Design and Implementation of Model Predictive Control for a Liquid Level System using LabVIEW

Pramod. Gondaliya[1] Prof. Manisha.C. Patel[2]
[1]P.G. Student [2]Assistant Professor
[1,2]Department of Instrumentation & Control Engineering
[1,2]L.D. College of Engineering, Ahmedabad

Abstract— This paper presents the design and real time implementation of model predictive control of liquid level process using LabVIEW software. The classical controllers like PI and PID controllers have so many limitations. These controllers provide better performance only at particular operating range. The specific control problems associated with the plant operations severely limit the performance of conventional controllers. The increasing complexities of plant operations demand the need for more sophisticated process controllers. Model predictive control (MPC) is an important branch of automatic control theory. MPC refers to a class of control algorithms in which a process model is used to predict and optimize the process performance. In this project, Liquid level in a process trainer is to be controlled using model predictive control in real time. Model predictive control will give better performance.

Key words: Model Predictive Control, Liquid Level System, System Identification, LabVIEW, Set-point tracing, Disturbance Rejection

I. Introduction

The classical controllers like PI or PID controllers are widely used in process industries because of their simple structure; assure acceptable performance for industrial processes and their tuning is well known among all industrial operators [2]. However, these controllers provide better performance only at particular operating range and they need to be retuned if the operating range is changed. Further, the conventional controller performance is not up to the expected level for nonlinear and dead time processes. In the present industrial scenario, all the processes require automatic control with good performance over a wide operating range with simple design and implementation. This provides the motivation for online tuning, where the focus is on the automatic online synthesis and tuning of the conventional controller parameters, that is, using the online data, the adopted intelligent system can continually learn which will ensure that the performance objectives are met. The online tuning of a conventional controller through an intelligent technique is one of the ways to automate the operator’s task and to obtain the better controller performance over a wide operating range.

Model predictive control (MPC) refers to a wide class of control algorithms that use an explicit process model to predict the behavior of a plant [2]. The most significant feature that distinguishes MPC from other controllers is its long range prediction concept. This concept enables MPC to perform current computations to account the future dynamics, thus facilitating it to overcome the limitations of process dead time and slow dynamics. In addition, MPC exhibits superior performance by systematically handling constraints violation

In the present work, the system identification of real time liquid level system is done using real time data. The paper is organized as follows. In Section-II, the process description is discussed. In section-III, In section-IV, the process identification of system is discussed. Section-V gives model validation and section- VI is about conclusion.

II. Description of the Liquid Level System

In the present work, the real time Level control trainer is used as dedicated system available in process control laboratory for collecting the input-output data. Level Control Trainer (product code 313,313A) supplied by Apex Innovation is used here [1]. The process setup consists of supply water tank fitted with pump for water circulation. The level transmitter used for level. The process parameter (level) is controlled by microprocessor based digital indicating controller (we will not going to use that controller, it is bypassed) which manipulates pneumatic control valve through I/P converter. A pneumatic control valve is used to adjust the water flow in to the tank. These units along with necessary piping are fitted on support housing designed for table mounting. The P&I diagram is as shown in fig.1

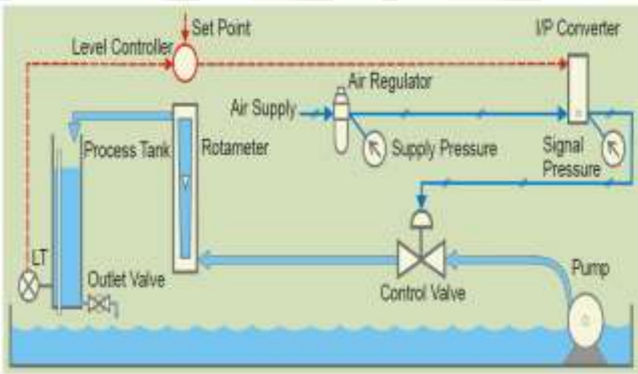

Fig. 1: P&I diagram of Liquid Level System

The real time level system is as shown in fig.2 and the specifications are tabulated in Table 1.

Components	Details
Rotameter	10-100 LPH
Process tank	Transparent, Acrylic, with 0-100% graduated scale
Supply tank	SS304
Level transmitter	Type- Electronic, two wire transmitter, Range 0–300 mm, Output 4–20mA
I/P converter	Input 4-20mA DC, Output 3-15 psig

Table 1: Instrument Specifications

In this project the level of tank is the controlled variable and the input flow rate of water to the tank is the manipulated variable. The level in tank is measured using level transmitter (gives 4-20mA output) and is given to a current to voltage converter. The controller shown in figure is isolated from system. Finally this system is interfaced with the LabVIEW through CB-68LP connector board.

