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The Contribution of Soft Computing Techniques for the Interpretation of Dam Deformation

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Agenda

- Introduction
- Structural Health
- Methods
  - Multiple linear regression
  - Multi layer perceptron
  - Validation
  - Performance Criteria
- Application
- Result and Discuss

Introduction

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- The structural health and reliable functioning of an arch dam requires good understanding of causative factors and the mechanism of deformations.
- This can be achieved only through proper monitoring and analysis of the investigated dam.

Introduction

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- The two main objectives of the comprehensive interpretation of measurement results are:
  - To get to know about the performance of the dam and to justify the mathematical model used for the structural analysis
  - To detect, **at an early stage**, deviations from what is supposed to be the "normal" dam behaviour.

Structural Health

- Why we must do deformation monitoring?

"Fire can be stopped by water, but nothing can stop a mass of hundred billion cubic meters of water going on a rampage. The collapse of a dam is a disaster that seconds only to such natural catastrophe same as an earthquake. *"

* An Italian Professor of Dam Engineering, 1950s

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Structural Health

The Val di Stava Dam collapse occurred on July 19, 1985. 268 people died.

http://www.youtube.com/watch?v=_DE9kqX9304&feature=related
http://www.youtube.com/watch?v=w0f-j4VZr7M

Methods

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- Multiple linear regression (MLR)
- Multi-linear perceptron (MLP)

are well known methods in dam deformation analysis.

Multiple Linear Regression

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- Multiple linear regression (MLR) is a multivariate statistical technique for examining the linear correlations between two or more independent variables and a single dependent variable

Independent Variables

$$\{x_{i,1}, x_{i,2}, \ldots x_{i,p}\}_{i=1}^{n}$$

Dependent Variables

$$\{y_i\}_{i=1}^{n}$$

Error Function

$$J = \frac{1}{2}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2$$

To Find Desired Coefficient

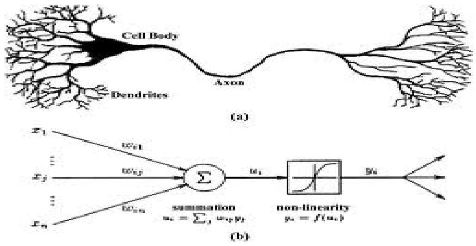
$$\left\{\frac{\partial J}{\partial \beta_i} = 0\right\}_{i=1}^{p}$$

Prediction of Dependent Variables

$$\hat{y}_i = \beta_0 + \beta_1 x_{i,1} + \beta_2 x_{i,2} + \ldots \beta_p x_{i,p}$$

Multi Layer Perceptron

- An appropriate model/simulation of the nervous system should be able to produce similar responses and behaviours in artificial systems.
- The nervous system is build by relatively simple units, the neurons, so copying their behaviour and functionality should be the solution.



Multi Layer Perceptron

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- MLP is a feed forward artificial neural network model that maps sets of input data onto a set of appropriate output.
- MLP consists of multiple layers of nodes in a directed graph, with each layer fully connected to the next one.
- Except for the input nodes, each node is with a nonlinear activation function.
- MLP utilizes a supervised learning technique called back-propagation for training the network

Multi Layer Perceptron

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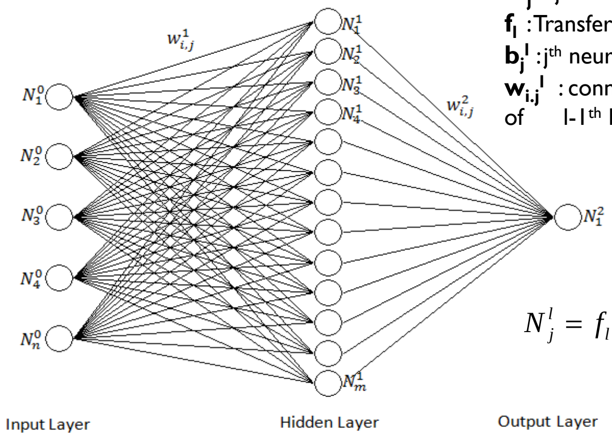
N_j^l : j^{th} neuron of l^{th} layers output
f_l : Transfer function of l^{th} layers
b_j^l : j^{th} neuron of l^{th} layers bias value
$w_{i,j}^l$: connection weight of i^{th} neuron of $l-1^{th}$ layer to j^{th} neuron of l^{tf} layer



