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Application of artificial neural networks to solar infrared Stokes spectra(*)

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Summary. — In this paper we have for the first time applied the new Stokes inversion approach of using artificial neural networks to measured Stokes data of a solar pore. We have demonstrated that this method is capable to produce the same results as other conventional methods, but at a much faster speed.

PACS `95.75.Pq` – Mathematical procedures and computer techniques.
PACS `95.75.Hi` – Polarimetry.
PACS `95.75.Wx` – Time series analysis, time variability.
PACS `96.60.Qc` – Sunspots, faculae, plages.
PACS `95.85.Jq` – Near infrared (0.75–3 μm).
PACS `01.30.Cc` – Conference proceedings.

1. – Introduction

In September 1999 a joint observing campaign was carried out (JOP097, see `http://sohowww.nascom.nasa.gov/soc/JOPs/jop097.txt`). The general aim of this campaign was to study the oscillatory behaviour of active regions with a variety of instruments and observing modes. In this contribution we apply artificial neural networks to invert measured Stokes spectra and we compare this new method with other, more traditional ways to retrieve physical quantities from the Stokes spectra.

2. – Observations

Near infrared observations were taken with the Tenerife Infrared Polarimeter (TIP [1]) at the VTT. The complete Stokes vector was measured for about 90 min with the Fe I lines at 15648 Å and 15652 Å at a cadence of 15.5 s. We observed AR 8693 (located

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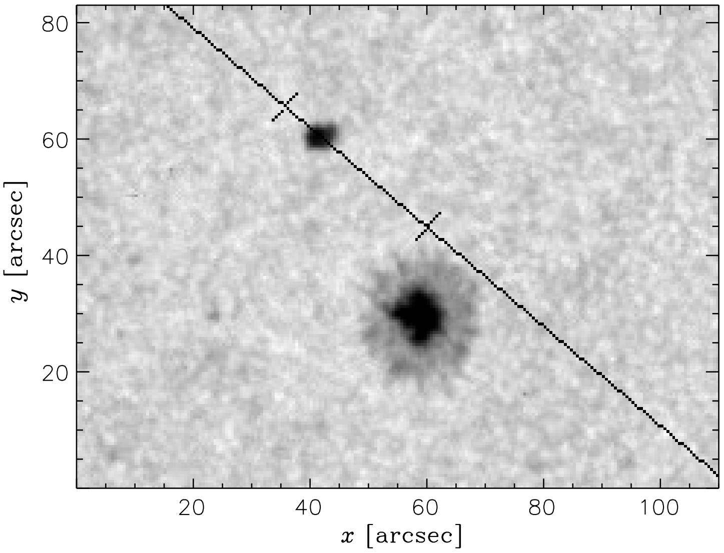

Fig. 1. – Photospheric image of AR 8693 taken with TRACE. The diagonal line indicates the position of the VTT slit.

at 13 N, 20 E) which also included a large pore, which we selected for this analysis. Figure 1 shows a photospheric white-light image of the active region taken with TRACE. Two times four rows of spectra in the central part of the pore are averaged and the observed parameters are calculated separately for these two positions. Details of the data reduction and analysis as well as results of this oscillation study are published in [2].

In this paper we will concentrate on two particular parameters, namely velocity v and magnetic-field strength B which we derive with three different methods from the same data set. Method 1 (described in [2]) calculates v and B directly from the observed Stokes parameters: the magnetic-field strength is obtained from a comparison of the observed Stokes V profiles with the calculated ones. This method is sensitive to the splitting of the V profile. Velocities are derived from the mean values of the positions of the two Stokes V extrema.

In method 2 we used the SIR inversion code developed by [3] to get v and B from Stokes I and V profiles of both lines with a high weight on Stokes V. SIR yields a stratification for temperature, electron pressure, magnetic-field strength, inclination and azimuth, Doppler velocity and microturbulence depending on an initial model atmosphere and on demands. From the results we extracted magnetic-field strength and Doppler velocity at $\log\ \tau = 0$ for this presentation.

Finally, we applied artificial neural networks for a direct inversion of the desired quantities from the observed Stokes spectra.