Fig. 2: Liquid Level Trainer

III. PROCESS IDENTIFICATION

The determination of the dynamic behavior of a process by experiment is called process identification. The system can be modeled by different methods like First Principle method and Empirical Method. The method for the system identification is Empirical method in which the experimental input- output data is used. In this section, the transfer function model using process reaction curve method is discussed for which the input and output data are generated from the real time system.

Figure 3 Liquid Level System interfaced with LabVIEW

Many industrial processes are of high order systems. To design a controller equations for such processes are not easily available. Hence, it is desirable to model these processes by low order models such as FOPDT or SOPDT models [3]. Here, the time domain curve fitting of step response is studied to identify an FOPDT or SOPDTZ model of a process. This method requires the response of process, initial estimates of model parameters and assumption of a suitable model. The initial selection of the model could be based on the shape of the open-loop step response. Open-loop identification is widely used in the industry. In open loop step testing, a step change in input is applied to the process which will produce a corresponding response. It is called process reaction curve. In the chemical industry, for many processes the process reaction curve is an S-shaped curve. To obtain an open-loop step response (Y_a), the process should be perturbed by introducing a step change in the manipulated variable (MV), as shown in Figure 4.

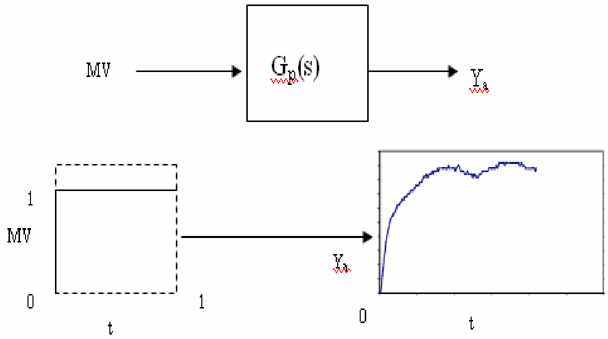

Fig. 4: Block diagram and input/output graph of open-loop test.

Here, input and output data is collected using LabVIEW interfacing and stored that data into Express files. These data is imported to System Identification Toolbox in MATLAB. The transfer function of the process is obtained in form of process model as FOPDT form

$$G(s) = \frac{0.9341}{79.76s + 1} e^{-3}$$

IV. MODEL PREDICTIVE CONTROL

Process industry is characterized by product quality specifications which become more and more tight, increasing productivity demands, new environmental regulations and fast changes in the economical market. In the last decades Model Predictive Control (MPC), also referred to as Model Based Predictive Control (MBPC), Receding Horizon Control (RHC) and Moving Horizon Control (MHC), has shown to be able to respond in an effective way to these demands in many practical process control applications and is therefore widely accepted in process industry. MPC is more of a methodology than a single technique. The difference in the various methods is mainly the way the problem is translated into a mathematical formulation, so that the problem becomes solvable in a limited amount of time.

MPC refers to a class of control algorithms in which a process model is used to predict and optimize the process performance [7]. MPC has been widely applied in industry. The idea of MPC is to calculate a control function for the future time in order to force the controlled system response to reach the reference value. Therefore, the future reference values are to be known and the system behaviour must be predictable by an appropriate model. The controller determines a manipulated variable profile that optimizes some open-loop performance objective over a finite horizon extending from the current time into the future. This manipulated variable profile is implemented until a plant measurement becomes available. Feedback is incorporated by using the measurement to update the optimization problem for the next time step. The block diagram of model predictive control is given below Figure 5.

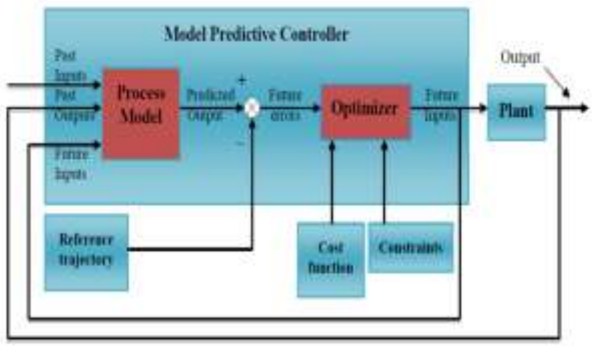

Fig. 5: Structure of Model Predictive Control.

In this work, we linearized the water tank system and used the linearized model as the process model to represent the original model inside the MPC controller, also in the form of state-space function. The process is described in FOPDT model as $G(s) = \frac{0.9341}{79.76s+1}e^{-3s}$. The discrete state space model is described with A, B, C, and D matrix as

$$\frac{dx}{dt} = [-0.0125376]x(t) + [1]t$$

$$y(t) = [0.0117114]x(t) + [0]t$$

V. LABVIEW IMPLEMENTATION

LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language from National Instruments. The purpose of such programming is automating the usage of processing and measuring equipment in any laboratory setup. LabVIEW simulation module is block diagram based environment for simulation of linear and nonlinear continuous time systems.

