KANZELHÖHE PHOTOSPHERE TELESCOPE (KPT)

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Abstract. The Kanzelhöhe Photoheliograph (PhoKa) was in operation since 1989 to obtain full disc photoheliograms in continuum (on film) for the derivation of sunspot positions with high precision. Recently the instrument was reconstructed completely to adapt for the application of a high resolution CCD cam as the image acquisition device instead of film plates. The design of the new Kanzelhöhe Photosphere Digital Camera (KPDC) is very similar to the established Kanzelhöhe H\textalpha{} high cadence imaging system and allows to obtain automatically full disc continuum images time series with 2kx2k spatial and down to a few seconds temporal resolution. The evaluation of the geometric and photometric precision is presently in progress.

Key words: Solar observations - telescopes - photosphere - continuum

1. Introduction

The main purpose of this instrument is a high precision full disc imaging of the photosphere in order to derive sunspot and faculae areas and positions as well. Other scientific objectives are studies of the underlying photosphere before, during and after chromospheric flares, hunting for the mystery white light flares at the begin of a new solar cycle and providing a data set for developing an automatic determination of sunspot relative numbers by image segmentation techniques. The obtained time series will also continue the support of the Debrecen Photoheliographic Data by daily synoptic images.

The KPT is based on the Kanzelhöhe Photoheliograph which went into operation in 1989 and was described in Pettauer (1990).
Figure 1: Layout of the Kanzelhöhe Photosphere Telescope. Choosing achromats for L1 and L2 reduces also non-chromatic aberrations. The effective focus length of the complete system is about 1460 mm which corresponds to a disc size of about 13.7 mm in diameter. The diaphragms D1...D3 for the reduction of stray light were kept from the old system. An extra neutral filter N with a transmission of 10% became necessary to avoid very short exposure times (< 2 ms) and smearing which is specific to interline transfer CCD cams. The lens L2, the interference filter IF, the neutral filter and the CCD cam are fixed in an inner tube which is inserted from the back end into the main telescope tube. The focus control is made manually by shifting the lens L1 back and forth with a worm gear.

2. Telescope

The proposed use of a CCD cam for the data acquisition required considerable changes of the telescope design in order to adapt for the relatively small detector and image sizes. In the old Kanzelhöhe Photoheliograph an eyepiece lens system enlarged the solar disc image in the focus of L1 onto a 13x18 cm² film. The selected CCD camera however has a chip size of 15x15 mm² – too small to obtain a full disc image in the primary focus. Downsizing the primary focus image with an eyepiece lens would be an option, but a calculation of the optical parameters showed, that this combination would need a field lens and increases the aberrations. The alternative was to insert another positive focus lens within the focus distance of the objective lens L1 and reduce the effective focal length (for details see Figure 1). The back side of the Jena AS front lens (air gap side) carries a gold coating with a transmission less than 0.1% to reduce the amount of light which enters the telescope. The spectral range of the solar continuum is limited by an interference filter with a FWHM of 10 nm at 546 nm.

The whole system is mounted piggy-back on the main patrol telescope cabinet.
3. Camera System

The experience gained during several years of Hα observations showed that mastering of not always perfect observing and seeing conditions might be even more important than maximum resolution. Key features for the selection of the camera model were

- presence of an electronic shutter, as mechanical shutters had problems with the huge number of exposures on high cadence time series
- high frame rate for use of frame selection
- software controllable exposure times to adapt for changing opacity of the atmosphere
- reasonable high resolution (spatial and intensity)
- digital read-out and progressive scanning which simplifies the data acquisition

The selected JAI Pulnix TM–4100CL features a Kodak interline CCD chip with microlenses and a built-in electronic shutter, the maximum of the spectral sensitivity is close to the observed band. The edge length of 7.4 \( \mu \text{m} \) of the 2kx2k square pixel corresponds to 1.04 arcsec/pix which is almost equal to the diffraction limit for the telescope of 1.06 arcsec at 546 nm. According to Nyquist’s sampling theorem the image is undersampled but it is a good compromise between mostly prevailing seeing conditions and present camera technology. The shutter can be controlled by the length of an external pulse, typical exposure times are in the range of 5 ms and the maximum frame rate is about 10 frames/s. The output is digitized to 10 bit, the upper and lower level as well as the gain can be set to match the incident light level to exploit the full dynamic range but avoid non-linearity due to saturation. The CameraLink interface transfers the data to a Silicon Software ME3 frame grabber in an Intel based 3 GHz industrial 19" PC and allows also the control of the camera by the image acquisition software.

The application is written in C++ and makes use of the Common Vision Blox library. It is running under Windows XP and grabs continuously frames from the camera. Each frame is evaluated in a user defined rectangle (Area-Of-Interest AOI) with regard to mean pixel value and standard deviation. The mean is used to control the exposure time and keeping the brightness
level of the images fairly constant, the standard deviation is a measure for
the blurring which is the main factor of the seeing at exposure times of
some milliseconds which freeze the image motion component. The image
with the best seeing of a consecutive number of frames is then written onto
hard disc, the standard format is FITS; JPEG copies are optional. The
whole procedure can be repeated after a user defined interval for automatic
acquisition of time series. A block diagram and further details of the software
which is also used for the Hα observations at Kanzelhöhe can be found in
Otruba (2005).

