Esko K. Juuso

Varying time delays in intelligent steady state and dynamic models

Abstract: A widely applicable solution for nonlinear steady state and dynamic models is to use intelligent interactions which are theoretically supported by the expert knowledge. These models can be tuned by using measurement data. The problematic part to select data values for the variables. In many modelling cases, this important issue is left out by assuming that time delays do not have essential effects. The model tuning can be done but the recent measurements of some variables cannot have any effect on the result. The structure of the model should be the basis. In many cases, a data-driven analysis of the time delays is enough. More problematic are cases where time delays are varying with time. A typical situation is that time delay depends on the flow speed. If the flow is constant for long periods this can be handled with working points. The most difficult situation is if the flow is a control variable or a variable which is fluctuating strongly. The key is to take the system operation as it really is. In lumped parameter models, the time delay can be uncertain if the input contains effects of several time periods. The model can be based on tube operation. The system may need distributed parameter modelling. This paper uses nonlinear scaling in relating effective time delays with the flow in application cases.

Keywords: intelligent models, nonlinear systems, varying time delay

Esko K. Juuso, Control Engineering, Environmental and Chemical Engineering, Faculty of Technology, P.O.Box 4300, FI-90014 University of Oulu, Finland, E-mail: esko.juuso@oulu.fi

1 Introduction and background

Steady state intelligent models can be extended to nonlinear situations by combining nonlinear scaling and linear equations. Linear interactions work in wide areas if differences between operating situations are handled sufficiently well with the nonlinear scaling of the variables. In dynamic intelligent models, the equations are based on dynamic structures. In case-based models, equations are tried to keep unchanged. The nonlinear scaling is the key part of the models, which are called linguistic equation (LE) models. [1]

The linear interactions can be tuned by using measurement data or scaled values with the same methodologies. It is important to select the values of the variables by using correct time delays. Identification methodologies operate well around the operating points where the time delays can be identified as model parameters. Data-driven analysis of time delays operate well for linear models. The time delays depend on operating conditions. Case-based models can be used if there are longer periods of similar situations which depend on the levels of the inputs. Alternatively, different areas can be defined with specific working point variables.

Varying time delays have been quantitatively identified from measurement data with a sliding window based information theoretic delay estimation methodology. The same methodology was used in finding the varying time delay in the widely used benchmarking case: Box-Jenkins gas furnace data [2].

The tuning of the models becomes more difficult if the variables vary strongly with very short time periods. These situations are active in wastewater treatment processes where the input comes from different parts of the main process. The control should adapt fast to these changes. In solar thermal energy applications, very fast irradiance changes need strong changes of oil flow. The fast flows can be five times bigger than the low flows.

2 Aims

This research focuses on modelling of nonlinear processes which have strong variations of operating conditions. Varying time delays are used selecting the data for the tuning of the interactions.

3 Methods

The LE models combine nonlinear scaling and linear interactions.

Nonlinear scaling

The z-score based linear scaling solutions are extended to asymmetric nonlinear scaling functions consisting of two second order polynomials. The parameters of the functions are defined with five parameters corresponding the operating point and four corner points of the feasible range. Feasible ranges are presented as trapezoidal membership functions defined by support and core areas. The scaling functions are monotonously increasing throughout the feasible ranges and the monotonous increase is certified by constraints [3]. In this study, the scaling functions are defined with five parameters corresponding scaled values {-2, -1, 0, 1, 2}.

Linear interactions

Interactions are represented with compact linear equations where each variable has an appropriate time delay to the calculation point. Monotonously increasing scaling functions allow the use of linear interactions for solving any variable from the other variables, i.e. they can be used as parts of a model, but also as model-based controllers or working point models for case-based models.

Dynamic structures

Linear interactions are used in steady-state models and can be extended to dynamic systems by parametric structures used in identification. If the nonlinear scaling operates well, only very simple structures are needed. In many applications, the new value of the simulated variable is calculated by using the current value of the simulated variable and delayed values of the control variables. The step size control is required for working with both fast and slow changes.

Case-based models

Variables, equation coefficients and scaling functions can be case specific. Cases are identified with fuzzy rules of input variables or additional working point variables. The nonlinear scaling used in LE models extend operating areas of the cases, which reduces the number of separate cases. Working point models can even remove separate cases by scaling the outputs.

Varying time delay

Modelling calculations are done for volumes whose sizes depend on the active flow. Time steps depend on the flow: time steps are short when the flow is fast and long when the flow is slow. The scaled values in the range [-2, 2] are used in a very compact way:

$$D + F_S = 0$$

where D is the scaled time delay corresponding the scaled flow F_S. Nonlinear behaviour is handled with the scaling functions.

The scaling function of the flow is analysed from the measurement data for the scaled values {-2, -1, 0, 1, 2}. The corresponding time delays are estimated for these flow levels to define the scaling function for the time delay. All scaling functions are continuous and monotonously increasing.

In each calculation point, the time delay is a weighted sum of the time delays of the previous steps. A compact solution is to use the time delays corresponding the flow measurements. Alternatively, the weighting can be based on the calculation steps adjusted with the step size control. The estimate of the time delay limits the number of time steps used in the summation. Only the new step calculations are needed and added in the stepwise array.

The simulation operates in the same way as the tuning presented above with one difference: the array of previous steps is constructed within the simulation run.

4 Case studies

Case studies start with a simple tube model. Uncertainties are studied in a lumped parameter model where the input contains inputs from several time steps. Distributed parameter models are needed if the inputs for calculation step are changing between the time steps of the measurements and the calculation step. Wastewater treatment processes and solar thermal energy collection processes are used as examples.

5 Conclusions

In wide operating areas, simulation models are improved by using more realistic time delays. The nonlinear scaling is needed for estimating the time delays from the flows. In future research, these methodologies can be extended to controller tuning and control.

References

[1] Juuso EK. Integration of Intelligent Systems in Development of Smart Adaptive Systems. International Journal of Approximate Reasoning. 2004;35(3):307–337.

[2] Ruusunen M. Signal Correlations in Biomass Combustion - an Information Theoretic Analysis. Acta Univ Oulu C 459, 2013. PhD Thesis.

[3] Juuso EK. Nonlinearity Analysis of Variables for Modelling and Control. In 3rd SIMS EUROSIM 2024, September 11-12, 2024, Oulu, Finland, p. 481-487. doi: 10.3384/ecp212.065.