FUZZY SYSTEM BASED ANALYSIS OF DEFORMATION MONITORING DATA AT EIBLSCHROFEN ROCKFALL AREA

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Abstract: In 1999, a rockfall occurred at the Eiblschrofen, near Schwaz (Tyrol, Austria). Immediately after this event, a monitoring system consisting of GPS, geodetic and geotechnical sensors was installed in this area. The data of this different group of sensors are now for the first time analysed together within a hybrid assessment tool. This tool shall imitate the knowledge and decision making process of a human expert looking at different data. Therefore a fuzzy-based approach is chosen to implement the assessment tool. The paper describes the situation at the Eiblschrofen area, the monitoring system as well as the first implementation steps for the fuzzy-based assessment tool.

1. Introduction

Eiblschrofen is one of the most well-known rockfall areas in Austria. It is located near the city of Schwaz, Tyrol (see fig.1).

Schwaz has a very long tradition in mining. Since the middle ages, silver was mined at the Eiblschrofen and the surrounding area. In the 15th and 16th century, Schwaz was the second largest town in Austria (30000 inhabitants) and the center of silver mining in Europe. This period ended when “cheap” silver was brought to Europe from the Americas. Since the 1950ies dolomite has been mined at Eiblschrofen area.

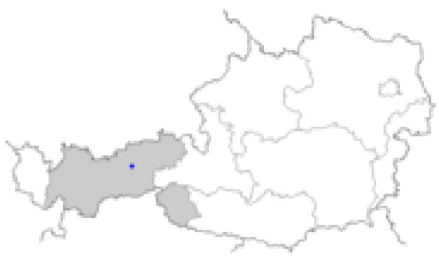

Figure 1: Location of the Eiblschrofen, Schwaz, Tyrol, [1]

2. Geology

The geological situation at the Eiblschrofen area is rather complex. Three materials form this area (see fig. 2):

- Dolomite forms the basic block of the Eiblschrofen. Here, the mining took place, so the dolomite has many excavations below ground.
- The bedding of the dolomite at the toe of the Eiblschrofen is formed by sandstone.
- Schist lies on top of the dolomite. The loading of the schist causes a compression which results in tilting and toppling of the dolomite.

