Design Issues of the GMDH-based Control System for Growth of Plant Species Irrigated with Processed Wastewater

Vladimir A. Vissikirsky[1], Volodymyr S. Stepashko[1], and Ioannis K. Kalavrouziotis[2]

[1]*Department for Information Technologies of Inductive Modeling, the International UNESCO Center of Information Technologies and Systems of the National Academy of Sciences of Ukraine, Ukraine*
[2]*Department of Environmental and Natural Resources Management , University of Ioannina, Greece*

vis@mathmod.kiev.ua, astrid@irtc.org.ua, ikalavru@cc.uoi.gr

Abstract. *In recent applications, the GMDH methods were applied by authors to estimate different aspects of behavior of plant species irrigated with processed wastewater. The purpose of this paper is to consider general features of the control system intended to provide integral and consistent framework for carrying out and implementation of different modeling, analysis, and control tasks in the field of forest plant species and agricultural crops irrigated with processed wastewater from the Wastewater Treatment Plants. The system shall provide intelligent storage and processing of accumulated estimation models, performance criteria, control strategies, include inductive modeling, quantitative and qualitative reasoning tools, etc.*

Keywords

Environment, irrigation, GMDH, control, wastewater, WWTP.

1 Introduction

The paper considers the issues concerning the design of a control system, the function of which is to provide integral tools for modeling, analysis, and control of growth of forest plant species and agricultural crops irrigated with processed wastewater (called below the Plant Species Growth Control System).

The reuse of reclaimed wastewater for agricultural irrigation provides economic and environmental benefits. Irrigation with processed wastewater can increase the available water supply, as well as prevent wastewater discharge into natural water bodies. In addition, wastewater contains chemical elements that are normally required for growth of plant species. At the same time, the reuse of wastewater for irrigation implies comprehensive study of species' behavior, considering ecological chains with complex interactions, specific climate, cultivation, and other conditions. A Wastewater Treatment Plant (WWTP) is also a complex dynamic system with unknown mathematical descriptions of processes. Therefore, the integrated study and design of such complex engineering and environmental system requires the application of a range of different analysis and modeling methods. It is also important to provide coherent interaction between the WWTP Control System and the Plant Species Growth Control System at the operation phase. General interface between the control systems is shown in Fig. 1.

The modeling and analysis of experimental results is intended to determine behavior of species, find dominant factors, and identify how good, safe, and reliable are the properties in order to utilize a species with processed wastewater supply. Since behavior and properties of species grown with wastewater supply are the result of complex ecological interactions, it is reasonable to apply the GMDH methods to obtain estimation models for those tasks. A number of relevant works with use of the GMDH and qualitative assessment methods have been carried out to study behavior of various agricultural and forest plant species grown under different conditions: mechanical properties of trees (axial compression and bending) depending on concentrations of chemical elements contained in wastewater [1], growth dynamics of trees irrigated with wastewater (development of tree height and mortality over time) [2, 3]. The qualitative analysis techniques were applied together with the GMDH, in order to assess the plant species behavior under different conditions: irrigation of forest species with wastewater and sludge [4], heavy metals impact on agricultural species cultivated near the highway [5, 6], etc. Different design issues of the modeling, analysis, and control system were considered in [7-9].

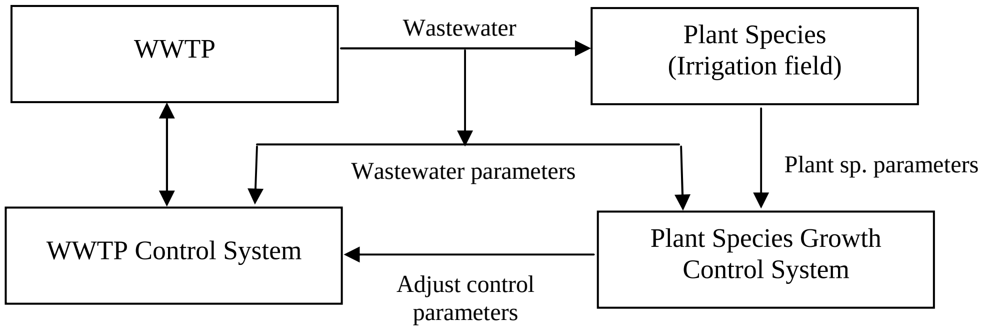

Fig. 1. General interface between the WWTP Control System and the Plant Species Growth Control System

