Moon Panorama

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***Abstract*—In this project, we take an image of a moon crater from NASA, which consists of several photos stitched together. However, the stitching of the different photos is still visible; we try to remove this artefact by creating a custom filter. Followed by this, we implement the same operation to a graffiti image by slightly modifying the filter.**

I. Introduction

MOON, our closest companion in the solar system, has been a source of curiosity for earthlings. It was used to navigate at night and keep track of time. Poets used the moon to draw inspiration for their poetry, while astrologers interpreted solar eclipses as a bad omen [1]. In one way or other, the moon has been a part of recorded and unrecorded human history. It was out of curiosity that Galileo —after learning about *Dutch Perspective Glasses* in the 1600s — within days had designed a telescope of his own, that too without ever seeing one. He recorded his observations of the moon as hand-drawn sketches shown in Figure 1. Galileo noticed that moon also has mountains and craters, just like earth. Craters are bowl-shaped depressions on heavenly bodies made as a result of powerful impacts from meteorites. They give us a sneak peek into the geological history of the stellar object and the solar system's past, present and future.

Our ways of looking at the moon and recording observations have changed with scientific advancement. Now we use much more powerful telescopes and cameras. NASA is one of the leading organisations in cosmic observations and photography. With state-of-the-art telescopes, scientists at NASA have captured clearer, sharp, and close-up photographs of the moon and its craters. A picture of one of the craters of the moon taken by NASA is shown in Figure 2. In fact, this picture was created by stitching together 10 panoramas. The artefacts of stitching the panoramas together are visible in the photograph as horizontal lines.

II. Methodology, Results and Discussion

We try to remove these stitching artefacts from the picture using *Octave* as our image processing tool. We create a custom filter that removes the frequencies corresponding to the stitching in the Fourier domain. The complete process has been divided into five steps for a better understanding.

A. Image Loading and Plotting

First, we load the image in octave using the built-in function *imread*. Since the image we are using is black-and-white/grey-scale, octave reads it as a $2D$ rectangular array of $M \times N$ size. We store the number of rows as Nr and the number of columns as Nc for later use. We plot the image using $imagesc$ function. Image produced by octave using the following lines of code is shown in figure 3.

```
[Image1]  = imread('MoonCrater.jpg');
[Nr Nc]   = size(Image1);
graph1    = imagesc(Image1);
colormap('gray');
colorbar();
```

Stitches between different photos appear as bright horizontal lines similar to the original image. We can safely say that loading and plotting the image in octave has done no harm to the image or the information present in the image.

B. Fourier Transform(FT) of Image

Since the image is $2D$, we need to perform FT in $2D$. For this purpose, we use the built-in octave function called $fft2$, which uses the Fast Fourier Transform algorithm to compute $2D$ discrete FT. Following this, we use $fftshift$ to move the low frequencies to the centre of the matrix [2]. The resulting matrix is a complex matrix. We plot the absolute values of the matrix elements and use the decibel scale for better visualisation. The resulting FT using the following code is shown in figure 4.

```
CF      = fftshift(fft2(Image1));
CF2     = log10(abs(CF));
graph2  = imagesc(CF2);
colormap('gray');
colorbar();
```

There are two main features visible in the FT. We see a sharp horizontal line and a sharp vertical line. These two lines are not the same. What seems to be the vertical line is actually not a line but is closely placed abrupt changes in the frequency. They are better visualised when plotted in $3D$. The vertical line in figure 4 corresponds to the unnatural peaks highlighted in red in figure 5. These peaks are the artefacts of the stitching that we want to remove.

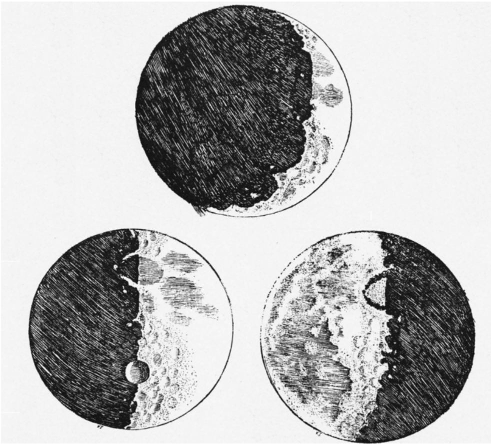

Figure 1: Galilio's hand-drawn sketches of moon [3].

