DEVELOPMENT AND TESTING OF AN X-RAY COMPUTED TOMOGRAPHY INSTRUMENT

Sean Quackenbush, CLASSE, Cornell University, Ithaca, NY 14853, U.S.A.

Abstract

This summer an experimental prototype was to be developed for Meredith Silberstein's geotextile experiment. A motor stage had to be constructed so that a textile held in place could be stretched and then rotated while staying within a hutch's x-ray beam. Designing, testing, and calibrating the prototype as well as finding any error played a key spotlight in this summer project.

INTRODUCTION

The experiment is to test geotextiles, which are mainly used in soil management and erosion control. Testing the tensile strength and how the fibers move when stretched is a task that can be done with computed tomography at CHESS. By passing monochromatic x-rays through the textile we can use a scintillator and optics to obtain a highly magnified image of the fibers in the textile based off absorption imaging. By combining many of these images at different angles we can construct a 3-D image of the textiles; computed tomography. To understand what happens when the fibers are stressed we will stretch them at different forces and distances and re-image the changed fiber patterns and see what happens to the textile as it was stretched. Figure 1 is the experimental setup [1]. The rotation stage and dual actuator (tensile load frame) is the prototype to be built, the design will be different than what is shown.

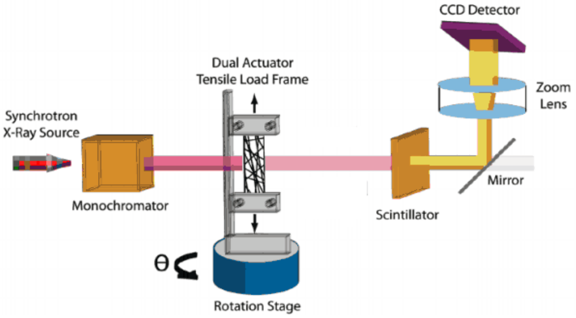


Figure 1: Meredith Silberstein's experimental proposal.

THEORY

X-rays from the wigglers in the synchrotron will enter into the hutch through a monochromator and the geotextile will absorb, scatter or let the x-rays pass through. Using a scintillator the x-rays that were not absorbed or scattered by the sample will cause viable light to be produced that we will reflect through a zooming lens and shine into our detector. We use this round about method of x-ray to light florescence because we can magnify and reflect light easier, leading to a sharper and larger image, and because putting a detector directly in the path of the x-rays could damage it.

By taking many images of the sample at different angles we can build a 3-D image through computed tomography. Figure 2 shows a sinogram demonstrating the ideas of computed tomography [2]. By tracing back a common point on each absorption image a singular point is shared in common for each image. By going through at every single pixel in the absorption images a full 2-D image can be obtained of the object imaged. Building up 2-D planes can then give us a 3-D image.

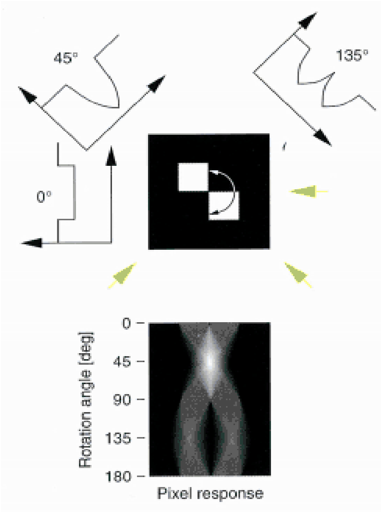


Figure 2: At different angles the absorption image is different based on what the x-rays passed through, the sinogram is a graphical representation of the images at each angle.

HARDWARE

To run this experiment we will need a stage to load the textile, stretch it and rotate it for imaging within the experiment hutch. The motors commonly used at CHESS are stepper motors. One step corresponds to a electromagnet turning on and rotating a gear a small amount. We can use 6 of these motors to control the x-axis, z-axis, and the rotation stages. SPEC controls the motors we use. By going into the config file we can tell SPEC how many steps it takes for the motor to make one full rotation, and how many rotations it takes for the motor to move the stage either a degree or millimeter. It turns out that it takes 2000 steps to move a degree and 5520 steps to move a mm. In the config file of SPEC we can tell it to move the stages at a certain speed, put limits on how far it can move and assign each motor to its own channel. Using SPEC it is possible to move motors, use a counter to pick up a voltage (useful for a later part of the prototype), and use macros to move stages/motors together to synchronize movement like pulling apart at the same distance/speed and rotating the object together.

