Tina Paper In Development

Your Name

November 5, 2024

Abstract

This is the abstract of your paper. Briefly describe the purpose of the research, the main results, and the conclusions.

1 Introduction

The study of tree rings has proven useful across multiple fields, proving to be a reliable subject for reconstructing past climates of regional and local environments, as well as a mechanism to understand tree growth response [1] [14] [5] [13]. To obtain these data from the tree rings, it is necessary to measure tree rings from a tree cookie or core. The first high precision tool for this purpose was a stage micrometer, involving a trained technician to incrementally shift a tree core under the objective of a microscope - informing a computer when a new ring is encountered [12]. While this method has very high precision, the data is only as accurate as the experience and knowledge of the technician at the time of recording [6]. The desire to remove repetition of errors in sampling and sampling bias across to individual technicians led researchers to an alternative - image analysis.

The first step in measuring tree ring width from images requires the digitization of the sample from one of two major methods. The original technique was as a flatbed scanner which can digitize the entire sample at once [4]. With a top of the line scanner, like the Epson Perfection V850 Pro, it's possible to scan at maximum resolutions of 4800 dpi and scan an area of up to 8.5" x 11.7". Analysis which relies on higher resolution larger samples require a different digitization approach.

The second digitization model was introduced with ATRICS [6]. Rather than scanning a whole sample at once, a high resolution camera takes multiple images across the surface of the sample and uses image stitching software techniques to combine them into one ultra high resolution image [9]. This methodology is often seen in other fields such as mineralogy and cellular biology [11, 8]. This method requires either the camera objective to move relative to the sample, or the sample move underneath a stationary camera. For ATRICS and a more modern do-it-yourself alternative, CaptuRING, the sample is moved relative to the camera [2]. Gigapixel takes a different approach by moving the camera relative to the sample, allowing for multiple samples to be recorded in sequence. While these machines can all digitize cores, none have been shown to digitize cookies.

Tina was made to combine the defining features of the previously mentioned machines into one while making the code open-source and chassis open-hardware device. We designed Tina to digitize both cookies and cores, extend the maximum sample length, perform image stitching without operator intervention, while minimizing cost. Successful functionality of this system is dependent on the major steps in tree cookie and core

digitization to be automated. The only specialized piece of equipment needed to build Tina is a 3D printer, but the parts can be readily ordered through 3D print shops if preferred. Excluding 3D printed parts, the total cost of the machine is approximately $2,200 USD compared to the $70,000 USD of the Gigapixel [3]. The total cost of the machine is almost comparable in price or less to many professional camera and macro lens combinations. Additional savings can also be made when factoring in the cost of a professional stitching software license such as PTGui.

2 System Overview

Tina can be thought of as a combination of multiple subsystems: the camera, computer, and gantry machine. The first system is the camera and computer. A 12MP Raspberry Pi HQ Camera equipped with a SEEED studio microscope lens is connected to an NVIDIA Jetson Orin Nano (Jetson) through a CSI cable. The Jetson is a powerful SoC edge computer which drives a computer monitor for a GUI, sends commands to the motor controller to move the machine, runs image processing calculations for automatic control, and performs calculations to stitch individual images into one mosaic. The gantry machine is built using the extruded aluminum and premade adapters from the OpenBuilds ACRO kit. Movement of the machine is originates from NEMA 17 stepper motors and is transferred to linear motion in the X and Y direction using timing belts and timing pulleys. Motion in the Z-direction is controlled by a NEMA 17 lead screw based linear actuator also supplied by OpenBuilds. Custom 3D models were designed in SolidWorks to create adapters to mount the camera to the Z axis as well as mounting the Z axis to the XY plate of the ACRO. The OpenBuilds X32 Motor Controller running GRBL firmware converts G-Code commands received via serial from the Jetson. GRBL then converts them to electrical signals to spin the lead screw and timing belts.

Interacting with the Jetson is similar to working with any Ubuntu based Linux distribution.

