REAL-TIME CONTROL OF REWINDING MACHINE
Comparison of Two Approaches

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Abstract: The paper deals with two simple approaches applied to the real-time control of rewinding machine and their comparison. In brief, the comparison of results obtained by nonlinear real-time control with pre-identification, and by adaptive real-time control with on-line identification was performed. The rewinding machine was controlled by PC from MATLAB's Real-Time Toolbox using technological card, terminal board and wires. Each of two used approaches has its advantages and its drawbacks, which was proven, and nonlinear control seemed to be more suitable for the rewinding machine, minimally because of the action signal history from the nonlinear control, the action is more consistent.

1 INTRODUCTION

As is stated in abstract, the comparison of two approaches of rewinding machine's real-time control was performed. Firstly, let us provide introduction to the control methods which were used.

Many processes can be marked as multivariable systems. For such processes, the centralized controller is commonly used because it provides the best closed loop performance. However, the centralized controller is less fault tolerant than the decentralized controller. This is the main reason why decentralized control strategy is often preferred. The used strategy is based on the linear model of the nonlinear plant and the design of a decentralized controller for this linear model (Li, *et al.*, 2000). Li, *et al.*, (2000) mentions that the plant decomposition is crucial for decentralized design and it is not always possible to obtain satisfactory decentralized control systems using a simple physical decomposition. However, the decentralized approach has one big disadvantage due to the decomposition, the reduction of control performance due to the restricted controller structure (Cui and Jacobsen, 2002). But decentralized control is popular in practice, see (Balachandran and Chidambaram, 1997).

Many nonlinear systems can be identified and controlled as linear systems around the steady state or working points. Nice application of feedback control was performed by Cottenceau et al. (Cottenceau et al., 2001). When nonlinear control is used, it possible to enlarge the working interval even in the case the linear control does not guarantee the sufficient quality of control. Moreover, some systems have nonlinearities, which cannot be linearly approximated, for instance friction, etc. Therefore, the necessity of nonlinear control occurs.

Nonlinear system is a set of elements of system, in which at least one of the elements is nonlinear (Modrlak, 2008).

Some nonlinear systems can be approximated by linear systems within the defined range and when specific conditions hold on. In practice, such systems can be divided into linear and nonlinear part. The dynamics of system can be approximated by linear model and its nonlinear part by the nonlinear characteristics. The superposition is not valid for the nonlinear systems, the output of Hammerstein model is different from the output of Weiner model (Lin, 1994).

This paper uses the simple nonlinear control introduced by Chen et al. (Chen et al., 2006) for nonlinear real-time control of rewinding machine. The simple nonlinear control was applied for instance by Perutka and Dostalek (2009), the application is in MATLAB because it is nice tool for Control Engineering at universities (Perutka, Hezcko, 2007).

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2 THEORETICAL BACKGROUND

2.1 Simple Nonlinear Controller

This method was introduced by Chen et al. (Chen, et al., 2006) and verified by Perutka and Dostalek (Perutka and Dostalek, 2009). The controller consists of three parts, “the pure controller” and generator giving together the nonlinear controller and the system model inversion (Chen, et al., 2006).

2.2 Pre-identification

Suppose the existence of continuous-time multivariable N x N system $\mathbf{S}(t)$. Moreover, let as assume the vector of reference signals $\mathbf{R}(t)$, its values are send to the input of the system $\mathbf{S}(t)$. They are same and for the same time as those one which are going to be used during the control. Each time interval of history of control of the system $\mathbf{S}(t)$, where all reference signals have the constant value, is identified separately. Every identification element is identified several times, every time with different identification algorithm, and the obtained model is verified with the measured data. The obtained model which gives the best agreement with the measured data is used for control.

2.3 Self-tuning Control

Self-tuning controllers (STC) belong to the class of adaptive control systems. Self-tuning controllers are based on on-line identification and on tuning the controller parameters with respect to identified changes in controlled systems (Bobal et al., 2005).

2.4 On-line Identification

The action (input) signal $u(t)$ is continuously approximated by Lagrange regression polynomial at the interval of given length during entire control. After the polynomial approximation, the approximating polynomial derivation $u^{(i)}_L(t)$ is counted. It is sampled in purpose to count the values of subsystem parameters using recursive identification algorithm.

2.4.1 Recursive Least-squares and Recursive Instrumental Variable

Least squares method is generally known, for instance presented by Bobal et al. (Bobal et al., 2005). Instrumental variable method is a modification of the least squares method. It does not allow us to obtain the properties of noise, but it has inferior presumptions than the least square method (Zhu & Backx, 1993).

2.5 Suboptimal Linear Quadratic Tracking Controller

Usage of adequate method of controller parameters computation is crucial for control. Linear quadratic control is a reliable method verified by many publications, for instance by Casavola et al. (Casavola et al., 1991), the used suboptimal method was introduced by Dostal (Dostal, 1997).

3 SHORT DESCRIPTION OF USED APPROACHES

The overall controlled system was controlled in the view of decentralized control. Nice paper useful to decentralized control was written by Seatzu and Usai (Seatzu and Usai, 2002).

3.1 Approach 1

This approach is a combination of simple nonlinear control (chap. 2.1) and pre-identification (chap. 2.2). Firstly, the pre-identification run and it provided the initial parameters estimates for the model used during nonlinear control.

3.2 Approach 2

Approach 2 is de facto self-tuning control in real-time. The controller parameters were counted according to the suboptimal linear quadratic method (chap. 2.5), identification was realized using least squares and instrumental variable (chap. 2.2.1).

