Abstract. The dynamics of the solar plasma is driven by strong localized magnetic fields. It is well known that activity like flares and CMEs are related to the dissipation and reconnection of these magnetic fields. These energetic releases influence and make up the so called space weather. It is therefore of vital importance to get a deeper understanding of the magnetic fields of the Sun. To get this insights, it is crucial to obtain information on the magnetic fields with spatial and temporal resolutions as high as possible. In this paper we outline an easy to apply method to obtain quasi total magnetic field strength magnetograms out of two simple filtergrams (blue continuum and G-band). We will present our simple approach and the first results of this method and give finally an outlook what has to be done in the future.

Key words: observation methods - magnetogram - Hinode/SOT

1. Introduction

The large scale dynamics of the solar atmosphere is governed by the 11-years sunspot cycle, which is driven by the 22 years magnetic cycle. Sunspots comprise extended and strong magnetic fields (on spatial scales of 1000 to 100 000 km) which are responsible for solar activity like flares and coronal mass ejections (CMEs). On the other hand the magnetic fields are not limited to these sizes and strengths but span a huge range down to smallest (single flux tubes with diameters as small as 100 km; visible as e.g. magnetic bright
points; e.g. Utz et al., 2009) and weaker fields (in the range of hecto gauss fields in inter/intra-network regions; e.g. Orozco Suárez et al., 2007).

To get a better understanding of the magnetic processes like magnetic field generation, amplification, annihilation and reconnection, we need sophisticated observational tools. The best way for investigating the dynamics of small scale magnetic fields is up to now the observation of spectropolarimetric data followed by the application of inversion codes (Beck et al., 2007, Viticchié et al., 2009). These observations are of course limited in their FOV (field of view) and/or in their dynamics (spatial and temporal resolution)\textsuperscript{1}. Therefore, other observation techniques are used for determining the dynamics of larger FOV regions. These techniques use mainly the Zeeman effect which leads to a polarization of the emitted light under the influence of magnetic fields. Under the restriction of not too strong fields, the polarization degree is linearly dependent on the magnetic field strength. This behaviour is used for determining the magnetic field strength via measuring the so called Stokes parameters (these are measures for the polarization degree). Longitudinal field strength magnetograms are widely known as V/I magnetograms (see e.g. the MDI instrument on board the SOHO spacecraft; Scherrer et al., 1995; or the NFI device of the SOT instrument on board Hinode; Chae et al., 2007).

In this paper we want to outline another way for investigations of magnetic fields. For our method we only need to obtain filtergrams in the blue continuum and G-band and once a magnetogram for calibration purposes. In the second chapter we outline the used data. The third section describes our easy to apply method for obtaining the “quasi” total field strength magnetograms (total refers to the norm of the magnetic field vector). The fourth section shows the obtained result, compares it with the original magnetogram and discusses future prospects. The fifth section gives our conclusions.

2. Data

We used data of the SOT (Solar Optical Telescope, see Tsuneta et al., 2008) instrument aboard the Hinode mission (Kosugi et al., 2007). The Hinode spacecraft was designed and is operated by the Japanese Space Authorities

\textsuperscript{1}One has to have in mind that the product of spectral/temporal/spatial resolution and FOV is a constant for a certain instrument.
in cooperation with NASA and ESA. The SOT has a 50 cm primary mirror and consists of 3 scientific instruments: a spectropolarimeter, a narrow band instrument for derivation of magnetograms and dopplergrams, and a broad band device. The broad band device uses 6 different filters. Three filters (red/green/blue) are in the continuum range and three are line filters (G-band, Ca II H, Fe 6302 Å).

The data under study stem from the 11th of December 2006 from about 17 to 18 UT. For our analysis we used one filtergram in the blue continuum, and the corresponding one in the G-band, furthermore we used a magnetogram, which was produced by inversion techniques from the spectropolarimetric observations by Bruce Lites et al. (see also Figure 1). Such magnetograms are available under: ‘http://sot.lmsal.com/data/sot/level2d/’, for more details see also this mentioned site. For details about the inversion code (MERLIN) see: ‘http://sot.lmsal.com/data/sot/level2dd/sotsp_level2_description.html’. The filtergram data were reduced by standard Hinode data reduction software which is distributed under SSW (solar software).

