Analysis Filling Factor Catalogue of Different Wavelength SODISM Images

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Abstract. The Solar Diameter Imager and Surface Mapper's (SODISM) recording of data on the PICARD satellite in five different wavelengths has increased the need to extract features such as Sunspots. This paper analyses the overall sunspot detection performance, examines the correlation between the filling factor of different SODISM wavelengths and the Solar and Heliospheric Observatory (SOHO) filling factor, and compares them with the USAF/NOAA catalogue. Four months of data from SODISM and SOHO, obtained for the period Aug–Dec 2010, are analysed and compared. This comparison identifies the best wavelength for sunspot detection in SODISM, and compares the overall detection performance of three wavelengths; 535.7 nm, 607.1 nm and 782.2 nm. Furthermore, the study proposes a novel SODISM catalogue summarising SODISM data details including the Filling Factor, area, and the number of sunspots.

Keywords: SODISM · Sunspots · Wavelengths · SOHO · PICARD · Filling Factors catalogue

1 Introduction

The 15th June 2010 saw the successful launch of the PICARD satellite; onboard was the Solar Diameter Imager and Surface Mapper (SODISM), the imaging telescope taking solar images at a rate of one image per minute to provide wide-field images of the sun in five bands centred at 215.0 nm, 393.37 nm, 535.7 nm, 607.1 nm, and 782.2 nm, usually abbreviated as '215', '393', '535', '607', and '782' [1]. However, there is no uniformity in the quality of SODISM images captured at various wavelengths; the difference in image quality is evident in the slightly higher degradation in wavelengths 215 nm and 393 nm, because of the combination of solar irradiation and instrumental contamination where the W.L. 215 nm channel lost more than 90% of the normalized intensity, and W.L. 393 nm lost about 80% [2]. Figure 1 shows a pronounced decomposition in the UV channels. Meanwhile, the visible and near-infrared channels present a temporal oscillation but remain relatively constant [3]. However,

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according to the previous degradation reasons, the comparison in this paper will be between visible and near-infrared constant wavelengths (W.L. 535 nm, 607 nm and 782 nm). Detecting sunspots as individual elements is equivalent to determining which pixels belong to each sunspot, thus determining which pixels are active points by using the accurate threshold intensity level to isolate these points from the background [4].

The method presented here detects solar disc edges, then it detects sunspot candidates, and by iterative threshold on the gradient image which has been previously normalized counting the number of the connected regions. Figure 3 charts the fundamentals of the applied segmentation method to detect sunspots [1].

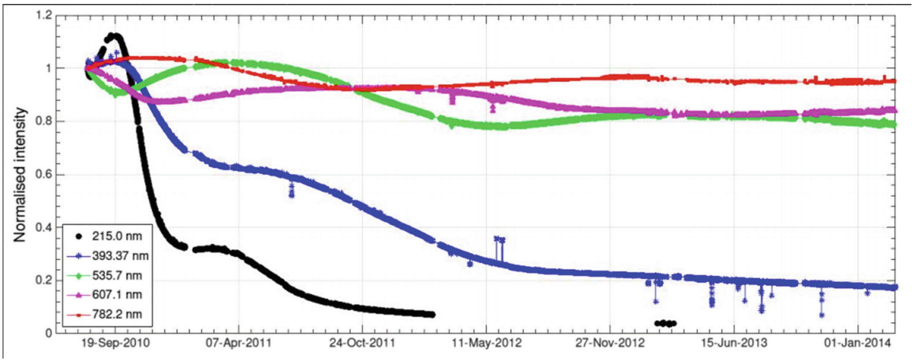

Fig. 1. Integrated intensity normalized time series of PICARD during his mission (Meftah et al. 2015).

Segmentation method was applied to images of 535 nm, 607 nm, and 782 nm wavelengths, which were available at level 1B. Level 1B data products include a number of corrections for any instrumental issues, all images were downloaded, which amounted to a total of 206 for W.L. 535 nm, and each image had a size of 2048 $\times$ 2048 pixels. The data obtained was from 5th August 2010 to 4th January 2014 besides 306 images taken at wavelengths of W.L 607 nm, and 300 images at 782 nm; these were collected between 2010 and 2014.

It is notable that many researchers use observatory images from the SOHO and SDO satellites to detect sunspots, but the five SODISM wavelengths have been relatively underused, and this prompted an interest in working with the SODISM images. This article makes the following contributions:

- Applying an automated method to detect Sunspots from SODISM images in W.L. 782 nm with verification.
- The provision of a filling factor of W.L. 782 nm and comparisons with SODISM W.L. 535 nm, 607 nm and SOHO images.
- Analysis of the correlation between SODISM wavelengths and USAF/NOAA catalogue, in number and size of sunspots.

