DEFORMATION ANALYSIS WITH KNOWLEDGE AND FUZZY BASED SYSTEMS

Klaus Chmelina[1], Andreas Eichhorn[2], Michaela Haberler-Weber[2], Heribert Kahmen[2]
[1]Geodata ZT GmbH, Vienna, Austria
e-mail: chmelina@geodata.at
[2]Institute of Geodesy and Geophysics, Engineering Geodesy
Vienna University of Technology, Vienna, Austria
e-mail: {heribert.kahmen, michaela.haberler-weber, andreas.eichhorn}@tuwien.ac.at

Abstract: Classical deformation analysis can benefit from methods based on tools of artificial intelligence. One advantage of these methods is that they can reproduce the human way of thinking, what means problem solving is done in a more intuitive way. This will be shown for three research fields: tunneling with the „New Austrian Tunneling Method“, monitoring of landslides and development of early warning systems.

1. Introduction

There is a long tradition in the geodetic society concerning the development of classical mathematical algorithms for deformation analysis. However, the processes to be monitored, are often influenced by effects which can not be described by physical modelling of discrete numbers but only by linguistic expressions describing the human way of thinking. Therefore modern techniques like fuzzy systems, neural networks and knowledge based systems started to be used for deformation analysis. By defining for instance input and output variables and heuristic rules connecting them the human way of thinking can be reproduced. In the following there will be described how fuzzy systems and knowledge based systems can be used for the interpretation of vector-fields occuring during tunneling with the „New Austrian Tunneling Method“ or during monitoring of landslides. Besides it will be shown how knowledge based systems can support early warning systems based on deformation analysis.

2. Knowledge based deformation analysis in tunneling

2.1. Current research activities

Due to the ever-increasing amount of deformation data obtained from geotechnical measurements carried out during tunnel excavation the classical way of data analysis and interpretation already is in troubles. In particular it becomes more and more difficult (but more and more necessary) to solve the interpretation of a huge amount of data quickly and at an excellent expert level at the same time. Thus, the tunneling community realized the need to develop automated and intelligent (smart) tools to support deformation data interpretation. Today, there are already several more or less advanced tools available on the market that help to make data interpretation easier and more efficient on site. But still no such tool contains and provides sufficient expert knowledge to be called intelligent. In trying to find better solutions current research activities concentrate on the development of knowledge based systems. In the following two such activities, GEOTEX and TUNCONSTRUCT, shall be presented.

2.2. GEOTEX (Geotechnical Expert System)

GEOTEX is a currently finished RTD project co-financed by the former FFF (Forschungs-förderungsfonds für die gewerbliche Wirtschaft). The Institute of Geodesy and Geophysics (Engineering Geodesy), the Institute of Information Systems (Knowledge Based Systems Group), both from the Vienna University of Technology and GEODATA ZT GmbH cooperated successfully over a period of two years. A prototype of a knowledge based system (figure 1) for the analysis of 3d-displacement data obtained during tunnel excavation was developed. The system was supposed to enable automatic, knowledge based evaluation of data quality and to assist geotechnical interpretation. In particular the developed software prototype is supposed to detect distinctive (e.g. suspicious or critical) patterns in displacement data by applying a pattern matching method based on heuristic rules.

