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Agent-Based Dam Monitoring

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SYNOPSIS. The monitoring of security relevant structures is a task of growing importance in civil engineering. Large structures such as bridges and dams demand the use of precise measuring systems and the collaborative work of engineers, geologists and geodesists. Considering the time and labour consumed by the acquisition, processing and analysis of measured data, concerned authorities, operators and companies are trying to automate these operational procedures. The existing computer-based solutions focus on remote monitoring and neglect a collaborative analysis of measured data. However, an appropriate and effective monitoring system must conduct all of the tasks performed by experts involved in monitoring.

The Institute of Computational Engineering of the University of Bochum, in co-operation with the Ruhrverband (Ruhr River Association), is developing a dam monitoring system based on software agents. The nucleus of the system's conceptual design is based upon the autonomous and collaborative analysis of measured data, associated with intelligent agents adopting the part of the experts generally involved in dam monitoring.

INTRODUCTION

Dam monitoring is based on precise measuring systems and the collaborative work of engineers, geologists and geodesists. Considering time and costs of acquisition, processing and analysis of measured data, an automated management of these procedures is desirable. Most of the existing computer-based solutions focus on remote monitoring, presentation and electronic transfer of measured data. To this end, they do not consider the cooperation between the experts involved in monitoring. However, an appropriate and effective monitoring system has to pay attention to the individual tasks performed by the experts. Furthermore, the distributed

collaborative data analysis and safety assessment has to be captured through the system established.
The Institute of Computational Engineering of the University of Bochum, in cooperation with the Ruhrverband (Ruhr River Association), is currently developing a dam monitoring system based on software agents. Software agents represent an innovative, powerful as well as robust software technology allowing not only the implementation of distributed applications but also complex interactions. Consequently, the agent-based dam monitoring system is capable of supporting the collaborative work of the involved experts and incorporates the distributed work flow of data analysis and safety assessment. Thus, the complete work flow of dam monitoring is mapped onto a multi-agent system: regularly performed tasks (i.e. measuring at specified locations at the dam) are carried out by specialist agents. By contrast, the involved human experts are assisted by means of personal agents, which support these experts in performing their specific tasks and allow a direct communication with the multi-agent system.

Software agents - autonomous, mobile and intelligent software programs - provide all the necessary characteristics to innovate and accelerate the development of distributed applications. They represent powerful and robust software technology for implementing distributed-collaborative work flows and complex interaction.

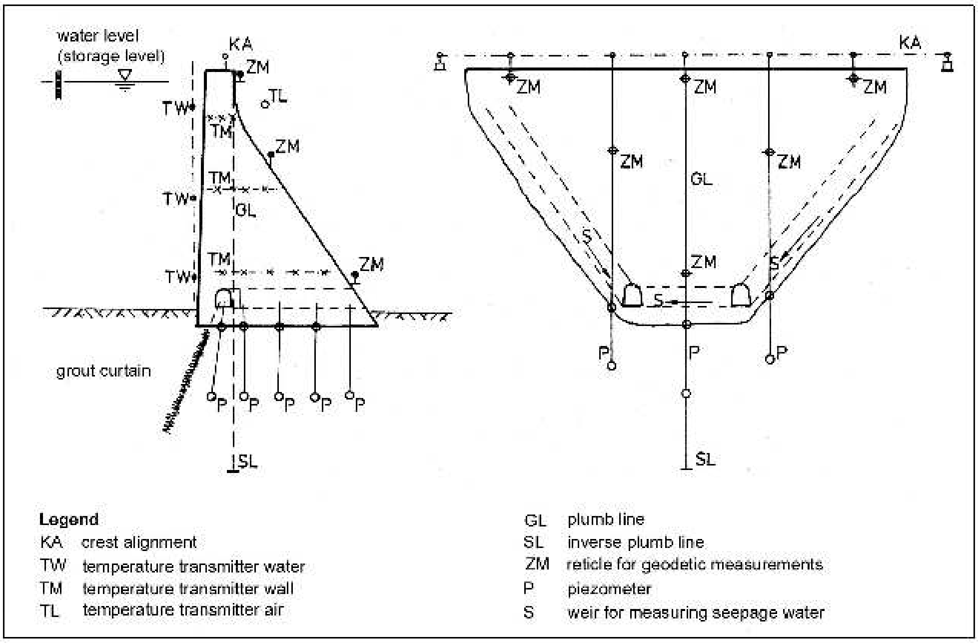

Figure 1: Example for the configuration of measuring devices [1]

