The Automatic Processing and Analysis of Solar Image Sequences[1, 2]

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Abstract—An algorithm for the analysis of sequential images of the Sun is presented and tested with the imagery obtained by the SOHO satellite. In the context of space weather monitoring, it is interesting to reveal the sources of fast solar wind on the surface of the Sun. Examples of such sources are coronal holes, which may cause a fast flow of solar wind when crossing the central meridian of the Sun. The proposed algorithm determines the area and location of coronal holes. The calculated dynamics of the hole areas and of the observed solar wind velocity are compared from August 1 to December 31, 2003.

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INTRODUCTION

The surface of the Sun is currently being actively studied. Recently considerable attention has been paid to the Sun surface analysis within European Space Agency programs. A number of satellites have been launched providing the possibility to obtain high-quality images of the Sun in several spectral ranges (e.g., the SOHO satellite, which carries sophisticated instruments including the EIT camera, http://sohowww.nascom.nasa.gov). The Sun imagery in the form of frame sequences can be found in the SOHO/EIT databases (http://sohowww.nascom.nasa.gov/cgi-bin/summary_query_form).

Images of the surface of the Sun are morphologically complex, with dozens of emerging and disappearing objects, which may be sources of geomagnetic storms [1]. Coronal holes represent a type of such objects [3]. Coronal holes are long-living formations with an average lifetime approximately several rotational periods of the Sun. The size of the coronal holes and their location on the surface of the Sun depend on the magnetic field configuration of the Sun. Coronal holes are sources of fast solar wind, which can cause intensive geomagnetic storms on the Earth [5]. Of much interest in this context are the automatic processing and analysis of coronal hole images, in particular, the determination of their location on the solar surface and calculation of their area. There are a number of methods to solve this problem [2]. In this study, we implement an algorithm that can be applied to analyze images not only of coronal holes, but also of other geoeffective objects (e.g., active regions) emerging on the Sun surface.

DESCRIPTION OF THE ALGORITHM

The objects under study were the SOHO/EIT 284 Å daily images acquired from 2000–2003 (Fig. 1). A tailor-made computer program capable of recognizing coronal holes in the images and determining their area and location has been developed.

The determination of the coronal-hole area relies on the classification of the image pixels with respect to threshold intensity. A distinguishing feature of the coronal holes is their low brightness in comparison

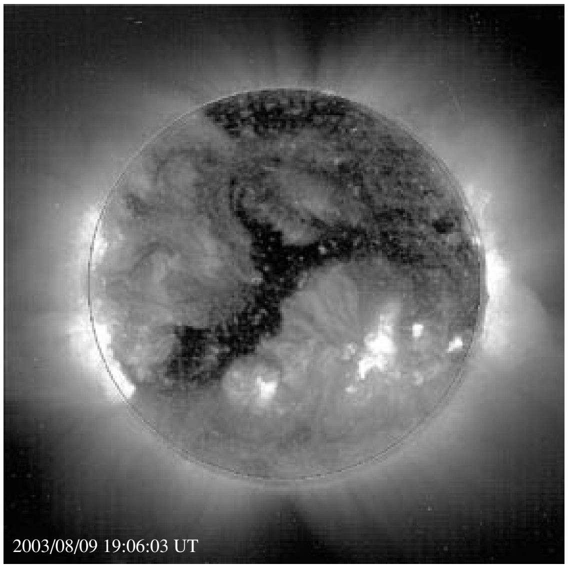

Fig. 1. An image of the Sun, SOHO/EIT, 284 Å.

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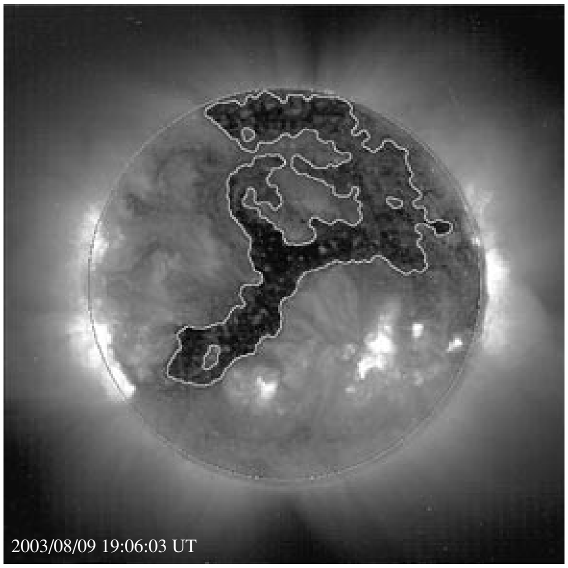

