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Ground-based Observations of Sunspots from the Observatory of Coimbra: Evaluation of Different Automated Approaches to Analyse its Datasets

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Abstract. The Geophysical and Astronomical Observatory of the University of Coimbra (OGAUC) has a collection of solar observations (spectroheliograms) that span near nine decades, acquired uninterruptedly until today on a daily basis since 1926 and already in digital format. This extensive collection acquired with the same instrumentation must be processed altogether since its large temporal coverage can provide important inputs for the knowledge of the solar activity. Therefore, this work aims to evaluate the capability of some methods in the automatic detection of sunspots from spectroheliograms. The objective of this work is to define a strategic action, concerned with sunsposts detection, to be applied to all spectroheliograms datasets. The final detection results of different methods are compared to reference detections provided by an expert solar observer, in order to evaluate the performances on the detection of the contour of sunspots and also on the ability to differentiate the umbra and penumbra areas. According to the best detection performances (its accuracy but also computational time, among others), a processing chain will be implemented and applied to the whole data series of OGAUC.

1. Introduction

Several image processing and detection approaches have being developed and tested in the last years in order to get information about solar activity (sunspots, filaments, CMEs, flares, etc) in a prompt and efficient way. The advancements and results of many applications developed by the community, especially as sunspots are concerned, have contributed for the building of solar activity catalogues, being the EGSO (European Grid of Solar Observations) a good example of this, Fonte & Fernandes (2009). Nevertheless, in addition to have more data from the new instruments and space missions, it is yet important to maintain older instruments working and to use their data, Ayres & Longcope (2012), Hill et al. (2012) for several important reasons. One of them is the long-term observations of, at least, several decades they have been performing, crucial to the understanding of the solar cycle. Besides, ground-based observations also allow us to preserve and extend consistent data sequences.

As it turns out there are a lot of solar images from both ground-based observations as solar missions. Therefore the use of digital image processing techniques has increased accordingly with the aim of getting information about the solar activity in a prompt and efficient way, Gill et al. (2010). The versatility of automatic methods is also high, not only due to its ability for characterizing and quantifying parameters of the solar activity, but also to its applicability in any type of solar image (from high resolution to spectroheliograms, for example). However, in what concerns ground-based images, the application of automatic methods can present some additional difficulties, due the Earth's atmosphere and meteorological factors, Curto et al. (2008). Thresholding techniques, mathematical morphology, region growing, edge detection, Hough transform, and fuzzy sets are among the many techniques that have been applied in the detection of sunspots, Curto et al. (2008), Qu et al. (2005), Zharkova et al. (2005). Hybrid methods that include different approaches have also been developed, Nguyen et al. (2006), Dorotovič et al. (2014). A common aspect between all these works is the need to incorporate pre-processing techniques, before the main processing and feature extraction task, with the aim of homogenizing the solar images in terms of dimension, size and intensity, and also of removing the limb darkening effect, Zharkov et al. (2005), Denker et al. (1999).

2. Data

A set of recent and different images, belonging to solar cycle 24, acquired at the OGAUC was chosen to test and validate several algorithms. The set comprises 25 and 20 images for the months of October 2014 and November 2014, respectively. These spectroheliograms are digital images of 8 bits (256 grey levels), with 1200 x1000 pixels, taken at Hα continuum line. For each image an expert solar observer delineated manually the umbra and penumbra regions to build the ground-truth data set.

3. Methods

Different automatic methods developed by different research groups (one already available, Ashamari et al. (2015), and two originally developed now) with quite different and up-to-date approaches from image analysis and pattern recognition, were applied to the dataset considered.

3.1. Method 1

ASAP-Automated Solar Activity Prediction[1] is a software developed by the University of Bradford, United Kingdom, which comprises morphological algorithms to detect sunspot candidates, morphological algorithms to detect active region candidates, region growing to combine sunspot and active region candidates, and neural networks to segment sunspots (example shown in Figure 1, top right). ASAP was developed for

[1]http://spaceweather.inf.brad.ac.uk/asap/

high resolution images from SOHO/MDI and, as input, continuum image and magnetogram are required. This software was tested considering Coimbra's data combined with magnetograms from SOHO/MDI.

3.2. Method 2

The second method tested starts with a pre-processing task in order to correct limb darkening. After that, smooth filters are applied to eliminate low frequencies and outliers and to increase the images contrast. Two thresholds are also applied to segment umbra and penumbra. Lastly an exclusion criteria relating to the size and intensity is considered (example shown in Figure 1, bottom left).

3.3. Method 3

In this third algorithm, the identification of sunspots is based on mathematical morphology operators (top-hat transform, area-opening and thinning). For each individual sunspot detected, the umbra-penumbra segmentation is performed using the respective histogram and taking as assumption that if the grey level distribution within the sunspot is uni-modal the sunspot is constituted only by umbra otherwise umbra and penumbra are presented and a threshold value is automatically estimated to segment them (example shown in Figure 1, bottom right).