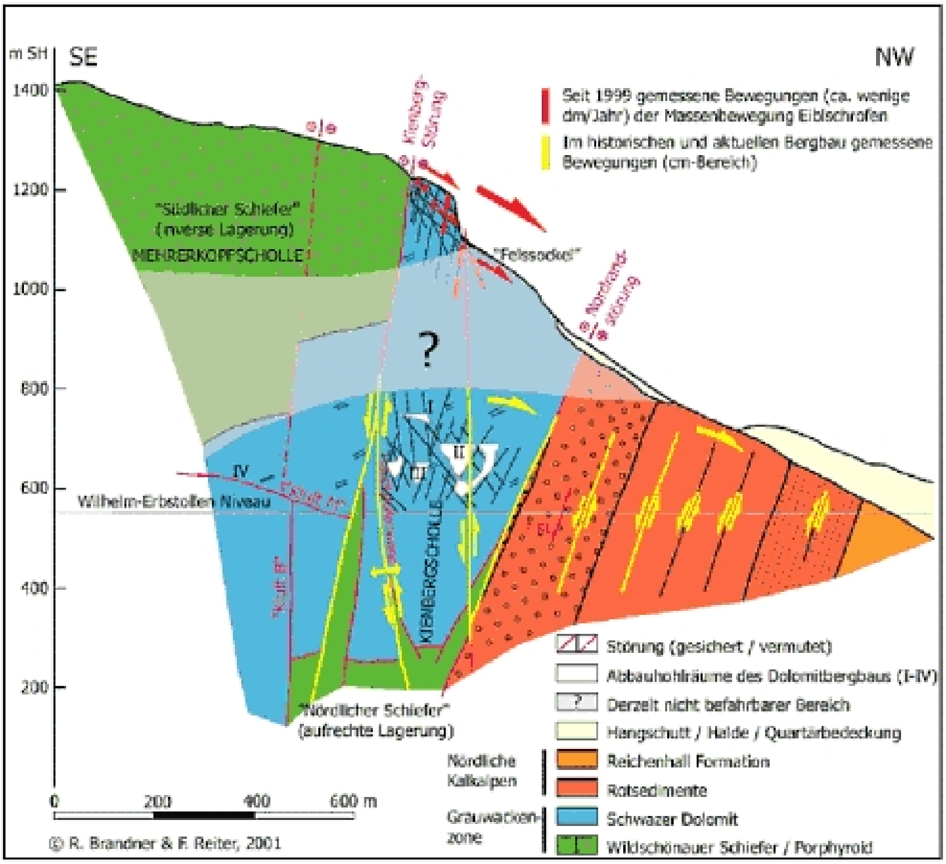

Figure 2: Geological situation at the Eiblschrofen [2]. Dolomite is shown in blue, sandstone in orange and schist in green.

3. The rockfall and the monitoring system

On July 10th, 1999 a rockfall (thousands of m³ material) at the Eiblschrofen endangered the inhabitants of Schwaz. About 50 buildings and 16 companies had to be evacuated in the risk area (see fig. 3). As a first measure some protection dams were built. To protect the people during the construction work and to observe the situation at the top of the rockfall, a monitoring system had to be installed immediately in the area.

Figure 3: The Eiblschrofen and the evacuation area of Schwaz [3].

3.1. Terrestrial measurements

A geodetic network consisting of approx. 20 points was established immediately after the rockfall. In the first weeks after the rockfall, measurements were done every day, but after the stabilization phase the interval between the measurements was increased by and by to 2 times a week. Today the geodetic network is observed once per year (see fig. 4 in black).

3.2. GPS Measurements

For a efficient monitoring of the rockfall area, a permanent monitoring system proved necessary. So, in 2003 three stations were equipped with L1-frequency GPS receivers (see fig. 4, in green). The reference station (dual frequency receiver) is approximately 1.5 km away. For the monitoring of the movement of this reference station, it was included into the tyrolian reference network TIREF.

The measurements for the reference epoch were done in October and November 2003; since November 2003 the data of the four stations have been transmitted to the office of the responsible surveyor by WLAN. As an analysis software, Leica Spyder was chosen.

After the testing phase, hourly data are sent to the office, which are averaged to two positions per day.

