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PERFORMANCE ANALYSIS OF TWO INTERACTING CONICAL TANK SYSTEM USING MODEL PREDICTIVE CONTROL

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ABSTRACT

Most of industrial process are Multi-Input/Multi-Output (MIMO) systems. The implementation of control algorithms for such MIMO systems is more complicated due to variations in process dynamics that occur because of change in operating point and nonlinear dynamic coupling. To solve this problem, there exist several control schemes that can be centralized (multivariable structure) or decentralized (multi-loop structure). Model Predictive Control (MPC) has become a leading form of advanced multivariable control in chemical industries. The objective of this work is to introduce a multiple model adaptive control strategy for multivariable MPC. It is used to design multiple linear MPC for Two Interacting Conical Tank System (TICTS). This strategy combines several multiple linear MPC controllers, each with their own linear state space model describing process dynamics at a specified level of operation. One of the linear MPC controller outputs is selected as multiple model adaptive controller outputs is based on the current value of the measured process variable

Keywords

Model predictive control, Linear model predictive control, Multi-model predictive control

1. INTRODUCTION

Conical tank finds wide application in process industries like waste water treatment industries, sewage water treatment industries, concrete mixing industries, food processing industries and hydrometallurgical industries due to their shape leads to better drainage of solid mixtures, slurries and viscous liquid at the bottom of the tank. The control of the conical tank presents a challenging problem due to its non-linearity and constantly changing cross sectional area from top to bottom of the tank.

The control of tanks liquid level and flow between the tanks is a fundamental problem in the industries. The process industries require the liquid to be pumped, stored in one tanks and then pumped to another tank. Many times the processing liquid are carried out using the chemical or mixing treatments in the tanks, but always the level of the liquid in the tanks must be controlled.

The level is too high which may upset the reaction equilibria and cause damage to the equipment, or result in spillage of hazardous material. If the level is too low, it may have bad consequences for the continuous operations. Hence, control of liquid level is a very important and common task in process industries. C.E.Garic *et al* have discussed that the MPC is the group of controllers in which there is an immediate use of an explicit and isolately identifiable model [6]. Madhubala *et al* [7] proposed the Tuning of the fuzzy system and Genetic algorithms are used to tune the membership function of fuzzy system. J.Richalet proposed two classical applications of the Model Based Predictive Control which enhance the advantages of the method like feed-forwarding, constraint handling, no-lag error on dynamic set points in addition to that easy trade-off between robustness and dynamics specifications [11].

Anandanatarajan *et al* [2] implemented two methods to control the level of the conical tank One is based on the Smith figured from the plant model in the modified space and other is on Newton's extrapolation method for non-linear system in first order representation with dead time.

N.S.Bhuvaneswari *et al* [3] proposed a time-optimal control for changes in set-point and an adaptive control for process parameter changes using neural network for a non-linear process K.Holkar *et al* proposed various control design methods based on model predictive control concepts, The most widely used strategies as dynamic matrix control (DMC), Model algorithmic control (MAC), Predictive functional control (EHAC) and Generalized predictive control (GPC) have been described with history, basic ideas, properties, and their controller formulation.

The organization of this work is as follows. In section II, Process description of TICTS are denoted. In section III,

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design and implementation of linear Mpc controller for TICTS are discussed. Multi-model Mpc for TICTS has been designed and implemented in section IV, design and implementation of are discussed. Finally results and discussion are presented in Section V.

2. PROCESS DESCRIPTION

The TICTS is a benchmark problem due to its non-linearity property. TICTS consist of two identical conical tanks (TANK1 and TANK2) , two self-ruling pumps that deliver the liquid flows F_{IN1} and F_{IN2} to TANK1 and TANK2 through the two control valves CV_1 and CV_2 respectively. These two tanks has the connection at the bottom of the tank through manual control valves MV_1 and MV_2 with valve coefficients β_1 and β_2 respectively. The schematic diagram of TICTS has shown in Figure 1.

