









PRACTICAL TOOLS

CaptuRING: A do-it-yourself tool for wood sample digitization

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Abstract

1. Standard procedures to obtain high-quality images of wood samples have become a bottleneck in the digitization of dendrochronology. Digitization is currently dominated by flatbed scanners, but the use of these devices is limited by sample length and surface flatness. Although several solutions based on digital photography have been published, they lack effective digitization processes or are too expensive to be widely adopted.
2. Free open-source software and hardware has emerged as an alternative to create research tools that combine reduced costs with high reliability. Here we present CaptuRING, an open-source tool for wood sample digitization combining a do-it-yourself hardware based on Arduino® with a DSLR camera and a free open-source software with an easy-to-use graphical user interface.
3. We compared CaptuRing with image acquisition from a standard flatbed scanner Epson® V750PRO. CaptuRING outperforms scanner image resolution and sharpness, while it removes sample size limitations. Moreover, CaptuRing performs this task in less than half of the time needed by Epson® V750PRO flatbed scanner.
4. CaptuRING emerges as a reliable and low-cost tool to capture high-resolution images of wood samples boosting current digitization processes. The combination of free open software and hardware empowers dendrochronology to advance in wood sample digitization.

KEYWORDS

dendrochronology, DIY, hardware, open source, sample digitization, software, wood cores, wood slices

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1 | INTRODUCTION

Biodiversity studies have recently evolved thanks to technological advances in digital real-time data sources. Data capturing from satellites (<http://www.copernicus.eu/>) to microscopic technology (Weber & Huisken, 2011) can be affordable and provide immediate digital information at multiple scales. However, due to the recent appearance of these data sources, they do not provide long temporal records, and other sources of information to complete this shortfall (Olano et al., 2021) are therefore required. This is the case with dendrochronology, the science that deals with tree rings, which provides a long-term perspective in ecological and biodiversity research through analysis of plants with annual secondary growth increments (Schweingruber, 2012).

Dendrochronology is following the scientific world's relentless step towards digitization (Schmidt et al., 2016). However, techniques for cross dating tree-ring series and ring width measuring still remain in the analogical world. Measuring processes from wood samples, generally increment cores, are mainly performed using a stereoscope and different, generally expensive, tree-ring measuring stages (e.g. Lintab: <https://rinntech.info/>, Velmex™: <https://www.velmex.com/>). These devices convert lead screw shifting into ring width measurements which are digitally saved. Alternatively, dendrochronologists have a wide array of reliable software to extract ring width measurements from digitized images of wood, transforming pixels into micrometres (e.g. MTreeRing: Shi et al., 2019, Coorecorder™: Larsson, 2014, Windendro™: Instruments, 2007). However, the full popularization of the use of these tools is hampered by our limited capacity to digitize images of wood with enough quality to serve as a digital model in a fast and low-cost procedure. Moving to 'digital cores' is not only an issue of novelty, as it would open the avenue to get a 'digital twin' that could dynamically replicate responses to intrinsic and environmental variables from a physical sample into the digital world (Fuller et al., 2020). Digital models enable storage of samples in an accessible digital format in private or public resource banks, from which samples can be easily available for checking and reusing for new analysis. Furthermore, effective digitization of samples promotes the exchange of information between researchers (Contreras, 2018; Davies et al., 2017).

The main physical obstacles to core digitization are their extremely large structure and their having a surface that is often not completely flat. Flatbed scans have dominated the acquisition of digitized wood samples, especially with the availability of high-resolution scanners (up to 6,400 dpi, 3.9 μm per pixel). However, core scanning at such high resolutions is very time-consuming and those extremely high aspect ratio images can cause problems due to the high computational requirements for image exportation. Moreover, since scanners require totally flat samples, a requirement that is rarely fulfilled in sanded wood samples, the output image can contain portions that are out of focus. Additionally, the size of scanner determines the maximum length of the image capturing limiting their use for large cores or slices. [Correction added on 8 April 2022, after first online publication: the unit 3.9 m per pixel has been corrected to 3.9 μm .]

