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MODEL PREDICTIVE CONTROLLER FOR A MIMO PROCESS

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ABSTRACT

Model Predictive Controller (MPC) is one of the advanced methodology in current control engineering which has become the attractive strategy that deals with linear/non-linear dynamic behavior of the system. Linear MPC approach is used in this work for the quadruple tank system by taking the lower two tanks into account. The aim of this work is to design and investigate the predictive controller for controlling the level of tanks in a quadruple tank process based on constrained and unconstrained type of problems. Various disturbance scenarios were also applied and proved by controller to show a good response to disturbance rejection. The best possible control is achieved by tuning the parameters of MPC based on a tuning algorithm. The controller is thus designed in the MATLAB environment and according to the gathered simulation environment results, the applied control method were best suitable for obtaining optimal control and the results were analyzed by performance measures.

Keywords: quadruple tank system, model predictive controller, IAE, ISE, ITAE.

1. INTRODUCTION

Developing efficient control strategies for the control of multivariable system for many areas of engineering is quite challenging due to cost and time consuming on model identification. It is necessary for the controller to have a prototype of the real process to get knowledge about the process it should control. Most of the difficult problems in industries can be preferred to be solved by using Model Predictive Controller as it has so much impact on industrial control by allowing system restrictions taken into consideration [1]. Liquid Level control for chemical process is a highly remarkable problem in industries. MPC is based on an optimal control algorithm that can yield a good performance under non-linearity and is increasingly significant and successful control approach because of its use of nonlinear multivariable process model and also its ability to handle constraints on inputs, states and outputs. The quadruple tank process in the laboratory is taken into consideration for the analysis by designing and implementation of the predictive controller. Quadruple tank process is a multivariable process which exhibit non-linear behavior [2]. In order to make it easier for deriving the process model that can be carried out to control the lower tanks in the system, its state-space model was developed. The efficiency of the designed MPC controller for constrained and unconstrained situation can be demonstrated by performing simulation studies on the tank system.

Various disturbance scenarios are applied to the system and found to produce good control action with disturbance rejection. The paper is organized as follows: Section II describes the quadruple tank process, Section III describes the mathematical modeling of process. Section IV describes Model predictive Controller, Section V describes simulation results. .

2. PROCESS DESCRIPTION

The laboratory based quadruple tank process is multivariable process control with an interconnected four tank with two pumps in which controlling the level in tanks will be of major concern[3]. In this work, target is to control the level in bottom two tanks by varying the manipulated variables (flow rates). Hence, the overall setup of system contains pumps, water reservoir, tanks, and valves. The water from the reservoir is extracted through pump1 and is poured to tank1 & tank4 while water is poured into tank2 and tank3 through pump2. The proportion of flow that flows into any of the tank pair is determined by the voltages of two valves. By using three-way valve, the output flows from the pumps are splitted into two. The valve position is determined or controlled by the proportion of output flow into the tanks. The regulation of this process for level maintenance is designed using MPC controller.

In the figure1, v1, v2, v3, v4 represents valves, u1 and u2 represents pump, γ1 and γ2 represents flow rates.

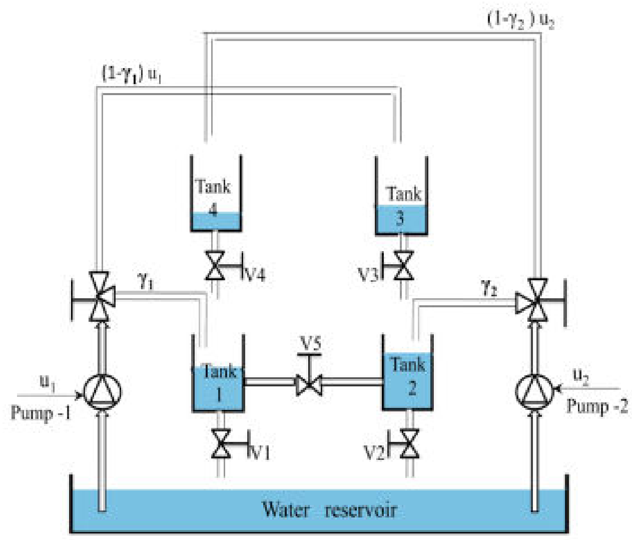

Figure-1. Schematic diagram of a Quadruple tank process.