The paper provides statistical means of characterising SODISM data and novel FF catalogue to summarise hundreds of experiments in a more concise manner, including

FF ratio, location and area of sunspots, this information will be the cornerstone in future for any new comparison with SODISM data.

This research study is presented as follows: Sect. 2 summarizes the literature; Sect. 3 presents the Pre-processing detection technique including verification and comparison with USAF/NOAA catalogue, Sect. 4 presents Filling Factor computation and catalogue; Sect. 5 discusses the results obtained from the previous sections; Finally, Sect. 6 summarizes the conclusions.

2 Literature Survey

Generally, the detection of the solar disk boundary limb is necessary to determine requirements such as the radius and centre of the disk, these requirements are necessary to obtain the segmentation features [4]. Once this information becomes available, any interior features such as Sunspots or bright regions can be analyzed on the solar disk. Particularly, SODISM images follow the same rules and use a thresholding approach to segmentation, because it is considered the simplest and quickest method [4]. But the unevenly distributed light of the background solar disk in SODISM images makes the global thresholding of the solar disk an impractical solution. Correcting in a pre-processing to normalize image brightness might lead to better segmentation. Most of the previous approaches applied on SODISM to detect sunspots have been summarized in previous papers, see [3] However Alasta et al's most recent papers in 2017 [5] and 2018 [3] on the topic of sunspot detection on SODISM images applied to 535 nm and 607 nm W.Ls described their methods as follows:

For the 535 nm W.L.

- Detect the solar disk border and record its centre and radius.
- Convert scale of the image from a signed 32 bit, to 8 bit.
- Remove noise by using Kuwahara and à Trous filters.
- Correct pixel brightness outliers and employ a Bandpass filter to display the sunspots on a normalized background.
- Finally, locate the sunspot by the use of the threshold method.

A comparison between the filling factor results produced by this method and the results produced by the SOHO method has established a correlation coefficient of 98.5%.

And recently, in 2018 Alasta et al. provided a new method for 607 nm W.L [3]; their methods were as follows:

[i] The Solar limb is extracted
[ii] The sunspot gradient is calculated
[iii] Use a closing operation to fill the holes.
[iv] Compute the image obtained in the gradient image and the original image
[v] Isolated noise from the sunspot gradient,
[vi] Use the Kuwahara filter to remove the unwanted noise.
[vii] Only those sunspots where the difference between the maximum and minimum grey values of a pixel is greater than 5 are verified.

Finally Fig. 2 shows an example of the result by applying a binary overlay in red colour and superimposing the original image. Their result is the first automated method to achieve 99% correlations between SOHO and SODISM.

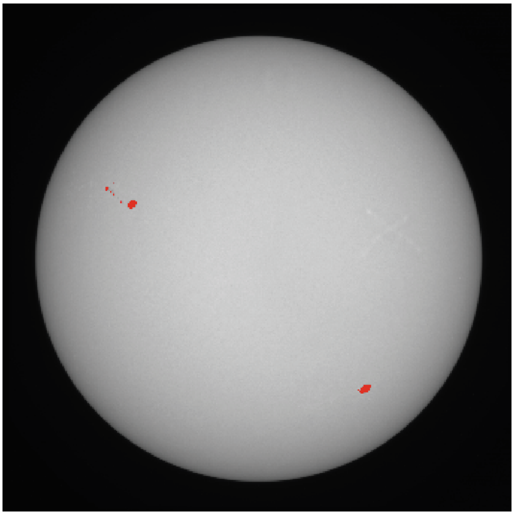

Fig. 2. The recognised sunspots on the original image (Color figure online)

3 Preprocessing and Detection of Sunspots

Detecting sunspots as individual elements are equivalent to determining which pixels belong to each sunspot, thus establishing which pixels are active points by using the accurate threshold intensity level to isolate these points from the background [4]. The threshold should be computed for each image because it varies from image to image. This method applied on SODISM images for W.L 782 nm to compare results with WLs, 535 nm and 607 nm from previous work [5, 6].

In total, 300 images were obtained at a wavelength of 782 nm. They were the same size as the images from the other wavelengths (2048 × 2048 pixels). The images at this wavelength are free from visible noise, and ghosting artefacts were not observed.

