Fuzzy Based Analysis and Assessment of Monitoring Data for the Eiblschrofen Rockfall Area

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SUMMARY

In 1999, a large rockfall occurred at the Eiblschrofen near Schwaz (Tyrol, Austria). Due to the imminent threat for the inhabitants, some geotechnical sensors were immediately installed at the top of the Eiblschrofen. Additionally, geodetic terrestrial and GPS measurements were started in that area.

After some years of operation, a renewal of the monitoring concept proves necessary now. This is supported by a diploma thesis, which is carried out as a cooperation between the Technical University of Munich, the responsible surveyors operating on site and the Vienna University of Technology.

The main focus of this thesis is the combined analyis of the various types of monitoring data within a fuzzy system based assessment routine. Details of the assessment method and the conclusions drawn within the data analysis are given here.

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1. INTRODUCTION

The Eiblschrofen rockfall area is located near the city of Schwaz, Tyrol, Austria. In 1999, a rockfall occurred endangering about 50 buildings and 300 persons living or working in that area.

Fig. 1: Location of Schwaz and the Eiblschrofen within Austria (Wikipedia 2006).

1.1 Geology

The area around Schwaz and the Eiblschrofen consists of three main materials:

- dolomite
- schist
- sandstone.

Two of them, dolomite and schist, are important for the understanding of the rockfall event. The main part of the Eiblschrofen is formed by dolomite, which was also mined there in the 20th century. The schist is lying on top of the dolomite, starting behind the tear off zone, where the rockfall occurred. The schist is compressing the dolomite towards the valley and the city (Brandner, Reiter 2001), so this is one probable cause for the movement in this area which resulted in the rockfall of 1999.

1.2 Rockfall

On July, 10th, 1999 an unexpected rockfall occurred at the Eiblschrofen. Several 1000 m³ of material were falling towards the valley, endangering the upper part of the city of Schwaz. About 50 buildings and 16 companies were evacuated, and about 300 inhabitants had to leave their homes immediately.

As a long-term counter measure, the construction of several protection dams was started. The last evacuated persons could go back to their homes by november, when the work was completed.

2. MONITORING SYSTEM

Immediately after the rockfall, geodetic and geotechnical monitoring started at the Eiblschrofen area for several reasons:

- monitoring of the actual situation
- to find out the long-term trend of the movement
- to guarantee the safety of the workers at the protection dams.

The monitoring system at the Eiblschrofen consists of several parts, which were installed at different times. The most important measurement systems for this study are described in the following (Gillarduzzi 1999; Kandler, Obex 2004; ARGE Monitoring Eibschrofen 2005).

2.1 GPS Measurements

Immediately after the rockfall, several epochs of static GPS measurements were observed in that area. After some time, it was decided to build up a permanent GPS monitoring system. It consists of three GPS receivers at the Eiblschrofen (see fig. 2) and one reference station about 1.5 km away from the unstable zone. The permanent measurements are transmitted to a local surveying office, and 12-hour mean values for the positions of the monitored points are calculated and archived.

2.2 Geotechnical Sensors

Mainly, there are three groups of geotechnical sensors at the Eiblschrofen plateau (see fig. 2 for a graphical overview). The first sensors (extensometers and crackmeters) were installed in summer 1999. Of course, some sensors have been upgraded or replaced since then, and new sensors like e.g. tiltmeters were added to the monitoring scheme. The current configuration consists of the following devices:

- extensometers: up to 11 invar wire extensometers have been measuring changes of length at the tear off zone and the area behind. At the moment, 5 of them are active.
- crackmeters: a maximum of 12 crackmeters have been installed at places where cracks were visible. 7 of them are still active.
- tiltmeters: 7 dual axes tiltmeters were installed, three of them along the tear off zone are still active.