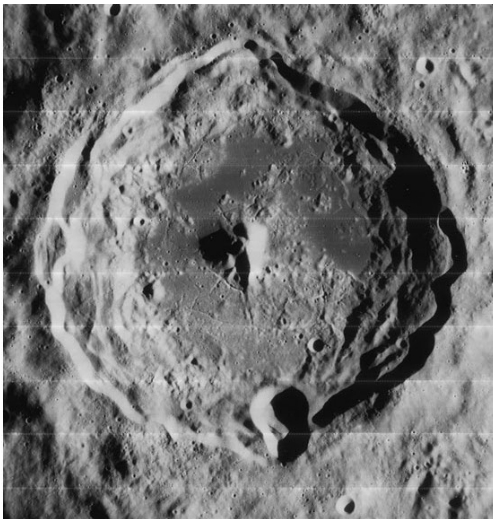

Figure 2: Image of moon crater captured by NASA.

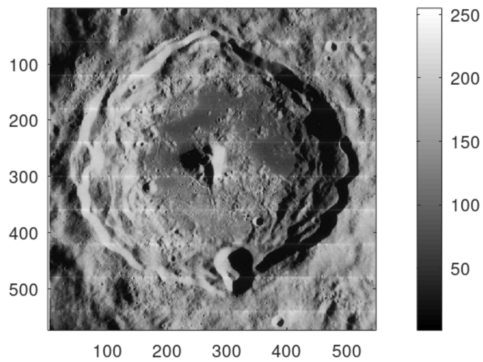

Figure 3: Image of moon crater produced using matrix.

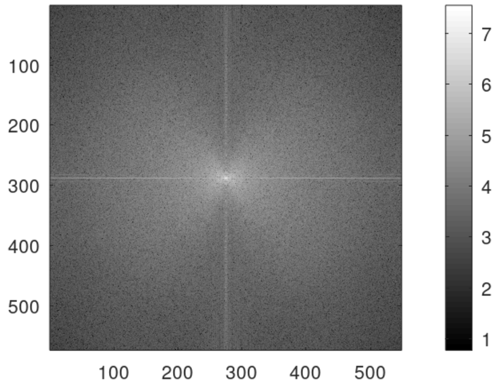

Figure 4: FT of figure 3.

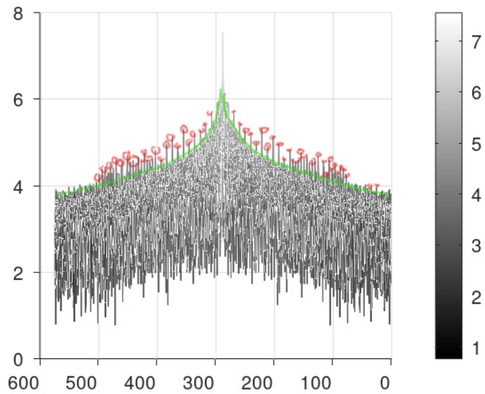

Figure 5: FT of figure 3.

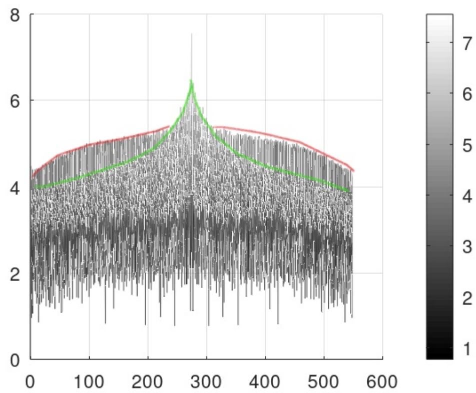

Figure 6: FT of figure 3.

The horizontal line shown in figure 4 differs from the one we discussed in the previous paragraph. It is not an artefact of the stitching; rather, it is the result of a thin white line on the left side of the image of the crater(figure 3) we used. Unlike the artefacts of stitching, as shown in figure 6, this line adds an almost constant increment to what would have been the natural frequencies of the image.

