are aligned, a vertically standing object can be inserted into the center from a lateral side. The lower plate has four adjustable legs that serves as a fixed platform. The upper plate supports a sector-scanning mechanism of an X-ray source and a group of detectors. Both plates are coupled by a rotation mechanism. After each scan, the upper plate rotates a few degrees. The process repeats itself until enough projection data are obtained for CT reconstruction. All the scanning and data acquisition processes are controlled by a microprocessor. [4]

Their scanner in this particular arrangement was equipped with an X-ray tube of 40-120 kV and three NaI (Sodium iodide) scintillation counters.

The tube and the detectors are fixed in an assembly, which rotates around the target focus of the X-ray tube; so that three collimated X-ray beams 8° apart, scan across the tested object. The target focus is eccentric from the center of the tree; hence, a fan-beam algorithm is used for reconstruction. Typically, 1200 samples of 16 bits of projection data are taken in 2° intervals. [4]

Onoe found out that the X-ray absorption in the sapwood region is so high that two views in different gray scales had to be taken: the first one was suitable to see annual rings in heartwood, whereas in the second we could see the rings in the sapwood. The main cause of this high absorption is due to a transpiration water stream. [4] To prove relations between water content and X-ray, an absorption comparison of the two scanned samples with the water content from drilled core samples was conducted.

The X-ray profile is smoothed by a running average, which corresponds to the water content profile, if the unavoidable dimensional change of core sample is taken into account. [4]

In order to prove the relations between the water content and X-ray absorption they did another scan sample a crack in the center and high water content, even in heartwood. Which was confirmed by the means of two core samples: again, profiles of X-ray absorption and water content are corresponding. It was pointed out that heartwood having a high water content is often called “black core,” which spoils its value as timber but was heretofore difficult to detect before cutting. [4]

According to Onoe et al portable scan is sufficient for common dendrochronology, where we are interested in the width and the density of tree rings, yet this portable scanner lacks sufficient resolution requirements for image processing techniques. In this scanner resolutions around 20-µm are not obtainable, so the machine in this setup is not usable for the archeological research if there is a need to determine the species from what the given object is made of. This fact does not makes the machine less useful, as its primary usage would be in field conditions right in the forest where the species is easily identifiable

The idea of creating a portable CT is not new at all. However applying CT scans to standing immovable objects was neglected and not researched. Portable scanner with this size and mobility are certainly an asset.

Bill, Daly, Johnsen, Dalen

Another study on CT devices was conducted in 2012; Bill’s team was mostly focused on comparison of CT machines and evaluation of the results on air-dried and waterlogged samples. Two scanners medical and industrial were compared and resulting images were analyzed.

The first was medical Siemens Somatom Emotion single slice scanner which parameters were given presented.

Minimum slice thickness is 1mm. The focal spot size of the scanner is 0.8mm×0.4mm, but quoted to IEC 336/93 standard 0.8mm×0.7mm (Keat et al., 2002: 16). The scanner operates with a picture matrix of 512×512. Each pixel in the matrix can vary from 0.1 to 1mmaccording to the field of view (FOV) or FOV from 50 to 500mm. With 0.1 mm pixel and 1mm slice thickness the voxel is $0.1\times0.1\times1.0 = 0.01$ mm^3. [5]

This scanner proved to be considerably useless. Even with certain improvements Bill’s team tried apply to the scanner was not able to produce image with sufficient resolution. Rings with width smaller than 1mm were practically invisible.

Second scanner was Nikon Metrology XT H 225 LC, which was labeled as micro-focus CT scanner. Some differences between medical and industrial scanners were pointed out. Exact parameters such as presented above were not given but some of the parameters were presented: the source produces a polychromatic conical X-ray beam, and for each angular increment of motion a projection image of the entire sample is cast on a 45×45 cm^2 Perkin Elmer panel detector with a 2048×2048 pixel matrix, and imaged.[5]

This scanner was able to reach a 5 µm voxel resolution with optimal sample – 1 cm, however, the maximum diameter of one scan was about 30 cm in length resulting in resolution of 150 µm. Maximum size of a sample that would be product of a several partial scans could be up to 135 cm or 165 cm with some size and resolution restrictions. For the best possible results, the team chose resolution within the range of 50-75 µm.

The results from medical CT were not used in further analysis. Images from industrial CT were scanned using Able Image Analyser© by Mu Labs. A calibration was successfully done by the means of length indicator. 93 samples were scanned, 5 were discarded because of containing too few rings of fault at the scanning, however how precise were the measurements was not disclosed.

2.7. Magnetic resonance

Dvinskikh,Henriksson,Berglund Furó

A use of new machine was presented in 2011by Dvinskikh, the MRI (magnetic resonance imaging) works on the idea of measuring springwood and summerwood rings on the basis of different heavy water (^2H_2O) absorption potential.

Cubic pieces of approximately 6=6=6 mm^3 are cut from the wood with the edges parallel tree axes, denoted as R, T, L (radial, tangential, longitudinal). The samples are dried in a vacuum oven at 60 °C for 4 days. Individual samples are then equilibrated for at least 4 weeks in closed containers with relative humidity set by saturated solutions of selected salts in D_2O, either KNO_3 (95% relative humidity, RH) resulting in a MC (adsorbed moisture content) of 25.9% or $NaNO_2$ (66% RH) resulting in a MC of 12.0%. Samples for spectral reference were also prepared with H_2O (instead of D_2O) as solvent for the salt solutions. [6]

Prior to measurement, the investigated wood piece was transferred into a 10-mm glass NMR (nuclear magnetic resonance) tube and fixed tightly between Teflon cylinders inside the tube. Hence, the orientation of the wood piece was reliable and reproducible. The direction of the magnetic field gradient was set parallel to the tube axis. The wood piece was reoriented between measurements (R, T or L). The tube was sealed with Parafilm to keep the MC constant during the experiments (up to 8 h total duration per sample). [6]

The sample mass were controlled before and after measurements. ^1H and ^2H NMR spectroscopic and imaging (Callaghan 1991; Blümich 2000) experiments were performed on a Bruker Avance II spectrometer with resonance frequencies of 300 and 46 MHz. A custom-modified Bruker DIFF25 probe with a unidirectional (z) gradient of maximum 9.8 T m^{-1} was used with exchangeable ^1H or ^2H single-frequency radiofrequency resonators that had 10-mm sample space diameter. The field of view was limited to 10 mm both by the radiofrequency coil and by the region of gradient linearity. The length of 90° radiofrequency pulses for ^1H and ^2H were 10 and 22 ms. All measurements were performed at approximately 23 °C, the same temperature at which the samples were equilibrated. We note here that ^2H NMR was previously used for evaluating the state of water in cellulose (Wong and Ang 1985; Li et al. 1992; Vittadini et al. 2001). [6]

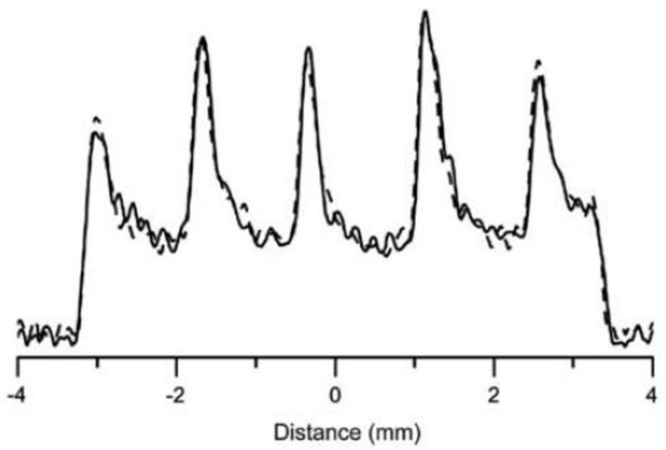


Figure 1: One-dimensional radial 1H (solid line) and 2H (dashed line) MRI signal intensity profiles depicting the relative volume density of protons in polymers and water in wood.

This method has a few disadvantages: one of them is a rather difficult sample preparation steps and the other is the size of the sample. Presented method provided surprising results with a sample that is only 6 mm long; the samples in dendrochronology are up to 50 centimetres in length and it could be only guessed what would happen with a sample many times larger than the one presented in this paper.

