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# USING WAVELET TRANSFORM (WTN) IN FABRY-PERROT INTERFEROMETER DATA PROCESSING

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**Abstract.** We represent some preliminary results of using the two-dimensional Wavelet Transform (WTN) for Fabry-Perrot interferometer data processing. Because of specific image geometry (concentric rings plus strong noise), WTN compression appeared to be very effective. The resulting image requires as little as 0.25 Kbytes of computer memory (~1.5 per cent of initial 16 Kbytes) and contains most of important information that initial frame provides. Another positive effect of WTN compression is a good image filtering and improving S/N ratio. The WTN-based data filtering can be successfully applied to many other kinds of information, for example, to auroral frames and keograms, VLF emission spectrograms, magnetic pulsation recordings and others.

## Introduction

Fabry-Perrot interferometer is a commonly used instrument for studying thermospheric neutral wind circulation. It has extremely high spectral resolution, which enables to reveal spectral shape of atmospheric emission lines, and accurately detect Doppler shift of line maximum, getting information on neutral gas temperature and wind velocities, respectively. As the device operates with a very weak light signal (it always works in a photon counting mode), a few decades ago, good photo multipliers were used with a standard method of line scanning by step changing the distance between interferometer plates [*Hays and Roble*, 1971, *Hernandez and Roble*, 1976]. Since this procedure is principally sequential, resulting time resolution of data was rather poor. Quite new opportunities in interferometric studying appeared with modern high-sensitivity CCD-TV cameras [*Batten and Rees*, 1990; *Leontyev*, 2000]. The camera collects photons over the whole interferometric image simultaneously, allowing for time resolution to be strongly improved. The absence of mechanical spectra scanning simplified the instrument and made it much more stable. Higher quantum efficiency, especially in the red range of the spectra is another positive feature of CCD-camera. A serious disadvantage of the ordinary, moderate price CCD-matrix is rather strong read-out noise, which can dozens of times exceed the photon noise), but technical progress in this field is very rapid, and, as we will show further, in interferometric study this disadvantage can be successfully overcome. Another problem is a big amount of recording information. Digital CCD-camera creates high-resolution image (typical size is 512*512 pixels, or 256 Kbytes) every 1-3 minutes, so there are serious problems of data storage and acquisition. Even after 16-point averaging an image, the size of the digital frame is 16 Kbytes. Special procedure of frame scanning by a spreading ring is typically applied, and only resulting information on the Doppler profile is recorded into computer (file size being reduced to ~1-2 Kbytes). But in this case all information on initial frame is lost, and e.g. CCD-matrix dark current control, which is important to correct detection of Doppler profile maximum, becomes difficult (the dark current is non-uniform over the frame and unstable in time). Further, we present some simple methods that permit to overcome this difficulty.

## Results

In PGI we use two types of CCD-matrix based cameras. One (Santa-Barbara production) is rather simple, easy to use and not very expensive. Fig. 1 presents some typical examples of interferometric images got with this camera. The top panel shows three Lee-filtered frames, and in the bottom panel one can see corresponding Doppler profiles. Frame (a) is an alight one, so it presents interferometric picture as concentric rings (they are completely invisible). CCD-matrix has non-uniform sensitivity over the frame, the image being definitely brighter in the top-right corner. Frame (b) is a dark one, i.e. only CCD-matrix noise exists in the image. Nevertheless, those two frames, (a) and (b), look quite identical, dark and bright elements in both frames are coincident with each other. Analysis of numerous alight and dark frames demonstrated very good noise stability, giving a proof that it is CCD-matrix read-out noise, and for low-level signals we deal with, this noise is 20 times more intense than the photon noise. Bottom panel in Fig.1 shows the results of usual spreading ring scanning procedure in Doppler profile drawing. In spite of strong noise, the profile is slightly pronounced (a) in the alight frame. The vertical arrows point to the common features in the profiles for the both frames. Frames identity with respect to the noise enables to exclude the noise and non-uniform sensitivity by simple subtracting of the dark frame from the alight one. The result is presented in Fig.1 (c). Interferometric rings became well seen, and corresponding Doppler profile looks much better, than for the initial frame. We note that Lee-filtering of frames in order to reduce the noise does not change noticeably the shape of a profile. The difference in ordinate scales directly demonstrates how much read-out noise exceeds useful image information.

