Astronomical Data Analysis Software and Systems VI
ASP Conference Series, Vol. 125, 1997
Gareth Hunt and H. E. Payne, eds.

Titan Image Processing

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Abstract. Images of Titan by the Hubble Space Telescope (HST) are very small in size and have very low spatial resolution. Special methods of image processing are required to extract information from these images. In this presentation, these methods are described and results are reported.

1. Introduction

Titan, one of the satellites of Saturn, has a planet-size solid body, and a thick atmosphere with molecular nitrogen as its principal constituent and with a considerable amount of methane (CH_4) (Beatty et al. 1990).

Currently, in searching for features on Titan's disk imaged by the HST PC1 detector, we are faced with two problems: (1) Low spatial resolution (Figure 1). The diameter of Titan's disk is only approximately 20 pixels. The pixel size corresponds to about 290 km at the center of Titan's disk. (2) Poisson noise on Titan's disk, which makes it difficult to detect features. For example, it is impossible to detect a point source having an amplitude of 12 DN (digital number) and sitting on Titan's disk with a uniform pixel value of 2000 DN, because the SNR (signal-to-noise ratio) is only 1.0. In contrast, it would be easy to detect the same source if it sat on an empty background, because the SNR is 13.1.

The two aforementioned problems necessitate processing Titan images by special methods to extract information for analysis. Each of the methods used by us is described in one of the following four sections, including the problem addressed, the method, the key computer programs (mainly in IRAF/STSDAS and IDL), and the results. In the conclusion we summarize our experience, and give suggestions for observing Titan in the future.

2. Image Restoration Using MEM and MLM

Problem: *Limb-brightening and -darkening.* The variation of brightness radially from the center of Titan to the limb is called limb-brightening or limb-darkening, depending on whether this variation is increasing or decreasing. Its determination is important for modeling Titan's atmosphere.

Method: *Remove the smoothing effect of the PSF (point spread function) of the HST.* Because of this smoothing effect, limb-darkening will be enhanced, while limb-brightening will be weakened so that a radial profile in an observed image may appear to be falsely limb-darkened or neutral. Therefore, in the case of (apparent) limb-darkening, it is required to restore the image to find out

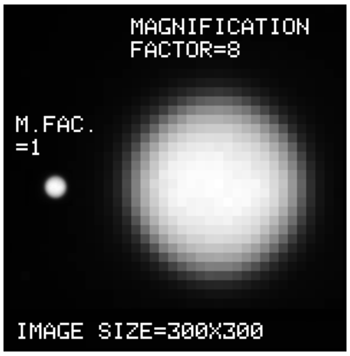

Figure 1. A typical Titan image.

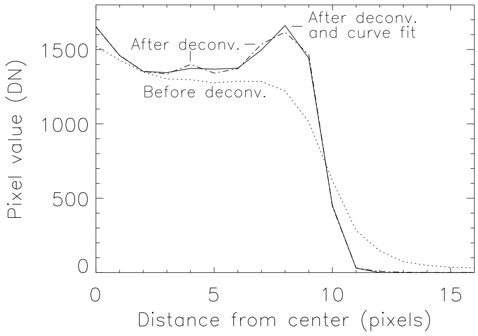

Figure 2. Profiles at position angle 0°.

the truth. This is accomplished by deconvolution using MEM (the Maximum Entropy Method) or MLM (the Maximum Likelihood Method). Furthermore, for accurate modeling, deconvolution is advisable in any case.

Programs: Two tasks in IRAF/STSDAS, **mem** and **lucy**, implement deconvolution by MEM and MLM, respectively, and give similar results in our case. The PSF associated with the observed image, necessary for executing these tasks, is generated by running the stand-alone program **TinyTim**.

Results: For a CH_4 image at 889 nm wavelength, out of twelve radial profiles at position angles 0° (Titan North), 30°, ..., 330°, seven appear to be limb-brightened, while five are limb-darkened in the observed image before deconvolution. In contrast, after deconvolution, four (at 0°, etc.) of the latter five profiles become limb-brightened, and the other is nearly flat to the limb.

Three radial profiles at 0° are plotted in Figure 2 to show the effect of deconvolution. Curve fitting is used for further clarification of limb-brightening after deconvolution.

3. Image Enhancement by Subtraction and Filtering

Problem: *Temporal brightness changes in images.* By detecting brightness changes in Titan images with time, we can discover transient features. The difficulty is that the changes may well be small compared with the noise, and the spatial resolution of the images is very low.

Method: *Taking differences between sequential images.* Before doing this, we must interpolate the images to reduce the pixel size, and register (align) them at the subpixel level. After the subtraction operation, we lowpass-filter (smooth) the difference images to improve SNR and eliminate small-scale fluctuations.

Programs: The key tasks used in IRAF/STSDAS are: **magnify** for interpolation; **crosscor** and **minmax** to find the relative shifts between images; **imshift** to shift images for registration; **imarith** for subtraction; and **gauss** for lowpass-filtering (convolution).