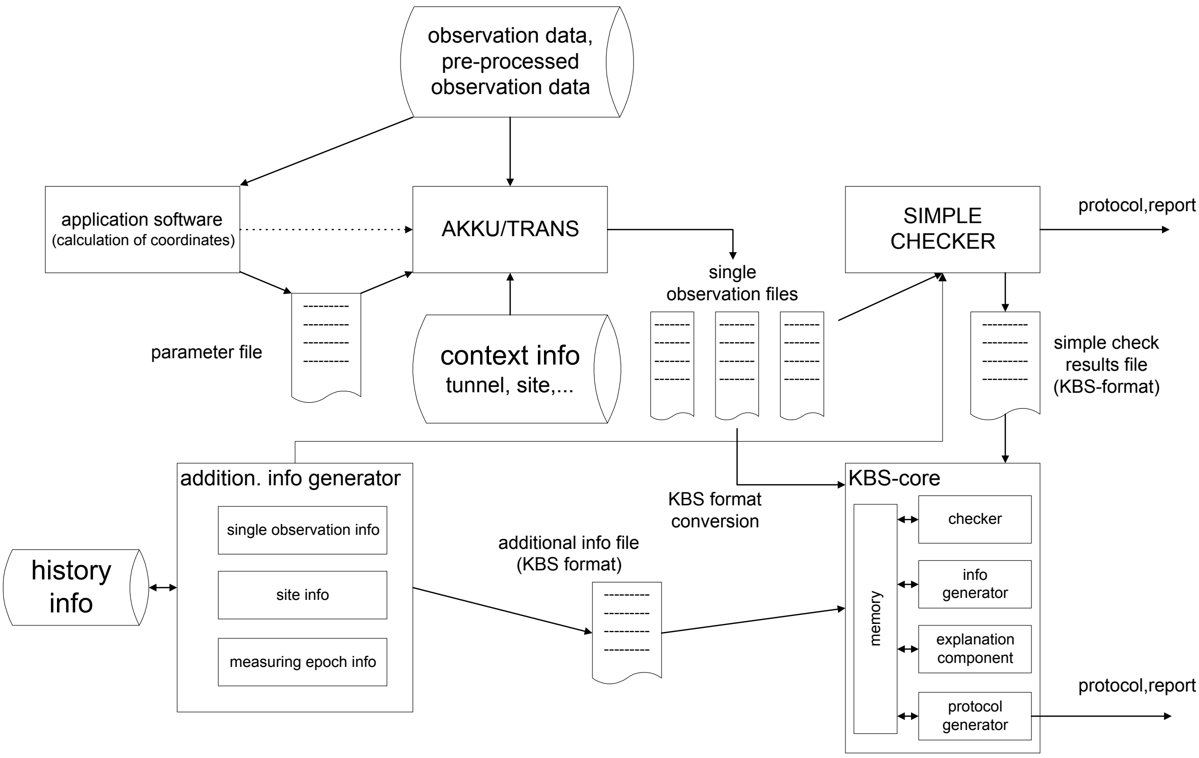

Figure 1: System architecture of the developed software prototype.

The input data of the system comprises the raw geodetic observations (angles, distances), the pre-processed observations (= raw observations after geometric and physical reductions), the calculation results (= displacements after 3d-coordinate calculation by application software) and a set of info data (context info, history info,…) necessary for interpretation (provided by diverse info-generators).

The input data is accumulated and transferred into knowledge based data structures by the module **AKKU/TRANS** (figure 1). This module converts the input data into facts and transfers them to the KBS-core.

Parallel the **SIMPLE CHECKER** module processes simple (not too complex) problems. This module is programmed conventionally and does not operate knowledge based. E.g. it serves for the detection of gross errors in observation data, of missing data, etc. Its results are reported and transferred to the KBS-core.

The **KBS-core** is the module which evaluates the complex problems. Inferencing is based on rule-based pattern matching. The additional information needed for this evaluation is provided by **info-generators**. In particular they provide knowledge about the construction progress, past deformation results, critical deformation patterns, etc.

The output of the system is a protocol reporting about what the system detected.

For an advanced visualization of the suspicious or critical patterns detected (and especially for a better understanding of their meaning in time and space) a virtual reality software application (figure 2) was developed in cooperation with the Austrian vrvis (Zentrum für Virtual Reality und Visualisierung). The software application allows the user to virtually fly through the tunnel at a certain (fixed) time to watch the spatial distribution of the 3d-displacements as well as to keep at a certain place to watch the 3d-displacements develop over time. In addition the excavation progress of the tunnel face can be visualized by animated geological tunnel face images.