PROTOTYPE DESIGN

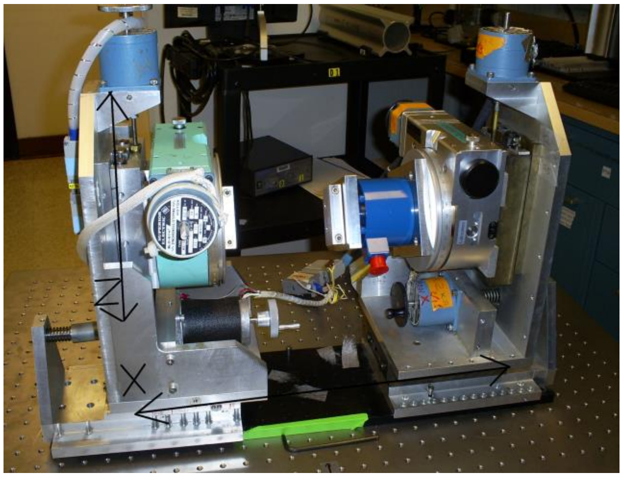


Figure 3 : The experimental prototype DUMI.

Figure 3 is our prototype DUMI (Dummy) (DUal Motor Imaging). A horizontal design was thought up to simplify the tensile load frame. Two translation stages that can pull apart from each other would provide the stretching needed, 2 translation stages on the z-axis to align the sample to the x-ray beam, and two rotational stages above would provide the rotation for imaging. An earlier version of DUMI was designed before this, however many errors and problems were present in that design. Stress, improper alignment and poor dimensions led to the refinement of this final version of DUMI. There are two separate pieces of the prototype, the left and right side. This is needed so we can pull the two stages apart from one another and still have a axis of rotation attached so we can spin the sample.

Clamping the textile to the stages was another consideration to take into account. A commercial clamp was considered to be bought but in the end two pieces of aluminum screwed together would work as well to hold the textile in place.

With being able to pull and spin reliably, we then also want to know the force applied to the textile. A load cell from the supplier Interface will be able to help us calculate the force exerted by the tension. The load cell takes any force exerted on its sensor and sends out a voltage linearly related to the force. Because it came pretested we know that the linear coefficient in converting voltage to force is 20.54 lbs/V.

TESTING

We want to know a few things about the how the textile rips that we can test without needing an x-ray source. Plotting the force vs. Distance we stretch the textile and it will give us Figure 4 below. We can see that as the textile is stretched tension builds up to a peak, and then it fails and rips relieving some tension until the fibers slowly break and the textile is fully ripped.

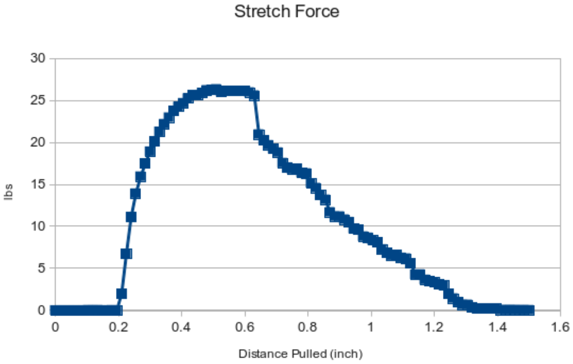


Figure 4: Graph of force vs. Distance stretched shows a buildup of tension until a tear forms and tension slowly is relieved by fibers breaking.

Another thing we can do is take a high magnification image of the textile in the prototype and stretch it and spin it to see if it will remain centered when a x-ray beam would normally image it, as seen in Figure 5 below.

