Deblurring and Enhancing Astrophotographs Using PSF Based Digital Image Processing Group - 19

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***Abstract*—The following Image Processing Pipeline is implemented to process raw astronomical data and create clean, colored astrophotographs using only classical image processing techniques.**

***Index Terms*—Wiener-Deblurring, Richardson-Lucy Deconvolution,**

I. Introduction

Astrophotography, the practice of photographing celestial objects, is highly crucial as it provides data and builds the foundation for observational astronomy. It enables the study of distant cosmic objects, such as neighborhood galaxies, star clusters, etc. However, astrophotography is highly constrained by atmospheric seeing and optical diffraction even in advanced optic imaging systems. Atmospheric seeing, which is the degradation of images due to turbulence in the Earth's atmosphere in ground-based telescopes, imperfect optics, optical aberrations, and diffraction, are the primary factors that cause this blurring. This blurring causes dispersion of light intensity, which in turn causes the light source to appear spread out rather than as a single point. This distribution of light intensity in a pattern is known as the Point Spread Function. The Point Spread function is defined as the response of an imaging system to a perfect point source. The Point Spread Function causes this blurring by creating a circular blur around the light source. Since this blurring significantly reduces visibility and makes it very difficult to distinguish celestial objects, image de-blurring and restoration are extremely necessary. Computational image processing techniques, such as deconvolution and color mapping, combined with other image enhancement techniques, will enhance image quality, aiding in its restoration. The goal of this project is to restore the image for better visibility and interpretation by using deconvolution. We use Level 1 WFC3 HST images (flc .FITS images) to model our PSF, since they are not drizzled and are calibrated enough such that they do not have loss of information which usually distorts the lesser processed images.

II. Methodology

The input image data has been acquired in the form of a level 1 (flc .fits) file from the Hubble Space Telescope (HST). The flc .fits file is a fully calibrated exposure in units of electrons. Since, this format is calibrated to possess the information of the image, PSF extraction can be done with greater accuracy. The level 1 of image shows that the image is calibrated according to the instrument; however, no processing for removal of PSF or noise has been applied to the image. The raw images with high-resolution data are more suited for accurate PSF estimation.

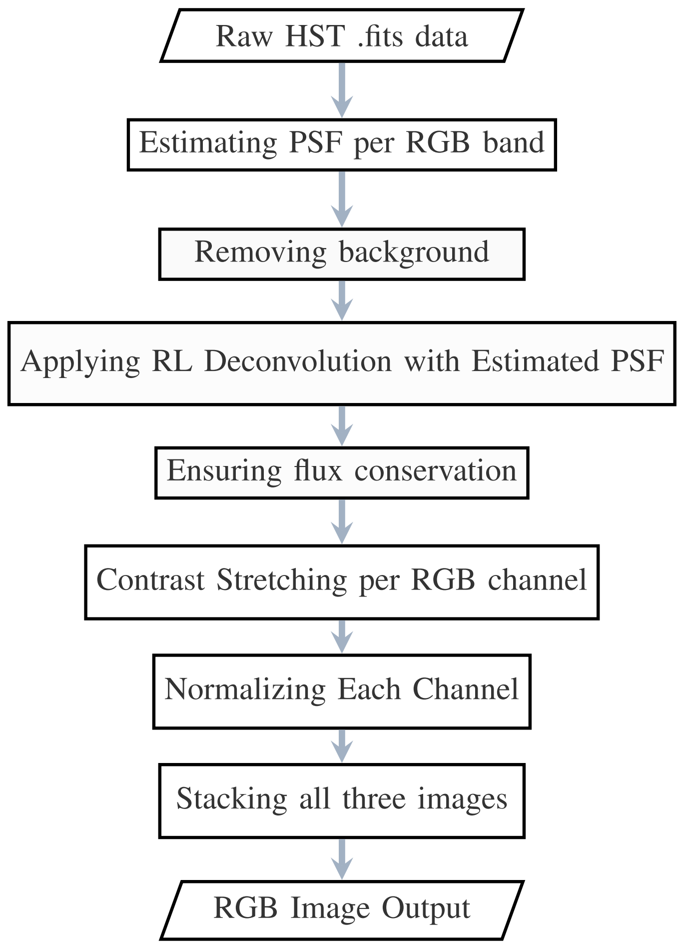

Fig. 1. Flowchart of PSF Estimation and Image Restoration

We know that the noise, in the form of a PSF, gets convolved with the image. Therefore, a deconvolution operation is required to remove the PSF. An instrument based PSF is implemented to enhance the deconvolution output as compared to a simple Gaussian PSF. The PSF is estimated for each of the R, G and B band of the image.