2.8. Terahertz pulse imaging

Jackson, Mourou, Labaune, Whitaker, Duling, Williamson, Lavier, Menu, Mourou

In 2009 a new popular method of scanning was researched for dendrochronological use by Jackson. His team presents innovative method in the field of non-destructive methods. Principles of terahertz pulse imaging are thoroughly researched only for about 20 years. [] This fact gives the standard non-destructive imaging methods advantage.

A principle of operation as described by Austrian Research Center for Non Destructive Testing (RECENDT)

1) A femtosecond laser emits very short laser pulses, which only last a few tens of femtoseconds (femto = a millionth of a billionth). The fs-laser pulses are divided by a beam splitter and are sent to [7]
2) a THz-emitter and a THz-detector, respectively, where they excite THz-radiation or are used for detecting the THz-pulse. In our case, the THz-emitter and THz-detector are photoconductive antennas, which consist of semiconductor material with a metallic antenna structure. [7]
3) A mechanical delay line introduces a variable time delay between excitation and detection of the THz-pulse, enabling time resolved sampling. [7]
4) The signal from the THz-detector needs to be amplified (using a current amplifier and a lock-in-amplifier), so that the very small THz-Pulse can be digitized and displayed on a computer. [7]
5) The THz-Pulse is transformed into a THz-spectrum by Fourier transformation (Fast Fourier transformation; FFT). The short duration of the pulse leads to a broad THz-spectrum, which can directly be used for spectroscopy. [7]

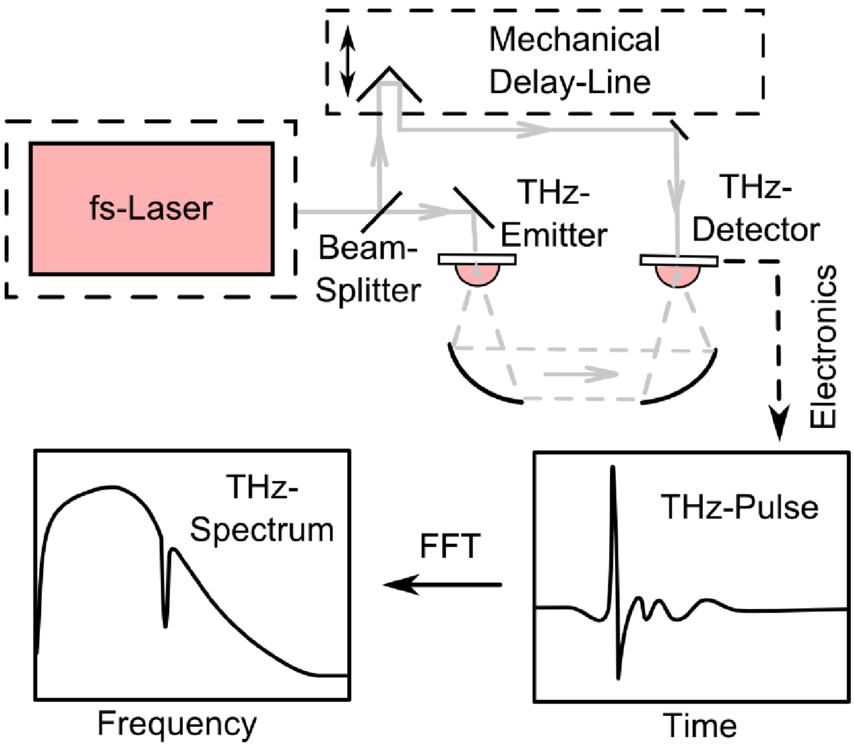


Figure 2 Schematic setup of THz-TDS-System [7]

Jackson’s team used Picometrix QA-1000 terahertz time-domain imaging system consisting of a femtosecond laser fibre-coupled to an XYZ-translatable, photoconductive and co-linear THz transceiver. The emitter and hyper-hemispheric silicon lens combination produces a slowly expanding, free-space terahertz beam, which partially transmits through a metalized pellicle and is focused with an aspheric lens (Numerical Aperture = 1) onto the sample plane at normal incidence. The reflected THz beam is collected by the same lens and partially reflected onto the photoconductive receiver, situated at 90° with respect to the THz emitter. One hundred waveforms were acquired per second, with 4 to 18 waveforms moving-averaged into a single pixel depending on sample area size. [8]

A comparison of image produced by THz imaging and photograph were conducted using CooRecorder 7 and CDendro 7 by CybisTM. It was found out that analysing shorter blocks of longer series is more precise than dating the whole sample in one scan.

Tests on walnut and pine were done with different sample preparation steps: varnished / unvarnished, application of primer and paint.

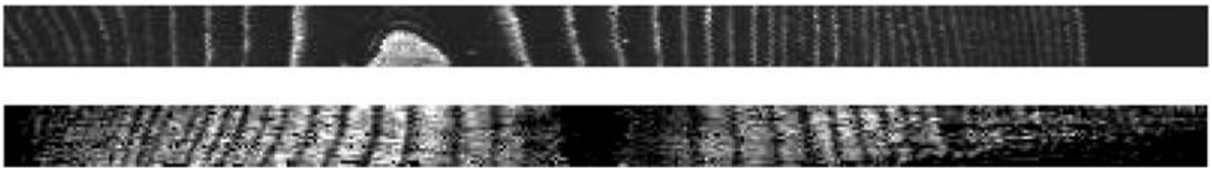


Figure 3 THz image samples upper unvarnished, lower varnished [8]

Jackson’s team researched a new method in the field of dendrochronology. It is expected that the first research does not usually bring a major breakthrough; in order to exploit all possible features that the THz imaging could bring more research is needed. It was pointed out that the direct measurement would be preferred rather than the analysis of THz output image even though the images of untreated samples were satisfactory, on the other hand, treated samples did not provide the required quality.

3. Measurement methods

All of the following methods apply to a prepared sample, if not stated otherwise in the given examples.

3.1. Laboratory measurement

Standard optometric measurement

The sample is put on a special measuring table with a shifting workspace, where all the movement is monitored and transferred into a computer. The accuracy still depends on the researcher: the researcher is looking in the microscope and moves with the sample and each time he passes over another ring, researches presses a button in order to register another new ring. The data in the form of the width of the rings are transformed into a series of numbers. Computer analyses the input series and compares them with the database consisting of all previously done measurements. Then the computer chooses the best possible match for the current sample.

Using this method also has advantages. Variable errors such as irregularities in tree ring formation due to climate or a fire can be detected and removed before contaminating the database, since current algorithms cannot detect and remove these errors.

The success rate of applying this method to different samples varies due to many factors. Even a careful handling may destroy some carbonized or soggy samples. The samples from warm or even temperate latitudes can have missed spring/summer rings which can lead to imprecise dating and false results. However even in these cases we can still determine location if set of examples had been researched and catalogued before.

The photos and CT scans have proven to be generally useful. Some conditions can cause a lack of appropriate quality or resolution. Onoe's device has one main positive: overall mobility -under given circumstances- highly exceed the major negative: the need for counting on two pictures. Attention needs to be paid in order to not mistake last counted ring for other one. This negative could be removed with the use of different algorithms for picture overlapping, producing a usable destruction free method for standing tree dating or with the usage of different technology.

3.2. Image processing methods

I have used data that is still relevant today; the researched period in software solutions is therefore from 1998 to present. Generally the programs could be sorted into two categories: image input and data input. Most of the papers revised in this thesis are the image input ones, as the researchers try to come up with a solution to different faults or problematics. Even though this chapter is named Image processing methods I mention the data input programs here, since the data is only a transformation of an actual scan of either image or sample of a tree ring series.

Conner, Schowengerdt, Munro, Hughes

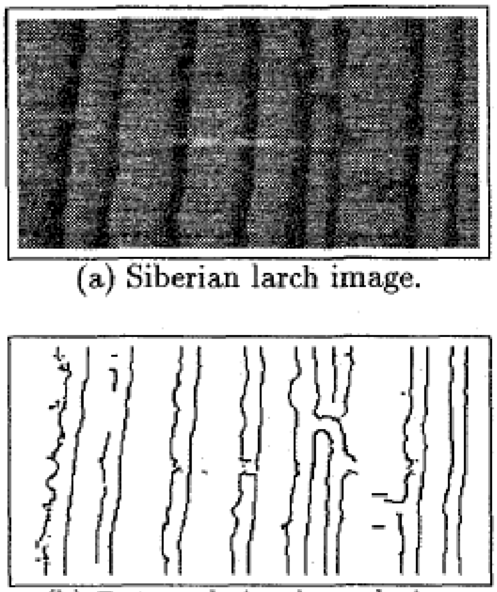
In 1998 Conner presented a tree ring dating system with a simple sample extraction. The system comprises digital camera mounted on microscope and positioning table.

