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# Towards an Information System for Early Warning of Landslides

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**Abstract**

More than four million people lost their lives in disastrous geological events such as earth quakes, tsunamis and strong rainfall combined with landslides during the last century. Obviously there is a strong demand for analyzing such events and for developing early warning systems to save lives and properties. The European GIS community is invoked to provide its knowledge for the development of new information systems for early warning of geological events. However, at present the analysis and information preparation are still particularly critical points of the early warning chain. Furthermore, the responsible decision makers are usually confronted with huge amounts of structured and unstructured data. Thus the question is how they can be provided with a reliable and manageable amount of information to create the warning decision and for taking preventive measures. In this paper the objectives and requirements of the joint project "Development of suitable information systems for early warning systems" are presented, examining methods of an information system for the early recognition of geological hazards in a mass movement scenario. In the project the simulation of landslides is executed on the basis of geotechnical, mechanically founded models. Thus a better understanding of the geological processes can be achieved. Furthermore, the improvement of the information analysis and preparation are investigated. Therefore techniques such as GIS, numerical simulations, spatial data mining, geo-databases and linguistic methods are combined with each other.

## 1. Introduction and Objectives

As the number of geological events such as landslides [3], [4], [5] has increased worldwide during the last decades, there is a strong demand for developing early warning systems to save lives and properties. The central components of an early warning system for natural phenomena are the recognition of the threats, the assessment and evaluation of the danger, the dissemination and communication of the warning, as well as the public reaction to the warning [7]. The effectiveness of an early warning system largely depends on the transformation of the event recognition into the report of warning to the population [4]. Obviously the analysis and information preparation are particularly critical points of the early warning chain. However,

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they contribute significantly to the warning decision and to the risk estimate and the extent of the natural event.

The objective of the joint project "Development of suitable information systems for early warning systems" (EGIFF) is to improve the early warning chain by the conception and development of new methods to be integrated into appropriate components for early warning systems. The main research objectives include:

- Conception of a distributed component architecture of an information system for early warning systems;
- Geotechnical evaluation of mass movements using the data of past events;
- Coupling of numerical simulations and GIS;
- Modelling and visualization of spatial relationships and their uncertainty as well as their extraction from textual and numerical data;
- Transfer of data mining and analysis methods to spatially referenced data (spatial data mining), as well as processing of structured and unstructured data (free texts of disaster and damage messages);
- web-based alerting;
- Geo-database support for handling data of different scenarios as decision basis for the geotechnical evaluation of mass movements;
- Development of a system for the support of the evaluation of risks and finally
- Evaluation of the developed prototype on the basis of concrete geological data and application scenarios.

## 2. Application Area

Main selection criteria for a suitable application area were the availability of detailed geographical data and sensor measurements, a coherent and comprehensive geology to verify the gained methodology in a generalized way and the potential risk for landslides. After the investigation of different landslide areas, a part of the Isar valley in the south of Munich, next to Pullach and Neugrünwald has been selected for the further studies. In this area the height difference of the slope is up to around 40 meters and endangered human infrastructure is located nearby the edge of the slope. Because of the risk potential, the area is observed by the responsible authorities and inclinometer, extensometer and groundwater level measurements and geodetic surveys are available.

## 3. System Architecture

The proposed system architecture corresponds to three subprojects. The following subchapters provide an insight into the objectives and applied methodologies of the subprojects.

## 4. Subproject I "Development of an interconnected information and simulation system"

The main objective of this subproject is the conception, prototypical implementation and evaluation of an interlinked Numerical Simulation System (SIMS) and a Geographical Information System (GIS). Its research contributions is in particular the development of coupled information and simulation models for mass movements. Another focus is put on a more precise predictability and a more exact determination of the exposure of slopes. Therefore a transferable numerical simulation algorithm for landslide movements has to be realised within the simulation system. Thus, it is possible, based on existing field data (sensor-and GIS data, for example DTM) and virtual exogenic scenarios, to predict the slope stability, future system behaviour and potential risk scenario. As a result, a „communication" between the sensor measurements, GIS and the geotechnical model is enabled.

The process starts with the selection of the parameters (Input Data) which may have influence on the occurrence of landslides. These parameters include temperature, precipitation and slope geometry. The parameter transfer is controlled by the GIS. In the simulation system the slope stability is calculated and, if possible, future behaviour predicted. Results of the simulation are parameters such as hazard potential, deformation and movement vectors and stability indices. These results are transferred to the GIS for visualization and, if possible, enrichment with other information. Furthermore, the data can be checked against rules to support the decision making process of the user.

