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Fuzzy Neural Networks for water level and discharge forecasting

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A new procedure for water level (or discharge) forecasting under uncertainty using artificial neural networks is proposed: uncertainty is expressed in the form of a fuzzy number. For this purpose, the parameters of the neural network, namely, the weights and biases, are represented by fuzzy numbers rather than crisp numbers. Through the application of the extension principle, the fuzzy number representative of the output variable (water level or discharge) is then calculated at each time step on the basis of a set of crisp inputs and fuzzy parameters of the neural network.

The proposed neural network thus allows uncertainty to be taken into account at the forecasting stage *not* providing only deterministic or crisp predictions, but rather predictions in terms of "the discharge (or level) will fall between two values, indicated according to the level of credibility considered, whereas it will take on a certain value when the level of credibility is maximum".

The fuzzy parameters of the neural network are estimated using a calibration procedure that imposes a constraint whereby for an assigned $h-$level the envelope of the corresponding intervals representing the outputs (forecasted levels or discharges, calculated at different points in time) must include a prefixed percentage of observed values.

The proposed model is applied to two different case studies. Specifically, the data related to the first case study are used to develop and test a flood event-based water level forecasting model, whereas the data related to the latter are used for continuous discharge forecasting.

The results obtained are compared with those provided by other data-driven models - Bayesian neural networks (Neal, R.M. 1992, Bayesian training of backpropagation networks by the hybrid Monte Carlo method. *Tech. Rep. CRG-TR-92-1*, Dep. of Comput. Sci., Univ. of Toronto, Toronto, Ont., Canada.) and the Local Uncertainty Estimation Model (Shrestha D.L. and Solomatine D.P. 2006, Machine learning approaches for estimation of prediction interval for the model output. *Neural Networks*, 19(2), 225-235.). The comparison shows the effectiveness of the fuzzy neural network forecasting model in estimating water levels or discharges under uncertainty. In particular, the fuzzy neural network enables us to define bands that describe, for an assigned h-level, the range of variability of the predicted variable. An analysis of the results obtained reveals that these bands generally have a slightly smaller width compared to the bands obtained using other data-driven models, the percentage of observed values contained within the bands being equal.