Initially, the pipeline detects stars in the given FITS image, by using DAOStarFinder or the brightest pixel in the image. The detected stars are then cut out or separated using square shaped stamps which are of default size 31x31 pixels. Background subtraction is then applied on the star stamps. Any outliers (negative values) do not correspond to the actual flux and hence are set to 0 to reduce bias and to avoid overestimating the PSF. The stamps are then centred on the star centroids by using the Fourier shift. This helps to avoid misalignment. Normalisation of the stamps is very crucial since it preserves the difference in shape instead of the difference in brightness. A PSF is then estimated by averaging the PSFs after stacking is performed. The stamps are then fitted to a 2-D Gaussian function to obtain the parameters for the averaged Gaussian PSF. Here, we obtain 2 PSFs: a 2D Gaussian fit average PSF and an estimated average PSF. Pre-processing is then applied on the test image, to get rid of outliers that could potentially distort the output.

Here are the images from which the PSF estimation is done. It can be observed that the point source is not spread by an ideal Gaussian function, which we were previously using. Therefore, a better PSF estimation method was required. The graph shows the number of photons captured by CCD (Charged-Coupled Devices) to the physical distance between captured. The PSF is close to an ideal Gaussian spread; however, it is not entirely aligned.

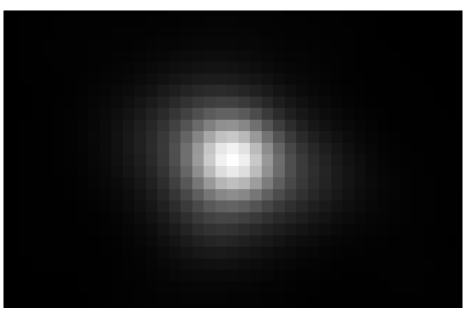

Fig. 2. PSF Example 1

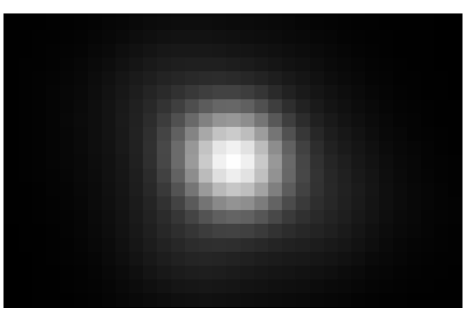

Fig. 3. PSF Example 2

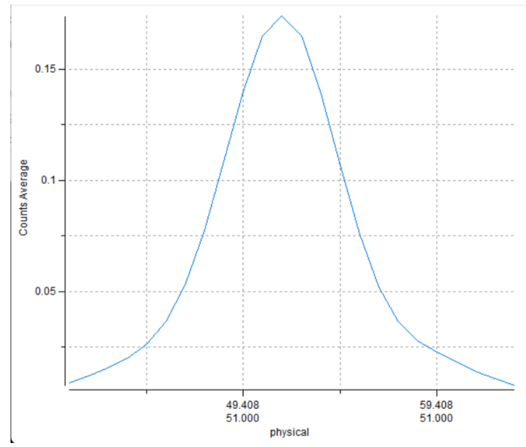

Fig. 4. PSF Graph Similar to Gaussian

Afterwards, the Richardson-Lucy deconvolution is applied over the aligned PSF. By iterating this process multiple times, we obtain a more accurate estimation of the original image. For the initial iteration, RL deconvolution begins with some estimated image, and applies the provided PSF to the estimated image. Afterwards, the blurred image is compared to the blurred image, which we want to restore. The brightness of the estimated image is increased if it is darker compared to the given image, and vice versa. After iterating through this process multiple times, we obtain an estimated image that becomes increasingly close to the original image, without PSF blurring. The PSF can never be fully removed from the image; we can only get the closest approximation to the original image. Lastly, we reconvolve the deconvolved image with the PSF to obtain the final output with enhanced quality. We then apply contrast stretching for enhanced visibility and normalization for each R, G, and B channels to map the pixels within range. Then, we again stack all the images to obtain the final RGB image output.