With the prototype of the Decision Support System (DSS) it will be demonstrated, how the linking of numerical simulations and GIS can improve predictions of landslides and calculation of potential danger and how the uncertainty of and lacks within the data can be considered. Additionally, it will be verified, if the output of simulations, enriched with GIS analytic methods, can optimize the decision making process for the prevention of catastrophic hazards.

Within the overall system architecture this DSS is integrated with the geo-database (Subproject III) and the data mining system components (Subproject II). The geo-database provides the input data for the simulation and the modelling of slope stability and stores the simulation results. The event messages detected by the data mining system will also be incorporated into the decision support.

The geotechnical models have to be modelled as follows. A slope profile can consist of different soil types whose mechanical attributes have to be characterized by different constitutive equations. For a realistic characterisation of the deformation specification of different soil types, the validity of distinct constitutive equations for each soil type has to be analyzed. Therewith the management of adequate constitutive equations for different soil types will be enabled. For the application of constitutive equations, first the material parameters have to be identified in these equations. Therefore, the parameter properties have to be analyzed, so that a concept for the determination of the material parameters can be developed. The material parameters will be stored in a database, so that the final numeric model can access the right model parameter. For numeric modelling of landslides initial- and boundary conditions have to be defined. These include the geometry of the slope as well as meteorological influences, etc. The actual initial- and boundary conditions are complex, this makes a simplification of the model necessary.

The main goal is to establish an efficient and reliable medium for distributing information to the responsible hazard managers. Furthermore, it will be investigated if and how uncertainties of the data used in the simulation and subsequent processes can be modelled. In particular, for visualization and for the support of the user in the decision-making process these uncertainties should be recognizable, in order to allow a validation of the results by the user. Moreover it will be investigated if and how this validation of uncertainties can be done automatically. Another emphasis is the convenient presentation of the extensive simulation results to the user and the development of a user friendly and intuitive system control.

## 5. Subproject II "Joining, analysis and valuation of fuzzy textual descriptions of geoscientific phenomena to support and improve early warning systems"

The objective of subproject II is the collection, pre-processing and analysis of relevant structured and unstructured data (numerical and textual measurements, observations and descriptions of specialists and laymen (citizens)) related to natural hazards in form of disastrous mass movements, with a focus on the development and application of novel computational methods, aiming at the combination of analysis results obtained from heterogenic data sources, followed by a prototypical implementation as suitable components of an early warning system. The following central tasks have been identified:

- development and application of techniques and methods aimed at an automatic extraction of early warning-relevant information and spatial references from textual messages;
- transfer of suitable techniques and methods for automated data analyses and an application thereof in the domain of applied geosciences;
- development and application of novel methods aimed at a combination of results of analyses of structured and unstructured data related to natural hazard phenomena of the type "disastrous mass movement";
- design of ergonomic user interfaces for the task of complex data analyses in context of early warning systems, with a focus on users with none or no profound IT knowledge.

All above tasks will be pursued in context of design, development and deployment of natural hazard early warning systems, with focus on disastrous mass movements.

Besides concentrating on disastrous mass movements, a high degree of transferability to other natural hazard types or even analytical tasks in the domain of applied geosciences is aspired. This is also seen as part of a general objective to maximize scientific connectivity as well as a prospective commercial value of the project's results.

In a first step analysing the application domain, a glossary of central concepts and terms will be developed in order to facilitate communication with the other subprojects and with end users. At the same time, relevant functional and non-functional requirements from end users' perspective and constraints for the information system have to be identified.

Focus is also set on the investigation of relevant preliminary work within and outside the domain of applied geosciences. Furthermore, the developed concepts have to be analysed with respect to the applicability and usefulness in the given problem setting. This will include a review of the SOKRATES system, a system developed by FGAN/FKIE (Wachtberg). Relying on a combination of methods from natural language processing and techniques of knowledge representation, the system can be used to display events on a tactical map by means of limited automated interpretation of battle field reports. The combination of techniques employed by SOKRATES can serve as a methodological basis for parts of the system envisioned in this subproject.

At the same time we will focus on an investigation of data mining techniques which could be transferred into the domain of applied geosciences in order to devise, develop and select suitable techniques, algorithms and tools. In this context, the assessment of algorithms and tools will also comprise an evaluation of the transferability and applicability of selected representation formalisms, methods and systems to other real-world applications, as well as their interoperability with established tools.

This work also has to consider specific requirements introduced with computational representation of three-dimensional spatial data and the representation of vagueness and uncertainty resulting from an analysis of textual spatial references.

In the context of spatial data visualization, characteristics of the data related to reliability and precision of spatial references will have to be presented in a way that they satisfy the requirements for adequate usability. In particular, previously established qualities like priority or urgency of information and their possible interpretations are major aspects. Also, scale-dependencies are playing a special role.