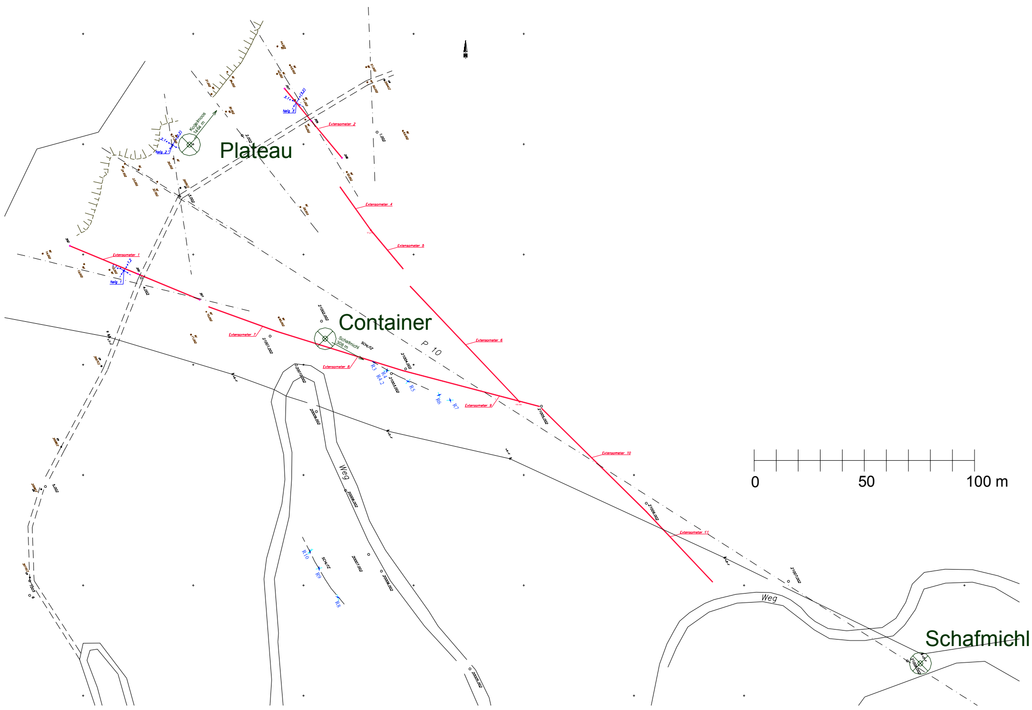

Fig. 2: overview of the installed monitoring systems. GPS receivers in dark green, extensometers and tiltmeters in red, crackmeters in blue. The tear off zone of the 1999 rockfall event is shown in dark brown at the upper left part, (Gillarduzzi 1999).

The data is collected on a permanent basis, but for archiving 3-hour mean values are calculated.

These sensors give measurements of a very high precision; e.g. the change of length between the two endpoints of the extensometer can be determined with an accuracy of better than 0.1 mm. One disadvantage of these sensors is that they are observing only relative movements; this has to be taken into account within the data analysis.

2.3 Other Measurements

The first measurements done at the Eiblschrofen directly after the rockfall were of course geodetic terrestrial observations with tacheometers. In the first weeks after the rockfall they were conducted every day, but soon the interval between two measurement epochs was increased. Nowadays, these measurements are done once per year, so this data is not included into this study.

3. FUZZY BASED DATA ANALYSIS

The main goal of this study is to combine all monitoring data within one analysis. Up to now, each group of sensors has been evaluated alone; then a human expert had to look at the individual results to build a combined analysis of the current situation.

The idea is to imitate this human expert by assessing the combined data within fuzzy systems. This methodology allows to copy the intuitive human way of thinking for an automated computer-based analysis.

In a first step, the provided data had to be assessed. Blunders occurred mainly in the GPS data because of the great obstructions in the forestal area at the Eiblschrofen. These gross errors were removed from the data series.

For a combination of the different data types it is important to get synchronous data, i.e. data from the different sensors at the same epochs of time. Here, the 12-hour mean values of the GPS data had to be interpolated to fit to the time steps of the 3-hour mean values of the geotechnical sensors.

To imitate the human way of thinking, linguistic descriptions of the parameters and linguistic rules connecting the input and output parameters are used within the fuzzy system. As a software tool, Matlab® has been chosen because of its powerful rule-based fuzzy toolbox. For a deeper insight into fuzzy theory see e.g. (Haberler 2005; Kahlert, Frank 1993).

