DLA Report 7

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7 December 2021

1 Description of what was done

1.1 Summary

For this report, I processed multiple different waves in a glass tray. I processed the least noisy images and placed them in a folder to view. The problem with the image sloping re-appeared, but was resolved using software, which is what Moisy (the original FS-SS author) did as well. I also found how to account for the glass/acrylic in Moisy's paper as well. As an aside, I cut the acrylic into four pieces as was requested in the last meeting. From here, I need to resolve a problem I encountered with the water drops structure and then begin work on setting up the water table.

1.2 Cutting the Acrylic

In our last meeting, Jeffrey mentioned that he might need the acrylic cut into four pieces by that Thursday. I ended up having time to cut the acrylic by 11am that Thursday.

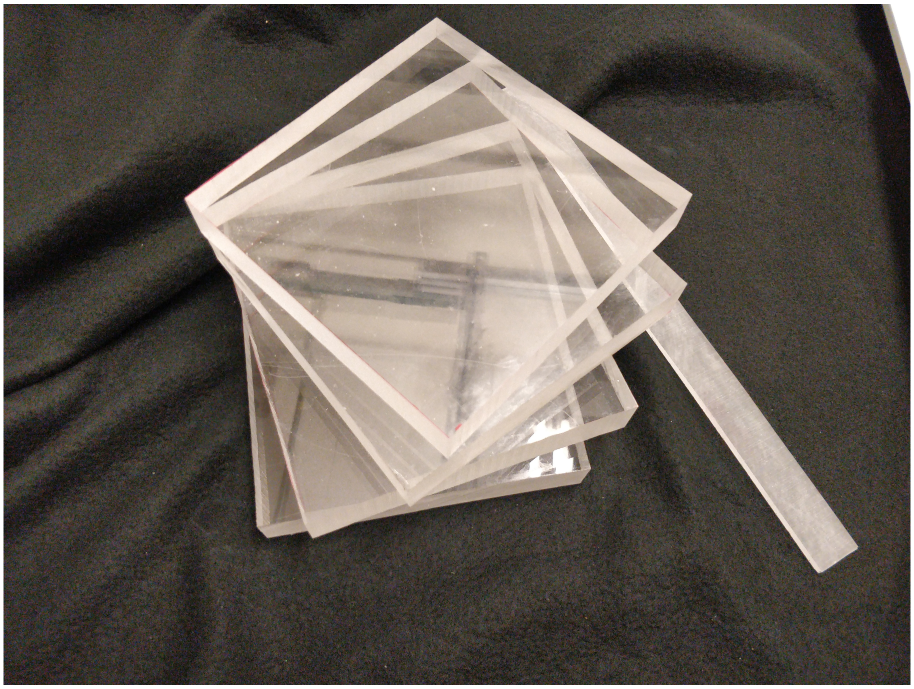

Figure 1: Cut Acrylic

1.3 Experimentation

In my previous reports, I focused on taking images of plane waves. For this report, my goal was to take images of waves that were not plane waves. I had one trial of three images with plane waves just to make sure I was receiving similar results as before; I also had one trial of three images with random waves; I processed nine trials of water drops out of the thirteen I took (I didn't have time to finish all of them); and I also took one pair of images of the glass tray with no water. Please note that images ending in `_flat` account for sloping and the glass/acrylic layer whereas other images do not.

Please go to the following link to view the various images! Each surface height image is paired with a set of still and moving water images used to generate the surface height.

1.4 The Return of Slope

During the creation of the surface heights, I noticed the water droplet images had slopes to them. Annoyed, I did some internet surfing to find that other research papers have a similar problem.

Moisy (2009) states: "It is worth noting that some vibrations in the optical setup may have a strong influence on the reconstructed surface height. In our experiments, vibrations in the camera position due to the internal cooling fan were found to produce an apparent circular translation of the image of about 5 μm (about 0.1 pixel) when imaging at a distance of 2 m. Although very weak, the resulting uniform displacement field, once integrated, produces a noticeable mean slope which superimposes to the measured height field. This uniform displacement can be readily subtracted before integration, but prevents from the measurement of slopes of characteristic length of the order or larger than the imaged area."

