INCREASING STABILITY OF SELF-TUNING CONTROLLER USING THE MULTI-CONTROLLER CONCEPT

Vlastimil Lorenc
Doctoral Degree Programme (2), FEEC BUT
E-mail: xloren05@stud.feec.vutbr.cz

Supervised by: Petr Pivoňka
E-mail: pivonka@feec.vutbr.cz

ABSTRACT

For control of the time invariant systems the two main solutions are known: robust control theory and adaptive control theory. This article deals with possibility of interconnection between both of these principles. The design of supervisor algorithm that is able to switch between adaptive and robust control law is described. The main idea is based on unfalsified control approach.

1. INTRODUCTION

The most industrial processes with varying parameters are controlled using classic PID controllers or its modifications. When the controller setup is sufficiently robust, the control process is stable; however it is not optimal. On the other hand the self-tuning control concept (STC) is able to produce optimal control actions. The most of STC uses identification algorithm that is used for design of mathematical model of the controlled plant. The mathematical model is for the synthesis of the control law used. The one of the main purpose why the STC aren't widely used in the industrial applications is that functionality of these algorithms is very dependent on the noise and accuracy of measurement of the output of the controlled system. That means, using classical STC concept with the identification algorithm the stability and desired quality of regulation isn't ensured.

The method how to increase the functionality of the STC is to use the multi-identification concept. This method is based on parallel computation of mathematical model of the plant. Using prediction error the accuracy of all models is evaluated. Every model can be using different identification algorithm created. This method can increase functionality of identification, but the stability of the closed loop is not ensured.

The other solution how to increase the quality of regulation in ceases when the identification algorithm produces inaccurate mathematical model is usage of parallel computation of robust and adaptive control laws. The supervisor that is able to analyze which control algorithm is more suitable for control of the plant in every moment have to be designed. In the next sections the supervisor based on unfalsified control concept is described.

2. SELF-TUNING CONTROLLER

This section contains the brief description of the self-tuning controller and algorithms which was in this work used. Figure 1 shows the architecture of the self-tuning LQ controller where $w(k)$ denotes desired value, $u(k)$ denotes action value and $y(k)$ denotes output of the controlled system.

The main part of this kind of adaptive controllers is the identification algorithm. In this work the identification based on the artificial neural networks with the Levenberg-Marquardt training method was used. In the identification algorithm, the method of training pattern selection was realized [4, 6]. The LQ controller based on pseudo state model with parallel computation of integral action was used as a control law [6].

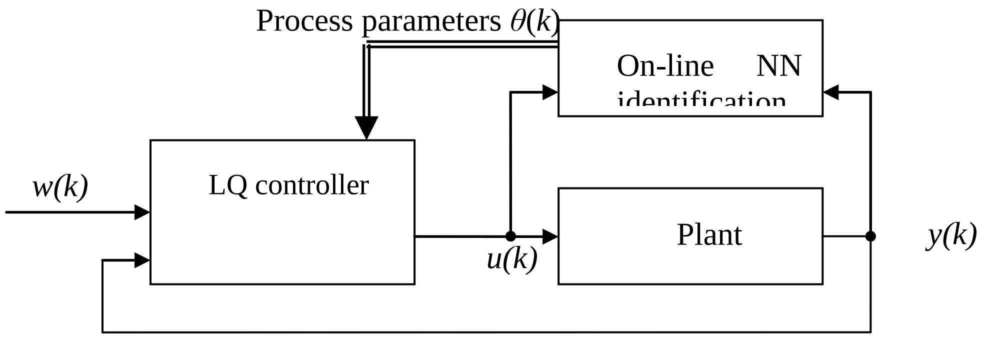

Figure 1: Architecture of self-tuning LQ controller.

3. THE UNFALSIFIED CONTROL APPROACH

In this section the unfalsified control approach is introduced. This concept gives alternative way how to create self-tuning control algorithm without identification of controlled plant [1, 2, 3]. The main idea is to determine the most suitable control law K from a class of candidate control laws K_i , $i = 1, .., N$.

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

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

For all candidate controllers K_i the stable inversion must exist. The most known control algorithms PID, LQ and MRAC satisfy this property [3]. Now the fictions control error can be defined as follows:

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

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 computed the cost function as follows:

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

where α is the non negative weighting factor and

$$\left\|x\right\|_k = \sum_{n=0}^{k} e^{-\lambda(k-n)} x(n), \tag{4}$$

is the norm of the signal with exponential forgetting technique [1]. The non-negative parameter λ denotes the forgetting factor.