The pre-processing is applied on SODISM images by using Alasta et al's. method [7] to prepare data to the next stage. The method detects solar disc edges then sunspot candidates, and by iterative threshold on the gradient image which has been previously normalized, counting the number of the connected regions. Because the method is automated, it does not invite the problems associated with the pressure of time, and can, therefore, be used on large data for W.L. 782 nm. The method is developed to automatically detect sunspots in 782 nm SODISM L1 images, and is programmed in MATLAB; it adopts the following steps; Fig. 3 shows the flowchart diagram for the basic fundamentals of the applied segmentation method to detect sunspots. The preview method for detecting sunspots by Meftah et al. [8] has limitations because a manual threshold has to be entered. Furthermore, these procedures take the most time, and the method applies only to 393 nm W.L. images, so does not apply to large data, while this study's method can be applied to 535 nm and 607 nm.

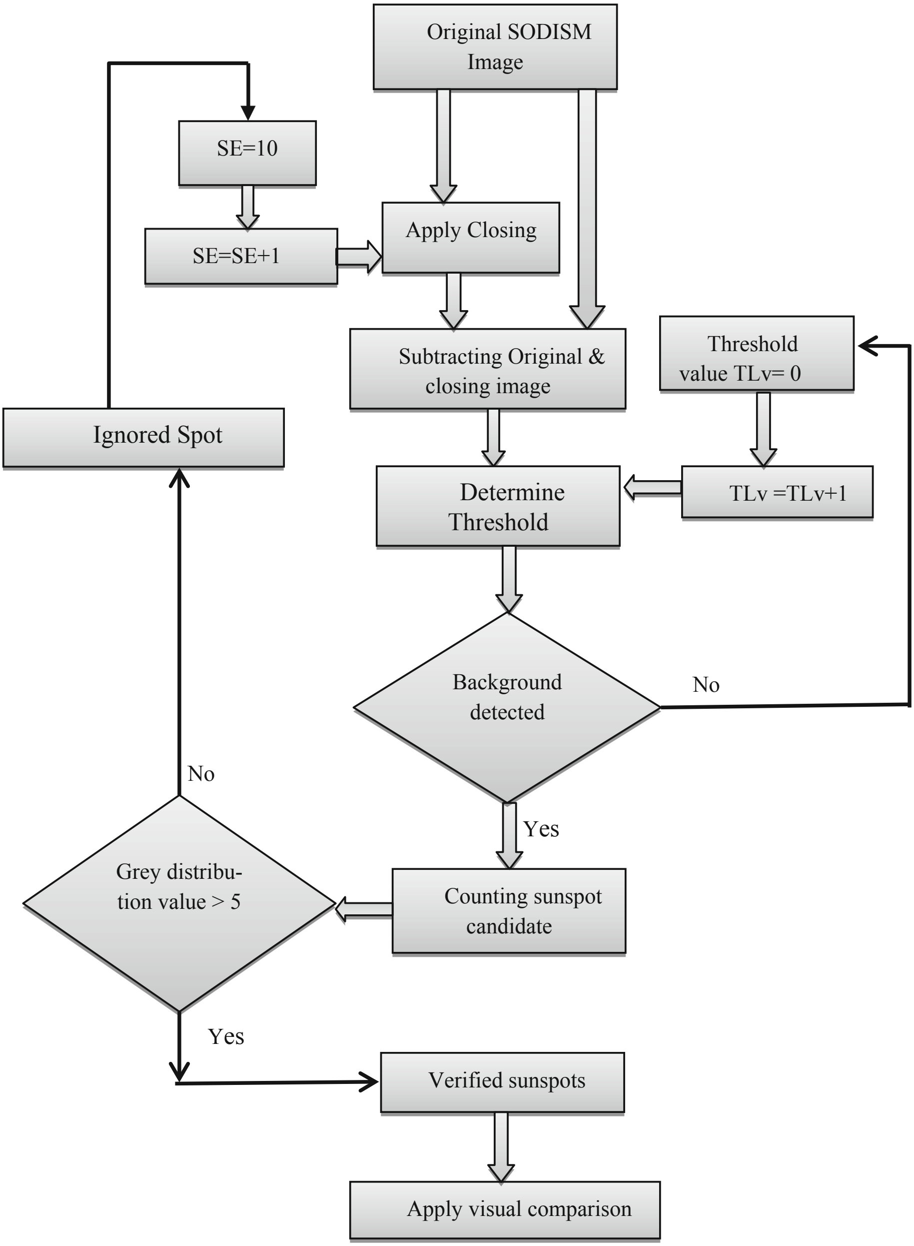

Fig. 3. Chart diagram of the sunspot detection procedure

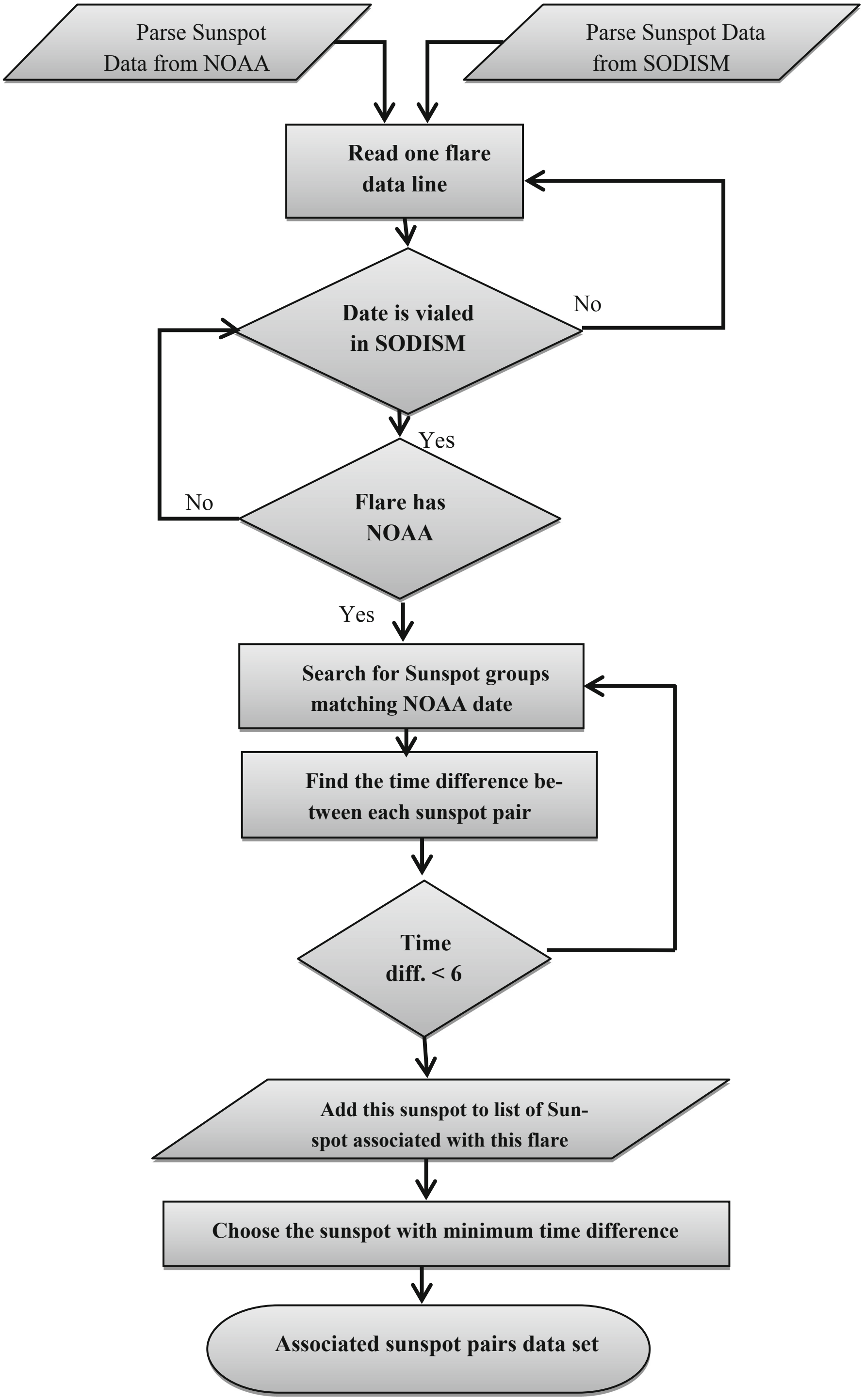

Fig. 4. Comparison between the numbers of sunspots

3.1 Verification

This stage includes the recognition of sunspots on the solar disk after the solar limb has been extracted. The umbra and penumbra are not separated in the SODISM images; they are considered and processed as a whole due to the limitation in the resolution of the data. The steps set out in Algorithm 2 facilitate the identification of sunspots (see Fig. 3 for the related images).

3.2 Accuracy of the Automatic METHOD Compared with the USAF/NOAA Catalogue

The Flowchart Fig. 4 has been applied to obtain a comparison between the number of sunspots detected in the SODISM WL 782 nm images and the USAF/NOAA catalogue. Depending on the NOAA catalogues, the accurate sunspot number results can be identified; Fig. 5 illustrates the structure of this catalogue. The algorithms were applied to the sunspot data for the period from 2010 to 2014.