3. – The neural-network approach

We have used a Multi-Layer-Perceptron (MLP) to find a direct approximation of the non-linear inverse relation between the Stokes profiles and the atmospheric parameters [4]. A detailed description of this method is given in [5]. Multi-Layer-Perceptrons—

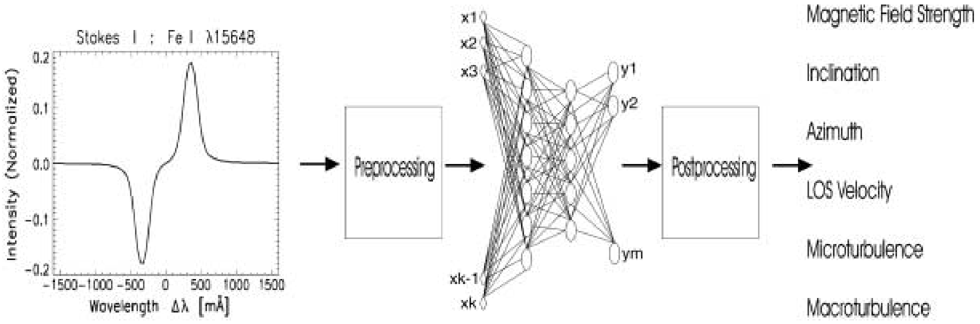

Fig. 2. – Schematic illustration of the inversion process. The discrete Stokes V profiles (left) are preprocessed by a linear transformation and then presented to the MLP which represents a non-linear approximation for the inverse problem. In a final postprocess the calculated values are rescaled.

as one particular type of artificial neural networks—are very general statistical tools for approximating multivariate non-linear functions. Since we have a good knowledge about the forward process of the polarized radiative transfer—at least under LTE conditions—we are able to train an MLP on a set of Stokes profiles and the underlying atmospheric parameters.

The training process consists of an optimization of the adaptive parameters of the MLP. In this optimization process the network tries to approximate the functional mapping which is represented by the input-output relation of the training set. Once a good approximation to the inverse problem is found, the MLP is able to retrieve reliable estimates of the physical parameters from the observed Stokes spectra with exceptional speed. Figure 2 shows the inversion process in a schematic way.

4. – Modelling the solar pore and training of the neural network

For the inversion of Stokes profiles of the observed Fe I line at 15648.5 Å the MLP is trained on the basis of a modified semi-empirical pore atmosphere from [6]. We have calculated a training set of 5000 synthetic Stokes profiles and another 3000 profiles as a validation set with the DIAMAG synthesis code (*i.e.* forward model) from [7] which implements a numerical integration of the radiative transfer equation by means of the diagonal lambda iteration method [8]. In order to achieve an appropriate representation of the inverse mapping (Stokes profiles to atmospheric parameters), we take into account the variation of six atmospheric parameters. The parameters for the calculation of the synthetic profiles are determined by a random generator. The intervals for the atmospheric parameters covering a range of 1000–3000 G for the magnetic-field strength, 0–70° for the inclination, 0–120° for the azimuth, -1000– $+1000$ m s^{-1} for the line of sight velocity, 0–1500 m s^{-1} for the microturbulence and 0–1000 m s^{-1} for the macroturbulence.

Since we are mainly interested in the retrieval of v and B, we decided to make only use of the Stokes V profile as an input to the MLP. The discrete Stokes V profiles are calculated in a wavelength range of +40 pm to −40 pm around the laboratory line center with a sample of 1 pm.

The training data set is then used to train different network architectures (with dif-

