Blind iterative deconvolution of binary star images

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Abstract. The technique of Blind Iterative De-convolution (BID) was used to remove the atmospherically induced point spread function (PSF) from short exposure images of two binary stars, HR 5138 and HR 5747 obtained at the Cassegrain focus of the 2.34 meter Vainu Bappu Telescope (VBT), situated at Vainu Bappu Observatory (VBO), Kavalur. The position angles and separations of the binary components were seen to be consistent with results of the auto-correlation technique, while the Fourier phases of the reconstructed images were consistent with published observations of the binary orbits.

Key words : speckle imaging, image reconstruction, binary stars

1. Introduction

Atmospheric turbulence degrades the images obtained by ground based astronomical telescopes. Schemes like speckle interferometry (Labeyrie, 1970), Knox-Thomson algorithm (Knox and Thompson, 1974), shift and add (Lynds *et al.*, 1976), triple correlation (Lohmann *et al.*, 1983) have been successfully employed to restore the degraded images. All these schemes depend on the statistical treatment of a large number of image. Often, it may not be possible to record a large number of images within the time interval over which the statistics of the atmospheric turbulence remains stationary. In such cases, where only few images can be used, there are a number of schemes to restore the image using some prior information about the image. The maximum entropy method (Jaynes, 1982), CLEAN algorithm (Hogbom, 1974), and BID (Ayers and Dainty, 1988) are examples of such schemes. In this paper, we employ a version of BID developed by P. Nisenson, (Nisenson, 1991), on degraded images of two binaries, HR 5138 (m_v = 5.57, Δm = 0.2), and HR 5747 (m_v = 3.68, Δm = 1.5) obtained at the 2.34 meter VBT at Kavalur.

2. Observations

The 2.34 meter VBT has two accessible foci for backend instrumentation – a prime focus (f/3.25 beam) and a cassegranian focus (f/13 beam). The latter was used for the observations described in this paper. The cassegranian focus has an image scale of 6.7 arcseconds per mm. This was further magnified to ~1.21 arcseconds per mm, using a Barlow lens arrangement (Saha *et al.*, 1987, Chinnappan *et al.*, 1991). This enlarged image was recorded through a 5 nm filter centred on Hα using an EEV intensified CCD camera which provides a standard CCIR video output of the recorded scene. The interface between the intensifier screen and the CCD chip is a fibre-optic bundle which reduces the image size by a factor of 1.69. A DT-2851 frame grabber card digitises the video signal. This digitiser resamples the pixels of each row (385 CCD columns of 512 digitised samples) and introduces a net reduction in the row direction of a factor of 1.27.

The frame grabber can store upto two images on its onboard memory. These images are then written onto the hard disc of a personal computer. The images were stored on floppy diskettes and later analysed on a pentium. The observing conditions were fair with an average seeing of ~2 arcseconds during the nights of 16/17 March 1990.

3. Data processing

The blind iterative deconvolution technique is described in detail in the literature (Bates and McDonnell, 1986). Essentially, it consists of using very limited information about the image, like positivity and image size, to iteratively arrive at a deconvolved image of the object, starting from a blind guess of either the object or both the convolving function. The implementation of the particular version of BID used by us is described in Nisenson (1991).

The algorithm has the degraded image c(x,y) as the operand. An initial estimate of the point spread function (PSF) p(x,y) has to be provided. The degraded image is deconvolved from the guess PSF by Wiener filtering, which is an operation of multiplying a suitable Wiener filter (constructed from the Fourier transform P(u,v) of the PSF) with the Fourier transform C(u,v) of the degraded image as follows

$$O(u,v) = C(u,v) \frac{P*(u,v)}{P(u,v)\,P*(u,v) + N(u,v)\,N*(u,v)}$$

where O is the Fourier transform of the De-convolved image and N is the noise spectrum.

This result O is transformed to image space, the negatives in the image are set to zero, and the positives outside a prescribed domain (called object support) are set to zero. The average of negative intensities within the support are substracted from all pixels. The process is repeated until the negative intensities decrease below the noise.

A new estimate of the psf is next obtained by Wiener filtering the original image c(x,y) with a filter constructed from the constrained object o(x,y). This completes one iteration. This

entire process is repeated until the derived values of o(x,y) and p(x,y) converge to sensible solutions.