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3. MATHEMATICAL MODELLING

Mathematical modeling that represents operation of a quadruple tank process based on input-output data sets which is usually developed from the system identification methodology. The non linear models obtained can be used to study the dynamics of the system to carry out the control of the system, which will be linearized and then its state space form is developed. The developed model was simulated by applying steps to its manipulated variables (flow rates of pumps) to obtain the responses of its output variables i.e., level of the system. The state space form of the model of the system can be given as:

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

The value of A, B, C and D matrices of the state-space model are obtained from the MATLAB after linearization is given as;

$$[A]= \begin{matrix} -0.005079 & -0.001388 & -0.004952 & -0.005203 \\ -0.0003191 & 0.004411 & 0.007311 & -0.07807 \\ 0.03799 & 0.001367 & -0.07103 & -0.2322 \\ -0.003554 & 0.03979 & 0.001704 & -0.9461 \end{matrix}$$

$$[B] = \begin{matrix} 0.00000145 & -0.000001114 \\ 0.00002862 & 0.00001738 \\ 0.00004317 & -0.0001347 \\ 0.0005344 & -0.0001366 \end{matrix}$$

$$[C]= \begin{matrix} 216.4 & -14.17 & -0.2514 & 0.04995 \\ 223.1 & 10.73 & -0.4417 & -0.2153 \end{matrix}$$

$$[D] = \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix}$$

The state space model representation obtained from the system identification has Fit to estimation data: [99.25; 99.31] %, FPE: 2.492e-07, MSE: 0.0004945 and thus can be used to control the level of tanks.

4. CONTROL STRATEGY MODEL PREDICTIVE CONTROLLER

Model Predictive Controller (MPC) is one of the highly developed and most proficient control strategies which are able to attain the better performance for complex industrial control troubles. Model predictive controller is based on the control algorithms that make use of dynamic process model to solve a finite horizon open loop optimal control problem by the possible optimized current input moves and predicting the future response of the plant. The figure2 shown below indicates the principle of Model Predictive control.

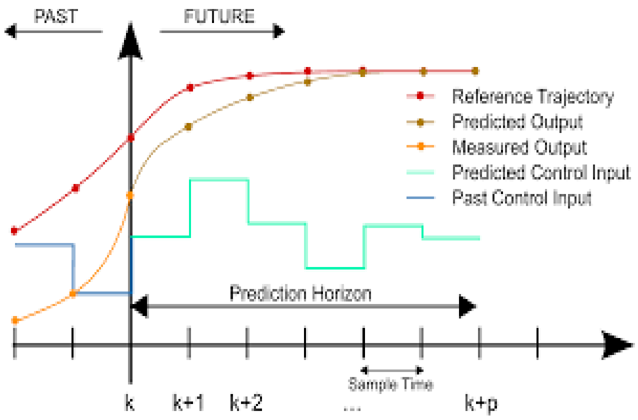


Figure-2. Basic principle of model predictive controller.

In order to keep the process to follow the set point or reference trajectory or approximate of it, future control signals is calculated by using the objective function or performance index. Minimizing the objective function can give solution to the problem over the future control sequence;

$$J = \sum_{i=1}^{N_p} \left| y(t+i) - r(t+i) \right|_Q^2 + \sum_{i=0}^{N_u - 1} \left\| \Delta u(t+i) \right\|_s^2$$

Here, r is the set point, N_p is the prediction horizon, N_u is the control horizon, Q and S are the weights used to adjust the error and inputs respectively. The first control move is implemented once the control sequence has obtained and consequently the horizon is shifted and the values of all sequences are updated and optimization problem is solved once again. The best possible control can be obtained by tuning the parameters of MPC such as sample time, controlled variable horizon, prediction horizon and weight matrices that are used during the simulation of algorithm.

Firstly control strategy is executed, then state of plant is sampled again and repeating the calculations from current state and thus attaining a new control and new predicted state path. As the prediction horizon is moving forward and this is the reason it is named as receding horizon control.

