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A DEVICE FOR PRECISE ORIENTATION OF SOLAR IMAGES

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ABSTRACT. A spirit level is used to get precise orientation of single solar images taken with a direct pointing photographic or CCD heliograph. A brief discussion of the alignment of this device and of the instrumental errors is given.

1. Introduction

There is a growing number of heliographs with CCD detectors used especially for photometric work. Data supplied by these instruments could also be used for positional work if properly oriented. A device for this purpose is described in the following.

To extract positional information from solar images taken with heliographs (like sunspot positions, correlation of images from time series or from different instruments etc.) the direction to celestial north on the images has to be known very precisely. The north direction is sensitive to alignment errors of the heliograph that may vary with time. Therefore, the angular orientation of each image with respect to an astronomical coordinate system has to be determined. The problem of angular orientation was analyzed by Dezsö et. al. (1987) for the purpose of deriving exact sunspot positions.

2. Principle

For a celestial object the angle between the altitude circle (parallel to the horizontal plane) and the declination circle (parallel to the plane of the equator) is the parallactic angle, η, in the nautical triangle (cf. Fig. 1a). In a direct pointing heliograph the angle between a fiducial mark, fixed in the image plane of the heliograph, and the horizon can be easily measured by using a spirit level (or alternatively a pendulum) and some angle-measuring device e.g. an incremental shaft encoder. This angle has to be measured for each exposure and gives the desired direction to the zenith with respect to the fiducial mark on the image. The measured angle depends on the type of heliograph mounting. With an equatorially mounted heliograph the angle is the sum of η and the orientation error caused by the imperfect mounting of the telescope (η_m in Fig. 1b), whereas with an alt-azimuth mounting only the orientation error is effective. In both cases a fixed offset can be present, depending on the initial setting of the fiducial mark. The angle η is calculated from

$$\sin\eta = \sin(\mathrm{HA}) \cdot \cos\phi / \cos(\mathrm{ALT})$$

$$\sin(\mathrm{ALT}) = \sin\delta \cdot \sin\phi + \cos\delta \cdot \cos\phi \cdot \cos(\mathrm{HA})$$

where HA is the hourangle, δ is the declination, ALT the altitude above horizon, and ϕ the geographic latitude.

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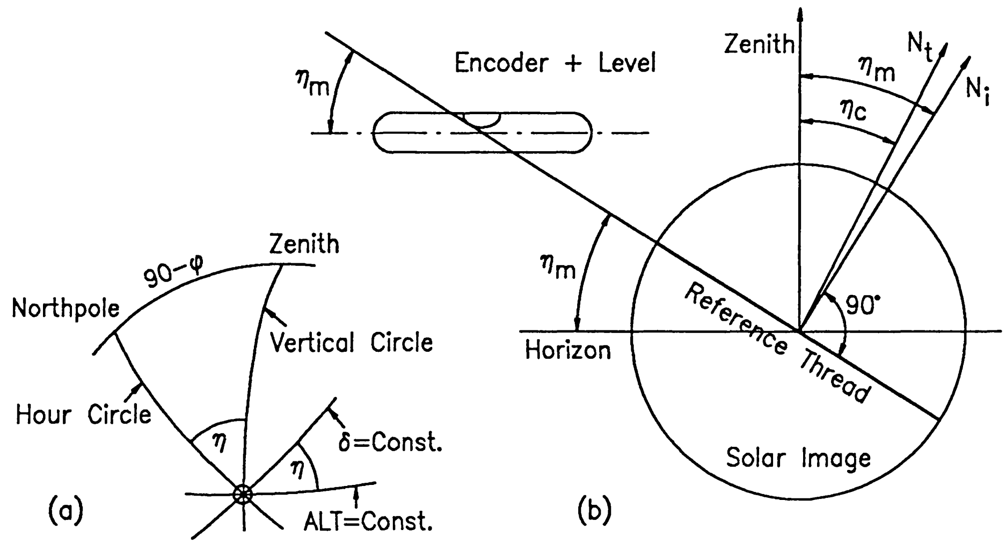

Figure 1: (a) The parallactic angle, η, in the nautical triangle. (b) Situation for an equatorially mounted heliograph. On the solar image the true north direction, N_t, can be found with the calculated angle, η_c, and the zenith direction. The direction to the zenith with respect to the known instrumental north, N_i, is the measured angle η_m (or the angle between reference thread and $\eta_m + 90°$). From this the orientation error is $\eta_m - \eta_c$.

The fastest change of η is in the meridian, where ALT is nearly constant. The change of η in one second of time for different geographic latitudes and for maximum solar declination (23.5°) is shown in Table I.

To estimate the neccessary accuracy in angular orientation a spatial resolution of 1 arcsec is assumed. This corresponds to 3.5 arcmin in position angle at the solar limb. UTC usually is the most accurate time in a solar observatory; it has a maximum offset of ±0.5 sec from mean solar time, which should be used to calculate η. Table 1 shows that even for altitudes as high as 83.5° an accuracy of ±1 arcmin can be reached for η using UTC.

