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# DESIGN AND VERIFICATION OF PREDICTIVE CONTROL ON LABORATORY MODEL AMIRA DR300

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***Abstract:*** *Purpose of this paper is to design a predictive control algorithm based on a GPC (Generalized Predictive Control) method with a constraint of manipulated variable for controling of the laboratory model AMIRA DR300 (made by Amira, Duisburg, Germany) in a real time. This laboratory device consists of two main parts. The first part is a mechanism itself and the second part is a transmission housing. The mechanism consists of two direct-current engines, whose shafts are connected together by a fixed shaft coupling. Rotation speed of the shaft coupling is an output value of a control loop, which is measured by a tachometer generator and an incremental position sensor.*

***Key words:*** *Predictive control, GPC, Constraint of manipulated variable, Laboratory model AMIRA DR300*

## 1. INTRODUCTION

A model predictive control is one of new methods of a process control in last years. It affords a systematic approach to the control of industrial systems with constraints of input, output or other signals in a control algorithm itself (Clarke, Mohtadi & Tuffs, 1987, Camacho & Bordons, 2004). The term model predictive control designates a class of control methods which are similar in following particular attributes:

- the future reference trajectory is known before a measurement starts,
- the mathematical model of process is used for the prediction of the future system behavior,
- the minimization of a suitable objective function with future increments of the control signal is belong to a computation of the future control sequence,
- only the first element of control sequence is applied. This whole procedure is repeated in the next sampling period.

The basic principle of the predictive control is shown in Fig. 1, where $y(t)$ is the output value, $w(t)$ is the reference signal, $u(t)$ is the control variable and $N_1$, $N_2$ and $N_U$ are called minimum, maximum and control horizons (Mikleš & Fikar, 2007). The basic principle follows.

(1) The model of the controlled process is explicitly a part of the controller and it is used for the prediction of future output values $\hat{y}(t)$ over some horizon *N*. Predictions are calculated based on the information available to the time *k* and a trajectory of control values, which is unknown and it is necessary to establish it.

(2) The control trajectory is obtained as a solution of the optimization problem, which consists of some possible constraints and an appropriate cost function, which includes the future output and control signal and the future reference signal.

(3) The first element of the whole control trajectory is used. This complete process is repeated in an every sampling period and it is called a *Receding Horizon* concept.

Nowadays the predictive control with many real industry applications belongs among the most often implemented modern industrial process control approaches. First predictive control algorithms were implemented in the industry more than twenty five years ago. The use of these methods was restricted on slow process, because of the amount of required computations, but today an available computing power is not essential problem. Some industrial applications are shown in (Quin & Bandgwell, 2003).

The goal of this paper is the verification of predictive algorithms functionality with a constraint of the manipulated variable on the laboratory model AMIRA DR300 in the real time. The GPC was applied on the control and the CARIMA (Controlled Auto-Regressive Integrated Moving Average) model was chosen for describing the controlled model. Transfer functions of both engines were identified by the recursive least square method in a previous research. Experimental results prove that the predictive control with the constraint of the manipulated variable is suitable for controlling of this laboratory equipment. In our next research a neural network will be implemented as the model of the measured system and these algorithms will be verified on other laboratory models.

A basic structure of the predictive control is shown in Fig. 2.

## 2. LABORATORY MODEL AMIRA DR300

The laboratory model AMIRA DR300 demonstrates a nonlinear one-dimensional process, which can be used for identification, design and verification of control algorithms in the real time and in the laboratory environment.

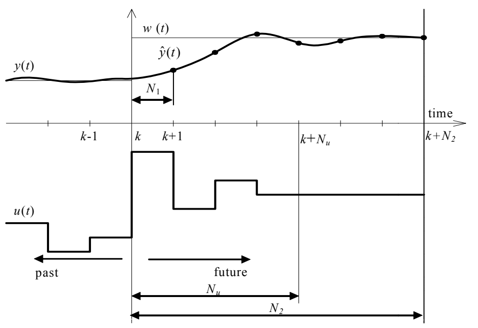


Fig. 1. The basic principle of the predictive control

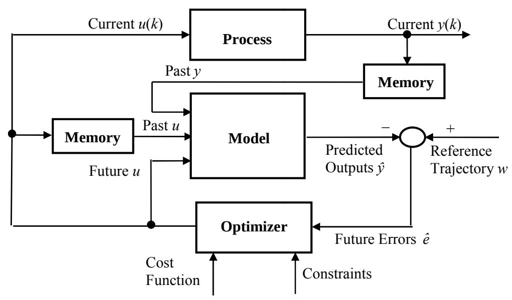


Fig. 2. The basic structure of the predictive control

Fig. 3. The laboratory model AMIRA DR300

This system consists of two basic parts. The first part is the mechanism itself, which can be seen in Fig. 3, and the second part is the transmission housing.
The mechanism consists of two engines whose shafts are connected by the shaft coupling. The first one is a direct-current motor. A controllable voltage $u$ is its input signal, and a shaft speed $\omega$, which is measured either by a tachometer generator, or by an incremental position sensor, is its output signal. The second one serves as a generator and it is possible to use it as a source of the faulty measured value (Hubáček & Bobál, 2010).
The producer claims that these motors are identical, but it was established experimentally, that this fact is wrong and these engines behave different.

