DESIGN OF PREDICTIVE CONTROLLER FOR THERMO-OPTICAL PLANT

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Abstract

In this paper predictive controller for a laboratory system is addressed, proposed and tested. The proposed algorithm is tested in predictive control of the light intensity of a thermo-optical plant. The paper deals with theoretical and practical methodology, offering approach for dynamic matrix control design and its successful application in Matlab.

1 Introduction

Predictive control has become popular over the past twenty years as a powerful tool in feedback control for solving many problems for which other control approaches have been proved to be inefficient [3]. Predictive control is a control strategy that is based on prediction of the plant output over extended horizon in the future, which enables the controller to predict future changes of the measurement signal and to base control actions on this prediction.

Model-based predictive control (MPC) is a particular class of optimal controller. The first main advantage of MPC is that constraints (due to: manipulated variables physical limitations, operating procedures or safety reasons) may be explicitly specified into its formulation [3]. The second main advantage of MPC is its ability to be used for both simple and complex model based processes (time delays, inverse responses, significant nonlinearities, multivariable interaction, modeling uncertainties).

The aim of this paper is to present predictive control modeling technique for a real process. Firstly, the basic principles of predictive control are proposed. The next part deals with Dynamic Matrix Control (DMC) algorithm. Then an application example is presented. The last section offers relevant conclusions.

2 Basic Principles of Predictive Algorithm

Basic principles of predictive control are:

- specifying reference trajectory $y_{ref}=r(k)$ and its prediction over the chosen horizon of prediction p (Fig.1.)
- prediction of a process output over the predefined time horizon ($N=k+i$), i.e. prediction of $\hat{y}(k+i)$ for $i=1,\dots,p$, (p is the prediction horizon length) in discrete steps based on real values of control input in the past steps $u(k+i)$ for $i=0,\dots, m-1$ (where $m\leq p$ is the length of the control horizon)
- computation of new control input based on the knowledge of the process mathematical model and optimal cost index J
- minimization of the cost and computation of control input which ensures that the predicted output tracks the reference trajectory
- correction of the prediction function error between measured and predicted variable.

The three basic elements of predictive control are the model, which describes the process, the goal defined by an objective function including constraints and the optimization procedure.

Parameters chosen by users are the prediction horizon, control horizon, parameters in the objective function and constraints.

Process interactions and dead times can be intrinsically handled by model predictive control schemes such as dynamic matrix control (DMC).

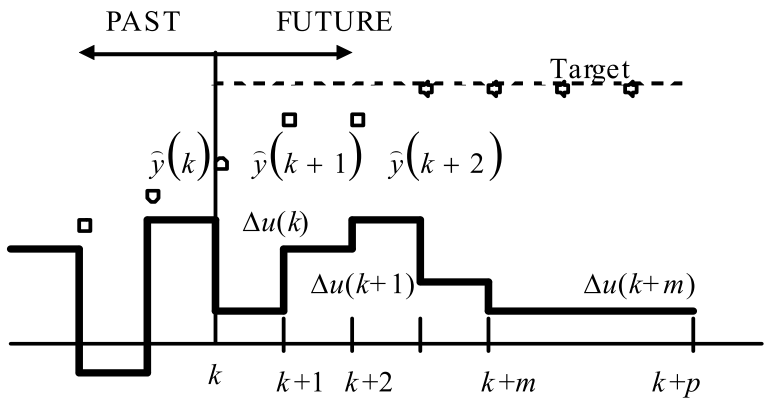

Figure 1: Basic principles of predictive algorithm

3 Dynamic Matrix Control

The sequence of future control signals is computed by optimizing of a given (cost) function. Often, the system needs to follow a certain reference trajectory defined through the set points. In most cases, the difference between system outputs and reference trajectory is used in combination with a cost function on the control effort. A general objective function is the following quadratic form

$$J=\sum_{i=1}^{p}[r(k+1\,|\,k)-\hat{y}(k+i\,|\,k)]^2\Gamma_y+\sum_{i=1}^{m}\Delta u(k+i-1\,|\,k)^2\Gamma_u \tag{1}$$

Here, r is desired set point, Γ_u and Γ_y are weight parameters, determining the relative importance of the different terms in the cost function, u and Δu are the control signal and its increment respectively. The parameter p is the length of the prediction horizon and m is the length of the control horizon. The output predicted by the nonlinear fuzzy model is $\hat{y}(k)$.

$$\hat{y}(k)=\sum_{i=1}^{\infty}s_i\Delta u(k-i) \tag{2}$$

Here, s_i are the step response coefficients. The model employed is the step response of the plant. The model predictions along the prediction horizon p are

$$\hat{y}(k+j\,|\,k)=\sum_{i=1}^{\infty}s_i\Delta u(k+j-i)+e(k+j\,|\,k) \tag{3}$$

Disturbances are considered to be constant between sample instants

$$e(k+j\,|\,k)=y(k\,|\,k)-\sum_{i=1}^{\infty}s_i\Delta u(k+j-i) \tag{4}$$

The measured value of the process output at time k is $y(k|k)$. So

$$\hat{y}(k+j|k)=\sum_{i=1}^{k}s_i\Delta u(k+j-i)+f(k+j\,|\,k) \tag{5}$$

where

$$f(k+j\,|\,k)=y(k\,|\,k)+\sum_{i=1}^{N}(s_{k+1}-s_i)\Delta u(k-i) \tag{6}$$

The prediction of the process output along the length of the prediction horizon, can be written compactly using matrix notation

$$y_p(k)=S\Delta u(k)+f(k) \tag{7}$$

where

$$S=\begin{bmatrix} s_1 & 0 & \cdots & 0 \\ s_2 & s_1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ s_m & s_{m-1} & \cdots & s_1 \\ \vdots & \vdots & \ddots & \vdots \\ s_p & s_{p-1} & \cdots & s_{p-m+1} \end{bmatrix}_{p\times m} \tag{8}$$

Matrix S is called the system's dynamic matrix. By minimizing its objective function the optimal solution is then given in matrix form

$$\Delta u(k) = (S^T \Gamma_y S + \Gamma_u)^{-1} S^T \Gamma_y (y(k) - f(k)) \tag{9}$$

4 Case Study

The thermo-optical plant [1] is a simple laboratory physical model of the thermo dynamical and optical system called DIGICON USB thermo-optical plant (Fig. 2).