DAM MONITORING - TECHNICAL ASPECTS

The aim of dam monitoring is to provide indicators for anomalous structure behaviour in order to be able to take necessary countermeasures in due time and without any reduction in safety. In Germany, the legal basis of dam monitoring is found in the German Code E DIN 19700 (2001). Further, recommendations for measuring devices have been published by the German Association for Water Resources and Land Improvement (DVWK) [1]. An example for the configuration of measuring devices is shown in figure 1.

The concept of dam monitoring is based on the systematic acquisition of all the relevant parameters, which concern static, hydrologic and operational safety. Therefore, each dam structure must be provided with a measuring and control system, which, then, has to be adapted to the type, size and location of the structure.
The conceptual design of a monitoring system has to consider the following principles:

- Dam and bedrock form a unity, which is embedded in a natural environment.
- An anomalous structure behaviour can occur either gradually or quickly.
- When an anomalous behaviour occurs, the origin should be identifiable by an analysis of the measured parameters.
- Inspection by qualified personnel is indispensable.

In addition, the monitoring system must be adapted to the characteristics of the dam structure and take into consideration the corresponding measuring categories. At arch dams it is important to monitor displacements, and at gravity dams pore pressures are of particular importance in addition to displacements.
An automatic monitoring system rests on extensive electronic measuring equipment. The equipment consists of two essential components: transmitters (sensors) and data recorders (data loggers). Recommended transmitters are i.e.:

- temperature sensors,
- ultrasonic sensors for measuring seepage water,
- laser for measuring displacements,
- vibrating wire piezometers for measuring pore pressure.

The sensors are installed at specified positions (figure 1) inside the structure or the bedrock and they are controlled by electronic equipment (e.g. data loggers) sending electronic impulses. After having received an impulse, the sensors return a signal which can be a measurement of voltage, resistance or frequency. The electronic equipment scales the signal into a value, and either stores it in an internal memory or transfers it to a local database. Data stored in an internal memory can normally be received via a COMMS port (RS232). This interface also allows that the electronic equipment can be programmed from a host computer. An automatic monitoring system is customarily completed with a local computer, usually placed in a control room near the dam. As the redundant data storage is essential in dam monitoring, measured data is stored in a local database and additionally transferred to a central database [4,5].

DAM MONITORING - ASPECTS OF ORGANISATION

Dam monitoring is not only based on instrumental supervision. Several experts have to take care of the data, i.e. they have to analyse the data. The experts view on the monitoring data may be very different, based on their profession and job. For example, a geologist may view at these data differently than a geodesist or a civil engineer.

At the Ruhr River Association the monitoring data have to pass several states of controls as it is shown in figure 2 (left side). Different experts have their view on the data, while on one hand the processing frequency decreases with every processing step, from temporal intervals of one day up to one year, on the other hand the time interval of the viewed data also decreases from an short interval to the whole existing data.

Each step can be briefly described as follows:

1. Data acquisition:

   At the reservoir the crew supervised the dam according to the monitoring plan. This includes daily measurement (manual or automatic) of the relevant parameters, in particular the rate of flow, water level, water pressures, displacements, changes of temperature and others.

2. Check of plausibility:

   Just in time, the manual or automatic measured data are checked with respect to their plausibility. These checks are based on the data of the measurement of the day before or on alarm values and are done by the measuring crew itself.

3. Check of short-time behaviour:

   In the week of the measurement the data are checked by the responsible engineer at the reservoir-administration. He compares the data with the measurement of i.e. the last week to find out anomalies in the short-time behaviour of the dam. After this the data are transferred to the dam safety department of the company.

