POSITION MEASUREMENTS ON SYNOPTIC SOLAR IMAGES

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Abstract. Procedures for finding the solar sidereal rotation rate, which are taking into account the height of tracers are described. The related algorithms for data reduction, including detailed corrections for the Earth’s motion, are presented.

Key words: position measurements - synoptic solar images - sidereal rotation rate

1. Introduction

Aside from the Doppler and helioseismic measurements, the solar rotation is frequently studied using measurements of the positions and apparent displacements of various tracers observed on synoptic solar images (Howard, 1984; Schröter, 1985; Stix, 1989; Wöhl, 1990; Snodgrass, 1992). One of the main problems related with the tracer-method is the difference between the real and projected coordinates due to the height of the traced object (Roša, Vršnak and Božić, 1995). Another problem is related to the data reduction - usually a large amount of data is involved in the analysis. In order to solve these problems we have developed a method providing a simultaneous estimation of the real rotation rate and the height of the tracer (Roša et al., 1998) and related algorithms for faster data reduction. Furthermore, we applied
the method to different kinds of tracers observed on the solar disc (e.g., H$_\alpha$ filaments, low temperature regions in the microwave range, and EUV bright points).

The project started as a collaboration between Hvar Observatory (Faculty of Geodesy, Zagreb) and Kanzelhöhe Solar Observatory (University Graz). Later, the Metsähovi Radio Research Station (Helsinki University of Technology) joined the project, providing microwave radio data. Then, Zagreb Astronomical Observatory took part helping in the theoretical part. Subsequently, the project extended to studies of large-scale patterns including meridional motions, which involved the Kiepenheuer-Institut für Sonnenphysik (Freiburg). Finally, the SOHO (Solar and Heliospheric Observatory, ESA - NASA) EIT data were included in the analysis.

2. Measurements and Data Reduction

The algorithm for data reduction starts with measurements of Cartesian coordinates on full disc images, which then are automatically transformed to heliographic coordinates (Figure 1). In the next step the synoptic chart (using the apparent heliographic latitude $B'$ and apparent central meridian distance $CMD'$) is constructed. On the synoptic chart an arbitrary object can be chosen and its apparent displacement traced to find the apparent synodic rotation rate $\omega'$. Depending on the nature of the tracers we proceeded in two directions. One procedure is adjusted for point-like objects. It is based on fitting the observed $CMD'(t)$ or $\omega'(CMD')$ to the theoretical curves where the height is an unknown parameter. The second one can be applied to irregularly shaped objects. It is based on the overlapping of successive images and $h$ and $\omega$ are found by analysing the function $\omega'(CMD')$ only. The procedures of estimating $\omega_{sid}$ are summarized in Figure 2.

3. Determination of the Sidereal Rotation Rate

To find the real sidereal rotation rate from the apparent rotation rate we have developed two methods. The first one is analytical. It is based on fitting the theoretical function $\omega'(CMD')$ to measurements. The
second one is a numerical procedure which can be performed in two manners: 1) varying the solar apparent radius (iteration); 2) fitting to the known function $CMD'(t)$ where $h$ is an unknown parameter which can be determined by the fitting procedure.

The analytical method for finding the real synodic rotation rate $\omega$ of the 'footpoint' of the traced object and the object’s height $h$ is based on the following equations (Roša et al., 1998):

\[
\omega^2 = \frac{\left( \sum_{i=1}^{N} \omega_i^2 \right) \left( \sum_{i=1}^{N} \frac{1}{\cos^4 \lambda_i} \right) - \left( \sum_{i=1}^{N} \frac{\omega_i^2}{\cos^2 \lambda_i} \right) \left( \sum_{i=1}^{N} \frac{1}{\cos^2 \lambda_i} \right)}{\left( \sum_{i=1}^{N} \frac{N}{\cos^4 \lambda_i} \right) \left( \sum_{i=1}^{N} \frac{1}{\cos^2 \lambda_i} \right)},
\]

\[
h = R(\sqrt{\beta^2 \cos^2 B' + \sin^2 B'} - 1),
\]

where $\omega'$ and $\lambda' = CMD'$ are the measured values of the apparent synodic rotation rate and the apparent central meridian distance, respectively.

The iterative method of varying the solar disc radius was already used by Aschwanden et al. (1995) for radio-objects.

The numerical method to estimate $\omega$ by fitting a known function $CMD'(t)$ to the measurements is based on evaluating the zero point of the function:

\[
f(\omega) = \frac{a}{b} - \frac{c}{d},
\]

where the parameters $a, b, c$ and $d$ are defined by the following relations:

\[
a = \sum_{i=1}^{n} \Lambda'_i \sin \omega t_i,
\]

\[
b = \sum_{i=1}^{n} \Lambda'_i t_i \cos \omega t_i,
\]

\[
c = \sum_{i=1}^{n} \sin^2 \omega t_i,
\]
Figure 1: The program for measuring heliographic coordinates takes into account all possible orientations of solar images.
\[ d = \sum_{i=1}^{n} t_i \sin \omega t_i \cos \omega t_i, \]  

(7)

where \( \Lambda' = \sin(CMD') \). The parameter \( \beta \), which provides an estimate of the height of the tracers by Equation (2) can be determined from:

\[ \beta = \frac{\sum_{i=1}^{n} \Lambda' \sin \omega t_i}{\sum_{i=1}^{n} \sin^2 \omega t_i}. \]  

(8)

The method of analytic fitting of \( \omega'(CMD') \) was applied to several stable filaments selected from the full-disk H\( _\alpha \) patrol observations of the Kanzelhöhe Solar Observatory. The accuracy of the position measurements and the procedure of the filament contours overlapping were tested. We found that the errors are caused primarily by intrinsic variations of the tracer’s morphology (Vršnak et al., 1999).

Finally, the sidereal rotation rate has to be found. In some cases it is important to perform calculations taking into account details of the earth’s motion. In such cases the relation between the observed synodic (\( P_{\text{syn}} \)) and sidereal (\( P_{\text{sid}} \)) periods can be calculated using the relation (Roša et al., 1995):

\[ P_{\text{sid}} = P_{\text{syn}} \left\{ 1 + \frac{P_{\text{syn}}}{360^\circ} \left( \arctan [\cos i \tan (\lambda_0 - \Omega')] \right. \right. \]
\[ \left. \arctan [\cos i \tan (\lambda_0 - \Omega)]] \right\}^{-1}, \]  

(9)

where \( i \) is the inclination of the Sun’s equator to the ecliptic; \( \Omega \) and \( \Omega' \) are the longitudes of the ascending node for the beginning and for the end of the observation date respectively; \( \lambda_0 \) and \( \lambda_0' \) are the apparent longitudes of the Sun for the true equinox of the date for the beginning and of the end of the observation date respectively.
4. Conclusion

The described procedures provide a relatively fast and accurate determination of the sidereal rotation rate measuring positions of tracers on synoptic solar images. They provide a possibility to use various categories of tracers that are present at all latitudes during the whole cycle. The procedures are "universal" and can be applied to tracers of unknown height. The related programs for data reduction are interactive and comparatively comfortable, providing various reduction algorithms.

References

MJERENJE POLOŽAJA NA SINOPTIČKIM SLIKAMA SUNCA

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Ključne riječi: mjerenje položaja - sinoptičke Sunčeve slike - siderički period rotacije