1 Paper Outline

I. Abstract

  A. Flatbed scanner alternative with improved resolution to digitizing tree cookies and cores

  B. Digital twins of samples is important for building data repositories and promoting replicable science

  C. Digitizing wood samples has limits to sample dimensions or lacks affordable implementations

  D. Current alternatives are very expensive ($70,000USD), lack a high level of detail (printer scanners), or cannot scan cookies (CaptuRING)

  E. Tina is open source and able to be assembled with 3D printed parts, OpenBuilds parts kits, and hand tools

II. Introduction

  A. Tree ring science overview
    i. tree rings provide critical data/insights across multiple fields
    ii. tree rings can help reconstruct past climates (dendroclimatology)
    iii. understanding tree growth mechanisms (plant bio/ecology)

  B. Getting these data means measuring tree rings – quick history
    i. originally done on scopes (stage micrometer)
    ii. eventually there was a shift to analyzing digital images of samples instead of stage micrometers
    iii. digital copies inherently allow for contributing to data pools
    iv. Development of image acquisition in dendrochronology
      a. two models: flatbed scanner or overlapping images and stitch
      b. beginning with flatbed scanners
        modern flatbed scanners can achieve high resolution (4200 dpi) but size of samples is limited
      c. overlapping images and stitching
        ATRICS, Gigapixel, CaptuRING
      d. taking advantage of improving cameras and lenses allows for very high detail
      e. overtime this idea has expanded into other alternatives: expensive Gigapixel, DIY CaptuRING

  C. Main reasons to build this
    i. further develop the affordable / open source alternatives for scientific equipment
    ii. extend the capabilities of CaptuRING by allowing to stitch cookies and multiple samples in a queue
    iii. reduce the need for proprietary software such as PTGUI for image stitching
    iv. increase the maximum size of a sample
    v. Digitizing wood samples for better data pooling / archiving

  D. Here we tell you about our new device
    i. We review hardware and software
    ii. total cost
    iii. Then show how the method can be used to record annual growth through current common programs
    iv. allows for multiple cookies / cores to be added to a queue for sampling
    v. stitching on device

III. Materials and Methods

A. Guiding design considerations

  i. Digitization of a tree cookie and core
  ii. Minimizing barriers to assemble (Cost effective, open source, open hardware, minimal use of specialized equipment/tools)
  iii. Reducing user interaction between sample prep and the final image
  iv. Achieving near microscopic detail with a field of view as large as the sample

B. Considerations for Digitizing Cookies

  i. Inconsistencies in cookie preparation, (different height, non parallel faces)
     figure for inconsistencies
  ii. Cookie's surface area requires movement in the X and Y direction
  iii. The inconsistencies require movement in the Z direction to maintain in focus images

C. Hardware Design

  i. Biggest cost in most alternatives is a professional camera, choosing a Raspberry Pi HQ camera avoids this. The camera also has a definitive obscelescence statement
  ii. But to use a CSI camera, we need special hardware. NVIDIA Jetson Orin Nano fits the bill and has enough computational power to handle the image processing tasks while powering a monitor and GUI
  iii. Ideally all non-structural components could be purchased off the shelf and assembled. Fortunately complex geometries, dimensional accuracy, quick iteration speed, and cost effectiveness can be achieved with 3D printing
     Parts can easily be ordered from 3D printing shops but also has a low technical barrier for personal use
  iv. to combat sample inconsistencies, a levelling table and bullseye level were designed to make the prepared surface of the cookie closer to parallel to the XY plane
  v. for the structure, the 1m x 1m OpenBuilds ACRO system was used. This kit is made of strong aluminum extrusion, has 4.5 micron resolution of accuracy, and is assembled quickly by following OpenBuild's detailed video instructions.
  vi. For the Z axis a lead screw linear actuator was attached to the mounting plate of the ACRO