4 MACHINE DESCRIPTION

The real-time control was realized on CE108 Coupled Drives Apparatus, see figure 1, which is manufactured by TecQuipment Ltd., United Kingdom. The rewinding machine is adapted for its usage in the laboratory. The properties of the apparatus had been studied in detail and its model in MATLAB – SIMULINK environment was created (Perutka, Dolezel 2009). The speed and tension of thread during spooling is an example of rewinding process. This situation is modified for laboratory experiments where the flexible belt is fastened on three wheels. Speed of two wheels is directly proportional to the number of revolutions of the servo-motors. Third wheel may move, because it is fixed on the moving jib which is hung on the spring. The measurement of speed and tension is indirect via the angle of the moving jib, from -10 deg to 10 deg, which correspond the voltage from -10 V to 10 V. The control voltages of the amplifiers of the servo-motors, which are bi-directional, are the inputs. The outputs are four, the voltage of the speed of two servo-motors, or two wheels respectively, and the voltage of the tension and the speed of the belt, or angular deflection and speed of 3rd wheel respectively. The apparatus is connected to PC via technological card Advantech. The control is realized in MATLAB using Real Time Toolbox.

Figure 1: CE108 Rewinding Machine.

5 REAL-TIME TOOLBOX DESCRIPTION

Real Time Toolbox is used for real-time control and it is based on a high performance real-time kernel and drivers for popular A/D and D/A boards, the toolbox includes drivers for more than 300 industry-standard data acquisition boars. The real-time kernel allows us to use sampling frequencies up to 66 kHz with no external clock source required. Besides standard analog and digital I/O many specialized devices are also supported. Multiple boards of the same or different type can be used simultaneously to offer sufficient I/O even for complex industrial applications (Real-time Toolbox: Introduction, 2010).

6 EXPERIMENTAL PART

In figures 2-5 there are obtained results of real-time control of rewinding machine. In these figures, the meaning of the symbols is following: w_1 – set-point of first subsystem, u_1 – action signal of first subsystem, y_1 – output signal of first subsystem, w_1 – set-point of second subsystem, u_1 – action signal of second subsystem, y_1 – output signal of second subsystem.

Figures 2 and 3 provide the results obtained by adaptive real-time control. It was the self-tuning control with online identification using least squares (figure 2) and instrumental variable method (figure 3). The suboptimal linear quadratic tracking was used as the method of controller parameters tuning.

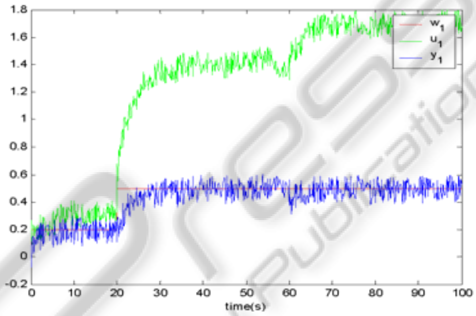

Figure 2: Adaptive real-time control – 1st subsystem.

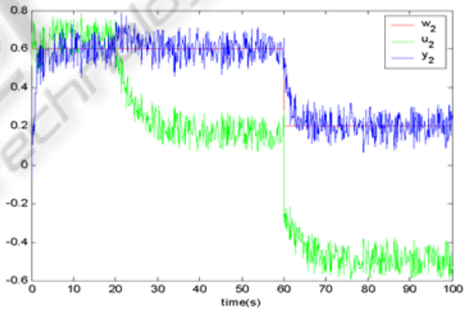

Figure 3: Adaptive real-time control – 2nd subsystem.

Figures 4 and 5 provide the results obtained by nonlinear real-time control, the combination of simple nonlinear controller (Chen et al., 2006) with pre-identification. The pre-identification provided the initial estimates of the used model's parameters.

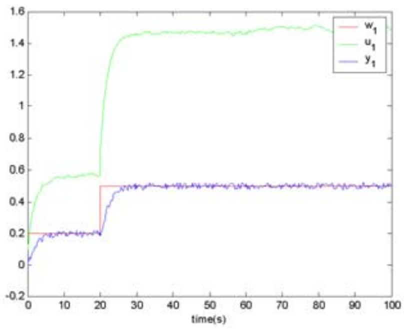

Figure 4: Nonlinear real-time control – 1st subsystem.

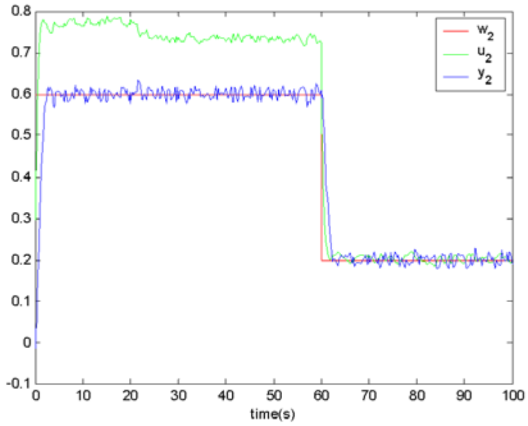

Figure 5: Nonlinear real-time control – 2nd subsystem.

Both used methods of real-time control provided the satisfactory results and they can be used for this machine, but there are some differences which should be mentioned. Nonlinear real-time control is less biased and seemed to be more suitable. The usage of pre-identification decreased the unwanted overshooting caused by interactions. Moreover, the adaptive real-time control is notably more sensitive to the changes of model parameters, whilst the used nonlinear real-time control does not need the change of model parameters.

7 CONCLUSIONS

The paper presented results of real-time control of rewinding machine by two approaches together with the necessary theoretical background. The nonlinear real-time control seems to be more suitable, but adaptive real-time control is also possible to use, because it is more sensitive on the changes during control.

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