Hierarchical Fuzzy-Adaptive Control Algorithm

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Abstract: An integration of fuzzy method and adaptive control has been presented. Some examples of the proposed algorithm have been given.

Keywords: Fuzzy Logic, Adaptive Control

1 Introduction

Adaptive control has developed drastically since the appearance of its basic concept until the present day. The application of adaptive control in industrial exploitation is limited by the following factors: the complexity of its mathematical theory, the necessary tools for its realization, and the apriori knowledge necessary for the effective tuning of algorithms. Within fuzzy control theory methods have been developed which are suitable to apply and integrate engineering expert knowledge into its structure and parameters. This paper introduces a fuzzy supervisor for the coordination of the free parameters of the adaptive controller. In the technical literature several works deal with the similar application of fuzzy theory [1,3].

2 Formulation of the Problem

The controlled plant is represent by the equation:

$$\dot{x}_p(t) = \mathbf{A}_p x_p(t) + \mathbf{B}_p u_p(t),\ x_p \in \Re^{n_p},\ u_p \in \Re^{m_p} \tag{1}$$

$$y_p(t) = \mathbf{C}_p x_p(t) + \mathbf{D}_p u_p(t),\ y_p \in \Re^{\ell_p} \tag{2}$$

where x_p is the plant state vector, u_p is the control vector, y_p is the output vector, and $\mathbf{A}_p$, $\mathbf{B}_p$, $\mathbf{C}_p$, $\mathbf{D}_p$ are matrices with the appropriate dimensions.

The goal of controlling is for the plant output $y_p(t)$ to follow the output $y_m(t)$ of the stable reference model:

$$\dot{x}_m(t) = \mathbf{A}_m x_m(t) + \mathbf{B}_m u_m(t),\ x_m \in \Re^{n_m},\ u_m \in \Re^{m_m} \tag{3}$$

$$y_m(t) = \mathbf{C}_m x_m(t) + \mathbf{D}_m u_m(t),\ y_m \in \Re^{\ell_m} \tag{4}$$

where x_m is the model state vector, u_m is the command vector and y_m is the model output vector. The reference model is designed to meet some desired performance properties and has the same number of outputs as the plant, but is otherwise independent of the controlled plant. It is possible to have $n_p >> n_m$.

Since the plant is unknown the actual controlof the plant will be generated by the following adaptive algorithm suggested by Sobel and Kaufman [2].

2.1 The adaptive algorithm

The control law for the problem is:

$$u_p(t) = \mathbf{K}_r r(t). \tag{5}$$

The vector $r(t)$ is defined as: $r^T(t) = \left[e^T(t), y_m^T(t), u_m^T(t)\right]$ $, r \in \Re^{2\ell_p + m_m}$ (6)

The definition of the output tracking error is

$$e(t) = y_m(t) - y_p(t). \tag{7}$$

The gains are concantenated into the matrix $\mathbf{K}_r(t)$ defined as:

$$\mathbf{K}_r(t) = \left[\mathbf{K}_e(t), \mathbf{K}_y(t), \mathbf{K}_u(t)\right]. \tag{8}$$

The gains are obtained as a combination of proportional and integral terms as follows:

$$\mathbf{K}_r(t) = \mathbf{K}_p(t) + \mathbf{K}_I(t). \tag{9}$$

The adaptation law is:

$$\mathbf{K}_p(t) = e(t) \cdot r^T(t) \cdot \overline{\mathbf{T}}, \tag{10}$$

$$\dot{\mathbf{K}}_I(t) = e(t) \cdot r^T(t) \cdot \mathbf{T} \tag{11}$$

where $\overline{\mathbf{T}} \in \Re^{(2\ell_p + m_m)\times(2\ell_p + m_m)}$ and $\mathbf{T} \in \Re^{(2\ell_p + m_m)\times(2\ell_p + m_m)}$ are positive definite matrices.

The quality of the adaptation depends on the values of the gain matrices. It is difficult to find the correct value of the gain matrices.