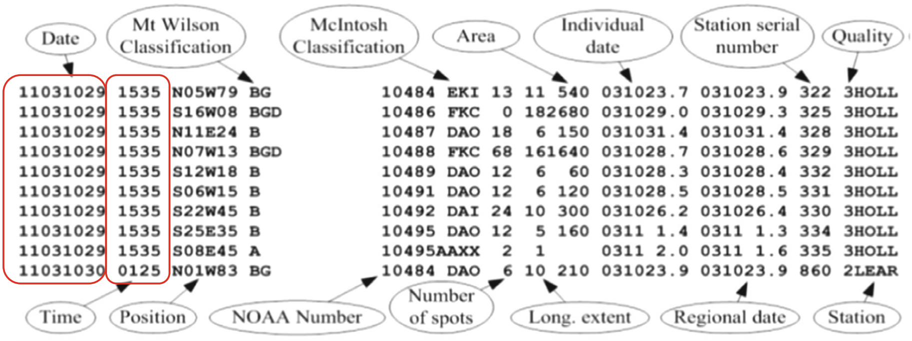

Fig. 5. USAF/NOAA sunspots catalogue data

The example in Fig. 6 shows an example of a sunspot recorded in a SODISM image on the 5th August 2010 at 04:49. Moreover, searches in the USAF/NOAA catalogue for 5th August 2010 show data for three different times, namely: 02:36, 07:35 and 16:35. Thus, the nearest time at 07:35 is chosen, the number of sunspots in the USAF/NOAA was four, and the SODISM segments map also show four; furthermore, the position of these sunspots is recorded as N13W24, N11E67, S19E56 and N25W49 respectively in the USAF/NOAA catalogue, which matches the results from the SODISM images inspection.

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11100805 0236 N12W21 A         11092 HHX  1  3 200 100803.5 ------.- 062 2LEAR
11100805 0236 N10E68 B         11093 DAO  4 10 160 100810.2 ------.- 063 2LEAR
11100805 0236 N25W46 B          //// CSO  8  4  40 100801.5 ------.- 064 2LEAR
11100805 0735 N13W24 A         11092 HHX  1  3 170 100803.5 ------.- 054 3SVTO
11100805 0735 N11E67 B         11093 CAO  4  8 150 100810.4 ------.- 055 3SVTO
11100805 0735 S19E56 A          //// AXX  2  0  10 100809.6 ------.- 056 3SVTO
11100805 0735 N25W49 B          //// DSO  5  5  50 100801.5 ------.- 057 3SVTO
11100805 1635 N13W30 B         11092 CSO  2  4 230 100803.4 ------.- 063 4HOLL
11100805 1635 S18E50 B          //// BXO  2  1  10 100809.5 ------.- 065 4HOLL
11100805 1635 N12E62 B         11093 CSO  4  8 190 100810.4 ------.- 066 4HOLL
11100805 1635 N25W55 B         11094 CSO  6  4  60 100801.4 ------.- 067 4HOLL
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Fig. 6. Example, Aug., 5th 2010 for USAF/NOAA catalogue shows time chosen

The sunspot detection and grouping algorithm was tested on the SODISM archived images for the period August 2010 – January 2014 for W.L. 535 nm. Figure 7 shows the comparison with the USAF/NOAA catalogue has been made and the correlation accuracy is 95.17%. Figure 8 shows the plot.

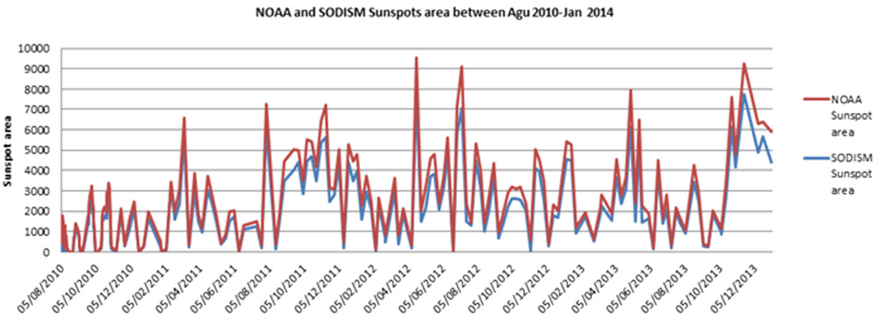

Fig. 7. USAF/NOAA sunspot numbers vs SODISM automated sunspot numbers.