Using computation of the cost functions for all candidate controllers is possible to determine which-one should be switched to the closed loop. The figure 2 shows the concept of described multi-controller scheme.

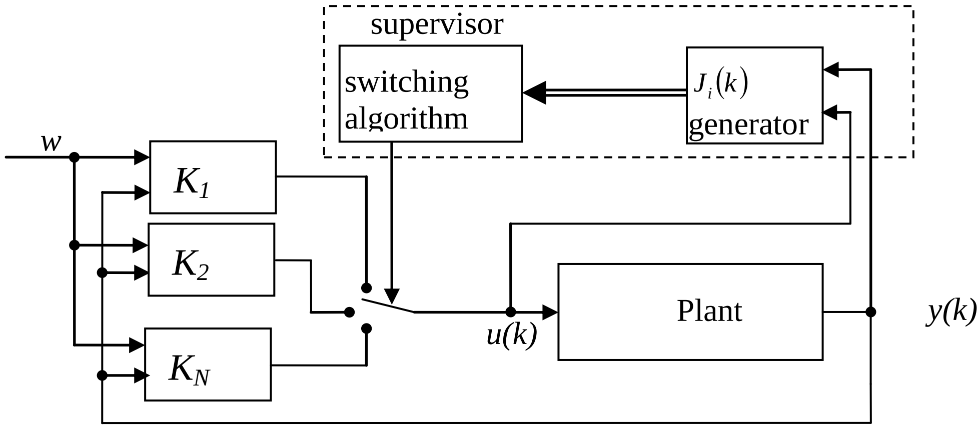

Figure 2: The multi-controller adaptive concept based on unfalsified approach.

The disadvantage of this kind of controllers is that we have to design many control laws K. In this work we mixed unfalsified control approach with the self tuning controller based on system identification procedure. In this case we have only two control laws, but one of them is adapted during the time to the current conditions in the closed loop. The unfalsified theory is in this concept used as a supervisor whose task is to switch between adaptive control law and some robust control law. The algorithm which is able to switch between adaptive and robust control law can be written as follows:

(1) set initial performance index $J_a(0) = 0$, $J_r(0) = 0$,
(2) connect the robust control law to the loop,
(3) starting the identification procedure and adaptation of the control law
(4) calculate performance indexes using equations 1 to 4,
(5) if $J^*(k) < J'(k) - \varepsilon$ then switch the control algorithms,
(6) go to step (4).

Where J_a denotes the cost function of adaptive control law, J_r denotes the cost function for robust control law, J' denotes the cost function of controller which is currently active and

J^* is const function of the inactive controller. The constant ε is the non negative hysteresis factor prevents fast switching when the performance functions of the both controllers have the similar values.

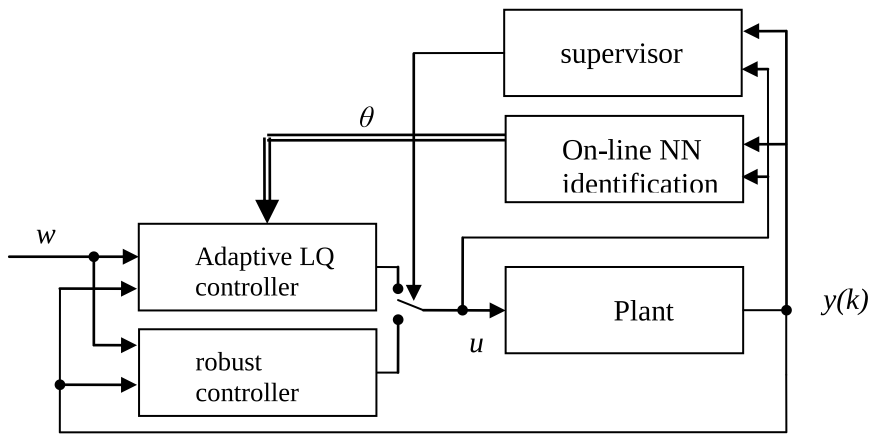

Figure 3: STC with the supervisor algorithm.

4. THE SIMULATION EXPERIMENT

The described algorithm was tested using Matlab/Simulink environment. The figure 4 shows the functionality of the switching algorithm. The identification procedure started in 30s of simulation. In this time the training patterns for the neural network training was prepared. One can see that in the time 53 seconds the cost function J_a reached the lower value than cost function of robust control law J_r and adaptive control algorithm was automatically connected to the closed loop. This example shows the ability of supervisor algorithm to recognize which control law should be connected to the closed loop.

