NUMERICAL IMAGE PROCESSING APPLIED TO THE SOLAR CORONA

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Abstract. Numerical data processing is applied to the high-resolution images of the solar corona obtained with the 20 cm coronagraph of the Pic du Midi observatory. Two complementary methods are proposed to solve some classical difficulties usually met in the morphological analysis of the solar corona, namely the brightness gradient in the inner and medium corona, the low contrast of numerous emissive regions and the superimposition along the line of sight of different structures. The methods which are described in this paper may help to resolve the complex coronal active regions into fine structures which is now necessary to interpret all observed corona data.

1. Introduction

The extreme inhomogeneity of the solar corona and the great complexity of active regions requires, for a fine coronal phenomena analysis, a precise knowledge of the morphological properties of the coronal structures.

The determination of magnetic fields, densities, temperatures, and the understanding of the mass and temperature balances in the inner and medium corona require that the instruments, such as coronameters, polarimeters and spectro-coronagraphs, have to be associated with image reflex systems. Such systems may be used to obtain monochromatic views (Ratier, 1975), and to locate the measurement points among the observed structures.

The determination of these parameters from the observed data cannot reach a fine scale without a realistic geometric model of the observed region. At the present time the field apertures (30 arc sec) used for the corona measurements are in general larger than the spatial resolution of the images (5 arc sec). Recent progress in detection techniques will soon improve the spatial and temporal resolution of the measurements. This will also require improvement in image analysis, in particular for the detection and recognition of the small and faint coronal structures.

Beside the question of the classical image quality restoration (seeing), the coronal physicist has to solve some other difficulties, typical of which are:

(1) The brightness gradient (corona, sky, and instrument scattered light) on the first 6 arc min from the limb.

(2) The low contrast of the coronal structures.

(3) The superimposition of the structures along the line-of-sight.

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In this paper we present two numerical methods which help to solve these three points and so make the recognition of the coronal structures easier.

2. Observations

The following computations were made on a typical image that we have selected from the pictures obtained with the 20 cm spectrocoronagraph of the Pic du Midi observatory (Noëns *et al.*, 1984). This image was obtained on an active region at the east limb on July 4, 1984 in the light of the 5303 Å emission line of Fe XIV, with a time exposure of 7 s. The quality of the seeing and the sky brightness were medium. The image was digitized with a scanning aperture and a step of 1.5 arc sec.

Fig. 1. The raw digitised image of the active region observed at the east limb on July 4, 1984 in the light of the 5303 Å coronal emission line. The size of the pixels is 1''.5 × 1''.5. The total size of the image is 256 × 256 pixels. The image is displayed in negative form.

The result is displayed in Figure 1 and reveals different spatial frequencies of intensities which are essentially the centre-to-limb large scale brightness gradient and the low contrast of fine coronal structures. The estimated spatial resolution is about 5 arc sec. The large brightness fluctuation prevents the identification of the fainter parts of the structures. The aim of the data processing presented in this paper is to remove that obstacle. But any image processing which increases the contrast of the coronal structures also increases the defects which appear above the background. We have first to minimise these defects.

3. Data Processing

3.1. Correction of the defects

The image produced by the coronagraph is formed on the entrance mirror slit of the spectrograph. The image reflex system was described by Noëns *et al.* (1984). The advantage of this system is the precise location of each measurement point among the coronal structures, but the main inconvenience is that the defects of the mirror slit such as aluminiuim coating inhomogeneities, surface polishing irregularities and dust are in the image plane. The different steps of the digital processing also introduce some defects. A defect is defined as a set of consecutive pixels, for which the ratio of intensity to the neighbouring average intensity is larger, or smaller, than a fixed value. The size of the defect is limited to three consecutive pixels in any one direction. The defects of larger size are not excluded by this method because their correction would also affect the real small coronal structures. The intensity of the detected defect is replaced by an value interpolated from the intensities of the neighbouring pixels. The 'cleaned' image resulting from Figure 1 is shown in Figure 2; only the largest defects remain, together with those on the dark occulting disk, because the computations were only performed from the limb to the outer corona.