$$N_j^l = f_l\left(b_j^l + \sum_i N_i^{l-1}.w_{i,j}^l\right)$$

Validation

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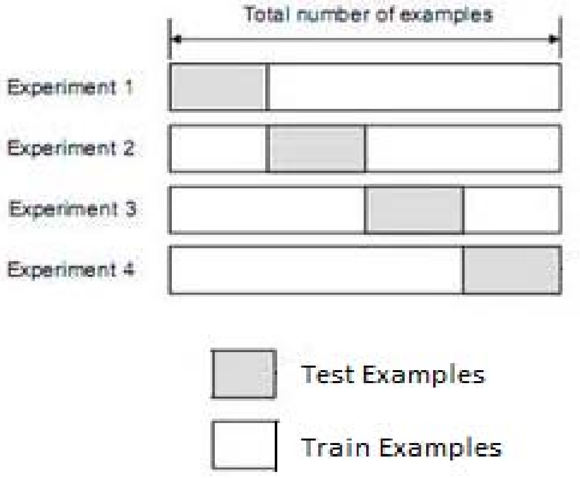
- Validation must be done to measure how much success regression is made by algorithms each of which is supervised learning method data points obtained from experiment.

- The most well known validation methods are hold out validation, k-fold cross validation, leave-one-out cross validation methods.

Validation

4-Fold Cross Validation



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Performance Criteria

- 5 different criteria were used for measuring predict success .
  - mean of errors (μ)
  - the standard deviation of errors (σ),
  - coefficient of determination (R^2)
  - centered values standard deviation of error (σ)
  - centered values coefficient of determination (R^2).

$$e_i = y_i - \hat{y}_i \qquad \mu = \frac{1}{n}\sum_{i=1}^{n} e_i \qquad \sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(e_i - \mu)^2} \qquad R^2 = 1 - \frac{\sum_{i=1}^{n}(e_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

Application

- The main objective of our application is the comparison of MLR, MLP and ICOLD Benchmark Workshop participants' methods to construct the daily displacement forecasting system.
- The most important problem in dam displacement problem is to determine how many previous days inputs the data will provide the model.
- We produced a solution via Validation Algorithm.

Instrumentation

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- The design of instrumentation has developed rapidly since the 1970s.
- To be useful instruments must be easy to maintain and repair, if they are accessible.
- A pendulum or plumb line is often used to detect differences with reference to a vertical datum.
- They are installed in shafts built either during construction or after.
- The average error is generally ±0.1mm and the better.
- Two pendulums are used in arch dams. One is direct and the other is inverted.

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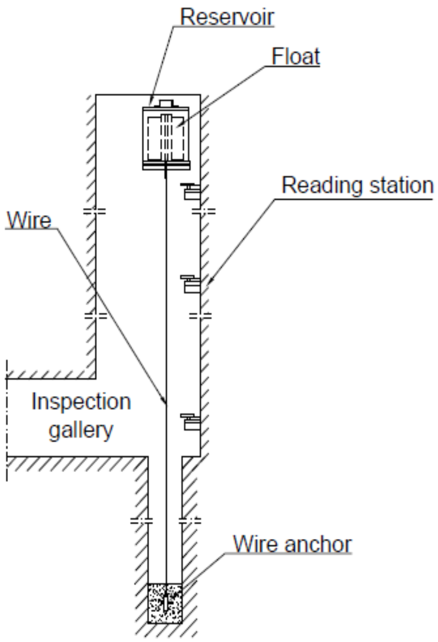