Overlapping images are acquired from the center of the tree (the pith) to the outer edge (the bark). These images are normalized for any variation in camera gain during capture and are mosaicked together into a single sample image. A region of interest window then traverses the image data, detecting and measuring tree rings. Tree rings patterns are determined, and may be matched to another sample. [9]

It was pointed out that before ring detection, image frames must be mosaicked into a single image and gain adjustment must be done to normalize contrast between frames.
A certain amount of overlap must be ensured to match the frames by the overlapping edges. One of the approaches to mosaic a series is to pair them in the order they were taken by the analyst. [9] Output of frame–grabber camera must undergo a contrast adjustment to prevent appearance of false rings at the frame overlap.

For better tree rings detection their orientation must be known since the detection algorithm may confuse other features for tree rings causing faults.

Tree ring orientations are found by computing the gradient direction at each pixel location within a region of interest via a directional filter such as Sobel or Roberts, and quantizing the results into one of eight sectors. Then the gradient magnitude can be used to compute the average magnitude for each direction sector. The direction with the largest average magnitude corresponds to the orientation that has the highest probability of being the ring orientation in the region of interest. [9]



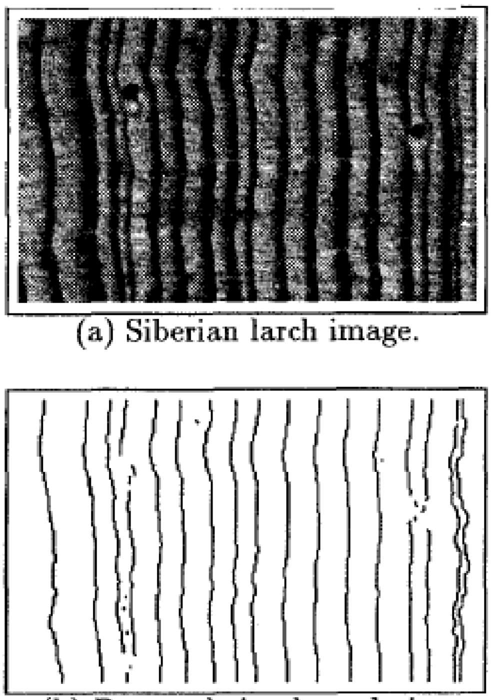
(a) Siberian larch image.

(b) Detected ring boundaries.

Figure 4 Input and output image (before/after applying Canny edge detector) [9]

Conner determined Canny edge detector as the best working for different types of wood. A simple Canny in the form of Gaussian smoothing filter was implemented. This detector however finds all the edges without considering the x/y axis and detects unwanted double edges and horizontal intra-ring connections. [9] In order to filter these unwanted edges, an optimization to detect vertical edges was implemented. [9] There are still some faults in the output image but major improvement has been done.

Even though the Enhanced Canny edge detector removed most of the faults, some remained; therefore, image post processing is required. A labeling algorithm was introduced in addition to size filter for removing fragments. The size filter could cause curved edges to be fragmented - this problem was removed by using robust linking technique.



(a) Siberian larch image.

(b) Detected ring boundaries.

Figure 5 Enhanced Canny edge detector [9]

Once the normal direction to a ring edge has been determined, the distance in this direction can be computed between the current ring and the ring next to it. The easiest way to compute this distance is to first travel along the two sector directions (Figure 6) that are closest to the normal direction at the current ring location, until the next ring is reached. The ring width at a given point is computed by interpolating the distance in the normal direction from the digitally measured distances. [9]

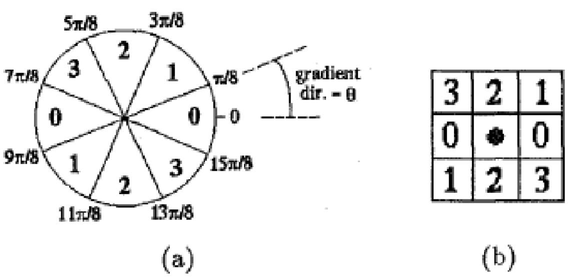


Figure 6 sector definitions for the Canny edge detector [9]

Carola Wenk

In 2003 Wenk described a standard procedure for comparing tree ring sequences. A filtration (standardization) process cleans the data from individual trends (thinner rings each year) after this standardization only general trends which occur in several tree ring sequences remain. Typically, high-pass filters such as the percentage of a five-year running mean or the logarithmic difference are used. In the sequel a tree ring sequence will thus be a standardized sequence of tree ring widths. [10]

Assuming that the trees built exactly one ring each year, a cross dating can be performed by sliding the undated sample sequence along the dated master sequence. At each position the distance (according to a predefined distance measure) between the overlapping parts of the sequences is computed and the position yielding the best distance is proposed as the correct dating position. The most common distance measures are the *t-value*. [10]
Since the data is very noisy it is usually not sufficient to simply date the sample sequence according to the crossing position.

If the sequence contains faults, most matching algorithms will not produce satisfying results since they do not take into account the transposition in time. Inconsistent samples (with faults) are usually split to smaller parts and measured individually (either manually or using Cofecha). Possible positions of missing or double rings are manually inserted. Cofecha is a quality control tool which checks a set of dated samples for mutual dating consistency by splitting up each sequence into small pieces and comparing these to the other sequences, producing a vast amount of data to be evaluated. [10]

Wenk also described two methods of space edition presented by other authors:

Van Deusen edit distance

The transformation space over which the simple edit distance is minimized includes in particular transformations containing many edit operations. Transformations like this correspond to paths in the computation matrix with many non-diagonal sections. Since a tree ring sequence usually contains only very few missing or double rings, Van Deusen [1989] reduced the transformation space by allowing only those paths in the matrix which stay inside a given strip of constant width around the diagonal. The width of a strip is given by a parameter α which denotes the width on each side of the diagonal. The in this way reduced transformation space contains only transformations in which the edit operations are locally balanced. Yet there are still transformations with many edit operations possible. For instance if the transformation sequence alternates between a merge and an insert operation the conforming transformation path still stays inside a strip of width 1 around the diagonal.[10]

α-edit distance

A straight forward improvement of Van Deusen edit distance is the following notion which we call *α-edit distance*. This type of edit distance has been proposed for strings by Sankoff and Kruskal [1983]. Since the number of edit operations (i.e. merges or inserts) contained in an optimal transformation should be small, the idea is to regard transformations and edit distances depending on the number of edit operations. [10]

Wenk structure for Cross dating algorithm:

Standardization of the master and the sample sequence

For all overlap positions of the sample in the master

Fill α-box

For all cells in the last row and last column of each level

Normalize edit distance

Compute optimal transformation

Store the distance, the transformation and the offset number in an overall result structure.

Sort all results in the result structure by decreasing normalized edit distance.
Display the best results (those with the smallest normalized edit distance).

However this algorithm was not successful as there was no definition of a distance measure known that correctly models the differences and similarities between tree ring sequences. [10]

Wenk presented heuristics that would be given a threshold (e.g. 10) for the minimum number of years between two opposite edit operations and 10 cells on the diagonal after an edit operation are marked so that the opposite edit operation is not allowed when calculating the edit distances for these cells. It was found that the simple comparison of all normalized edit distances (which means sorting them and taking the smallest as the best) proved not to be useful. At this point there were many edit operations that could compromise results; therefore an approach to minimize edit operations was taken by the means of improving the heuristics by conducting redundancy tests that removed edit distance operation. [10]

Another improved cross dating algorithm was presented:

Standardization of the master and the sample sequence:

For all overlap positions of the sample in the master

    Fill α-box

    For all cells in the last row and last column of each level

        Normalize edit distance

        Compute optimal transformation

        Redundancy check 1: Check with normalized edit distances on transformation path.

        If edit distance is not redundant:

            Store the distance, the t-value, the transformation and the offset number in an overall result structure.

Redundancy check 2: Remove inter-box-redundant results.

Sort all results in the result structure by decreasing t-value.

