Sunspots and Coronal Bright Points Tracking using a Hybrid Algorithm of PSO and Active Contour Model

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Abstract. In the last decades there has been a steady increase of high-resolution data, from ground-based and space-borne solar instruments, and also of solar data volume. These huge image archives require efficient automatic image processing software tools capable of detecting and tracking various features in the solar atmosphere. Results of application of such tools are essential for studies of solar activity evolution, climate change understanding and space weather prediction. The follow up of interplanetary and near-Earth phenomena requires, among others, automatic tracking algorithms that can determine where a feature is located, on successive images taken along the period of observation. Full-disc solar images, obtained both with the ground-based solar telescopes and the instruments onboard the satellites, provide essential observational material for solar physicists and space weather researchers for better understanding the Sun, studying the evolution of various features in the solar atmosphere, and also investigating solar differential rotation by tracking such features along time. Here we demonstrate and discuss the suitability of applying a hybrid Particle Swarm Optimization (PSO) algorithm and Active Contour model for tracking and determining the differential rotation of sunspots and coronal bright points (CBPs) on a set of selected solar images. The results obtained confirm that the proposed approach constitutes a promising tool for investigating the evolution of solar activity and also for automating tracking features on massive solar image archives.

Keywords: Sunspots, Coronal bright points, Tracking algorithm, Particle swarm optimisation, Active contour model.

Introduction

Huge image archives both from the ground-based and the space-borne solar instruments (existing and future missions) require efficient automatic image processing software tools capable of detecting and tracking various features in the solar atmosphere. Results of application of such tools are essential for studies of solar activity evolution, climate change understanding and space weather prediction.

Solar surface rotates differentially but the mechanism of this rotation, most probably governed by interaction between convection and rotation, is not clearly understood yet. Based on the analysis of almost 5000 measurements of position of coronal bright points (CBPs), in images taken at a 9.4 nm wavelength by the Atmospheric Imaging Assembly (AIA) 094 instrument on board the Solar Dynamics Observatory (SDO) satellite, Lorenc et al. (2012) inferred that the tracer method (either interactive or manual) is sufficiently precise, hence the obtained values of the angular rotational speed are reliable. However, their method is laborious and becomes practically unworkable on a large number of images.

Therefore, here we propose using a hybrid algorithm for automatic detection and tracking CBPs in SDO/AIA images. We already tested the code implementation of the algorithm on white-light photospheric images from the SOHO/MDI instrument (Shahamatnia et al., 2012) and in this work also on images taken by Solar Magnetic Activity Research Telescope (SMART) at Hida Observatory, Kyoto University. We downloaded the SMART data from T1 Data Archive http://www.hida.kyoto-u.ac.jp/SMART/T1.html. The preliminary results obtained demonstrate the potential of this hybrid approach for space weather research. The developed software tool will be very useful for investigating the evolution of solar activity and its impact on space weather and also for automating tracking features on massive solar image archives.

Automatic Detection and Tracking Algorithm (ADTA)

In this section we describe the hybrid algorithm for detection and automatic tracking of sunspots and coronal bright points (CBPs). The algorithm is a merge of a Snake model and Particle Swarm Optimization, first proposed in (Shahamatnia and Ebadzadeh, 2011) and then, successfully, tested in tracking sunspots (Shahamatnia et al., 2012)..

Snake model, also known as Active Contour Model, is an energy minimization algorithm induced not only by low level image features such as image gradient or image intensity, but also with higher level information such as object shape, continuity of the contour and user interaction (Kass et al., 1987). Given an approximation of the object boundary, the snake model will be able to find the precise boundary of that object. The second part of the tracking approach is the Particle Swarm Optimization (PSO) algorithm, which is an evolutionary optimization technique consisting of a number of particles, each representing a potential solution to the problem (Kennedy and Eberhart, 1995). The Swarm is initialized with random solutions, i.e. random positions and velocities for the particles.