3 Sample Digitization

The subsystems can be best understood by following the path from sample setup through the computing process to create the stitched image.

To achieve this with a fixed focus camera, the samples must be nearly orthogonal to the camera lens. Misalignments between the sample and lens can be corrected by using the 3D printed sample levelling table we designed. Once the sample is level, the operator interacts with the machine through the GUI to navigate the camera to the center of the sample, and initializes focus to be sharp. The height and width dimensions are then entered in the GUI to be saved along with the center XYZ coordinate of the sample. This procedure can be repeated to create a queue of samples to digitize.

Sample height, width, identifiers, and centering an in focus sample is sufficient information to digitize.

3.1 Image Capturing

Once prompted the system begins to exhaustively traverse the surface area of the sample. The goal of this traversal is to obtain in-focus images that have a region of overlap with

all its neighbors - the basis of image stitching. Digitizing cores can often be done without needing to traverse in both the X and Y axis as the field of view in an image can capture the core's entire axial diameter in its field of view when moving along the core's length. Spanning the surface area of a cookie is more complicated as it needs move in both the X and Y axis (see Figure).

By centering the design around a fixed focus camera and lens, it is necessary to implement some sense of automatic control to focus the images. In this system, the only way to control focus is by changing the lens's distance to the sample. And with the microscope lens, the depth of field of the image is so sensitive that a perturbation of less half of a millimeter can move an entire image out of focus. Solving this in a time efficient manner involves two stages. The first stage takes advantage of the requirement to navigate and focus the camera to the center of the sample. This allows the initial Z_0 value from (X_0, Y_0, Z_0) to be a fantastic initial guess as to what value would have an in focus image across the entire surface. Sample surface misalignment and a non flat sample (bumpy) surfaces require more than one image to be taken at each image (X, Y). From the first (X_0, Y_0) coordinate captured, 11 images are taken at different Z values in $\boldsymbol{Z}_{\text{focus}}$. So long as Z_{sample} is within this set, an in focus image exists.

$$Z_{sample} \in \boldsymbol{Z}_{\text{focus}} = Z_0 + \begin{bmatrix} -0.5 \\ -0.4 \\ \vdots \\ 0.4 \\ 0.5 \end{bmatrix} \exists Z_{focused}$$

Beginning at 0.5 mm above Z_0 and the last image finishing at 0.5 mm below Z_0. To reduce motion blur in the images, this $\boldsymbol{Z}_{\text{focus}}$ is traversed at constant velocity and images are captured without stopping. The 11 images then have their normalized variance calculated in a separate thread to measure the image sharpness [7]. The image with the maximum score is saved while the rest are deleted from storage.

$$i_{\max} = \arg \max_i \boldsymbol{Z}_{\text{focus}}$$

This focusing procedure works well alone when the sample alignment has a difference in height no greater than 1 mm. Greater alignment error can be managed by having the control over adjusting $Z_{0,k}$ for (X_k, Y_k). The likelihood of an adjacent (X_{k+1}, Y_{k+1}) containing an in focus image is highest when the current $i_{\max,k}$ is at the middle index of $\boldsymbol{Z_{focus}}$. A PID control algorithm with a process variable of i_{max} and control variable of $Z_{0,k}$ allows a negative feedback loop to improve focusing across the entire sample [10].

After the capturing process, the images are stitched and are stored on the device along with metadata of relevant machine settings and sample information.

The frame, camera, computer, software, and sample leveling tables, work cohesively to address the nuances of digitizing both cookies and cores. Each of these subsystems will be reviewed along with the design considerations involved to make a complete machine. Considering Tina is an imaging machine, we will start off by looking at the camera and move outward.