2 Overview of main features of the Plant Species Growth Control System

Here, we consider main features of the Plant Species Growth Control System. This system shall be developed for two phases: design and operation phases. At the operation phase, the system shall provide real-time monitoring of the wastewater and plant species parameters, and advise the WWTP control system on wastewater content, water supply mode, etc., to be met in order to observe the constraints and ensure criteria of optimum plant species performance. Prior to the operation phase, it is required to design a comprehensive study of plant species behavior under different wastewater supply cases, obtain estimation models, include them into the knowledge base, develop control strategies proceed from the constraints and performance criteria.

The tasks at the design phase are shown in Fig. 2. The experiments directed to identify effects of process wastewater on species' behavior are conducted by series, during long-term period, with the extension of number of investigated species and measured wastewater parameters. Therefore, measurement data are obtained by portions, and analyzed for both current set of experiments and the whole scope of all previously obtained results.

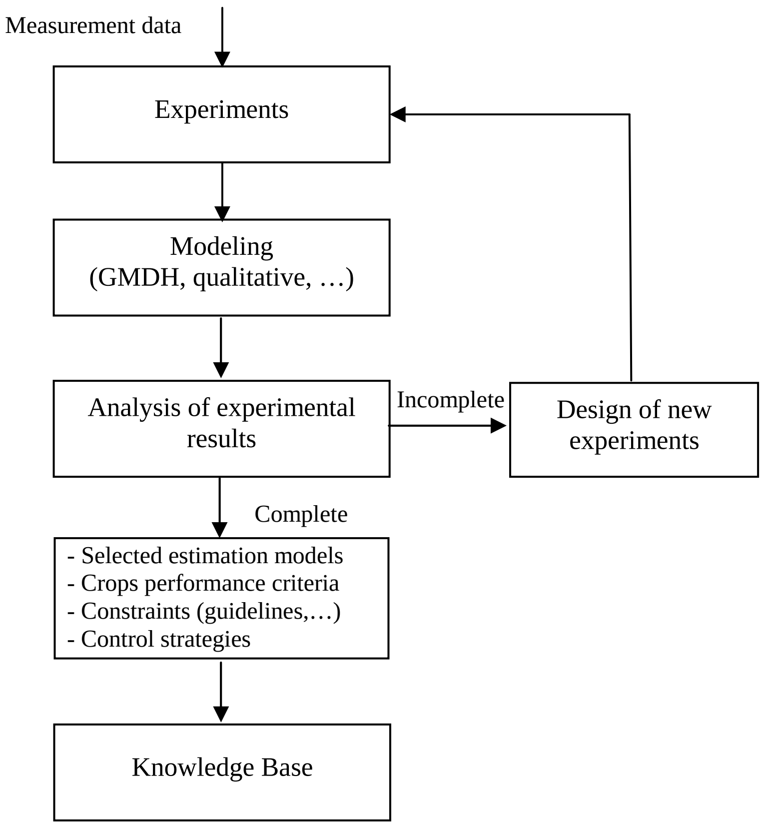

Fig 2. Flowchart of the Plant Species Growth Control System development at design stage

At the design phase, the system shall provide the decision-making support for the following main stages:

1) Stage of experimental study. This stage (design of experiments, planting of species, measurements, data processing and analysis) is a long-term iterative process due to complex nature of ecological interactions and slow growth of plant species. Design of the next-phase experiments implies making the decisions about what kind of experiments shall be carried out to decrease the degree of uncertainty of currently available results. In addition, in each iteration, reliability and completeness of the experimental results shall be considered to make decision whether to continue the experiments or stop them.

2) Stage of making the conclusion: if the results of experimental study are successful or not, i.e. if it is possible to implement them into the real-word applications or not.