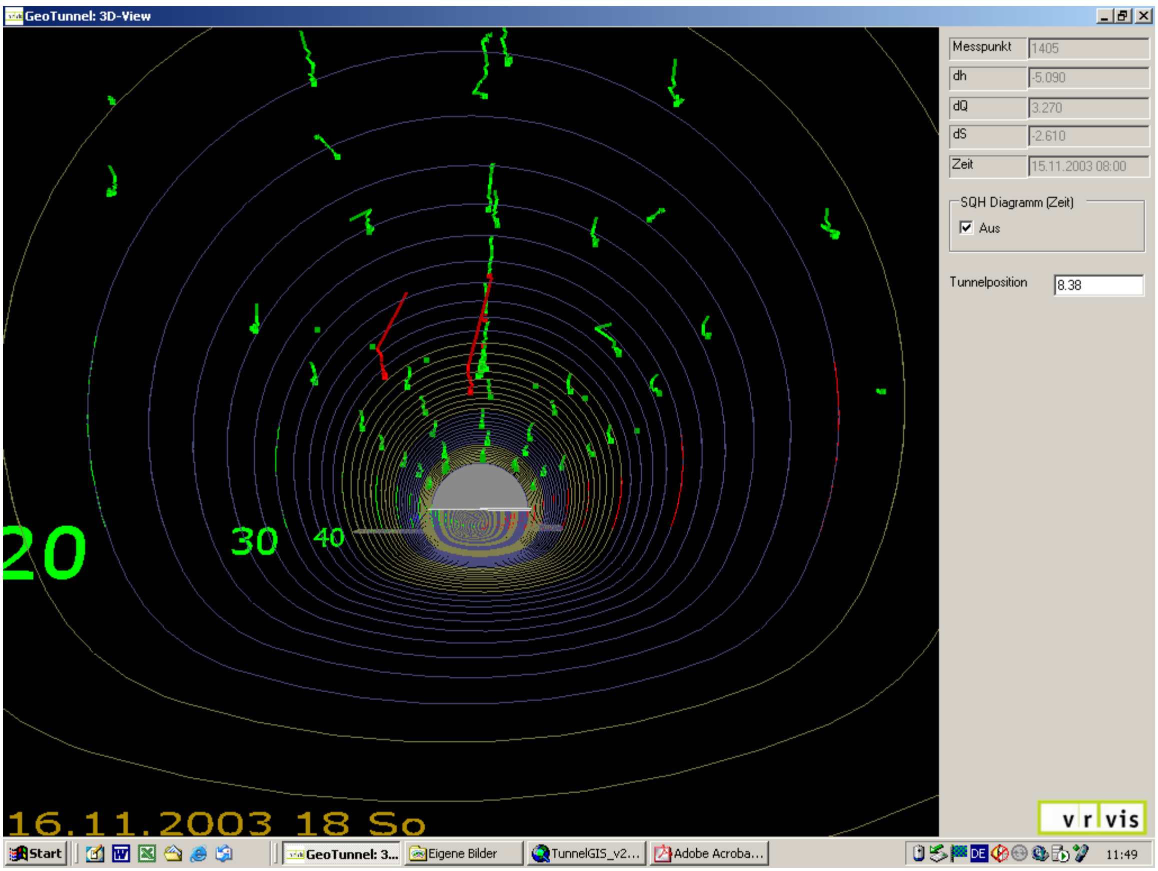

Figure 2: 3d-virtual reality visualization of detected critical displacements.

The developed system is designed to assist the geotechnical engineer on site in his daily interpretation work. At current stage such kind of systems already can reach a certain (low to medium) level of competence. This will be improved by future developments.

2.3. TUNCONSTRUCT (Technology Innovation in Underground Construction)

Currently the issue of knowledge based deformation data analysis gets further treated in the wider frame of TUNCONSTRUCT which is a multi-disciplinary research project that promotes the development and implementation of European technological innovation in underground construction.

