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DESIGN OF A SUPERVISOR FOR THE SELF-TUNING CONTROLLER

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Abstract: *This paper deals with a design of a supervisory algorithm for the self-tuning controller. The main idea is a parallel computation of an adaptive and robust control law. The supervisor evaluates the behavior of the control process. The control algorithm which currently produces better results is switched to the closed loop. The supervisor algorithm is based on the unfalsified control approach.*
Key words: *adaptive control, supervisor, self-tuning controller, unfalsified control theory*

1. INTRODUCTION

Many industrial processes are time-invariant systems. A process which changes its parameters with time can be controlled using two main approaches: adaptive control and robust control.

The disadvantage of robust control is that the results of the control process are not optimal in term of quality. That means, using the robust control we are able to ensure the stability of the closed loop, however we waste energy or material because the control law is not updated according to the current conditions. On the other hand the self-tuning controller is able to adapt the control law and can produce the optimal control actions as per the designer requirements. The problem is that the stability of the closed loop is not ensured. If the identification of the plant which is the main part of the self tuning-controller failed, the control law can produce the control actions that can lead to instability or dangerous conditions. The main idea of our work is to connect both mentioned approaches and design the adaptive control system which is able to distinguish which control algorithm will produce better solution and should be connected to the plant. The algorithm is tested using a MATLAB/Simulink environment and also using PLC and real process - optimization system of a solar panel (project FRVS G1 532/2010).

2. SELF-TUNING CONTROLLER

This paragraph includes the short description of the self-tuning controller and the algorithms which was used for the design in this work. Figure 1 shows the scheme of the self-tuning LQ controller where $w(k)$ denotes the reference signal, $u(k)$ is the action value, and $y(k)$ is the output of the plant. The critical part of the self-tuning controller is an identification algorithm which creates the mathematical model of the plant. It is obvious that bad behavior of identification could leads to the instability of the closed loop. The identification algorithms are very depended on the noise and disturbances.

The identification based on the artificial neural networks with the Levenberg-Marquardt training method was used. A method of training pattern selection was realized in the identification algorithm. The LQ controller based on a pseudo state model with a parallel computation of an integral action is implemented as a control law (Lorenc, 2009).

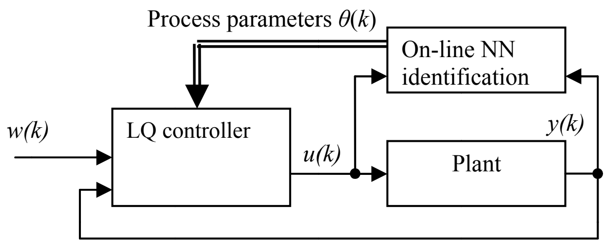

Fig. 1. Block diagram of the self-tuning LQ controller

3. SUPERVISORY ADAPTIVE CONTROL

Supervisory control is the method of adaptive control that uses on-line data to determine which controller from the set of candidate controllers should be connected to the closed loop. Early work on supervisory control used sequence of switches over set of candidate controllers and monitoring function for evaluation of the cost function during the finite time. Controller with the best performance was finally switched to the closed loop.

The example of model-based supervisory control is presented in (Navrátil, 2007). The multi-estimator scheme is used for the self-tuning controller. The supervisor in this case evaluates the one step prediction error. The most accurate mathematical model obtained from the set of individual identification algorithms is used for the design of the control law.

However, in some cases all identification algorithms can lead to the mathematical model which is not sufficiently accurate (high level of noise, nonlinearities etc.). The better solution is parallel computations of the robust and adaptive control law and supervisor which is able to asset the performance of the controllers and switch the better controller to the closed loop. The sequentially switching strategy described above is not acceptable because the destabilizing controller can be connected to the loop.

Alternate approach for the design of the supervisor is the cost based unfalsified approach (Safanov & Tsao, 1997) or method based on a calibrated forecasts (Al-Shyoukh & Shamma, 2009). The supervisor based on unfalsified control theory was used in our work.

4. BACKGROUND OF THE UNFALSIFIED ADAPTIVE CONTROL

The idea of unfalsified control approach is to determine the most suitable control law C from a class of time invariant candidate control laws C_i , $i = 1, .., N$.