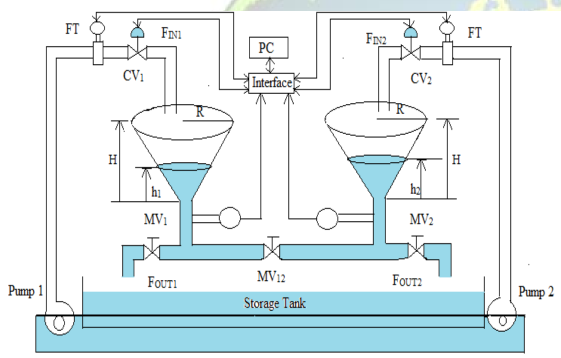

Fig 1: Schematic Diagram of TICTS

Table 1.Operating Parameters of TICTS

Parameters	Description	Values
R	Top radius of the conical tank	19.25 cm
H	Maximum height of TANK1 & TANK 2	73.00 cm
F_{IN1} & F_{IN2}	Maximum Inflow to TANK1 & TANK 2	500 LPH
β_1	Valve co-efficient of MV_1	50.00 cm^2/s
β_2	Valve co-efficient of MV_2	50.00 cm^2/s
β_{12}	Valve co-efficient of MV_{12}	35.00 cm^2/s

The above Table I represent the operating parameters of TICTS which are given in benchmark (Ravi V.R. et al 2011).

The non-linear equations represents the open loop dynamics of Two Interacting Conical Tank System is derived using mass balance equation and energy balance equation. The mathematical model of two tank interacting conical tank system is given in [10]

$$\frac{dh_1}{dt}=\frac{F_{IN1}-\beta_1\sqrt{h_1}-sign(h_1-h_2)\beta_{12}\sqrt{|h_1-h_2|}}{\pi\frac{R^2h_1^2}{H^2}}$$

$$\frac{dh_2}{dt}=\frac{F_{IN2}-\beta_2\sqrt{h_2}+sign(h_1-h_2)\beta_{12}\sqrt{|h_1-h_2|}}{\pi\frac{R^2h_2^2}{H^2}}$$

Where,

F_{IN1} =Inflow rate of the TANK1 (cm^3/s)
F_{IN2} =Inflow rate of the TANK2 (cm^3/s)
F_{OUT1} =Outflow rate of the TANK1 (cm^3/s)
F_{OUT2} =Outflow rate of the TANK2 (cm^3/s)
h_1 =Liquid height in TANK1 (cm)
h_2 =Liquid height in TANK2 (cm)
$A(h_1)$ =Cross sectional area of TANK1 at h_1 (cm^2)
$A(h_2)$ =Cross sectional area of TANK2 at h_2 (cm^2)
β_{12} =Valve coefficient of MV_{12} (cm^2/s)

3. MODEL PREDICTIVE CONTROL

3.1 Principle

MPC predicts and optimizes the time-varying processes over a future time horizon. MPC refers to a family of control algorithm that employs an explicit model to predict the future behavior of the process over an extended prediction horizon.MPC is a multivariable control algorithm that uses for an internal dynamic model of the process and history of past control moves and also an optimization cost function J over the receding prediction horizon.

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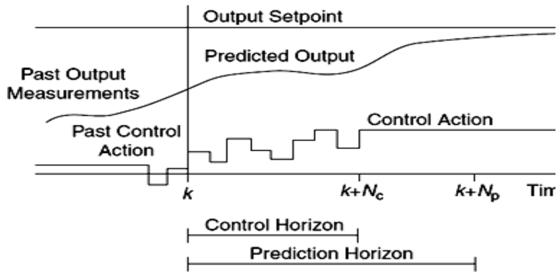

Fig 2: General Response of Model Predictive Control

3.2 Types of MPC

Linear MPC are used only in the small operating region. These approaches are used in the majority of applications with the reverse feed forward mechanism of MPC compensating for prediction errors due to structural mismatch between the model and the process.

When linear models are insufficiently accurate to represent the real process nonlinearities, several approaches can be used. The process can be controlled with nonlinear MPC that uses a nonlinear model directly in the control application. The nonlinear model will be in the form of an empirical data fit (e.g. artificial neural networks) or a high-fidelity dynamic model based on fundamental mass and energy balances.