III. Results

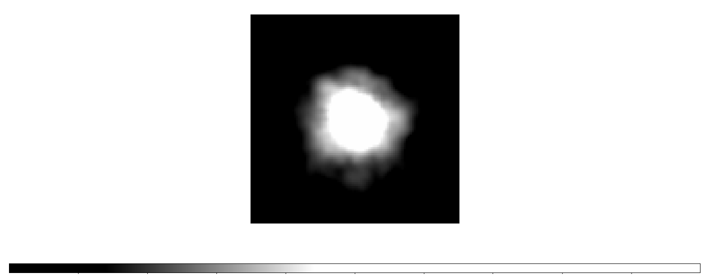

Fig. 5. A PSF Image from HST

Fig. 5 shows a sample PSF image from the Hubble Space Telescope. The image has a very distinct spread from the center. After deconvolving the image with the aforementioned

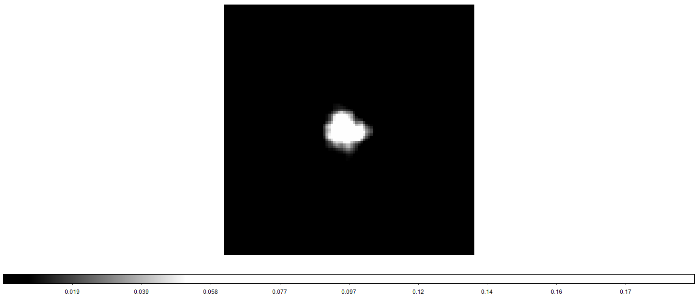

Fig. 6. PSF Image Deconvolved

method, it was observed that the spread was contained more in the deconvolved image.

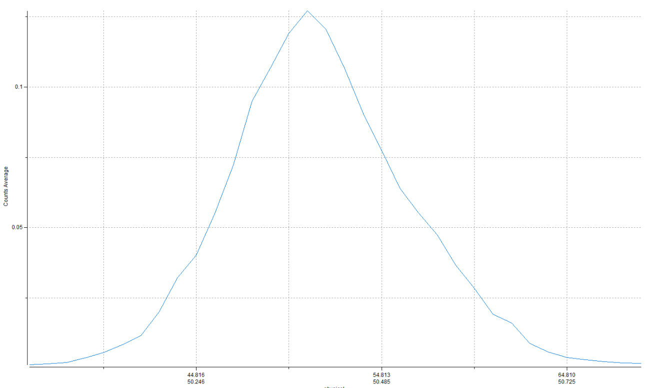

Fig. 7. 2D Plot Analysis of Fig. 5

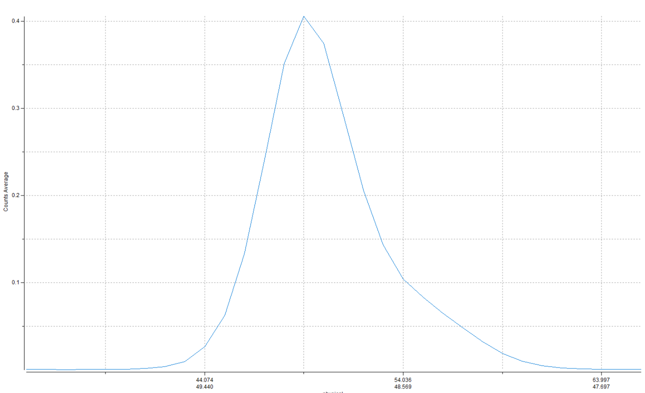

Fig. 8. 2D Plot Analysis of Fig. 6 (Deconvolved Image)

We observe that the graph plot for the intensity for the PSF image has a wider, spread out curve, as seen in Fig. 7. However, in the deconvolved image, the curve is much steeper and narrower. Ideally, the a point source should be just a single discrete line on the x-axis garnering all the intensity of the image, however, due to optical restrictions of the telescope, it is impossible.

Fig. 9. PSF Image from Hubble Space Telescope

Fig. 10. Deconvolution of Fig. 8

Fig. 7 shows a globular star cluster named Omega Centauri, the Milky Way's largest star cluster. The image shows blurred stars with flux spread around the stars. Fig. 8 shows the deconvolved image of Fig. 7. We observe that the stars resemble "point-sources" in the processed image.

Fig. 11 shows an RGB stacked image of the NGC 5457 object in the space. We see that there is some grain in the image and a mismatch in the dimension of the different channel images. In general, a high-fidelity color image is obtained.

IV. Discussion

The raw images captured from the Hubble Space Telescope contain noise and blurriness due to the PSF. Therefore, removal of the PSF is necessary for the accurate representation of scientific images.

The results show that the estimation of the instrument-based PSF can be significantly useful for discarding the PSF based on noise and restoring the images captured by that particular instrument. The PSF, then used for Richardson-Lucy deconvolution, leads to better estimations of the original image.