A recent synthetic schlieren paper by Li et al. (2021) found that camera vibrations resulted in "relative error up to approximately 30%". They recommend having the center of the image for measuring surface height and the outer edges to contain still objects.

All of this is to say that slanting might not be possible to remove experimentally and other techniques are necessary. I have already implemented Li et al.'s suggestion of using objects outside of the water to stabilize the images through image registration. Compare the following pairs of images, which is the surface height reconstruction of just the glass tray with no water. We expect the reconstructions to be flat.

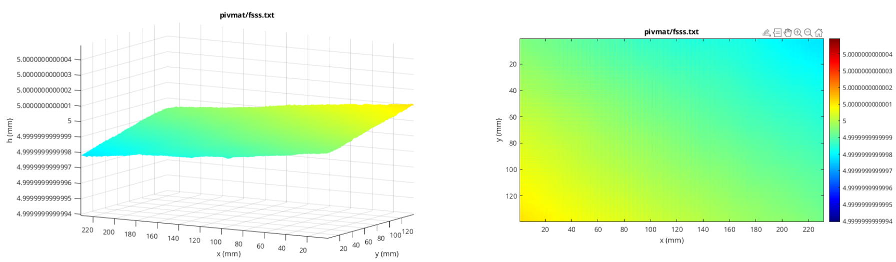

Figure 2: No Image Registration (same image)

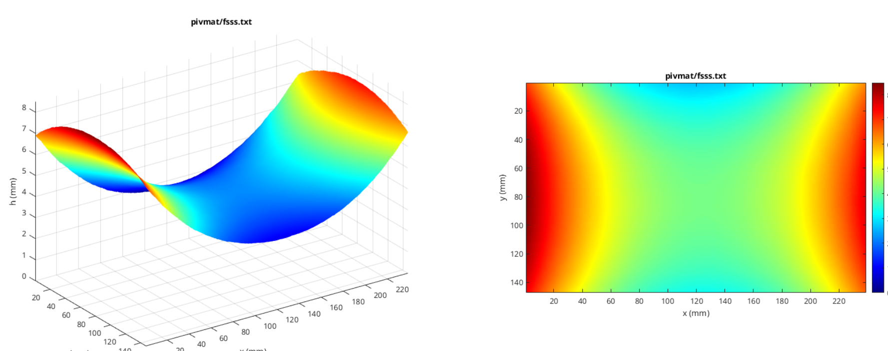

Figure 3: No Image Registration (two images 20s apart)

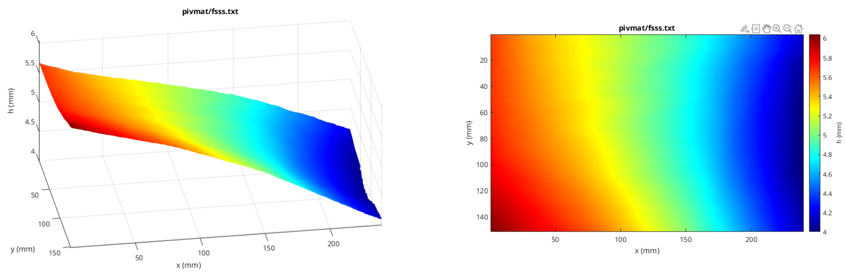

Figure 4: Non-Reflective Similarity Image Registration (two images 20s apart)

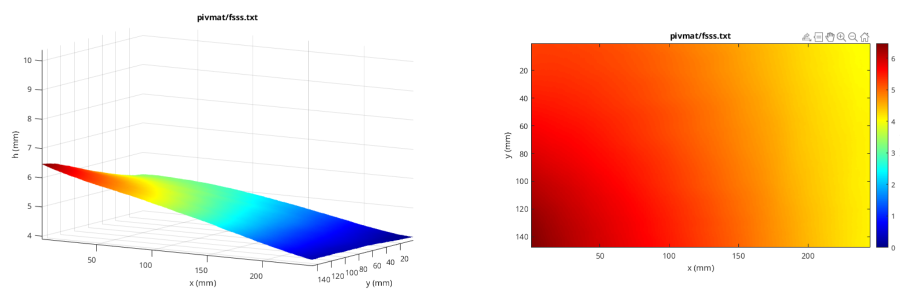

Figure 5: Projective Image Registration (two images 20s apart)

As you can see, clearly something changes in pixel locations between camera shots. The two images used for surface reconstruction were spaced 20 seconds apart, yet 3 has an interesting non-flat structure (a saddle). Both the projective and non-reflective similarity image registration techniques resulted in flatter, more accurate reconstructions, though the non-reflective similarity surface was more accurate (resulting in a smaller height difference between its maximum and minimum).