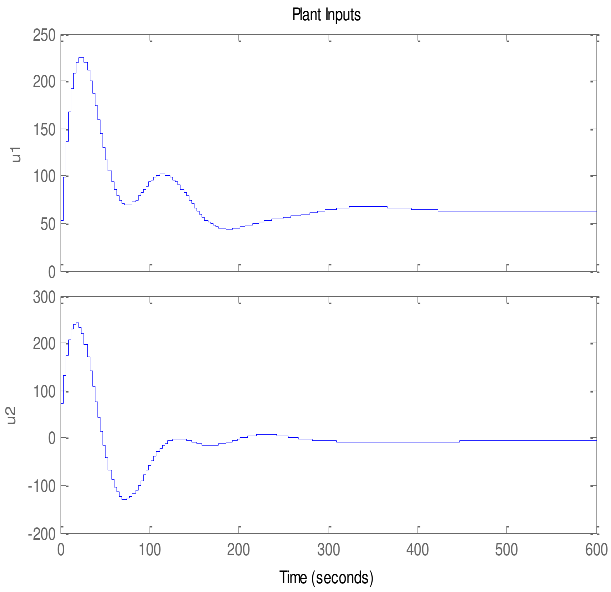
5. SIMULATION RESULT AND ANALYSIS

The Model based Predictive Controller (MPC) for a quadruple tank system [4] is developed to control the level of tank based on two inputs (u1 and u2) and two outputs (y1 and y2) MIMO system with constraints and without constraints type of problems. The inputs to the system are the varying flow rates corresponding to the tanks and output is controlling the level of two tanks at the bottom. The state space model developed using mathematical modeling in section III is used to design the predictive controller in MATLAB environment [5]-[7].

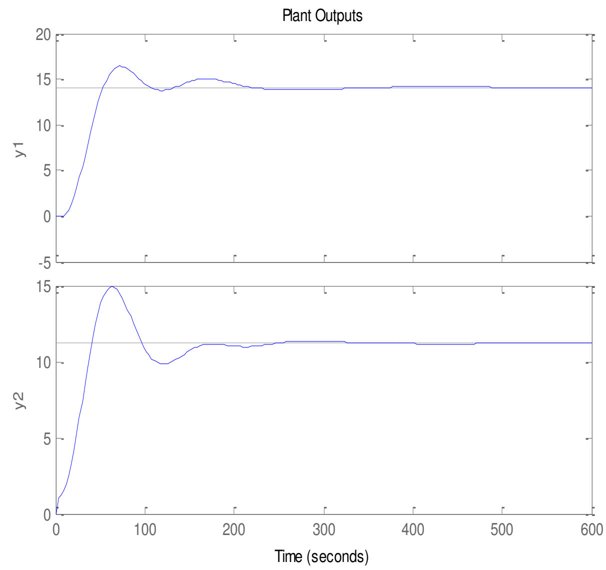
A. Unconstrained MPC

The controller is designed for an unconstrained case by providing the set point to be 14.11 cm and 11.2cm for tank1 and tank 2[8], [9] and is shown in Figure3. The adjustable parameter which is chosen to obtain the control level action is;

- Control horizon = 3
- Prediction horizon = 10
- Control interval = 2



(a)



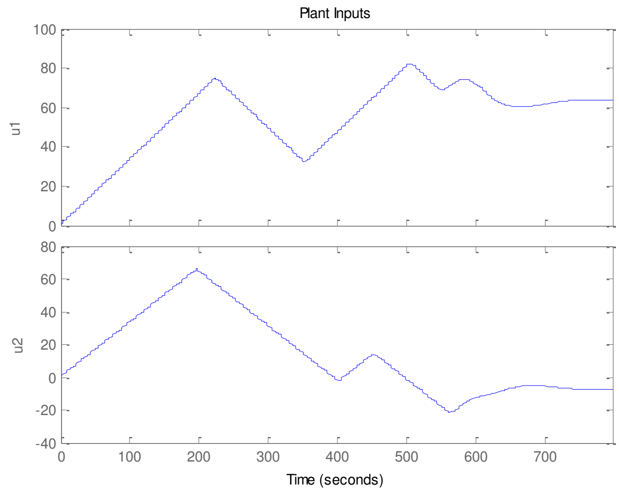
(b)

Figure-3. Unconstrained MPC controller response (a) plant inputs response (b) plant outputs response.

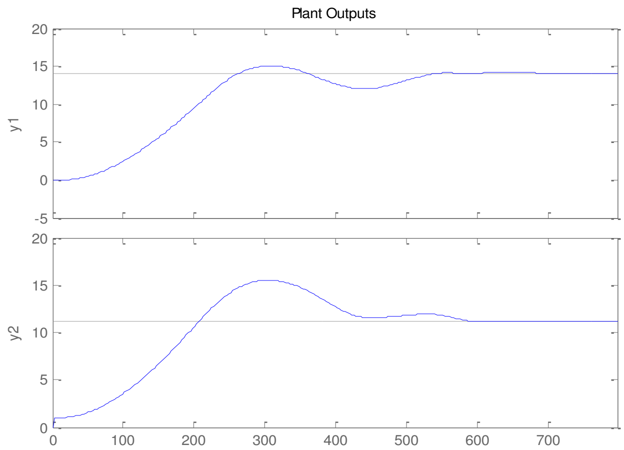
B. Constrained MPC

The major achievement of MPC in industrial process application is its ability to handle constraints [10], [11]. Here the constraints are provided on both the flow rates at ± 1 with the same set points on the level. The controller shows a fine set point tracking even in the presence of constraints.

