METHOD OPTIMIZATION FOR CALCULATING THE SOLAR LIMB POSITION

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ABSTRACT

The different techniques employed in the precise determination of the edge of the solar disk create some uncertainties in the identification and interpretation of the high-degree p-modes. There are two main methods which were described by Korzennik (1990) and which were used for reducing MOF-data obtained at Mt. Wilson Observatory in the 60" Solar Tower. These were a “derivative-based” algorithm and an “activity-based” algorithm. As was discussed by Korzennik (1990), the two algorithms differed somewhat in the sizes which they computed for the same solar images. However, the standard deviations from the mean image size were practically the same in both cases.

In the present work the solar limb figure was determined using the middle of linear segments, which were drawn by a least squares method through brightness profiles and which had maximum slopes. The brightness profiles which were employed were equally spaced in the azimuthal angle. We will show here that there is an optimal width for the ring-shaped zone (r/R ~ 5%) which is used for the limb determination. In this case the run of standard deviations of the limb points from a circle has a clear minimum which is 1.3 times smaller than the standard deviation found with the “activity-based” algorithm. During iteration cycles the error in determining the centre of the solar image gets smaller and reaches a limiting value which is conditioned by the shape of the image.

Our proposed method of solar limb determination is intended to decrease possible errors in the identifying the degrees of the high-l oscillation modes as well as to achieve higher computational efficiency.

Keywords: helioseismology, solar limb determination.

1. INTRODUCTION

The possibility of revealing high-degree p-mode oscillations is determined, mainly, by spatial resolution of the instrument. The technique for reducing of observational data may affect precision and single-meaning interpretation. To decrease possible errors in calculating oscillation modes associated with the highest spatial resolution of the instrument, it is necessary to ensure as much as possible co-ordinate matching for all the successive raw filtergrams which are commonly used for calculating Doppler velocity map or magnetogram.

As a rule, filtergrams differ considerably in revealing small details, which might be assumed to make matching of filtergrams impossible. Nevertheless, the solar disk centre or solar limb can be used as reference points for matching filtergram pairs. There are different techniques used for solar limb determination (Ref.1,2) but these result yield discrepancies. All of these factors lead to certain errors when calculating spatial power spectra for very short wavelength oscillations.

Therefore, we considered certain factors affecting the precision of determining the solar limb by using Doppler velocity and brightness observational data obtained with the Magneto-Optical Filter (MOF) at Mt. Wilson Observatory. As a criterion of iterative approximation to the most precise limb position, we chose the minimization of Root-Mean-Square deviation of limb position points from a circular shape. Note that perfect alignment of the optical layout of the instrument significantly decreases ellipticity of the image (Ref.3), which makes filtergrams matching easier.
2. OPTIMIZATION

Methods for determining the solar limb in MOF-observed data were proposed by Korzennik (Ref.2). He used several different methods for processing the data observed with the MOF at the 60' Solar Tower. The two main methods were "derivative-based" and "activity-based" algorithms. These algorithms differed in output solar limb size values, though both had nearly the same calculation error (standard deviation).

In order to achieve the minimal standard deviation when calculating the solar edge position, series of successive filtergrams from different dates and times were analyzed in detail. Brightness profiles near the solar limb were studied and it was found that due to some alignment breaches one could see signal disturbances at near-limb areas. In these cases, the technique for finding point positions with maximum slope within a narrow annular zone (as used before) can show possible casual errors.

The maximum-slope positions were found as the middle of linear segments built by the LSQ method through certain portions of data in each radial direction. Standard deviations calculations were carried out on solar limb positions from a circular shape as a function of the data portion size. (Data portion size means the length of data segment on each given radial direction near the limb.) Both data obtained in the standard MOF configuration (contiguous lines in Fig.1), and data with the single-cell filter (no wings selector; dashed lines in Fig.1).

In Fig. 1: vertical axis represents the standard deviation of maximum-slope points from a circle and horizontal axis shows length of data segment as a percentage of disk radius. Filtergrams that had small brightness breaches profile near the limb (marked with triangles) give a significant easily seen RMS minimum. Those filtergrams with brightness breaches profile show larger dispersion of points and the displacement of the minimum tending to the direction of segments lengthening up to 6-8% of the radius (marked with diamonds) and, sometimes, even more. Filtergrams obtained with the single-cell configuration had signal levels approximately three times greater. Those filtergrams show smaller RMS values, but have no clear minimum. The main reason of this is that there are dark rings on brightness profiles near the limb caused by some alignment defects. As expected, RMS errors in this case tend to decrease with increase of segment size.

Figure 1. Dependencies of the RMS deviation of solar limb points from a round shape on the relative length of radial segments.

Figure 2. Solar limb points distribution.

Fig. 2 shows the calculated limb points for two segment sizes r/R = 1.6% (upper figure) and 4.6%...
(lower). The thin lines refer to the circles with radius 204.95 ±0.91 (upper) and 204.30 ±0.68 (lower) pixels. The thick lines refer to ellipses fit to limb points by the LSQ method.

![Graphs](image)

Mark, that the deviation amplitude from circle (A), sinusoidal periods, the peak in power spectrum, and their phases practically coincide. The Fourier transform also shows that for 4.6% segment all other peaks in the power spectrum are non-significant. Quite a different power spectrum is seen for 1.6% segment: there are many peaks for other significant periods. In this case we have a very high level of uncertainty in ellipse fitting and determination of its amplitude.

An iterating process is used to determine limb points, disk center coordinates and its radius. The program first uses rough center coordinates and radius values. Limb position points are made in 360 equally spaced azimuthal angle radial directions. Then each pair of opposite radii gives a middle of a diameter. Having 180 values of diameter middles we can calculate a new disk center coordinate which is now used as reference for the new cycle of calculation. The algorithm will iterate until standard limb position deviations from the mean-radius circle does not decrease significantly, usually no more than 5-7 iterations are needed.

So we found optimal size of segments for calculation limb position points, disk center and disk radius. It must be chosen in 5-7% range of solar disk radius for observations with the MOF in Na lines. In comparison with known “activity-based” and “derivative-based” algorithms which give practically the same calculation errors, the new technique gives better results making these errors at least 1.3 times less.

3. CONCLUSIONS

The criterion of decreasing of standard deviation of limb points from a circle applied in iterating algorithm of solar limb determination enables to get all disk parameters with a high level of certainty and does not depend on deviation of disk shape from a circle. To increase precision in disk shape determination it is necessary to remove all optical breaches connected with imperfect alignment and poor instrument adjustment.

The proposed technique for determining the solar limb, disk center and disk radius will enable to expand the range of detecting high-degree p-modes oscillation of the Sun due to significant reduction of errors when matching successive filtergrams, and, hence, to improve the effectiveness of the instrument.
4. ACKNOWLEDGEMENTS

This work was supported by the ISF Supplementary Grant SBM000 at Crimean Astrophysical Observatory and the NSF Grant ATM-9119617 at U.S.C. and Mt.Wilson Observatory.

REFERENCES

