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Image processing for the Arcetri Solar Archive

M. Centrone, I. Ermolli and F. Giorgi

INAF Osservatorio Astronomico di Roma, via Frascati 33, 00040 Monte Porzio Catone, Italy
e-mail: name@mporzio.astro.it

Abstract. The modelling recently developed to reconstruct with high accuracy the measured Total Solar Irradiance (TSI) variations, based on semi-empirical atmosphere models and observed distribution of the solar magnetic regions, can be applied to construct the TSI variations back in time making use of observations stored on several historic photographic archives. However, the analyses of images obtained through these archives is not a straightforward task, because these images suffer of several defects originated by the acquisition techniques and the data storing. In this paper we summarize the processing applied to identify solar features on the images obtained by the digitization of the Arcetri solar archive.

Key words. Sun: historical data – Sun: variability – Sun: magnetism

1. Introduction

A central question for understanding solar variability is to what extent surface magnetism determines irradiance variations. Following initial studies that used proxies of the magnetic field, more recent approaches to answering this question use atmospheric models and observed surface distributions of the solar magnetic field to reconstruct the irradiance. This approach has succesfully reproduced with high accuracy total and spectral irradiances measured from space, but has so far been restricted to MDI (Krivova et al. 2003), PSPT (Penza et al. 2003) and KPVT - MDI (Wenzler et al. 2005) data, available only for a period covering part of solar cycles 22 and 23. However, the temporal baseline of the period analyzed through this modelling can be remarcably increased taking advantage of the great amount of highly valuable information stored in some existing solar photographic archives. Those archive mainly contain full disk observations performed at the CaII K, H_α and continuum radiation through spectrographs. Thus, in analogy with the modelling applied to "reconstruct" measured variations, TSI variations can be extended back in time, assuming atmosphere models and observed distributions of the solar magnetic regions attained from the analysis of these photographic archives. However, the analyses of images obtained by these archives is not a straightforward task. These images suffer of several defects originated by the acquisition techniques, as well as by the data storing.
In this paper we summarize the processing applied to identify solar features on the images obtained by the digitization of the Arcetri solar archive.

Send offprint requests to: M. Centrone

2. The Arcetri Solar Archive

The Arcetri synoptic solar archive contains 12917 plates of full-disk CaII $K_{2,3}$ and H_α spectroheliograms acquired during 5042 observing days at the Arcetri G.B. Donati tower from 1925 to 1974 (Godoli e Righini 1950; Gasperini et al. 2004). A brief description of the Arcetri instrument charactersistics at the time of observations is given by Marchei et al. (2005); Giorgi et al. (2005). Details about the digitization work carried out by the CVS (Centro per lo Studio della Variabilita del Sole) project at the Rome Astronomical Observatory, with the sponsorship of Regione Lazio, can be found in Marchei et al. (2005). In brief, the archive digitization produced 16 bit 8435×11153 pixel tiff images including four plates, from which 2k×2k 16 bit fits images were singled out for each original plate.

3. Image processing

Prior to any processing the images are pre-analyzed and calibrated (Fig. 1) using dedicated procedures described by Giorgi et al. (2005). Some geometric and photometric issues have also to be taken into account before the application of the image decomposition for the solar feature identification. In fact, working with the data it became evident that some additional processing would reduce the spurious detections and enhance the feature identification. In fact, specific defects can appear on a significant set of the digitized images. For example, the passage of clouds during observations appear as a local darkening over the disk, dust particles on the optical component of the instrument result in dark lines across the disk, modifications of the atmospheric turbulence produced a change in the image sharpness. The degradation effects produced by the first two issues can be solved through a proper limb darkening compensation, as described in the following. Moreover, as the images corrupted by dust on the optics show lines in one prodominant direction, this also makes it possible to develop a simple method to detect and to restore them before the application of the limb darkening compensation. At last, some possible instrumental defects also produced geometric distorsions on the image stored on the plates. The most frequent problem was due to differencies on the velocity setting of the driving motors which translate the input solar image and the photographic plate. The image resulted elliptic, the axes of the ellipse being parallel and perpendicular to the slit. The differential refraction of the atmosphere also resulted in an oblateness of the solar disk. Procedures for the recovery of geometric degradation effects on Arcetri plates have not yet been developed. These procedures have to take into account the shape of the solar limb, that represents the only way to infer accurately the geometrical distorsions inside the disk. However, a first evaluation of the geometric distorsions obtained by the ratio of vertical and orizontal disk diameters showed that the ellipticity is of order than 10% on the sample of most degradated images, while the median value for the whole data collection resulted 3.75%.

4. Limb darkening compensation

Decomposition methods that allow the extraction of the various disk features are usually applied to images in which the solar limb darkening has been carefully removed. Moreover, the comparison of geometric and photometric properties of the identified features on a daily basis also requires the normalization of each image of the data collection to the same intensity scale. The assumption made in normalizing each image to the same intensity scale is that the quiet sun intensity does not change with the solar cycle. Even though small changes of the quiet sun irradiance can not be ruled out, these can probably only be detected through space based observations or ground based measurements obtained with precise photometric telescopes. It seems certainly very difficult a detection of these possible variations through analyses of archive spectroheliograms. In fact, these observations even after application of a careful photographic calibration still contain appreciable variations of the disk average intensity due to variations of the sky transparency and of the exposure time among data collected on different days.