3.3 Representation of Model for TICTS

Keeping in mind the end goal to speak to the model of plant,it is necessary to consider different operating regions for linear MPC and multi-model MPC (non-linear MPC) An operating point is selected around mid operating region of TICTS for linear MPC. For multi-model MPC based on insights and knowledge of TICTS, the nonlinear open loop characteristics of TICTS can be represented as piecewise linearized region around five operating points.

Table 2.Operating Points for Linear MPC and Multi-Model MPC

Controller	Operating points	**F_{IN1} (LPH)**	**F_{IN2} (LPH)**	**h_1 (cm)**	**h_2 (cm)**
Linear-MPC	Operating point 1	400	40	27.74	12.40
Multi-model MPC	Operating point 1	350	0	19.79	6.709
	Operating point 2	475	110	43.42	26.12
	Operating point 3	500	138.5	49.99	32.48
	Operating point 4	10	380	8.575	23.75
	Operating point 5	100	500	26.55	46.87

In order to obtain a linear discrete state space model for linear MPC and non-linear MPC, using the non-linear differential equations (4.11) and (4.12), the mathematical model of TICTS is developed with the help of SIMULINK/MATLAB. The SIMULINK model of TICTS is shown in Figure 3.

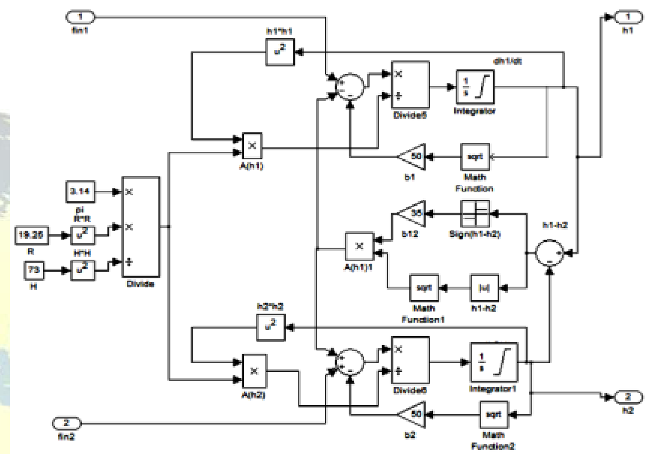

Fig 3: SIMULINK Model of TICIS

4. LINEAR MPC AND MULTI-MODEL MPC

The linear MPC is implemented for TICTS using MATLAB/SIMULINK as shown in Figure.4. A single linear MPC controller can adequately utilize the information stream rates to manage the fluid heights around a small operating range. To examine the closed circle control execution of straight MPC, the set focuses of level in TANK1 and TANK2 are changed throughout the operating regions of TICTS and inputs of the system are considered to be manipulated variables which get tuned by linear MPC controller. The outputs of the system are h_1 and h_2

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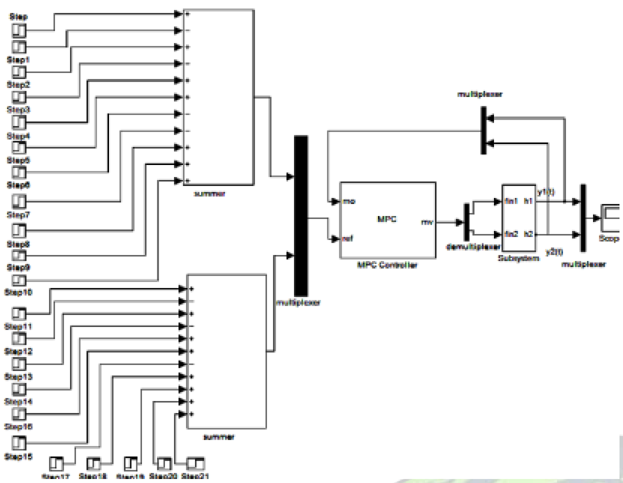

