Fuzzy Based Model Predictive Control for a Quadruple Tank System

Harihara Subramaniam S C*, Harish C

St.Joseph's College of Engineering, Chennai

*scharihara@gmail.com

ABSTRACT: This paper presents a control strategy that combines the predictive controller and fuzzy logic. A fuzzy based model predictive control has been employed to cope with multivariable systems. The fuzzy controller acts a predictor that makes the Model predictive control (MPC) to work with future data. The performance of this control strategy is studied using a quadruple tank problem. The results proved that incorporation of fuzzy into predictive control outperformed MPC and PID controllers.

Keywords

Fuzzy logic, MPC, Quadruple tank, PID, ANFIS, Neural network, MIMO

1. INTRODUCTION

The basic need for the controller lies in the aim to achieve the process variable to the given set point value in a smooth way. Besides this, thecontroller should be flexible with changesinset point and disturbances. In the modern control scenario various intelligent controllers have emerged like predictive controller, fuzzy control, neural networks and expert systems. These controllers can either be used independently or can be used in combinations to obtain best control solution.

The need to achieve tighter control of strong nonlinear process has led to more general MPC formulation in which nonlinear dynamic model is used for prediction. One of the techniques is by using non-linear approximators such as Neural Networks (NNs) and Fuzzy Logic (FL) which have been used in various engineering domains. As a subset of Artificial intelligence, both emulate the human way of using past experiences, adaptingitself accordingly and generalizing. When applying the model based predictive control with Takagi–Sugeno fuzzy model, it is always important how to choose fuzzy sets and corresponding membership functions.

In most fuzzy systems, fuzzy if-then rules were obtained from a human expert. However, this method has great disadvantages becausehuman expertise mostly leads to erroneous rules [1]. For this reason,NNs were incorporated into fuzzy systems, which can acquire knowledgeautomatically by learning algorithmsof NNs. These systems are called Neuro-Fuzzy systems and have advantages over fuzzy systems.In order to achieve faster response and accurate set point, the predictive control is added with a fuzzy controller. This paper uses a predictive control strategy based on fuzzy controller with a self – learning capability for achieving prescribed control objectives.

2. MODEL PREDICTIVE CONTROL

2.1 Classical MPC

An advanced control methodology for discrete-time application is the

Model Predictive Control (MPC) which is the most commonly used techniquein chemical process industries [2]. The basic idea behind MPC is that at each step time k, an optimization problem is solved using an objective function based on output predictions over a Prediction Horizon of P times. A selection of manipulated variables moves over a control horizon of M control moves.

Although M moves are optimized, only the first move is implemented.

The MPC optimization is performed for a sequence of hypothetical future control moves over the control horizon and only the first move is implemented. The problem is solved again at time k+1 with the measured output y(k+1) as the new starting point.

2.2 FUZZY BASED MPC

Predictive control is closely related to decision making. The decision making can be effectively carried out by using fuzzy logic. In our paper, the system consists of two inputs and two outputs and hence the rule set is as follows:

R_{ij}: if y(k) is $A1_i$ and u(k) is $A2_j$ then $y_p(k+1)=d_{ij1}$ and $y_q(k+1) = d_{ij2}$

Where R_{ij} is the fuzzy implication and d_{ij} is the output parameter of fuzzy. Using a fuzzy inference, the rule set can be framed for the system as per our requirements. But, framing rule sets manually for Multivariable systems is erroneous and time consuming. So, automatic estimation of fuzzy rules can be achieved by training and testing a neural network model. This neuro-fuzzy inference system is an adaptive estimator model which is closely associated with mixture of decision making and artificial intelligence.

3. AIR - CONDITIONING SYSTEM

Conventionally, a Comfort Air Conditioning (CAC) System is installed with a PID or ON/OFF control system. The control objective is focused on the indoor temperature and energy efficiency is seldom and hence a sophisticated control strategy is needed [3]. We have considered a SISO type CAC as a case study and applied predictive control strategy in it. The system considered is a first order system without delay but with a negative gain. The model obtained using complimentary response method [4]is as follows:

$$G(s) = \frac{-0.634}{300s + 1}$$

The negative gain indicates that energy consumption increases with decrease in internal temperature.

