Monitoring and Diagnosis of Monuments through Artificial Intelligence

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Abstract

The paper describes the results of a project which aims to improve the capabilities of a monitoring system which supports the management of safety of historical monuments. The improvement has been achieved through the incorporation of additional components developed using artificial intelligence concepts and technologies.
We describe the functions, the architecture and the AI techniques of the system (KALEIDOS) added to the monitoring system
The first version of the system was installed in Pavia to interpret data gathered by the monitoring system of the Cathedral and of six towers. The system is operational since January 1994.

1 Introduction

During the last five years the software development unit of ISMES has worked in the field of the artificial intelligence applications to structural safety.

We dealt with two main problems: the vulnerability assessment of masonry buildings and the management of dam safety. This work has led to the development of three main decision support systems, called IGOR, DAMSAFE and MISTRAL [1, 2].

On the other hand, the civil engineering unit of ISMES has gained great experience in monitoring historical monuments and in interpreting and modelling data collected on them: the Leaning Tower of Pisa or the Cathedral of San Marco in Venezia are examples of structures analysed by ISMES.

On the ground of the above mentioned expertise, we developed a new system, called KALEIDOS, for the on-line management and interpretation of the measures gathered on monuments. The first version of the system was delivered for the management of the safety of the Cathedral of Pavia and of six towers in the same town.

This paper shortly reports about this application, by describing the context, the general architecture and the key ideas which drove the development of KALEIDOS.

2 The context

On March 17, 1989 the Civic Tower of Pavia collapsed. After this event, the Italian Department of Civil Defence appointed a technical-scientific committee to analyse the causes of the collapse and to check the state of other monumental structures of the town. The work of the Committee includes a plan of monitoring surveys and interventions to be carried out on the Cathedral of Pavia and on six towers.

This plan led to the installation by ISMES, in 1990, of an automatic monitoring system linked via radio to a control centre, located at the University of Pavia.

The instrumentation installed on the Cathedral and on the towers allows to acquire the most important *measures* on each monument, such as opening/closure of significant cracks, displacements, stresses and also *cause variables*, such as air temperature, solar radiation, groundwater level and so on.

The data gathered on the monuments are checked by the monitoring system to evaluate the reliability of the measures and to highlight any anomaly. Then, the data are periodically transferred into the historical data bank MIDAS, which allows the off-line analysis, post-processing and plotting of data.

In such situation, two risks were identified, which suggested the development of an *intelligent* system for the monitoring of the structures.

First of all, the monitoring systems currently available allow the carrying out of checks on single values gathered by each instrument. Therefore, these checks neither deal with more than one instrument at a time, nor with more than one reading at a time for each instrument. In addition, any behaviour (either of the structure, or of the instruments) which is not consistent with the reference model generates a warning message. Because of the limited interpretation skills of the people on-site, false alarms cannot be identified and therefore require expert attention.

On the other hand, off-line expert analysis on series of data may require delays not compatible with the needs of the safety management of the structures.

The use of artificial intelligence techniques allowed to improve the capabilities of the monitoring system. AI contributed in collecting the expert knowledge related to data interpretation and delivering it through a system linked with the existing monitoring system. The system can filter and classify the anomalies by using different types of knowledge (e.g. geometrical and physical relationships). It can take into account the whole set of measurements and warnings to identify the state of the monitored structures and to explain it. This allows a part of the expert interpretation to be performed on-line, and therefore to *reduce* the requests for expert intervention and to *increase* the level of safety of the structures.

3 KALEIDOS

KALEIDOS is an on-line interpretation system linked to the monitoring system of a structure to provide a global interpretation and explanation of its state. KALEIDOS is comprised of the following modules:

- ☎ communication module: manages the data transfer from the monitoring system;
- ✍ evaluation module: identifies the state of the structure;
- 📖 explanation module: generates natural-language explanations of the deductions of the evaluator;
- 🖥 man/machine interface: allows the user to access the results of the computation;
- ☻ database management module: manages a database of measurements and evaluations.

The communication module calls the monitoring system and receives the data gathered during the last acquisition (normal real-time procedure) or collected while KALEIDOS was, for some reason, not active.

The *evaluator* is comprised of two sub-modules, a numerical processor and a symbolic processor.

The numerical processor codifies the *deep knowledge* about the structure: it contains analytical models of the behaviour of the structure and allows to highlight processes currently going on, such as, for instance, opening or closure of cracks or foundation settlements of columns.

The symbolic processor performs more shallow analysis of the state of the structure, performing qualitative interpretation of the data. Congruency relationships among data are defined, using concept such as the order of magnitude of measures or their direction.

Moreover, heuristic knowledge about the structure is codified by empirical formulas, which define relations based on the alarm state of single instruments, taking into account their reliability and significance. These rules are aimed to catch and highlight any possible dangerous situation not yet described analytically by the numerical processor.

The result of the checks performed by the evaluator is the identification of the current state of the structure. From the trace of execution, using knowledge about the behaviour of the structure and the instruments, the *explanation module* generates natural language messages. They describe the current state of the structure and the deductions of the system.

The user can access the results of the processing through a *window-based interface*. The interface draws on the screen graphical representations of the objects which have been assessed (instruments, towers, columns, ...) and displays them using a colour scale based on the state of the object. Interactors are available to get more refined information about the state of the structures, by focusing on interesting details

KALEIDOS provides the users with a *static data base* of test cases, and a *dynamic database* collecting all the data related to the control system (measurements, evaluations, explanations). It is possible to select a situation from the data base and show on the screen its graphic representation and explanations.

KALEIDOS was developed and delivered on personal computers using Prolog, C and VisualBasic under MS Windows. It deals with 120 instruments installed on the Cathedral and on the six towers.

Acknowledgements

References

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