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RESEARCH REPORT

ATRICS – A NEW SYSTEM FOR IMAGE ACQUISITION IN DENDROCHRONOLOGY

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ABSTRACT

We developed a new system for image acquisition in dendrochronology called ATRICS. The new system was compared with existing measurement methods. Images derived from the ATRICS program and processed in any of the available programs for automatic tree-ring recognition are of much higher detail than those from flatbed scanners, as optical magnification has many advantages over digital magnification (especially in areas with extremely narrow tree rings). The quality of stitching was tested using visual assessment - no blurred areas were detected between adjacent images and no tree rings were missing because of the stitching procedure. A test for distortion showed no differences between the original and captured square, indicating that the captured images are distortion free. Differences between manual and automatic measurement are statistically insignificant. The processing of very long cores also poses no problems.

Keywords: dendrochronology, measuring techniques, image acquisition, image analysis.

INTRODUCTION

Measuring tree-ring widths by hand is a tedious and challenging task involving routine work and years of experience. The importance of "*careful measurement*" where "*accuracy still depends on the operator*" has been stressed by many authors (Fritts 1976; Schweingruber 1983; Stokes and Smiley 1996). From the professional point of view, hand measuring is hard to repeat and re-checking often consists of re-measuring the same sample. The main disadvantage of this is that the same mistake can be repeated (*i.e.* deciding whether a particular ring is false or real). One must often re-examine a sample to check whether the decision to select a certain ring boundary was right or wrong. This is especially true when working with long sequences of very narrow tree rings. In such situations re-measuring the entire sample is often necessary. Having a system to facilitate this important step in dendrochronological work is highly desirable.

Many researchers are already using images from flatbed scanners for automatic recognition of conifer tree rings in systems such as WinDENDRO from Régent Instruments (Guay *et al.* 1992), or LignoVision from RINNTECH (Frank Rinn Engineering & Distribution, Bierhelder Weg 20, D-69126 Heidelberg, Germany, http://www.rinntech.com/). We found this combination suitable for fast growing trees and samples in which the tree rings are not too narrow. However, in several cases we needed to measure very narrow tree rings (sometimes 4–5 cells wide) where the scanner resolution is pushed to its limits, producing an image unsatisfactory for reliable tree-ring recognition. In such cases we observed that digital magnification is no match for optical magnification. Theoretically, a scanner with an optical resolution of 4800 dpi should produce images with a pixel size of around 5 μm, so that one might suppose that their images were of comparable resolution to those produced by cameras mounted

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on microscopes. However, in practice a good stereo microscope will yield a much clearer image, and this can be critical for resolving subtle ambiguities of wood anatomy, such as false or micro rings (particularly when combined with the higher optical magnifications available on the microscope). To overcome this problem, we developed a new system that would replace flatbed-scanned and digitally magnified images with optically magnified, stitched images from a high-resolution digital video camera attached to a high quality stereo microscope. Such high quality images can be further processed in any tree-ring recognition program that is able to read TIFF files. We call this new image-capturing system, **ATRICS** (**A**dvanced **T**ree-**R**ing **I**mage **C**apturing **S**ystem) and present its potential as a digital replacement for existing, manually operated, tree-ring measuring systems.

CONSTRUCTION DETAILS

Hardware

Our system is made of parts available on the market; nothing was developed solely for this device. It has three components, 1) a motorized stage (minimum precision 0.01 mm) with a controlling unit, 2) a stereo microscope with a high-resolution, real-time, digital video camera with 1.3 million pixels, equipped with a polarized light source, and 3) a fast computer with at least 2 Gbytes of RAM, 350 Gbytes storage, graphics card, IEEE-1394 and an RS-232 connector to connect the controlling unit of the motorized stage (Figure 1, Table 1). The cost of the system, including software, providing that one already has a stereo microscope and light source, is between 6000 and 7000 USD.

Software

The basic function of the ATRICS program (see Figure 2) is to capture images with a digital video camera, save the images, move the measuring stage one step and repeat these three tasks until the whole sample is scanned. The ATRICS program also controls the camera's gamma, white balance, color, exposure and gain. In addition, it controls the motorized stage's movement, the stage's total travel distance, image overlap and image file manipulation, which includes file generation, naming and saving.