3.2   Camera

In the Gigapixel and CaptuRING, a professional handheld camera was used to capture images. While this benefits from a wide variety of lens and camera choices - and principally autofocus - they come at a cost. Beyond its literal price tag, a professional camera also carries a significant weight, demanding a more robust and therefore more costly machine frame. These cameras are also optimized for handheld use, not for integration into computer driven machines. This results in clunky access to images from software. Designing around a machine vision camera such as the 12MP Raspberry Pi HQ Camera drastically reduced the camera cost while improving the access to the data stream coming from the camera sensor. Pairing the Raspberry Pi HQ Camera with a high magnification C-Mount lens allows for images with very high resolution in dots-per-inch (DPI) to be captured. (THIS IS AN ESTIMATE, GET THE REAL VALUES FROM TINA) If the field of view of the image

3.2.1   Focusing

Normalized variance process goes here.

Achieving a focused image across the entire surface area of the sample is the basis for an accurate stitch and effective analysis. By saving costs on a fixed focus camera and lens, it was necessary to implement a method to focus the images. Focus is solely a function of distance to the subject in the regime. With this high magnification lens, having an image go from in-focus to out-of-focus was sensitive to sub millimeter variation in distance to the lens. This requires cores and especially cookies to be as close to orthogonally aligned to the lens as possible. A 3D printed levelling table and bullseye level were used to correct plane misalignment of up to 10 degrees in cookies (CALCULATE THIS?). Slight sample misalignments are corrected within a closed loop automatic control PID algorithm.

4   Results

4.1   Scans of Cookies and Cores

The microscope lens greatly improved the maximum resolution of the digitization. Resolutions of up to 13,400 DPI were achieved, a large improvement when compared to both high resolution flatbed scanners (Epson® Perfection v750 PRO) and CaptuRING.

4.2   Functional Limits

With such high resolution, multiple logistics concerns arise. First is the file size. With such a high resolution, the size of the images can become extremely large. A cookie 5 inches in diameter would result in an image with 67,000 pixels squared. This easily exceeds the 2.5 GB maximum file size in a TIFF - most software for viewing the file will also be incompatible with any file this big as well.

5   Discussion

Discuss the implications of your results here.

5.1 Strengths and Opportunities

5.2 Opportunities for Improvement

6 Conclusion

Summarize your key findings here.

References

[1] Harold C. Fritts. Dendroclimatology and dendroecology. *Quaternary Research*, 1(4): 419–449, December 1971. ISSN 0033-5894. doi: 10.1016/0033-5894(71)90057-3. URL `https://www.sciencedirect.com/science/article/pii/0033589471900573`.

[2] Miguel García-Hidalgo, Ángel García-Pedrero, Daniel Colón, Gabriel Sangüesa-Barreda, Ana I. García-Cervigón, Juan López-Molina, Héctor Hernández-Alonso, Vicente Rozas, José Miguel Olano, and Víctor Alonso-Gómez. CaptuRING: A do-it-yourself tool for wood sample digitization. *Methods in Ecology and Evolution*, 13(6):1185–1191, 2022. ISSN 2041-210X. doi: 10.1111/2041-210X. 13847. URL `https://onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.13847`. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/2041-210X.13847.

[3] Daniel Griffin, Samantha T. Porter, Matthew L. Trumper, Kate E. Carlson, Daniel J. Crawford, Daniel Schwalen, and Colin H. McFadden. Gigapixel Macro Photography of Tree Rings. *Tree-Ring Research*, 77(2):86–94, July 2021. ISSN 1536-1098, 2162-4585. doi: 10.3959/TRR2021-3. URL `https://bioone.org/journals/tree-ring-research/volume-77/issue-2/TRR2021-3/Gigapixel-Macro-Photography-of-Tree-Rings/10.3959/TRR2021-3.full`. Publisher: Tree-Ring Society.

[4] Régent Guay, Réjean Gagnon, and Hubert Morin. A new automatic and interactive tree ring measurement system based on a line scan camera. *The Forestry Chronicle*, 68(1):138–141, February 1992. ISSN 0015-7546, 1499-9315. doi: 10.5558/tfc68138-1. URL `http://pubs.cif-ifc.org/doi/10.5558/tfc68138-1`.