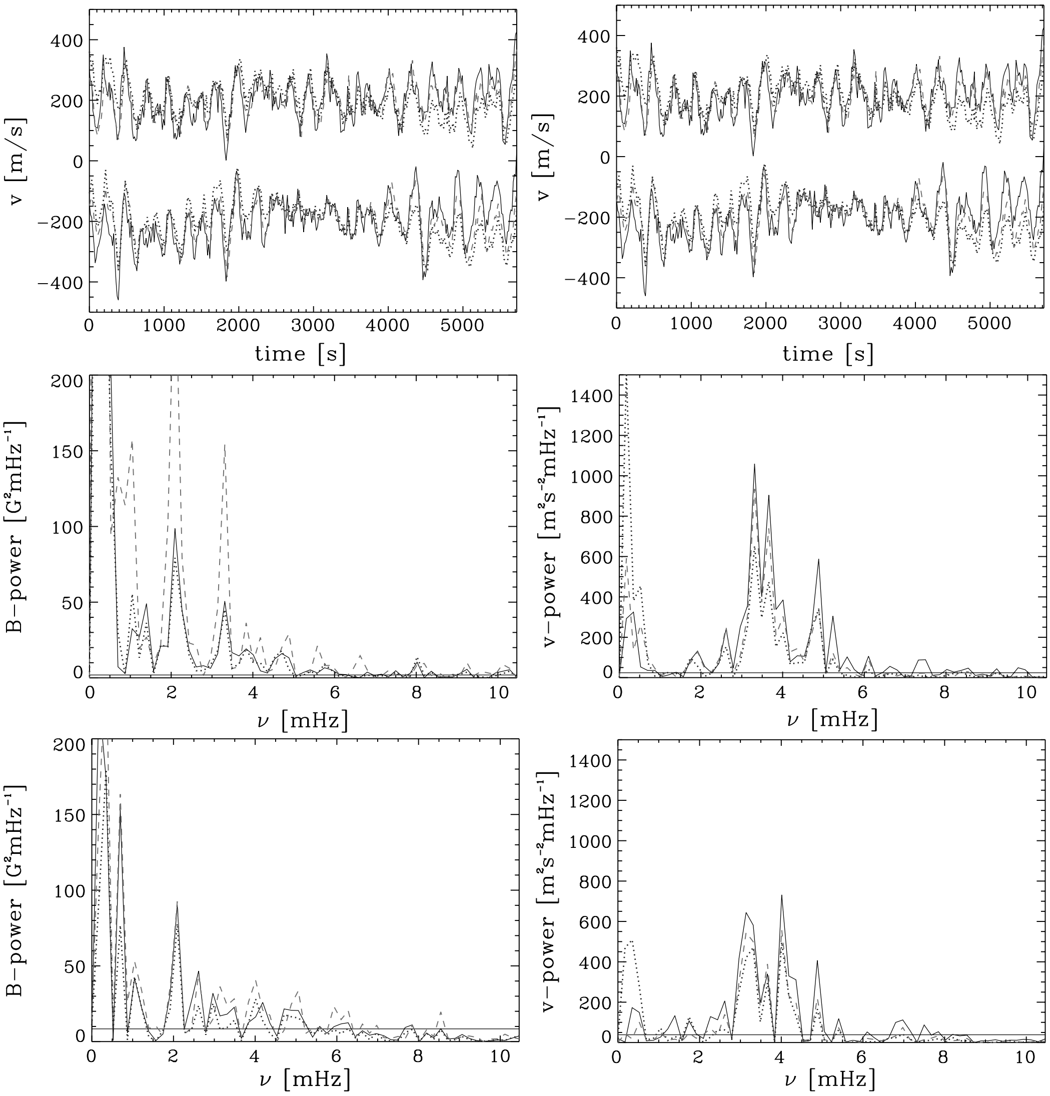

Fig. 3. – Time sequence of magnetic field B (left) and velocities v (right) for two positions in the pore (top row), below are the respective power spectra. The solid line results from method 1 (Stokes V splitting), the dashed line from method two (inversion with SIR) and the dotted line from the MLP. The horizontal line represents the 98% significance level according to [9]. The sequences of the two locations in the pore have a constant offset for clarity in the top panel and are shown seperately in the middle and bottom panel.

ferent numbers of hidden layers and elements in those layers). After extensive statistical tests on an independent test set we determined the network which performed best under these tests for the following analysis of the oscillating behaviour of the observed pore.

5. – Comparison of v and B

Figure 3 (top, left) shows the time sequence of the magnetic-field strength B for the 2 locations of the pore and the same for the velocity v (top, right). The sequences of the two locations in the pore have a constant offset for clarity in these plots. In the middle and bottom panels the respective power spectra of v and B for each position in the pore are shown. All three methods give very similar results, except SIR producing higher power peaks in one case. Slight differences between the three methods might be explained by the fact that we had to clip the short wavelength wing of the 15648 Å line to be able to observe the other line simultaneously.

Finally, we want to compare the computing times of the three methods. Each time sequence consists of 370 Stokes profiles from which v and B are determined. With SIR (method 2) it took about 2–3 days on a HP workstation. Calculation from Stokes V splitting (method 1) took about 2 h, and the MLP (method 3) took about 2 s for the inversion.

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