High resolution reconstruction of solar prominence images observed by the New Vacuum Solar Telescope

Yong-yuan Xiang\textsuperscript{a,b,*}, Zhong Liu\textsuperscript{a}, Zhen-yu Jin\textsuperscript{a}

\textsuperscript{a}Yunnan Observatories, Chinese Academy of Sciences, Kunming 650011, China
\textsuperscript{b}University of Chinese Academy of Sciences, Beijing 100049, China

\textbf{HIGHLIGHTS}

- We proposed a modified cross correlation method to align prominence data.
- We compared the alignment accuracy of the conventional method and the modified method.
- We successfully reconstructed the prominences and other off-limb objects observed by NVST.
- The results demonstrate that the high resolution observation of solar prominence by a ground-based solar telescope is feasible.

\textbf{ARTICLE INFO}

Article history:
Received 11 December 2015
Revised 5 May 2016
Accepted 6 May 2016
Available online 14 May 2016

Keywords:
Methods: solar image reconstruction
Techniques: speckle imaging
Sun: prominences

\textbf{ABSTRACT}

A high resolution image showing fine structures is crucial for understanding the nature of solar prominence. In this paper, high resolution imaging of solar prominence on the New Vacuum Solar Telescope (NVST) is introduced, using speckle masking. Each step of the data reduction especially the image alignment is discussed. Accurate alignment of all frames and the non-isoplanatic calibration of each image are the keys for a successful reconstruction. Reconstructed high resolution images from NVST also indicate that under normal seeing condition, it is feasible to carry out high resolution observations of solar prominence by a ground-based solar telescope, even in the absence of adaptive optics.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Solar prominences are thread-like clouds consisting of relatively cool, dense magnetized plasma suspended in the hot tenuous corona (Tandberg-Hanssen, 1995). They are one of the most striking features in the solar atmosphere. The study of prominences is very important for understanding their formation and equilibrium, even their connection and relationship with other activity phenomena (Yan et al., 2014). Recent high resolution observations obtained by meter-class telescopes show that there are many fine structures such as the sharp border of a bubble, details of mass flows, and vortices inside the prominences (Berger et al., 2008; Berger et al., 2010; Yan et al., 2015; Shen et al., 2015). Deeper understanding of these complex dynamic structures needs ever higher resolution data to address.

High resolution observations of ground-based solar telescopes mainly rely on the adaptive optics (AO) and the image reconstruction techniques. With the waveform compensation of the AO, it is easier to achieve diffraction limit after the image reconstruction. In the past three decades, a great deal of solar activity phenomena (sunspots, flares, and so on) have been clearly observed by using image reconstruction techniques or in combination with the AO (von der Lühe, 1994; Denker, 1998; Denker et al., 2005; Mikurda and von der Lühe, 2006). Normally, the general AO is hard to lock onto faint prominence structures. During recent years a purpose-built off-limb solar AO that can directly lock onto solar prominences have been reported by Taylor et al. (2013; 2015). But overall, an applicable AO system to observe solar prominences is lacking on ground-based facilities. Therefore, most of the high resolution observations of solar prominences have to rely on image reconstruction.

Speckle imaging is one of the most effective image reconstruction techniques in high resolution solar observations. The popular methods are known as the Labeyrie (Labeyrie, 1970) method, the Knox-Thompson (Knox and Thompson, 1974) method, and the speckle masking (Weigelt, 1977; Weigelt and Wirth, 1983; Lohmann et al., 1983). When applying the speckle imaging method for solar high resolution reconstruction, the image motion of each frame should be well corrected if the motion is significantly greater than the size of the seeing disk. For the normal observations of the solar disk activities, because the correlation tracker

* Corresponding author at: Yunnan Observatories, Chinese Academy of Sciences, Kunming 650011, China. Fax: +86 87163020832.
E-mail address: binghe065@ynao.ac.cn (Y.-y. Xiang).

http://dx.doi.org/10.1016/j.newast.2016.05.002
1384-1076/© 2016 Elsevier B.V. All rights reserved.
amplitude and the where

3.2. Key points for prominence reconstruction

3.2.1. Alignment method

The basic process for prominence reconstruction is similar to that for other on-disk solar objects such as the granulation or sunspots. However, as mentioned in Section 1, the current AO system of NVST cannot track an off-limb object. So, additional processes especially for the image motion correction are necessary. Cross correlation is the commonly used method for image motion correction. The cross correlation function $C(d_x)$ of a target image $i(x)$ and a reference image $k(x)$ can be described as

$$ C(d_x) = i(x) \ast k(x). $$

(5)

Where the symbol $\ast$ is the correlation operator, and $x$ denotes two-dimensional spatial variable. Normally, assuming the origin of the coordinate is the center of the image, the position $x_M$ of the maximum value of correlation function represents the offset between the target image and the reference image. Shifting this offset can make the target image well aligned with the reference image. In the case of prominence, due to the dimness of the object and the brightness sudden change at solar limb (see Fig. 2), $x_M$ is usually not the correct image offset. This is called the correlation error. Therefore, a modified cross correlation is adopted to reduce the correlation error and improve the alignment accuracy. This modified cross correlation function could be expressed as

$$ \hat{C}(d_x) = [i(x) \ast f_1(x)] \ast [k(x) \ast f_2(x)]. $$

(6)
دانلود مقاله

http://daneshyari.com/article/1778720

امکان دانلود نسخه تمام متن مقالات انگلیسی ✓
امکان دانلود نسخه ترجمه شده مقالات ✓
پذیرش سفارش ترجمه تخصصی ✓
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله ✓
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب ✓
دانلود فوری مقاله پس از پرداخت آنلاین ✓
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات ✓