It's also clear that image registration isn't enough to fix the problem of slanting in the surface reconstructions, so I implemented a solution in MATLAB.

1.5 Fixing slope

The solution I decided to implement to resolve sloping is the one Moisy recommends, where I extract the slope as a plane and subtract it from the surface reconstruction. To do so, I fit a plane to four in the corners of the surface reconstruction, subtract the plane from the surface reconstruction, and add the average height subtracted from the plane back to the surface reconstruction. This removes the sloping effect from the surface heights and keeps the average height of the surface.

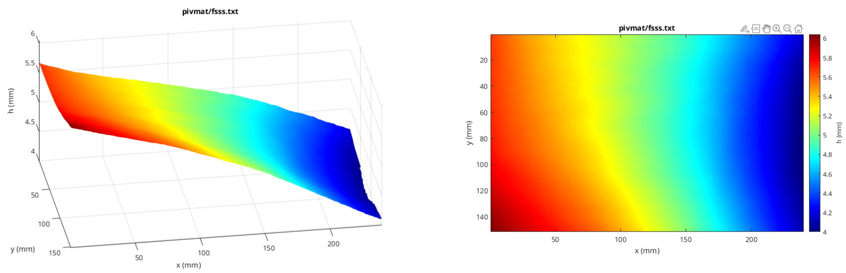

Figure 6: No water before adjusting for slope

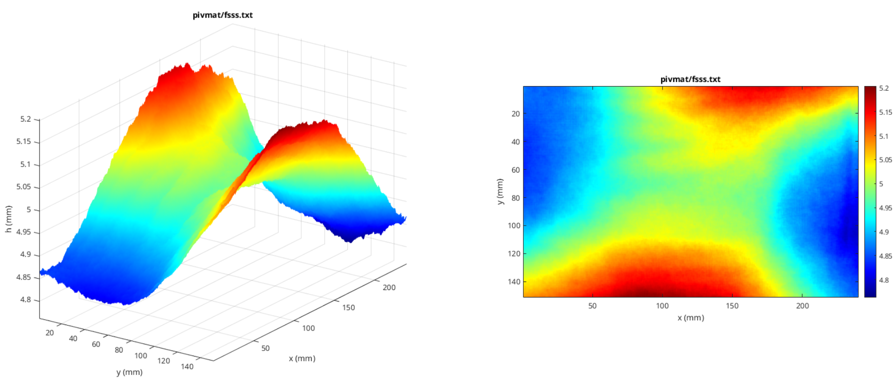

Figure 7: No water after adjusting for slope

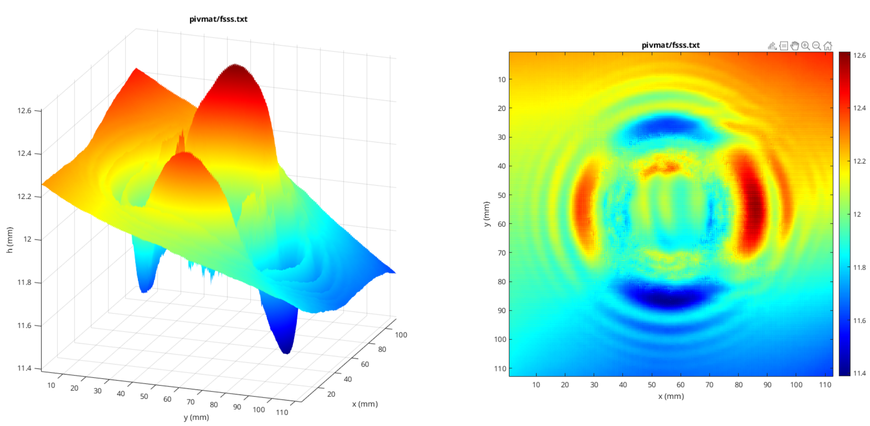

Figure 8: Water drop before adjusting for slope

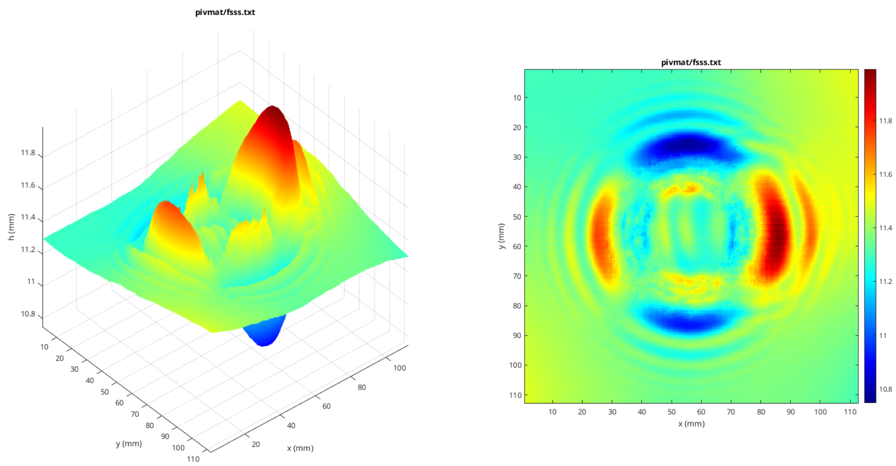

Figure 9: Water drop after adjusting for slope

(Please disregard the change in heights for figures 8 and 9, figure 8 did not yet implement the following section's solution to accounting for glass/acrylic, resulting in a height discrepancy)

From the no water images it's clear that this post-processing reduces error in the final image reconstruction, from around 1.5mm to around 0.35mm. Clearly, however, this is not a perfect solution as there is still some error.

Please note that this solution will only work if we have at least three points in our images from which we can reliably construct a plane. Images that have waves across the entire surface won't allow this to happen. Due to this, the water drops are good examples of removing the sloping while the plane wave and random waves are not. We need to keep this in mind when imaging on the water table.

1.6 Water Drops Structure

