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Automated detecting and removing cloud shadows in full-disk solar images

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HIGHLIGHTS

- We propose a novel algorithm for detecting and removing cloud shadows in full-disk solar images.
- We use Hα full-disk images obtained with the GONG instruments to illustrate the performance.
- We utilize the structural similarity method to evaluate the performance of the algorithm.
- The results demonstrate that the cloud-covered images are improved in vision as well as in image intensities.

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ABSTRACT

Sky clouds affect full-disk solar observations significantly. Their shadows obscure the details of solar features in observed images. Cloud-covered images are difficult to be used for further research without pre-processing. We proposed a technique for detecting and removing cloud shadows in full-disk solar images. In the detection procedure, a two-step approach is applied: (1) identifying the deviation of a cloud-covered image from a perfect disk; (2) quantifying the cloud cover by an index that we defined in this paper. In the removal procedure, the transmittance of clouds is measured by comparing the cloud-covered image with a "Quiet Sun" that getting from a normal observation. A restored cloud-free image can be obtained after correcting the absorption by clouds. We tested the procedures using the full-disk solar Hα images of the Global Oscillation Network Group (GONG), and utilized the structural similarity (SSIM) algorithm for evaluating the performance of image restoration. The results demonstrate that both procedures are significant effective, and that the cloud-covered image is restored not only in visual effect but also in intensities of solar features.

1. Introduction

There are many ground-based observations that provide a large number of full-disk solar images in every day. For example, the Global High Resolution Hα Network (GHN, for details, visit the site: http://swrl.njit.edu/ghn_web/) (Steinegger et al., 2000) has nine Hα full-disk solar telescopes, and the Global Oscillation Network Group (GONG, for details, visit the site: http://gong.nso.edu/) (Harvey et al., 1996) has six instruments. The full-disk images observed by these networks provide a near real-time solar activity patrol for space weather applications, such as the web-based solar Active Region Monitor (Gallagher et al., 2002). The GONG's Hα images are collected once per minute, and then sent to computer servers via the Internet after corrected dark, smear, and flat. Various reduced images are usually available on their website within a minute after exposure (Harvey et al., 2011). Although the observatory sites are selected carefully, there are still many sunny days with clouds in routine observation. For example, at the Big Bear Solar Observatory (BBSO) in California, USA, the days that neither the completely clear nor the completely dark occupy 55% of total days based on the site survey of the GONG (Hill et al., 1994). In these days, instruments work normally; however, if sky clouds cover the Sun, their shadows will degrade the observed images significantly. Fig. 1 shows two full-disk Hα images that were observed by the GONG Hα instrument of the BBSO on 2013 January 1. Fig. 1a is normal, which was captured at 22:02:54 UT, but Fig. 1(b) is cloud-covered, which was captured at one minute

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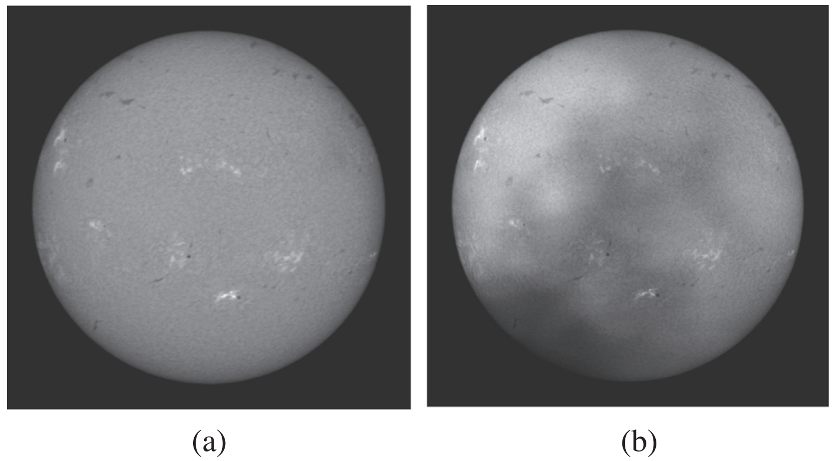

Fig. 1. (a) A normal full-disk image; (b) a cloud-covered image. Both of them were obtained with the GONG Hα instrument of the BBSO on 2013 January 1. The time interval is one minute.

later, 22:03:54 UT. Usually, instruments continue working and obtaining images under this weather condition because these images may be useful for further automatic solar activity detection and feature segmentation (Veronig et al., 2000; Benkhalil et al., 2003; Zharkov et al., 2005), although they are not perfect.