4. QUADUPLE TANK SYSTEM

Quadruple tank process is a commonly used MIMO process in the modern control literature to illustrate dynamics of a multivariable system and their non-linearity.It consists of four interconnected water tanks and two pumps. Its manipulated variables are voltages to the pumps (ultimately input flow) and the controlled variables are the water levels in the two lower tanks[5]. The quadruple-tank process can easily be built by using two double-tank processes. The overall setup of the system is as shown in figure 1. The transfer functions of individual tanks[6] are as follows:

$$G(s) = \frac{0.0509}{4.16\, s + 1} \text{for tank 1}$$

$$G(s) = \frac{0.0184}{(11.46\, s + 1)(3.5\, s + 1)} \text{for tank 2}$$

$$G(s) = \frac{0.0293}{(7.63\, s + 1)(4.17\, s + 1)} \text{for tank 3}$$

$$G(s) = \frac{0.03706}{3.506\,s + 1} \text{ for tank 4}$$

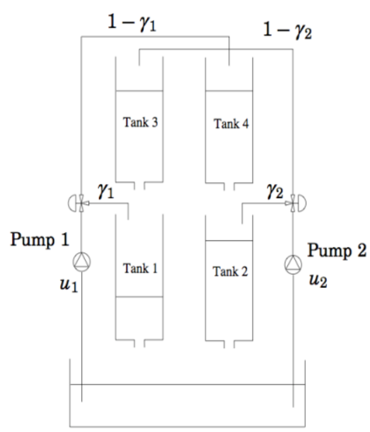

Figure 1 Setup of quadruple tank system

5. ANFIS AS AN ESTIMATOR

ANFIS is a sophisticated tool for the fuzzy modelling procedure where the membership function parameters are computed in such a way that the associated fuzzy inference system can track the given input-output data[7]. It serves as a basis for building the fuzzy if-then rule set with appropriate membership functions to generate the input output pairs. As a first step to design an estimator, training data setsshould be generated that consists of estimator inputs and desired output values. In our study, the input output data of the MPC is taken and trained to generate the ANFIS structure. It is then loaded into the Fuzzy controller block and executed to observe the results. The steps in ANFIS estimator design utilizing the SIMULINK fuzzy logic toolbox are as follows:

1. Training data is generated and loaded to the Editor GUI.

2. Number of input MF, type of input and output MF, are chosen. Thus, initial ANFIS structure is formed.

3. The FIS file is generated for training data and exported to the model file.

4. The ANFIS structure is imported into the Fuzzy controller block, saved and simulated.

The response of PID, MPC and FMPC applied to SISO system is shown in figures 2, 3 and 4 respectively.

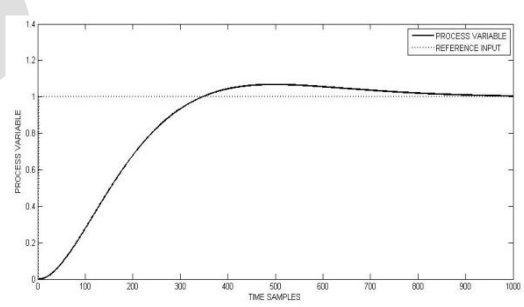

Figure 2- PID response – SISO

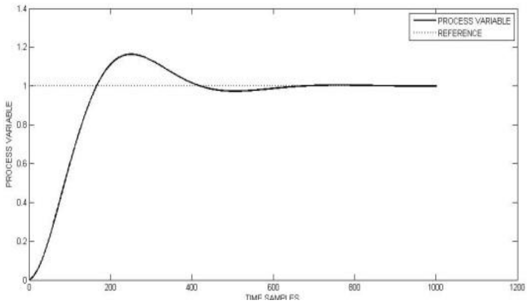

Figure 3- MPC response – SISO

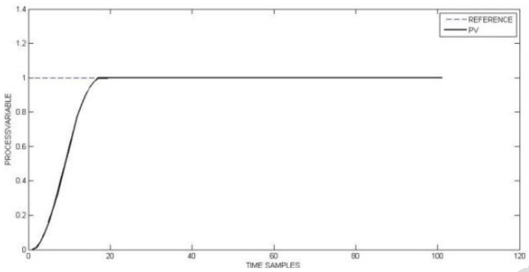

Figure 4- FMPC response – SISO

The developed controller was checked for servo and regulatory operation to check its ability to track changes in set point and reject unwanted disturbances. As far as CAC is considered, set point tracking is mandatory because set point temperature for an AC keeps differring from one day to another.

The set point tracking is shown in figure 5 and disturbance rejection is shown in figue 6.

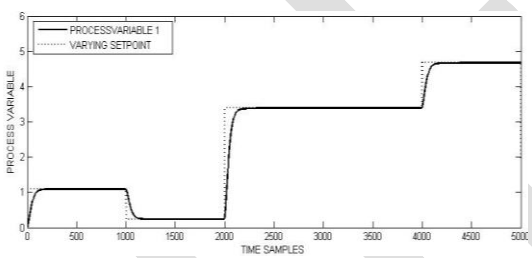

Figure 5- Set point tracking

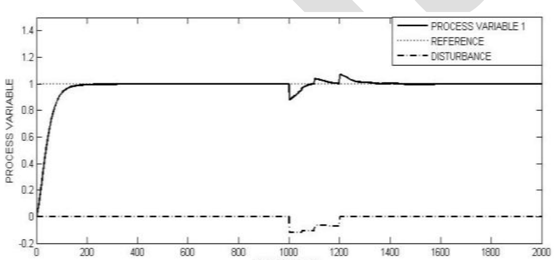

Figure 6- Disturbance rejection

From the above simulations, it is observed that PID controller produces slow response. Though with bearable overshoots, MPC was able to outperform PID in terms of faster settling. FMPC did not produce any overshoot and had a smooth response.