4. Data Processing

4.1. Positional Information

In order to derive heliophysical coordinates from solar features one has to
know the orientation of a pixel axis of the CCD with respect to celestial
coordinates. The equatorial mounting of the telescope has the advantage
of no image rotation during the diurnal movement of the Sun across the
celestial sphere. Apart from small errors due to imperfect telescope setup
or bending of the optical axis (on the changing direction of the weight of
the telescope during a day) the angle Θ between the pixel axis and e.g. the
celestial E-W-direction should be constant as long as the system will not
be disassembled for maintenance. If the tracking system of the telescope is
switched off and one neglects the change of the solar declination and of the
refraction during a few minutes the track of a solar feature or of the disc
centre will represent the celestial E-W-direction. Therefore we obtain from
time to time a series of about 20 images with no tracking having the solar
disc moving across the field of view. Applying an edge detection filter, fitting
circles through the solar limb points and calculating the centre coordinates
yield finally a track of the disc centres and the angle Θ. The standard error
of this procedure is about 0.02° for Θ and the daily variation due to the
above described imperfections is in the order of 0.05°. The standard error
for the deviation of individual limb pixel from the calculated circles is within
one image less than 1 pixel, the observed variation of 2...3 pixel typically in
the disc radii of about 930 pixel in image series is rather an influence of the
seeing than an error in the fitting procedure. So the individual calculated
disc radii have an error in the order 0.1% and we can estimate a reliability
Figure 2: Single dark current frame of the TM4100CL. The mean of the pixel values is $\overline{dc} \approx 4.3$ counts with $\sigma \approx 2.8$. The read-out noise, defined as the standard deviation of the pixel differences of 2 dark current frames, is $rmsnoise \approx 2.77$ which yields a dynamic range of 51 dB and 8.5 significant bits.

of better than 1° in heliographic positions in our images.

4.2. PHOTOMETRIC INFORMATION

CCDs have basically a linear relation between the produced charge (and the output voltage) and the amount of the incident light, but there exists a level of saturation which limits the linear range. Therefore the amount of light during exposure has to be limited to that level. The TM-4100CL allows to set the gain and the upper and lower level of the A/D converter, so that the full dynamic range (which corresponds to pixel value 0...1023) can be mapped into the linear part of the CCDs charge vs. incident light relation. The zero level is set properly when some noise floor (dark current) is visible. Signal noise limits the dynamic resolution of the pixel (the number of useful bits). The flat-field frame is a map of non-uniform gain of the individual pixel. For setting and checking of these properties we used a simple procedure which was proposed by ESO (Deiries, 1995). In the lab the cam was illuminated with a stable and uniform light source (e.g. a LED with diffuser) and a set of paired frames (with equal exposure times) were taken.
Figure 3: Comparison of flat-field methods described in the text, left method a) and right method b). Clearly visible that in method a) the noise which is from nature variable from frame to frame produces more small-scale non-uniformity than any visible large scale variation. Method b) uses only a single frame and no differences, assumes large scale circular symmetry and stops compensation of variation at a certain scale.

in a wide range of exposure times. Pixel statistics were made on sub-fields to avoid averaging over non-uniform areas: The means of the pixel values as a function of the amount of incident light (i.e. of the exposure time) showed a non-linearity of 0.2%. The standard deviations of the difference of the equally exposed frame pairs give the noise in the data. The dark current is fairly independent from the exposure time and noise dominated (see Figure 2), probably produced by the electronics (read-out noise). The ratio between full scale and noise yields finally the useful dynamic range and can be expressed in the effective number bits. The flat-field was investigated by 2 methods: a) by a set of consecutive taken displaced solar image frames which assume to show the same "solar image" (see Kuhn et al., 1991), and b) by assuming circular symmetry in a spotless solar disc image and fitting polynomials into concentric rings of the solar disc to correct asymmetries (see Burlov-Vasiljev and Brandt, 1996).

Both methods showed that the effect of noise dominates over non-uniformity which is in the single percent range (Figure 3). Figure 4 shows the comparison of very high contrast spotless disc image where limb darkening is compensated with both methods. It is clearly visible that both methods fail at the extreme limb regions, but method b) seems to be a little bit
Figure 4: Very high contrast images of the spotless Sun from 2007-08-01 to check the quality of the flat-fielding methods. Left processed with method a) and right with method b). Limb darkening is compensated by applying the CLV function derived from the flat-fielding procedures. Between the black and white level is only an intensity variation of 1%.

better, but it has to be further checked on images with sunspots.

5. Data Archives and Policy

The time series are obtained with a cadence of 1 image/min as the standard observing program. Each image is the frame with highest contrast in the AOI selected over at least 100 consecutive frames. From this series we will pick one best image per hour on solar low activity periods and up to 1 image/5 min on periods with high activity for the long term archives. This second step of image selection is done by evaluating the images with the optimum window method (Giammanco, 2000).

For synoptic purposes 1 image per day is selected, processed and published on the web. The processing comprises the application of the above described flat-fielding by method b), which yields also a Centre-to-Limb Variation (CLV) function, and the presentation as a normal contrast image and a high (CLV compensated and enhanced) contrast image, both in FITS and JPEG. The JPEGs are downsized to 1024x1024 pixel and rotated to have solar N up. To demonstrate the data quality of our instrument in
Figure 5: Left: A full disc image observed at 2007-07-14 6:20:53 UT shows the capability of the new telescope. The inset bottom right is a zoom-in into AR 10963. For comparison the same region from SOHO/MDI full disc observed at 20:48 UT same day (top right).

comparison to the well-known full disc images from SOHO/MDI we show Figure 5. The full data set will be available in our online archives CESAR (http://cesar.kso.ac.at) and is open for use by the scientific community if you acknowledge the source of the data. However we ask you to contact us before publishing your results.

References

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