Fig 4:Closed Loop Control of TICTS using Linear MPC

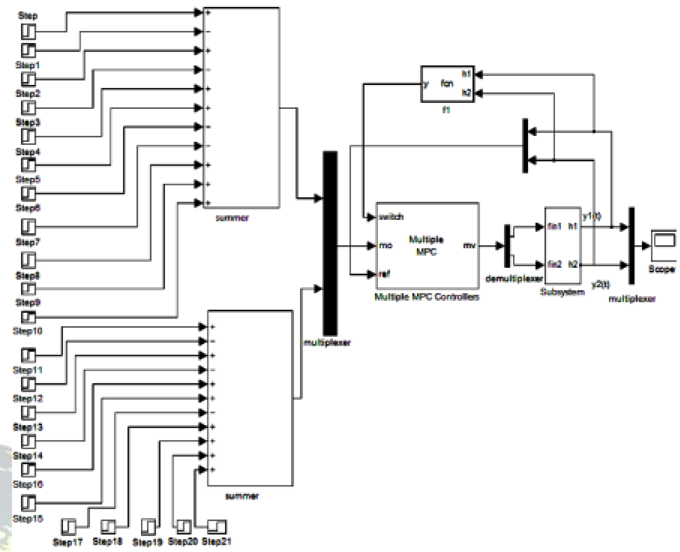

Fig 5 Closed Loop Control of TICTS using Multi -Model MPC

The multi-model MPC controller is designed with multiple linear MPC controllers. Each linear MPC controller is designed to work well in particular region. Hence multiple linear MPC controllers allow controlling non-linear process like TICTS in extensive variety of working focuses. In conventional feedback control, non-linear behavior of a process compensated with increase planning. Correspondingly, the non-direct MPC controller allows to transit between multiple linear MPC controllers in a pre-ordained manner. Five linear MPC controllers are constructed for five operating points. When the plant moves far from this working area, the control framework switches to another linear MPC controller. When the process variable (manipulated variable) is going through different operating regions, the respective linear MPC controllers are chosen from numerous MPC piece taking into account switch info signal.

The multi-model MPC is implemented for TICTS using multiple MPC controller block in MATLAB/SIMULINK as shown in the above Figure 5. The five linear MPC controllers are designed. The controllers are loaded into multiple MPC block in SIMULINK.

Based upon the various operating level, the corresponding controllers are selected and the control process of the level in TANK1 and TANK2 are completed. Each of the controllers will act as a better controller for particular region. To execute this different exchanging condition for TICTS in SIMULINK/MATLAB embedded C code is written and used as a function call program in multi-model MPC SIMULINK block The coding is written based on if-else condition.

The switch input signal is generated from switching function block based on conditions given in Table 3

SWITCHING CONDITION	CONTROLLE R SELECTED
IF((h_1>h_2) AND (h_1>=0) AND(h_1<=25))	MPC1
IF((h_1>h_2) AND (h_1>=27) AND(h_1<=50))	MPC2
IF((h_1>h_2) AND (h_1>50))	MPC3
IF((h_2>h_1) AND (h_2<25))	MPC4
IF((h_2>h_1) AND (h_2>=27))	MPC5

5. RESULTS AND DISCUSSIONS

Figure 6 represents the process output of TICTS plant model using Linear MPC controller for a single set point

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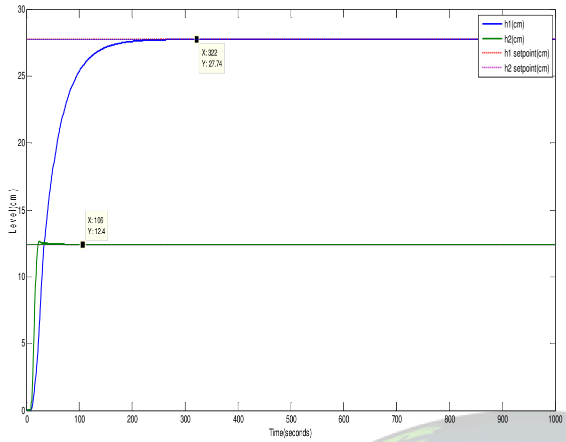

Fig 6 Response of Process Output using Linear MPC

Figure 7 represents the process output of the TICTS plant model using Multi-mode MPC controller for single set point.