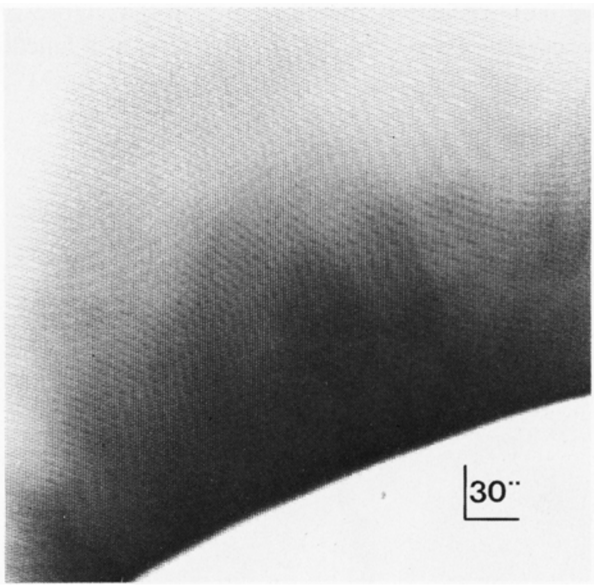

Fig. 2. The 'cleaned' image after correction of the defects.

3.2. The blurred mask processing

A way of reducing the large-scale gradient of brightness is to suppress the low-frequency component of intensity which includes the background of the image. Such a processing was described by Roudier *et al.* (1985) in Fourier space (k_x, k_y). A simple way to carry out that processing in direct space (x, y) is to smooth the image and subtract the result from the initial frame. This operation in direct space is equivalent to filtering in Fourier space using a high-pass filter of spatial frequencies k, k_y:

$$F(k_x, k_y) = 1 - \tilde{S}(k_x, k_y),$$

where $\tilde{S}(k_x, k_y)$ is the Fourier transform of the smoothing function $s(x, y)$. Here we have chosen an uniform smoothing corresponding to the function

$$\tilde{S}(k_x, k_y) = \left(\frac{\sin K_x l}{K_x l}\right)\left(\frac{\sin K_y l}{K_y l}\right),$$

where l is the half-width of the smoothing area. The processing improves the contrast of the small coronal structures without introducing artefacts, and displays the high spatial resolution arches in their entirety. One of the disadvantages of this method is the border effect which is important at the limb limit where the intensity gradient has its maximum value. The image displayed in Figure 3 illustrates the method, using a bidimensional smoothing over 21 × 21 pixels performed upon the 'cleaned' image of Figure 2. The result shows up the projection and integration of all the emissive regions on the sky plane but does not show their spatial organisation. An improvement of the treatment would be to use a gaussian smoothing, instead of a uniform one, which would eliminate the decreasing oscillatory behaviour of the filter as a function of (k_x, k_y).

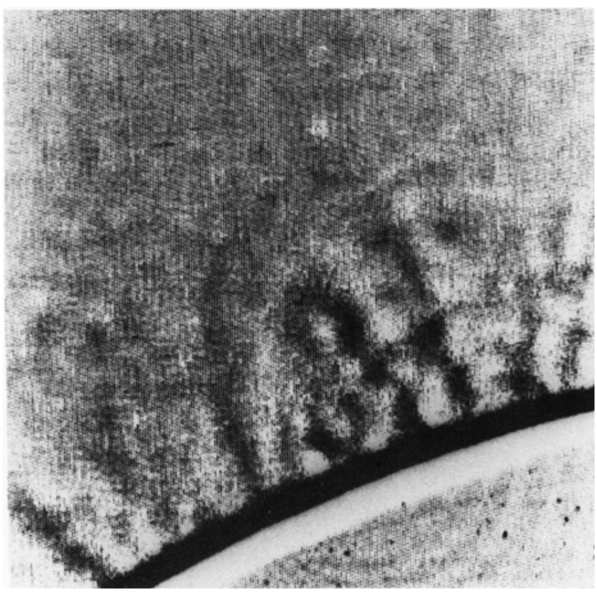

Fig. 3. The image obtained from Figure 2 after applying the 'blurred mask' method.