Fig. 2. The result of identifying coronal holes in the image in Fig. 1.

with other objects on the surface of the Sun. However, the total brightness of the SOHO images may considerably vary from image to image; so the threshold value for each image has to be determined automatically based on the brightness histogram analysis.

First, the intensities of all pixels in an image are normalized to fit in an interval from 0 to 255. The normalized intensities are then put into a histogram, and the maximum intensity ($I_{\max}$) is determined. The threshold intensity is calculated by the formula

$$I_{\text{thr}} = kI_{\max},$$

where k is the threshold coefficient, which varies in the interval from 0 to 1 but is usually set at 0.6.

Pixels with an intensity less than the threshold are set to be black. The result of the classification is a black-and-white image with its black part assumed to be the objects sought for.

To remove high-frequency noise from the image, we use the following algorithm. A square region with side length equal to $2r + 1$ (r is the smoothing radius) is selected around each pixel, beginning from the upper left corner of the image. Then, the black-and-white pixels falling into the selected region are counted and the central pixel is assigned the color of the majority of pixels in the smoothing region. If the pixel's original color is changed, the algorithm recedes $r + 1$ pixels left and $r + 1$ pixels up. The described algorithm is relatively slow, but it is effective and simple to implement. The resulting black pixels are conglomerated and classified as coronal holes (Fig. 2).

When the area of the coronal holes is calculated, it is necessary to bear in mind that the surface of the Sun is spherical while the used images are flat. Thus the area of the coronal holes is calculated in pixels with regard to the curvature of the Sun.

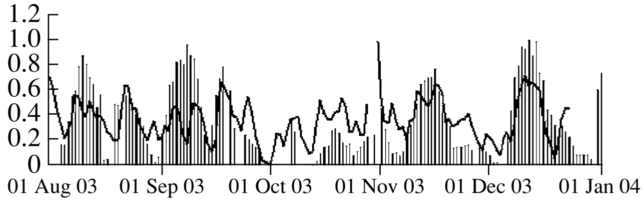

Fig. 3. Daily mean solar wind velocity (solid curve) and total area of coronal holes (bars) for the period from August 1 till December 31, 2003. The data is normalized to fit into the interval [0, 1].

RESULTS

The algorithm described above was used to calculate the coronal-hole areas from August till the end of December 2003. During six rotational periods of the Sun, partial recurrence of the fast solar wind was observed and twelve time intervals when the wind velocity exceeded 700 km/s can be specified. Undoubtedly, these flows are connected with the passage of extensive coronal holes across the disk of the Sun.

It is difficult to find an exact correspondence between the coronal holes and the parameters of solar wind, because of the different configuration and strength of their respective magnetic fields. However, generic resemblance is clearly seen in Fig. 3, which shows the solar wind velocity together with the total area of coronal holes. The values of the total area of coronal holes are three days ahead of the associated solar wind velocities. This delay corresponds to the average time that the solar wind plasma takes to travel from the Sun to the Earth (the parameters of solar wind are detected in the orbit of the Earth). A good correlation between the total area of the coronal holes and the solar wind velocity is observed. This result might be expected based on the general concepts of the fast solar wind flow formation.

CONCLUSIONS

An algorithm for the automatic detection and calculation of the coronal hole area on the surface images of the Sun has been designed and tested. The described algorithm can also be used to analyze active regions (regions of increased brightness) on the images and the regions of strong magnetic field on the magnetograms of the Sun, as well as to study other possible sources of geomagnetic disturbances.

To find a direct link between geomagnetic storms and a certain phenomena (combinations of objects) on the Sun still presents a problem. The selection of the most typical objects in the Sun images, the description of their morphological features, and the subsequent neural network analysis [4] are believed to help in relating geomagnetic storms to solar phenomena.

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