## 3. CALCULATION OF PREDICTIVE CONTROL

The cost function in the GPC is shown in the following equation.

$$J = E\sum_{i=N_1}^{N_2}\left[\delta(i)\hat{y}(k+i) - w(k+i)\right]^2 + \sum_{i=1}^{N_U}\left[\lambda(i)\Delta u(k+i-1)\right]^2 \qquad (1)$$

where

- $\hat{\boldsymbol{y}}(k+i)$ - is the predicted output vector $i$ steps in the future indepence on the information available to the time $k$,
- $\boldsymbol{w}(k+i)$ - is the reference trajectory,
- $\boldsymbol{\Delta u}(k+i-1)$ - is the vector of control value differences, which has to be calculated.

The predictor can be written in the matrix notation.

$$\hat{\boldsymbol{y}} = \boldsymbol{G}\tilde{\boldsymbol{u}} + \boldsymbol{y}_0 \qquad (2)$$

where

- $\boldsymbol{G}$ - is the matrix of step response coeficients,
- $\boldsymbol{y}_0$ - is the free response.

Then criterion (1) can be rewritten in the following matrix form.

$$\begin{aligned} J &= (\hat{\boldsymbol{y}} - \boldsymbol{w})^T(\hat{\boldsymbol{y}} - \boldsymbol{w}) + \lambda\tilde{\boldsymbol{u}}^T\tilde{\boldsymbol{u}} = \\ &= (\boldsymbol{G}\tilde{\boldsymbol{u}} + \boldsymbol{y}_0 - \boldsymbol{w})^T(\boldsymbol{G}\tilde{\boldsymbol{u}} + \boldsymbol{y}_0 - \boldsymbol{w}) + \lambda\tilde{\boldsymbol{u}}^T\tilde{\boldsymbol{u}}. \end{aligned} \qquad (3)$$

The minimum of this matrix criterion is obtained by the first derivation with the respect to the control vector and equate it to the zero. The final relation is shown in the equation (4).

$$\tilde{\boldsymbol{u}} = -\left(\boldsymbol{G}\boldsymbol{G}^T + \lambda\boldsymbol{I}\right)^{-1}\boldsymbol{G}^T(\boldsymbol{y}_0 - \boldsymbol{w}) \qquad (4)$$

If the first row of the matrix $\left(\boldsymbol{G}\boldsymbol{G}^T + \lambda\boldsymbol{I}\right)^{-1}\boldsymbol{G}^T$ is designated as $\boldsymbol{K}$ then the first member of the control sequence can be computed as follows.

$$\Delta u(k) = \boldsymbol{K}(\boldsymbol{w} - \boldsymbol{y}_0) \qquad (5)$$

## 4. RESULTS

The CARIMA model with the measurable faulty value was used for the prediction and it is showed below.

$$y(k) = \frac{b(z^{-1})}{a(z^{-1})}u(k) + \frac{\xi(k)}{\Delta} \qquad (6)$$

This equation can be rewritten to the following form.

$$\Delta a(z^{-1})y(k) = b(z^{-1})\Delta u(k) + \xi(k) \qquad (7)$$

It is considered that the last member of equation (7) is equal to zero. Future outputs were calculated from this relation and matrixes $\boldsymbol{G}$ and $\boldsymbol{y}_0$ were established from these predictions. And a final difference of the actual control value was obtained from the equation (5) in each sampling period.

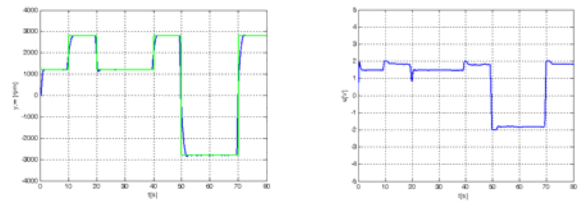

Fig. 4. Control of DR300 using GPC with constrained $u(k)$

In the case of the Amira DR300 laboratory model, the actuator has a limited range of action. The voltage applied to the motor can vary between fixed limits. As it was mentioned in the Introduction, the MPC can consider constrained input and output signals in the process of the controller design. The general formulation of the predictive control with constraints is then as follows

$$\min_{\Delta\boldsymbol{u}} 2\boldsymbol{g}^T\Delta\boldsymbol{u} + \Delta\boldsymbol{u}^T\boldsymbol{H}\Delta\boldsymbol{u} \qquad (8)$$

owing to

$$\boldsymbol{A}\Delta\boldsymbol{u} \le \boldsymbol{b} \qquad (9)$$

The inequality (9) expresses constraints in a compact form. Particular matrices in our case of constrained input signals can be expressed as follows.

$$\boldsymbol{A} = \begin{bmatrix} -\boldsymbol{T} \\ \boldsymbol{T} \end{bmatrix}; \quad \boldsymbol{b} = \begin{bmatrix} -\boldsymbol{1}\boldsymbol{u}_{min} + \boldsymbol{1}\boldsymbol{u}(k-1) \\ \boldsymbol{1}\boldsymbol{u}_{max} - \boldsymbol{1}\boldsymbol{u}(k-1) \end{bmatrix} \qquad (10)$$

where

- $\boldsymbol{T}$ - is a lower triangular matrix, whose non-zero elements are ones,
- $\boldsymbol{1}$ - is a unit vector.

The final time behaviour of the AMIRA DR300 control with the constrained manipulated variable is shown in Fig.4.

## 5. CONCLUSION

This paper deals with the proposal and application of the predictive control with the constraint of the manipulated variable to the control of the nonlinear time varying system – the laboratory model DR300. The control test executed on the laboratory model gaves satisfactory results. The objective laboratory model simulates a process, which frequently occurs in industry. It was proved that the examined method could be implemented and used successfully to the control such processes.


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