## 6. Subproject III "Geo-database support for the geotechnical evaluation of mass movements"

In this subproject III the primary geological data will be modelled and managed in a geo-database management system. The management of the geological spatial and time-related primary data enables its usage for analysis, simulation, and 3D visualization at any time. Figure 4 shows an example for data of the application area managed by the geo-database management system, visualized with the GoCAD® 3D modelling and visualization system [6].

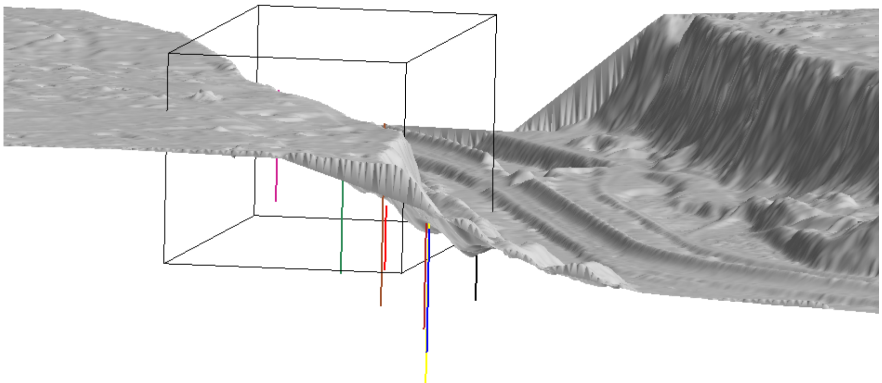

Fig. 1: 3D database query example for data of the application area managed by the geo-database management system

In a second step, finite element model parameters and results of finite element computations will be stored in the geo-database. They can be used to support the geotechnical evaluation of mass movements providing suitable database queries. Finally, the development and implementation of geometric, topological and time-related operations as input for spatial data mining methods, shall provide new spatio-temporal patterns for the recognition of mass movements hazards. The developed methods are to be evaluated on the basis of concrete geological application data from the selected application area.

Here geo-databases are used for archiving and for providing fast and efficient access to geo-data. This enables the reuse of geo-data, e.g. for upcoming new natural events. In addition, the geo-database can also manage models and their results and even become active, e.g. by computing geometric intersection queries between a set of geo-objects. The following three main tasks have been identified:

- Geometric and topological management and 3D visualization of existing geological primary data and time-dependent data.
- Management of FE model parameters and their results for the use in geotechnical evaluations of mass movements.
- Development and implementation of geometric / topological and time-dependent operations as input for spatial data mining methods.

For the first task, selected test data from the application area has to be examined and managed in the geo-database in close cooperation with the geotechnical group of subproject I. This includes a first interpretation of the primary data. In particular the representation of discontinuities (e.g. with already existing faults in the slope) has to be taken into account. This work can benefit from the development of geo-data management for complex geological models, i.e. surface layer and volume models [2]. The available data structures and operations have to be transferred to the special requirements of mass movements. If necessary they have to be adapted and extended to fit the new special requirements.

The second task basically concerns the management of the input data and results from 3D model calculations within the geo-database. This has also to be done in close co-operation with the geotechnical group. With the FE model calculation a second kind of data interpretation takes place. The management in a geo-database creates new possibilities for further use of such modelling results and for the overlay with further information like special utilization data.

Furthermore, the results of a larger number of model calculations can be stored in the database and on later demand they can be compared and queried from different points of view. For example, versions or scenarios of model calculations can be stored and compared with each other. Additionally, taking the use of a "4D model" into consideration, i.e. different time steps of the FE model, the data for the temporal analysis of mass movements will be managed in the geo-database.

The third task consists of developing geometric, topological and time-dependent database operations, which support the geotechnical analysis of mass movements. Not only simple range calculations between point geometries (like it is the case in classical 2D GIS buffer operations) are of interest, but the movement/speed of complex 3D geometries and the direction of the movement have to be considered. The implemented operations can be used afterwards in the data mining methods, in order to determine a priori unknown spatial patterns from the combination of spatial and non-spatial attributes for upcoming mass movements.

## 7. Conclusions and outlook

In this paper the objectives of the joint project "Development of suitable information systems for early warning systems" (EGIFF) have been presented. Hitherto, GIS research in the field of early warning systems aimed at the system design for special applications such as a special volcano monitoring etc. In the presented project, however, the focus is on the design and implementation of new general methods and on the combination of methods from the fields of simulation, GIS, spatial data mining, geo-databases and linguistics to be used in an early warning system. Furthermore, the simulation of landslides is executed on the basis of geotechnical, mechanically founded models. Thus a better understanding of the geological processes can be achieved.

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