Display the best results (those with the highest t-values).

This enhanced algorithm was implemented in C++ and a few tests were run on previously dated samples with and without induced disturbances. The dating accuracy of undisturbed samples was 98% whereas samples with disturbances showed only 33%

accuracy [10] (since all the measurement are compared with a database where no random disturbances exist).

Katsuta, Takano, Okaniwa, Kumazawa

In the same year as Wenk's image processing method, Katsuta's team presented a paper dealing with laminated sedimentary rocks, however as the authors stated, the approach in the study may be applicable to other fields of study such as dendrochronology.

Katsuta presented a method of image processing to extract a sequential profile from a map showing a folded pattern of laminations with boudinage, overlapping noise and deficits in order to obtain reliable data for sequential analysis of sedimentary rocks on their cross-section.

The input is a digital photograph of any striped pattern such as rocks represented by 2D distribution of density with a certain resolution.

The image processing consists of several steps.

1) The distribution of local slopes (strike) of laminations is derived by means of statistical analysis of the first and the second spatial derivatives of the density map. Filtering of the local slopes leads to the elimination of noise amplified by differential operations. [11]

2) A set of curved isochronous lines is determined by integrating the local slopes to smoothly trace the local strikes of laminae. [11]

3) The original folded pattern of laminations is converted to an ‘‘unfolded image’’ with straight laminations by using the isochronous lines. [11]

4) A set of a reliable 1D sequential profile of density and its uncertainty profile are derived by computing the mean and variance of density along each of the isochronous lines on the unfolded pattern of laminations. [11]

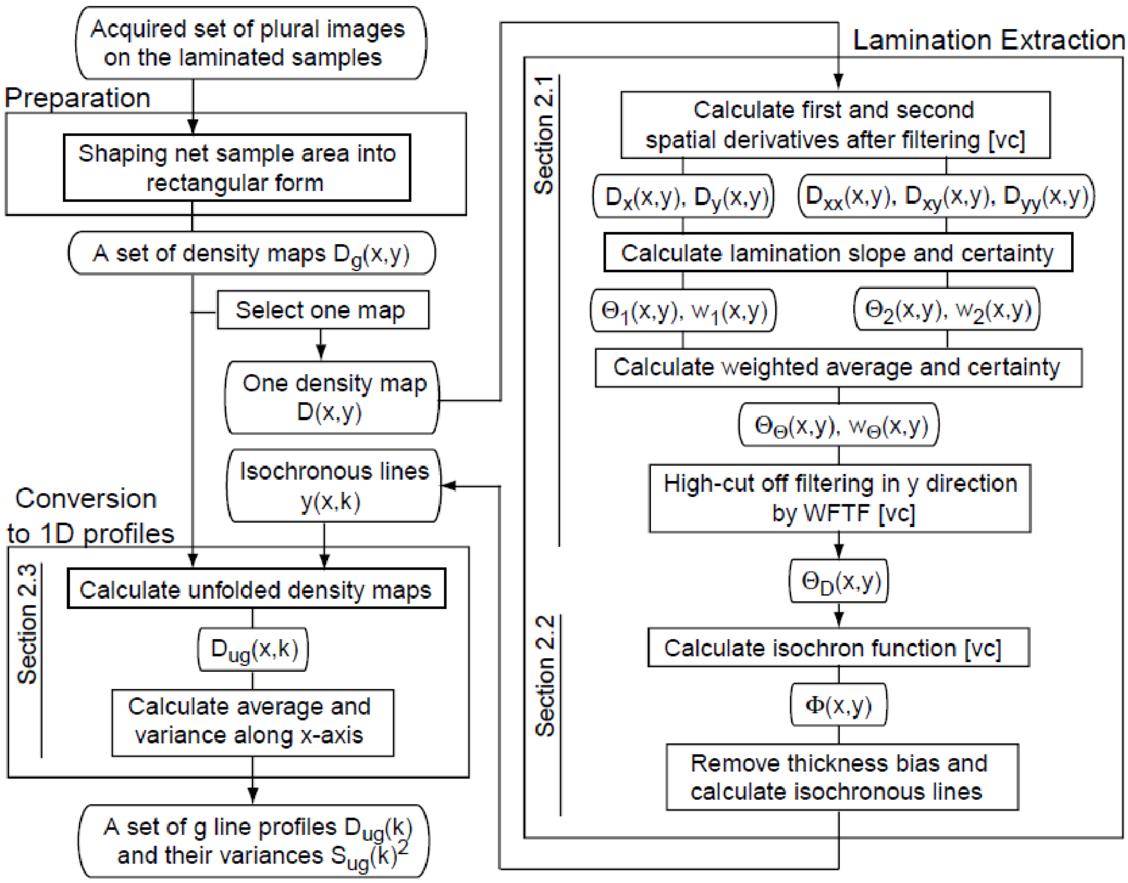


Figure 7 Flowchart of 'lamination tracer'. The preparation step is mostly to convert raw data image to a rectangular shape. The major step is lamination extraction, in which local trends of lamination are traced to obtain a set of isochronous lines, or curved coordinates to fit with curved laminations. Visual checks are necessary to select suitable the filter lengths. [11]

The computer code is tested successfully on the synthetic map data and applied to a set of abundance maps of major elements in an Archean banded iron formation to characterize the striped pattern. High resolution is achieved objectively to recognize even thin and faint seams in the laminations. The computer code, lamination tracer, is expected to be useful for the analysis of other types of laminated pattern in various fields such as dendrochronology and sequence stratigraphy. [11]

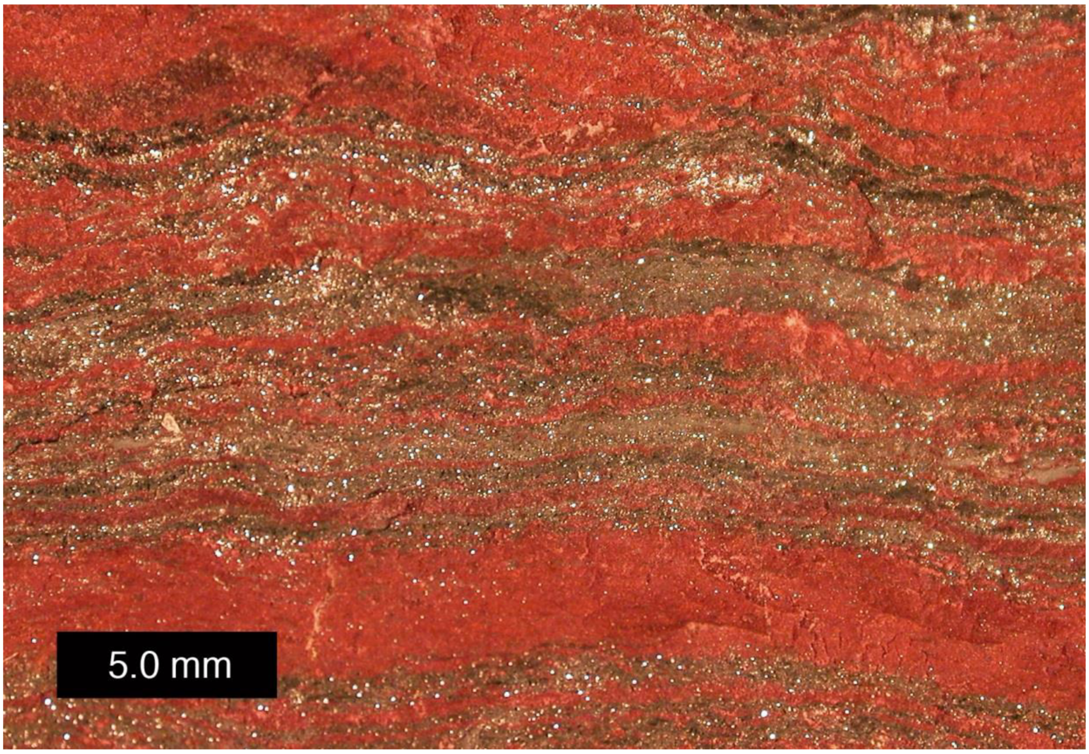


Figure 8 a sample of Branded Iron Formation [28]

The main goal of Katsuta's team was not only to simply introduce an image processing technique for shapely formed sedimentation lines, but for lines with deformations and abrupt patterns. In order to be able to analyze such a formation, an X-ray analytical microscope (SXAM) [11] was used in order to gain a sufficient image resolution and quality. The paper mostly deals with the sedimentation rock and conversion of irregular patterns on the basis of different element volumes which wouldn't work in the dendrochronology branch. A proposed structure would be to increase sensitivity in the detection of patterns with the different contrast.

