Application of NN-SANARX model for identification and control liquid level tank system

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Contribution

The present contribution may be seen in application of the classical control technique (linearization via dynamic output feedback) and neural networks based modeling to control a water level in a tank system. In the paper we describe all design steps: starting from collecting the input-output (i/o) data of a process and finishing with implementation and test of the synthesized controller on a real plant. Therefore, the research, presented in the paper, can be seen as a preliminary step towards real industrial application.

Mathematical model

The model of a Multi Tank system provided by INTECO. The differential equations, describing dynamics of the Tank system, can be derived, assuming the laminar outflow rate of an *ideal fluid* from a tank, by means of mass balance as

$$\begin{aligned}\dot H_1 &= \frac{1}{aw}(u - C_1 H_1^{\alpha_1})\\ \dot H_2 &= \frac{h}{cwh + bwx_2}(C_1 H_1^{\alpha_1} - C_2 H_2^{\alpha_2})\\ \dot H_3 &= \frac{1}{w\sqrt{R^2-(R-H_3)^2}}(C_2 H_2^{\alpha_2} - C_3 H_3^{\alpha_3}),\end{aligned} \tag{1}$$

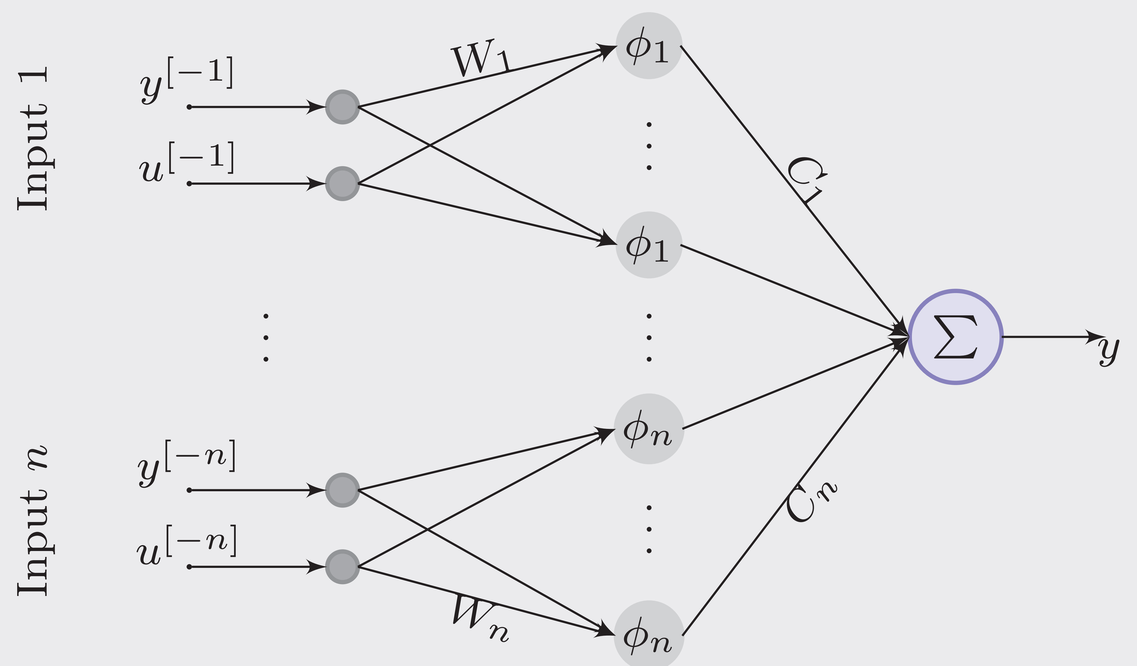
where the physical meaning of parameters is H_i - fluid level in the ith tank; w and a are the width and length of the upper tank, respectively; C_i is a resistance of the output orifice of the ith tank; b, c lengths of the upper and lower part of the middle tank; R is length of the upper part of the lower tank; and $H_{2\,\max}$ - height of the middle tank; α_i - flow coefficient for the ith tank. Furthermore, it is important to mention that x_1, x_2, x_3 and u have natural saturations due to the physical limitations of the system and power of the pump. In addition, control signal has a significant dead zone that has to be taken into account.

Multi Tank system

NN-ANARX model

$$y^{[n]} = \sum_{i=1}^{n} C_i \phi_i\left(W_i \left[y^{[n-i]} \quad u^{[n-i]}\right]^{\mathrm{T}}\right), \tag{2}$$

where $\phi_i(\cdot)$ is an activation function of the ith sublayer neurons, C_i and W_i are $1 \times l_i$ and $l_i \times 2$ dimensional matrices of the ith sublayer output and input synaptic weights, respectively. Here l_i is the number of hidden neurons in the ith sublayer.
A schematic diagram of the neural network, representing ANARX structure, is depicted below.