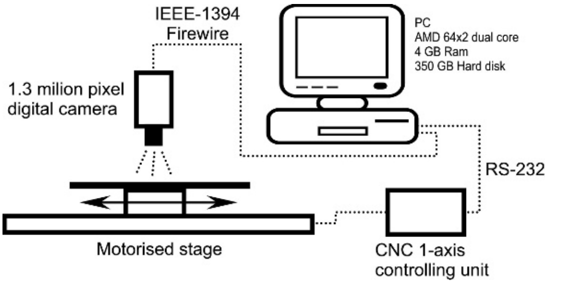

Figure 1. The ATRICS system.

The program also displays a live feed of the sample being processed in a separate window (Figure 3). Consistent magnification is maintained throughout the capturing process, although the magnification can be changed if necessary to increase the resolution of very narrow rings. Equal sharpness of the images is attained with careful preparation of the samples in the workshop. All cores are placed in wooden holders and sanded using sand paper of increasingly fine grade (180–360–500 or 600). A specially designed stage is used to maintain constant distance between the lens and the surface of the sample.

Captured images are stored in bitmap format (BMP). The first image always contains a calibration square, which is later used for calibrating measurement parameters by the image analysis software that automatically detects and measures ring widths. The ATRICS program also generates a command file for the batch mode of PanaVue ImageAssembler 3 – Enterprise edition, which stitches the many captured images into a single large image.

Depending on the length of the sample, many individual frames may be necessary, resulting in a single 24-bit image up to 40,000 × 2,500 pixels large. Image stitching is thus a very demanding procedure and this is why a powerful processor is required to stitch all the images together in a reasonable time. One core-sample image, made out of many small high-resolution images, can be between 80 and 150 Mbytes. The final image is stored in a non-compressed TIFF format and its quality can always be improved in commercially available

Table 1. Description of main modules of the ATRICS system.

Item	Main Characteristics	Producer
Motorized stage	Model LES 2 (1000 mm long version). A stepper motor and ball screw drive position a 125 × 65 mm platform equipped with linear ball bearing tracks along paired aluminum guides with an accuracy of ± 0.01 mm	www.iselautomation.de
1-axis stepper motor controller	Stepper motor controller, model IT-116G with programming software, connected via RS-232 to computer	www.iselautomation.de
Stereo microscope	Standard Olympus zoom stereo microscope SZ60 used in life sciences, it must be equipped with C-mount to attach a digital video camera	www.olympus.com
Light source	Volpi, strong and high quality light source, 150W/21V with constant color temperature, diaphragm for light adjustment and illumination intensity at approx. 12.3 Mlx	www.volpi.ch
Ringlight	Volpi, diameter 66 mm, length 750 mm with active fiber bundle 9.2 mm in diameter, art.no. 10530.000	www.volpi.ch
Polarizing filter set	VOLPI, art.no. 27770.000 – consisting of polarizer and analyzer for 66 mm ringlight	www.volpi.ch
Digital video camera	PixeLINK PL-A662 kit, real time uncompressed video and or digital image acquisition, color, resolution 1,280 × 1,024 pixels, ½″ CMOS, 8 or 10 bit depth, fast connection with computer via IEEE-1394 FireWire card. Comparing to CCD sensors, CMOS sensors are cheaper to produce and use less power, although the light sensitivity of the CMOS sensor tends to be lower comparing to CCD. However, when there is a very bright object in the scene the CCD may bleed, causing vertical stripes below and above the object (so called smear).	www.pixelink.com
Software Development Kit	The PixeLINK SDK provided the drivers and application programming interface that custom C++ programs need to control the camera.	www.pixelink.com
Image stitching software	PanaVUE Image assembler 3 – Enterprise edition, can stitch very large images, works in a command line mode and has support for batch processing (only Enterprise edition has support for batch processing).	www.panavue.com
Microsoft Visual C++.net programming environment	Main programming environment	www.microsoft.com

image-processing software. Alternatively, JPEG format could be used because of its ability to compress image information, resulting in a smaller file. However, the lossy compression algorithm used in JPEG format would degrade image quality and make it less suitable for image analysis.

