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HARDWARE IMPLEMENTATION OF MODEL PREDICTIVE CONTROL BASED FUZZY LOGIC CONTROLLER FOR TEMPERATURE PROCESS STATION

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ABSTRACT: In this paper, Model based Predictive Control (MPC) and fuzzy logic controller (FLC) for temperature process station was proposed. This controller design gives an optimum performance even under process disturbances. Conventional controllers like P, PI, and PID controllers fail to control the process effectively under disturbances, conventionally accurate model of the process and complex algorithms are needed to design the self tuning of PID controller. Here an attempt was made to implement MPC based FLC which does not involves developing any complicated model and the usage of complex algorithms. FLC and MPC were designed to provide a timely control action ensuring optimum performance from the controller and the proposed controller hardware design was implemented to control the temperature process efficiently.

Keywords: Temperature process station, PID, FLC, MPC, MATLAB.

I.INTRODUCTION

Temperature monitoring and control is an essential process in the continuous process industries like that of the Petrochemical industries. Starting from the every storage of the different chemicals to their cracking and distillation, temperature plays a very important role in all these processes. The heat treatment process makes strict demands on the stability of furnace temperature, so does the testing of furnace temperature uniformity in the field of furnace verification. Therefore, furnace temperature control and measurement should be made. Here, challenge is the furnace has to be turned off when the temperature crosses the desired set value and it has to be turned again when the temperature gets lowered than the set value. This process is done using the closed loop implementation where the feedback loop senses the temperature and then gives it to the controlling section.

A Controller controls the temperature automatically based on the measured value. The total process consists of two major parts, such as the sensing of the temperature using a Temperature sensor and hence the controlling of the same is using a real time controlling software**.** MATLAB is used to implement a closed loop system controlling the process. The temperature sensor is being simulated by a power resistor and a Thermistor .The heat treatment process makes strict demands on the stability of furnace temperature, so does the testing of temperature uniformity in the field of verification. Therefore, temperature control and measurement should be made [3]. The temperature measurement and control system of heat treatment was developed using MATLAB. This kind of intelligent algorithm is implemented on the MATLAB platform combined with the system hardware module used to do data acquisition and signal conversion, the whole control system is able to hold the temperature to a certain degree rapidly, steadily and accurately, which makes great sense to the heat treatment process and the Temperature uniformity testing in verification. Experiments of data acquisition and processing were made on temperature rising, holding and measurement, during heating zone of heat treatment.

Many practical results show that the utilization of virtual instrument improves the performance of temperature control and measurement. The temperature measurement and control system is real-time, exact and reliable. MATLAB is used to implement a closed loop system to control a temperature (to heater, turn ON & OFF). Thermistor and some other temperature sensors are used to sense the temperature in closed loop control system. Error is proportional to the

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difference between the set point and measured output. Set point is the desired temperature of the process station. Basically the system consists of four parts.

They are Plant, Measurement device, Controller and Actuator. Plant and feedback system setup is controlled by designed controller, some external circuit likes Thermistor, Power resistor couple, Operational amplifier and Relays are used. The role of operational amplifier is to allow the resistance of the Thermistor to be determined without passing current through Thermistor. The relay and Transistor is to allow the digital input output of the DAQ to turn on and off the higher power resistor. Here the MPC based FLC has to be proposed to maintain constant temperature. Using MATLAB tools MPC and FLC design was made to control the proposed work efficiently.

II. MODEL PREDICTIVE CONTROL

MPC is a form of control in which the current control action is obtained by solving on-line, at each sampling instant, a finite horizon open-loop optimal control problem, using the current state of the plant as the initial state, the optimization yields an optimal control sequence and the first control in this sequence is applied to the plant. Model Predictive Control refers to a group of algorithms in which an internal model is used by the controller to predict how past and present measurements will affect the real plant. From this model the optimal sequence of control moves to be computed [6] [7]. The first of these is then implemented, and a new set of measurements is taken at the beginning of the next time step, providing a feedback mechanism for the controller. The future sequence of control moves to be calculated by optimizing an objective function, commonly a weighted sum of squares of the set point tracking error and the manipulated variable moves. A common formulation of this type is Dynamic Matrix Control, or DMC, which was first developed by Cutler and Ramaker 1979 at Shell Oil for tackling the multivariable control problems [5]

