2d Lt Aaron Bonner

Image Registration and Polarization

1. Prompt

Find the scaling in both the horizontal and vertical directions as well as the rotational angle and translational shifts that will match the image created by Starry Night of the moon on March 14, 2025 at 240AM with images of the moon taken at the same time. Provide a visual side by side comparison of the two images once they are fully registered.

2. Data Representation

For this project three datasets were provided. Two of the datasets consist of sets of real imagery take of the moon, and the last dataset was a simulated image of the moon that had the same parameters as the real imagery. The first frame of each dataset is shown in Figure 1.

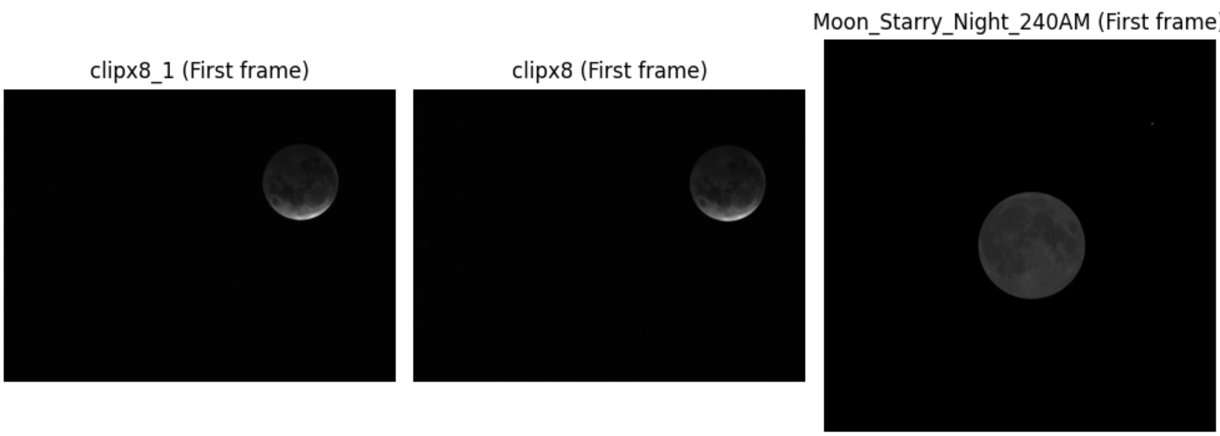

Figure 1. First frame in each dataset.

When the data was loaded into the program, the two sets of real imagery were combined into a single variable containing 105 images at a resolution of 2472x3296. The simulated dataset contained one image with a resolution of 757 by 757. Visually analyzing the differences between the sets of images indicates that pre-processing will be required for both datasets to properly register the simulated data to fit the captured data. The two datasets have different resolutions as well as the moon being in different locations in the existing images.

3. Data Processing and Interpolation

The step in data processing was to align and consolidate the captured images. The fundamental process used for this step was the $phase\_cross\_correlation()$ function from the $skimage.registation$ Python library. This function provided a shift estimate in the Fourier domain when provided with a reference image and a moving image. For this step the first frame in the captured moon data was used as the reference. Once the shift estimate was calculated, the moving image was converted to the Fourier domain, shifted, then converted back to the spatial domain. For the programmatic implementation of this alignment function, initially it was performed one frame at a time taking approximately three minutes. To aid in future performance, it was then converted to be multi-threaded and use 100% of the CPU, bringing the final calculation time to approximately 30 seconds.

Following the alignment process, the mean of the dataset was taken to generate the average frame captured, shown in Figure 2.