Pendulum System in an Arch Dam

Direct and Inverted Pendulum System

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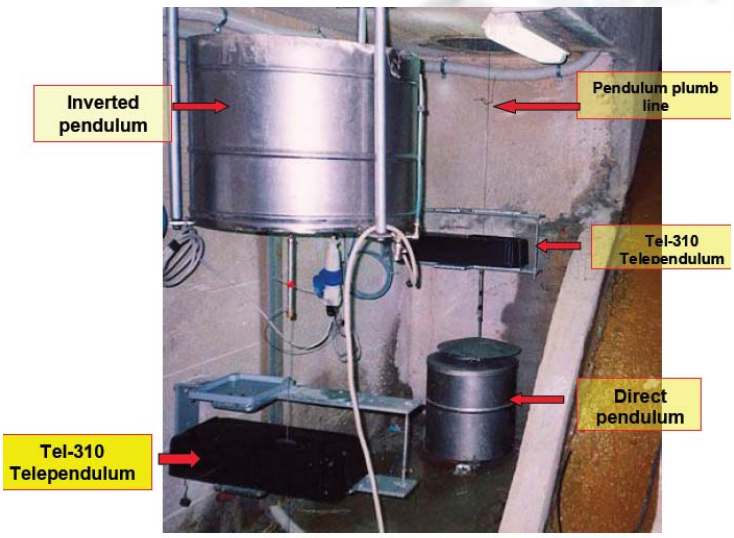

Schlegeis Arch Dam

- Data are taken from the 6th ICOLD Benchmark Workshop on Numerical Analysis of Dams (2001, Salzburg).
- The aim of this workshop was being interpretation and a subsequent prediction of the crest displacements of Schlegeis arch dam.

Schlegeis Arch Dam

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- Constructed between 1969 and 1971.
- Double curvature
- Height: 131m,
- Crest length: 725m,
- Max water level: 1782m (a.s.l.).
- The observed radial crest displacements of dam are analyzed using the time histories of water level, air and concrete temperatures as input parameters.

Benchmark Data

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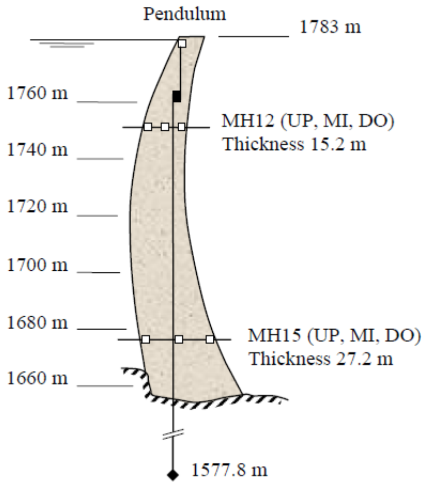
- The provided data (input data):
  - water level,
  - the air temperature
  - the concrete temperatures at 6 points

  (One value per day for the period 1992 to 2000).

- Response Value (Output)
  - Radial crest displacement of the central cross section.

  One value per day is provided for 1992 to 1998.



Benchmark Data

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$\{w_t, w_t^2, w_t^3, w_t^4\}$ 1,2,3 and 4th power of water level at time t

$\{T_{t,up}^{H12}, T_{t,mid}^{H12}, T_{t,down}^{H12}\}$ Temperature of upstream, middle and downstream concrete at H12 location

$\{T_{t,up}^{H15}, T_{t,mid}^{H15}, T_{t,down}^{H15}\}$ Temperature of upstream, middle and downstream concrete at H15 location

t Air temperature

e^t e^{-t} Positive effect of time and negative effect of time

years	1992	1993	1994	1995	1996	1997	1998	1999	2000
	Train & Validation Set							Test Set	

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Results of MLR

- How many past days' input data will provide the best regression success with MLR model is investigated. MLR model, which used past m days inputs shown as MLR_m .
- To decide which MLR model is the best predict success, all models from MLR_1 to MLR_{40} were tested. 4-fold cross validation process was implemented to decide best MLR model over the 7-years train set.