3. The Calibration

Introduction and Idea:
It is well known that the intensity in the G-band is tightly correlated with magnetic fields. This was shown e.g. by Berger et al. (2004). In the paper of Shelyag et al. (2004) Figure 4 shows a result of a MHD simulation and synthesized G-band spectra. One can see that the brightness in the G-band increases with the corresponding magnetic field strength. On the other side it is visible that for low magnetic fields there is a whole bunch of scatter points spanning over a huge brightness range. This cloud of data points corresponds to the granulation. We see that the brightness in the G-band alone is not sufficient to deduce the magnetic field strength. The idea is to suppress the granulation brightness variation. In the blue continuum image the effect of the magnetic field (at least for small scale and weak fields) is very low. For practical reasons we assume that there is no relation between brightness and magnetic field strength (in quiet granulation regions). If we obtain the ratio between G-band and blue continuum we therefore suppose that we get rid of the granulation pattern.
Figure 1: Fully processed magnetogram (top), followed by a G-band filtergram (middle) and a blue continuum filtergram (bottom). The magnetogram was prepared by Bruce Lites. The FOV of these images is about 200 arcsec by 100 arcsec. One should have in mind that the magnetogram was taken in a scanning mode lasting roughly an hour (left side corresponds to about 17 UT; right side to about 18 UT).
First Step:

The first step (after careful temporal and spatial alignment) is to align the intensity distributions of the blue continuum and G-band image. Due to different filters and different exposure times, the distributions span over different ranges. For this purpose we take the clearly visible granulation peak (visible at intensities of 1200 and 2100, respectively; see Figure 2) and calculate with it the alignment factor (multiplication factor) between these two distributions. The result can be seen in Figure 2. The figure shows in the top row from left to right the original brightness distribution of the two filtergrams and the brightness distribution after the brightness alignment process. The second row shows the so called G-band excess, which is just the ratio of these two images minus one. One can clearly see the facular and small scale magnetic field regions as bright patches.

If we investigate the scatter distribution between this excess and the...
magnetic field strength in more detail (Figure 3) one sees that the scatter comprises different regions, which correspond to different physical features in the FOV:

1. Non inverted pixels: These pixels were not inverted by the inversion code (i.e. pixels at the centre of the sunspot in Figure 1).

2. Sunspot pixels: Very strong magnetic fields and very high negative excess. One sees that our method is not perfectly suited for such situations as small changes of the excess could imply strong changes of the derived magnetic field strength.

3. Penumbral pixels: Next to the sunspot lies the penumbra with strong fields and high negative excesses.

4. Small pore pixels: Negative brightness excess due to their large size but similar magnetic field strength compared to small scale fields.

5. Granulation pixels: Very weak field and very weak brightness excess.

6. Small scale magnetic field pixels: medium magnetic field strength but positive brightness excess.
Calibration Curves:
The next step is to find appropriate functional relations between the brightness excess and the magnetic field strength. We can think of a general equation of the following form:

\[ B_{mag} = f(I_{blue}, G_{ex}), \]

(1)

where \( f \) stands for a general functional relation dependent on the blue continuum intensity \( I_{blue} \) and the G-band excess \( G_{ex} \). The idea is now to get rid of the double dependence. For this purpose we divided the complete blue continuum intensity range in many different classes, which can be arranged in three different domains (three different functional relations). It is well known that regions with very strong and extended fields (sunspots and large pores) are darker than their surroundings (due to the suppression of convective motions and energy transport; e.g. Stanchfield et al., 1997). On the other hand small scale fields appear slightly brighter than their vicinity. Therefore we choose the different intensity domains to be: dark regions corresponding to strong and extended fields, medium bright regions corresponding to granulation and field free pixels, and bright pixels corresponding to small scale fields. For each domain we derived its own calibration model (functional relations \( f, g, h \)) between the excess and the magnetic field strength.

\[ B_{mag} = f(\text{para}, G_{ex}) \quad \forall \text{pixel} \in \text{domain I} \]
\[ B_{mag} = g(\text{para}, G_{ex}) \quad \forall \text{pixel} \in \text{domain II} \]
\[ B_{mag} = h(\text{para}, G_{ex}) \quad \forall \text{pixel} \in \text{domain III} \]

(2)

