New Developments in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics. Volume II: Applications

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Dedicated to Professor Beloslav Riečan on his 75th anniversary

PID controller tuning of glucose control using generalized nets

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Abstract

In this paper a generalized net for tuning the PID controller is proposed. A universal discrete PID controller for the control of fed-batch cultivation processes is considered. The controller is used to control feed rate and to maintain glucose concentration at the desired set-point. The generalized net allows tuning the PID controller, to achieve good closed-loop system performance, using different optimization methods, for example genetic algorithms. As a result the optimal PID controller settings could be obtained. For a short time the controller could sets the control variable and maintains it at the desired set point during the process.

Keywords: generalized net, auxin, cytokinin, molecular interactions, self regulation.

1 Introduction

A number of processes in the biochemical industry are controlled using proportional-integral-derivative (PID) controllers. Highly changing dynamics of most

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bioprocesses, which is caused by the non-linear growth of the cells, the metabolic changes as well as changes in the overall metabolism are the reason that the PID controllers are usually poorly tuned. A higher degree of experience and technology are required for the tuning in a real plant. Tuning a PID controller appears to be conceptually intuitive but can be hard in practice, if complex systems as cultivation processes are considered. For the quality controller tuning optimization methods could be applied, although the tuning procedure is a big challenge for the conventional optimization methods. As an alternative to overcome the controller tuning difficulties various metaheuristics, for example genetic algorithms, could be used [5, 6].

This paper focuses on using generalized nets (GN) (see [2, 3]) for optimal tuning of universal digital PID controller. The PID controller is used for glucose control of a fed-batch cultivation process. To achieve good closed-loop system performance, optimization method based controller tuning is considered. Several GN models of GA [1, 4, 7, 8, 10, 11, 12, 13, 14] have already been published. Each GN model could be applied in the proposed GN model. In the same way the developed GN models of fed-batch cultivation processes [9, 15, 17] also could be build in the here considered GN. Moreover there is a GN model of PID control algorithm [16] that could be used in the tuning procedure.

2 Background of the control algorithm

A PID controller is a generic control algorithm widely used in industrial control systems. The controller parameters used in the calculation must be tuned according to the nature of the system. The standard PID controller calculation (algorithm) involves three separate modes; the proportional (P), the integral (I) and derivative (D) (see [16]). A typical structure of a PID control system is shown in Fig. 1. The error signal $e(t)$ is used to generate the P, I, and D modes, with the resulting signals weighted and summed to form the control signal $u(t)$ applied to the plant model. In real applications discrete time PID controller is implemented. The mathematical description of discrete-time universal PID controller is:

$$u(k) = u_p(k) + u_i(k) + u_d(k), \tag{1}$$

$$u_p(k) = K_p(br(k) - y(k)), \tag{2}$$

$$u_i(k) = u_i(k-1) + b_{i1}(r(k) - y(k) + b_{i2}(r(k-1) - y(k-1)), \tag{3}$$

$$u_d(k) = a_d u_d(k-1) + b_d(cr(k) - cr(k-1) - y(k) + y(k-1)), \tag{4}$$

where k is the number of sample, $u_p(k), u_i(k)$ and $u_d(k)$ are respectively proportional, integral and derivative modes of control signal, $r(k)$ is the reference signal,

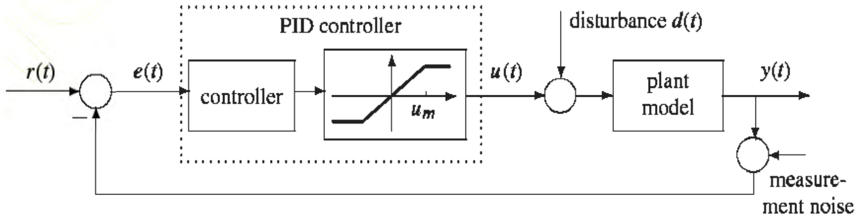

Figure 1: Typical structure of a PID control system

$y(k)$ is the output signal, $u(k)$ is the control signal, K_p is the proportional gain, T_i -is the integral time, T_d is the derivative time, T_d/N is the time constant of first-order low pass filter, T_0 is the sample time, b and c are the weighting coefficients, $b_{i1} = K_p \frac{T_0}{T_i}$, $b_{i2} = 0$, $a_d = \frac{T_d}{T_d + NT_0}$, $b_d = K_p \frac{T_d N}{T_d + NT_0}$.