The project´s 41 partners (one of it GEODATA), from 11 European countries, integrate not only the on-the-field engineering experience and technical know-how of the industry, but also the research capabilities and conceptual innovation of the academic sector.

The project started in Sept., 2005, will last four years and is co-financed by the European Commission, under its 6th framework program, which provides 54% of its 26 million Euro quadrennial budget. Coordination rests on the Graz University of Technology, Austria.

Within TUNCONSTRUCT knowledge based libraries will be developed (as just one of many research topics) gained from displacement data and an expert system for detecting critical trends in the development of displacements. The libraries will contain a description of displacement characteristics for different and typical geological situations (= a catalogue of normal displacement behaviour and critical displacement trends). They will be set up by the evaluation of displacement data gained from existing projects and numerical simulations. The expert system will make use of the libraries by comparing the displacement characteristics described therein with the actual displacement monitoring data of a concrete project. Appropriate comparison methods have to be found. This specific research topic will be investigated under the scientific leadership of the Institute of Rock Mechanics and Tunnelling (Technical University of Graz).

The mentioned research activities highlight the general trend and need to introduce knowledge based systems and methods to technical fields and in particular to geodesy and tunneling.

3. Fuzzy based enhancement of geodetic deformation analysis

The classical geodetic deformation analysis of quasi-static networks results in a set of displacement vectors for the object points investigated. For some application, a deeper insight into the actual situation is necessary. Very often, an analysis of the movement of different blocks within the unstable area is of great interest [1].

The block detection was not possible in an automated way up to now. Here, an application of fuzzy based methods for the automated block detection is summarized [2].

3.1. Overview of the block detection method

The 2D displacement vectors which are the result of the geodetic deformation analysis are the input for the block detection algorithm.

The block detection algorithm was implemented in Matlab®. The algorithm starts by finding all possible blocks consisting of four neighbouring points using the displacement vectors given by the deformation analysis (see figure 3). A minimum of four points per block is necessary due to the over-determined calculation of the indicating parameters. The fuzzy system selects the 'best' set and in an iterative process the best fitting neighbouring points are added to the block until the following fuzzy systems 3 and 4 determine that the block is complete, i.e. that no neighbouring points with a similar pattern of movement exist. Then the algorithm starts again finding four neighbouring points out of the remaining points.

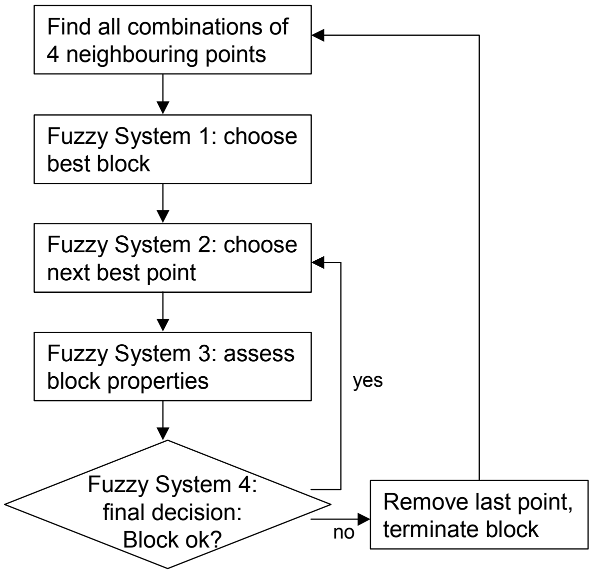

Figure 3: Structure of the developed algorithm.

3.2. Fuzzy based algorithm

The block detection is based on the idea that one block consists of points with a similar pattern of movement. This rule cannot be implemented with a strict deterministic model, it is a so-called linguistic rule. The human everyday language is full of linguistic rules. Humans can interpret these rules according to their knowledge in a very intuitive way, e.g. 'a similar pattern of movement' in combination with a diagram of displacement vectors will be interpreted by a human expert that points with similar (length and direction of the) displacement vectors have to be grouped.