4. Check of long-time behaviour:
   At the head office of the company several specialist have their own view at the data. At the geological department the data concerning groundwater flow and seepage are checked. Geodesists and Engineers will inspect the movement data. This investigation will be done once a month, in order to find abnormal behaviour in a long-time view of the data.
5. Safety assessment:
   Once a year the responsible engineer has a view over all the data collected. His task is to supervise the measurements and to analyse the data by using statistical tools and computer models. At last he has to compose the annual report, documenting the safety of the dam, not least for the surveillance authorities.

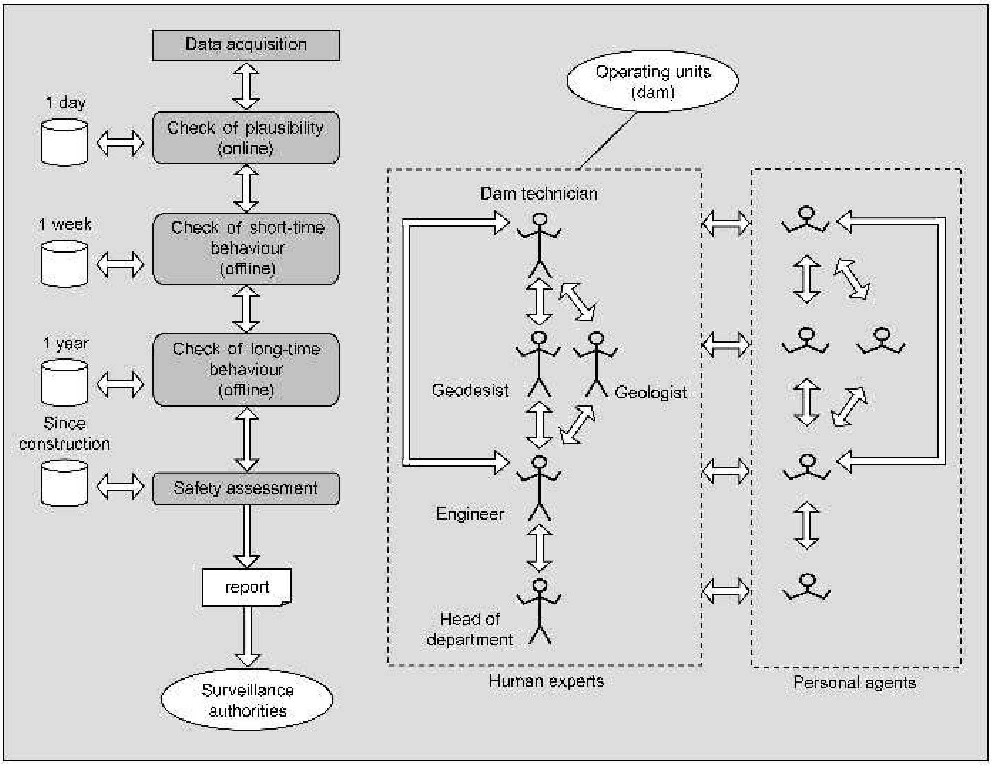

Figure 2: Conceptual design of dam monitoring

CONCEPTUAL DESIGN OF THE DAM MONITORING SYSTEM

The analysis of the described work flow applied by the Ruhrverband indicated that there is a chain of five tasks regularly performed by the responsible experts or in collaboration with other experts. Thus, the basic principle of the conceptual design is to map the regular performed tasks, the individual experts and the interaction between themselves onto a multi-agent system. By that, the software agents can be divided into two categories: specialist agents mapping the regularly performed tasks and personal agents mapping the experts involved in dam monitoring. The conceptual design for the organisation of the agents is shown in figure 2 (right side).

In order to provide smooth communication between the human experts and the multi-agent system (MAS), each human expert involved in dam monitoring is allocated with a personal agent. This software agent represents the interface “human/MAS” and has to be proactive. A proactive agent is able to realise its environment, to recognise the situation represented by the data and to identify the human user. Depending upon the situation it informs the human user or contacts to other agents, in order to request further information (see figure 3).
The corresponding agents are organised using the same relationships as the human experts do (see figure 2).