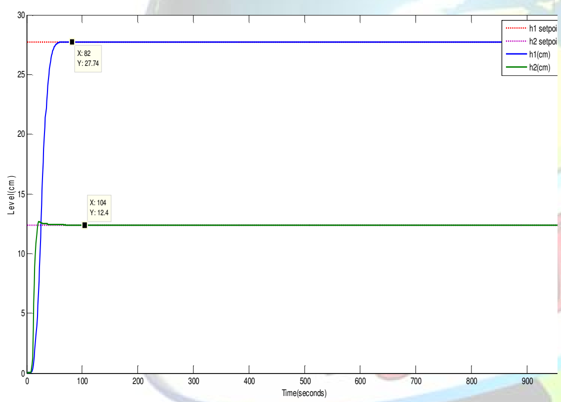

Fig 7 Response of Process Output using Multi-model Linear MPC

The graph 6 represents the time taken to reach the desired set point level (h_1 and h_2) is 322(seconds) and 106(seconds) for tank1 and tank2 individually. The graph 7 represents the time taken to reach the desired set point level (h_1 and h_2) is 82(seconds) and 104(seconds) for tank1 and tank2 respectively.

Table 4. Performance Analyses of Linear MPC and Multi-model MPC

Set point	Controller	Settling time for h_1	Settling time for h_2
h_1=27.74 cm	Linear MPC	322 (seconds)	106 (seconds)
h_2=12.40 cm	Multi-model MPC	82 (seconds)	104 (seconds)

A servo response is one which responds to a change in set point. The set point may be changed as a function of time and therefore control variable must follow the set point.

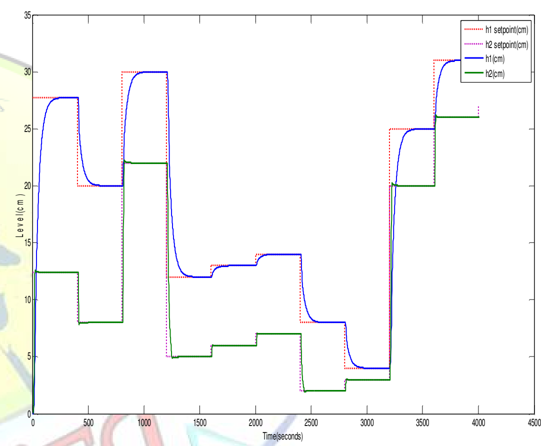

Fig 8 Servo Response of TICTS using Linear MPC

The servo response of TICTS controlled using Linear MPC is shown in the Figure 9

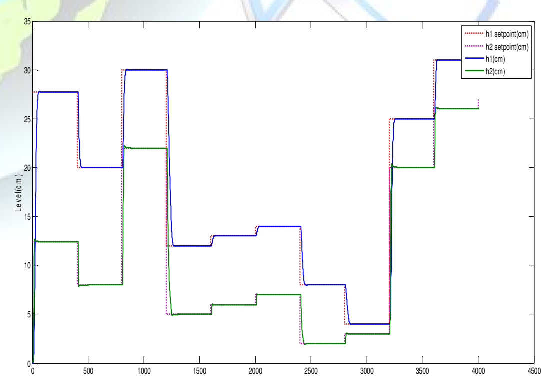

Fig 9 Servo Response of TICTS using Multi-model MPC

From the obtained results, it has been viewed that the level of the TICTS is controlled in an allowable limit of 50cm. The settling time of the level in TICTS framework for linear MPC is higher so it is better to go for multi-model MPC controllers

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6. CONCLUSION

The control of fluid level in tanks and flow between the tanks is a basic problem in process industries. The modeling of the TICTS process is necessary to understand the behavior of the process taking place in the plant. The plant model provides the better understanding of the system. From the simulation study, it reveals that the Linear MPC controller was not able to provide perfect control action for the entire operating of TICTS. The settling time for h_1 response is much higher. To overcome the drawback by using Linear MPC controller, Multi model MPC controller (five Linear MPC's) were composed and anticipated for TICTS process. The settling time for h_1 response is much reduced when compared with Linear MPC controller.

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