By tuning the constants (K_p, T_i, T_d, b, c and N) in the PID controller algorithm, the controller can provide control action designed for specific process requirements.

3 Generalized net model

The GN model of the PID controller tuning is shown on Fig. 2.

Initially, five tokens α, β, γ, δ, ξ and η enter the GN with the following initial characteristic:

- "reference signal (set-point) $r(t)$" - in place l_1,
- "initial substrate concentration" - in place l_2,
- "initial parameters of optimization algorithm" - in place l_3,
- "initial concentrations of the process state variables" - in place l_8,
- "process noise" - in place l_9,
- "measurement noise" - in place l_{12}.

In the tuning procedure measurement and process noise are taken into account. The first transition Z_1 has the following definition:

$$Z_1 = \langle \{l_1, l_2, l_{15}\}, \{l_4\}, r_1, \wedge(l_1, (\vee(l_2, l_{15}))\rangle,$$

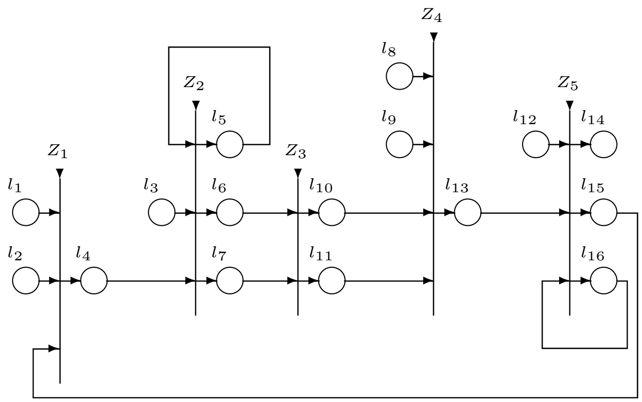

Figure 2: GN model

$$r_1 = \begin{array}{c|c} & l_4 \\ \hline l_1 & W_1 \\ l_2 & W_2 \\ l_{15} & W_1 \end{array},$$

where
W_1 =“calculation of the error $e(t)$ as the difference between the set-point $r(t)$ and the estimated substrate concentration (place l_{15})”,
W_2 =“calculation of the error $e(t)$ as the difference between the set-point $r(t)$ and the initial substrate concentration (place l_2)”, in case of the generalized net first run.

To evaluate the significance of the tuning procedure and controller performance different criteria could be used, for example: integrated squared error (I_{ISE}); integrated absolute error (I_{IAE}); integrated time-weighted absolute error (I_{ITAE}) etc.:

$$I_{ISE} = \int_0^T e(t)^2 \mathrm{d}t, \quad I_{IAE} = \int_0^T |e(t)| \mathrm{d}t, \quad I_{ITAE} = \int_0^T te(t)^2 \mathrm{d}t$$

where t is time, T is end time of the cultivation.

As a result in place l_4 the error value is recorded. Obtained error is further used as an objective function value for chosen optimization algorithm to be find the optimal parameters of the PID controller. Next GN transition presents the estimation of the controller parameters. If genetic algorithms are considered one of the developed GN models in [1, 4, 7, 8, 10, 11, 12, 13, 14] could be added in place l_5. In this case in place l_3 the genetic parameter and operators should be defined.