Digital photography has appeared as an alternative to scanning. Some previous studies have used digital single-lens reflex (DSLR) cameras to capture tree core images (Fonti & García-González, 2008; Souto-Herrero et al., 2018). However, the first published approach for core digitization was ATRICS (Levanič, 2007) in which Levanič proposed a video camera assembled to a stereoscope which digitized tree core as it was moved by a worm gear. Recently, Griffin et al., 2021 published Gigapixel, which reaches an impressive image quality with very high resolution (19,812 dpi, 1.28 μm per pixel) in the verge of being able to analyse xylem cellular structure. Despite Gigapixel being based on free open software, final image hosting requires the payment for cloud computing services, and hardware costs (\$70,000) are beyond the budget of most research groups, especially in developing countries.

Free open-source software and hardware have emerged as innovative systems to make research with precise and accurate open tools more accessible (Gibney, 2016). Accordingly, open-source packages for different dendrochronology tasks have been published (Campelo et al., 2012; García-Hidalgo et al., 2021; Rademacher et al., 2021). However, there is currently a lack both in proprietary and open specific software focused on image acquisition process.

The aim of this manuscript is to present an open-source tool that generates high-quality images in a fast and low-cost way to boost the digitization of wood samples. In order to fit with this aim, we combine an affordable do-it-yourself hardware with open-source software graphical user interface (GUI) as an effective digitization tool for tree-ring studies. Hardware can be assembled with just basic skills, whereas CaptuRING software provides an effective and intuitive digitization of the core samples. In the following sections, we explain the main components, software options and availability of CaptuRING System.

2 | CaptuRING SYSTEM

CaptuRING basic functionality guides the sample across the visual range of the DSLR camera, as well as controlling the image acquisition and storage. The CaptuRING tool is comprised of a DIY hardware module and a software module. Since a computer must be in use for the capturing process, the system is run using a Raspberry Pi (<https://www.raspberrypi.com/>) to optimize the digitization pipeline, although CaptuRING software is a cross-platform tool and can be run in any operative system.

2.1 | Hardware

Hardware components of CaptuRING arrange the sample by moving it at equal steps through the camera's visual field during image capturing (Figure 1). The sample holder (Supplementary Material 1) is carried by a ball screw Linear Motion Guide (50cm/stepper motor mod. 42BYGH48; 1.8, 1.2 A, 0.4 Nm, DFA), hereafter spindle, which is moved by the stepper motor. That motion is controlled