The dynamic output feedback can be written by using parameters of the neural network as

$$\eta_1 = C_1\phi_1\left(W_1 \left[y \quad u\right]^{\mathrm{T}}\right) \tag{3}$$

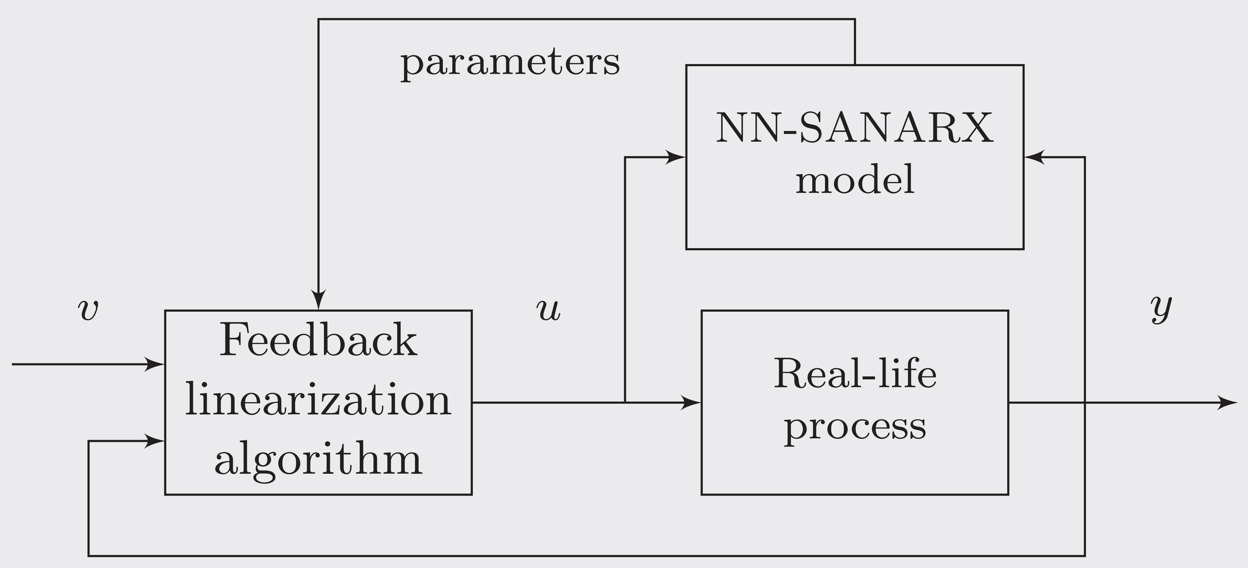
and

$$\begin{aligned}\eta_1^{[1]} &= \eta_2 - C_2\phi_2\left(W_2\left[y \quad u\right]^{\mathrm{T}}\right)\\ &\vdots\\ \eta_{n-2}^{[1]} &= \eta_{n-1} - C_{n-1}\phi_{n-1}\left(W_{n-1}\left[y \quad u\right]^{\mathrm{T}}\right)\\ \eta_{n-1}^{[1]} &= v - C_n\phi_n\left(W_n\left[y \quad u\right]^{\mathrm{T}}\right).\end{aligned} \tag{4}$$

In order to simplify the calculation of the control signal in (3), we assume that $\phi_1(\cdot)$ is a linear function, resulting in a simplified structure of the neural network known as a NN-SANARX model. It means that (3) can be rewritten as follows

$$u = T_2^{-1}(\eta_1 - T_1 y), \tag{5}$$

where T_1 and T_2 are the first and second elements of the vector $C_1 W_1$, respectively. Note that T_2 has to be a nonsingular square matrix. This fact has to be taken into account on the identification stage. The overall structure of the corresponding control system is represented below.



Algorithm

Algorithm:

Step 1. Collect training data performing real-life experiment.

Step 2. Use *a priori* information of the process to determine important parameters of the neural network such as order of the identified model, number of sublayers, etc.

Step 3. Train neural networks based Simplified ANARX model.

Step 4. According to the pre-specified control requirements, write down equations of the controller.

Step 5. Put plant and controller into the closed-loop and verify the designed control system.