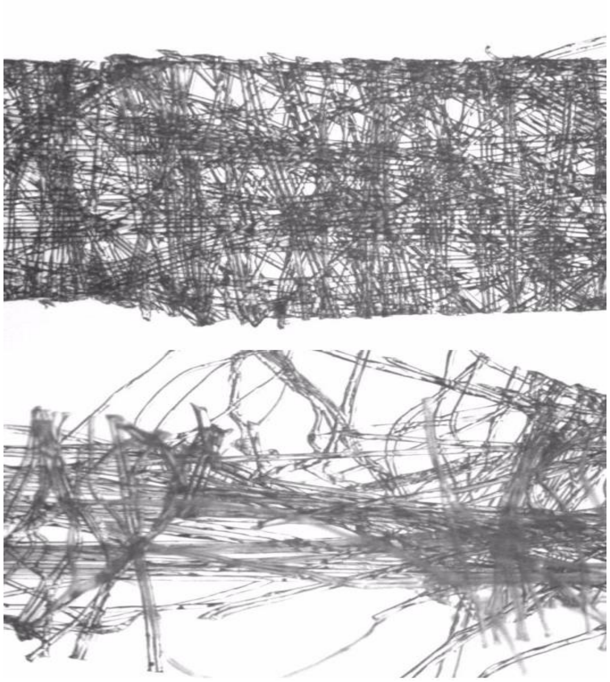


Figure 5: Shows a zoomed in image of the textile being stretched. We can see that the center remains in the center of the image, meaning that x-ray imaging is possible.

The breaking point of the geotextile seems to remain centered in the image as it is stretched. This shows that the stretching aspect of the prototype is accurate. When rotated a video was captured that showed the textile rotating around an axis within the textile. We can focus on one point in the textile so it is centered while spinning and stretched.

One problem we may encounter is the relaxation of the fibers as seen in Figure 6. As we pull the textile the fibers are tensed and tangle with each other, the fibers are also thermally fused to one another. If at any given point in the stretching process the textile were to stop the individual fibers would slowly break free of one another and relax, thereby releasing the tension of the fabric. If we want to image the textile during a stretch we would have to stop the stretch and image. The imaging process takes time and therefore the force we stopped it at would slowly and the fibers move in the imaging process which may cause difficulties. Errors induced by unexpected movements should be accounted for.

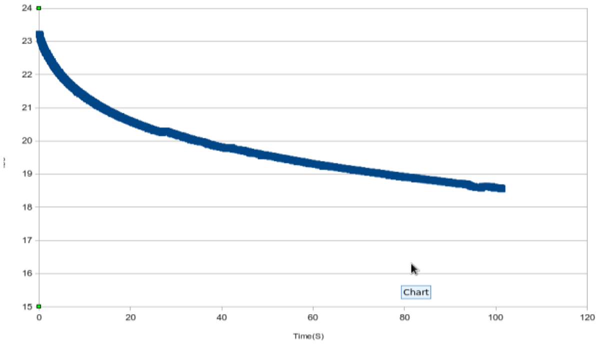


Figure 6: Shows the force vs. Time of a stretched textile. The exponential drop in force is due to the fibers relaxing and rearranging.

ERROR

Many errors would influence any imaging we might want to do, alignment stress and other errors would mean our images would not sync to obtain the 2-D or 3-D images that we want. In order to solve this problem we can look into where error is introduced. We want to make sure that the planes of direction in the different motor axes are not wandering off axis. In other words we want to make sure that the direction we pull a motor stage in is aligned with the axis it should be. Also needed is to make sure the rotational stages turn together and are parallel with each other so the sample does not have an angle or movement within the x-ray beam.

Data was collected with a dial indicator; small changes in position can be measured as we move a motor stage. When the x-axis motors were pulled apart, the stretching axis, the motors did drift in the y and z axis. The right motor drifted 6 microns in the y axis and 70 microns in the z axis, while the left motor drifted 11 microns in the y axis and 33 microns in the z axis. This is fairly small error, as the x-motors pull the stages apart the alignment would stay within a tenth of a millimeter, because the x-ray beam and textile width is on a few orders of magnitude greater it is not our biggest problem. We also tested the rotational stages for any x variation, that is did the axis of rotation change. The right motor shows the 70 microns in x-axis change and left showed 4 microns of change. These readings were taken at the edge of the rotational plate, while at the center the axis of rotation shift is about .0001 degrees of change, exceptionally small. We can be assured that the rotational stages spin parallel to the x-axis as we want.