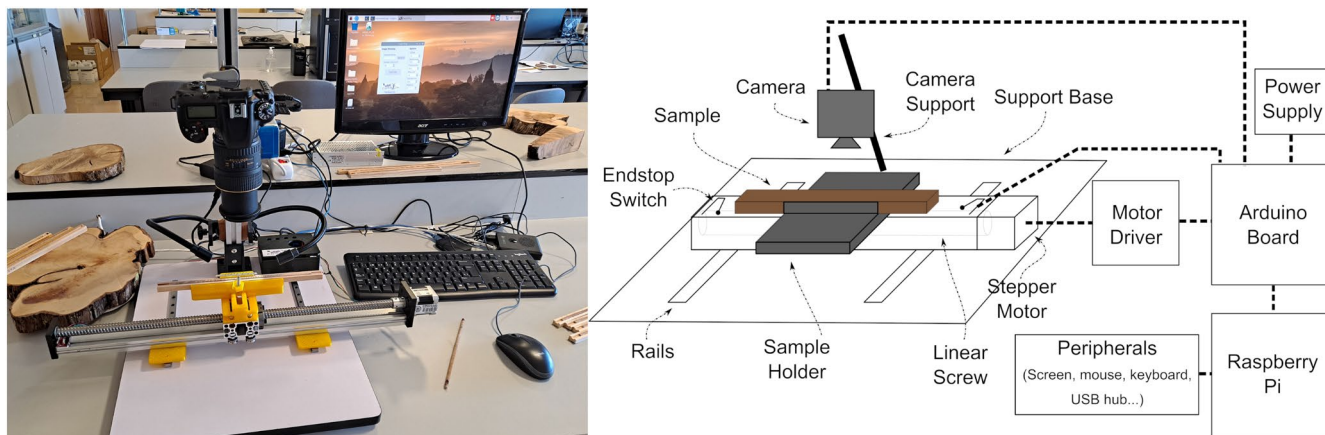


FIGURE 1 CaptuRING device and components' connection scheme

TABLE 1 CaptuRING components and estimated price

Component	Price (€)
CaptuRING motion hardware	284–407
Photography enlarger base	50–60
Led lighting	80–100
C-Beam linear actuator (500 mm) + NEMA 23 stepper motor	100–150
Endstop switch	1–2
Linear rails (2)	20–40
Driver IC for stepper motor	3–5
Arduino® based 3D printer controller	20–30
Power supply (12 VDC/150 W source)	10–20
Sample holder ^a	DIY
Rail adapter ^a	DIY
Optical and controlling devices	1,450–1,850
Raspberry Pi Kit (with microSD, power source, cables and case) ^b	100–150
Peripherals (screen monitor, keyboard and mouse) ^b	150–200
DSLR camera ^b	800–1,000
Camera lens ^b	400–500

^aDo-it-yourself with a 3D printer according Supplementary Material 1 design.

^bComponent election may diverge from user objectives and requirements.

by an Arduino® 3D printer controller (MKS-GEN L V1.0) (<https://www.arduino.cc/>) which obtains the information from the end of track sensor and the computing system, a Raspberry Pi 4 model B. All those driving components are, in addition to the camera, set up in association with a photographic enlarger base (Figure 1).

The Raspberry Pi comprises every control by sending orders via USB to the 3D printer controller and to the DSLR camera (Nikon D7500 with Tokina 100 mm f/2.8 ATX M Pro D Macro lens) using the CaptuRING software. Although those hardware elements are not made specifically for scientific tasks, the software component can manage

them to be used for image acquisition in dendrochronology or any sequential image capturing purposes. CaptuRING motion hardware can be acquired for <300 €, meanwhile the complete digitization device from scratch can be purchased for approximately 1,700 €. All the component specifications and the estimated prices are listed in Table 1.

2.2 | Software

CaptuRING software controls image capturing by a DSLR camera while the sample goes through its visual field. This software is written in Python (<http://www.python.org>) and controls spindle movement with Arduino® and DSLR camera shooting with gphoto2 library (<https://pypi.org/project/gphoto2/>). The whole capturing process is controlled by a specific interface made with the use of PyQt5 library (<https://pypi.org/project/PyQt5/>). CaptuRING code is available through Zenodo (10.5281/zenodo.6351358) (García-Hidalgo, García-Pedrero, Colón, Sangüesa-Barreda, Rozas, et al., 2022).

The interface consists of just one window in which the user enters hardware and sample characteristics (Figure 2). The user completes the 'Options' box with CaptuRING hardware settings according to the device characteristics. Although these Options can be changed anytime, they are saved for future CaptuRING use. In the 'Image Shooting' box, the user enters sample name and size. Sample name must be confirmed by clicking the 'Name It!' button before image capturing. Thus, a specific folder with sample name is created and the digitized images will be saved there. Once the sample digitization is completed, the user can change the sample name and size for the next process.

2.3 | Acquisition process

The wood increment core must be mounted and sanded with progressive grain sizes as in standard dendrochronological procedures. For an optimum acquisition, we highly recommend reducing illumination to increase contrast and obtain sharper images. Once the

sample is placed on the device at the sample holder, the user enters sample name and length in millimetres in the interface. Additionally, process parameters for mismatched position (offset), screw speed, step size, spindle size or platform size can be modified by the user depending on hardware characteristics. Once the sample size is entered and name is confirmed by clicking the 'Name it!' button, 'CAPTURE' runs image acquisition.