It is necessary to stress that ATRICS has no automatic ring recognition features; its only task is to provide high-quality images to commercially available systems for tree-ring recognition such as WinDENDRO, LignoVision or others. As such, it is also not designed for analysis of different tree-ring features such as EW/LW measurements, blue reflectance (McCarroll *et al.* 2002), tree-ring density (see Schweingruber *et al.* 1978) and so on. All such measurements can be done in commercially available systems with images produced in ATRICS.

IMAGE STITCHING PROCEDURE

The PanaVue ImageAssembler 3 – Enterprise Edition program handles the image stitching. We did not expect image stitching with a commercially available program to be a major issue. However, it turned out that the software's default settings were inadequate and some fine-tuning was necessary. The biggest problem with the default settings was

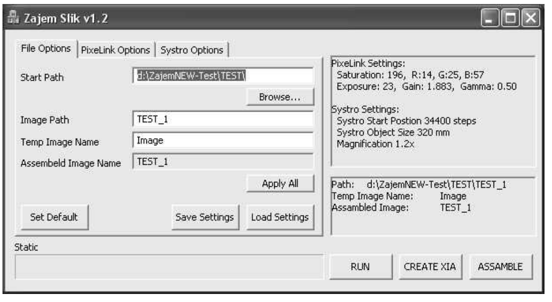

Figure 2. Example of an ATRICS main screen. All functions of the program can be controlled in three different tabs. The ''File Options'' tab is used to set different file manipulation parameters (*e.g.* file locations, naming, directory, *etc.*); the ''PixeLink Options'' tab is used to control digital camera parameters such as color mixture, gamma, exposure, *etc.*; the ''Systro Options'' is a tab for controlling the motorized stage's parameters.

they did not provide adequate overlap of the stitched images (Figure 4a). Overlap in the capturing procedure within ATRICS was set to 10%. We tried different overlap percentages within the ImageAssembler (from 8–25%) and found that 25% is the best setting of overlap percentage to create the most seamless image. The final image is created after optimization and fine-tuning of the image stitching parameters (Figure 4b).

Based on this experience, we were still not sure whether the stitching had been done properly or if the stitching procedure was ''removing'' or ''distorting'' rings unintentionally. We tested the quality of the image stitching procedure on two sample collections– simple and complex. The simple sample collection consisted of 20 Norway spruce (*Picea abies* Karst.) cores from a productive forest site, around 100 years old, producing very complacent rings. The purpose of this test was to investigate potential problems in automatic pattern recognition and image stitching algorithms, which might result from processing many similar tree rings. We found that image stitching ran flawlessly. The overlap between the images was optimal and no blurred areas were detected between adjacent images (Figure 4).

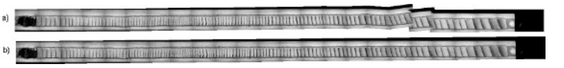

Figure 4. (a) Incorrectly stitched image, (b) after fine-tuning of the image stitching parameters.

The complex sample collection was selected from 15 very sensitive European larch (*Larix decidua* Mill.) cores from the upper timberline, up to 400 years in age, with many extremely narrow and missing rings. Once again, the presence of very narrow rings did not present any problems in the creation of the final image – all images were stitched correctly and no blurred or out-of-focus areas between images were detected.

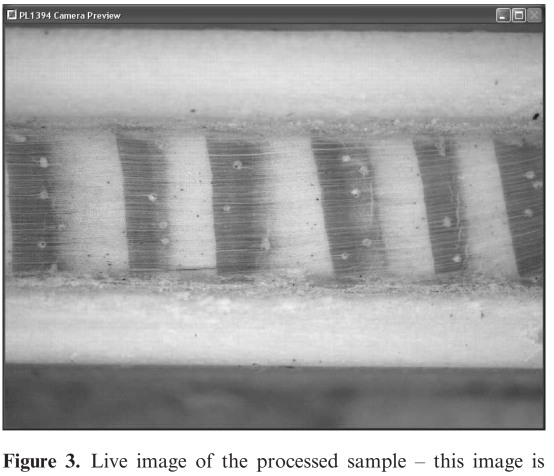

Figure 3. Live image of the processed sample – this image is used to orient samples properly and to control the scanning procedure.