3) Stage of the development of monitoring and control techniques. At this stage, the decisions shall be made about what monitoring and control techniques to be used in a real-world application, are the most suitable.

4) Stage of implementation. At this stage, the decisions shall be made if it is reasonable to apply the results to the specific area.

The purpose of the knowledge base (KB) is to provide integral data and model storage and handling. Among other, it shall describe a set of estimation models $M = \{m_i\}$ obtained for different series of experiments. Each estimation model in the KB shall be described so as to represent relationships with measurement data and other estimation models via variables and objects involved, and to provide further handling and analysis of the models in common. Basic components included in the description for the considered application domain are the following:

Objects:

1) Set of investigated species (*S*) with hierarchical description of measured species' parts (*G*), e.g. roots and leaves.

2) Set of water supply cases (*W*): processed wastewater, control (irrigation) water, irrigation water + added chemical elements, etc.

Variables and parameters:

3) Set of chemical elements and indices (*E*): general indices (acidity, hardness, conductivity, radioactivity, etc.); inorganic constituents (Ca+2, Mg+2, K+2, NO3, SO4,...); organic constituents; heavy metals and trace elements (Cd, Mn, Cu, Zn,.Co,...); solids, and other components.

4) Properties of species (*R*): mechanical properties (axial tension, axial compression, cross compression, bending); physical indices (height, mortality rates).

5) Other conditions (*K*) (area, facility, environmental conditions, etc.).

Basic operations with estimation models in the knowledge base

The knowledge base describes global sets of input variables (*X*), output variables (*Y*) and parameters (*P*), as well as relationships between them and estimation models. Depending on the specific model, different subsets from sets of objects and variables play role of input or output variables, e.g., chemical elements are input variables ($X_i \subseteq E$), mechanical properties are output variables ($Y_i \subseteq R$), and environmental conditions (temperature, etc.) are parameters ($P_i \subseteq K$). Description of an estimation model m_i can be generally represented as follows:

$$D_i = D(m_i, X_i, Y_i, P_i, (W_i, S_i)), \quad (1)$$

where $X_i \subseteq X, Y_i \subseteq Y, P_i \subseteq P, W_i \subseteq W, S_i \subseteq S,$

The knowledge base shall provide conventional data and models handling, as well as reasoning techniques, in particular, possibilities for qualitative reasoning. Data and models handling is used for information and analysis purposes. For example, the investigator may want to retrieve details about what models and results have been obtained for a species or for a subset of species, thus analyzing similarity or difference between the results, comparing input variables; searching for a subset of species grown under specific water supply case, subsets of contained chemical elements, etc.

In addition, there shall be operations that provide grouping, amalgamation or other transformations of estimation models. For example, measurement data obtained at different experimental stages can be grouped and, as a result, two or more correspondent estimation models are re-estimated and merged into a common model, $(m_i, m_j) \to m_k$, in order to take into account new obtained measurements or generalize the results for different species, water supply cases, etc.

Another operation is useful for the assessment of stability and completeness of the estimation models obtained. When we have new measurement data in addition to the experiments that have already been estimated (m_i), the process of inclusion of new measurement results, re-estimation and analysis may be the following. If there is a sequence of models with identical objects and variables but with different number of measurement data, then we have a sequence of models:

$$m_i^1, m_i^2, ..., m_i^k \ (\mathrm{N}_\mathrm{i}^1 < \mathrm{N}_\mathrm{i}^2 < ... < \mathrm{N}_\mathrm{i}^\mathrm{k}), \tag{2}$$

where $\mathrm{N}_\mathrm{i}^\mathrm{j}$ is number of measurement data for the model m_i^j.

In case if new measurement data are obtained, the current model m_i^1 is being re-estimated $m_i^1 \xrightarrow{\mathrm{N}_\mathrm{i}^2} m_i^2$ and two models m_i^1, m_i^2 are compared by their approximating capabilities, by representative input variables and influence on output variables. The sequence of models with new obtained data allows the investigator to analyze the model stability for a given investigation case (D_i). If $m_i^1, m_i^2, ..., m_i^k \Rightarrow m_i^{k-1} \cong m_i^k$, then the model m_i^k can be considered as stable, with representative associations between input and output variables allowing meaningful interpretation.