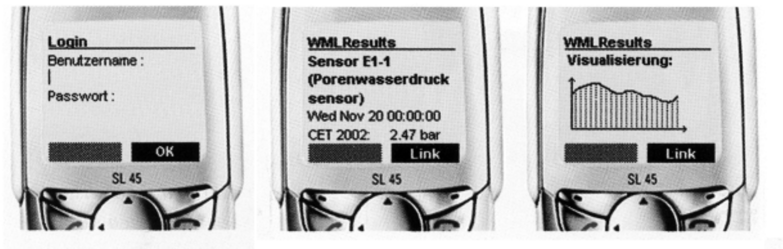

Figure 3: Informing the dam technician by mobile phone

IMPLEMENTATION OF THE DAM MONITORING SYSTEM

Considering the agents to be applied in the dam monitoring system, there are some basic requirements to be met by the conceptual design of the agent architecture. In the following an appropriate agent architecture is developed by focusing on the basic requirements of agent-based applications.

Interaction, and in particular its basis, **communication**, is an essential element of the networked and collaborative systems of the present time and future. Capable solutions must provide several communication protocols for different requirements. For example, in some environments the HTTP protocol is required in order to avoid firewall problems.

The inter-agent communication within the MAS is to be realised according to FIPA specifications [8], since FIPA is one of the central standards in the agent world. Furthermore, this approach allows inter-platform communication with other FIPA-compliant agents on various platforms.

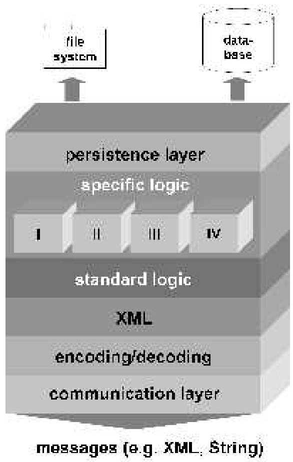

Figure 4: Conceptual design of the agent architecture

When dealing with complex problems, the agents have to be provided with logic. In the current architecture, the logic elements are divided into two categories: **standard logic** and **specific logic** (knowledge). In this particular case the standard logic contains the ontology of the domain “dam monitoring”, by which the agents possess the required vocabulary and basic knowledge in order to communicate and to execute simple tasks.

Via modules the individual knowledge of the involved experts can be integrated very easily. This approach enables the user to adapt the agent to new tasks, goals or environments, too. In other words, the agent becomes more “intelligent” [6,7].

The last layer of the given architecture is a **persistence layer** to keep the state of the agent persistent. In case of a system crash this layer helps to identify the actual state of the agent and to continue the work without any loss of time.

Control of automatic measuring devices - Logger API

As an important factor, a capable computer-based monitoring system must cover the applied electronic equipment. In order to control the measuring devices installed within the structure, there are two popular solutions: systems based on process control systems and systems based on data loggers. In the following, only data loggers are discussed. From an objective point of view, they are the better and more transparent solution for dam operators in planning, use and maintenance.

Since the control of the data loggers depends on the specific communication protocol and the instruction set predetermined by the specific manufacturer, a Java-based programming interface, called Logger API, was developed to encapsulate specific loggers. Specific loggers can be added to the developed library without expenditure.

Data processing and visualization – the evaluation module

Data processing and visualization are provided by an evaluation module which has been conceived thus far with a web-based front end. The web-based paradigm has been chosen such that an acceptance test could be performed in practice in a simple manner and so that no further client-sided software would be necessary.

The task of this web-based evaluation module is to read the acquired data of the dam monitoring from the database and to evaluate, edit and prepare the data in a user-oriented way, graphically and/or tabularly [3].

• *Visualization component*

The visualization component (**view**) acts as a graphical user interface which allows database inquiries, administration of users, etc. (*inputs*) on the one hand and visualizes the requested result quantities in different data formats (*outputs*) on the other hand

An additional task of the visualization component is the representation of the requested data in the format indicated by the user. Output objects are instantiated in order to produce the appropriate outputs depending on the desired format (s. figure 5).

