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Software tool for automatic detection of solar plages in the Coimbra Observatory spectroheliograms

T. Barata [a], S. Carvalho [a,b], I. Dorotovič [c,d], F.J.G. Pinheiro [a], A. Garcia [a,e], J. Fernandes [a,e,f,*], A.M. Lourenço [a]

[a] Centre for Earth and Space Research of University of Coimbra, 3040–004 Coimbra, Portugal
[b] Centre for Mathematics, University of Coimbra, 3001–501, Coimbra, Portugal
[c] Slovak Central Observatory, 94701 Hurbanovo, Slovak Republic
[d] Computational Intelligence Group of CTS/UNINOVA, 2829–516 Monte de Caparica, Portugal
[e] Geophysical and Astronomical Observatory of University of Coimbra, 3040–004 Coimbra, Portugal
[f] Department of Mathematics, University of Coimbra, 3001–454, Coimbra, Portugal

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ABSTRACT

Full-disk spectroheliograms have been taken in Coimbra on a daily basis since 1926 in the Ca II K-line (K1 and K3). Later, in 1989, with the upgrade of the equipment it was possible to start the observations in the H-alpha line. The spectroheliograms of Coimbra constitutes a huge dataset of solar images, which requires an efficient automatic tool to detect and analyze solar activity features. This work presents a mathematical morphology approach applied to the CaII K3 series. The objective is to create a tool based on the segmentation by watershed transform combined with other morphological operators to detect automatically and analyze chromospheric plages during the solar cycle 24. The tool is validated by comparing its results for cycle 23 with those presented by Dorotovic et al. (2007, 2010). The results obtained are in very good agreement with those, including on images obtained in non-ideal meteorological conditions (eg. some clouds in sky). The results were also qualitatively compared with the results obtained through the application of ASSA model to SDO HMI magnetograms.

1. Introduction

The Sun shows its activity in several ways, like active regions, flares, coronal mass ejections, etc. The characterization of solar features, traditionally made by hand by an expert user, is of great importance to monitor and forecast the solar activity and to obtain results for the Space Weather study (Veronig et al., 2001).

The success of several solar missions has allowed to obtain a vast group of high resolution images. In relation to this available information source, the solar physics community is comparatively small, and therefore the resource to the images digital processing has increased, with the aim of getting information about the solar activity in a prompt and efficient way (Gill et al., 2010; Falconer et al., 2011). Neural networks have been used to detect the solar activity of the solar wind's proton events (Borda et al., 2002), and automatic tracking of solar flares (Caballero and Aranda, 2014). Threshold techniques, region growing, edge detection, segmentation, Hough transform, fractal analysis and fuzzy sets have been applied in the detection of sunspots, active regions, plages, filaments and CMEs (Nesme-Ribes et al., 1996; Benkhalil et al., 2004; Zharkova et al., 2004; Qu et al., 2005; Scholl and Habbal, 2008; Aboudarham et al., 2008; Fonte and Fernandes, 2009; Gafeira et al., 2013). Hybrid methods that include different approaches have also been developed (Qahwaji and Colak, 2005; Manish et al., 2014; Dorotovič et al., 2014). The mathematical morphology has been applied to sunspots (Curto et al., 2008; Carvalho et al., 2015; Zhao et al., 2016), in the filaments' recognition (Fuller et al., 2005) and plages (Meunier and Delfosse, 2009). A good review is made in by Aschwanden (2010). A common aspect between all these works is the need to incorporate pre-processing techniques, such as Wavelets (Irbah et al., 1999), to normalize the solar images, with regard to dimension, size and intensity, and limb darkening correction (Walton et al., 1998; Denker et al., 1999; Walton and Preminger, 1999; Zharkova et al., 2004; Zharkov et al., 2005). All these techniques are tailored to detect features in various types of observations at different heights in the solar atmosphere (Verbeeck et al., 2014). Automatic tracking of solar features has been developed for filaments (Gill et al., 2010; Goussies et al., 2010; Higgins et al., 2011) active regions (Pérez-Suárez et al., 2011; Martens et al., 2012), and solar flares (Higgins et al., 2011), coronal

* Corresponding author at: Centre for Earth and Space Research of University of Coimbra, 3040–004 Coimbra, Portugal.
E-mail address: jmfernan@mat.uc.pt (J. Fernandes).

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mass ejections (Olmedo et al., 2008) which constitute the first steps for the building of an approach that can allow to follow and to characterize the solar activity evolution.

A comparison between automatic and manual methods was made by Zharkova et al. (2005), proving the big efficiency of the automatic methods. Carvalho et al. (2015) compares the results from different sunspot detection methods. The robustness of automatic methods to detect sunspots and active regions are also made by Verbeeck et al. (2013).

Traditionally the solar catalogs were created by hand, but the results of these many applications have contributed for the building of solar activity catalogs, being the EGSO (European Grid of Solar Observations) a good example of this (Fuller and Aboudarhma, 2004). Another pioneer example is the Solar Monitor, which labels active regions using NOAA's (National Oceanic and Atmospheric Association) numbers and heliographic positions (Higgins, 2012).