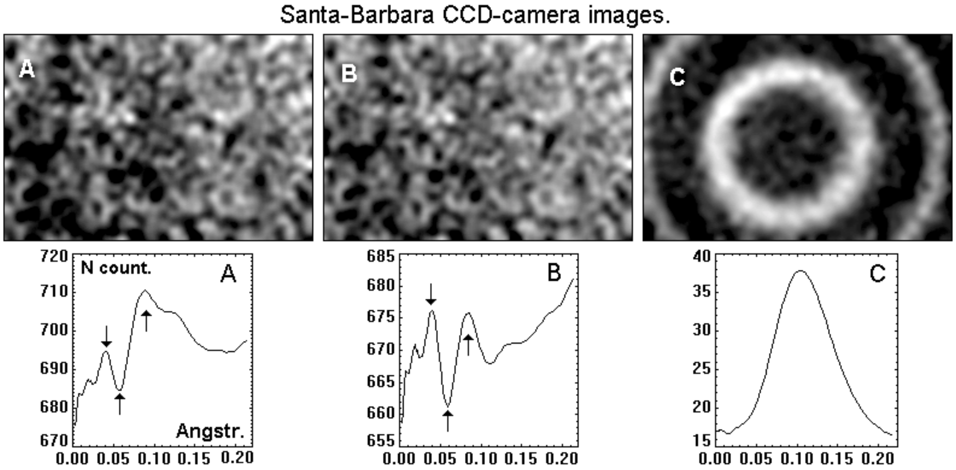

**Fig.1**. Examples of Santa-Barbara CCD-camera images and corresponding Doppler profiles: (a) alight frame with interferometric rings, masked by CCD-matrix read-out noise; (b) dark frame; (c) result of subtraction of the dark frame from the alight one.

The other CCD camera, we use, is the Pentamax model. Unlike Santa-Barbara camera, this one has an image intensifier unit, enabling to increase sensitivity. Including intensifier creates one serious problem. The intensifier noise of thermoemission nature is rather strong and exceeds CCD-matrix read-out noise. Moreover, this noise, unlike the matrix read-out noise, is unstable in time, though changing rather slowly. Therefore, this noise cannot be removed by simple subtraction of initial and once detected reference frames. During observations we have rather often (every 5 – 10 minutes) to record new dark frames and use them for subtraction procedure, obviously losing useful information. In this regard, in the future we are going to test a promising method, presented in Fig. 2. Unfortunately, we have not many real interferometric frames at the moment, so the results of modeling are shown.

Fig. 2 (a) shows real Pentamax-camera interferometric frame with a model “noise” added. The noise is taken as a two-dimensional signal gradually increasing from the bottom-left towards top-right corner, so that the right corner looks much brighter. Because the noise exceeds the signal by more than 20 times, interferometric rings are almost invisible, and corresponding Doppler profile is totally corrupted (a). Image (b) is a result of subtraction from the initial frame (a) the frame, smoothed by sliding square box with 25*25 pixel dimension. This technique is well known as “unsharp masking” procedure. The size of the box is close to the characteristic thickness of interfetometric rings. One can see that such a simple procedure completely removes changes of brightness slowly varying along the frame, with recovering the initial frame almost without distortion. The Doppler profile of the corrected frame is completely coincident with the profile of the initial frame. We hope, these results can be very helpful in our practical work with Pentamax camera images, since it will be not necessary to record reference dark frames or, at least, we could record them not so often.