Figure 2: Thermo-optical plant

Its thermal channel consists of one heater represented by an electric bulb and one cooler represented by a small fan [2]. The output of this channel is the temperature inside the tube. Measurement of the output value is performed by a thermal sensor. The second dynamics is represented by the optical channel. Within this channel it is possible to generate light by a LED and measure the intensity of the light by photo resistor. The optical channel is even more comfortable for conducting experiments because the time constants are much smaller compared to the thermal channel. The base of the model covers also the electronic part. This part includes one connector for input (voltage) and two others connectors for data communication. One of these is used for communication with the data acquisition card AD512 and another one is the USB port that can be connected directly to the computer (instead of using an expensive data acquisition card). The front panel of the base has five information LEDs. The body of the electronic part is equipped by integrated circuits for communication and signal conversion.

The thermo-optical plant was controlled by Matlab. The dynamics of this plant is not so fast, therefore it is not necessary to have a special data acquisition card to perform control algorithms. So the thermo-optical plant can be connected to the USB port of any PC or notebook where Matlab is running. In our experiments intensity of light using the photo resistor was measured. The input to the model is voltage (0-5 V). The I/O characteristic of the thermo-optical plant is shown in Fig. 3.

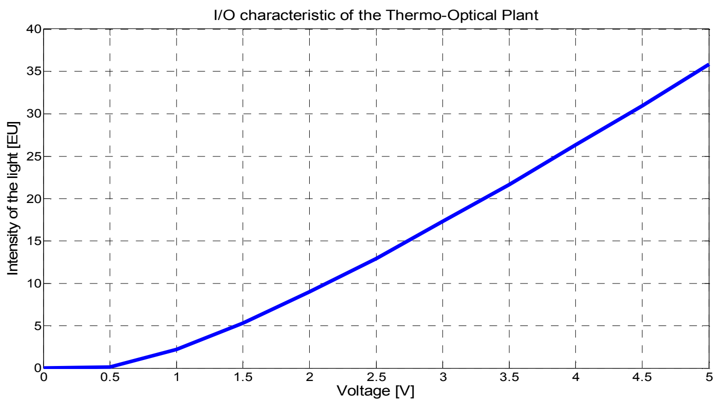

Figure 3: I/O characteristic of the thermo-optical plant

5 Simulation Results

Parameters of predictive DMC are: weight parameters $\Gamma_u = I_{(mxm)}$ and $\Gamma_y = 0.7 I_{(pxp)}$ (I is the unit matrix), the length of the prediction horizon p=10 the length of the control horizon m=5. Time responses of DMC control are shown in Fig. 4.

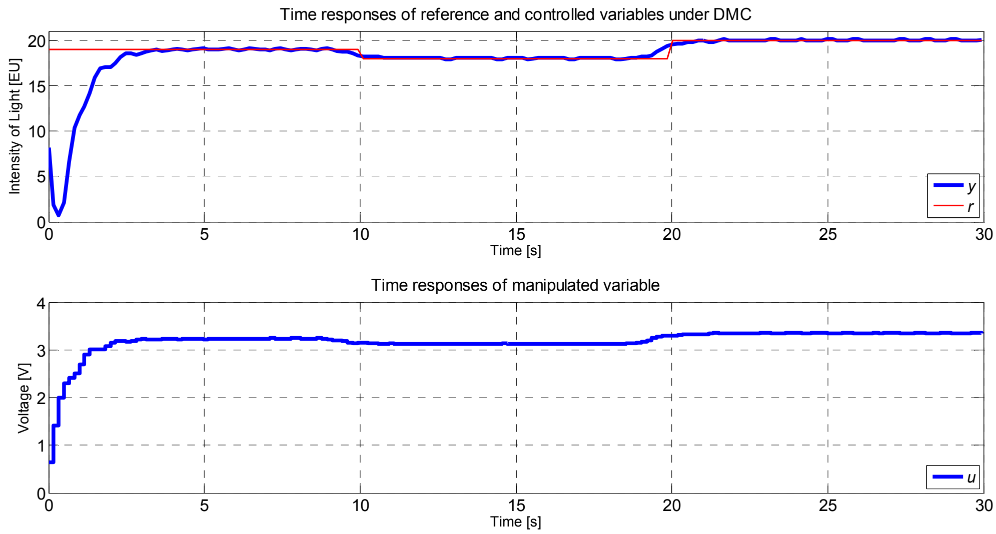

Figure 4: Time responses of the variables under DMC

6 Conclusions

In this paper, predictive control of the light intensity of a thermo-optical plant is designed. DMC is very effective method. Obtained results of simulation in this paper can be possibly used and implemented in a form of control modules into existing packages of control algorithms by control systems manufactures. Knowledge described in this paper can be used as a basis for analysis and solutions of any problems in modern methods and systems modelling areas.

Acknowledgments

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