Generally, a limb-darkening removal procedure is applied to a full-disk image for obtaining a flat high-contrast image (Fuller and Aboudarham, 2004). The procedure is based on the average radial profile by computing the median values at each radial position in polar coordinates (Denker et al., 1999; Preminger et al., 2001; Zharkova et al., 2003; Fuller et al., 2005). It might not work very well in the presence of clouds because the variations of intensities are not radial. Therefore, an image restoration technique is necessary.

In this paper, we proposed an automated technique for detecting and removing cloud shadows in full-disk solar images. The layout of the paper is as follows. Section 2 presents the detection procedure for cloud shadows. Section 3 details the removal procedure. In Section 4, the performance of our technique is evaluated. Finally, the conclusions are given in Section 5.

2. Automated identification of partially obscured solar disks

A cloud-covered image, especially the partially obscured disk, should be automatically identified from all observed images. We classify the degradation caused by clouds into two types. In type I, clouds are extremely non-uniform and heavy. The edge enhancement of solar disk with thresholding will no longer lead to a filled circle. In type II, the detected edge of solar disk keeps a circle, but the details of solar features are partially obscured. Fig. 2 presents twelve degraded full-disk images that were observed by the GONG Hα instrument of the BBSO on 2013 January 1.

2.1. Identifying the deviation of a cloud-covered image from a perfect disk

Ideally, the edge of solar full-disk is perfectly circular. If it is fitted by an ellipse, the ratio E of the length of major axis to the length of minor axis is one. Thus the ratio E can be used to quantify the deviation from a perfect disk. The E value that we measured for the images observed by the GONG instruments in a good weather condition is 1.0010 ± 0.0015.

The ratio E can be calculated by the principal axes method. Principal axes of a given structure can be uniquely defined as the two segments of lines. They cross each other orthogonally in the centroid of the geometrical shape and represent the directions with zero cross-correlation. The two segments of lines of the image can be obtained by a covariance matrix. The covariance matrix is described as follows:

$$J = \begin{pmatrix} J_{xx} & J_{xy} \\ J_{yx} & J_{yy} \end{pmatrix}, \tag{1}$$

where

$$\begin{aligned} J_{xx} &= \frac{\sum (x - x_c)^2 \rho(x,y)}{\sum \rho(x,y)}, \\ J_{xy} &= \frac{\sum (x - x_c)(y - y_c) \rho(x,y)}{\sum \rho(x,y)}, \\ J_{yx} &= \frac{\sum (x - x_c)(y - y_c) \rho(x,y)}{\sum \rho(x,y)}, \\ J_{yy} &= \frac{\sum (y - y_c)^2 \rho(x,y)}{\sum \rho(x,y)}. \end{aligned} \tag{2}$$

Clearly, here $J_{yx} = J_{yx}$. $\rho(x,y)$ is the intensities of the coordinates (x,y), and x_c and y_c are the centroid of the structure. The lengths of the two principal axes, λ_1 and λ_2, can be calculated by:

$$\begin{aligned} \lambda_1 &= 2\sqrt{2\left(\left[J_{xx} + J_{yy} + \sqrt{(J_{xx} + J_{yy})^2 - 4(J_{xx}J_{yy} - J_{xy}^2)}\right]\right)}, \\ \lambda_2 &= 2\sqrt{2\left(\left[J_{xx} + J_{yy} - \sqrt{(J_{xx} + J_{yy})^2 - 4(J_{xx}J_{yy} - J_{xy}^2)}\right]\right)}. \end{aligned} \tag{3}$$

Then, the ratio E can be calculated:

$$E = \lambda_1 / \lambda_2. \tag{4}$$

Based on the E value of the GONG's image, we set 1.1 as a threshold in our approach. If E is greater than the threshold, the image will be classified into type I and excluded in further processing. The first two images captured at 22:05 UT and 22:06 UT in Fig. 2 belong to this type because the ratio E of them arrives to 1.2.

2.2. Quantifying the cloud cover by an index

Perfect radial intensities profiles of a "Quiet Sun" should be symmetrically passing through the center of the Sun, and their shapes should be identical in different azimuth. The profiles will overlap if drawn together. A cloud-covered image makes the profile significantly different with a normal one. Fig. 3 shows eight