C. Custom Filter Creation

To remove the stitching artefacts, we need to remove the corresponding frequencies from the Fourier domain. We design a custom filter to accomplish this task. We initiate a matrix of ones that has the same size as the original image size and then change those elements of the matrix to zero, where we want to remove the frequency. We also do not want to remove the very central part of the FT, as it contains most of the information in the form of low frequencies. The desired filter we created using the following code is shown in figure 7.

```
FW  = 2;
RS  = 6;
MyF = ones(Nr,Nc);
for i=1:Nr
  for j=1:Nc
    if((i<(Nr/2 -RS) || i>(Nr/2 + RS)) &&...
      ... (j >(Nc/2 - FW) && j<(Nc/2 + FW)));
      MyF(i,j) = 0;
    end
  end
end
graph3 = imagesc(MyF);
colormap('gray');
colorbar();
```

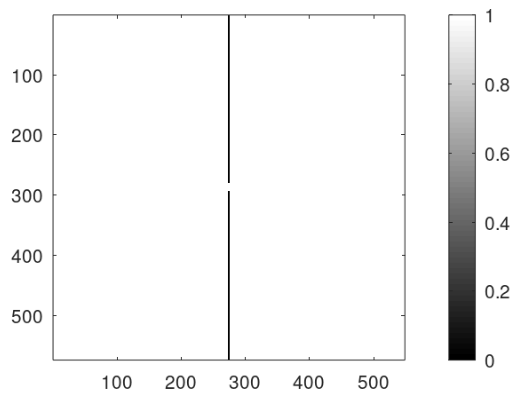

Figure 7: Custom filter for image processing.

We can adjust the filter width (FW) and row skip (RS) to increase/decrease the number of frequencies we want to remove. Making RS very small will remove the low frequencies; if we make it very large, we might retain some artefacts. So we adjust it according to what we see in the FT of the image. Similarly, increasing the size of the FW could introduce some unwanted results.

D. Testing the Filter

Now we can apply the filter we have created to the FT we obtained in figure 4.

```
MyFFT   = MyF.*CF2;
graaph4 = imagesc(MyFFT);
colormap('gray');
colorbar();
```

The product of the filter and FT of the image is shown in figure 8. Our filter removes the correct frequencies. Now we can use this filter to remove the undesired frequencies from the complex FT matrix.

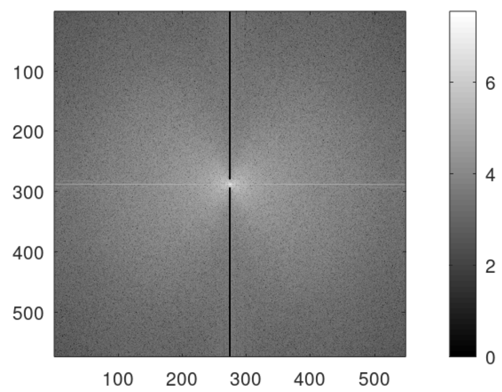

Figure 8: Product of filter and FT of the image.

E. Filtering and Inverse Fourier Transform (IFT)

To apply this filter to the FT of the image, we take the product of the filter matrix with the original (complex) FT matrix of the image. After applying the filter, we take inverse fourier transform shift using the built-in $ifftshift$ function to remove the effect of $fftshift$ followed by inverse fourier transform of the image using $ifft2$ function.

```
ConvF   = MyF.*CF;
IFTI    = (ifft2(ifftshift(ConvF)));
igraph5 = imagesc(abs(IFTI));
colormap('gray');
colorbar();
```

The inverse fourier transformed image is shown in figure 9. Stitching artefacts have been removed. It is also worth noting that we have retained the thin white line on the left side of the image by not removing horizontal anomalous frequencies shown in figure 4.

References

[1] Tristan Gooley. *The natural navigator*. Random House, 2020.
[2] John Wesley Eaton, David Bateman, Søren Hauberg, et al. *Gnu octave*. Network thoery London, 1997.
[3] Galileo Galilei. Sidereus nuncius. *CSIllAGATLASZ kistávcsövEkhez*, 1948.