Entacher, Planitzer & Uhl

In 2007 Entacher presented an image processing technique consisted of six stages, namely: pre-processing, skeletonization, post-processing, pith detection, profile creation and fusion into single profile.

Stage 1. The pre-processing consists of the noise reduction by applying a Gaussian pixel filtering with a 3x3 window. A local contrast enhancement function is applied; the Mexican hat operator is then used for edge detection. A new 5x5 window is created and the

Mexican hat operator computes the center pixel. Using 50% cut-off point step function converts the picture into black (background) and white (tree rings) image. Using a thinning algorithm reduces the errors caused by the variable tree ring width.

Stage 2. A skeletonization algorithm based on Zhang-Fu [12] algorithm improved by Steinfold [13] is used to remove small irregularities. A standard Zhang-Fu algorithm is applied and finally the image is post-processed by Holt [14] procedure.

Stage 3. The task of the post-processing stage is to skeletonize the image that no tree ring fragments and artifacts that might be misidentified as independent tree rings by the ring profile creation [15] meaning all the twigs are removed by scanning and removing the undesirable curves. The tree ring fragments are removed, if the measured length in both directions along the curve is smaller than a user provided threshold, then the curve is considered a tree ring fragment and deleted from the image. [15]

Stage 4. In order to find the pith, gradients are computed and accumulated. A barycenter of all accumulator cells is computed in practice since various errors in gradient computation may occur.

Stage 5. A tree ring profile is generated by scanning pixels along a straight line starting outside the bounding box of the tree ring image and going in the direction of the pith using the Bresenham line algorithm. Scanning process must use a 2x1 or a 1x2 window, depending on whether the scan line is predominant along the x or the y axis, as otherwise we might step through a tree ring without recognizing it since we do not hit any of the ring pixels directly. [15] A transition from a black pixel to a white pixel is then considered a tree ring and the distance is measured in the pixels as well. The distance between the two rings must not be greater than the provided threshold. More than one profile can be created if the image is rotated.

Stage 6. A single profile is created by averaging of the normalized widths of all the profiles. It must be noted that different profiles might have different rings missing and the program must be kept from creating a new ring, deleting a ring and merging two existent rings into one via setting an appropriate threshold of the distances between rings.

The name of the paper was quite confusing because it indicated a general approach to tree-ring detection software; however, the paper was only about creating a new standalone program.

Bunn

In 2008, Bunn presented a paper with a new software package in the R statistical programing environment for dendrochronology that uses decadal-format data as input information. A discussion with my supervisor pointed out that there is a need to detrend data series because of lags in data processing units of the scanners. [16]

Bunn claimed that the raw ring-width data can be detrended interactively. Either one series at a time or all at once, where the user chooses the best method. The second method is useful to ensure replication. There are three standard detrending methods: a modified negative exponential curve, cubic smoothing spline, or a horizontal line. Cook et al (1990) and Fritts (2001). Results can be seen in Appendix 1 with a different level of success.

The program can also build a mean value chronology either by averaging each year's RWI (ring-width indices) using the arithmetic mean or using Tukey's biweight robust mean which minimizes the effects of outliers. Prewhitened chronologies can also be built where autocorrelation is removed from each series before averaging using the R function ar. The prewhitening is performed by fitting an autoregressive model to the data where the complexity of the model is selected by Akaike's information criterion (Venables and Ripley, 2002).[16]

Bunn's work offers no concluding part but presents lot information about usage of the presented program and its code for the R programing language.

Lyubenova, Chikalanov

In 2008, Lyubenova presented a paper in closely specified field: a mathematical approach for analysing the stress periods of trees.

Created software, SP-PAM, uses following parameters: interval, cardinality (Card), coverage (Co, %), average duration, frequency, amplitude, alpha, standard deviation and confidence.

The implemented software application facilitates discovering the most common SPs from the samples supplied by their statistical analyses. Data on SPs is obtained through analysing of 121 dendrochronological samples. Dating is done using software COFECHA. [17]

The mathematical approach is applied to statistics about tree ring formation and results are transformed to useful data for enhancing SP-PAM abilities.

The main functions of the proposed software are: generalizing of stress periods of random sample; statistical analysis on common stress periods; analysis of common stress periods characteristics. These analyses can facilitate to determine the tendencies in the forest ecosystem development. [17]

It was clear that the paper deals with problems of research on stress periods in different scientific branch than dendrochronology and arguments about quality and validity of gained data in comparison to known facts. The software was built on mathematical statistics which were the basis of this program. It is important to realize that in order to be able to produce a program with certain degree of quality an abundance of data must be processed in order to have the slightest possible faults in the eventual automated process.

Chanwimaluang, Siricharoenchai, Sunpetniyom, Sinthupinyo

In the same year, Chanwimaluang presented a tree-ring mark detection program for tress with poorly recognizable tree-rings.

First, Anisotropic diffusion technique is employed to enhance boundaries, and at the same time, try to eliminate noise and wood patterns. Then, strong edges are detected by using Canny method. Next, convolutional kernels are applied to extract horizontally-inclined lines. Subsequently, connected component labeling is used to get rid of the remaining noise. After that, mathematical manipulation is exploited to get the tree ring marks. With the conventional low-pass filter and linear diffusion, the price paid for eliminating the noise and for performing scale space is the blurring of edges. Hence, we employ the anisotropic diffusion technique proposed by Perona and Malik. The multi-scale method was brought in by Rosenfeld and Thurston. Then, the scale-space filtering idea was introduced by Witkin. Later, the formalism of the problem was further developed by Koenderink, Babaud, Duda, and Witkin, and Hummel. [18]

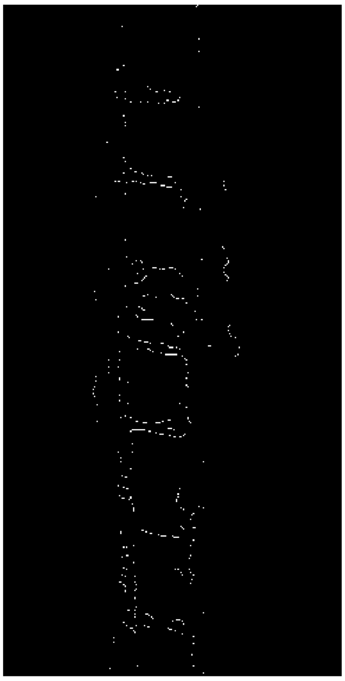


Figure 9 result of image processing [18]

Figure 11 first stage of superimposing [18]

Figure 10 final superimposed structure [18]

The researchers claim 80% accuracy with 12 test samples. From the Figure 3 it can be determined that the sample was a photo of a sample extracted by the increment borer. Chanwimaluang and his team were focused solely on the ring detection and no tree-ring counting method was presented in the research.

Popov

Popov presented a mathematical model in 2012 that deals with calculation of an azimuth and root-mean-square width of annual tree rings maximum growth area, width indexes calculation of annual rings of trees growth, assessment of environment. [19]
In order to be able to produce such a model they considered various environmental parameters such as dynamics of climatic trends, anthropogenous factors, and dynamics of ecosystem changes and so on.

They claimed that the two-dimensional analysis of disks is not fully applied in modern techniques even in such area as dendrochronology because it doesn't have the sufficient algorithmic and program support and it supposes the processing of a large amount of data collected in geographically distributed places. [19] It was possible to fix anisotropy of a radial tree growth by the means of the distributed calculations.

Popov divided their method into six steps, where a researcher handles the first two and the following four are automatic.

