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Automated coronal hole segmentation from Solar EUV Images using the watershed transform ☆

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ABSTRACT

Region of interest segmentation in solar images is the subject of frequent research in solar physics. This study outlines watershed by immersion segmentation to identify coronal hole areas in solar images acquired using the Extreme UV Imaging Telescope (EIT). Solutions presented here produce highly accurate segmentation results of coronal holes of irregular shape, and what is more, they do so for images representing varied solar activity, recorded in different years and months. In addition, the solutions presented here make all the methods used operate very quickly. These methods include: the preprocessing step before the watershed segmentation, the watershed segmentation itself, and also the postprocessing of solar images after the watershed segmentation. The mean duration of the entire segmentation process of solar images amounts to 342 ms for a single coronal hole, without the parallel implementation of the methods used. The experiments were carried out on a computer with an Intel Core i7 CPU @ 2 GHz and 4 GB RAM. After the seed point is identified inside the coronal hole, the segmentation runs automatically.

1. Introduction

This study concerns images showing coronal holes on the Sun, selected by astrophysicists and downloaded from a web database provided by the European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) [1]. Coronal holes are researched in solar physics and show up in solar images as irregular darker areas on the solar disk. They are caused by the magnetic field of the Sun and highly variable in time and space. In general, their temperature is lower than of their surroundings, which can be observed in images in which cooler areas are less bright. Fig. 1 presents an example coronal hole in the middle of the solar disk and a model of the Sun's magnetic field. Charged particles from the Sun's magnetic field frequently reach the Earth and cause magnetic storms producing e.g. northern lights. Research work was carried out on solar images acquired by the EIT imaging telescope installed on a space probe called the Solar and Heliospheric Observatory (SOHO). This telescope can record images in extreme UV, e.g. at the wave length of 195 angstroms, abbreviated to EIT195, which bring solar coronal holes out really well. The names of EIT195 solar images contain information on the date and time of their acquisition, e.g. 19980523_1942. Obviously, apart from EIT195, other types of images are also recorded, for instance: EIT171, EIT284, EIT304. Altogether, ten different types of solar images can be downloaded from the web database [1].

A segmentation allowing regions of interest to be detected and followed in solar images is the subject of constant research for various types of images recorded using the SOHO satellite. In general, the two most frequently used approaches are: edge-based methods and region-based methods, very often used in conjunction with various techniques of preprocessing the analysed images.

Edge-based methods are broadly presented in [2–5]. On the other hand, region-based methods are used to detect sunspots [6,7], thread-like filaments [8,9], coronal holes [10,11], and active regions [12]. Region-based approaches use statistical data from sub-regions and enable the optimum energy based on which the model fits the image best to be found. Mumford and Shah [13] present a solution in which the image is approximated using a smooth function inside every area in the analysed image. Chan and Vese [14] propose a solution allowing every region of the image to be approximated using a certain constant function. Region-based methods approximate weak edges much better than active contour edge-based methods [16]. What is more, they are much less sensitive to the initial location of the contour for its initialisation. Some of the better known and more widely used methods assume that there are regions of interest in the image which are statistically homogeneous [14,15]. Some classes of images, however, contain

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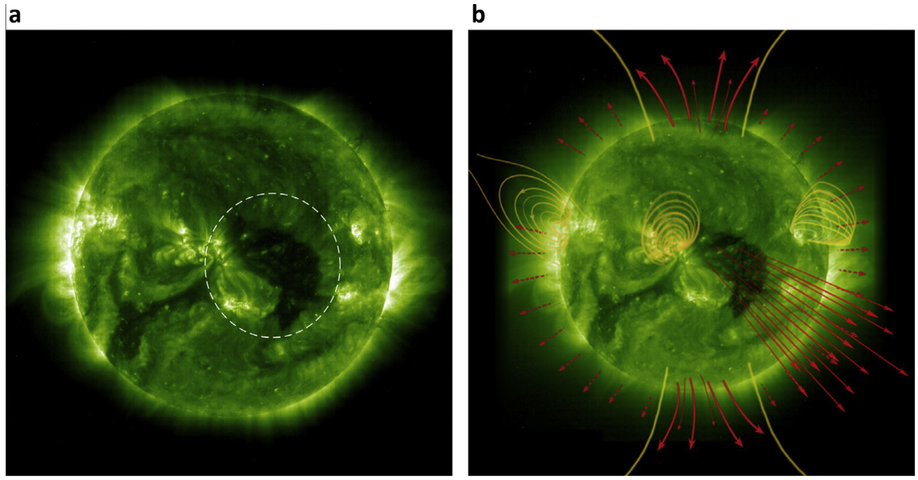

Fig. 1. Example solar image: 19980523_1942_eit195. (a) The coronal hole area in the centre of the solar disk is marked. (b) The model of the Sun's magnetic field including open field lines coming out of the coronal hole area. Courtesy of SOHO (ESA & NASA).

non-homogeneous areas, for example medical images like ultrasonograms (USG).