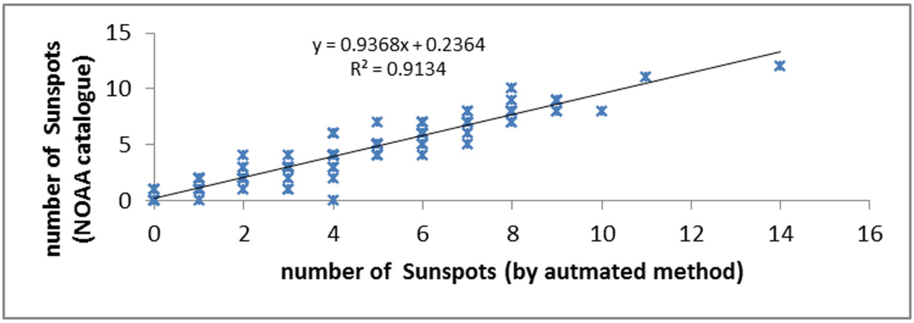

Fig. 8. Showing the plot of sunspots VS the time for SODISM (2010-2014).

The sunspot areas calculated by the automated sunspot detection method were compared to those recorded by the USAF/NOAA. More than two hundred individual images were compared, from August 2010 to January 2014, and results are summarized in Fig. 8. With the exception of regions with images from 2013 and 2014, where there was degradation in the images, there is a strong correlation between the automated sunspot area and the USAF/NOAA sunspot area. A visual inspection of the SODISM images seems to confirm that the automated procedure works well and confirms the results

3.3 Visual Sunspot Verification

In order to verify the detection results, a few randomly selected images of recognized sunspots were chosen. The detected areas are magnified and compared with the original images, and Fig. 9 shows an example of the results.

4 Filling Factors Computation

The filling factor (FF) is a function of the radial position on the sun disk. Thus, the calculated FF for any chosen feature reflects the fraction of the solar disk covered by that feature. For identification purposes, the system generates and assigns a synthetic spectra reference. [9] Eleven rings divide the solar disk beginning with an inner radius (RI), and concluding with an outer radius (RO).

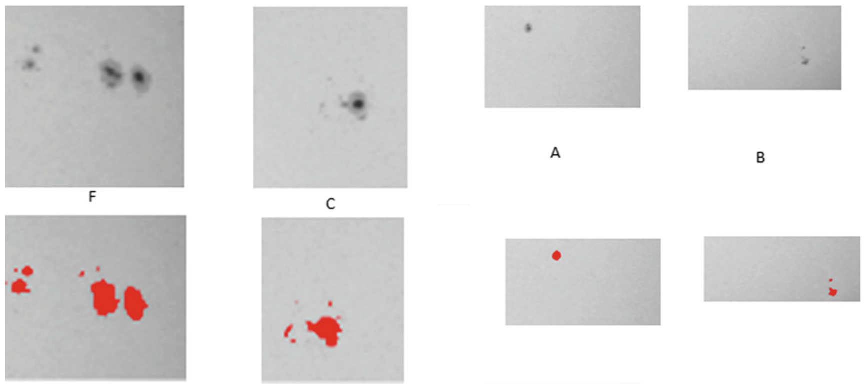

Fig. 9. Enlarge most of the recognised sunspots: the top images show the original sunspot images and the bottom images show the zoomed images.

For the SODISM WL 782 nm images, a correlation of 93% with SOHO was achieved for the same period (from 22 Sep. 2010 to 25 Dec. 2010), and Fig. 10 illustrates this comparison.

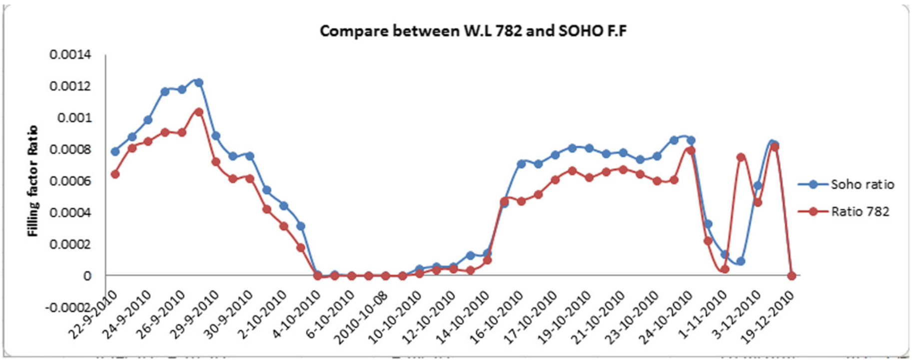

Fig. 10. A comparison of sunspot FFs ratio calculated from SOHO and SODISM images from 22 September 2010 to 25 December 2010.