A frequent choice with matrices is the diagonal structure. In the example below $\overline{\gamma}_e$, $\overline{\gamma}_y$, $\overline{\gamma}_u$, γ_e, γ_y and γ_u are diagonal submatrices respectively.

If
$$\overline{\mathbf{T}} = \begin{bmatrix} \overline{\gamma}_e & 0 & 0 \\ 0 & \overline{\gamma}_y & 0 \\ 0 & 0 & \overline{\gamma}_u \end{bmatrix}, \mathbf{T} = \begin{bmatrix} \gamma_e & 0 & 0 \\ 0 & \gamma_y & 0 \\ 0 & 0 & \gamma_u \end{bmatrix} \tag{12}$$

then:

$$\mathbf{K}_{ep}(t) = e(t) \cdot e^T(t) \cdot \overline{\gamma}_e, \mathbf{K}_{yp}(t) = e(t) \cdot y_m^T(t) \cdot \overline{\gamma}_y,$$
$$\mathbf{K}_{up}(t) = e(t) \cdot u_m^T(t) \cdot \overline{\gamma}_u \tag{13}$$

$$\dot{\mathbf{K}}_{eI}(t) = e(t) \cdot e^T(t) \cdot \gamma_e, \dot{\mathbf{K}}_{yI}(t) = e(t) \cdot y_m^T(t) \cdot \gamma_y,$$
$$\dot{\mathbf{K}}_{uI}(t) = e(t) \cdot u_m^T(t) \cdot \gamma_u . \tag{14}$$

2.2 Demonstration of the problem

In case of structure or parameter change of the plant, in order for the optimal adaptation to be reached the gains of the adaptation must be altered. The presented adaptive method has significant nonlinearities therefore the gains ought to be defined by multiple simulations. In Fig.1. below a fuzzy supervisor is presented for automatic tuning of the mentioned parameters. The inputs of the supervisor controller are the system error and error rate vector. The outputs are the adaptation gains.

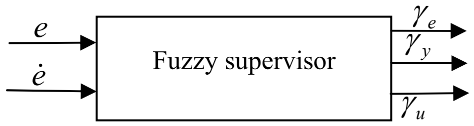

Fig. 1. The supervisor architecture.

3 Results

The proposed hierarchical fuzzy-adaptive control algorithm was applied to the SISO linear system and SISO linear referent model. The simulations were performed using the following constant plant model:

$$G_p(s) = \frac{1}{40 \cdot s^2 + 10 \cdot s + 1} \tag{15}$$

During the first simulation the stable reference model was:

$$G_m(s) = \frac{1.5}{s^2 + s + 0.5} \,. \tag{16}$$

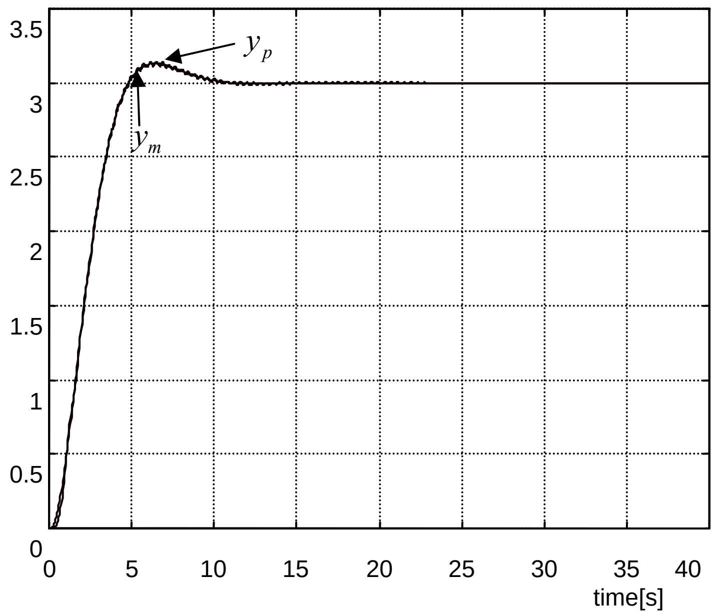

Fig. 2. Results of the first simulation.