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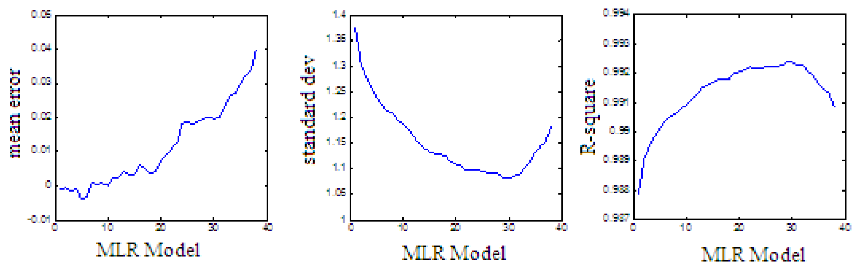
Results of MLR

- According to k-fold validation process, each model's mean error, standard deviation, and R^2 values obtained are shown.



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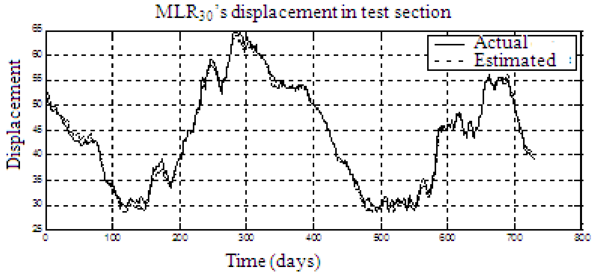
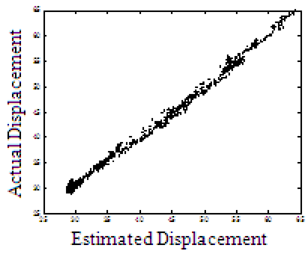
Results of MLR

- The result of validation process shows that MLR_{30} performed the best validation performance. It shows that MLR_{30} will show the best test set performance too. The success of MLR_{30}'s prediction of test set is shown.





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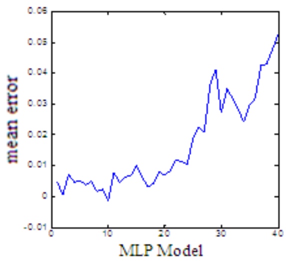
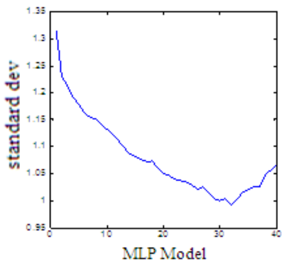
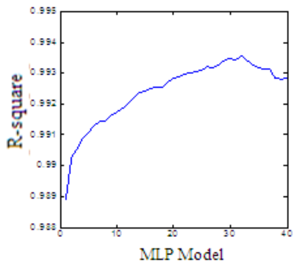
Results of MLP

- MLP model, which used past m days inputs and has h hidden layer's neuron shown as MLP_m^h. To investigate the best MLP model, the performance of all 7-years training data was confirmed by two different 4-fold cross-validations. In the first validation process how many days' inputs will be used is determined. This validation process results are shown.