6. SIMULATED RESULTS FOR QUADRUPLE TANK

The following figures show the responses for PID, MPC, FMPC controllers incorporated for a MIMO system.

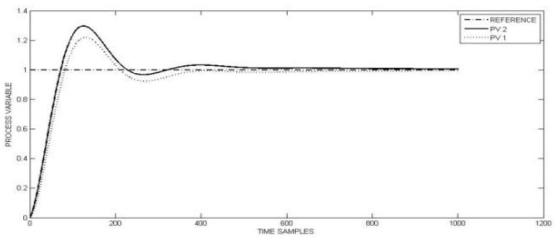

Figure 7- PID response – MIMO

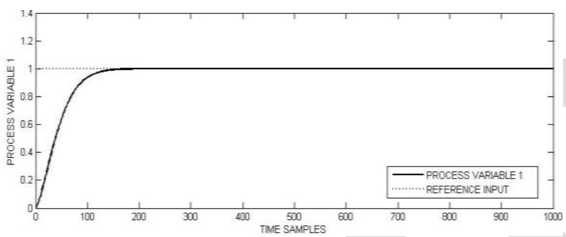

Figure 8- MPC response – MIMO

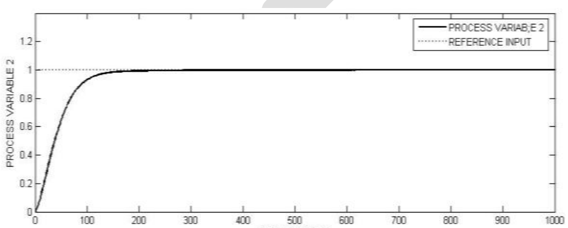

Figure 9- MPC response – MIMO

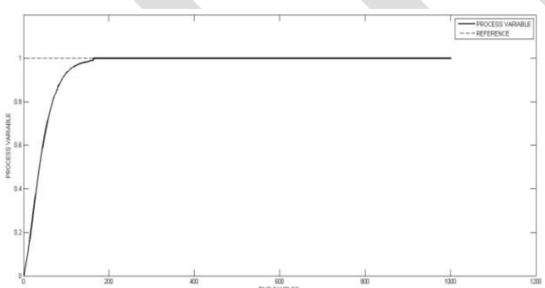

Figure 10- FMPC response (tank 1)

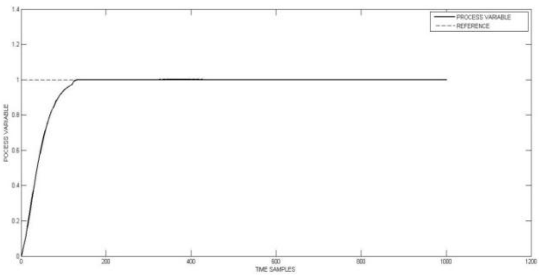

Figure 11- FMPC response (tank 2)

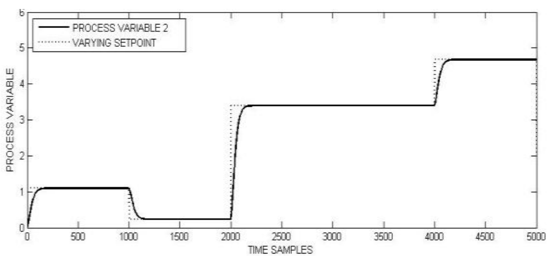

Figure 12- Set point tracking

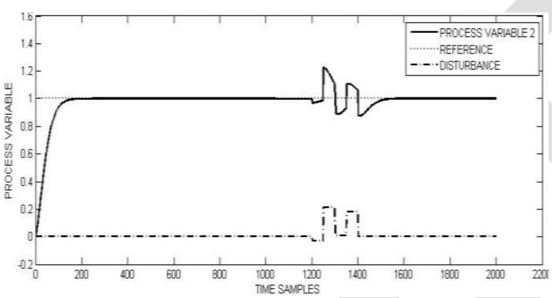

Figure 13- Disturbance rejection

The results clearly show that interacting MIMO systems cannot be controlled with good accuracy using PID controller. MPC can provide a feasible solution to control MIMO systems but it cannot handle non-linear models directly. The FMPC can deal with direct non-linear models and provide a faster, offset-free and smooth response.

7. CONCLUSION

For the CAC system, PID was controller was very slow. MPC was able to provide a faster response but with little overshoots. The incorporation of fuzzy into MPC gave a smoother response that was both devoid of overshoots and faster. As far as Quadruple tank system is considered, PID was not able to handle interaction between inputs and outputs. MPC and FMPC both gave a feasible solution for MIMO system but FMPC has an advantage of handling non-linear models directly.

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