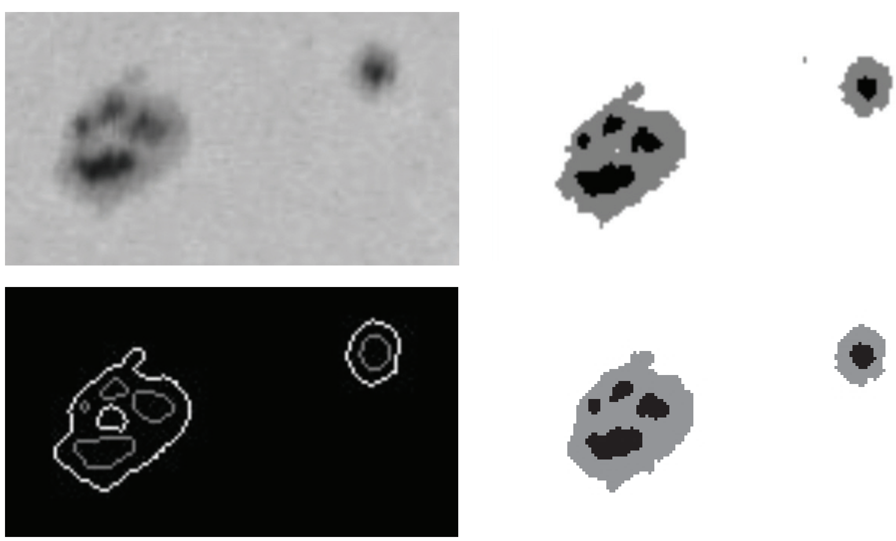

Figure 1. Example of detected and segmented sunspots. *Top left:* Initial image. *Top right:* Method 1. *Bottom left:* Method 2. *Bottom right:* Method 3.

4. Results

The evaluation of the obtained results was carried out comparing the output of each image for each method with the reference/ground-truth, previously built by an expert sun observer. In order to evaluate the performance of each method, two distinct evaluations stages are considered, one for quantifying the quality of sunspots detection (table 1), the other for measuring the ability to separate umbra from penumbra (table 2):

- sunspots detection (these quantities are the same as the ones used by Pedrosa et al. (2015) in a similar detection problem)

  Detection rate (%): $D = \frac{TP}{TP+FN} \times 100$

  Branching factor: $B = \frac{FP}{TP}$

  Quality index (%): $Q = \frac{TP}{TP+FP+FN} \times 100$

  with TP: true positives; FP: false positives; FN: false negatives.

- umbra-penumbra segmentation (analysed by the respective confusion matrix)

  Overall accuracy (%): $OA = \frac{UU+PP}{UU+UP+PU+PP} \times 100$

  with UU: pixels of umbras detected as pixels of umbras; PP: pixels of penumbras detected as pixels of penumbras; UP: pixels of umbras detected as pixels of penumbras; PU: pixels of penumbras detected as pixels of umbras.

All these quantities rely on pixel-based comparisons.

Table 1. Evaluation of results - sunspots detection

	Method 1			Method 2			Method 3		
	D	B	Q	D	B	Q	D	B	Q
October	67.6	0.02	66.7	75.5	0.23	64.9	90.3	0.05	86.7
November	74.5	0.05	71.9	75.8	0.27	63.8	88.4	0.08	82.6

Table 2. Evaluation of results - umbra-penumbra segmentation

	Method 1	Method 2	Method 3
	OA	OA	OA
October	88.1	86.7	93.9
November	90.6	84.5	90.8

5. Discussion and Conclusions

This work aims to evaluate the capability of some automatic methods to detect sunspots from spectroheliograms. From the analysis of the results, method 3 is undoubtedly the best method, in what concerns quality index, the higher detection rates of sunspots, as well as, the best separation between umbra-penumbra. Although the lower detection rate of sunspots obtained by method 1, the umbra-penumbra separation is better than method 2. However, the quality index is better for method 1, because it detects less false positives. Therefore, the strategy to be defined in the future, should be strongly based on the method 3 taking into account some limitations that can be observed on the OGAUC data series. More recently, some improvements in the OGAUC's spectroheliograph have been carried out (e.g. in 2007 photographic plates were replaced by a CCD camera), which led to enhanced but also heterogeneous datasets. As a future work, it is intended to join efforts to make the data series as homogeneous as possible. To extend the same study to the CaII and the K3 series, as well as to other solar structures, are other goals to be achieved. We expect that all these results will enable validating mathematical models of sunspots evolution with a higher detail in a longer time series.

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