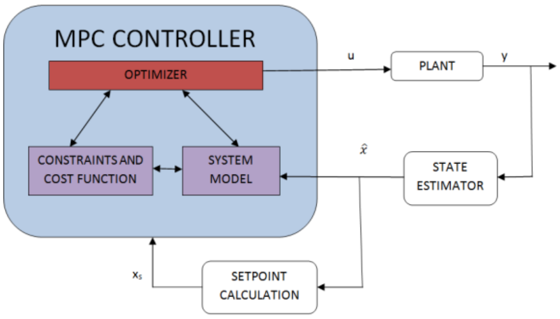

Fig.1 Basic Structure of MPC

Model can be developed by means of past inputs and outputs, and then the predicted output from the model is compared with the reference trajectory. Future errors can be calculated by optimizer using its cost function and constraint then future inputs are given to the predefined model from the optimizer shown in fig.1.

Linear and nonlinear MPC model is explain blow

Linear MPC:

$$\dot{x} = Ax + Bu \tag{1}$$

$$F = x^T Q_X + u^T Ru \tag{2}$$

$$Hx + Gu < 0 \tag{3}$$

1st equation denotes linear model, 2nd equation denotes quadratic cost function and 3rd equation denotes linear constraints these are all the mathematical equation for linear MPC

Nonlinear MPC:

$$\dot{x} = f(x, u) \tag{4}$$

$$F(X, u) \tag{5}$$

$$h(X, u) < 0 \tag{6}$$

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4th equation denotes nonlinear model, 5th equation denotes non-quadratic cost function and 6th equation denotes nonlinear constraints these are all the mathematical equation for nonlinear MPC
Model plant in state space

$$x(k+1) = Ax(k) + Bu(k) \quad (7)$$

$$y(k) = C_y x(k) \quad (8)$$

$$z(k) = C_z x(k) \quad (9)$$

Equation 7,8and 9 denotes that the state space representation of the system.

III. FUZZY LOGIC CONTROLLER

Fuzzy logic is problem solving control system methodology and Quick tracking under changing conditions. One of the computational methods which have demonstrated fine performance under different environmental operating conditions is the fuzzy based temperature control process.

The fuzzy control has the advantage to be robust and relatively simple to design, since it does not require the knowledge of the exact model. A Mamdani fuzzy logic controller has been proposed to perform the temperature process, this kind of controller are usually used in feedback control mode, because they are computationally simple, present low sensibility to noise in the input and can easily represent the knowledge about the control action [1] [2].

Basically FLC has three parts namely: Fuzzification, Inference Engine and Defuzzification.

A. Fuzzification

The fuzzification is the process of converting the crisp set into linguistic fuzzy sets using fuzzy membership function. The concept of linguistic variable was introduced to process the natural language. The membership function is a curvature that describes each point of membership value in the input space. Variables are assigned as Negative Big $(-ve\ B)$, Negative Medium $(-ve\ M)$, Negative Small $(-ve\ S)$, Zero, Positive Small $(+ve\ S)$, Positive Medium $(+ve\ M)$, and Positive Big $(+ve\ B)$.

The inputs of fuzzification are the error and change in error. The value of input error E (k) and change in error CE (k) are normalized by an input scaling factor. The input scaling factor has been designed such that input values are between -0.028 and 0.028. Membership function has many structures; among those triangular memberships function is used shown in fig.2 because for any particular input there is only one dominant fuzzy subset.