D. Software Design

  i. Everything was designed in Python
  ii. GUI to load samples and their identifiers to the queue to be digitized
  iii. image focusing
     a. A routine was made to take multiple images at varied Z-heights as a proxy for autofocusing. The image with the highest normalized variance score was chosen as the in focus image and is kept.
     b. Rather than moving the Z-axis, taking a photo, then moving again, the images are taken when the Z-axis is moving at constant velocity and are triggered with a time delay. Stopping and starting the Z-axis results in significant vibration blur in the image, requiring 2 to 3 seconds of inactivity after coming to a stop before taking an image
     c. It's possible for the height variation to exceed the range of the multiple images taken. A PID automatic control algorithm was used to make adjustments to the initial Z-height of the image stack. This is done by adjusting to keep the focused image in the center of the image stack
     d. figure for focusing
     e. figure for sample setup ideal/realistic
  iv. obtaining a large field of view with a grid of small field of view images
     a. When the sample is loaded into the machine, the machine traverses the user defined bounding box of the sample

b. It automatically takes a grid of images where each image has overlap with its adjacent neighbors

c. The overlap in the images allows for the images to be aligned and combined to their neighbors. Stitching an image to its neighbors is done by comparing calculated key points on each image and stitching them on their matches.

d. A python package Stitch2D was made to stitch together a grid from a set of structured images

We made changes to the package's stitching algorithm for memory efficiency as samples with thousands of images needed more RAM than what was available

e. figure for grid traverse

IV. Results

A. scans of cookies / cores

i. ultra high resolution scans (DPI 13,500 +)

ii. downscaled versions as high resolution is not necessary for all applications

iii. Digitization time and file size as a function of surface area. Large cookies can scan only a portion of the cookie including the center and half of the rings.

iv. large surface areas can produce files that are inconveniently large

B. File-size results in functional limits

i. max filesize for TIFF files is 2.5 GB

ii. other lossless filetypes for larger images are not compatible with standard image viewers

iii. workaround with NumPy memory maps and cropped viewing

C. Images/tables

i. Scale test image, proves the generated DPI calculation negates need to image with a ruler in frame

ii. Sample size vs image capturing time graph

iii. Hopefully sample size, dpi, automated tree ring time

iv. Table with results of Equation for uncompressed filesize, emphasize lossy vs lossless compression, and true filesize

V. Discussion (for MEE Only)

A. Quick overview (TODO)

i. X,Y,Z imaging machine which acts as a scanner

ii. obtains a grid of in focus images and slightly overlapping images which get stitched together to form one large mosaic

iii. designed for other labs with minimal engineering experience or equipment to build this for themselves

B. strengths and opportunities

i. Ability to capture multiple cores / cookies simultaneously

ii. cost effective

iii. vessel counting requires detail at the sub-vessel level

iv. tested on CooRecorder + CDendro

a. Maximum filesize

b. Coordinates were registered on to the cookie scans

c. Note to self: using CDendro for multiple samples from the same tree... (cookies)

v. tested on R-CNN for deep learning tree ring identification

a. potential for integration with a more powerful computer to automatically identify rings while imaging

b. potential for final stitched images to have rings automatically counted

c. Cookie with a dpi of SMALL and dpi of 13500 were tested. With total pixel count of SMALL and BIG

NEEDS specific: DPI, height and width of pixels, record runtime

NEEDS specifications of server computational power (GPU count/other metric for ANN power)

C. opportunities for improvements

i. Software support for large files than 2.5GB ¿

a. Not all software can support this, especially if the computer is RAM constrained. Ring analysis tool which uses BigTIFF, HD5, or memory maps and loads only partial portions of the full image would be useful

ii. Integration with automatic tree ring identification model

a. It would be interesting to analyze the images before stitching in a different thread to potentially stitch together a binary bitmap which highlight tree rings

b. This could potentially drop the need for a hypercomputer if inference could be made concurrently with the images being captured

iii. Identifying vessel counts in each growth year

D. Conclusions (optional for MEE)

i. empty