3.1 Modelling of Input and Output Parameters

In a first step, the input parameters and the output parameter have to be defined and modelled by so-called membership functions. Fig. 3 shows one example, where the change of length of one extensometer is modelled by 7 linguistic terms. The more terms are chosen to describe a parameter, the more sensitive the fuzzy analysis will react. One disadvantage of a large number of terms is the huge number of rules, which are necessary to cover all possible situations. So, for practical applications, a maximum number of about 10 terms per parameter is recommended.

For this study, the following input parameters were used:

- the change of the length of each extensometer (see fig. 3 for an example)
- the change of the tilt of each axis of the tiltmeters
- the x- and y-coordinates of the GPS-points

The output parameter of this fuzzy system is representing a numerical value (within the interval from 0 to 1) for the potential of danger, calculated out of the input data vector of a given time step.

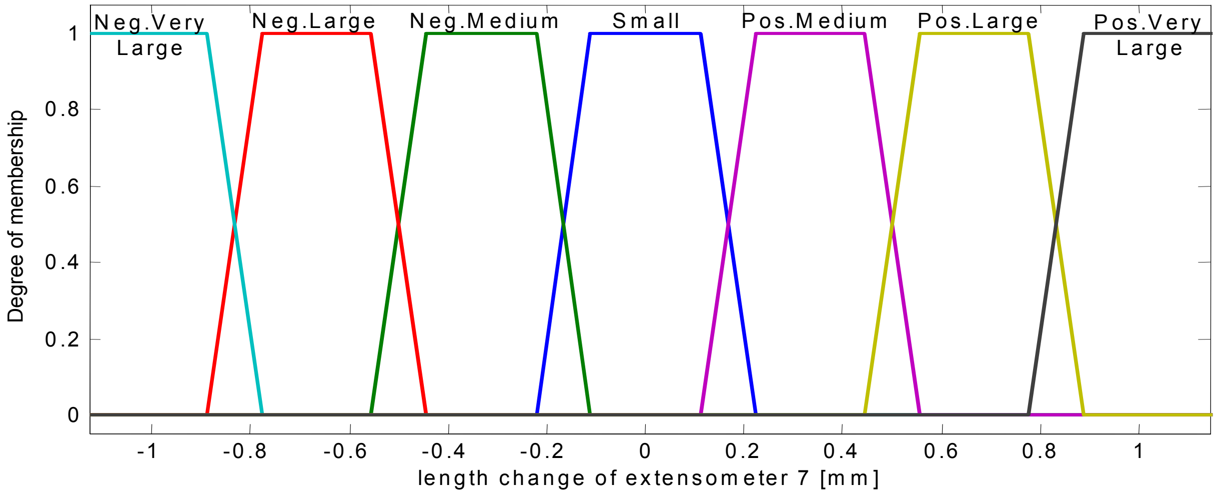

Fig. 3: Example of the modelling of one input parameter. The change of the length of the extensometer is described by 7 linguistic terms (small, negative/positive medium, negative/positive large,…).

3.2 Rule Base

The rule base is a summary of all if-then-rules implemented in the system. It connects the input and the output parameters according to the human expert knowledge. In a first step it is necessary to collect the rules describing best the situation under investigation. In this study, the idea was to detect the following two situations out of the collected data:

- increasing danger: two or more sensors show the same trend of movement, i.e. the pattern of the change of the length, tilt and positions fit together.
- Sensor error or external influences: sometimes only one sensor shows a slight movement, whereas all other sensors remain stable. This situation can happen, if e.g. a branch of a tree is falling on a wire extensometer due to a storm etc.

Due to the quite large number of sensors at the Eiblschrofen, the various instruments can be grouped to form several self-controlling configurations. This means that e.g. at the tear off zone of the 1999 rockfall the data of the GPS-point can be checked by a comparison with the data of the tiltmeter installed directly beside the GPS antenna. Additionally the endpoint of one extensometer is located in the vicinity of these two sensors, so there is another possibility for a quality check.