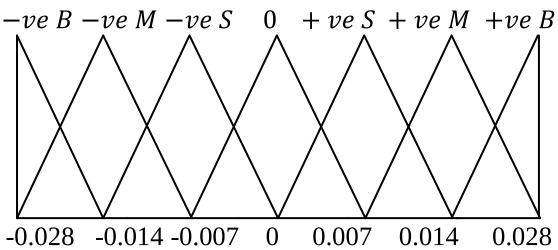

Fig.2 Triangular membership function

Fuzzy rule base is the basic function of fuzzification. A collection of rules referring to a particular system is known as fuzzy rule base. Fuzzy rule base for these seven linguistic variables is shown in table.1

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TABLE 1
FUZZY RULE BASE

E(k)	CE(k)						
	$-veB$	$-veM$	$-veS$	$Zero$	$+veS$	$+veM$	$+veB$
$-veB$	$-veB$	$-veB$	$-veB$	$-veB$	$-veM$	$-veS$	$zero$
$-veM$	$-veB$	$-veB$	$-veB$	$-veM$	$-veS$	$zero$	$+veS$
$-veS$	$-veB$	$-veB$	$-veM$	$-veS$	$zero$	$+veS$	$+veM$
$zero$	$-veB$	$-veM$	$-veS$	$zero$	$+veS$	$+veM$	$+veB$
$+veS$	$-veM$	$-veS$	$zero$	$+veS$	$+veM$	$+veB$	$+veB$
$+veM$	$-veS$	$zero$	$+ves$	$+veM$	$+veB$	$+veB$	$+veB$
$+veB$	$zero$	$+veS$	$+veM$	$+veB$	$+veB$	$+veB$	$+veB$

B. Inference Engine

Fuzzy inference engine is an operating method that formulates a logical decision based on the fuzzy rule setting and transforms the fuzzy rule base into fuzzy linguistic output. Fuzzy linguistic descriptions are formal representations of systems made through fuzzy IF-THEN rules. They encode knowledge about a system in statements of the form: IF (a set of conditions) are satisfied THEN (a set of consequents) can be inferred. There are several methods for this such as Max-Min method, Max-Dot method. Inference engine is otherwise called as decision-making logic.

C. Defuzzification

The last step in the FLC process is the defuzzification. These will have a number of rules that transform a number of variables into a fuzzy result, that is, the result is described in terms of membership in fuzzy sets. Several methods are available for defuzzification such as centroid method, centre of sums, and mean of maxima. The Centre of Gravity (COG) defuzzification method is used. Centre of gravity method is otherwise called as, Centre of area method.

IV. SIMULATION OF PROPOSED WORK

A. Verification by simulations

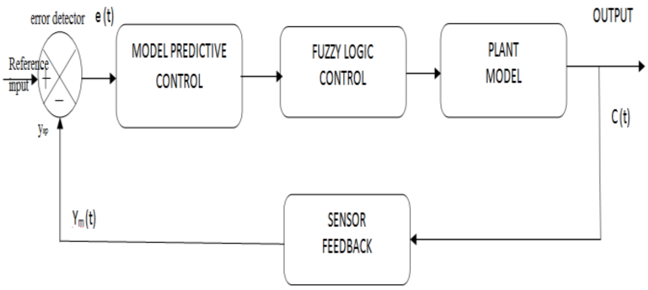

Fig.3 proposed controller design for temperature process

Plant model is a temperature process which was described by means of transfer function approach. The MPC based mamdani method of fuzzy logic controller was designed to control the plant effectively and the simulation outputs were carried out using MATLAB simulation.

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B. Real testing in process control laboratory

