Structural Monitoring of Dams using Software Agents

Ingo Mittrup¹ and Dietrich Hartmann²

¹Institute for Computational Engineering (ICE), University of Bochum, Mail Universitaetsstr. 150, 44801 Bochum, GER Germany; PH +49 (234) 32-26122; FAX +49 (234) 32-14292; email: mittrup@inf.bi.rub.de
²Professor, Institute for Computational Engineering (ICE), University of Bochum, Mail Universitaetsstr. 150, 44801 Bochum, GER Germany; PH +49 (234) 32-23047; FAX +49(234) 32-14292; email: hartus@inf.bi.rub.de

Abstract

The present paper reflects the development of an innovative, agent-based software system for structural monitoring of dams which is capable of supporting the collaborative work of experts involved in monitoring. In contrast to conventional software systems, the agent-based approach is focusing on the distributed work flow of structural monitoring and considers structural monitoring as a result of collaborative work. For this, the complete work flow of dam monitoring is mapped onto a multi-agent system: the involved human experts are represented by personal agents, which assist the human experts in their daily work and allow a direct communication between the experts and the multi-agent system. In addition, regularly performed tasks are carried out by task-oriented agents. Supporting the collaborative work of multiple experts and the access to electronic measurement and control systems, the introduced concept provides a significant enhancement compared to existing monitoring applications.

The present paper gives a short introduction to dam monitoring, then, outlines the conceptual design of the monitoring system and presents an insight into the current implementation. It is to be pointed out that the realization is still incomplete and a part of ongoing research.

Key Words

Structural monitoring, surveillance, software agents, multi-agent system, dam engineering, safety analysis.

Dam Monitoring

Structural monitoring has become an integral part of the safety concepts for large civil engineering structures such as bridges or dams. Hereby, the main goal is to recognize damages, defects in structural safety or external threats to safety, such that necessary measures can be taken in due time and without any reduction in safety
The concept for the structural monitoring of dams is based on two major elements: (i) regular checks of dam condition and dam behavior and (ii) periodical safety assessments. Customarily, the regular checks encompass measurements of behavior parameters and, as an indispensable part, visual checks of dam and site. These checks are conducted frequently, at least, once a month (measurements of dam and foundation behavior parameters) or once a week (visual checks), respectively. In contrary, periodical safety assessments are performed less frequently, e.g. in terms of 5 and more years, depending on dam size and type.

In practice, the regular checks of the dam behavior are based on measurement and control systems adapted to type, size and location of the dam. To give an example [Dvwk91], the configuration of typical measurement and control devices, recommended by the German Association for Water Resources and Land Improvement (DVWK), is shown in figure 1. The given example is focused to gravity dams with a height of up to 60 m and arch dams with a height of up to approx. 100 m and a length of up to 400 m.

![Figure 1. Example for the configuration of measurement and control devices](image)

From figure 1, it can be seen that myriad measurement devices are used to measure the corresponding phenomena. Typical devices are e.g. plumb and inverse plumb lines for measuring displacements, temperature transmitters for measuring temperature, and piezometers for measuring pore pressures. All the measuring devices have to be installed at specified positions in the dam and the foundation, according to the characteristics of the dam and the foundation (see fig. 1).

In the last decade, dams were more and more equipped or upgraded with electronic measurement and monitoring systems which allow for automatic measurements. As a main benefit of this instrumentation, measurements can be done more frequently, at any time and without additional personnel on site. The equipment with electronic measurement and monitoring systems consists of two essential components: (i) transmitters (sensors) and (ii) data recorders (data loggers). Automatic monitoring systems are usually completed with a local computer on site.
As redundant data storage is essential in dam monitoring, measured data are stored in local databases and also additionally transferred to a central database [Bett97].

**Software Agents**

Software agents represent a new technology for the development of distributed systems which combines concepts derived from speech act theory and from (distributed) artificial intelligence as well as modern software technologies. The nucleus of the agent technology is the agent paradigm. This considers an agent to be a software component that is

- **autonomous**: Software agents have, to some degree, control over their own actions and own their own thread of life. To this end, agents are active software components being able to say “yes” or “no”. It is not possible to invoke methods of an agent externally.
- **communicative**: Inter-agent communication is based on messages and high-level languages. The languages are speech act-oriented, i.e. languages use communicative acts, such as “request” or “query”. Furthermore, agents are, under some circumstances, able to understand the semantic meaning of the underlying communication.
- **social**: Based on their communicative capabilities, agents are able to interact in a dynamic relation network. To achieve their goals, agents may act in cooperation with other agents.
- **proactive**: Agents do not only react in response to events but they act goal-directed and are able to overtake initiatives. Moreover, agents have an internal representation of their environment.

In this respect, the agent paradigm is a novel paradigm that is well suited for the decomposition of complex distributed systems and for the simulation of workflows in decentralized problems [Jenn01].