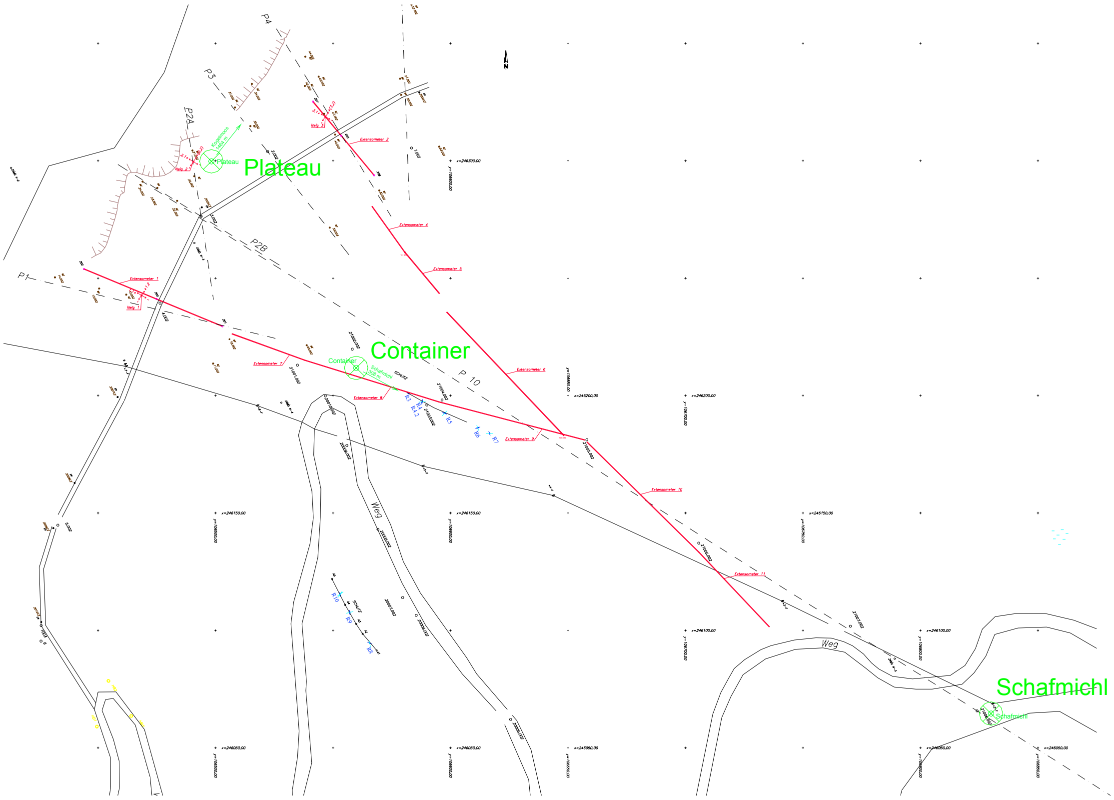

Fig. 4: Overview of the installed measurement systems. The tear-off zone is at the upper left corner of the figure. GPS measuring points in green, tacheometric profiles shown in dashed black lines, extensometers and tiltmeters in red, crackmeters in blue, [4].

3.3. Geotechnical equipment

Shortly after the rockfall, a continuously monitoring system consisting of several geotechnical sensors was installed at the top of the Eiblschrofen. The aim was firstly to protect the workers building the dams at the toe of the rockfall area and secondly to monitor the longterm behaviour of the Eiblschrofen.

The following sensors were installed since 1999 ([4], [5], [6]):

- Extensometers: Up to 11 wire extensometers (Hottinger) were installed since 1999; at the moment 5 of them are active.
- Crackmeters: a maximum of 12 crackmeters (Hottinger) were installed; 7 of them are active at the moment.
- Tiltmeters: 3 out of 7 tiltmeters (dual-axis, Althen) are still active.

Fig. 5: GPS point ‘Plateau’ with tiltmeter and WLAN antenna.

