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Computational Fuzzy Processing of Uncertainty in Environmental Modelling and Simulation

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Abstract

Impreciseness, incomplete knowledge, linguistic vagueness and randomness are the main sources of uncertainty in environmental engineering. The enhancement of the information content of environmental data by including a quantification of the resulting uncertainties is very important to help the engineer make better informed decisions. The development of a fuzzy mathematical and computational framework for the consistent estimation and propagation of the uncertainty that is induced by the inherent impreciseness and incomplete knowledge in environmental data and simulation techniques for the purpose of a well-informed decision making process is the subject of this thesis.

A robust mathematical framework of fuzzy numbers based on their interpretation as possibility distributions are introduced and further developed. The adoption of the concept of non-separable fuzzy points in this thesis has fulfilled the usually missing consistency of fuzzy functions with the possibility and necessity measures. Differentiation and integration of fuzzy functions with domains of fuzzy numbers are developed so that uncertainties inherent in the measured quantities as well as in the coordinates of the samples of environmental data sets are correctly dealt with.

The computational foundation of fuzzy environmental modelling and simulation is also improved. An enhanced evolution strategy is developed to correctly evaluate the α-cut sets formulation of Zadeh's extension principle. New fuzzy interpolation methods are developed to meet the need of reflecting the uncertainty resulting from the discrete and distributed state of the measured data sets as well as the intrinsic impreciseness in the measured quantities and coordinates of the locations of the measurements. Mathematically thorough and rigorous fuzzy numerical methods for the solution of fuzzy initial and boundary value problems are also addressed. The uncertainty in the initial and boundary conditions or in the model parameters along with the uncertainty resulting from the discretisation of the domain of the problem are, thereby, dealt with explicitly. Generalised stabilisation techniques are suggested for these numerical methods to overcome the non-physical oscillation in the approximation resulting from solving an advection dominated problem. Two academic case studies of morphodynamic analysis and groundwater and contaminant transport modelling and simulation are demonstrated as prototypes of the applications of the achieved results.

This dissertation is a contribution to the efforts made to establish an environmental modelling and simulation practice that considers the uncertainty as a non-separable part of the results it delivers.

Keywords: uncertainty in environmental engineering, fuzzy interpolation, fuzzy FEM and FVM