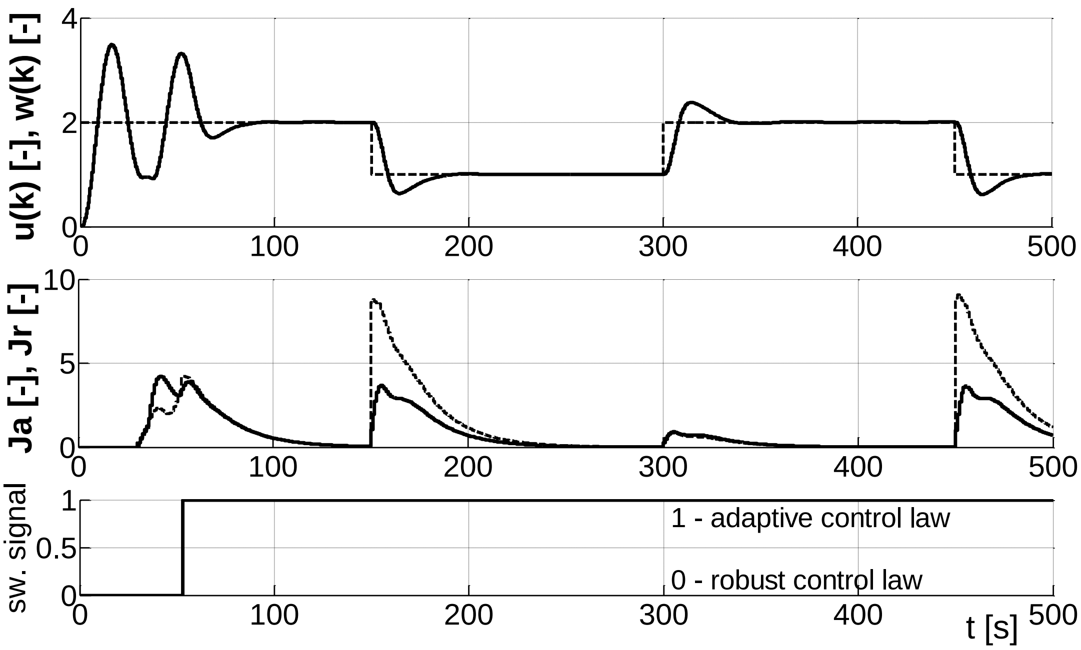

Figure 4: The functionality of the switching algorithm (1st chart shows the plant output, 2nd chart shows the comparison of both const functions and 3th shows switching times).

The experiment shows the initialization of the control procedure. In this case the automatic connection of adaptive algorithm, when it is ready to use, to the closed loop was showed. It is obvious that in the case when the adaptive control law produces the worst control results, it is using computation of cost functions detected and the robust control law is connected to the plant. In this case the identification procedure can be reset, because the bad behavior of STC is caused by inability of identification algorithm to create sufficiently precise mathematical model of the plant.

5. CONCLUSION

The design of supervisor for the self-tuning controller based on unfalsified approach was described. This supervisor is able to switch between adaptive and robust control law. By comparison of values of a cost functions is the case when the active controller is failing detected. This technique significantly increases the stability of the closed loop with the self-tuning controller.

REFERENCES

[1] Ayanendu, P., Stefanovic, M.: Safonov, M., Akar, M.: *Multi–Controller Adaptive Control (MCAC) for a Tracking Problem using an Unfalsification approach*, Proceedings IEEE Conf. on Decision and Control and European Control Conference, 2005

[2] Chang, M., Safonov M.: *Unfalsified Adaptive Control: The Benefit of Bandpass Filters*, AIAA Guidance, Navigation and Control Conference and Exhibit, 2008

[3] Dehghani, A., Anderson, B., Lanzon A.: 2007, *Unfalsified Adaptive Control: A New Controller Implementation and Some Remarks*, Proceedings of the European Control Conference 2007

[4] Vychodil, H.: *Geometric properties of the on-line identification (Geometrické vlastnosti on-line identifikace)*. Doctoral thesis in Czech, Brno, ÚAMT FEKT VUT, 2005.

[5] Bobál, V., Bohm J., Prokop R. and Fessl J.: Practical Aspects of Self-Tuning Controllers, Algorithms and Implementation (Praktické aspekty samocinne se nastavujících regulátorů, algoritmy a implementace), VUTIUM, 1999, in Czech, ISBN 80-214-1299-2.

[6] Lorenc, V.: *Improving performance of the on-line neural network identification using selection of patterns In the training set*, EEICT 2009, Brno