Results

The physical parameters of the plant have the following numerical values $w = 0.035$m, $a = 0.25$m, $\alpha_1 = 0.2497$, and the maximal inflow provided by the pump is $1.0284 \cdot 10^{-4}\mathrm{m}^3/\mathrm{s}$. In addition, the resistance of the output orifice of the first tank was determined experimentally $C_1 = 11.08 \cdot 10^{-5}\mathrm{m}^2/\mathrm{s}$, using MATLAB routine provided with the installation package.

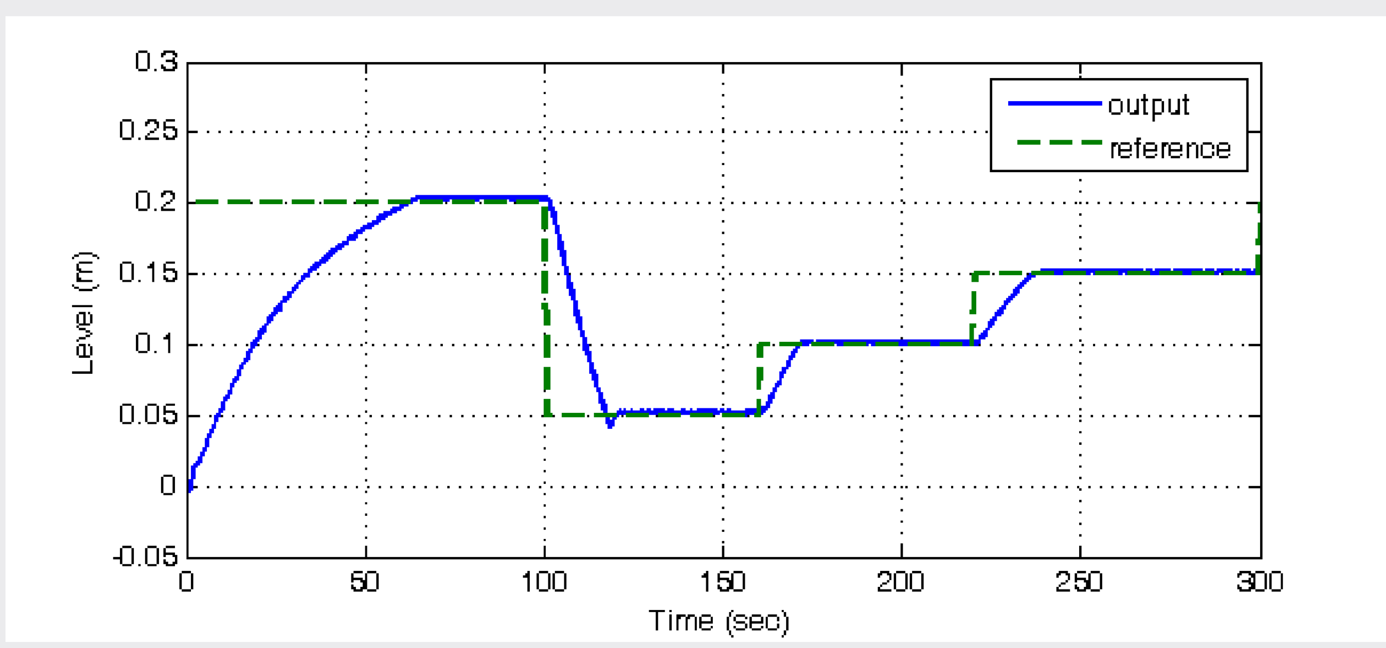
The identified model has the following structure

$$y = C_1 W_1 \left[y^{[-1]} \quad u^{[-1]}\right]^{\mathrm{T}} + C_2 \mathrm{tansig}\left(W_2\left[y^{[-2]} \quad u^{[-2]}\right]^{\mathrm{T}}\right). \tag{6}$$

Since the identified model is of the second order, using (4), (5) and parameters of the identified model (6), we get dynamics of the controller in the following form

$$\begin{aligned}u &= T_2^{-1}(\eta_1 - T_1 y)\\ \eta_1^{[1]} &= v - C_2 \mathrm{tansig}\left(W_2\left[y \quad u\right]^{\mathrm{T}}\right).\end{aligned} \tag{7}$$

After verification of the algorithm we applied it to control the real plant. It should be mentioned that C/C++ builder, provided by Real-Time Windows Target, does not allow functions that are not available in the core version of MATLAB. Therefore, activation function, used in (6), has to be implemented by means of standard blocks in the explicit form using formula $\mathrm{tansig}(x) = \frac{2}{1+\mathrm{e}^{-2x}} - 1$.



It can be seen from figure that the control system is capable of tracking the reference signal v and react correctly to the changes in a set point within the $\pm 1\%$ deviation from the final value, when the NN-based SANARX structure and the corresponding control algorithm are used.

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