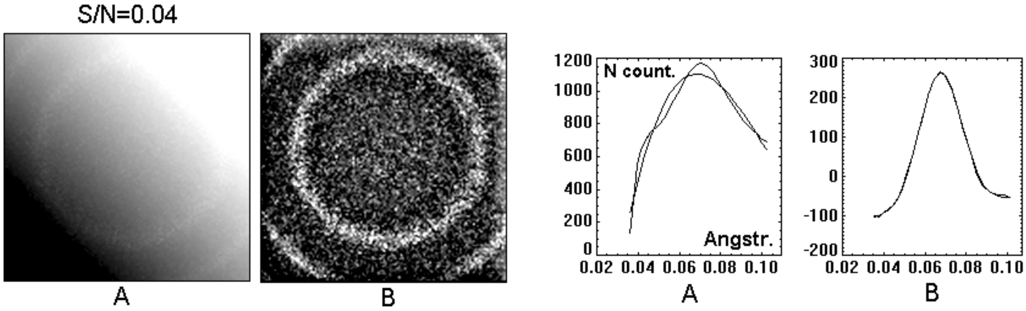

**Fig.2.** Modeling of Pentamax-camera non-uniform image distortion compensation. The resulting image (b) is a difference of the initial frame (a) and 25*25 pixels smoothed by so-called “unsharp masking” procedure. Corresponding Doppler profiles are also shown.

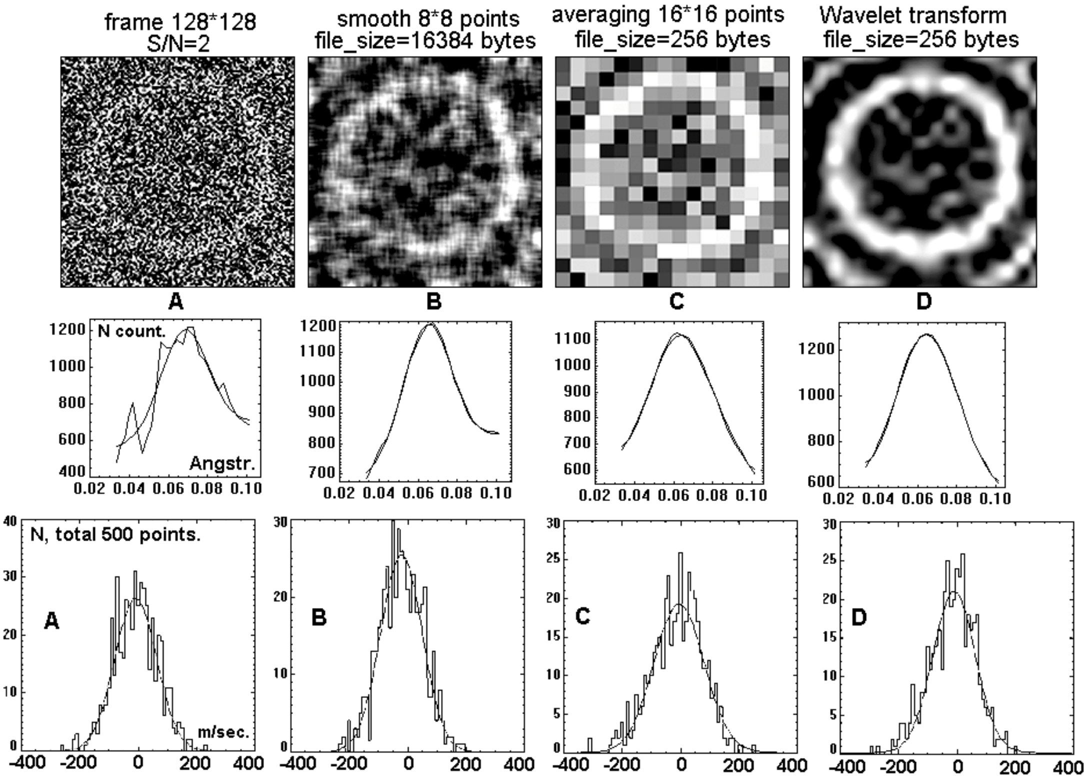

**Fig. 3**. Example of using two-dimensional Wavelet Transform (WTN) for Fabry-Perrot interferometer data compression. Top panel: (a) initial image with noise added; (b) result of 8*8 point box sliding smoothing; (c) averaging over 16*16 points; (d) restored image after wavelet compression. Middle panel presents corresponding Doppler profiles. Bottom panel shows histogram distribution of profile maximums for the random noise of 500 times intensity added.