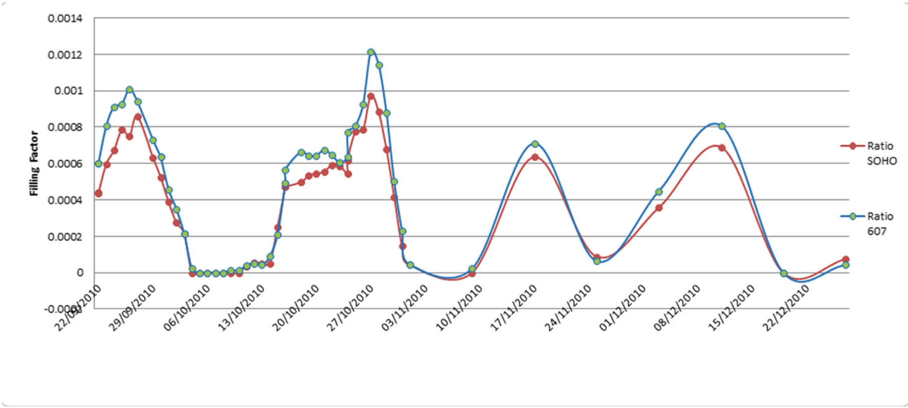

Fig. 11. FF calculation of sunspot from SOHO and SODISM images from 22th Sept. 2010 until 25 Dec. 2010 [3].

The researchers' previous paper [3] clearly mentions the data obtained for the 607 nm W.L. were 306 images collected between 22nd Sep. 2010 and 1st Jan. 2014. The FF of this data sharing with SOHO has been calculated and compared with SODISM over the same period (i.e. Sep., Oct. Nov. and Dec. 2010). The correlation coefficient was 99%. While the correlation coefficient of WL 535 nm FF with SOHO was 98% [5] (Fig. 11).

4.1 Filling Factor Catalogue

In the literature, the FF, specified as a function of radial position on the solar disc, is calculated and then tabulated for each image. However, this process does not provide extensive conclusive data concerning the experimental research carried out on the many hundreds of these images. To provide a means of tabulating these findings such that a single glance at a table would give an overall picture of the work done, a cataloguing procedure was proposed. The FF catalogue holds records of SODISM images information; this catalogue will be organized as follows:

The first column records the sunspot date in the dd/mm/yy format, the second column will record the time of the sunspot in SODISM, and the third column is the equivalent time in the USAF/NOAA catalogue. The fourth and fifth columns show the number of sunspots in SODISM images, and the equivalent number of sunspots in the USAF/NOAA catalogue, the location of SODISM catalogue sunspots is shown in the sixth column and their size in the seventh. The filling factor ratio is recorded in the eighth and final column. Figure 12 shows an example for the FF catalogue. It is notable that the SODISM data is available from August 2010 to January 2014, and that explains that Fig. 13 shows only one month in 2014.

Date	Time of Sunspot in SODSIM	Time of NOAA Sunspot	number of sunpots SODISM	number of spots NOAA	Loction of Sunspot SODISM	Size of Sunspots SODISM	Total FF Ratio
05/08/2010	04:49	07:35	4	4	N13W24	530	0.000531
05/08/2010	04:49	07:35	4	4	N11E67		
05/08/2010	04:49	07:35	4	4	S18E56		
05/08/2010	04:49	07:35	4	4	N25W49		

Fig. 12. FF catalogue for SODSIM images

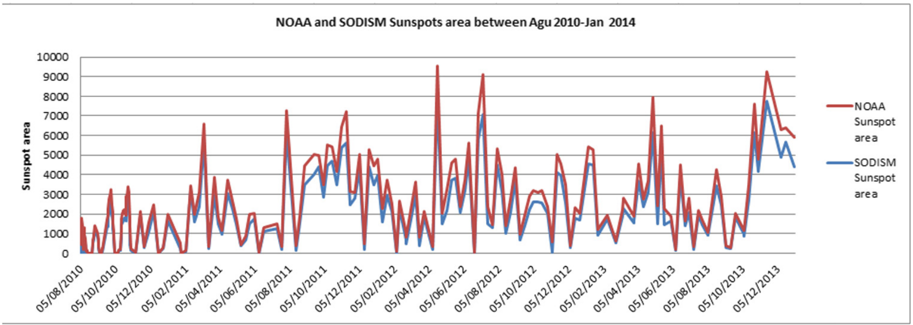

Fig. 13. Sunspot areas extracted from SODISM by the automatic method; and sunspot areas provided USAF/NOAA in Aug. 2010 – Jan 2014

The comparison is made of daily sunspots (illustrated in Fig. 13) extracted by the automatic method from SODISM images from August 2010 until January 2014, with those available as TXT files at USAF/NOAA catalogue. The horizontal axis represents the date of image capture; the vertical represents the sunspot area, in units of millionths of a solar hemisphere. The correlation coefficient in the same tendency is 93% shown in Fig. 14.