Step 1. The researcher specifies the initial approach of the tree annual rings borders (piecewise linear function) on the entrance function of growth. [19]
Step 2. The target function of growth is a subtraction of piecewise linear function values from the corresponding entrance function. Thus, the target function of growth gains positive and negative values according to which the annual rings borders are determined. The positive values of this function (rings of light color and of smaller wood density) correspond to a summer growth, and the negative (rings of dark color and of bigger wood density – to winter growth. [19]
Step 3. The difference between values of the previous and the subsequent (next) entrance functions of growth (discriminant) is calculated. [19]
Step 4. To create the subsequent piecewise linear function the discriminant calculated at the previous step is subtracted from the value of the previous piecewise linear function. [4]
Step 5. The piecewise linear function constructed at the previous step is smoothed by the polynomial function. [19]
Step 6. The target function of growth is a subtraction of the smoothed piecewise linear function values from the corresponding entrance function. [19]

After applying these steps, a two-dimensional analysis, calculation of azimuth and root-mean-square width of tree rings of output images is done in three stages:

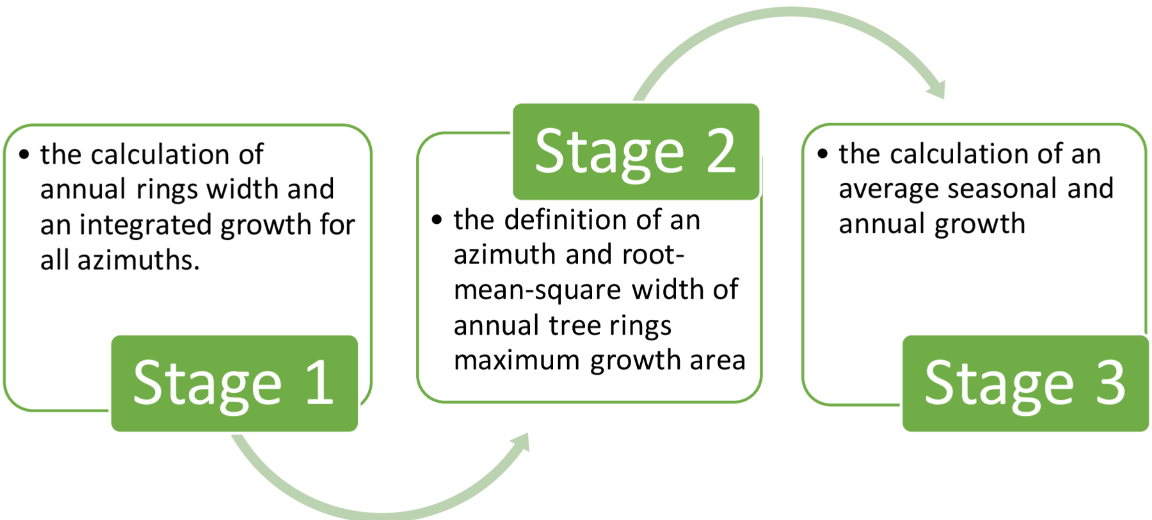


Figure 12 Stages of root-mean-square process [19]

Bunn, Jansma, Korpela, Westfall, Baldwin

In 2013 Bunn presented a paper which dealing with mean sensitivity that was conceived as a statistic, which would indicate whether or not a series was useful for cross dating or responsive to climate.

By the means of examining and processing 500 previously dated samples from database, researchers managed to produce results that they were expecting – the use of mean sensitivity in dendrochronology should be avoided for at least two reasons. [20] Firstly the mean sensitivity is confusing and ambiguous statistic for describing the variations in tree growth; secondly values are often interpreted as reflecting the influence of growth limiting phenomena, which ignores the dependency of mean sensitivity upon the variance of the biological variable that is studied. [20]

This research 'reinvents' something that has been already known but not researched as thoroughly as in this paper, the abstract of this paper acknowledged this in the first place. This study was probably conducted because the trend of using mean sensitivity was on the rise.

Sundari and Kumar

In 2014, Sundari and Kumar described an experimental method using image-processing techniques in the dendroclimatological research.

Describing that the modern techniques applied for the two-dimensional analysis are not sufficient in some areas like dendrochronology, because it does not have the sufficient algorithmic and program support for processing the tree rings. [21] With respect to the dendrochronological research, a V. N. Popov mathematical model of a radial section of annual rings described as section of annual rings that can be presented as the sum of noises and the pro-modulated valid fluctuation [19] was used.

It was mentioned that there are many models but without sufficient algorithms for implementing the models, for many aspects, which were described as overlapping rings, large crack, false ring etc. [21] The method was described as a detection of the tree rings in five steps, which are input image, image filtering, edge detection, delineating and output image. [21]

The procedure is dependent on the quality of the pictures, in the beginning they used photographs, yet for the quality, the time and the price requirements CT scans started to be used for the first step. In the second step, a Gaussian-filtering method was used in order to get a smooth greyscale picture. Third step was about an edge detection. The sobel operator was used because it emphasizes the high spatial frequency region that correspond the edges of the images. In the following step, the edge points provided by the sobel operator were combined into edge chains. This step was described as necessary because there may be discontinuity in the boundary due to cracks in the image. In the final step, a circular closed active contour algorithm (snake) defined as a parametric curve which moves itself into a position where its energy is minimized [21] was used.

The resulting image consisted of a set of white circles, where the center needed to be find. Finally, density of the rings could be calculated and age could be predicted.

3.3. Field methods

Magnifying glass

Using a special magnifying glass with a built-it light can be used for counting the rings in the field conditions. This method still requires a sawn sample with clearly visible tree rings. This method can be used outside the laboratory, yet the results will be only informative in the field conditions, since you cannot measure the width accurately and produce viable data.

The magnifying glass is also used as laboratory equipment for a simple ring counting. [1]

Portable scanner

WinDENDRO LC4800P offers a portable scanning version. Scanning surface of 21.6x28 cm gives sufficient size for most of the samples. The scanner must have a computer with a graphic display and an interface. A whole sample can be scanned. For improved performance only a small part of the sample is recommended to be scan. The tree rings are then recognized interactively with the help of the interface and graphic display. [22] This is description of portable version of WinDENDRO, however, the software is usually used in laboratories on desktop computers.

3.4. Wiggle-Match Dating

Wiggle-Match Dating is a non-standard radiocarbon technique, where the non-linear relationship between the ^{14}C age and the calendar age is used. This method is not as useful to the dendrochronology as it may seem, since the dating is very imprecise.

A brief explanation to whole problematic is introduced in 2004 by Galimberti:

Given the non-monotonic form of the radiocarbon calibration curve, the precision of single ^{14}C dates on the calendar timescale will always be limited. A possible way to overcome this limitation is through comparison of time-series, which should exhibit the same irregular patterning as the calibration curve. This approach can be employed where the tree-ring series of an unknown date can be compared against the similarly constructed 14C calibration curve built from known-age wood. This process of curve fitting is called 'wiggle-matching'. [23]

Other problems of wiggle match dating is addressed in 2007 by Nakamura:

This method is based on measuring ^{14}C (radiocarbon) in samples in Japan. Similar method has already been applied in Europe and America. The machine placed at Nagoya University (Tandetron accelerator mass spectrometer) has been calibrated according to data from European and American measurements. Researchers indicated that calibration could be a possible liability, since amount of carbon in Japan trees tend to be higher. [24] Another liability is uneven distribution of 14C carrier CO_2 in the atmosphere.

Nakamura's work is aimed to historical dating (archeology) much more than to dendrochronology; most of the text is concerned about validity of the values. The results produced by such a method might be valuable for determining unknown historical samples. In the field of dendrochronology, this measurement is only partially valid since it does not bring precise information although it could possibly help the researcher to assign the sample with similar pattern. The exact dating is still not an option since the dates are given with a possible fault range of 28-37 years.

A description of sample preparation method is borrowed from Santos, since previous papers presented excessively long explanation with the same basics.