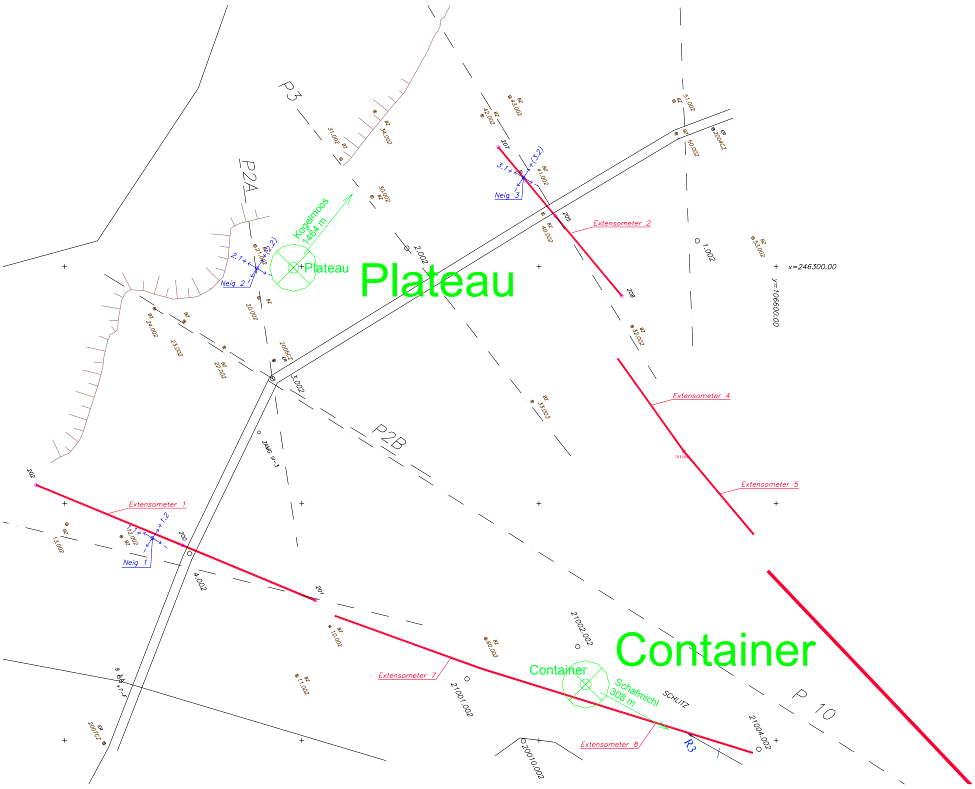

Figure 6: Detail of the installed monitoring system. 2 GPS points in green, extensometers in red, tacheometric profiles in black dashed, tiltmeters and crackmeters in blue [4].

3.4. Assessment of the existing monitoring system

The existing monitoring system consists of three different parts (see 3.1 – 3.3) which cannot directly be combined to get a hybrid result. The data can be distinguished by several properties:

- Different data rates: The coordinates calculated from the geodetic terrestrial measurements are available once per year. GPS coordinates represent hourly mean values of the permanent monitoring. The continuously monitoring data of the geotechnical sensors is archived with three-hour-values. In case of anomalies in the data the data saving rate can be decreased, e.g. to 10-minutes-intervals.
- Different data types: GPS and terrestrial measurments give (absolute) coordinates of the observed points as a result. The geotechnical sensors can only give relative information like changes in length or tilt.
- Different reference frames: The reference frame for the GPS stations is the TIREF, the tyrolean representation of the ITRF. The geodetic terrrestrial measurments are calculated within the Austrian reference frame, which is a Gauss-mapping of the Austrian Bessel-ellipsoid. The measurements of the geotechnical sensors can only be described in this reference frame, if there have been considered the local ties, i.e. the connection between the sensors and at least one geodetic point in the vicinity of the sensors.
- Different accuracy: the geotechnical sensors give data with the greatest accuracy, usually in the range of approximately 0.1 mm or better. The accuracy of GPS and terrestrial measured coordinates is usually about 1 cm.
- Different software: for every group (terrestrial measurements, GPS observations, geotechnical sensors) a different software package is used for data collection, processing and archiving.
- Different authorities: in the beginning, different companies were responsible for the measurements and sensors. Now this will be unified so that one local surveying office is the contact point for the monitoring of the Eiblschrofen.

4. Fuzzy based data analysis system

4.1. Basics of fuzzy-based decision making

The task is to develop an analysis and assessment tool for the varous monitoring data gained at the Eiblschrofen. The Matlab fuzzy toolbox is used due to its broad mathematical functionalities.

The individual software for each group of sensors is still used for the data transfer and first processing of the data in the office. Then the data is exported to the fuzzy analysis tool. The aim is to combine the corresponding data within the analysis tool to imitate the human expert who does this combination in his mind while looking at the different sensor diagrams.

Using a rule-based decision making system like the Matlab fuzzy toolbox, the rough procedure is as follows:

- Input and output parameters

In a first step the desired output parameter(s) and the therefore necessary input parameters have to be identified (in most cases by empirical methods).

- Modelling of parameters

The parameters have to be modelled by at least two terms. In most cases 3 to 7 terms are used (e.g. fig. 7); the more terms the finer will be the decision making process, but also the more rules are needed to describe the system.

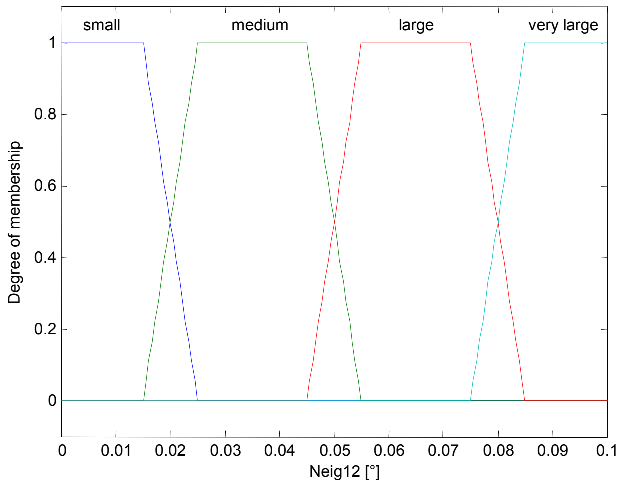

Figure 7: Example of the modelling of the parameter 'tilt of tiltmeter 1, Axis 1.2' with 4 terms (small, medium, large, very large).