The criterion of quality J_i is computed for each candidate control law. The problem is how to compute the criterion for control laws which are not currently connected to the closed loop. For this reason is necessary to define the factious reference signal $\tilde{w}(k)$:

$$\tilde{w}_i(k) = C_i^{-1}u(k) + y(k). \quad (1)$$

One can see that the inversion of C_i occurs in the equation (1), however in (Dehghani at al., 2007) is shown that the computation of the inversion is not necessary. Now the fictions control error can be defined as follows:

$$\tilde{e}_i(k) = \tilde{w}_i(k) - y(k) \quad (2)$$

Finally we can define the performance cost function $J(k)$. There is many proposed cost functions in the literature of unfalsified adaptive control. In this work we compute the cost function as follows:

$$J_i(k) = \frac{\left\|\tilde{e}_i^2\right\|_k + \alpha\left\|u^2\right\|_k}{\left\|\tilde{w}_i^2\right\|_k} \quad (3)$$

where α is the non negative weighting factor and

$$\|x\|_k = \sum_{j=k-N}^{k} e^{-\lambda(k-j)}x(j) \quad (4)$$

is the norm of the signal with exponential forgetting factor λ.

Using computation of the cost functions for all candidate controllers is possible to determine the control law with the best performance.

We adopted the unfalsified control concept and connected the self-tuning controller described in the section 1 with the supervisor based on the unfalsified control approach. The following algorithm describes the principle of our algorithm:

1. Initialization: a robust control law C_r is selected as the initial controller, select λ and $\alpha < 1$, set time T
2. Start identification of the plant, when the mathematical model of the plant is created stop the identification, design the temporary control law C_{at}, and go to next step.
3. Start with the evaluation of the cost function for robust control law- J_r, temporary adaptive control law J_{at}, and if it is defined adaptive control law J_a using the equation (3).
4. After time T compare the values of the criterions and switch the controller with minimal value of J to the closed loop.
5. If the robust control law was selected, restart the identification and go to the step 2.
   If the new (temporary) adaptive control law was selected, update $C_a \leftarrow C_{at}$ and go to step 6.
   If the new adaptive control law which is currently connected to the loop was selected, retain it in the loop, restart the identification and go to step 2.
6. After time T_i start again the identification procedure and go to step 2.

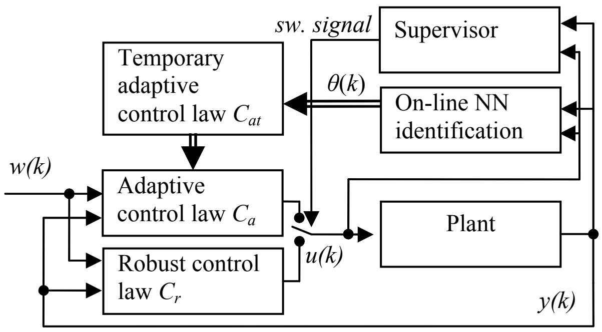

Fig. 2. Self-tuning controller with supervisor

A parameter T denotes a sufficiently long time interval for evaluation of the cost functions. If the identification procedure is stopped in the step 5 then the identification is executed again after predefined time T_i.

The identification procedure is stopped if the following condition is satisfied: $S < \varepsilon$, where

$$S = \frac{1}{M}\sqrt{\sum_{j=k-M}^{k}[\hat{e}(j) - \bar{\hat{e}}]^2}, \quad \bar{\hat{e}} = \frac{1}{M}\sum_{j=k-M}^{k}\hat{e}(j) \quad (5)$$

A symbol $\hat{e}$ denotes the one-step prediction error, ε is a decision threshold and M is a number of used past samples.

A block diagram of the described algorithm is shown on the figure 2. A figure 3 shows the simulation experiment using MATLAB/Simulink environment. The initial robust controller was chosen stable, however as it can be seen the performance is not optimal. The identification of the plant procedure finished at time 34s. The parameter T was set to 20s and one can see that at time 54s the supervisor switched the new designed control law to the closed loop.

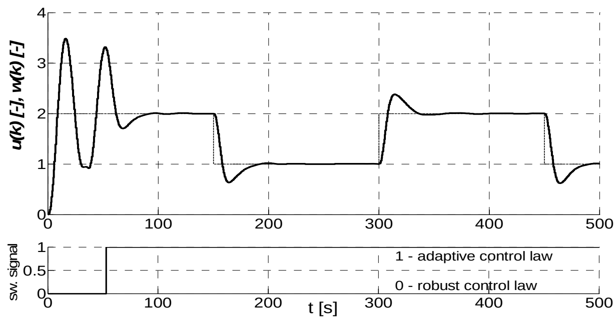

Fig. 3. Switching of the adaptive control law to the closed loop

5. CONCLUSION

The novel supervisory algorithm for the self-tuning controller was designed. The supervisor evaluates the performance indexes of the robust and adaptive control law. The supervisor is model independent and it is implemented using unfalsified control approach. The described algorithm improves the reliability of the self-tuning controller.

In the (Dehghani at al., 2007) was shown that in some cases the unfalsified approach can failed and some improvements was suggested in (Chang & Safanov, 2008). The interesting topic for the future work can be the comparison of the supervisor designed using unfalsified control approach and using calibrated forecast (Al-Shyoukh & Shamma, 2009).

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