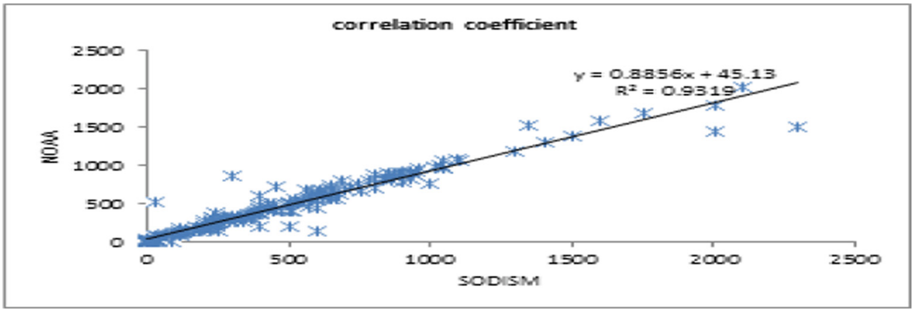

Fig. 14. The correlation coefficient between USAF/NOAA and SODISM Sunspot area

One aim of this study is also to obtain solar spectral variation on SODISM images at 782 nm (Fig. 15). We can check with the SES sensor onboard PICARD, which measured the solar spectral irradiance at 782 nm during the same period, and on the same spacecraft. When we will confirm the Alasta et al. method at 782 nm between SES data and SODISM images, we will make the analysis for the other wavelength in the solar continuum (535 and 607 nm). For this analysis with PICARD/SODISM images, we need to correct the data with the limb darkening function of the Sun [10].

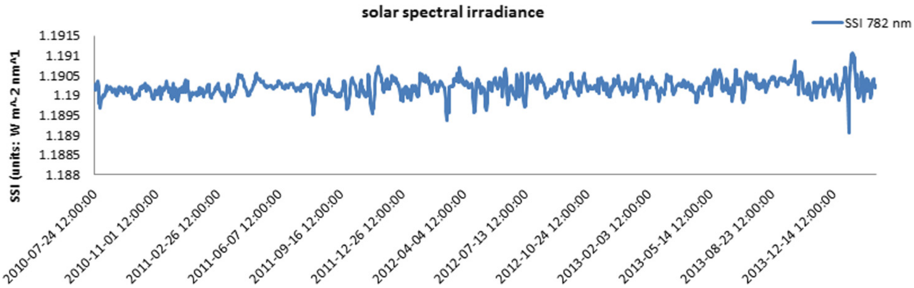

Fig. 15. Solar spectral variation on SODISM images at 782 nm

5 Results

The correlation between SOHO and SODISM data, or measure of dependence between the two quantities, is calculated as Pearson's correlation coefficient, which is 93% in 782 nm while it is 99% in WL 607 nm [6] and 98% nm in WL 535 nm [5]. Figure 7 shows sunspot numbers coverage from October 2010 until the end of life for the Picard satellite on 1st January 2014, also Fig. 10 shows a comparison between the filling factors calculated for the SODISM 782 nm images from the Picard satellite and the MDI intensity-gram images from the SOHO satellite over a similar period. This result leads us to concede that WLs 535 nm and 607 nm are the best bands to detect sunspots in SODISM images.

The comparison has been made between the SODISM catalogue and the USAF/NOAA catalogue in the number of sunspots detected and their location and size over the same period of time. The accuracy comparison for the period August 2010 to January 2014 shows a correlation coefficient of 95.17% (Fig. 13). Moreover, the sizes of sunspots match 93% in the USAF/NOAA catalogue (Fig. 14).

6 Conclusions

The proposed segmentation method has been applied to the entire image data downloaded for 782 nm to detect sunspots and calculate their filling factors. A comparative analysis of the proposed segmentation method in relation to the USAF/NOAA catalogue has been completed. An automated method is used to detect sunspots on SODISM images, despite the image degradation throughout the lifetime of PICARD.

Perhaps the most significant contribution of this research is the SODISM FF catalogue; the novel catalogue summarizes information and details of available SODISM images including size, number and location of sunspots.

The proposed and implemented cataloguing procedure gives a clear representation of the SODISM data. It is hoped that researchers will use the proposed technique in their future work.

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