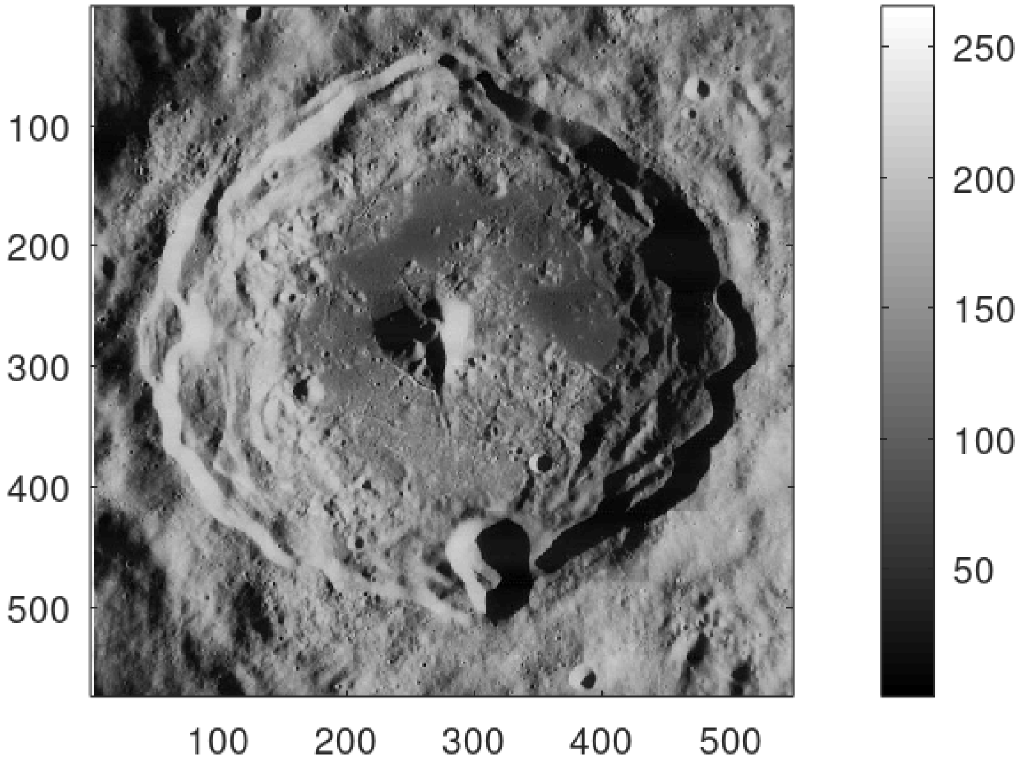

Figure 9: Filtered image of crater featuring no artefacts of stitching.

GRAFFITI ANALYSIS

We perform the same analysis on the Graffiti image shown in figure 10 using the code we developed for Moon Panorama. The only changes we need to make are in the filter we want to apply. To summarize,

1) We load and plot the image. (Figure 10)
2) We calculate and plot its FT. (Figure 11)
3) We modify the code.
   - Looking at the FT of graffiti shown in figure 8, we can quickly analyze that vertical frequency bursts are unnatural, which are there due to the joints between bricks. We want to remove the joints so we can view the graffiti without seeing the bricks on which it is painted. We made slight changes to the code, particularly to the filter we developed for the moon panorama.
   - We introduce a new parameter, Top and Bottom Row Skip (TBRS), to change the shape of the filter. We also change the Filter Width (FW) and Row Skip (RS) values to make it as good as possible for the Graffiti image. The new filter is shown in figure 12.
4) We test the filter by applying it to the matrix of figure 11. The product of the filter (figure 12) and FT (figure 8) is shown in figure 13. It indeed removes the frequencies we targeted.
5) We apply the filter to the complex matrix of fourier transform, take the inverse FT using $ifft2$ and plot the image. The inverse fourier transformed image is shown in figure 14.

We managed to decrease the visibility of the brick joints, but at the cost of image quality. We ended up blurring the image. In principle, we can improve the filter by being more selective on which frequencies to delete; however, not so easy in practice.