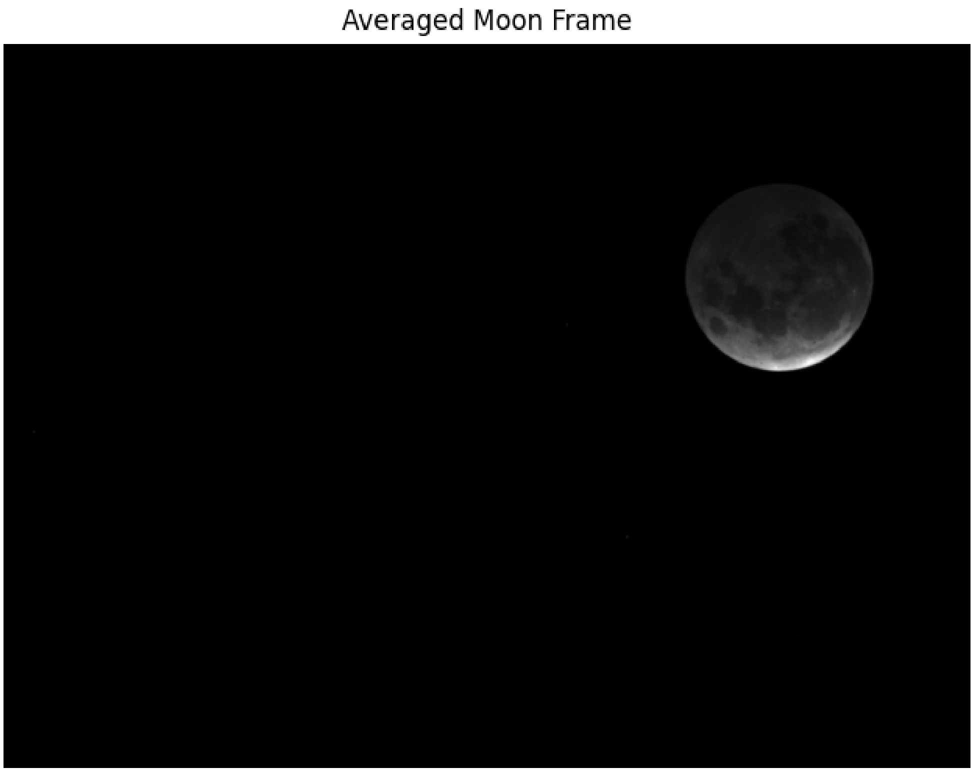

Figure 2. Averaged moon frame after alignment.

Additionally, to eliminate the background, the median of the frame was subtracted from itself. Following this procedure, any negative value was set to 0.

Next, the simulated image had to be processed. The two primary discrepancies were that the image resolution did not match the captured moon data, and it was in the center of the frame.

To address the image resolution, Fourier interpolation was implemented. The upscaling size was dynamically calculated to best fit the dimensions of the captured Moon data. A complex array of the desired size was created, and the 2D Fourier Transform of the Starry Night image was placed in the center. The array was then inversely Fourier Transformed, preserving only the real components, resulting in an interpolated image at the new resolution as seen in Figure 3.