The results of the first simulation are shown in Fig.2., where the gains of the adaptation are optimal and their values are: $\bar{\gamma}_e = 1000$, $\bar{\gamma}_y = 1000$, $\bar{\gamma}_u = 1000$, $\gamma_e = 10$, $\gamma_y = 10$ and $\gamma_u = 10$.

In the second simulation the adaptation gains were used unchanged, but the reference model was modified and it was as follows:

$$G_m(s) = \frac{1.5}{s + 0.5} \,. \tag{17}$$

Fig.3. illustrates the results of the second simulation. The output of the plant is significantly worse than in the first case. The only way to increase the quality of the output tracking is to change the adaptation gains. The third simulation was done with fuzzy supervisor.

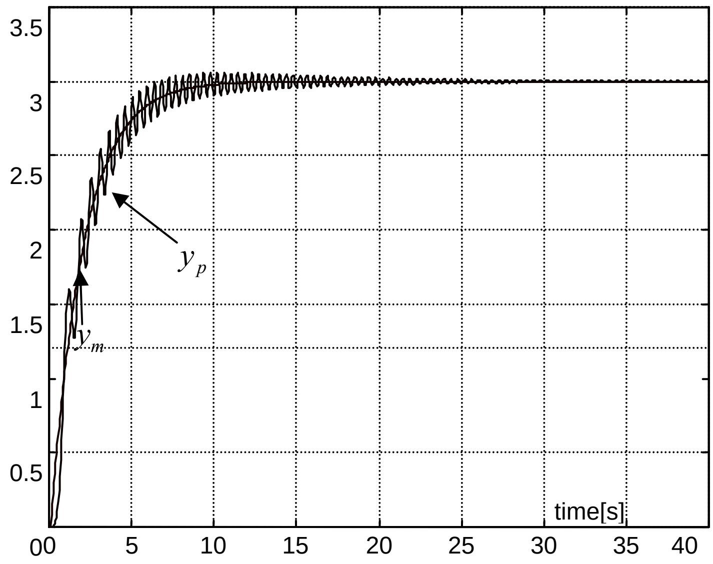

Fig. 3. Results of the second simulation.

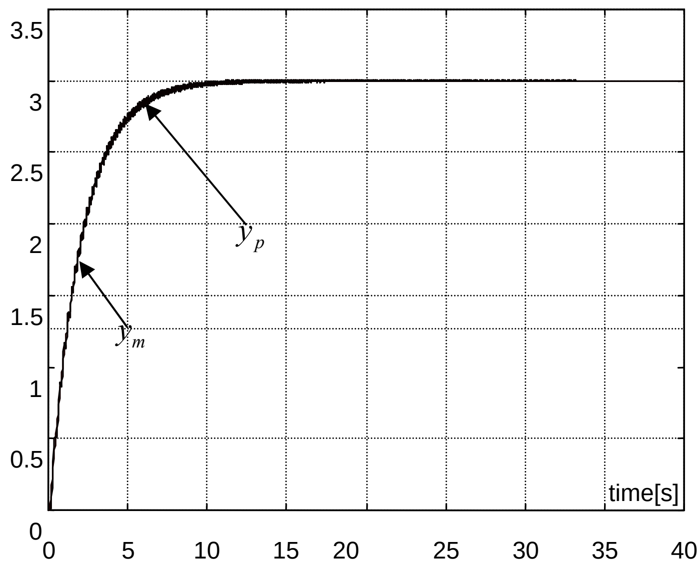

Fig. 4. Results of the third simulation.

The result of the third simulation is shown in Fig.4., where the gains of the adaptation are modified and their values are: $\bar{\gamma}_e = 91736$, $\bar{\gamma}_y = 1000$, $\bar{\gamma}_u = 1000$, $\gamma_e = 10$, $\gamma_y = 10$ and $\gamma_u = 10$.

4 Conclusion

In this paper a new approach to fuzzy tuning of the adaptive algorithm is presented. It is shown by examples, which indicate that the proposed method is able to correctly modify the controller's parameters.

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