Despite having more data from new instruments and space missions, it is yet important to maintain older instruments working and to use their data for several important reasons (Hill et al., 2010; Ayres and Longcope, 2012). One of them is the long-term observations of, at least, several decades they have been performing, crucial to understanding the solar cycle. Besides, ground-based observations allow us to preserve and extend consistent data sequences.

Solar faculae or plages are bright areas on the solar surface surrounding active regions and sunspots (Kostik and Khomenko, 2014). They are magnetic structures constituted of flux tubes where a strong magnetic field creates extra heat (about 300 degrees K above surrounding). The interest in facular regions is due the fact they may presage sunspot formation. This interest has increased even more with the discovery that the total solar irradiance increases when the Sun is more active (Solanki and Fligge, 1999; Solanki and Unruh, 2013). In addition, the variability of facular areas it is one of the most important solar indices required to understand the activity of solar cycle (Göker et al., 2016).

This paper intends to contribute towards an automatic detection of facular regions acquired at the Geophysical and Astronomical Observatory of the University of Coimbra during cycle 24. The basic morphological operators are introduced in next section. The data used in this work and the automatic method based on mathematical morphology transforms are described in detail in Section 3. Data analysis and discussion of the results are performed in Section 4. Finally, the conclusions are presented in Section 5.

2. Basic concepts of mathematical morphology

Mathematical Morphology is an image analysis theory created in the middle 1960s by George Matheron and Jean Serra in the École des Mines de Paris. Its initial purpose was related to an application in porous media to describe the geometric features of structures (Matheron, 1967). The further developments since then have permitted to construct a solid framework (Matheron, 1975; Serra, 1982) and have successfully reached new application areas (good overview in Soille, 2002), including solar physics (Aschwanden, 2010).

One of the great potentialities of using mathematical morphology is the power to deal with the geometry of complex and irregular shapes (Barata et al., 2015). From the visual analysis of solar images, facular regions present these characteristics which led to exploring an approach based on morphological operators.

Initially developed for binary images this theory was generalized for gray-scale images. Any operator or morphological transform implies the comparison of the features to analyze with a known object, the structuring element. The success of the application of any mathematical transform depends on the choice of the structuring element. The mathematical morphology operators can be used directly or applied sequentially to obtain more elaborated morphologic transformations, for specific ends. Matheron (1975) and Serra (1982) present a detailed description of the mathematical morphology method. In the following paragraphs are presented the main ideas (Soille, 2002).

2.1. The basic transforms

The first morphological transforms defined by Matheron (1967), are the erosion (ε) and dilation (δ). To gray scale images, the erosion ($\varepsilon_B(f)$) of an image f by a structuring element B of size λ, is the minimum of the translations of f by the vectors $-b$ of B (Soille, 2002):

$$\varepsilon_B(f) = \min_{b\in B} f_{-b}. \tag{1}$$

The dilation of an image ($\delta_B(f)$) of an image f by a structuring element B of size λ, is the maximum of the translations of f by the vectors $-b$ of B:

$$\delta_B(f) = \max_{b\in B} f_{-b}. \tag{2}$$

The final results for both operators are poor in details when compared with the initial image. If it is necessary to enhance dark areas in a gray image, the erosion shows good results and the dilation has the opposite effect, because white zones in an image are more easily detected.

2.2. The morphological gradient

The objective of the morphological gradient is to enhance and extract the contours of the homogeneous regions of gray levels in an image. From the two basic operators, erosion and dilation, the morphological gradient or *Beucher gradient* (Beucher, 1990) is defined as the arithmetic difference between the maximum and the minimum of the function f, divided by the size or diameter (λ) of the structuring element (B):

$$\rho_B = \delta_B - \varepsilon_B/2\lambda. \tag{3}$$

The objective of the morphological gradient is to enhance and extract the contours of the homogeneous regions of gray levels in an image.

2.3. Opening and closing

The erosion and dilation can be combined to perform two important transforms: opening and closing. The opening (γ) consists of submitting an image f to an erosion followed by a dilation, both by a structuring element B of size λ. In the final image the opening cuts peaks and removes small object protuberances:

$$\gamma B(f) = (\delta B(f))[\varepsilon B(f)]. \tag{4}$$

In the same manner, the closing transform (ϕ) consists in applying a dilation to an image f followed by an erosion. This operation suppresses (or closes) all the valleys smaller than a certain dimension given by the size λ of the structuring element B:

$$\phi B(f) = (\varepsilon B(f))[\delta BB(f)]. \tag{5}$$

Although possible, the isolated application of each operator is not a very powerful filter. However, the alternate application of these operators is the basis of the majority of morphological filters.

2.4. Top-hat

The top-hat transform was introduced by Meyer (1979, 1986) based on combinations of openings and closings. The white top-hat