Using individual stars as isolated stamps also helps in the better estimation of the PSF, as the fainter background can be subtracted from the relatively brighter star. This removes unnecessary brightness data, which can cause deviation or noise in the PSF estimation. This ensures that the ringing effects, added during the restoration process, are diminished.

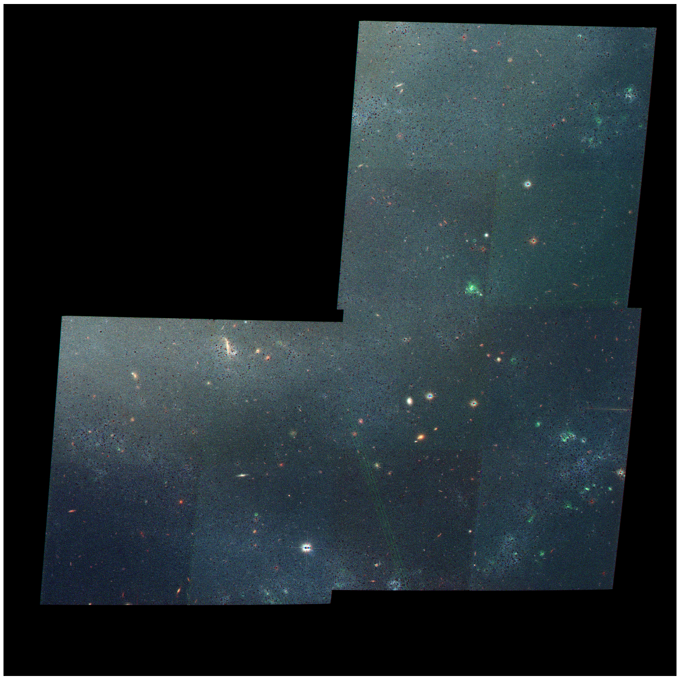

Fig. 11. RGB Image of a Star Cluster

The PSF is deconvolved from the individual star stamp to get better results rather than deconvolving the entire image all at once.

This sequence of steps makes the image clearer and the stars more distinct. The contrast stretching makes the star more distinct against the fainter background. The deconvolution using the estimated PSF and contrast stretching process significantly enhances the image quality, from a blurred, spread star to a point-like source.

V. Conclusion

As a result of our work, utilizing instrument based PSF deblurring methods gave a significant increase in the recovery of the details of the astronomical images compared to implementing a simple Gaussian PSF. After the Richard Lucy deconvolution aided in recovering the fainter features of the images. Since, the PSF and deconvolution was now just applied on masked stars, the output had minimized noise. The flux was conserved after the PSF was removed. Color mapping was implemented, which also gave a better output visually as compared to stacking using Gaussian PSF and Gaussian estimated average PSF. A total of 4256 FITS files were used to set the parameters for an estimated Gaussian PSF for deblurring as well as color mapping. The robustness of this model can be enhanced by further expanding the dataset.

References

[1] Amateur Telescope Optics, "Point Spread Function (PSF)," [Online]. Available: www.telescope-optics.net/diffraction_image.htm

[2] Space Telescope Science Institute, "WFC3-ISR-2022-05: Instrument Science Report," 2022. [Online]. Available: https://www.stsci.edu

[3] Space Telescope Science Institute, "Point Spread Function (PSF)," [Online]. Available: https://www.stsci.edu/hst/instrumentation/wfc3/data-analysis/psf

[4] R. Lucy and W. Richardson, "Richardson–Lucy deconvolution as a general tool for combining images with different signal-to-noise ratios: a fluorescence microscopy application," *ChemPhysChem*, vol. 15, no. 5, pp. 761–767, 2014. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC3986040/

[5] NASA / Science, "PASP article," 2024. [Online]. Available: https://science.nasa.gov/wp-content/uploads/2024/08/draft-pasp-article.pdf

[6] STScI / JWST Documentation, "James Webb Space Telescope — Near Infrared Camera (NIRCam)," [Online]. Available: https://jwst-docs.stsci.edu/jwst-near-infrared-camera#gsc.tab=0

[7] Optica, "Optics Express," vol. 32, no. 16, 2024. [Online]. Available: https://opg.optica.org/oe/fulltext.cfm?uri=oe-32-16-27278

[8] Mikulski Archive for Space Telescopes (MAST), "MAST Portal." [Online]. Available: https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html

[9] Space Telescope Science Institute (STScI), "WFC3: Point Spread Function (PSF) — Data Analysis." [Online]. Available: https://www.stsci.edu/hst/instrumentation/wfc3/data-analysis/psf