CaptuRING takes a series of sequential and partially overlapped photographs after individually autofocussing for each image. The autofocus process is particularly important when the sample is not totally flat and the distance from the camera lens may vary at different points of the sample surface. Subsequently, the camera takes one picture when the core stops in its stepped-carried way across the platform. During the capturing process, the individual images are saved in a sample-specific-named folder with an individual and consecutive name. When the capturing process is finished, the tool comes to the starting position to restart with the next sample. CaptuRING captures and saves sequential images, but the whole sample image must be generated by using a stitching software. There are a wide range of tools to complete this step in FOSS (e.g. ImageJ: Schindelin et al., 2012 or OpenCV: <https://opencv.org/>) as well as proprietary software already reviewed for quantitative anatomy (von Arx et al., 2016). Due to the limited hardware capabilities in Raspberry Pi, image files should be shared with a standard computer to optimize the whole capturing process.

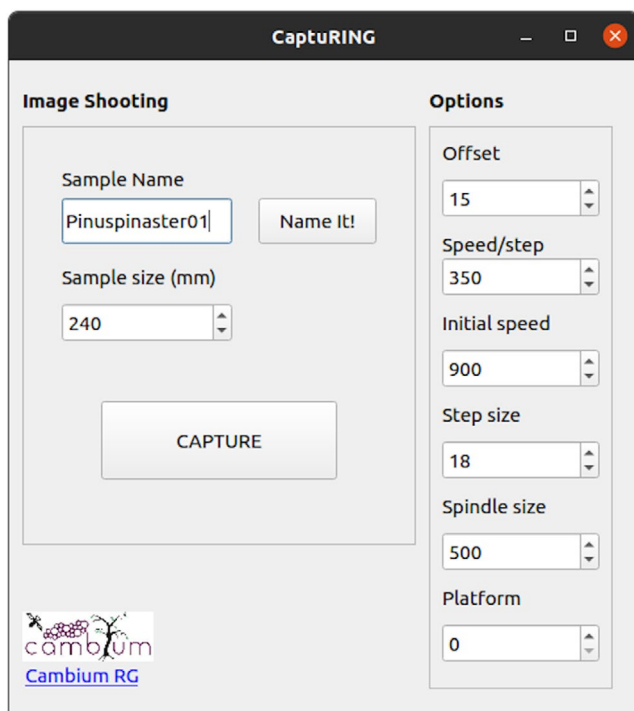


FIGURE 2 CaptuRING interface. Options section must be completed with hardware requirements while Image Shooting section controls sample digitization

3 | COMPARISON WITH FLATBED SCANNER

Increment cores from conifer and broadleaved species were selected to test image acquisition differences using a flatbed scanner Epson® Perfection v750 PRO (maximum resolution 6,000 dpi) and CaptuRING. This flatbed scanner is a common digitization tool in dendrochronological research (Marcelo-Peña et al., 2019; Navarro-Cerrillo et al., 2020; Venegas-González et al., 2015).

The samples were mounted and sanded at progressive grain sizes (from 80 to 800) before digitization. Eight incremental cores were individually digitized with each device and information recorded about sample characteristics (species, length), image resolution (in dots per inch) and time (in seconds) for image acquisition (Supplementary Material 2). Since the scanning process is computationally limited to 20,000 pixels width and 30,000 pixels length by Epson Scan software®, complete sample cores were scanned at feasible maximum resolution. CaptuRING shooting and image stitching by using PTGui v8.3 (New House Internet Services BV, Rotterdam, NL) was measured in order to get comparable results using both CaptuRING and scanning digitization methods for the complete sample. Complete images are available at Zenodo (10.5281/zenodo.6365664) (García-Hidalgo, García-Pedrero, Colón, Sangüesa-Barreda, García-Cervigón, et al., 2022).

CaptuRING increases resolution acquisition from 4200 dpi maximum resolution at scanning with Epson Perfection V750PRO up to 5339 dpi (4.76 μm per pixel) with a 24MP non-professional DSLR camera (Nikon D7500). [Correction added on 8 April 2022, after first online publication: the unit 4.76 m per pixel has been corrected to 4.76 μm .] Thus, this tool provides sharper images in contrast to the classical blurry scanned images (Figure 3). At the same time, average image acquisition time decreases by 60% using CaptuRING (Figure 4). Furthermore, CaptuRING removes the sample size barrier associated with flatbed scanning, usually 216 \times 297 mm at maximum, by using a lead screw of the desired length.