Another thing tested was if the axis of rotation change when the x-stages are moved into a stretching position. Using the high magnification camera we can measure how the run out of a pin aligned with the axis of rotation changes. The right axis only changed by .651 microns and the left 11 microns when the x stages moved back 1 inch.

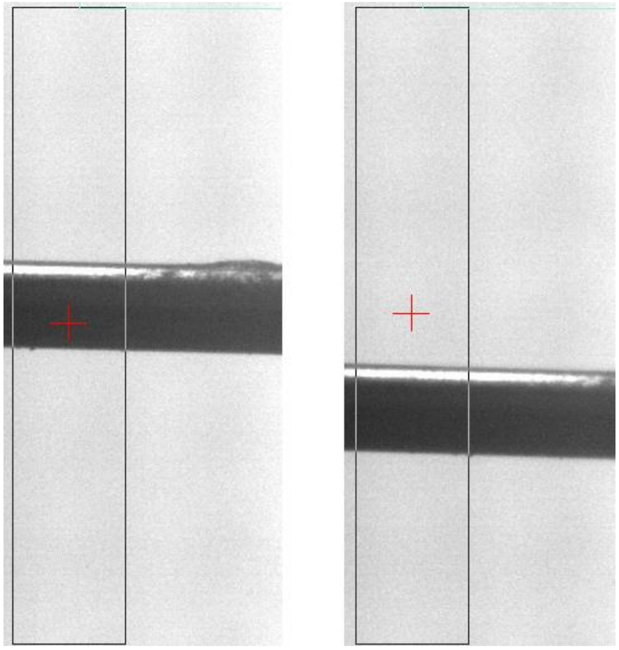


Figure 7: Left is a pin aligned to the center of rotation under no stress. Right is same pin but with 40 lbs of stress. The center of rotation is noticeably pulled downwards.

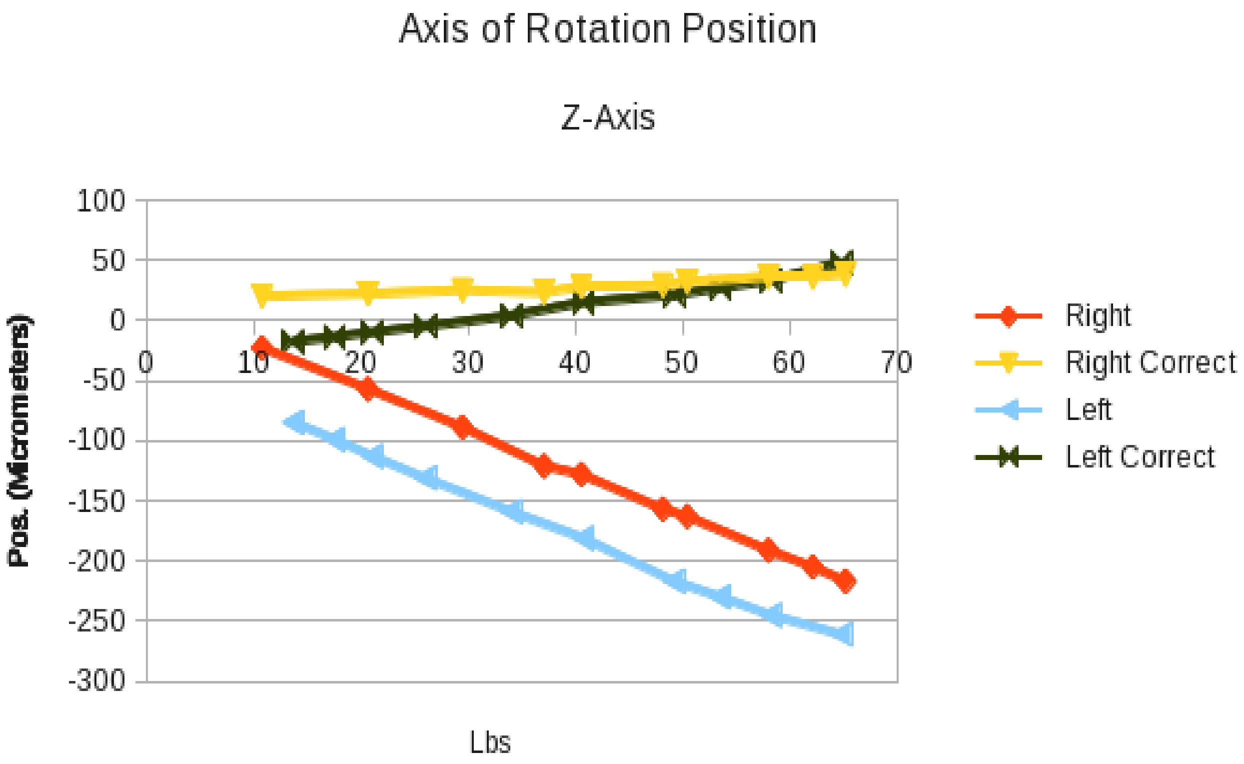
The biggest error is the stress on the system when the textile is stretched. The ball bearings used for the x-axis motors are between the rotational and translation stages. The clamps where the textile is stretched is about 4 inches above the interface, and with around 20 to 40 lbs of force the system will experience torque. As a result the center of rotation where the textile would be is pulled downwards as seen in Figure 7.