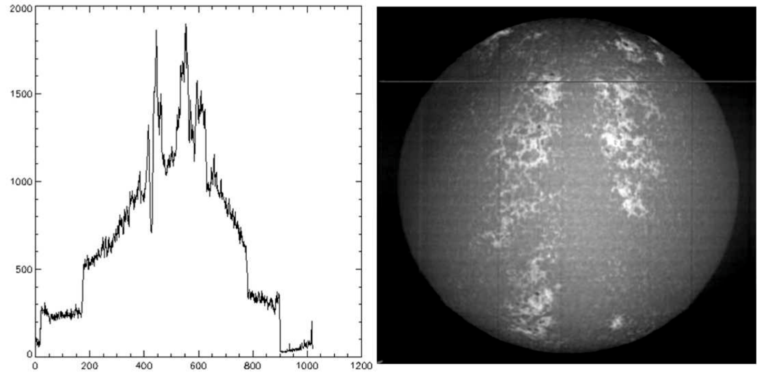

Fig. 1. Intensity profile along the marked row of the image, that has been pre-processed and photographic calibrated as described by Giorgi et al. (2005).

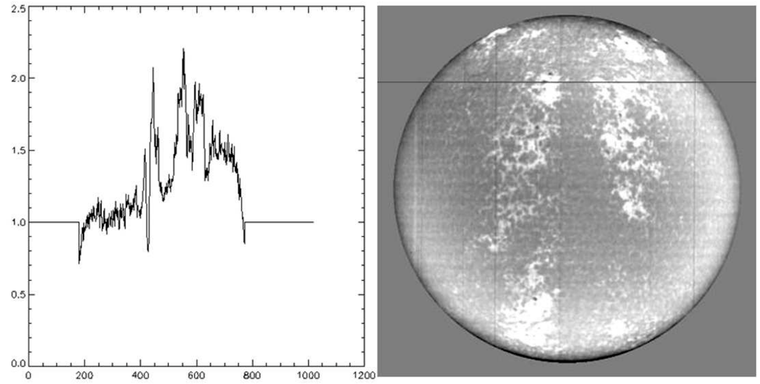

Fig. 2. Intensity profile along the marked row of the image, that has been compensated for the limb darkening variation as proposed by Brandt and Steinegger (1998).

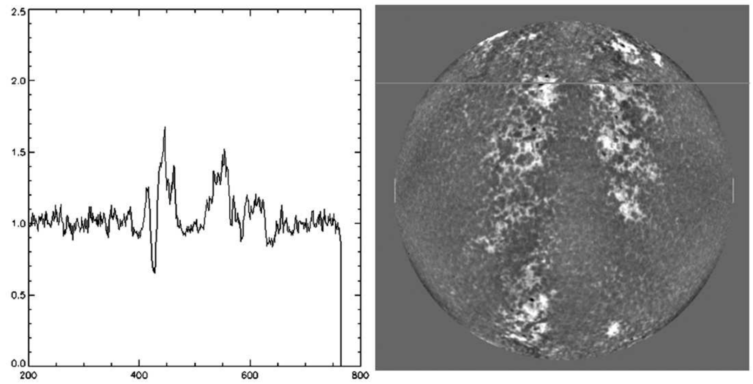

Fig. 3. Intensity profile along the marked row of the image, that has been compensated for the limb darkening variation through an iterative polynomical fitting applied by rows and by columns as described in the text.

Several methods have been proposed in literature (Johannesson et al. 1998; Worden, White and Woods 1998; Caccin et al. 1998; Brandt and Steinegger 1998; Zharkova et al. 2003) to obtain a reliable limb darkening compensation on spectroheliograms. We show for example the results obtained by applying the method proposed by Brandt and Steinegger (1998) to the Arcetri data collection. This method is based on the calculation of cumulative intensity histograms for rings of constant area, i.e. assuming a circularly symmetric fitting of the intensities on the solar disk. We found that this method allows limb darkening compensations and solar disk intensity computations that are very stable respect to the activity level. However, the images obtained through this method suffer for the presence of large scale non circularly-symmetric intensity patterns (fig 2). Moreover, the limb darkening is accurately compensated only in the about 5% reduced inner part of the solar disk. On average the limb darkening compensation is obtained through this method with an accuracy worse than 10%. This accuracy can be improved to better then 5% by dividing iteratively each row and column of the photographically calibrated image for a 2-nd order polynomial fit on the quiet solar background intensities. These intensities were obtained leaving out all the pixels with a contrast differing more than 2σ respect to the values preliminary attained through a 4-th and 2-nd order polynomial fit performed by row and column respectively. The application of a non-circularly symmetric fitting allows the compensation of the solar limb darkening together to the removal of large scale intensity patterns affecting the original spectroheliograms. In fact, by this method we make a rough correction for the transparency fluctuations of the atmosphere during the observation, as well as for the presence of scratches resulted by dust. However, we found that the images obtained with this iterative fitting also suffer for overcompensation effects (Fig. 3) around extended active regions that decrease the efficiency of the polynomial fitting. We found that the compensation accuracy increases remarcably by applying the polynomical fitting already described on the quiet sun background pixels selected by applying the method proposed by Brandt and Steinegger (1998). The contrast images obtained in this way allow the application of simple feature identification methods based on intensity thresholding and revealed themselves useful to perform analyses of morphological and photometric properties of active regions on the solar disk.

5. Summary

This paper briefly describes the image processing developed for the analysis of the Ca II K images obtained by the digitization of the Arcetri solar archive. The same processing is now being applied to Ca II K images obtained from the Mt Wilson and the Meudon archives. The ability to perform a uniform processing of images coming from different historic archives will allow a rather remarcable extension of the temporal baseline of the data available for long term solar variability studies.

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