4. Results

The results for HR 5138 and HR 5747 were arrived at after 350 iterations. Since the intensity of the stars were different, the value of the Weiner filter parameters also had to be chosen accordingly. Figures 1(a-c) show the speckle image, PSF, and deconvolved image of HR 5138 respectively. Figures 2(a-c) are for HR 5747 respectively. The companions of HR 5138 and HR 5747 are separated by 0.27 and 0.20 arcseconds respectively. Measurements of position angle (235 and 110 degrees for HR 5138 and HR 5747 respectively) and separation were compatible with the values published in the CHARA catalogue (McAlister and Hartkopf, 1988). Horch (1994), too found similar results. The magnitude difference for the reconstructed objects were 0.04 and 1.65 respectively for HR 5138 and HR 5747. Although these values compare quite well with those published in the Bright Star Catalogue (Hoffleit and Jaschek, 1982) one needs to treat many more objects before one can characterise the photometric quality of the reconstructions.

5. Discussion and conclusions

The present scheme of BID has the chief problem of convergence. It is indeed an art to decide when to stop the iterations. The results are also vulnerable to the choice of various parameters like the support radius, the level of high frequency suppression during the Wiener filtering, etc. The availability of prior knowledge on the object through autocorrelation of the degraded image was found to be very useful for specifying the object support radius. In spite of this care was taken in the choice of the support radius, the PSF for each star contains residual signatures of the binary sources. Although suggestions have been made for improving the convergence (cf. Jefferies and Christou, 1993), these improved algorithms require more than a single speckle frame.

For the present, it is noteworthy that useful reconstructions are possible using single speckle frames. Questions regarding their dynamic range and linearity can be answered only after examining a wide range of reconstructions. The iterative nature of the algorithm does not lend to an explicit estimation of these parameters from a limited sample. New developments in camera electronics promise the capability to acquire several images within a short time. This will also reduce the level of artifacts. The chief achievement in this paper is a demonstration of the scientific potential of BID for resolving bright objects acquired using simple apparatus.
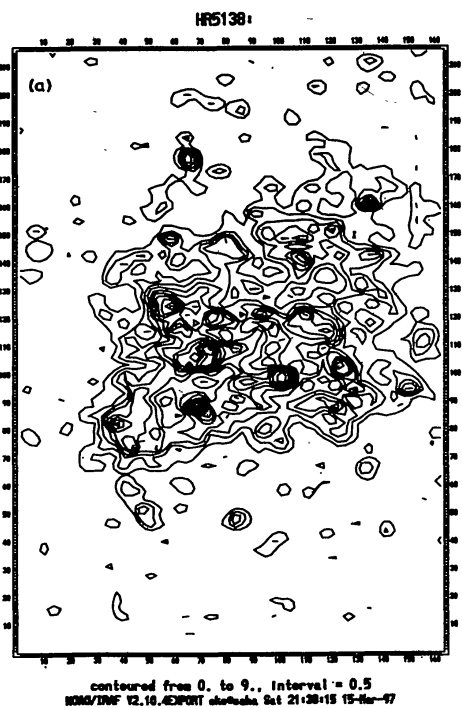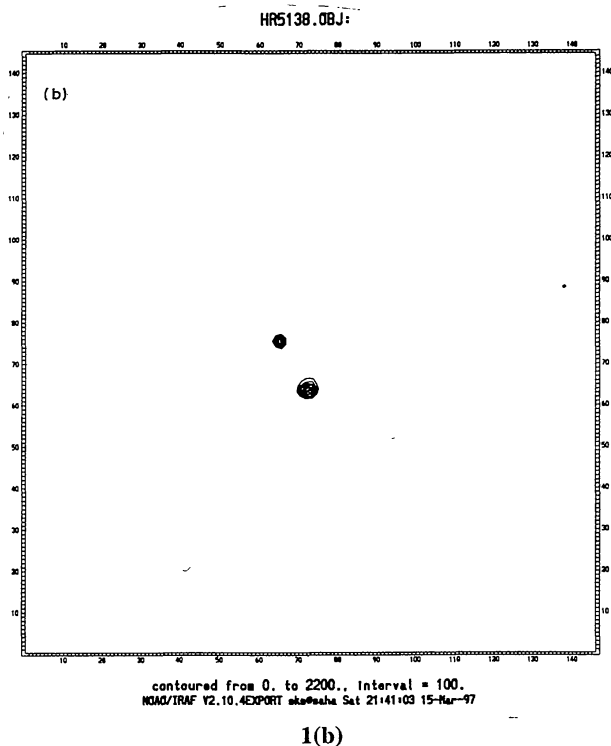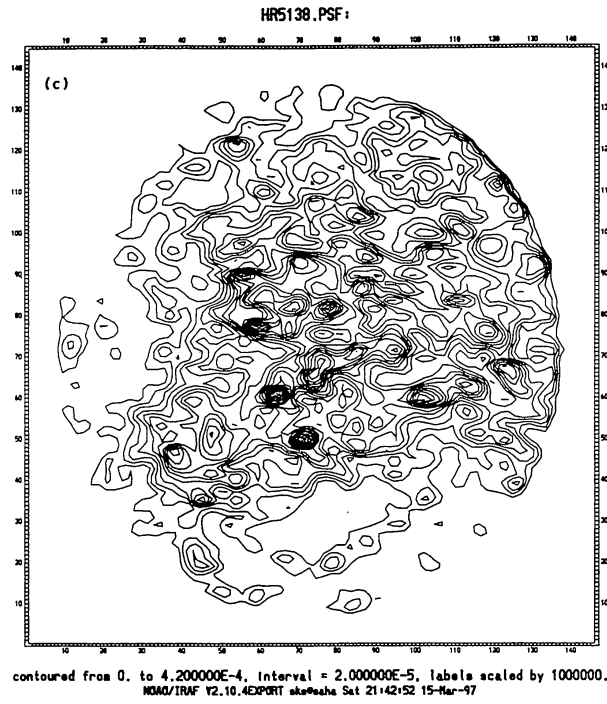
HR5138:

contoured from 0. to 9., interval = 0.5
NOAO/IRAF V2.10.4EXPORT sks@saha Sat 21:38:15 15-Mar-97

Figure 1(a–c). The speckle image, PSF, and the deconvolved image of HR 5138 are shown respectively. The numbers on the axes denote pixel numbers with each pixel being equal to 0.02 arc sec.
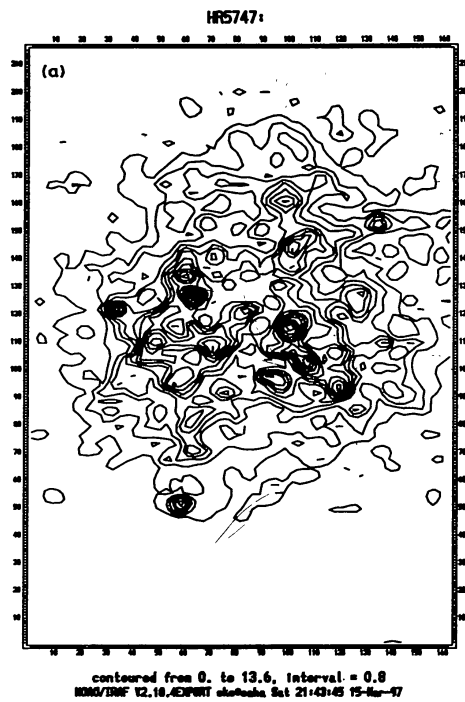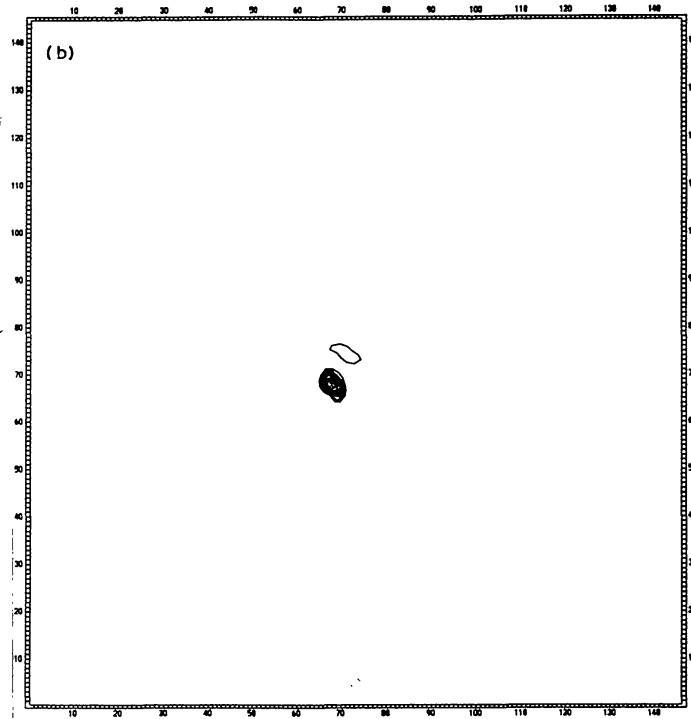
HR5138.OBJ:

contoured from 0. to 2200., interval = 100.
NOAO/IRAF V2.10.4EXPORT sks@saha Sat 21:41:03 15-Mar-97