The final resolution and quality of the CaptuRING image depend on camera and lens features. Sensor size modifies lens magnification power, APS-C cameras have a magnification factor (1.5–1.6) when compared to full frame cameras, albeit at the expense of image quality (Santosi et al., 2017). Additionally, the dynamic digital camera industry improves image quality and resolution at an impressive speed. Finally, lens election is critical and moving from the 1:1 macro standard to super macro lenses dramatically increases magnifications up to 5:1 albeit at the cost of notably reducing depth of field.

4 | LIMITATIONS AND IMPROVEMENT POTENTIAL

CaptuRING has been already tested by obtaining high-resolution images from more than 3800 tree cores. During its use, some issues and pitfalls were tackled in order to produce a robust and reproducible protocol for obtaining accurate digitized samples. The main obstacles encountered were related to sample flatness, image stitching and

FIGURE 3 Detailed images from wood samples obtained with CaptuRING (left) and Epson® Perfection V750PRO (right) of *Fagus sylvatica* L. on the top and *Pinus nigra* Arn. at the bottom

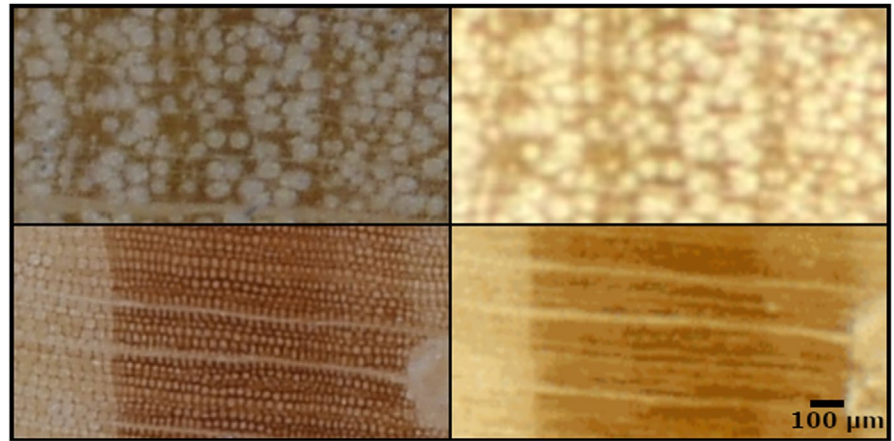
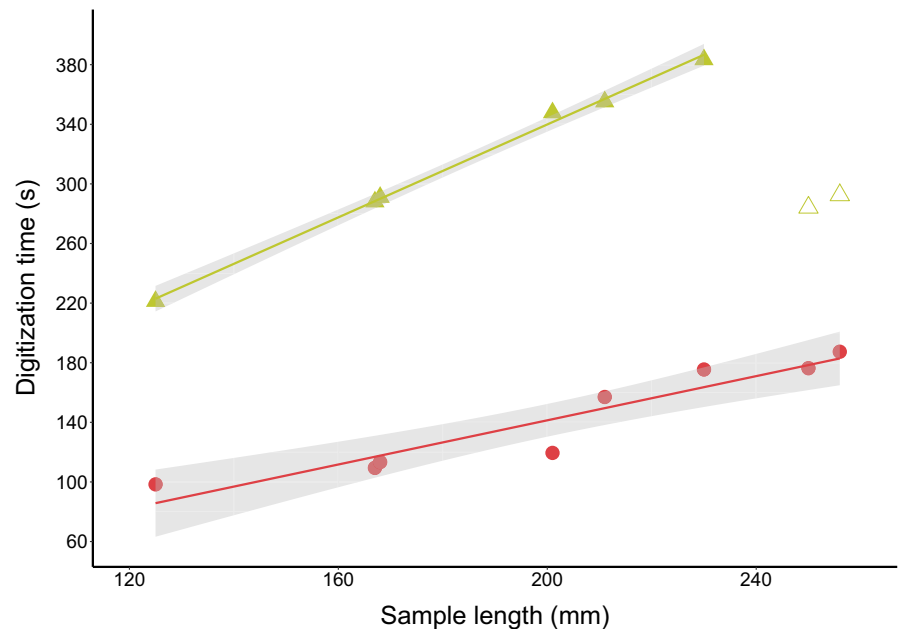