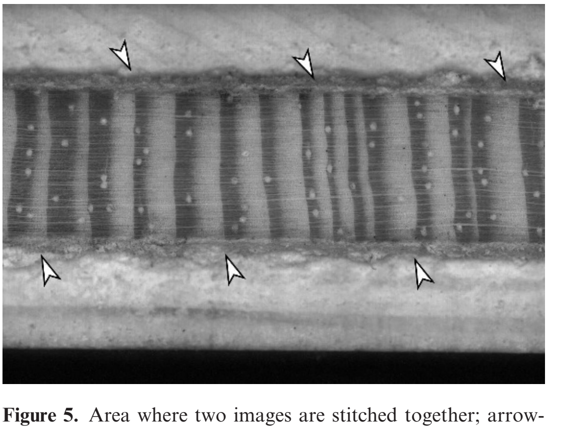

Figure 5. Area where two images are stitched together; arrowheads indicate parts of the images where potential inaccuracies due to stitching procedure can occur.

TEST FOR POTENTIAL OPTICAL DISTORTION

To test for potential optical distortions, a 5 × 5 mm calibration square was placed on a sample and digitally captured along with the tree rings. When the stitching procedure was finished, we imported the final image into the image-processing program and overlaid a 5 × 5 mm square on the captured square to identify any departures in size and shape. It can be seen in Figure 6 that the geometry of the captured image was not distorted and that the calibration square retained its original dimensions.

ATRICS VERSUS HAND MEASURING

Finally, we wanted to compare manually obtained ring-widths measured with a hand-driven LINTAB measuring system to automatically derived measurements, in order to identify potential errors in determining ring widths at locations where image stitching took place. For this test we intentionally selected cores with very complacent growth, assuming that the image stitching program could potentially have problems with the stitching of complacent tree rings. We also expected missing rings caused by incorrectly stitched segments. As can be seen from the time series plots in Figure 7, there were minor differences between the manually obtained measurements and those derived from the image using WinDENDRO. The biggest difference between the two methods was seen at the beginning of the measurements (close to the pith) where WinDENDRO was far more accurate. In general, we found an average difference between manual and automatic measurement, based on 2458 tree rings, to be 0.0094 ± 0.0102 mm. A t-test for paired samples showed no statistically significant difference between the manual measurements and the ATRICS based measurements.

A study of the time necessary to measure one simple core favors manual measuring. However, when it comes to a large number of complex samples, the time needed to measure 10 samples, including scanning, stitching, automatic ring processing and error checking, is approximately 30% shorter.

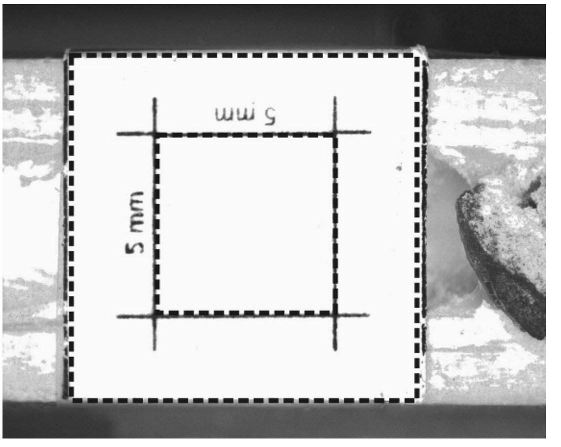

Figure 6. Test for distortion – image of the calibration square was captured using the digital video camera connected to a stereo microscope. Black dashed square (dimension 5 × 5 mm) was superimposed in a drawing program to test for deviations from a perfect square (square with solid lines).

Additionally, ATRICS might also offer flexibility of using images stored on a PC for other purposes. This could lead to a more automated system and processing of properties other than ring widths.