Though all important interferometric information is contained in Doppler profile shape, and, in principle, it is enough to keep only that information in computer, very often registration of the frame itself is extremely desirable. In this case, we could accurately control image dark current, different distortions and parasitic illumination. Keeping a big amount of information is the main problem. Each frame requires ~16 Kbytes (in some experiments up to 256 Kbytes), so requirements to computer memory space are rather severe. We think that the use of two-dimensional wavelet transform for direct interferometric image compression could be a good solution of this problem.

Since their introduction in the 1980s, wavelets have become a powerful tool in mathematical analysis, with applications such as image compression, statistical estimation and numerical simulation of partial differential equations. One of their main advantages is the ability to accurately represent the whole spectra of analytical and numerical one-and-multidimensional functions with a small number of appropriately chosen wavelet coefficients. Wavelets have a vast range of applications, and can be very useful for filtering and compression of a large variety of data and images. Many interesting papers and references can be found in Internet (*wavelet.org*, Russian site *wavelet narod.ru*).

Two-dimensional wavelet transform (WTN) provides a simple, fast and effective method of direct interferometric image data compression. Because of specific image geometry (concentric rings plus strong noise), WTN compression appears to be very effective, the resulting image size being as small as 0.25 Kbytes (about 1.5 per cent with respect to initial 16 Kbytes) and containing most of non-compressed frame important features. Another positive effect of WTN compression is a good image filtering and improving S/N ratio. Figure 3 presents an example of wavelet transform applied to interferometer images processing. Fig.3 (a) is a Pentamax-camera image with addition of computer generated uniformly distributed random noise. Sliding box smoothed image is shown in Fig.3 (b), and it has the same file size, as the initial frame. The result of simple averaging, i.e. resampling initial 128*128 pixel image to 16*16 one, is presented in Fig.3 (c). The file size became much smaller, but the picture became too rough. Much better results we can see in Fig. 3 (d), which illustrates the results of wavelet transform application for interferometric data compression. One can see that the frame restored after wavelet compression looks much better even than the smoothed one, though it was reconstructed from only 1.5 per cent of initial information. As distinct from simple averaging image presented in Fig. 3 (c), details of interferometric rings are preserved, while the high frequency noise of initial frame is removed. Middle panel of Fig.3 shows corresponding Doppler profiles. Profile of initial frame is rather noisy, and all other methods of smoothing and averaging give nearly identical results and can be used in practical work, but the results of WTN-compression are definitely the best. The bottom panel of Fig.3 shows histogram distribution of Doppler profiles maximum positions. The histograms are the result of 500 runs with a new computer-generated noise added every time. The noise has uniform distribution with dispersion, twice exceeding useful signal intensity. This procedure permits to roughly estimate mistakes in wind velocity calculations, though it would be much better to analyze a long series of real interferometric images.

## Conclusions

1. Santa Barbara CCD-camera read-out noise can be suppressed by subtraction of initial and single reference dark frames.
2. Nonuniform noise of Pentamax CCD camera with a characteristic spatial size larger than interferometric ring thickness can be successfully removed by unsharp masking procedure.
3. Application of wavelet transform for image compression and filtering (that is a fundamental part of modern JPEG-2000 standard) is quite useful in Fabry-Perrot interferometer data processing. Though to get a compressed image only 1.5 per cent of initial information is used, it looks more accurate, and reproduces a greater number of important details than the non-compressed, smoothed over 8*8 pixel frame, one.

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