FIGURE 4 Processing times for digitization of tree cores with different length by using Epson® Perfection V750PRO (green triangles) and CaptuRING at 5,931 dpi (red dots). Linear regression models are shown with 95% confidence interval (grey) for maximum resolution data. Non-filled triangles represent scanning times at 2,400 dpi due to scanning size limitations for 3,200 dpi



scale. As a result of this assessment, we noticed that proper sample preparation is essential in order to minimize future artefacts in the generated images. Furthermore, sample flatness minimizes the need of autofocus, which could reduce image stitching quality. We use a thickness planer process prior to sanding. In this way, we minimize the need of autofocus. Another point of potential difficulty is related to the stitching process, where image artefacts can appear. In order to avoid them, in case of using PTGui, we highly recommend the use of the standard protocol developed by von Arx et al. (2016). In any case, maximizing the number of control points in the overlapping images minimizes the risk of image artefacts. Finally, scale is another important issue, as even when images are nearly at the same scale, small differences in focal distance can lead to measurement errors. So, we attach a graphical scale on the CaptuRING sample holder that allows to measure the effective resolution of each sample.

There is an ample room for further improvement. Light control is a critical field. We are currently developing a system to isolate the sample and the camera lens tandem from environmental light, which will allow the user to standardize lighting by removing diffuse light. File management is also important, and developing a

detailed metadata file could enable the standardization across labs. Developing specific software for automatic stitching process attached to CaptuRING could be also relevant. Moreover, the design of a specific sample holder for wood slices of different sizes will vastly increase the possibilities of this tool. Resolving these issues with open-source tools will optimize the entire digitization process and could increase the possibilities of CaptuRING becoming widely used for any wood digital sampling.

5 | CONCLUSIONS

CaptuRING does not have the same susceptibility to hardware limitations or flawed flatness as flatbed scans do and streamlines the process of automatically storing each digital sample and associated metadata in optimized time, being more than 50% faster than a flatbed scanner in our comparative tests. Moreover, CaptuRING increases resolution acquisition from 4200 dpi maximum resolution with scanning to 5931 dpi with a 24 MP non-professional DSLR camera, controlling sample illumination and without any sample

size limitation. Nonetheless, image quality and resolution could be greatly improved with a professional DSLR camera and super macro lens. By combining free open-source hardware and software within an affordable budget, of <1,500 €, CaptuRING paves the way to move tree-ring measurements to the digital world.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

J.M.O. and V.R. conceived the idea; V.A.-G. and M.G.-H. designed the hardware; D.C., V.A.-G., Á.G.-P. and M.G.-H. designed the software; A.I.G.-C. and G.S.-B. collected the samples; G.S.-B. analysed the data; J.L.-M. and H.H.-A. tested the tool reliability. All authors contributed critically to the drafts and gave final approval for publication.

PEER REVIEW

The peer review history for this article is available at <https://publons.com/publon/10.1111/2041-210X.13847>.

DATA AVAILABILITY STATEMENT

Supplementary Material 1 includes component models for 3D printing through <https://doi.org/10.5281/zenodo.6365717> (Alonso-Gómez & García-Hidalgo, 2022); Supplementary Material 2 includes summary table from image comparison data and digitized samples through <https://doi.org/10.5281/zenodo.6365664> (García-Hidalgo, García-Pedrero, Colón, Sangüesa-Barreda, García-Cervigón, et al., 2022); CaptuRING® software code in <https://doi.org/10.5281/zenodo.6351358> (García-Hidalgo, García-Pedrero, Colón, Sangüesa-Barreda, Rozas, et al., 2022) and GitHub.

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