The form of the transition Z_2 is:

$$Z_2 = \langle \{l_3, l_4, l_5\}, \{l_5, l_6, l_7\}, r_2, \wedge(l_3, l_4)\rangle,$$

$$r_2 = \begin{array}{c|ccc} & l_5 & l_6 & l_7 \\ \hline l_3 & W_3 & false & false \\ l_4 & W_4 & false & false \\ l_5 & false & W_4 & W_5 \end{array},$$

where
W_3 ="first run of the optimization algorithm",
W_4 ="tuning procedure is proceed",
W_5 ="end of the tuning procedure", where the termination criterion is set in place l_3 - "initial parameters of optimization algorithm".

In place l_6 the current PID controller parameters are recorded. In place l_7 the final optimal PID controller parameters are memorized.

The form of the transition Z_3 is:

$$Z_3 = \langle \{l_6, l_7\}, \{l_{10}, l_{11}\}, r_3, \vee(l_6, l_7)\rangle,$$

$$r_3 = \begin{array}{c|cc} & l_{10} & l_{11} \\ \hline l_6 & W_4 & false \\ l_7 & false & W_5 \end{array},$$

where W_4 and W_5 are defined above.

The form of the transition Z_4 is:

$$Z_4 = \langle \{l_8, l_9, l_{10}, l_{11}\}, \{l_{12}\}, r_4, \wedge(l_8, l_9, (\vee(l_{10}, l_{11})))\rangle,$$

$$r_4 = \begin{array}{c|c} & l_{12} \\ \hline l_8 & true \\ l_9 & true \\ l_{10} & W_4 \\ l_{11} & W_5 \end{array},$$

where W_4 and W_5 are defined above.

In place l_{10} the control signal (feed rate profile - $u(k)$) calculated from PID controller using estimated parameters (place l_6) is evaluated (see Eqs. (1)-(4)). In this transition a simulation of the cultivation process is performed using the signal $u(k)$. The simulation is based on a mathematical model of the process. In place

l_{13} a generalized net of considered cultivation process could be included, based on [17].

The form of the transition Z_5 is:

$$Z_5 = \langle\{l_{12}, l_{13}, l_{16}\}, \{l_{14}, l_{15}, l_{16}\}, r_5, \wedge(l_{12}, l_{13}, l_{16})\rangle,$$

$$r_5 = \begin{array}{c|ccc} & l_{14} & l_{15} & l_{16} \\ \hline l_{12} & false & true & false \\ l_{13} & false & W_4 & W_4 \\ l_{16} & W_5 & false & W_4 \end{array},$$

where W_4 and W_5 are defined above.

In account of measurement noise (place l_{12}) current measurement of glucose concentration is recorded in place l_{15}. The obtained value is returned in the beginning of the net to form next error. In place l_{16} current concentrations of all process variables are stored. In the end of the tuning procedure final data are recorded in place l_{14}.

Based on the obtained controller parameters control system successfully controls the substrate concentration at desired set-point using calculated feed-rate profile $(u(t))$. For a short time the controller sets the control variable and keeps the glucose concentration stable at the desired set-point during the process.

4 Conclusion

In the case of cultivation processes control the usual practice is to select PI or PID mode. In the article a Generalized Net model for tuning the PID controller is presented. The controller is used to control the feed rate and to maintain the glucose concentration at the desired set-points for fed-batch cultivation processes. Controller tuning is a subjective procedure and is certainly process dependent. The proposed GN model allows us to find a feed rate profile to establish small glucose concentration preventing the accumulation of growth inhibiting metabolites. Moreover the GN model enabled to be used different optimization methods for controller tuning to achieve good closed-loop system performance. As a result, the optimal PID controller settings will be obtained. These settings will indicate high quality and better performance of the designed control system.

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The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.
It may be viewed as a result of fruitful discussions held during the Tenth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2011) organized in Warsaw on September 30, 2011 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT - Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bystrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, and the University of Westminster, Harrow, UK:

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The consecutive International Workshops on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGNs) have been meant to provide a forum for the presentation of new results and for scientific discussion on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems have also been included. The Tenth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2011) is a continuation of this undertaking, and provides many new ideas and results in the areas concerned.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

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