All these connections between the different sensors have to be collected and implemented in the rule base of the fuzzy analysis tool. One example for a rule connecting two of the sensors mentioned above is given below (see also fig. 4). For this study, about 180 rules were implemented in the fuzzy analysis system.

If the x-coordinate of GPS point 'Plateau' is increasing
and the corresponding y-coordinate is decreasing
and tiltmeter 2 shows a tilt in the same direction (i.e. increase of values of axis 2.1)
then a toppling of the front part of the Eiblschrofen could be the reason.

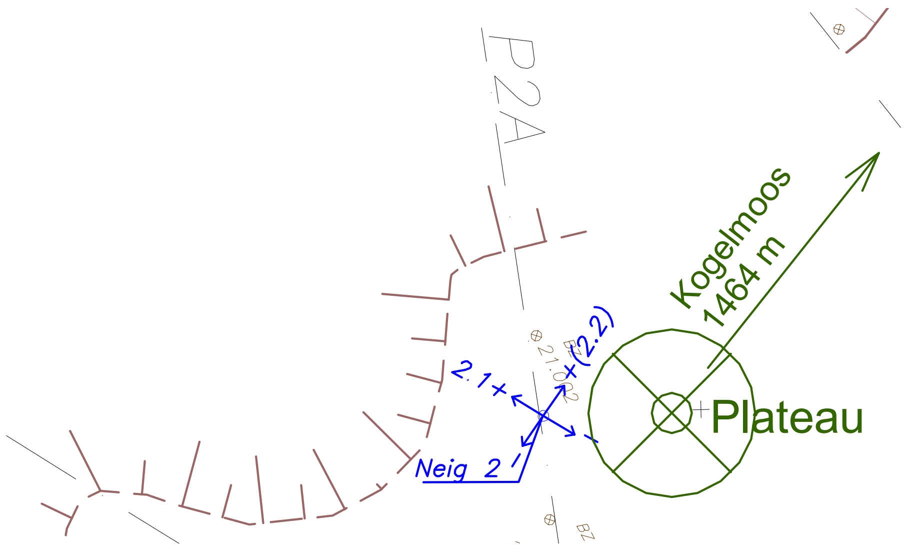

Fig. 4: Front part of the Eiblschrofen showing the relation between the GPS-point 'Plateau' (in green) and the tiltmeter 2 (in blue), (Gillarduzzi 1999). The tear off zone of the rockfall is shown in brown.

3.3 First Results of the Data Analysis

Out of the monitoring data available for the Eiblschrofen, a three months interval was chosen for the analysis. The data was checked for errors, then the GPS positions were interpolated to guarantee time synchronous data within 3-hour intervals.

These data vectors were loaded into the fuzzy analysis system; for each time step, the output value of the fuzzy system, i.e. the potential of danger, was calculated applying fuzzy algorithms.

Fig. 5, 6 and 7 show an example for the input and output of the analysis tool. Fig. 5 gives the changes of the x- and y-coordinate of one GPS-point at the Eiblschrofen for the 3-months-interval. Fig. 6 shows the corresponding measurement values of extensometer 7. These values are simulating the situation that a branch of a tree has fallen on the wire extensometer. This situation results in the output values of fig. 7. It can be seen that the calculation gives only a very small potential of danger, because the 'movement' visible in the extensometer´s data can not be confirmed by the GPS data.

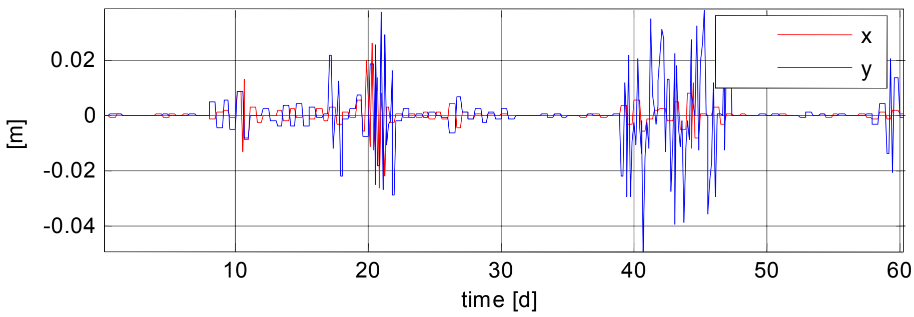

Fig. 5: changes of the GPS-positions (x- and y-coordinate) in the investigated time interval.