As can be seen in 9 and the other water drops, there appears to be an emergent structure that one does not expect physically. In all the water drops, there are two global minima and two global maxima. The minima occur along the y-axis from the center of the water drop and the maxima occur along the x-axis from the center of the water drop. The diagonal directions from the center of the water drop seem to be flat. We'd expect concentric circles centered in the middle of the water drop instead. I need to look into the software and reference images further to resolve the problem, since it could impact other images we take in the future.

1.7 Accounting for Glass/Acrylic

I mentioned in my previous reports that we should account for the layer of acrylic/glass between the pattern and water for our experiments. This is addressed in Moisy's paper on FS-SS. All that needs to be done is set the surface-pattern distance h_p by the following equation:

$$h_p = h_0 + \frac{n'}{n_g} h_g \tag{1}$$

where h_0 is the water depth, n' is the index of refraction of water, and n_g is the index of refraction of glass. This finds an *effective* surface-pattern distance by accounting for the additional layer between the water and the pattern. Then, in *pivmat* all that's necessary is to use this new value for h_p. Note that the equation can be expanded to account for an air gap between the pattern and the glass/acrylic as well. I did not include it here since I assume we won't be including such a gap. This change in h_p allows the software to more accurately reconstruct the shape of the waves.

2 Description of Next Steps

The first step I need to take after this is to resolve the problem with the water drops. The step after that would be to set up the water table. There are some adjustments I could focus on with the glass tray set up, from minimizing vibrations on the tripod to optimizing the software removing slope, but this would be better served in the final environment we hope to be working in. Setting up the water table will also allow me to begin working on smoothing the surfaces as well, since I will be able to take many pictures of the same water surface.

3 Questions

- Are there any other ideas as to how to reduce slope in software during post-processing?
- Are there any ideas as to how to reduce vibrations in the camera to minimize error?
- Any ideas as to why figure 3 has a saddle shape? It seems too defined to just be a coincidence.