Extractives and the lignin from the original wood samples were removed by a holocellulose extraction procedure carried out on subsamples of 10 - 20 mg placed into 13 mm culture tubes. Wood aliquots were initially subjected to an acid-base-acid (ABA) pretreatment at 70 °C with 1 N HCl for 30 min, 1 N NaOH for 60 min (the bath solution was repeated until supernatant was clear). Followed by 1 N HCl for another 30 min. Holocellulose was isolated using equal volumes of 1 N HCl and 1 M NaClO2 at 70 °C in a fume hood for approximately 4 h, or until the yellow/golden color subsided. After bleaching, the holocellulose was rinsed with warm Milli-Q water (70 °C/30 min) until pH >six. Samples were dried at 50 °C for several hours on a heat block, and the tubes were capped with gastight closures prior to undergoing combustion and graphitization for ^{14}C analysis. Samples were loaded into pre-baked quartz tubes with Ag wire and 60 mg CuO in preparation for combustion offline, then evacuated, sealed, and baked at 900 °C for 3 h. The CO2 was cryogenically cleaned and reduced to graphite in the presence of H2 at 550 °C on pre-reduced Fe powder following established protocols. Graphite samples were pressed into Al targets and placed in the sputter ion source for measurement. [25]

In this case AMS system NEC 0.5 MV 1.5SDH-1, with a fast beam switcher for sequential injection of ^{12}C, ^{13}C, and ^{14}C was used. [25]

The revision stops here since the aim of the work is aimed to the improvement of local calibration curves for the given location. The main reason this article was presented here was to compare the sample preparation method to other 'conventional' methods, the measurement methods will not be presented either since none of the papers described extraction of the results by the AMS machine; in other words: the researchers were 'only' users of AMS systems.

3.5. Other work

Henri Grissino-Mayer gives a brief explanation of 26 software applications related to tree-ring dating science. One of the programs is the Bunn's dendrochronology program library in R (dplR) [16] which is also briefly described in this paper.

WinDENDRO was already presented as a mobile solution for dendrochronological research. Definition of the software is given by Grissino-Mayer, it is presented in this work as it is one of the most popular and mostly used within the Czech universities.

Without a doubt, this suite of programs, written by Richard L. Holmes, Edward R. Cook, and Paul J. Krusic, has had a great impact on the way the dendrochronological community analyzes tree-ring data. Routines are provided to edit tree-ring data, change formats, verify reconstructions, read or create files in spreadsheet formats, and estimate missing climate or tree-ring data. To make downloading an easier process, I provide links directly to the individual zipped files. [26]

Freeware licensed software ImageJ must also be mentioned, specifically a plugin named ObjectJ which may serve for dendrochronological research. This software was unsuccessfully tested at Mendel University.

In 2011 Brewer, Marty and Jansma presented a paper with Supplementary Materials: Dendro Data Formats [27] which was a summary of data formats used in dendrochronology where 21 data formats were presented. Brewer's created software named Tricycle that could be used to convert data from one format to another.

Conclusion

My thesis deals with the current dendrochronological research activities and progress. In the process of researching the subject I have read through several research papers and gained a certain idea of where is the dendrochronological research aimed. I was fortunately able to visit two different universities dealing with the dendrochronology and my point of view changed permanently. The papers reviewed in my thesis surely presented new approaches to specific problems but the researchers in actual laboratories deal with these problems for quite a long time in the same manner. When another new paper presents a new approach about how to deal with a certain problem, the researcher reads the paper to keep in touch with the current notions and go back to his microscope since it is the most reliable approach to the dendrochronology yet.

The main disadvantage of the software implementations is the lack of sufficiently advanced self-learning algorithm that could be able to process randomly occurring mistakes without faults. The researchers in laboratories are able to recognize faults in tree ring formations, since thy have the precise idea of a standard tree ring formation and they can apply it to any sample they receive, therefore, they are able to recognize any fault that occurs in the formation and handle it in proper way. If you want to use software to do this you have to use samples with certain properties or a program that can correctly date a sample with presented fault in tree ring formation.

If we compare steps required to produce a dated tree series, the software process usually comprises more steps than the direct optic method. The sample preparation steps for software dating are: a sample acquisition –photo, CT scan, X-ray scan– where the quality may vary, then a certain edge detecting algorithm is presented –quality of tree ring detection may vary– and finally a dating can start with a certain accuracy and fault. It can be seen that the quality requirements occur in two steps and all of this is even topped with the accuracy of the final step. Even though program such as WinDENDRO use graphical interface where you can adjust the automatically detected rings; the time required to prepare, scan and adjust the sample is about the same for standard samples, or even more time is required if the sample exhibits some kind of deformations.

On the other hand, researchers use samples from increment borer which he/she treats with sandpaper, glue it to sample holder -usually there are more samples to be dated so when the researcher stops gluing the first sample is already dry- and start dating. It can be seen that there is only one factor that involves quality – the accuracy of the researcher.

Presented sample acquisition techniques have different uses; we can use photos, X-ray, CT or terahertz images for direct counting. However the X-ray seems to be quite dependent on the quality of the sample [2] but if the sample has high quality the X-rays presents quite cheap way to produce high quality images, CT scanner has a problem with the absorbed water [4] only dried samples or more than one image must be taken and overlapped to produce the whole image. On one hand MRI surely presents interesting results, on the other hand the preparation steps are rather exclusive [6]. THz imaging presents new method in the field of dendrochronology yet the main disadvantage of the modern machines in given field remains - the sample cannot be larger than few tens of centimetres. The drilled sample presents the most used technique today with minimum destructive impact on environment; surely it cannot be used on the archaeological samples; in these cases CT or X-ray techniques are advised. Photography is probably the cheapest method of acquiring a sample one of the advantages is that the photography can take larger samples at once; the only disadvantage is that the sample must be a sawn or drilled.

The software implementation problematics presented in this thesis can be generally divided to two categories: according to processed sample (image of a sawn log / data series) and spectrum of the research (whole / narrow). If we divide the software according to input we see that majority of the presented work are dealing with the image processing rather than with data series input. The second group is more valuable from the dendrochronologist point of view since it can address more specific problematics. The development of the general dating software is certainly continuous which shows the presented papers. [9, 10, 15, 21] The research in narrow spectre is also intensive [11, 17, 18], this research intensely helps the progress of general software since the presented work can be implemented in programs and the overall accuracy of dating can be increased.

Even though I wrote that the human is usually the most inaccurate step in any process; I conclude that the direct measuring method will be the best for at least a few years yet. However, the new technology may bring a fully automated tree ring detection unit that could be capable to produce results matching the human ones in a few decades.