[5] Frédéric Guibal and Joël Guiot. Dendrochronology. In Gilles Ramstein, Amaëlle Landais, Nathaelle Bouttes, Pierre Sepulchre, and Aline Govin, editors, *Paleoclimatology*, pages 117–122. Springer International Publishing, Cham, 2021. ISBN 978-3-030-24982-3. doi: 10.1007/978-3-030-24982-3_8. URL `https://doi.org/10.1007/978-3-030-24982-3_8`.

[6] Tom Levanič. Atrics – A New System for Image Acquisition in Dendrochronology. *Tree-Ring Research*, 63(2):117–122, December 2007. ISSN 1536-1098, 2162-4585. doi: 10.3959/1536-1098-63.2.117. URL `https://bioone.org/journals/tree-ring-research/volume-63/issue-2/1536-1098-63.2.117/Atrics--A-New-System-for-Image-Acquisition-in-Dendrochronology/10.3959/1536-1098-63.2.117.full`. Publisher: Tree-Ring Society.

[7] Hashim Mir, Peter Xu, and Peter Van Beek. An extensive empirical evaluation of focus measures for digital photography. page 90230I, San Francisco, California, USA, March 2014. doi: 10.1117/12.2042350. URL `http://proceedings.spiedigitallibrary.org/proceeding.aspx?doi=10.1117/12.2042350`.

[8] Fatemeh Sadat Mohammadi, Hasti Shabani, and Mojtaba Zarei. Fast and robust feature-based stitching algorithm for microscopic images. *Scientific Reports*, 14(1): 13304, June 2024. ISSN 2045-2322. doi: 10.1038/s41598-024-61970-y. URL `https://www.nature.com/articles/s41598-024-61970-y`. Publisher: Nature Publishing Group.

[9] Jeremy L. Muhlich, Yu-An Chen, Clarence Yapp, Douglas Russell, Sandro Santagata, and Peter K. Sorger. Stitching and registering highly multiplexed whole-slide images of tissues and tumors using ASHLAR. *Bioinformatics (Oxford, England)*, 38(19): 4613–4621, September 2022. ISSN 1367-4811. doi: 10.1093/bioinformatics/btac544.

[10] Aidan O'Dwyer. A Summary of PI and PID Controller Tuning Rules for Processes with Time Delay. Part 1: PI Controller Tuning Rules. *IFAC Proceedings Volumes*, 33(4):159–164, April 2000. ISSN 1474-6670. doi: 10.1016/S1474-6670(17)38237-X. URL `https://www.sciencedirect.com/science/article/pii/S147466701738237X`.

[11] Sung-Hyok Ro and Se-Hun Kim. An image stitching algorithm for the mineralogical analysis. *Minerals Engineering*, 169:106968, August 2021. ISSN 0892-6875. doi: 10.1016/j.mineng.2021.106968. URL `https://www.sciencedirect.com/science/article/pii/S0892687521001977`.

[12] William J Robinson and Robert Evans. A MICROCOMPUTER -BASED TREE -RING MEASURING SYSTEM.

[13] Paul R. Sheppard. Dendroclimatology: extracting climate from trees. *WIREs Climate Change*, 1(3):343–352, 2010. ISSN 1757-7799. doi: 10.1002/wcc.42. URL `https://onlinelibrary.wiley.com/doi/abs/10.1002/wcc.42`. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/wcc.42.

[14] A. Park Williams, Joel Michaelsen, Steven W. Leavitt, and Christopher J. Still. Using Tree Rings to Predict the Response of Tree Growth to Climate Change in the Continental United States during the Twenty-First Century. December 2010. doi: 10.1175/2010EI362.1. URL `https://journals.ametsoc.org/view/journals/eint/14/19/2010ei362.1.xml`. Section: Earth Interactions.