1(b)

HR5138.PSF:

contoured from 0. to 4.200000E-4, interval = 2.000000E-5, labels scaled by 1000000.
NOAO/IRAF V2.10.4EXPORT skeesaha Sat 21:42:52 15-Mar-97

1(c)

HR5747:

contoured from 0. to 13.6, interval = 0.8
NOAO/IRAF V2.10.4EXPORT skeesaha Sat 21:43:45 15-Mar-97

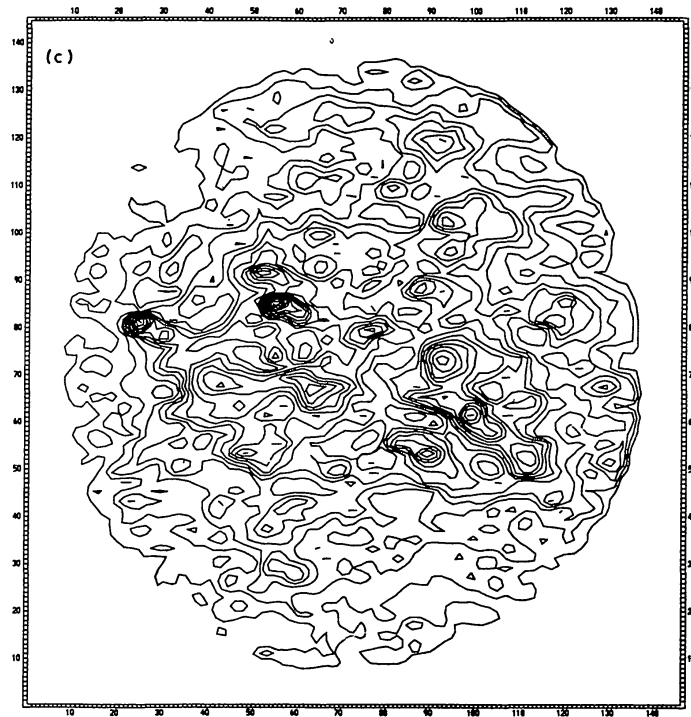**Figure 2(a-c).** For HR 5747 respectively.

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HR5747.OBJ:

(b)

contoured from 0. to 3800., interval = 200.
NOAO/IRAF V2.10.4EXPORT sks@saha Sat 21:44:32 15-Mar-97

2(b)

HR5747.PSF:

(c)

contoured from 0. to 4.000000E-4, interval = 2.000000E-5, labels scaled by 1000000.
NOAO/IRAF V2.10.4EXPORT sks@saha Sat 21:45:23 15-Mar-97

2(c)

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References

Ayers G.R., Dainty J.C., 1988, Optics Letters, 13, 547.

Bates R.H.T., McDonnell M.J., 1986, "Image Restoration and Reconstruction", Oxford Engineering Science 16, Clarendon Press, Oxford.

Chinnappan V., Saha S.K., Faseehana, 1991, Kod. Obs. Bull. II, 87.

Hoffleit D., Jaschek C., 1982, "The Bright Star Catalogue", Yale University Observatory.

Hogbom J., 1974, ApJS., 15, 417.

Horch E.P., 1994, Ph.D Thesis, Stanford University.

Jaynes E.T., 1982, Proc. IEEE, 70, 939.

Jefferies S.M. Christou J.C., 1993, ApJ., 415, 862.

Knox K.T., Thompson B.J., 1974, ApJ., 193, L45.

Labeyrie A., 1970, A&A, 6, 85.

Lohmann A.W., Weigelt G., Wirnitzer B., 1983, Appl. Opt., 22, 4028.

Lynds C.R., Worden S.P., Harvey J.W., 1976, ApJ., 207, 174.

McAlister H.A., Hartkopf W.I., 1988, CHARA contribution no. 2.

Nisenson P., 1991, in Proc. ESO-NOAO conf. on High Resolution Imaging by Interferometry, ed. J.M. Beckers & F. Merkle, p 299.

Saha S.K., Venkatakrishnan P., Jayarajan A.P., Jayavel N., 1987, Current Science, 56, 985.