Both rotational stages actually experience a different downward pull, not only will the sample be pulled out of the beam, but the two axis's of rotation will also be misaligned. This is the one source of error that will definitely make imaging impossible.

CORRECTING

To solve this misalignment problem we can use SPEC to move the motors in the z-direction back to where they should be. Reading off the load cell we can plug the voltage into SPEC and convert it into force. Taking the data from the misaligned stress vs. Position data we can find the slope of the graph. Using a known force on the system and our slope we can say that our slope divided by

Figure 8: Graph of the center of rotation z position vs. the force applied. Pre-corrected and post-corrected for left and right are shown.



the force should give us the deflected position of the center of rotation and move the stage up to where it needs to be.

We can use SPEC to do this all with one command. We can have it count the voltage, convert it into lbs and then into microns and have a move command to move the motor to the correct position.

```
Def  correct right '
        count_em 1
        w
        get_counts
        w
        mv rightz S[ICR]*20.54/100000*(slope)
```

this definition of correct will count for 1 second, put the value in the S[] array and then move the right z motor be the counted voltage, convert it into lbs, divide by 100000 due to the way SPEC calculates the voltage, and then times this lbs by microns/lbs and it should leave us with the motor at a the correct value.

Figure 8 shows our data for our attempt to correct the data. We went from the wildly uncorrected red and blue line for right and left, and corrected it to green and yellow. While not exactly at zero, with a better slope value we can in the future have the alignment correct itself when the stages are under stress.

CONCLUSION

Overall this summer has been a success for the project. The prototype has been built so that we can stretch and rotate our sample to image it at different tensions. The errors analyzed so far have been small. The biggest source of error in the deflection due to the stress has nearly been corrected to the point of a non-issue. Using the high magnification camera we simulated what the x-ray would see and the stretching and rotational alignment appears to be satisfactory. The future of the prototype lies in more corrections of the small misalignment in the stages and a full proof of concept imaging session in the x-ray source. While the prototype was only built to test the feasibility of a horizontal setup, it may go on into early testing of textiles.

ACKNOWLEDGMENTS

Special acknowledgments go out to Ernest Fontes, Margaret Koker, Meredith Silberstein, Naigeng Chen, Robin Baur, Chris Conolly, Mike Cook, Peter Revesz, Phil Sorensen, and Jerry Houghton.

This work is supported by the National Science Foundation under Grant No. 0841213 and DMR-0936384.

REFERENCES

[1] Meredith Silberstein, (2013).
[2] An Introduction to Synchrotron Radiation by P. Willmott (2011)