Modified Filter for Graffiti Analysis

```
FW    = 40;
RS    = 50;
TBRS  = 300;
MyF   = ones(Nr,Nc);
for i=1:Nr
  for j=1:Nc
    if( ((i>TBRS && i<(Nr/2 -RS)) ||  (i>(Nr/2
     + RS) && i<Nr-TBRS )) && (j >(Nc/2 - FW)
    && j<(Nc/2 + FW)));
      MyF(i,j) = 0;  end; end; end;
graph3 = imagesc(MyF);
colormap('gray'); colorbar();
```

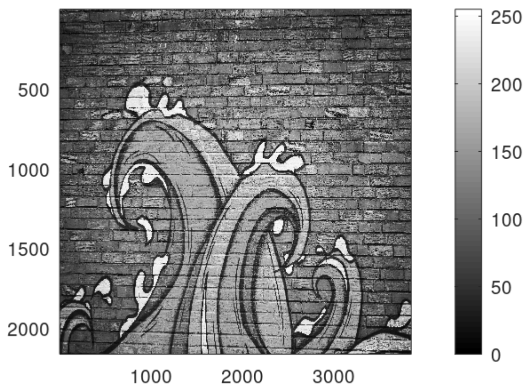

Figure 10: Graffiti on a brick wall.

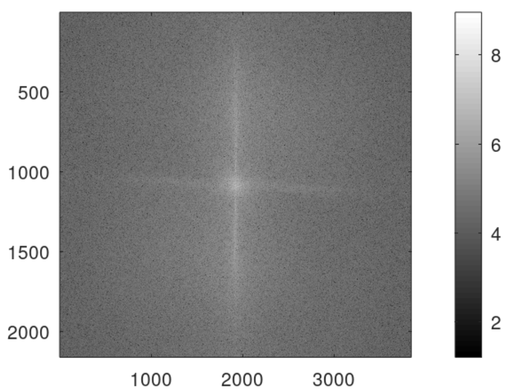

Figure 11: Fourier transform of figure 10.

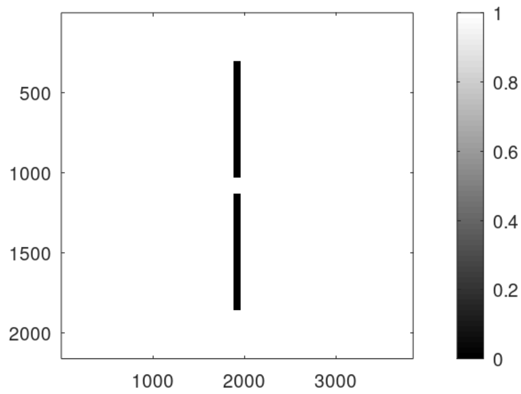

Figure 12: Filter to be used for graffiti image.

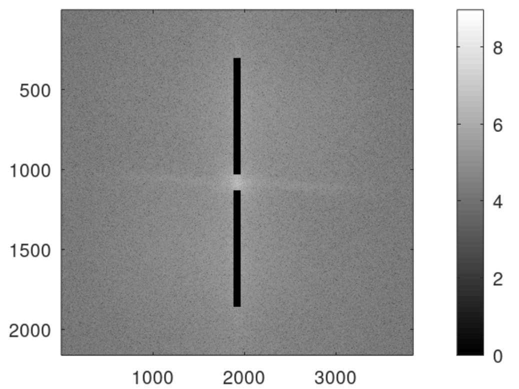

Figure 13: The product of filter (figure 12) and real matrix of FT (figure 11) of graffiti.

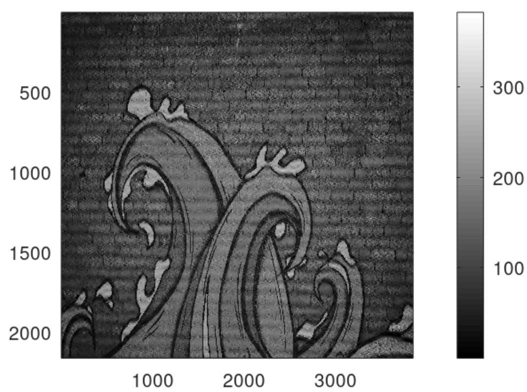

Figure 14: Inverse fourier transformed graffiti image.