The tracking approach adopted combines advantages of high-level object detection capacities of the snake model with the PSO algorithm to achieve a promising system for automatic CBP tracking. The main steps of the ADTA algorithm are described in (Shahamatnia et al., 2012). In this paper we adapted the software code of ADTA to test its suitability for CBPs tracking.

Illustrative Results

Sunspots

SOHO/MDI:

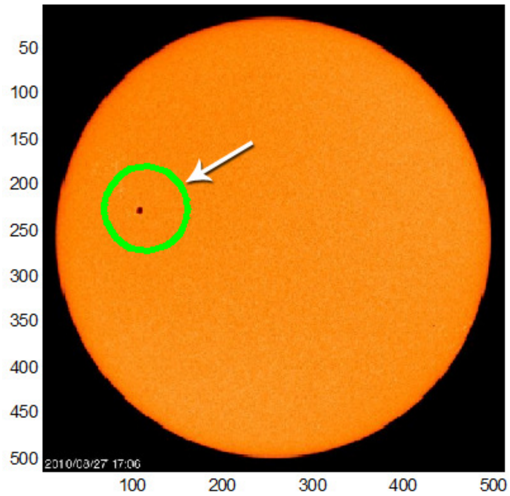

Figure 1: Initial snake on first image (2010/08/27).

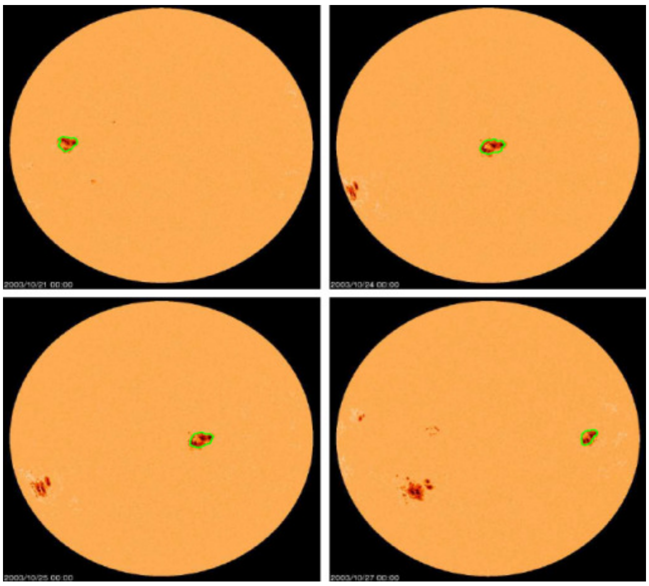

Figure 3: Tracking a sunspot group in SOHO MDI images, 21 till 27 of October 2003.