Fuzzy based methods can be used to imitate this human intuitive way of thinking for a computer based processing. E.g. the modelling of the property 'similar' is realized by the assessment of the similarity of the length and the direction of the displacement vectors. In figure 4 the modelling of the input variable 'similarity of length' is shown. Two displacement vectors are said to be similar, if the ratio of the length of the vectors is approximately 1.

In the same manner, the modelling of the similarity of the direction of two displacement vectors is described (see figure 5). Two displacement vectors have a similar direction, if the difference of the azimuths of these vectors is approximately 0 gon. The greater the difference in azimuth, the less 'similar' are these vectors.

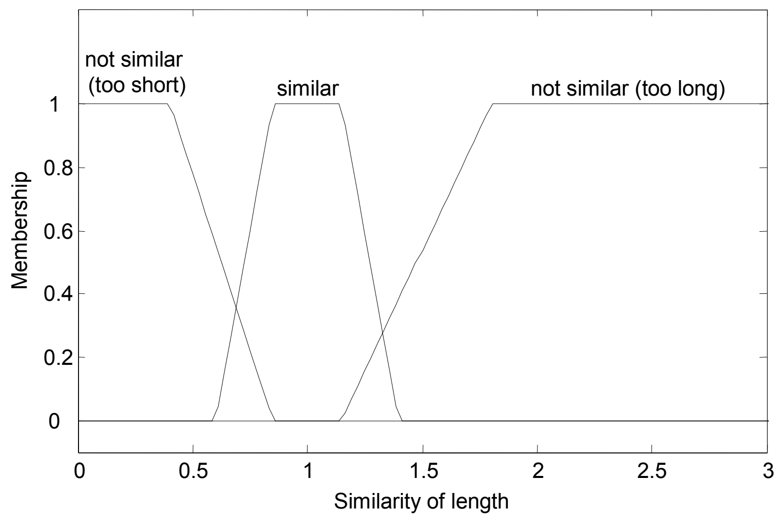

Figure 4: Modelling of the input variable ‘similarity of length’ of the displacement vectors by the ratio of the lengths of the vectors.

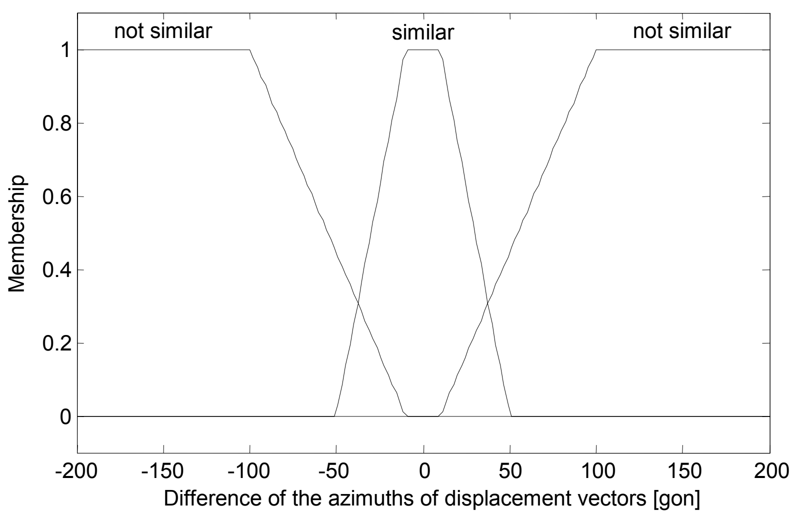

Figure 5: Modelling of the input variable ‘similarity of direction of displacement vectors’ by the difference of the azimuths of these vectors.

