SOLAR ACTIVITY MONITORING – A NEW APPROACH USING COMBINED DATASETS, PATTERN RECOGNITION AND NEURAL NETWORKS

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Abstract. In this paper we give an overview of the activities of the recently established solar activity monitoring and flare alerting working group at the University of Graz and its planned activities. Solar flares can trigger events at the earth environment that can be dangerous to technological systems as well as to human life. Therefore, it is an important target in solar physics to predict such events, providing an essential contribution to space weather forecasts.

Key words: solar activity monitoring, datasets, pattern recognition

1. Introduction

Due to the direct influence of the high energetic particles on the terrestrial magnetosphere and atmosphere, flares are a main source for variations of the space weather. According to the United States Space Weather Program space weather refers to “conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and

can endanger human life and health”.
(see http://www.geo.nsf.gov/atm/nswp/nswp.htm)

Today we have similar capabilities of space weather forecasts that were at disposal for meteorologists 70 years ago. To be more precise in the forecast of possible solar events affecting the space weather, the combination of more detailed observations in different wavelengths as well as the application of new models is necessary. At the Kanzelhöhe Solar Observatory we have at our disposal a set of high quality observations which can be obtained simultaneously with high time cadence. These data set in combination with elaborated models of automatic image analysis and forecasting shall be the basic components of the planned solar flare alerting system.

2. Flares and Space Weather

A solar flare is the sudden release of stored magnetic energy in active regions and one of the most energetic phenomena on the sun. Flares release their energy (up to some $10^{27}$ Joule!) in the solar atmosphere within a few minutes. This comprises an increase of radiation from radio to gamma rays, the acceleration of elementary particles to relativistic energies and possibly the launch of shock waves.

It is reasonably certain that the flare energy is previously stored by the magnetic field above an active region and that some magnetic process is involved in the sudden release of this energy. Most attention has been focused on the concept of reconnection of magnetic field lines.

Since the flare energy is stored in the solar magnetic field, it is essential to examine which type of magnetic field configuration produces strong flare activity and how it is formed. Many flares take place over complex active regions (between sunspots) near the neutral line. This means a shearing of the magnetic field where energy can be stored, and after the change in a more favorable magnetic configuration the energy is released. Many observations reveal that flare activity occurs mainly along the strong magnetic shear region (e.g., Hargard et al., 1984; Sivaraman et al., 1992; Ambastha et al., 1993).

Together with coronal mass ejections (CMEs), flares belong to those
solar events which are strongest affecting the space weather at the earth environment (for a review see Crosby, 1999). Major flares influence the earth’s upper atmosphere and can even lead to large geomagnetic induced currents (GIC) on the ground as happened in Quebec 1989. A flare blocked out the Quebec power system. Transformers failed, hundreds of relays and protective systems malfunctioned and voltage and power fluctuations were widespread in North America. Power networks now extend over such distances that extreme differences in ground potential arise, inducing strong currents (Kappenman and Albertson, 1990).

In addition to that, the enhanced X-ray emission of flares increases the ionization in the ionospheric D-region and disturbs the propagation of radio waves, influences global positioning systems (GPS) or radar stations due to time delays in the signals. Furthermore, flares can cause aurorae, damage satellites or endanger astronauts. In the polar region of the earth the hazard is even bigger because the magnetosphere does not shield against solar cosmic rays. This causes a danger for passengers on Concorde flights due to the high radiation doses.

3. Observations

Currently the following observing facilities are available at the Kanzelhöhe Solar Observatory:

1. a white-light imaging system for taking images of the photosphere on high resolution black and white film at low time cadence;
2. the Hα system which provides ground-based support to SOHO;
3. the Na-D magneto-optical filter (Cacciani et al., 1999), which is a compact imaging doppler-magnetograph;
4. the photometric solar telescope (Steinegger and Hanslmeier, 1999).

The characteristics of these instruments are summarized in Messerotti et al. (1999).

All the instruments except the white-light imaging system produce digital images. This variety of observing facilities gives us the opportunity to obtain photometric full-disk images of the photosphere and chromosphere.

simultaneously with full-disk magnetograms and dopplergrams. Moreover, we want to stress the fact that it is a considerable advantage to obtain all these data at one single site and under the same observing conditions.

The photometric solar telescope (PST) will be mounted before summer 2000 at the Kanzelhöhe Observatory. It was already tested during the 1999 total solar eclipse at the Lustbühel Observatory, Graz, and proved its functionality. The main aim of the PST is to study the Sun at different wavelengths. Currently the following three spectral lines are covered by the PST (in future also observations in the G-band will be be included):

- Ca K 393.3 nm (chromosphere),
- blue 409.4 nm (photosphere),
- red 607.2 nm (photosphere).

With these instruments, we have the following set of observations at our disposal, which can be obtained simultaneously and with high time cadence at the Kanzelhöhe Observatory:

1. full-disk white light images with high precision of position determination,
2. full-disk Hα images,
3. full-disk magnetograms,
4. full-disk doppler velocity fields,
5. full-disk filtergrams at 393.3 nm, 409.4 nm, and 607.2 nm.

4. Image Analysis

A key point for a reliable flare alerting and forecasting system is the automatic detection of flare activity and the extraction of features from the images which can act as indicators for future flare activity. In this course several fundamental steps of image analysis have to be performed (e.g., Pratt, 1991; Gonzalez and Woods, 1992; Jähne, 1997).