Each domain was further divided into several brightness classes (e.g. \( 210 \leq I_{blue} < 220 \) is one brightness class spanning from 210 intensity data units to 220 intensity data units). The parameters \( \text{para} \) of the functional relations (fit coefficients) were calculated for each of those brightness classes:

\[ B_{mag} = f_{210\leq I_{blue}<220}(G_{ex}) \]
\[ = f_{220\leq I_{blue}<230}(G_{ex}) \]
\[ = f_{230\leq I_{blue}<240}(G_{ex}) \]
\[ = \ldots \]
\[ B_{mag} = g_{800\leq I_{blue}<1050}(G_{ex}) \]

(3)
Figure 4: Scatter plot between very strong magnetic fields (sunspot umbra) versus the brightness excess. The corresponding fitting model for this scattering behaviour is a linear fit (functional relation $f$), shown by full line. The $1\sigma$ error bandwidth of the fit is indicated by the dashed lines.

For strong and extended fields we find a linear behaviour between field strength and G-band excess (functional relation $f$) in all brightness classes within this domain. The excess decreases with increasing magnetic field strength (Figure 4). For medium-bright pixels (granulation) we applied a second type of fitting model (see Figure 5; $g$-relation). For this and the last fitting model we sort the brightnesses and the field strengths in an ascending order. We suppose that with this method we can reduce the scatter, which should be mainly due to an imperfect alignment (temporal and also spatial) between the used exposures (blue continuum, G-band and magnetogram). This method should not falsify our values too much as we can presume that there should be a more or less strict unique relation between excess and field strength (i.e. the larger the excess the larger the field strength). Therefore we can compensate more of the scatter error than we introduce by the sorting. Finally, we have adopted a third fitting model ($h$-relation) for the small scale fields (which are related to the brightest pixels; see Figure 6). The figures show always only one presentable brightness class case for...
each functional relation. Our total calibration consists of these three fitting models for the three different intensity domains. Every fitting model was divided in several blue continuum brightness classes, which gives about 60 different parameter sets for the low-intensity regions $f$, 1 for the medium-intensity ones $g$ and about 55 parameter sets for bright regions $h$. In total we have therefore about 120 calibration curves for the different blue continuum brightness classes.

**Figure 5**: Scatter density plot between magnetic field strength and brightness excess for medium-bright pixels (granulation brightness range). The second fitting model was adopted (functional relation of $g$ type). The right side of the plot shows the sorted magnetic field strengths and excesses (full line). The fit is shown by the dotted line.

**Figure 6**: Scatter density plot between the magnetic field strength vs. brightness excess for the brightest pixels of the FOV. The second plot shows the sorted pairs of magnetic field strength and brightness excess (full line). The corresponding fit is given by the dotted line (functional relation of $h$ type).
4. Results and Discussion

**Quasi Magnetogram:**
After obtaining the calibration coefficients for the fitting models we can invert the excess image to obtain our quasi total field strength magnetogram (total means the norm of the magnetic field vector). The result of this inversion is displayed in Figure 7. It can be seen that the general correspondence between the observed and reconstructed magnetogram is quite high. The difference of the total magnetic flux is smaller than 1.2%. The largest deviations between the original magnetogram and our quasi total field strength magnetogram can be seen in the penumbra. Therefore we have to test and improve our method in the penumbral region and in general for sunspots.

**Future Work:**
A verification and also improvement could be achieved by using MHD simulated and synthesized data instead of observational data. The advantages are clearly the perfect alignment of the data and the well known magnetic field strength for the simulation. Therefore this investigation can be made with much more precision for such data. Another issue would be a more sophisticated investigation of the errors of our method and improvement of the calibration factors. The change of the calibration models can also introduce some discontinuity jumps in our results. Finally we have to extend the investigation and the comparison of the data to other data sets to investigate if the obtained calibration factors hold for other data sets too.

5. Conclusion

In this paper we shortly outlined a new approach to obtain quasi total magnetic field strength magnetograms. We described the motivation and background for our endeavour. There are clear advantages which can be gained by our approach like: easier access to the needed data, more data available and of course higher temporal and spatial resolutions combined with a larger FOV. We think that our approach is promising but there is still much work to be done.
Figure 7: Quasi total magnetic field strength magnetogram obtained with our approach is shown (top). Below one can see the corresponding 'real' magnetogram which was obtained by an inversion code (courtesy of Bruce Lites).
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References