In addition to the ‘visual’ input parameters like the neighbourhood of points, the length and the direction of the vectors, some geodetic parameters are used for the block detection algorithm. Here, the geometric situation is assessed by the strain analysis, where the inner distortions resulting from the deformation of the point cloud are investigated. Some of the parameters used are

- the semi-axes of the strain ellipse, resulting from the strain analysis: The absolute values of the semi-axes as well as the change of the values between two subsequent steps of the block detection algorithm are used for the assessment.
- the interquartile range of the residuals after the overdetermined strain analyis: Whenever a non-fitting point is added to the existing block within the iterative block

detection, the range of the residuals increases significantly. This change of the variable between two subsequent steps of iteration can be used as an indicator.
- the ratio of the standard deviation of unit weight s_0 after the overdetermined strain analyis: According to the interquartile range, s_0 is changing significantly if a non-fitting point is added to the block under investigation. This change is an indicator for the assessment.

The developed algorithm is intended to be used after the geodetic deformation analysis of quasistatic networks to get a deeper insight into the actual situation. The results of this block detection can be used to develop e.g. a suitable and efficient monitoring scenario.

4. Knowledge based alert systems with identified deformation predictors

4.1. Research field and objectives

The research field “Knowledge based alert systems” is cocentrated on the development of knowledge based approaches for the automated analysis and alerting of deformation processes.

One emphasis is focussed on the investigation of landslides. Within these applications the detection / prediction of significant changes in the motion of the slide can be defined as a central task ([1], [3]). It is the precondition for the installation of an adequate and economical instrumentation design, for a suitable measuring rate and the in time warning or alerting.

To solve this problem it is necessary to combine analysis strategies from system theory [4] with an expert system. This combination of the classical “data based system analysis” with a “knowledge based system analysis” can be concretised by the definition of two research tasks:

- Prediction and statistical evaluation of the slides motion using calibrated deformation transfer functions
- Integration of additional sources of hybrid (expert-) knowledge and the establishment of automated decision processes (raise in sensitivity and reliability of the alert system)

4.2. Data and knowledge based system analysis

In figure 6 the process chains of data and knowledge based system analysis and its relevant dependencies are presented.

The central component of the expert systems knowledge base and knowledge acquisition com-ponent is the quantification and identification of the deformation processes using geodetic and geotechnical observations (= “data based system analysis”). The identified and verified ex-perimental process models shall be used as deformation predictors ([5], [6]).

The expert system is regarded to be a kind of “supervisor” managing the selection of deformation models and instrumentation and interpreting the predicted and measured results from the data based system analysis under special consideration of additional hybrid sources of knowledge. Its “inference”-component enables an improvement of classical data based (statistical) verification methods [7] with rule-based extensions.

The main task of the expert system is to make proposals to the user for holding the old state or changing to the next alert step (= “knowledge based system analysis”).

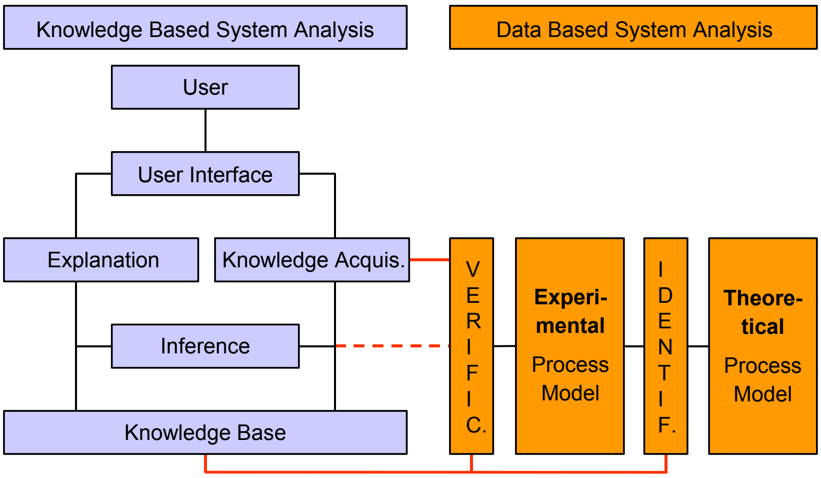

Figure 6: Knowledge and data based system analysis

4.3. Functional architecture of the alert system

The main components of the functional architecture (see figure 7) of the knowledge based alert system can be specified by the following procedural arranged steps:

1. In the **configuration phase** the knowledge based system decides which kind of deformation models and observation designs are suitable for the quantification of the present state of the (possible) landslide. The knowledge base must include i.e. available instrumentation and measuring results from preliminary investigations, possible measuring rates, economic restrictions and accessible additional expert knowledge (geotechnics, soil mechanics etc.). The selected deformation models can be descriptitive or causative, static or dynamic respectively parametric or non-parametric [7].
2. The **identification** of the deformation processes is realized using geodetic and geotechnical measurements. This calibration step is precondition for the close-to-reality prediction of the progress of the landslide.
3. In the third step the calculated **predictions** of the slides motion are used as one main input for the knowledge acquisition component of the expert system. The system has to decide whether the predicted progress will be conform with reality or not (**verification step**). Considering additional hybrid knowledge the verification is not only based on incoming measurements (classical procedure) but also on expert prognoses. It enables the evaluation of the predictions at an early stage ("preverification"). If the predictions are evaluated as not confirm with reality a feedback to the systems configuration is induced for modification / adaptation of the deformation models (e.g. static to dynamic). In addition this may be an efficient indicator for a significant change in the slides motion [3].
4. The predictions are used as input for the **first decision level** whether to change the alert step or not. Additional expert knowledge (excluding the predictions) is used to define the **second decision level**.

5. The **final decision** is made combining the results from the first and the second decision level. In case of a change of the alert step the verification component of the alert system will indicate if an additional modification (and identification) of the deformation models is required.