In the first, the preprocessing phase, a possible degradation of the image has to be restored. In the case of the present project this means basically
to remove effects caused by non-uniform illumination, and also to remove
the center-to-limb variation from the solar full-disk images. Moreover, it
can be useful to apply methods of image enhancement to receive images
which are better suitable than the original ones for the further analysis.

The next, very important step, since it strongly determines the outcome
of the following image analysis, is the image segmentation. Segmentation
describes the process of subdividing the image into its constituent parts, i.e.,
the interesting parts are separated from the rest of the image. Segmentation
algorithms for monochrome images are based on one of two fundamental
properties of gray level values: discontinuity or similarity. In the category
of discontinuity, the partitioning of the image is based on abrupt changes
in the gray level. This method favors to detect isolated parts, lines and
edges in an image. Image segmentation based on the property of similarity
uses methods of thresholding, region growing, splitting and merging. Image
segmentation algorithms are applicable to both static as well as dynamic
images (i.e., time series of images). The main aim of this phase is to detect
and separate individual active regions.

After an image is segmented into its constituent parts, the data have to
be represented and described. Choosing a representation means to trans-
form the raw data output of the segmentation process into a form which is
suitable for further computer processing. Basically, there exist two choices
to represent a region: representation in terms of its external characteristics
(boundary) or its internal characteristics (the pixels comprising the
region). Image description means to select characteristic features from the
extracted objects that result in some quantitative information of interest
(e.g., areas, perimeters, diameters, curvatures, intensities, etc.). The de-
scriptors should be as insensitive as possible to changes in size, translation,
and rotation. The output of this step of analysis is no longer an image but
compact formalized information.

During the process of recognition a label is assigned to an object based
on the information provided by its descriptors, classifying the object. Re-
cognition can be done by decision-theoretic or structural methods. In
decision-theoretic recognition the patterns are represented in vector form,
in structural recognition in symbolic form. The principal approaches to
decision-theoretic recognition are minimum classifiers, correlators, Bayes classifiers, and neural networks. The latter, i.e. neural networks, will be used in the frame of this project (see the following section). In the final step of image interpretation meaning is assigned to an ensemble of recognized image elements. This can simply be a binary information of interest, as e.g., “flare activity” or “no flare activity”. A fundamental concept underlying image interpretation is the previous knowledge on the considered problem domain. This means, for instance, the knowledge on preferred magnetic field configurations, filament shapes, sunspot types, etc., associated with the occurrence of solar flares.

5. Artificial Neural Networks and Pattern Recognition

A pattern recognition system based on Artificial Neural Networks (ANNs) will be developed with the aim of automatically identifying and relating specific structures and phenomena of solar activity (flares, filaments, sunspots, faculae, etc.) On the one hand the temporal evolution of the solar activity parameters to be derived for these structures (e.g., areas, intensities, shapes, magnetic field strengths) will be analyzed in order to identify the most suitable descriptors for solar flares, on the other hand indices shall be derived which can act as precursors for flare activity. The neural network will be created with the Brain-Maker software (from California Scientific Software).

A neural network is a information processing system, consisting of simple units/processors, the so-called neurons, which are highly interconnected (e.g., Fausett, 1994; Haykin, 1994; Rojas, 1996). The development of artificial neural networks is based on the natural neural networks in the brain of living beings, in which the information processing consists of quite simple neurons, compared to the complexity of the overall system.

An remarkable feature of ANNs is their ability to learn, i.e. the capability to solve a problem is not explicitly given by equations but the ANN acquires knowledge during a training phase. Neural networks learn by examples, e.g., by feeding the ANN with data during the training phase. A successful training enables the network to capture the essential relationships
among inputs and outputs, and the trained net shows remarkable general-
ization capabilities, being able to correctly relate inputs and outputs which
were not included in the training set. The ability of generalization, based
on implicitly existing knowledge makes ANNs to an alternative tool for
forecasting.

A neural network basically consists of many simple processor (units),
each possibly having a small amount of local memory. The units are con-
ected by communication channels (connections), which usually carry nu-
meric (versus symbolic) data, encoded by any of various means. The units
operate only on their local data and on the inputs they receive via the
connections. This simulated neuron is viewed as a node connected to other
nodes via the connections. The restriction to local operations is often re-
laxed during the training phase.

Each node combines the separate influences received on its input links
into an overall influence using an activation function. One simple activation
function simply passes the sum of the input values through a threshold
function to determine the nodes output. The output of each node is either
0 or 1, depending on whether the sum of the inputs is below or above a
certain threshold value.

Various types of neural networks exist. The most common used is
the feed-forward-net, a layer oriented network consisting of input, output
and hidden layers. In this type of network, the net itself learns from an
algorithm (mostly using the back-propagation-algorithm).

6. Summary and Conlusion

We have seen that using combined methods such as pattern recognition,
neural networks together with a uniform dataset, it will be possible to
contribute to space weather forecasting. All these data will be at disposal
at a single observatory. The ANN software was already tested.
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References

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PRAČENJE SUNČEVE AKTIVNOSTI – NOVI PRISTUP UZ UPORABU SPOJENIH SKUPOVA PODATAKA, RASPOZNAVANJA UZORAKA I NEURALNIH MREŽA

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