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Neural nets and structural safety: applications and ideas

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Abstract

The paper describes the first achievements and the future developments of the application of neural networks to structural engineering at ISMES.
Two main fields of applications are presented: neural nets in design, with reference to the design of arch dams, and in data interpretation, with reference to the management of structural safety.

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 engineering, developing knowledge-based systems dealing with different tasks, such us the vulnerability assessment of masonry buildings, the management of dam safety, the design of dams and the monitoring of historical monuments.
These systems often manage and integrate different kinds of knowledge, such as deep engineering knowledge of physical mechanisms and behaviours (e.g. rotation of a dam), qualitative understanding of phenomena (e.g. congruency relationships among displacements) and heuristic knowledge.
While deep knowledge is usually codified by numerical algorithms, and qualitative reasoning may be implemented by symbolic processing, neural networks seem to be the best choice in many cases when heuristic knowledge is involved.
In the following, some applications of neural networks to structural engineering are presented, derived from projects developed or under development at ISMES. Two main families of applications are taken into account: the design of arch dams and the management of structural safety.

2 Neural nets in design: the DESARC system

Where local conditions (shape of valley, foundation quality) are favourable, arch dams can offer quite attractive solutions for creating artificial impoundments. However, the analysis and design process is considered to be more complex, costly and time consuming for arch dams than for

alternative dam types. This drawback is particularly felt in the preliminary stage, during which quite often several different shapes have to be analysed.
For such reasons ISMES developed an interactive design environment for preliminary analysis of arch dams (DESARC), that allows the user perform in real-time the design the dam shape, then to analyse the stresses, make changes and analyse how the stress pattern is modified [1].
Within DESARC, a PC based application written in C and VisualBasic, the task of identifying the initial near optimal dam shape, to be subsequently analysed and optimised, is carried out by a neural network.
The net, a multilayer perceptron, was trained to build minimum volume dams for a given shape and boundary conditions. Starting from six parameters defining the characteristics of the valley, the net is able to identify the values of six main parameters which define the shape of the arch dam to be built.
The net was comprised of three layers, with 6 neurons in the input layer (one for each input parameter), 12 neurons in the hidden layer and 6 neurons in the output layer (one for each output characteristic). The was trained using a training set comprised of 180 dams, both real and artificial, and achieves very good results in generalising its knowledge on new cases.

3 Neural nets for the management of structural safety

The increase, in recent years, in the use of automatic instrumentation, telemetry and data storage in structural monitoring has resulted in large amounts of data requiring analysis and interpretation.
Developments in the field of neural networks have provided new methods of processing data and opportunities for building data classification systems. These techniques provide the possibility of extending the use of computers to assist engineers in interpretation of the data.

4 Pattern recognition in monitoring data

The interpretation of monitoring data performed by structural safety experts seems to be based on a process of pattern recognition and classification: the experts take drawings of monitoring data and identify features of the drawings which are considered to be relevant to dam safety. Possible features may be trends, spikes, steps or plateaux.
Automatic pattern recognition of such features is a difficult problem, because it is hard to define deterministic or statistical models of features in data which are significant with reference to dam safety. However, heuristic rules are used by experts to interpret data and sets of already interpreted data are available. This seems to be a good reason to train and use artificial neural networks for such task.
Within the framework of the DAMSAFE project [2], which aims to investigate the application of Artificial Intelligence techniques in the field of dam safety, a neural network classifier was developed, in order to provide a software tool for better using data gathered by monitoring systems and supporting the tasks of the safety managers [3].
The tool identifies and classifies features in data which are considered to be significant to dam safety. At present a prototype has been developed which is concerned with the problem of identifying steps and plateaux. The core of the system is a neural classifier, that identifies features of the input diagrams; the classifier is comprised of three specialised nets, for recognising upward and downward steps and plateaux.
The neural model used for developing the prototype was the multy-layered feedforward network with the backpropagation learning. Several different topologies were tried to identify features within hourly time series 84 hours long. The best performance was achieved by a three-layer net,

with 84 input nodes, 5 hidden nodes and 2 output nodes. A smaller number of hidden nodes was not enough to correctly generalise after the training phase; a larger number of hidden nodes required excessive computational resources and implied problems concerned with the convergence of the learning algorithm.
The classifier was trained with 575 time series extracted from a data base of information related to a gravity dam. The data were collected by an instrument that measures seepage through the dam. After 33837 training iterations, the net was able to recognise features belonging to the training set with no errors. When processing features outside the training set, the net agreed with the user in about 90 percent of the cases, with reference to a validation set comprised of 516 time series.
The neural classifier was written in C on a personal computer.

5 Empirical evaluation of monitoring data

ISMES has developed two systems (MISTRAL and KALEIDOS) for the management of the safety of dams and monuments [2]. Their task is the interpretation of monitoring data. A part of this task, codifying the shallow knowledge about the structure and the instrumentation, is implemented through empirical rules ba-sed on the alarm state of single in-struments, taking into account their re-liabi-lity and significance. Such rules are derived from the analysis of a set of exemplary cases, which allowed to identify weights to be given to the parameters used by the rules.
This process, time consuming and boring for the experts, seems a good field of application for neural networks: a neural network is currently under development, which is expected to perform the empirical evaluation of data with the same results of the symbolic processors previously used, but with more light development and tuning effort.
Some feed-forward networks have been trained, which agree with symbolic processing in the 98% of cases. It seems a very good result, which could be exploited in two ways: the net could substitute the pre-existing symbolic processor; at the end of the training of the net, the weight on the synapses could be used within the symbolic processor as parameters of the empirical evaluation.
The design and training of the networks were performed using NeuralWorks Professional Plus.

References

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