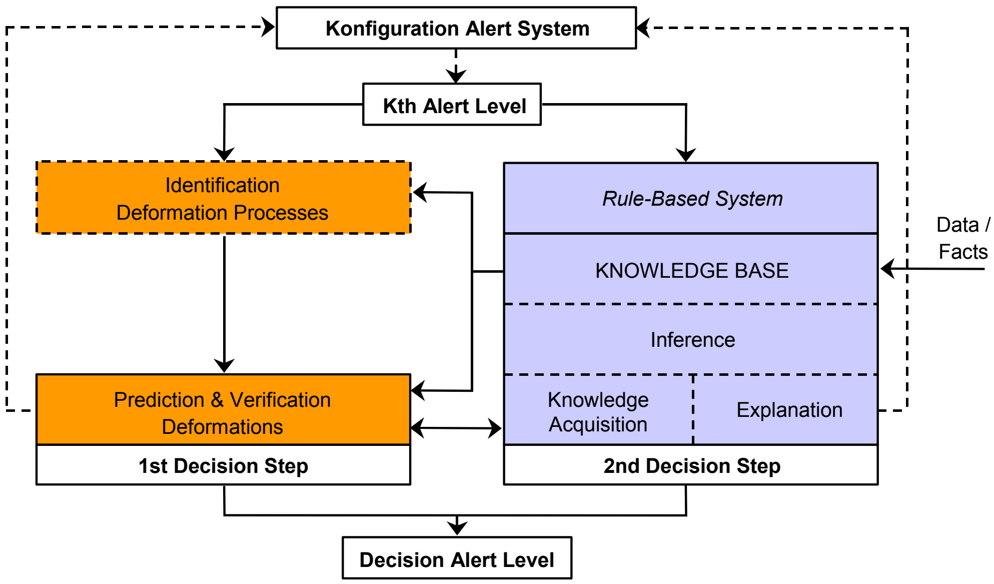

Figure 7: Architecture of the knowledge based alert system

The integration of suitable deformation models into the data based system analysis and its calibration to "deformation predictors" must be the first principal task. As suitable tool for the calibration of parametric deformation models adaptive KALMAN-filtering techniques (i.e. [5], [6]) are suggested. KALMAN-filtering offers the optimal combination of theoretical and empirical system analysis to identify the deformation processes. The statistical evaluation of its innovation is a very sensitive tool to detect contradictions between the filters predictions and incoming measurements (=> sensitive for changes in the slides motion). The filter concept enables the estimation of à priori unknown physical model parameters. Especially within the range of dynamic deformation processes the identifaction and verification task is still a research field with high scientific potential.

5. Conclusions

It was shown that there is a wide field of research if classical deformation analysis is combined with methods reproducing the methods of human thinking. This was shown for three research areas: tunneling with the New Austrian Tunneling Method, monitoring of landslides and development of early warning systems.

References:

[1] Kahmen, H. / A. Eichhorn / M. Haberler-Weber: A Multi Scale Monitoring Concept for Landslide Disaster Mitigation. In: Proceedings of the IAG Conference "Dynamic Planet 2005", Cairns, 2005, in print

[2] Haberler, M.: Einsatz von Fuzzy Methoden zur Detektion konsistenter Punktbewegungen. Schriftenreihe der Studienrichtung Vermessungswesen und Geoinformation, Technische Universität Wien, Heft Nr. 73, 2005

[3] Eichhorn, A.: Geomechanical modelling as one central component of an alert system prototype: case study 'test-slope in opencast mine'. In: Vienna Consulting Engineers VCE (Ed.): Final report on EU project OASYS, Vienna, 2006

[4] Isermann, R.: Identifikation dynamischer Systeme. Band 1, Springer-Verlag, Berlin/ Heidelberg/NewYork/London/Paris/Tokyo, 1988

[5] Heunecke, O.: Zur Identifikation und Verifikation von Deformationsprozessen mittels adaptiver KALMAN-Filterung (Hannoversches Filter). Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universität Hannover, Nr. 208, Hannover, 1995

[6] Eichhorn, A.: Ein Beitrag zur Identifikation von dynamischen Strukturmodellen mit Methoden der adaptiven Kalman-Filterung. Deutsche Geodätische Kommission, Reihe C, Nr. 585, 2005

[7] Welsch, W.M. / O. Heunecke / H. Kuhlmann: Auswertung geodätischer Überwachungsmessungen. In: Möser, M. / G. Müller / H. Schlemmer / H. Werner (Eds.): Handbuch Ingenieurgeodäsie, Heidelberg, Wichmann Verlag, 2000

[8] Chmelina K.: A Concept for Intelligent 3-d Displacement Monitoring. In: Proceedings of the "2nd Symposium on Geodesy for Geotechnical and Structural Engineering". Berlin 2002.

[9] Chmelina K.: Knowledge Based Analysis of 3-d Displacements in Tunnelling. In: Proceedings of the "5th Conference on Optical 3-D Measuring Techniques". Vienna 2001.

[10] Schubert P.: Funktion und Grenzen der Geotechnischen Messungen im Tunnelbau. Felsbau 13 Vol. 6/95

[11] Schubert W., Vavrovsky G.M.: Interpretation of Monitoring Results. World Tunnelling. Nov.1994

[12] Steindorfer A., Schubert W.: Selective Displacement Monitoring during Tunnel Excavation. Felsbau 4 Vol.2 /1996

[13] Steindorfer A., Schubert W.: Application of new methods of monitoring data analysis for short term prediction in tunnelling. Tunnels for People. Vol.I, Balkema Rotterdam. 1997

[14] Steindorfer A.: Short Term Prediction of Rock Mass Behaviour in Tunnelling by Advanced Analysis of Displacement Monitoring Data. Doctor Thesis. Dept. of Civil Engineering. TU Graz. 1998