3.3. The Multidirectional Maximum of Absolute Derivatives

The one-directional derivative of an image is a classical way to cast off the large-scale intensity radial gradient. This kind of processing increases the contrast of the small-scale structures above the background but dramatically loses all the structures which are parallel to the chosen direction. The best way to keep the derivative properties in all directions is to compute the multidirectional maximum of absolute derivatives around each pixel. This method uses the following transformation, operating in four spatial directions:

$$\max\left(\left|\frac{\partial}{\partial x}\right|, \left|\frac{\partial}{\partial y}\right|, \frac{1}{\sqrt{2}}\left|\frac{\partial}{\partial y}+\frac{\partial}{\partial x}\right|, \frac{1}{\sqrt{2}}\left|\frac{\partial}{\partial y}-\frac{\partial}{\partial x}\right|\right).$$

Such a processing emphasises the directional properties of the coronal matter. For example, the image of Figure 4, obtained from Figure 2 by this method, exhibits some structures like coronal arches which are not clearly seen on the first figure. In particular a system of about five arches is evidenced, some of them appearing to be tilted from the sky plane. The feet of the arches show a narrow repartition of the emissive matter with a single peak of intensity, which may be interpreted as a set of thin unresolved features. The fact that this method shows the directional organisation of structures and also of the magnetic features helps to solve the difficult interpretation of the superimposition of the structures.

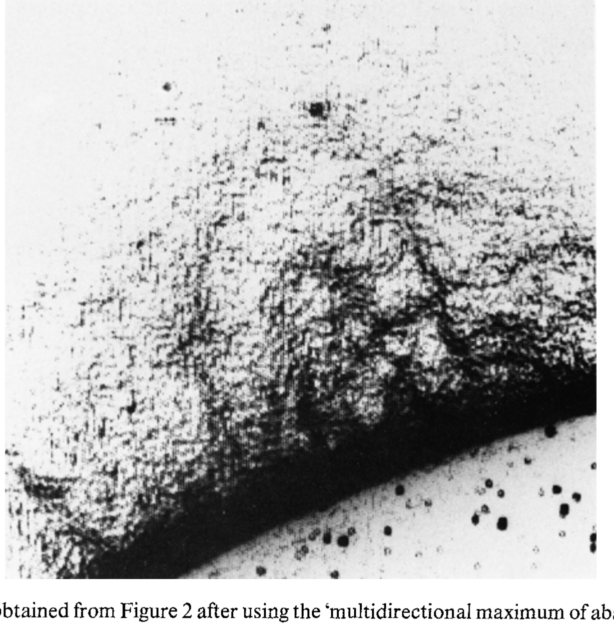

Fig. 4. The image obtained from Figure 2 after using the 'multidirectional maximum of absolute derivatives' method.

4. Conclusion

The two numerical processings presented in this paper appear to be complementary. The 'blurred mask' method is used for the subtraction of the sky brightness and the radial intensity gradient. It increases the contrast of the emissive coronal material, and shows, on the same image both the inner and outer parts of the structures. The 'multidirectional maximum of derivatives' method is used to reveal the fine-scale fluctuations of intensity: it shows the directional distribution of the structures and solves, to a great extent, the difficulties due to their superimposition on the sky plane. The set of these two processings allows the resolution of fine structures of complex active regions at the scale permitted by the real spatial resolution of observation. This is of prime importance not only for morphological studies of coronal matter and magnetic field organisation, but also for the interpretation of coronal measurements in terms of local parameters like density, magnetic field and temperature. The analysis of the coronal image processed by our treatment has somewhat improved our view of the fine coronal structure, which has to be taken into account in the parameter determination.

This result shows that future studies of coronal properties require a considerable effort to improve the spatial resolution of the physical measurements.

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References

Noëns, J. C., Pageault, J., and Ratier, G.: 1984, *Solar Phys.* **94**, 117.
Ratier, G.: 1975, *N. Revue d'Optique* **6**, 169.
Roudier, Th., Coupinot, G., Hecquet, J., and Muller, R.: 1985, *J. Optics* **16**, 107.