Figure-4 represents the action of controller to the inputs and outputs of plant.



(a)



(b)

Figure-4. Constrained MPC controller response (a) plant inputs response (b) plant outputs response.

C. Disturbance scenarios

The situation in which a random Gaussian disturbance noise is provided to the system with variance of 0.1 and the MPC controller is giving the disturbance rejection with set point tracking control action. Figure-5 shows MPC with the introduction of disturbance.

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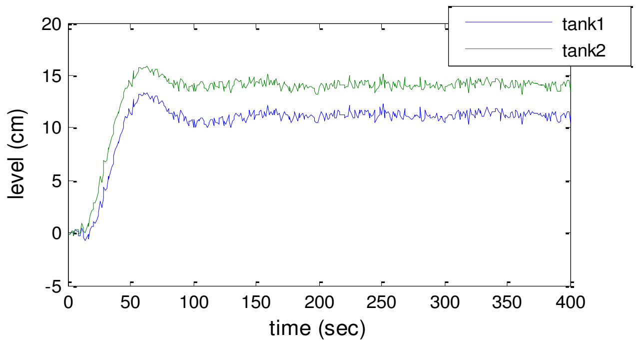


Figure-5. MPC with Gaussian disturbance noise

Also, while providing a step disturbance at a step time of 20 with an initial value of 0 to final value 50, the controller action is given in the Figure-6.

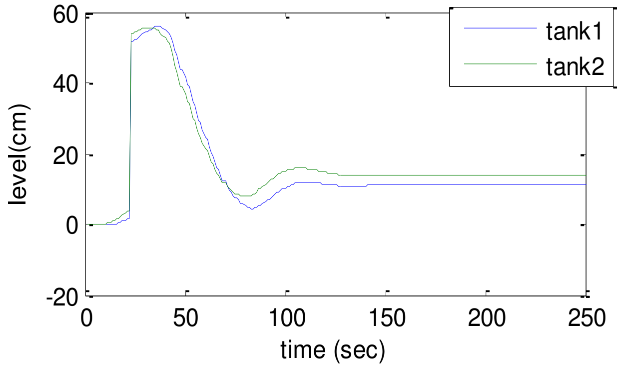


Figure-6. MPC with step disturbance.

D. Tuning strategy

The analysis of MPC controller design is that the adjustment of control horizon and prediction horizon will provide an optimal or best control action for the process. Hence tuning the parameters of MPC such as sample time T, control horizon M, prediction horizon P can give a better performance of level control for the tanks. In this work an easy to use tuning strategy is used based on an algorithm that will calculate the above mentioned parameters for an unconstrained MIMO system is defined [12]. The algorithm is described as follows from shredhar and cooper work;

- Approximate the process dynamics with FOPDT
- Selection of sample time as close as possible