CONCLUSIONS

The ATRICS system has been in use in the Laboratory for Dendrochronology at the Slovenian Forestry Institute for more than a year. During this period, we digitally captured more than 600 different samples from various tree species – *Quercus* sp., *Fagus* sp., *Acer* sp., *Alnus* sp., *Picea* sp., *Pinus* sp., *Larix* sp. and *Betula* sp. varying between 40 and 500 years and core lengths between 100 and 700 mm. In addition to processing core samples, we have also used the ATRICS system to measure stem discs (mainly for stem analysis) providing they are not too heavy (> 3 kg) for the stage. Image stitching of non-core samples was also no problem for Image Assembler 3.

One of the main advantages of capturing images and processing them in programs for automatic tree-ring recognition is that it is always possible to return to problematic sample images and discuss their issues. We have also found it useful to have a review process through which a second operator or supervisor can verify or correct problematic sample

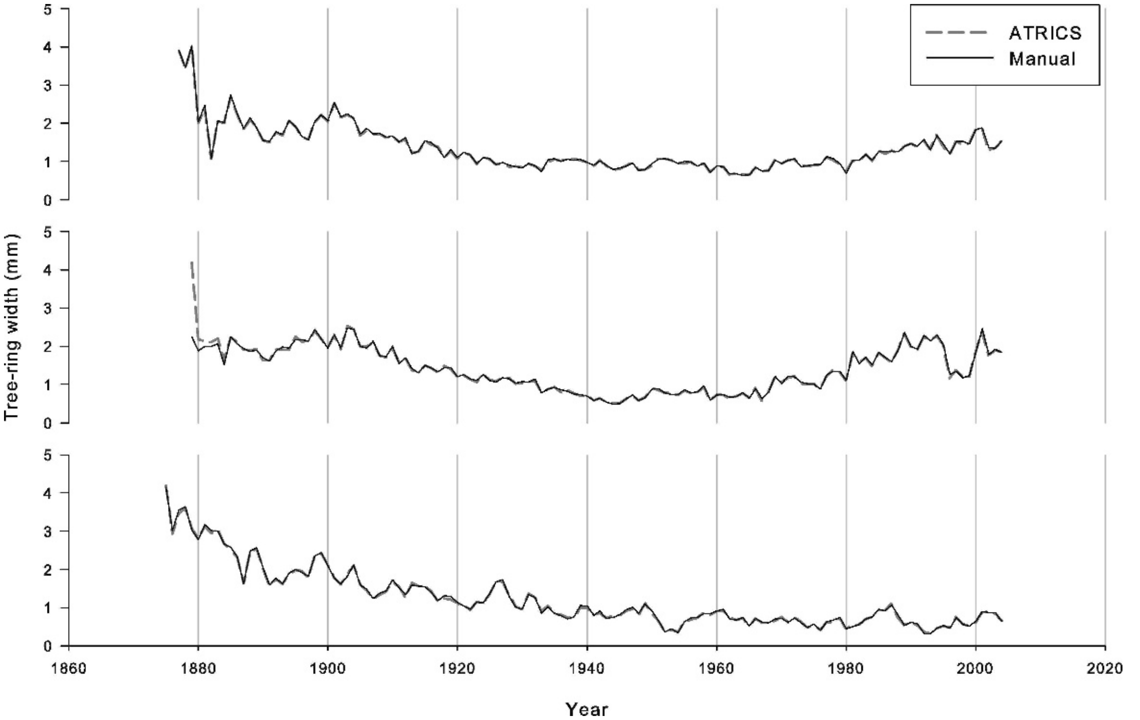

Figure 7. Manually derived ring-width measurements compared to ATRICS measurements of three cores. Automatic tree-ring recognition and measurement was done in WinDENDRO.

measurements. In some cases, the quality control procedure can be done remotely, because all the information needed is digital (assuming the problem is not with the sample image itself). The ATRICS system is very useful for teaching students how to measure tree-ring widths and highlighting potential problems that may arise during measuring.

Images derived from the ATRICS system are of much higher resolution that those from flatbed scanners, optical magnification having many advantages compared to digital magnification (especially in areas with extremely narrow tree rings). The processing of very long cores also poses no problem. In addition, the final images that are created by ATRICS are a useful backup copy (not replacement) of the original samples. They can be archived in a database for easy retrieval.

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