• *Database adapter*

In order to be able to attach several (replaceable) databases, the **model** is realised as an exchangeable database adapter. The assigned tasks are to generate a connection between the database(s) and the controller component, to pass on inquiries which concern measured data to the database, and to return the received results to the controller component

Due to the modularity and expandability of the evaluation module developed, this module can be used in a multi-agent system, for example as a wrapper agent, in order to read measured data from a database. A further possibility is the employment of the module as an interface agent, i.e. as an interface between a human and a multi-agent system which converts "clicked" mouse events into messages understandable for agents.

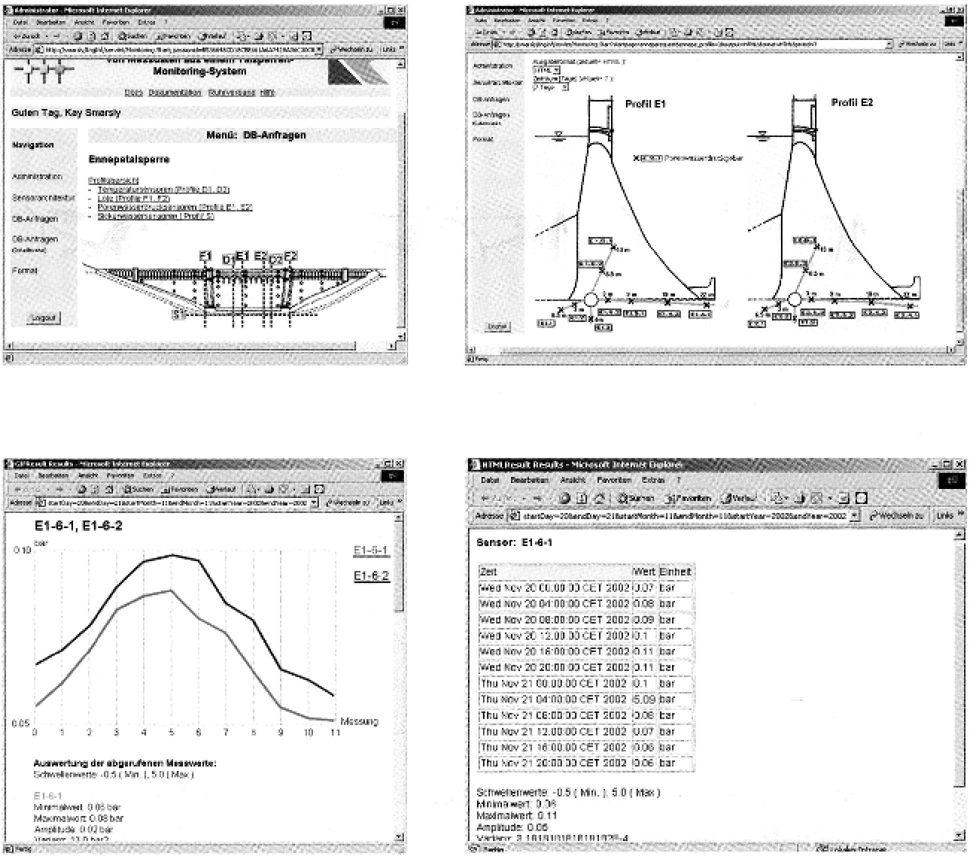

Figure 5: User-specific visualization of the measured data

CONCLUSIONS

Applying software agents, the Institute of Computational Engineering, in co-operation with the Ruhrverband (Ruhr River Association) is taking an innovative approach to developing a modern dam monitoring system, which is capable of supporting the collaborative work of experts involved in monitoring.

The conceptual design of the organisation and the architecture of the agents to be applied in the multi-agent system have been shown. By substantiation, the implementation of two important modules - the logger API and the evaluation module - has been explained.

Actually, these two modules represent a conventional, web-based monitoring system. The measuring devices installed within a dam can be controlled online, and measured data can be read out of the databases and processed according to user preferences.

The multi-agent system is designed to map the distributive-collaborative work of the concerned experts and to integrate their specific knowledge about dam monitoring and dam behaviour. This conceptual design differs significantly from conventional monitoring systems and represents an innovative approach which is capable of demonstrating the enormous potential of agent-based applications.

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