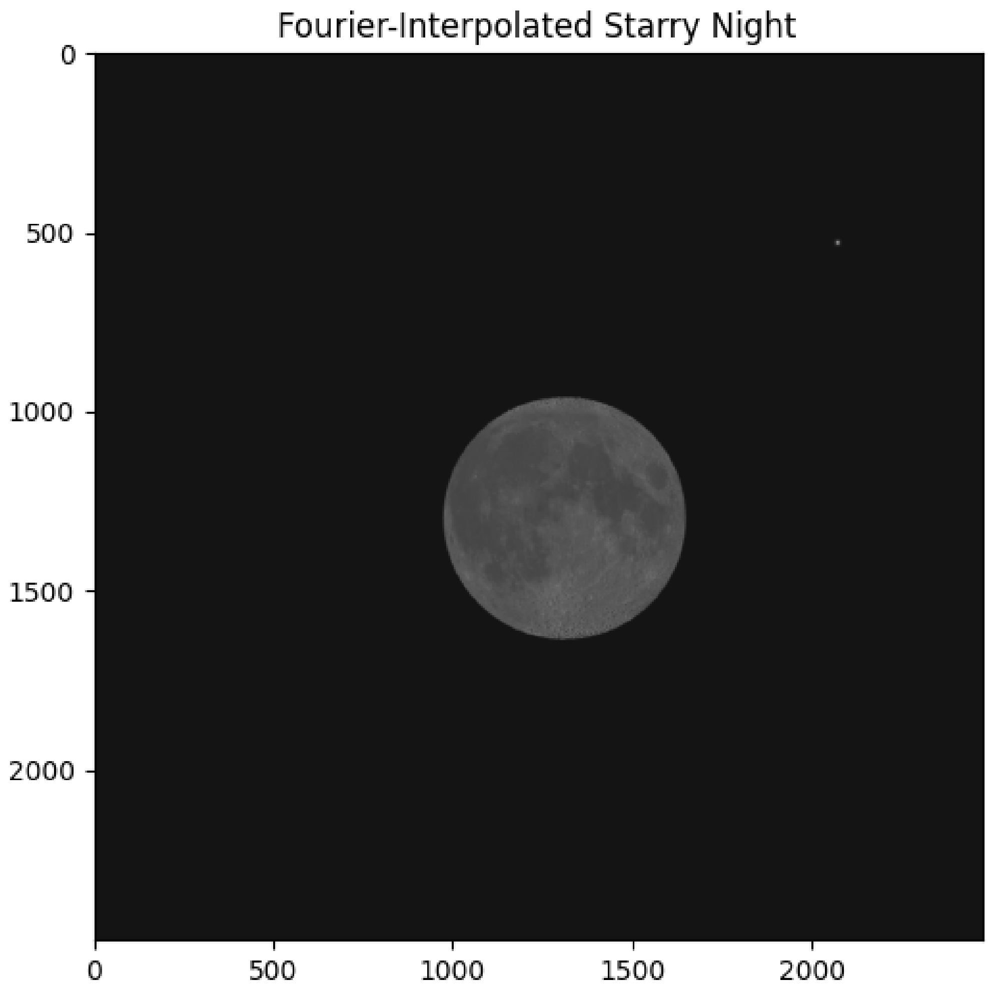

Figure 3. The upscaled Starry Night image.

This image matched the vertical resolution of the captured data, but did not match the horizontal resolution. To fix this, 412 pixels were added to the image using the $np.pad$ function with the $constant$ parameter for the mode.

4. Registration

Now that the two images had the same resolution, the next step was to find the scale, shift, and rotation required for the moon data to match the padded simulated data.

First, the two datasets were converted to the frequency domain, and their magnitudes were calculated. Next, the data was converted to log-polar form with the $warp\_polar()$

function with the scaling parameter set to log. Then, the polar shift was calculated with the $phase\_cross\_correlation()$ function using the simulated data as the reference frame. The rotation and scale factors were then calculated using the output of the previous function call and applied to the moon data. Then, the function was called again to calculate the translation shift, which was then applied to the moon data as it converted back to spatial domain with an inverse Fourier transform. The final registered moon image compared to the reference simulated data is shown in Figure 4.

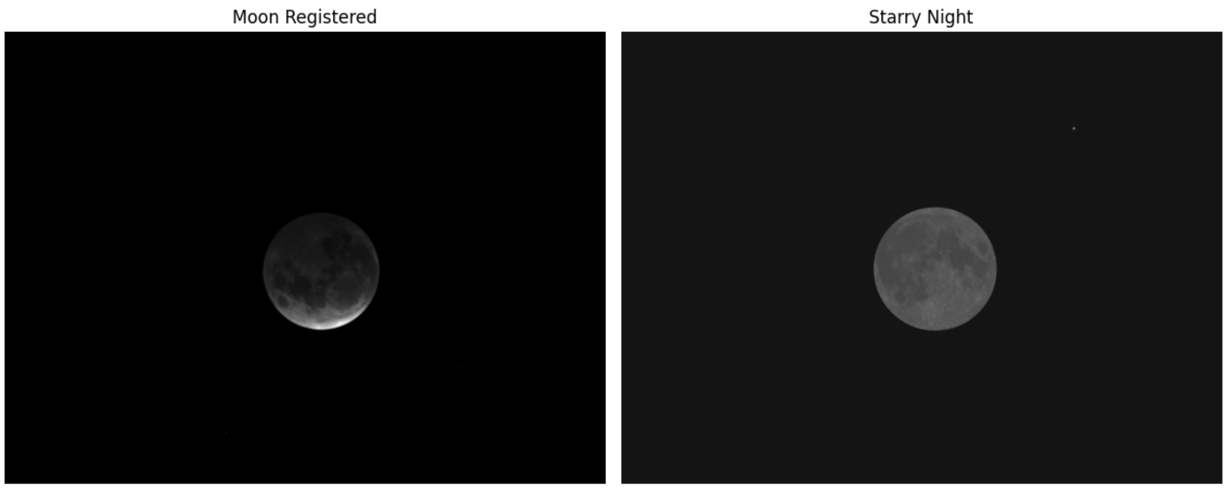

Figure 4. Registered moon data next to the reference simulated data

During the registration process, the values for the scale, rotation, and shift were found. The scale factor for both the X and Y axis was found to be 1.000, which makes sense given the distance to the moon is so great that any small discrepancy between the simulated and captured data would be inconsequential given the sampling rate used. The rotation was found to be $0.02°$, which also is reasonable given the previous argument. The shift in pixels space was found to be -908.80 for the X dimension, and 508.70 for the Y dimension, which makes sense given the moon was in a significantly different location in each dataset.