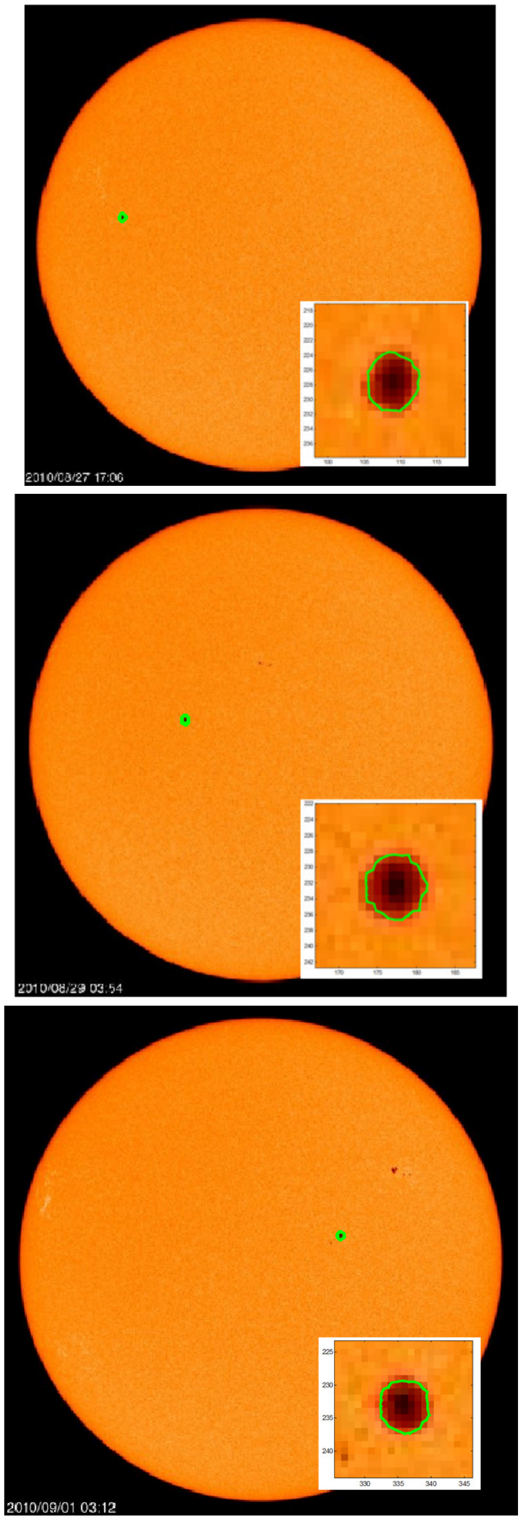

Figure 2: Detection and tracking process of the selected sunspot. Identified sunspot at E38N12 on 2010/8/27 (top panel), tracked sunspot two days later at E12N12 (middle panel), tracked sunspot five days later at W22N12 (bottom panel).

SDO/HMI:

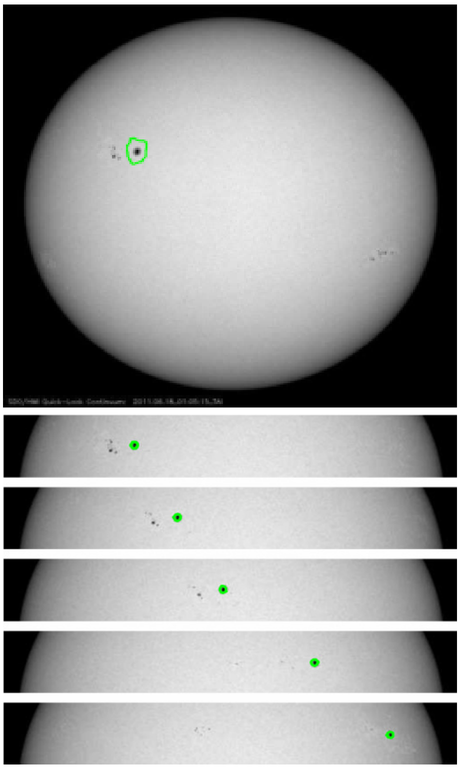

Figure 4: Initial snake on first image, 2011/06/18 (top panel) and tracking of a sunspot in SDO HMI images from 18 to 24 of June 2011 (bottom panels).

SMART (Hida Observatory):