However, it should be emphasized that the agent paradigm has an abstract nature and requires the application of advanced software technologies. The development of agent-oriented software is still a matter of current research and modeling techniques, e.g. the Agent Unified Modeling Language (AUML) [Auml05] are in its infancy. At present, there exist only few software systems that have the capabilities of software agents, but various frameworks are available that support the development of agent-oriented software [Jade04, Agle02].

**System Design**

The central task in designing an agent-based monitoring system is to map the real-world work flow of structural monitoring onto an effective multi-agent system. In this context, regularly performed tasks, organizational structures, personnel and the interactions within the work flow have to be represented by a system of software agents.
In a first step, the work flow applied by a German dam operator, the Ruhrverband (Ruhr River Association), has been analyzed. The analysis indicates that in total, there is a chain of five regularly performed tasks where the processing frequency of the tasks decreases with every processing step, having time periods of single days up to one year and more. Each of these tasks is briefly described as follows:

**Data acquisition:** Involves the daily measurement of hydrologic parameters, in particular seepage water, water level, water pressures, displacements and changes of temperature.

**Checking plausibility:** Measured data are checked with respect to their plausibility. The checking must provide mechanisms to identify measuring errors, and to notify the responsible expert(s) in case of anomalies. This task is performed in hourly intervals up to daily intervals, depending on the importance of the data.

**Checking short-time behavior:** Parameters measured within every week are checked. The corresponding experts are notified in case of an anomalous behaviour. This task is performed weekly.

**Checking long-time behavior:** This step involves checking of the measured data in respect of their long-time behavior, and is carried out annually.

**Safety assessment:** Safety of the considered structure is verified by regulation. Measured parameters have to be scrutinized and the result of each analysis has to be summarized in annual reports.

The problem analysis also indicates that a group of at least 9 experts is permanently involved in the monitoring process. Each of these experts, encompassing the dam warden and the experienced civil engineers, is responsible for one single specific area of expertise. Altogether, they are organized in four working groups representing four
areas of expertise: (i) dam operation, (ii) geology, (iii) geodesy, and (iv) dam safety. Thus, the complex task of monitoring can be decomposed in several subtasks corresponding to the above areas of expertise, as the result of collaborative work of several experts. These considerations led to the conceptual organigram depicted in figure 2.

**System Implementation**

For the purpose of implementation of the multi-agent system, a workflow has been defined that mimics the approach applied by the Ruhrverband as well as the real world measurement and monitoring systems of the chosen reference structure, the Ennepe dam. The Ennepe dam is an arch gravity dam of 51 m height and 320 m length that was erected from 1902 to 1904 as a masonry dam. In the years 1997 - 2001 it was subjected to extensive rehabilitation and, as an important part of the rehabilitation concept, it was provided with extensive electronic measurement and control systems, such as transmitters (sensors) and data recorders (data loggers) [Bett01].

![Figure 3. Reference structure Ennepe dam.](image)

Basically, the agent-based monitoring system has been implemented according to the conceptual design outlined above. One major element of the concept are the so-called personal agents. Each personal agent represents one human expert involved in structural monitoring and, in particular, maps his expert knowledge. Consequently, the created agents fulfill the tasks of the corresponding experts and work in cooperation with co-agents. Therefore, the personal agents have been modeled as proactive, reasoning agents and implemented on the basis of a “belief-desire-intention” (BDI) architecture [Brat87]. In addition, they provide graphical user interfaces (GUIs) by which users can communicate with the MAS in a comfortable way. Main functions of the GUIs are to display incoming messages (from other agents and users) as well as measurements of the dam behavior (see fig. 4).
However, some of the tasks identified in the work flow of structural monitoring do not correspond with tasks individual experts are charged with. For this reason, two additional agent categories have been introduced: (i) “task-oriented agents” and (ii) “wrapper agents”. Task-oriented agents carry out the generic tasks in the analyzed work flow, such as data acquisition on site or preprocessing of raw data. Wrapper agents encapsulate hardware or legacy software systems and provide services that allow other agents to invoke functions of the wrapped hardware or software, respectively. Both agent categories have been implemented as reactive agents, i.e. they mainly act in response to external event or requests by other agents.

Conclusions

The multi-agent system presented in this paper is designed to support the collaborative work of experts involved in structural monitoring of dams. To this end, all relevant processes and tasks identified within the work flow of dam monitoring have been represented by software agents. As a result, the developed multi-agent system supports the distributed-collaborative work of human experts and provides real-time access to electronic measurement and control systems. It should be emphasized that this solution differs significantly from conventional monitoring systems and stands for an innovative approach. The applicability of the parts implemented could already be verified in a series of field tests at the Ennepe dam. The results obtained are convincing.
References