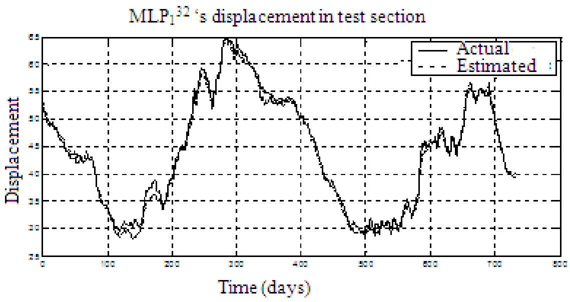
Results of MLP

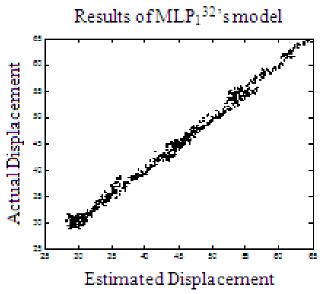
- The second validation process is applied to determine the best MLP models hidden layers neuron number. According to this analysis it shows that when the number neurons in the hidden layer increases, the performance of MLP deteriorates. This information is proves that dam displacement prediction problem is nearly linear as chosen independent variables. The result of second validation process is shown in Table.

	Model	MLP_{32}^{1}	MLP_{32}^{2}	MLP_{32}^{3}	MLP_{32}^{4}	MLP_{32}^{5}	MLP_{32}^{6}	MLP_{32}^{7}	MLP_{32}^{8}	MLP_{32}^{9}	MLP_{32}^{10}
R-square	Validation	0.9901	0.9900	0.9867	0.9831	0.9864	0.9881	0.9718	0.9817	0.9559	0.9750
	Train	0.9932	0.9953	0.9953	0.9993	0.9992	0.9984	0.9980	0.9974	0.9991	0.9991

Results of MLP

- According to all two validation process MLP_{32}^{I} has the best validation performance. It shows that MLP_{32}^{I} will show the best test set performance too. The success of MLP_{32}^{I}'s prediction of test set is shown in Figure.





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Results and Discuss

- According to the 6th ICOLD Benchmark Workshop on Numerical Analysis of Dams synthesis report, 9 participants attended to the competition.

Participant	Authors	Methods
1	S.Bonelli, H. Felix	MLR+ARMA
2	A.Carrere, C. Noret-Duchene	MLR
3	M.Fanelli,G.Guiseppetti	MLR+FE
4	P.Palumbo, L.Piroddi	MLR+NARX
5	F.Perner, W.Koehler	FE+MRL+ANN
6	A.Popovici,R.Sarghiuta	MLR+FE
7	R.Promper	MLR+TLM
8	V.Saouma,E.Hansen	NP
9	B.Weber	MLR

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Results and Discuss

- According to the table, both MLR_{30} and MLP_{32}^{l} model performances are better than all competition participants' performance. MLR_{30} and MLP_{32}^{l} performance are close to each other, but MLR_{30} is the best model

	MLR_{30}	MLP^{1}_{32}	P1	P2	P3	P4	P5	P6	P7	P8	P9
Mean Error	0.3095	0.4073	-0.81	-0.05	-0.71	-0.14	-0.93	-0.79	-0.67	-1.02	-0.73
St.Dev.	0.8056	0.8423	1.30	1.62	1.75	1.20	1.39	1.20	1.77	2.40	1.26
R-square	0.9925	0.9912	0.983	0.974	0.969	0.986	0.980	0.985	0.968	0.942	0.984
(St. Dev.)	0.8056	0.8423	1.01	1.62	1.61	1.19	1.03	0.890	1.64	2.18	1.02
(R-square)	0.9934	0.9929	0.99	0.974	0.974	0.986	0.989	0.992	0.973	0.952	0.989

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Conclusion

- In this study, the comparison of MLR, MLP and ICOLD Benchmark Workshop competition participant's methods to construct daily displacement forecasting system to insure the Schlegeis arch dam structural health safety has been presented.
- In statistical methods such as MLR and MLP, the most important problem in dam displacement problem is to determine the number of data belonging to the past days.
- In addition to the classical statistical methods, some more sophisticated methods such as Validation algorithms are needed for optimized that number.
- Implementation of machine learning methods at dam displacement prediction is possible with working civil, surveying and computer science engineer together.

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Thank you very much for your attention and patience

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