Model Predictive Control of level trainer is implemented in LabVIEW. The level of liquid input is given in terms of voltage .Block diagram and front panel diagram of the model predictive control simulation is shown below Figure 6.

The main part of the controller design is its tuning parameter. Here, the tuning parameters are Prediction Horizon (N_p) and Control Horizon (N_c). The prediction horizon can be decided from the open loop settling time of the system. The open loop settling time of the system is around 290 seconds.

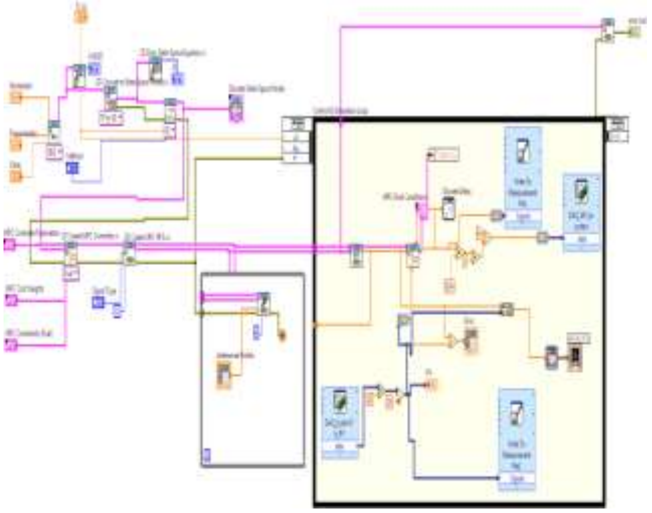

Fig. 6: Block diagram of MPC

N_p can be tuned as around 10th of open loop settling time, so it is 29. Here nearby of 29 we take 25. Similarly, the Control Horizon (N_c) is decided as 1/3rd of N_p, so it is 8.

VI. RESULTS

A. Set-Point Tracking:

When we apply SP of 50 and run the mpc.vi, it gives response as shown in fig 7. It gives a single overshoot of 2% at SP of 50% level (reach max 51.3% of level) and finally set to desired reference with 0.7% error. So we can say that MPC is precisely work for set point tracking.

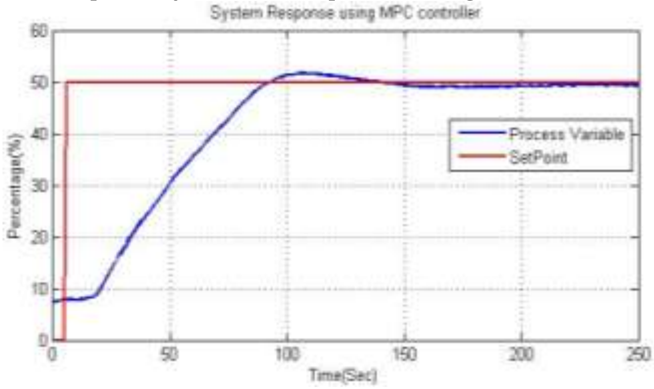

Fig. 7: System response using MPC controller for set point tracking

B. Disturbance Rejection:

Similarly first simply apply a set point of 50% and let to do function of controller, once it tracks the reference point most correctly then apply disturbance (at 340sec) by closing drainage valve of the level tank. So the level is drastically increased above set point. The controller will continuously try to reduce the level by applying appropriate control action U(k). The figure 8 shows how disturbance can be rejected.

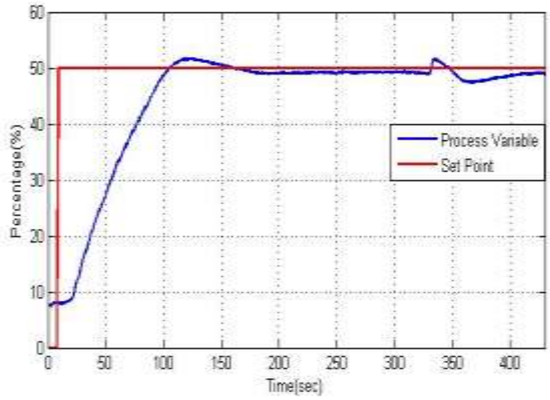

Fig. 8: System response with disturbance rejection using MPC

VII. CONCLUSION

In this project, the system identification of the level system is done and the mathematical model of the system is obtained. A dedicated MPC controller has been design for the system and implementation of MPC controller has been done in real time.

The MPC is implemented to level system for set-point tracking as well as disturbance rejection. The real time graph implies that controller would able to track the target continuously as well as it rejects the disturbances and resettle over reference point. The MPC controller gives smooth control action as per constraint provides and continuously provides control action for error.

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