- Rules

The if-then-rules connecting input and output have to be collected (e.g. by means of interviews with experts). The rule-base represents therefore the expert knowledge.

- Weighting

The rules can get different weigths according to their influence on the decision (i.e. output).

- Decision making

For the calculation of a new output (=decision), the actual/current input parameters are fed into the system. Each rule is evaluated and gives a contribution to the final output. All these sets are merged ('aggregation'), and a final (distinct) value is calculated out of the aggregated fuzzy set. In most cases, the 'Center of Gravity'-method (CoG) is used (see fig. 8).

For further information on fuzzy set theory and the application in geodesy see e.g. [7],[8],[9].

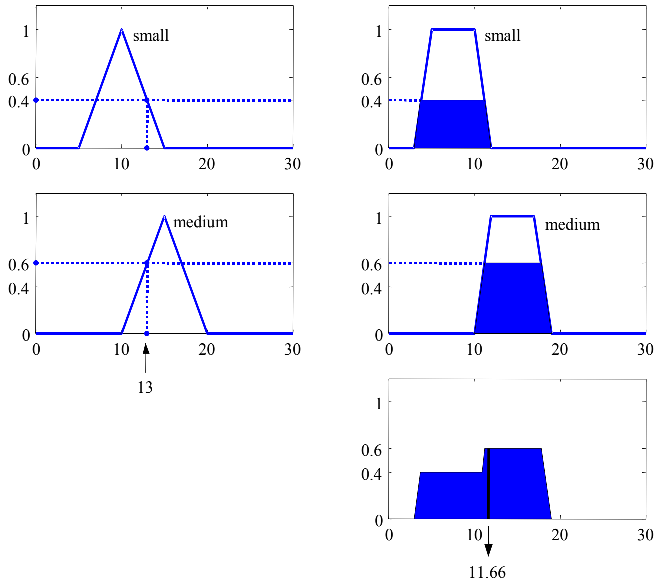

Figure 8: Very simple example showing 2 rules (= first 2 rows); in the left column the input values are given (0.4 and 0.6), in the right column the output set for the current input values are shown. The lower right figure shows the fuzzy output set after aggregation (in blue) and the defuzzified distinct output value (11.66, CoG-method).

4.2. First results of the fuzzy-based analysis of monitoring data

Out of the longterm monitoring data at the Eiblschrofen, a time interval of three months was chosen for the design of the system and the first analysis. As a first step, the relations between the different sensor groups have to be identified, taking into consideration the geological situation. This means that if one sensor shows an increase of movement, some other sensors must show the same tendency so that the situation is assessed as potentially dangerous. If only one sensor is showing a movement and the other related instruments are stable, then another reason must be found, e.g. measurement errors or an animal touching the instruments. For the synchronization of the data a time interval of 3 hours was chosen.

During the data import blunders like bad GPS positions due to bad satellite constellations have to be removed from the data. Then the relationships between the various sensors are investigated. One of these relations exists between the GPS point ‘Plateau’ and the tiltmeter number 2 just beside the GPS station:

If the x-coordinate of GPS point ‘Plateau’ is increasing and the y-coordinate is decreasing and tiltmeter 2 shows a tilt in the same direction (increase of measurement values of axis 2.1) then a toppling of the front part of the Eiblschrofen could be the reason (see fig. 9).