The literature also includes works making use of clustering methods, but they are much less numerous than the previously mentioned edge-based and region-based ones. Clustering is to help reduce the amount of data by categorising or grouping similar features in the analysed data set. For instance, in [17] an unsupervised spatially-constrained fuzzy clustering procedure is used to segment the EUV image into active regions (AR), coronal holes (CH), and the quiet Sun (QS). Fuzzy clustering was also used in [18] to automatically detect active regions in EUV images.

Obviously the review of literature on various groups of segmentation methods is much broader than that on the segmentation methods applied to solar images. Important segmentation methods should also include: compression based methods [19,20], histogram based methods [21–23], partial differential equation-based methods (PDE) [24,16,25], graph partitioning based methods [26–29], model based methods [30] and methods taking into account the interaction between edges [31]. A review of various segmentation techniques can be found e.g. in [16,32,33].

Hitherto work can be summarised by saying that, unfortunately, it is difficult to unambiguous choose one of the proposed methods for segmenting regions of interest in solar images, which would simultaneously fulfil the following three conditions:

– Support automating the segmentation process.
– Ensure high accuracy of segmentation results for areas of frequently variable, irregular shape, particularly in images showing various solar activity, e.g. for different months and years.
– Operate fast.

Segmenting coronal holes in solar images is difficult as these holes are of very variable shapes in different periods of time and do not have clear edges.

Fig. 2 shows examples of EIT195 solar images from two subsequent months. Examples from Fig. 2(a) and (b) show the middle coronal hole which is absent from the solar image taken a month and 10 days later and shown in Fig. 2(e) and (g). The upper coronal hole, in turn, is very poorly visible in the solar image from Fig. 2(a) because it is only beginning to form, but it becomes clearly visible some 40 days later. The lower coronal hole, in turn, is visible in both images from two subsequent months, but its shape and size are different.

If thresholding is used, the area of a coronal hole can be determined in a single image or a short sequence in which the corona does not change noticeably [11]. However, for a longer period of time, the value of the threshold would have to be adjusted to the current conditions. What is more, several coronal holes of various contrasts can occur in a single solar image. Hence a method for extracting coronal holes must account for their diversity, especially as the purpose of research is to obtain a universal method, i.e. one which can, without major modifications, be used to detect coronal holes in the majority of solar images.

In this study, the watershed segmentation method [34–36] first presented in [10] was used to identify areas of coronal holes. The watershed segmentation method makes use of the notions from topography, but expressed in the mathematical morphology language [34]. In addition, it has many applications and is considered to one of the most effective tools for digital image segmentation. There is a lot of literature describing the use of watershed segmentation and its very good results in processing various types of images, for instance those shown in [37–41]. The watershed segmentation is effective mainly due to additional, auxiliary transformations of the processed images before and after the segmentation itself is completed. Most frequently, these additional operation are used to eliminate the excessive fragmentation of regions, which is the main shortcoming of the watershed segmentation. Such operations can consist in, for instance, preliminary image filtering or marker application [34].

This study introduces new solutions into the process of segmenting coronal holes from EIT195 images compared to [10]. They relate both to the watershed segmentation algorithm used and the method of merging segments after the segmentation into the resultant coronal hole area. As a result, high convergence of segmentation results with those obtained by experts (astrophysicists) is achieved, while maintaining the high operating speed of the entire segmentation process. Based on the research conducted for 180 coronal hole areas, the mean duration of segmenting coronal holes including preprocessing and post-processing EIT195 images after the segmentation amounts to 342 ms for a single coronal hole, even without a parallel implementation of the methods employed. It should be noted that after the seed point of the coronal hole area has been identified, the segmentation process runs automatically. In the available example implementations by authors of other methods [20,31] executed in Matlab, the parameters of the computer have a significant impact on the time needed for the segmentation: these methods generally require a large amount of RAM memory and a fast CPU.

To provide a benchmark for the results achieved by the watershed segmentation method, the geometric active contour model