$$T = \max(0.1\tau_{rs} + 0.5\theta_{rs})$$

- Computing the prediction horizon, P

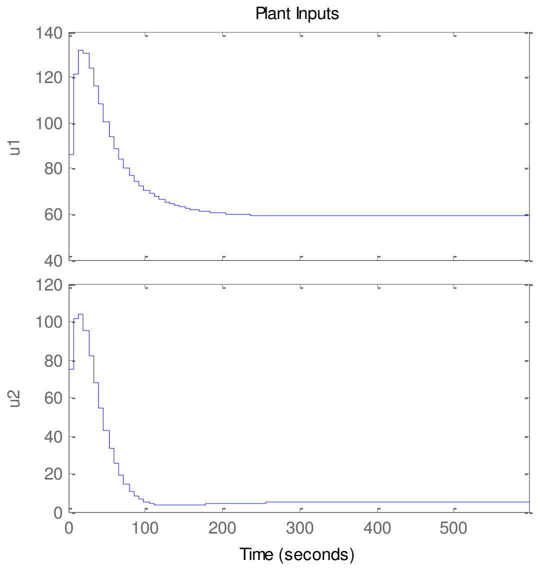
$$P = \max(\frac{5\tau_{rs}}{T} + K)$$

- Select the control horizon, M

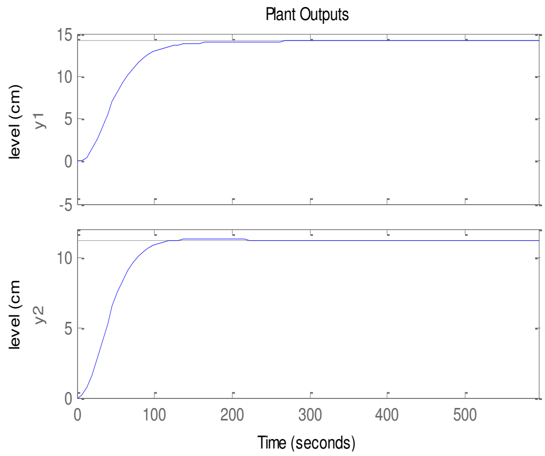
$$M = \max(\frac{\tau_{rs}}{T} + K)$$

Where,

$$K = \frac{\theta_{rs}}{T} + 1$$



(a)



(b)

Figure-7. Response of MPC after tuning (a) input response (b) output response.

The values obtained after the tuning strategy is given as;

Sample time	=20.14
Prediction horizon	=20
Control horizon	=6.5549

6. CONCLUSIONS

The Model Predictive Controller (MPC) is very well-to-do control methodology with large advantages to hold different problems such as process nonlinearity, constraint handling, stochastic disturbance, tuning etc and is used in many different applications like aerospace, automotive, water, energy etc. In this work, the quadruple tank system is taken for investigation and state space model is developed. The linear MPC controller is designed based on unconstrained and constrained cases and the plant output response is analyzed. Also the scenarios such as random Gaussian noise and step disturbances provided shows that disturbance rejection is well suited in the control action. Tuning of the controller parameter for an unconstrained MIMO system provides an optimal and best control by giving no overshoots for the process, thereby regulating the level actions in two tanks. The work can be extended to give tuning for constrained systems.

REFERENCES

[1] Austin P.C. and Bozin A.S. 1996. Applying Dynamic Matrix Control in the Process Industries. Transactions of the Institute of Measurement & Control. 18(1): 32-41.

[2] Edward p. Gatzke, Edward S. Meadows, Chung wang, Francis j doyle. 2000. Model based control of a four tank system. Elsevier computer and chemical engineering. pp. 1503-1509.

[3] AS. Dormido, F. Esquembre. 2001. The quadruple tank process: An interactive tool for control education. Universidad Nacional de Educación a Distancia. Departamento de Informática y Automática. pp. 670-683.

[4] Dai, L., & Astrbm, K. J. 1999. Dynamic matrix control of a quadruple tank process. In Proceedings of the fourteenth *ZFAC*, China. pp. 295-300.

[5] A. Bemporad. 2006. Model-based predictive control design: New trends and tools. in Proc. 45th IEEE Conf. on Decision and Control, San Diego, CA. pp. 38-52 .

[6] J.B. Rawlings. June 2000. Tutorial overview of model predictive control. IEEE Control Systems Magazine. pp. 124-156.

[7] E.F. Camacho and C. Bordons. 2004. 2nd edition, Textbooks in Control and Signal Processing, Springer-Verlag, London. pp. 11-30.

[8] Muthukumar. N., Gomathi. V, Dr. Ramkumar, Dr. G Balasubramanian. 2013. Prediction based optimal control of a quadruple tank process. International Conference on circuits, power and computing technologies [ICCPCT-13].

[9] K.H.Johansson. 2000. The Quadruple-Tank Process: A Multivariable Process with an Adjustable Zero. EEE Trans. Control Syst. Technol. 8(3): 456-465.

[10] D.Q. Mayne, J.B. Rawlings, C.V. Rao, and P.O.M. Scokaert. June 2000. Constrained model predictive control: Stability and optimality. Automatica. 36(6): 789-814.

[11] J.M. Maciejowski. 2002. Predictive Control with Constraints. Prentice Hall, Harlow, UK.

[12] Rahul Shridhar and Douglas J. Cooper. 1998. A Tuning strategy for Unconstrained Multivariable Model Predictive Control. Ind. Eng. Chem. Res. pp. 4003-4016.