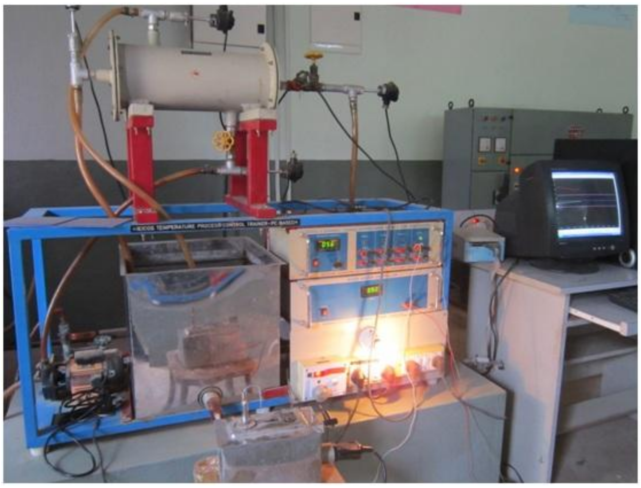

Fig.4 Experimental setup for temperature control process station

Temperature process station was used to conduct the experiments and data were collected. The computer acts as a controller. It consists of the software used to control the temperature process station. Process station consists of a process tank, reservoir tank, Signal conditioning module, temperature sensor, heater, pneumatic signals from the compressor and temperature controller module. When the set up is switched on, temperature sensor senses the actual temperature values initially then this temperature signal is converted into electrical signal. This signal is then given to computer through data acquisition cord. Based on the values entered in the controller settings and the set point, the computer will take control action. The signal sent by the computer is taken to the station again through the cord. This signal is then converted into physical signal using Signal conditioning module then the temperature is controlled to its set point value by means of final control element then the experimental values were tabulated and the graph was plotted for analysis purpose.

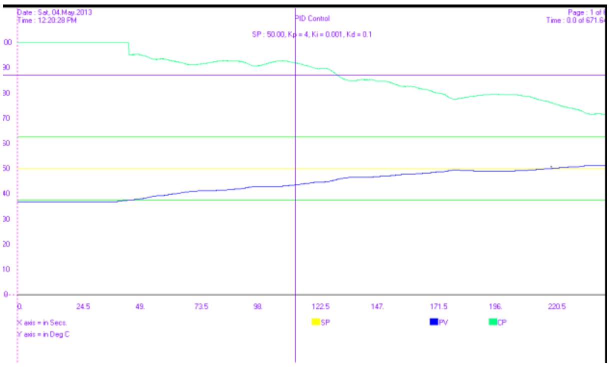

Fig.5 Response curve of temperature process station

The PID controller response curve shows that the temperature increasing from its nominal room temperature to the set point value, the controller action taken place when it cross the set point and try to maintain the temperature value at its set point value with the steady state error with kp : 4.00, ki : 0.001, kd : 0.10.System model can be described by transfer function which is from conducting the open loop test using temperature control process station and it is given as
$G(s) = 0.92/(144s + 1)$ and transport time delay 10seconds [4].

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TABLE 2
EFFECT OF PID CONTROLLER PARAMETERS

Parameters	Rise time	Overshoot	Settling time	Steady state error
k_p	Decrease	Increase	Small change	Decrease
k_i	Decrease	Increase	Increase	Eliminate
k_d	Small Decrease	Decrease	Decrease	None

Table 2 shows the controller parameters with its time domain specifications of rise time, overshoot, settling time and steady state error.

C. MATLAB simulation platform for proposed work

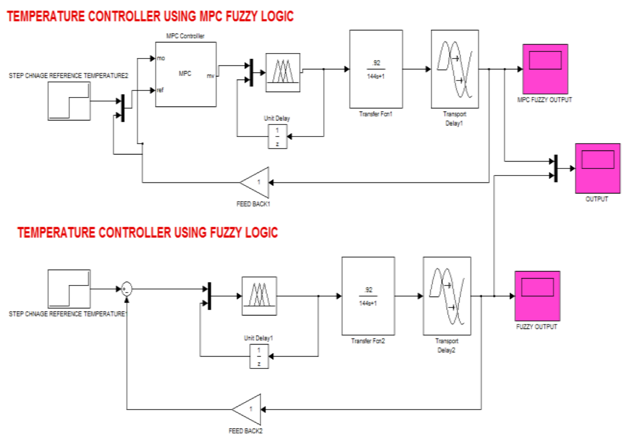

Fig.6 MATLAB simulation for proposed work

Initially step change reference temperature set as 70^o C and controller rise the temperature and make to reach the steady state value, suddenly the temperature set point has to changed 100^o C and 120^o C respectively. Even though the temperature has to be changed the proposed controller follows the set point changes and makes the process faster to attain its steady state value with minimum steady state error.