At the operation stage, the Plant Species Growth Control System operates with the KB which includes the sets of estimation models, control techniques, performance criteria, etc. covering different irrigation and growth conditions. The KB shall include reasoning tools to facilitate the analysis of complex relationships, as well as to meaningfully advise how to maintain/change the WWTP control parameters.

3 Conclusion

The experience gained in recent applications of the GMDH methods and qualitative assessment techniques in the considered field has shown the advantages of those methods and techniques to estimate and analyze complex effects inherent in the growth of plant species irrigated with processed wastewater from the WWTPs. The GMDH methods were applied to estimate different aspects of plant species behavior, to provide the basis for qualitative assessment, obtain general models that describe combinations of irrigation regimes, as well as to establish the control procedures for suitable or optimum irrigation processes. Qualitative assessment techniques were intended to facilitate clear understanding of the experimental results, easily classify different irrigation/plant species cases and identify the best ones.

At the same time, with the accumulation of measurement data, estimation models, and analysis results, the problem arises to organize them in a consistent way. The purpose of this paper was to consider general features of the Plant Species Growth Control System intended to provide integral and consistent framework for different modeling, analysis, and control tasks for forest species and agricultural crops irrigated with processed wastewater.

References

[1] Kalavrouziotis I. K., Stepashko V. S., Vissikirsky V. A., Drakatos P.A.: Group Method of Data Handling (GMDH) application for modelling of mechanical properties of trees irrigated with wastewater. *International Journal of Environment and Pollution*, p. 589-601, 18 (6), 2002.

[2] Kalavrouziotis I. K., Stepashko V. S., Vissikirsky V. A., Drakatos P.A.: Group Method of Data Handling (GMDH) in modelling of growth dynamics of trees irrigated with wastewater. *International Journal of Environment and Pollution*, p. 350-364, 21 (4), 2004.

[3] Vissikirsky V.A., Stepashko V.S., Kalavrouziotis I.K., Drakatos P.A.: Growth Dynamics of trees Irrigated with wastewater: GMDH Modeling, Assessment and Control Issues. *Instrumentation Science and Technology,* p. 229-249, 33 (2), 2005.

[4] Kalavrouziotis I. K., Pantazis V. N., Vissikirsky V. A., Stepashko, V. S.: Irrigation of Forest Species with Wastewater and Sludge: Experiments, Modeling, and Qualitative Assessment, *Instrumentation Science and Technology,* p. 727–742, 34, 2006.

[5] Vissikirsky V.A., Stepashko V.S., Kalavrouziotis I.K., Varnavas S.P.: The Road Pollution Impact on Zea mays: Inductive Modeling and Qualitative Assessment. *Water, Air & Soil Pollution*, p. 301-310, 195, 2008.
[6] Vissikirsky, V.A., Stepashko, V.S., Kalavrouziotis, I.K.: Application of GMDH to the Environmental Modeling with Short Samples, *Proceedings of International Workshop on Inductive Modeling (IWIM 2007), Prague, 22-26 September*, pp. 18-25, 2007.
[7] Drakatos, P.A., Vissikirsky, V.A., Kalavrouziotis I.K., Skuras, D.G. and Drakatu S.P.: Usage of Fuzzy Modeling for Cultivation of Forests Irrigated by Wastewater Treatment Plants, *International Journal of Environmental Studies*, pp. 813-833, 58, 2001.
[8] Vissikirsky V.A., Kalavrouziotis I.K., and Drakatos, P.A.: Fuzzy logic on decision making of processed wastewaters, *Proceedings of ESDA2002: 6th Biennial Conference on Engineering Systems Design and Analysis, Istanbul, Turkey, July 8-11*, 6 p., 2002.
[9] Vissikirsky, V.A., Stepashko, V.S., Kalavrouziotis, I.K.: GMDH-based decision-making support for ecological processes, *Proceedings of the 2-nd International Conference on Inductive Modeling (ICIM 2008), Kyiv, 15-19 September*, pp. 310-313, 2008.