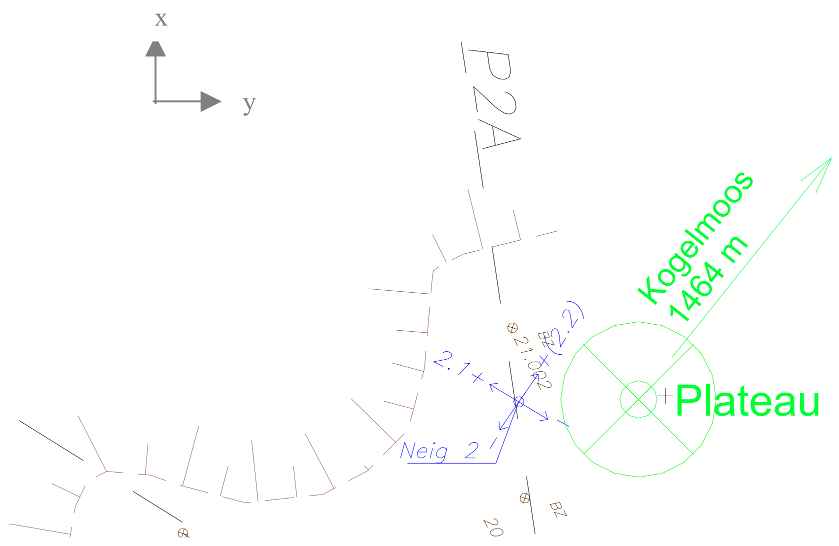

Figure 9: Example of the relation between the GPS station 'Plateau' (in green) and the tiltmeter number 2 (in blue) [4].

With new input values given by the monitoring system, the fuzzy-based tool checks the suitable rules available in the implemented rule base. As a result, the potential of danger is assessed for the Eiblschrofen area with a rating between 0 and 1 (see fig. 10 for a first example). Note: due to the actual small movement rates at the Eiblschrofen, the measurement values had to be slightly enlarged to get a potentially dangerous situation for fig. 10.

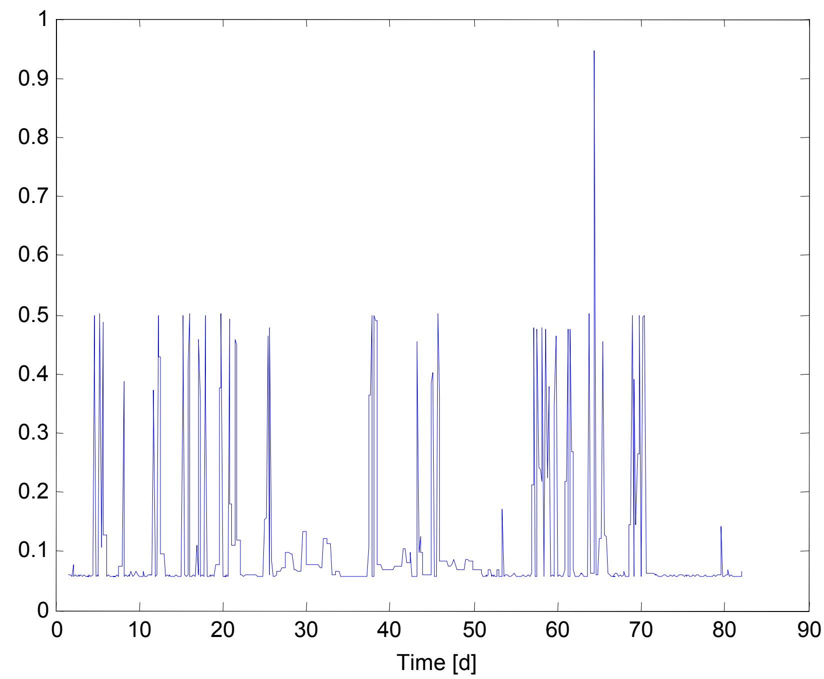

Fig. 10: First results of the post processing calculation of the 'potential of danger' (range: 0 = small to 1 = large) for the investigated data (3 months).

5. Conclusions and outlook

The first steps in design and modelling show a great potential for an ‘intelligent’ fuzzy-based analysis and assessment tool for geodetic monitoring data. The first relations between different sensors have been found and implemented in the fuzzy system until now, but further investigations are necessary to build an efficient assessment tool. After the implementation phase, the analysis tool will be tested with data from other time intervals collected by the Eiblschrofen monitoring system. The final assessment tool shall of course work in near real-time.

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