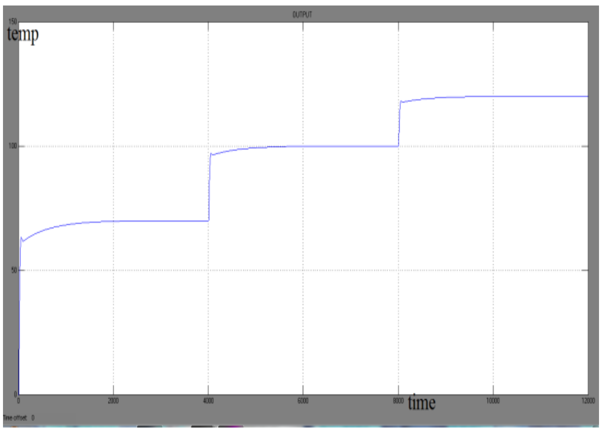

Fig.7 Response curve of Fuzzy controller action

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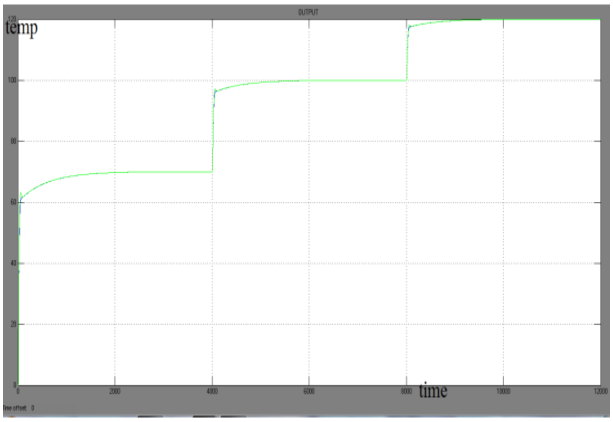

Fig.8 Response curve of MPC based Fuzzy controller action

The above Fig. 7, 8 clearly shows that the fuzzy and MPC based fuzzy controller performs the control action faster and smooth operation while controlling the temperature process with minimum steady state error when compared to that of conventional controller which can be validated by its performance analysis with conventional and intelligent controller.

V. RESULT AND DISCUSSION

The performance of MPC based fuzzy logic controller were designed and validated with the Integral Square Error (ISE).
Values are tabulated below in Table 3.

TABLE 3
Performance analysis of various controllers with ISE

PID	FUZZY	MPC BASED FUZZY
$2.01*10^{-3}$	$0.75*10^{-3}$	$0.62*10^{-3}$

The above analysis implies that the intelligent controllers have a very low value of ISE when compared to that of conventional controller also provides the smooth control action in real time systematic control.

VI.CONCLUSION

The conventional controller was designed to control the temperature in process station laboratory and its results were simulated using MATLAB then the conventional controller was replaced by MPC based Fuzzy logic controller for the same experimental setup. The performance of all the controllers was validated using ISE. It is evident for the proposed controller was better than conventional controller. The proposed MPC based FLC was successfully applied to the temperature process station which showed the practicability of the novel MPC based Fuzzy control strategy algorithm. The author will continue to study the MPC based Fuzzy control algorithm for Multi input and Multi output systems.

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BIOGRAPHY

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T.Rajesh was born in Virudhunagar, Virudhunagar District, Tamilnadu, India in1989. He got his B.E degree (Electronics and Instrumentation Engineering) in Noorul Islam College of Engineering and Technology Anna University, Chennai,Tamil Nadu, India, In 2010 and received his M.E(Control and instrumentation Engineering) in Anna University of Technology, Coimbatore, Tamil Nadu, India, In 2012. Now, he is working as Assistant Professor in J.J. college of Engineering and Technology, Trichy, Tamil Nadu, India. He published many papers in various national and international conferences. His research interests include in Control system and process control.