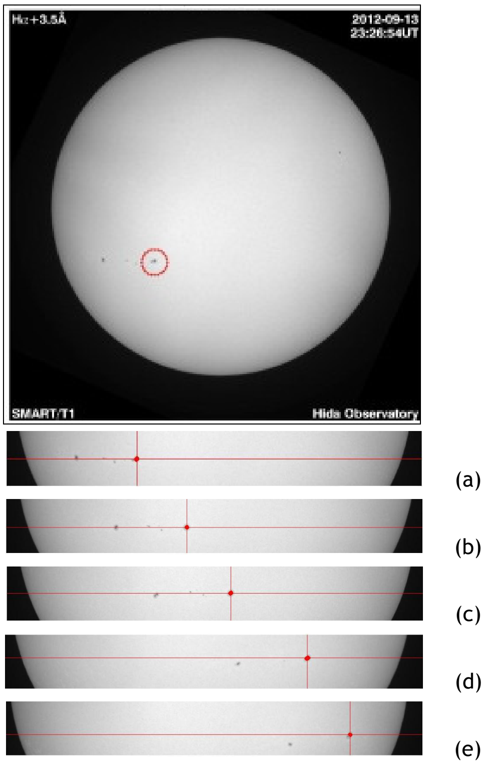

Figure 5: Initial snake on first image (top panel, 13 September 2012) and detection and tracking process of the selected sunspot for 6 days (bottom panel).

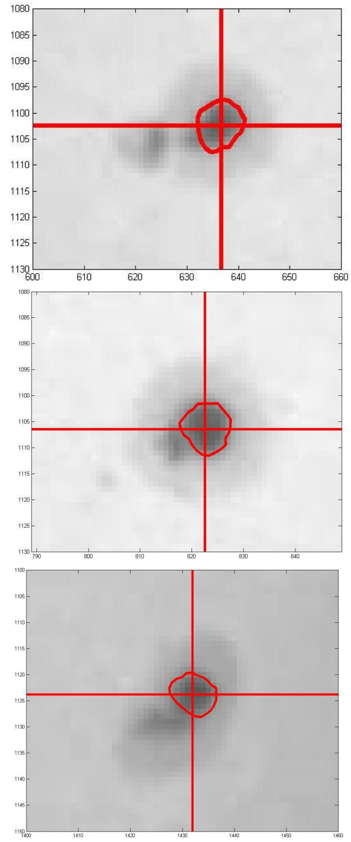

Figure 6: Detailed views of the tracked sunspot in the fig. 5, from top to bottom: a, b and e. The red contour delineates the umbra and the center of axes represents the center of the sunspot.

Discussion and Conclusions

As mentioned before, the method for determining the sidereal angular speed of rotation of CBPs, presented in Lorenc et al. (2012), is laborious and with a large number of images it becomes unworkable for practical reasons. Here, we tested the ADTA software tool and the results obtained clearly matched the precision in Lorenc et al. (2012) method. Further, we discussed the suitability of using a computer-aided tool for tracking sunspots and CBPs, which includes a combined optimization process, based on a Snake model and the PSO evolutionary algorithm.

The obtained results confirmed that the proposed approach constitutes a promising tool for investigating the evolution of solar activity and also for processing massive solar image archives. At this stage, our approach automatically tracks the sunspot or CBP after being initially marked (chosen) by the researcher and provides as output the tracking of the feature, along time, plus the heliographic coordinates. In the near future we plan to add an area calculation (with foreshortening correction included) and an option to save an output file with information on angular speed of rotation. Afterwards, we will also perform an analysis of the huge number of sunspots and CBPs to obtain statistically relevant information on differential rotation of these solar features.