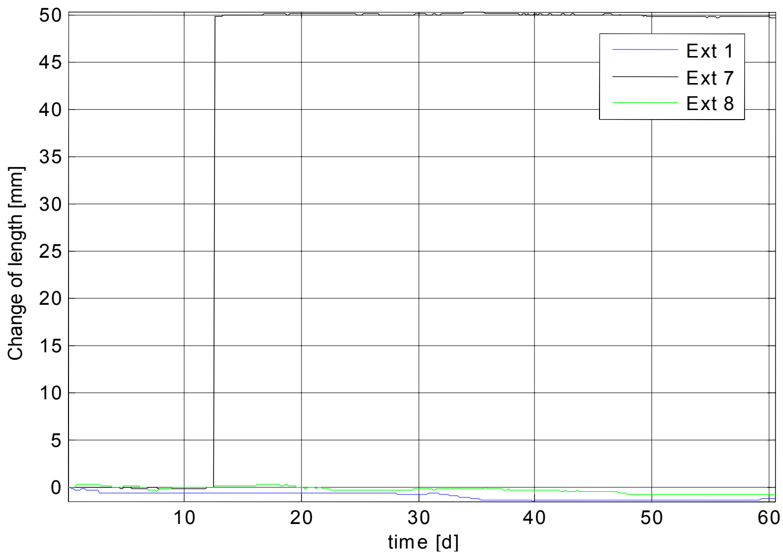

Fig. 6: changes of the length of extensometer 7 (simulation) in the same time interval.

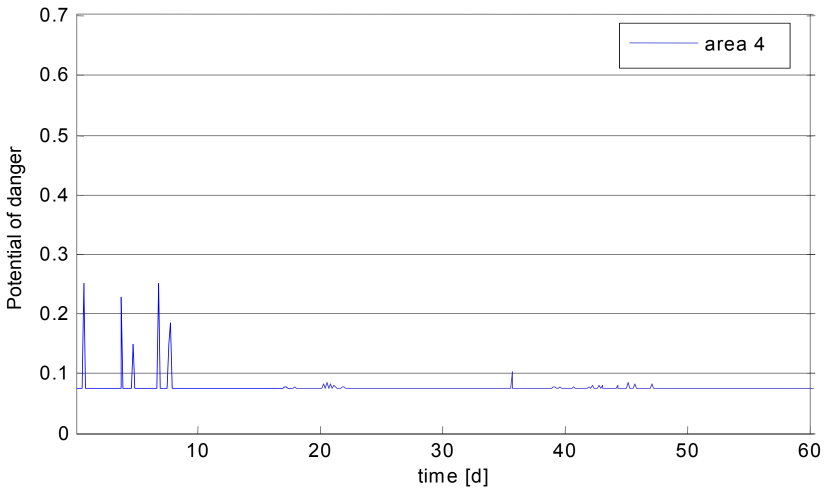

Fig. 7: result of the post processing calculation of the 'potential of danger' (range: 0 = small to 1 = large) for the investigated data (fig. 5 and 6).

4. CONCLUSIONS

The investigations carried out within this study show a great potential for an application of 'intelligent' fuzzy-based methods for the analysis of geodetic and geotechnical monitoring data. Up to now, the assessment tool is still working in post processing; one future goal is of course a near realtime processing of the incoming data. A further extension of the analysis system can be the implementation of other, non-geodetic data like e.g. geology. Here, new rules can be defined by taking into consideration geological structures and their properties. Of course, a close cooperation with experts from other disciplines like geology, geomorphology etc. is necessary for meaningful results.

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