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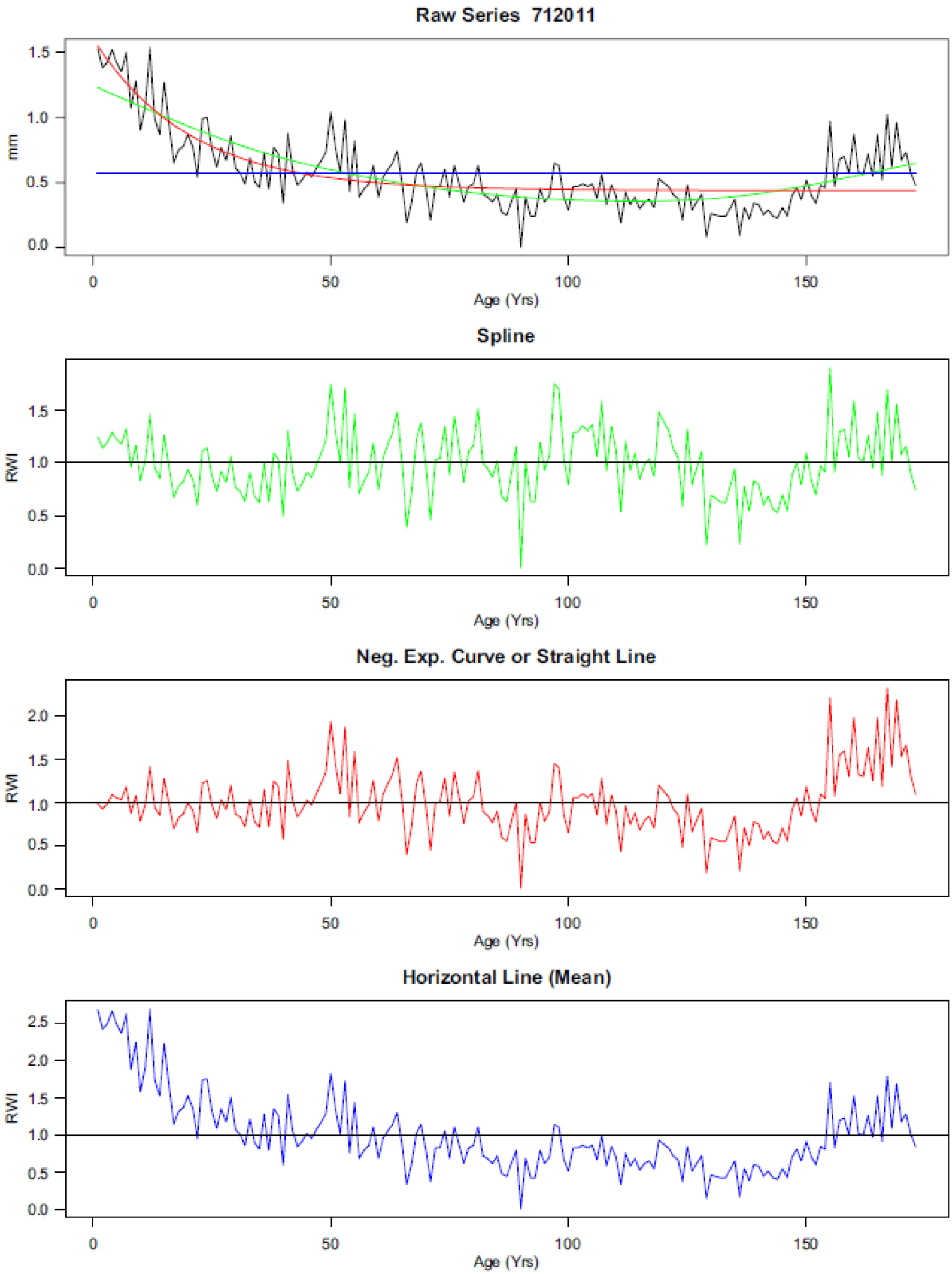
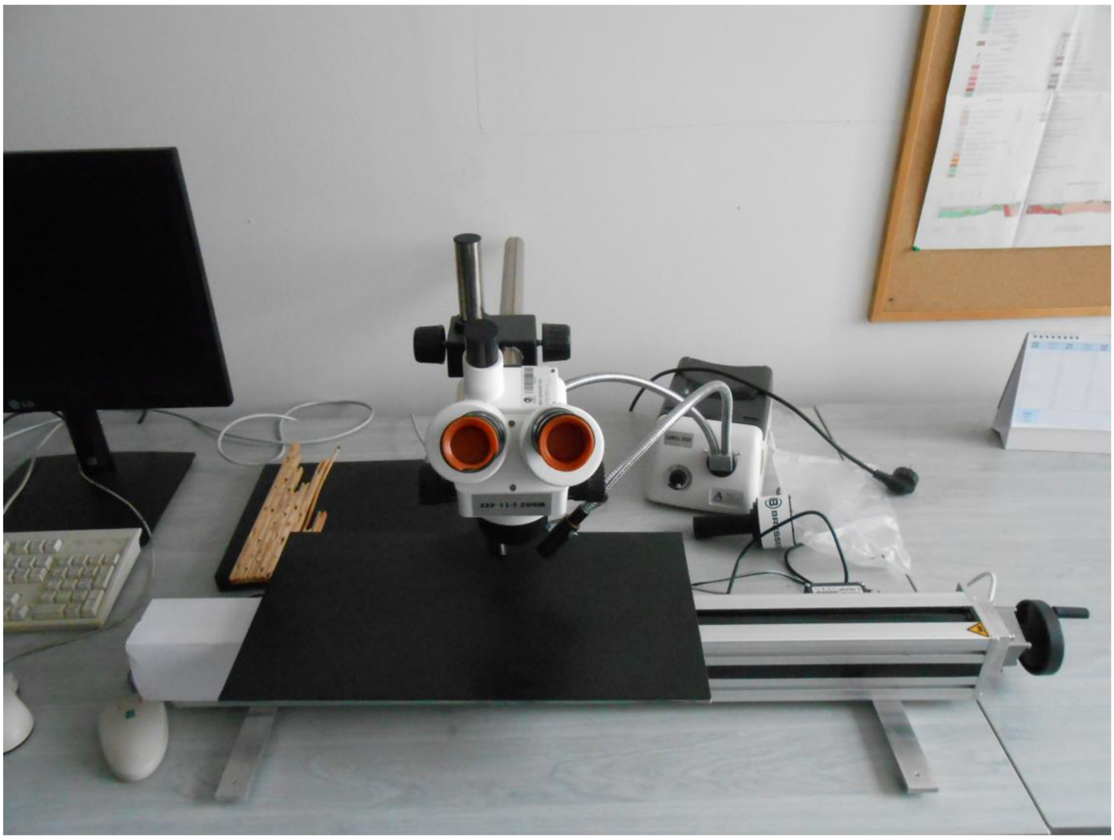
A. Appendix



Appendix 1 Examples of detrending according to Bunn 2008

Appendix 2 Dendrochronological station at Mendel University in Brno

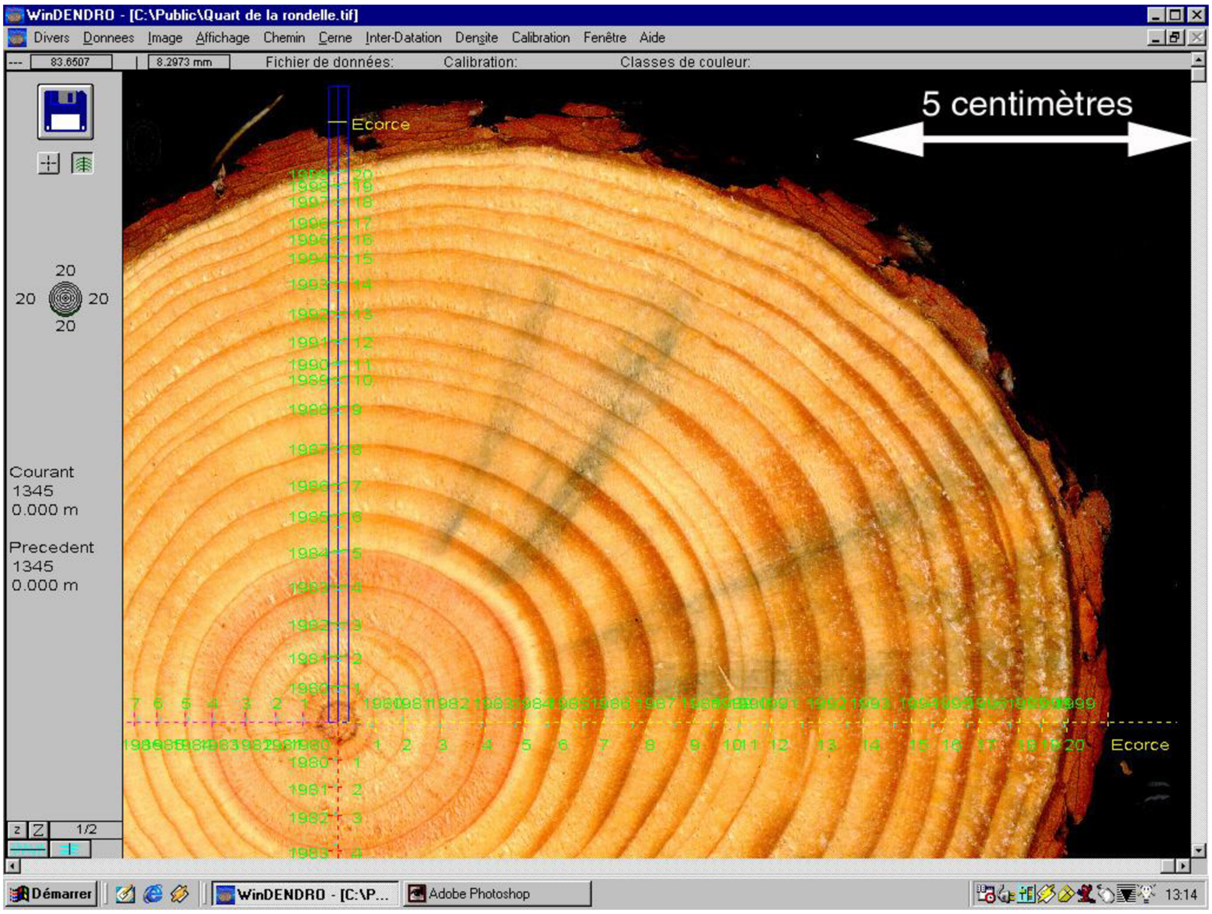


Appendix 3 Dendrochronological station at University of Ostrava

Appendix 4 Microscope calibration device

Appendix 5 ‘Raw’ sample

Appendix 6 Sample treated with sandpaper



Appendix 7 WinDENDRO screenshot of working interface