Coronal Bright Points

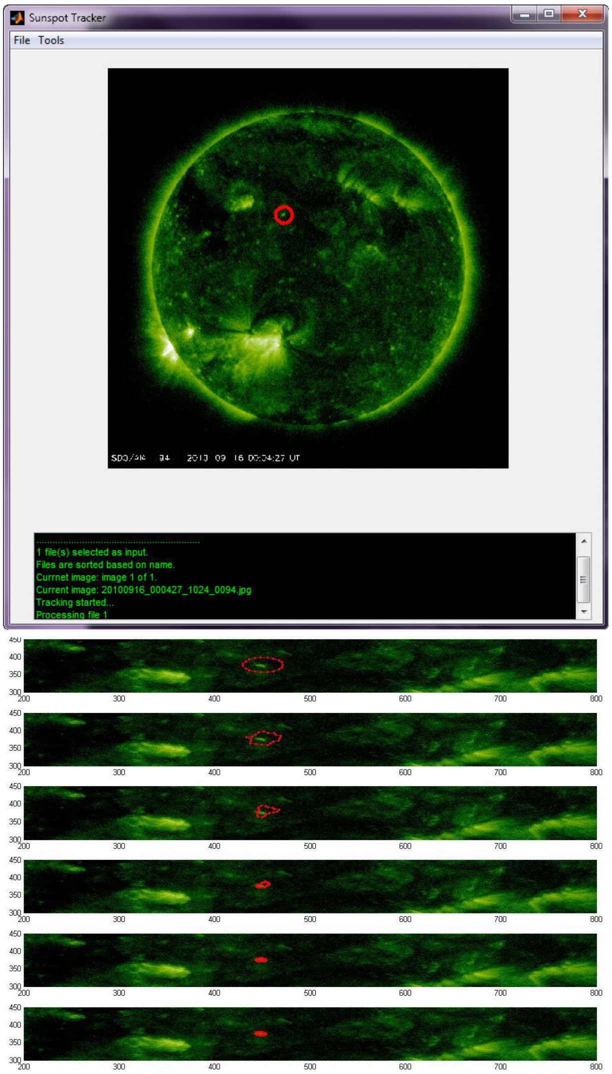

Figure 7: Initial snake on first image (top panel, 16 September 2010). Detection and tracking process of the selected CBP (bottom panels).

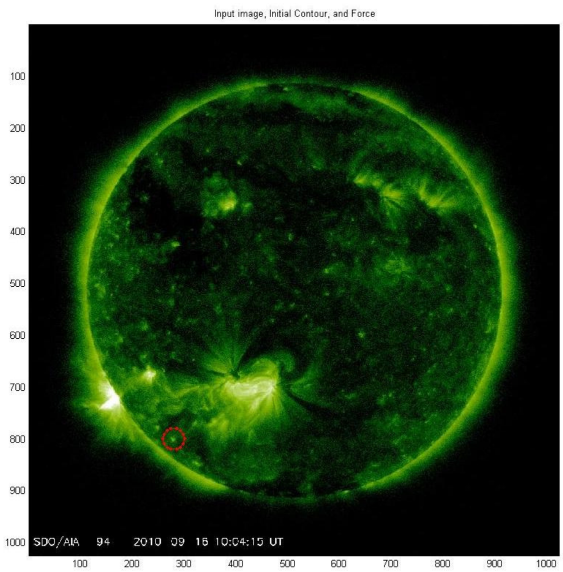

Figure 8: Initial snake on first image (16 September 2010).

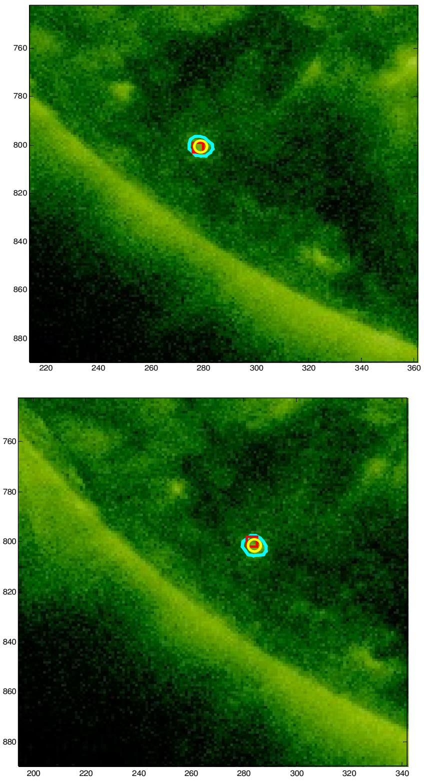

Figure 9: Tracking process of the selected CBP over time (top and bottom panels). The cyan contour is the tracked CBP and yellow circle denotes its center of mass. The center of red square represents the coordinate of CBP marked by an expert operator for comparative studies.

Acknowledgments

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