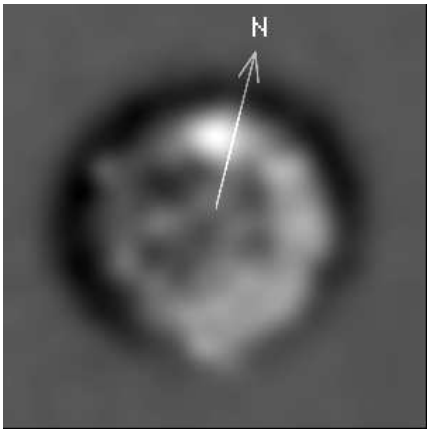

Figure 3. One of the six filtered difference images.

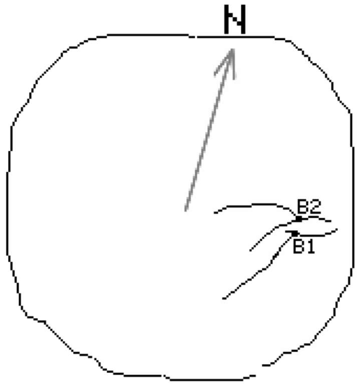

Figure 4. Bifurcation points in two groups of images.

Results: Two groups of images at 673 nm wavelength, with a time difference of $2^d9^h20^m$ are processed. The groups have two and three images, respectively. The magnification factor is 9, i.e., the pixel size is reduced to 1/9. The FWHM (full width at half maximum) of the Gaussian filter is 18 (reduced size) pixels.

A bright area is detected in all six (2×3) difference images, being centered at position angle $+8\overset{\circ}{.}3$ with respect to Titan North, latitude $+45\overset{\circ}{.}4$. One of the six filtered difference images is shown in Figure 3. The pixel values in the bright area increased noticeably during this period of time. Similar results have been reported and discussed by Lorenz et al. (1995).

4. Image Enhancement by Edge Detection and Morphological Processing

Problem: *Wind velocity.* Measuring the wind velocity in Titan's atmosphere is difficult. Theoretical wind speeds ranging up to 360 km/hour are possible, but the image pixel size is 290 km. Results may be questionable.

Method: *Detect cloud edges and their motions in a time interval.* To increase accuracy, the pixel size must be reduced by interpolation. The time interval should be reasonable. If it is too small, then no significant motion will be detected. If it is too large, on the other hand, clouds may disperse so much that no corresponding edges can be identified. Furthermore, to determine the velocity (including speed and direction) at least two crossed edges in each image must be detected. This is accomplished by image edge detection (enhancement) and morphological processing.

Programs: The key programs are: **magnify** in IRAF for interpolation; and **sobel** and **thin** in IDL for detecting edges and then thinning (morphological processing) them, respectively.

Results: Two groups of CH_4 images at 889 nm wavelength, with a time difference of 1.017 hours are processed. The two images within each group are combined to improve SNR. The magnification factor is 9, resulting in a (small) pixel size of 31.8 km.

Numerous edges were detected, but discounted because of apparent alignment with rows, columns or diagonals. Only one bifurcation point detected in each of two groups is considered to be significant (Figure 4). There is a displacement from B_1 to B_2 of 7.0 small pixels. The apparent speed is $31.8 \times 7.0/1.017$ $\sim$220 km/hour. The direction is $-5\overset{\circ}{.}3$ with respect to Titan North.

5. Dithering

Problem: *Low spatial resolution.* The pixel size on the CCD chip (PC1 in our case) is large compared with the width of PSF, resulting in "undersampling."

Method: *Combine images shifted by subpixel amounts.* Increasing spatial resolution means reducing the pixel size. We can change the pointing of the telescope so that successive images are shifted along each axis by subpixel amounts, say a multiple of 1/2 or 1/3 pixel size, then combine these images to obtain a single image having a smaller pixel size on a finer grid. This technique is called dithering (HST WFPC 2 Handbook 1995).

Programs: The program **TinyTim** is used to generate PSFs associated with dithered images. These images and PSFs are input to the task **acoadd** in IRAF/STSDAS to get a single image with improved resolution.

Results: Simulation gives good results, but our HST data do not. The reasons include: insufficient pointing accuracy of the HST, and insufficient SNR in the images. Also, better software for dithered image processing may be needed.

6. Conclusion

Image processing techniques do help to extract information from HST images. MEM and MLM can be used for deconvolution. The method *subtraction and filtering* can be used to detect changes between images. More experiments using the method *edge detection and morphological processing* are necessary. For the sophisticated method *dithering* to succeed, every effort should be made to achieve the nominal pointing accuracy of the HST, 3 milliarcseconds. At least two observations must be made at each position to increase SNR and facilitate cosmic ray removal.

References

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