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The KALEIDOS system for structural monitoring of monuments

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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 arti¬ficial intelligence concepts and technologies.

We describe the functions, the architecture and the key ideas 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.

INTRODUCTION

[…] 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.

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.

[…]

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:

1. communication module: manages the data transfer from the monitoring system to KALEIDOS and broadcasts automatic telephonic alarms when needed;
2. evaluation module: identifies the state of the structure;
3. explanation module: generates natural-language explanations of the deductions of the evaluator;
4. man/machine interface: allows the user to access the results of the computation;
5. database management module: manages a database of measurements and evaluations.

[…]

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

DISCUSSION

The key idea which drove the design and development of the evaluation module of KALEIDOS is that the diagnostic process is performed by exploring paths of reasoning within state spaces describing the physical system. In the following paragraphs this topic is discussed with reference to specific parts of KALEIDOS' reasoning .

Reasoning paths

An expert engineer is able to use different types of knowledge, such as empirical associations and causal models, compiled knowledge, qualitative and quantitative models and hierarchical descriptions. He is also able to organise and use the above mentioned knowledge through reasoning processes related to the specific tasks to be performed. A model of this kind of expertise is presented in [4]; different layers of knowledge are described:

1. domain level;
2. inference level;
3. task and strategic level.

[…]

State spaces

Different reasoning paths may be used to solve interpretative problems. In the following we will relate all these reasoning paths to a common system view. In this view the state space of a system is the set of possible (and not possible) states of the physical system. Moreover the state space includes, within the area of possible states, two sets defining desirable and undesirable states.

Note that the set of possible states is not the union of the desirable and undesirable states. The reason is that, while (im)possible states express the semantics of the model, (un)desirable states express the pragmatics (we want that the system behaves as near as possible to the desirable states and as far as possible from the undesirable ones). This is a common way to try to control systems which are not completely known (i.e. the system may reach not optimum states or not well known states but has not to reach critical states). Based on the space state, different tasks are possible:

[…]

Paths of reasoning in monitoring of civil engineering structures

Typical paths of reasoning in monitoring of civil engineering systems are described in the following. These reasoning paths are used by KALEIDOS for interpreting the state of the monuments to be checked.

Reasoning about single measurements (RP1)

The state space is identified by effect variables (e.g. settlements of columns are effect variables, while solar radiation and air temperature are cause variables) which are measured by the monitoring system. Each variable has real values and is considered separately.

Desirable and undesirable states are defined through thresholds. Each variable has a set of

[…]

Reasoning about cause-effect measurements groups and associated models (RP2)

Groups of causes and related effect variables are considered. For each group (a set of causes and one effect) desirable and undesirable states are defined using quantitative models and thresholds. The models may be derived from past observations or from the design behaviour of the structure. For each group all the measurements are filtered, then the model is used to compute the effect from the measured causes. Then the measured effect is compared with the computed one. Possible situations may be:

[…]

Reasoning about families of measurements (phenomena) (RP3)

The state space is identified by sets of effect variables belonging to the same type of instruments (e.g. the set of deformometers installed on a tower). Each set identifies a global behaviour of the physical system which we call phenomenon. The identification of a phenomenon means that we are not able to identify a particular physical process in the structure (e.g. a highly anomalous settlement of a column). Nevertheless we may identify a more general and uncertain situation (e.g. highly anomalous movements of the structure). In some cases the available information could be not sufficient to identify a particular process, but the general behaviour of a family of instruments may provide sufficient evidence for an abnormal situation.

The desirable and undesirable states are defined though sets of empirical rules which take into account the significance and the reliability of each instrument. The values of each set of variables

[…]

Reasoning about processes (RP4)

The state space is identified by a set of possible physical processes which may be active in the structure (e.g. rotation, translation, seepage). Each process has a state, from a desirable one (normal) to a highly undesirable (very high anomaly). This state is defined through qualitative models expressing relations among effect variables. The models describe physical or geometrical constraints among measurements. The values of the variables are abstracted from real values to qualitative descriptions (e.g. a structural process may be not active, low, medium, high, very high).

[…]

The integration of different reasoning paths

Monitoring systems such as KALEIDOS use more than one reasoning path. An obvious problem arises: how to integrate different paths and the different interpretations they provide?

A first consideration is that all the measurements, models, phenomena or processes are referred to

[…]

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