A cross hair in photographic instruments or a pixel line in instruments using CCDs can serve as a fiducial mark (reference direction). The optical axis of the heliograph has to be exactly parallel to the rotation axis of the shaft encoder. Therefore, for stability the part representing the fiducial mark and the encoder should be mounted on a common, stable baseplate. The mechanical axis of the spirit level has to be perpendicular to the rotation axis of the encoder.

3. Calibration

Only one calibration, the zeropoint of the angle scale, is necessary, which can be done with great accuracy in the laboratory. With the optical axis approximately horizontal, one has to align the crosshair (pixelline) precisely horizontally, e.g. with the help of a microscope on a horizontal slide. With this setting and the spirit level balanced the zeropoint of the system is defined. The calibrated camera-encoder unit

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TABLE I

Change of the parallactic angle η in one second of time for maximum solar declination and for different geographic latitudes

ϕ	ALT_{max}	$\cos\phi/\cos(ALT_{max})$	$\Delta\eta$ in 1 sec	$\tan(ALT_{max})$
47°	66.5°	1.71	26"	2.30
40°	73.5°	2.70	41"	3.38
30°	83.5°	7.65	114"	8.78

should be mounted on the telescope to give nearly zero offset. This means that a properly oriented system should read zero when pointing to the meridian.

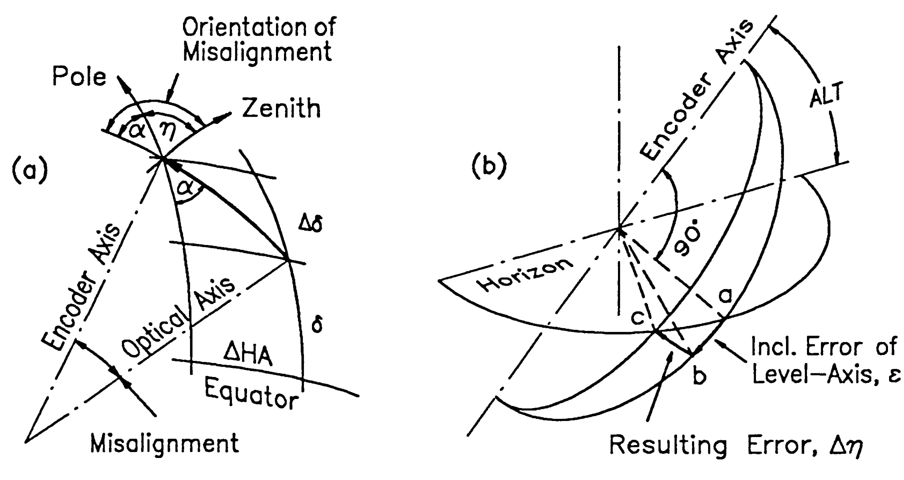

Figure 2: (a) In case the encoder and optical axes are not parallel to each other, the angle η_m is not measured at the position where the optical axis points to the sphere. The correction to η_m is the difference of the calculated values of η for both directions. (b) An obliquely mounted spirit level causes an error in η. If the level axis, a, in the horizontal plane and normal to the encoder axis gives the correct value of η an inclination error of the level axis puts the level out of balance (axis b). Turning axis b back to the horizontal plane (axis c) results in an incorrect value for η. For small angles $\Delta\eta = \epsilon \tan(ALT)$

4. Errors

There are always some misalignments which cause errors that one has to account for. The most common errors are shown in Fig. 2.

1) With precise calibration in the laboratory there should be no zeropoint error.

2) The misalignment between the optical and the rotation axes can be determined either in the laboratory or on the telescope if it is possible to reverse the whole

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instrument (German mounting). The applicable laboratory method depends on the layout of the whole camera, on how the optical axis can be defined etc. Depending on the arrangement, a second shaft output on the encoder (to mount an autocollimation mirror) can be of great help.

3) The error of the 90° angle between the mechanical axis of the spirit level and the encoder rotation axis can be found by reading the angle twice, the second time after a half revolution. This can be done for the actual measurement, or better with a series of readings at different inclinations on the telescope or in the laboratory. The contribution of this error increases with tan(ALT). At different altitudes, and especially at reverse reading of the level, different sections of the spirit level tube are used, therefore the level tube should be rotationally symmetric (so–called reversible levels).

5. Conclusion

From the description it is clear, that this method, at least in its simple form, can only be used for heliographs pointing directly to the Sun and with the Sun not close to the zenith. With the Kanzelhöhe photoheliograph we have been using such a device for several years with success (Pettauer, 1990). The technical data for this instrument are: spirit level of 20 arcsec sensitivity per part, 1 arcmin angle readout accuracy of the angle encoder and UTC at full second reading.

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