Application of MATLAB/Simulink Program for Wireless Generalized Predictive Control

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Abstract— in this work, wireless Generalized Predictive Control (GPC) of temperature is applied to a process simulator. The process control simulator consists of two main units, an instrument console and a framework carrying the process equipment. Wireless experimental input/output data is obtained from process control simulator. Wireless control is achieved by utilizing GPC algorithm which is written in Matlab-Simulink program is used for control experiments. The λ weighting was varied in order to achieve optimal GPC performance. The efficiency of the GPC is observed by calculating the integral of the square of the error (ISE) and the integral of the absolute value of the error (IAE) from experimental results. The wireless experimental GPC comes to the set point much quickly. Because of the good results of wireless temperature control experiments this technique can be proposed for the industrial processes.

*Index Terms—***Generalized Predictive Control, process simulator, Matlab/Simulink program, wireless control**

I. INTRODUCTION

Today an industrial wireless network is revolutionary technology for reducing costs and expanding the application of industrial measurement and control systems. In the field of industrial control, the industrial wireless network has become another hot spot after field bus, which has changed the information delivery of existing control systems. Wireless communication technology makes measurement and control systems to be low cost, easy to use, maintain and has more broad potential applications. However, spesific requirements of industrial measurement and control applications bring some new challenges to wireless networks, specifically regarding the more strict and deterministic performance of real-time and reliability, the dynamic adaptability of the environment, low cost and low power consumption [1-2]. In recent years, Generalized Predictive Control (GPC) has become a popular technique to control difficult processes. GPC has been widely applied in the industrial processes including distillation columns, polymerization reactors, exothermic chemical reactions, pH neutralizations and biochemical processes. The popularity of GPC due to its relatively simple time-domain formulation and good performance on the process. The basic principle of GPC is to predict the process output over a long range time horizon using a mathematical model. GPC was introduced by Clarke et al. [3-4] to overcome the control related problems concerning non-minimum phase zeros, open loop unstable or poorly damped poles, unknown or variable dead times and unknown plant orders i.e. plants with over or under parameterization. Practically GPC applied with four parameters. There have been a few papers that have suggested how to tune the four parameters. These parameters are following abbreviations:Nu is the control horizon, N_1 and N_2 are the minimum and maximum prediction horizons, respectively and λ is the control weighting. McIntosh et al. [5] provide three tuning strategies for GPC. In each strategy, all parameters except one are fixed, while the remaining parameter was tuned. The first tuning strategy varies N_2, the prediction horizon, to match the desired speed of response, i.e. the ability to force the output to respond to step changes in setpoint. The control horizon is set to one, making this method relevant only to industrial-type plants. The second strategy tunes λ. The tuning starts with λ=0, which results in a deadbeat controller and is then progressively detuned by increasing λ. Again, this approach is appropriate for the industrial setting. The third approach is detuned model following. This is accomplished by filtering the output sequence. This in essence allows the user to place the poles at an arbitrary, yet predetermined position. McIntosh et al. [5] show how to make this position equivalent to first-order and second-order systems, whose closed-loop characteristics are well-defined. This method is also appropriate only for low-order industrial-type plants. MATLAB, developed by the MathWorks Inc., has been a powerful software for mathematical computations and visualisations. Sımulınk is a part of MATLAB for modelling, simulation, and analysis of dynamical systems in a flowsheeting environment. It supports linear and nonlinear systems, modelled in continuous time, sampled time, or a hybrid of the two. Bequette [6] illustrated that the interactive MATLAB/Simulink tool enhances the ability to learn new model-based techniques and provide an inside depth of the dynamic nature and control of chemical processes. For modelling,Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. With this interface, you can draw the models just as you would with pencil and paper. Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. Users can also customize and create own block models using the S-Function format. This approach provides insight into how a model is organized and how its parts interact. After defining a model, user can simulate it, using a choice of integration methods, either from the MATLAB/Simulink menus or by using MATLAB's m-files. The menus are

particularly convenient for interactive work, while the m-file approach is very useful for running a batch of simulations. Using scopes and other display blocks, user can see the simulation results while the simulation is running. In addition, user can change parameters and immediately see what happens, for "what if" exploration. The simulation results can be put in the MATLAB m-files for post processing and visualization. MATLAB and Simulink are integrated user can simulate, analyse, and revise your models in either environment at any point [7]. Therefore, modelling and control of stagewise processes is now common using MATLAB/Simulink with its versatile environment to get rapid and accurate simulation for models of varying degree of complexity. In the present study, experimental input/output data is obtained from process control simulator. Wireless temperature control is achieved by utilizing GPC algorithm which is written in Matlab-Simulink program is used for control experiments. The experimental GPC results with different λ values are compared by observing the temperature profiles and calculated ISE, IAE values compared for determining efficiency of GPC.

II. EXPERIMENTAL SYSTEM

The process ccontrol simulator consists of two main units, an instrument console and a framework carrying the process equipment which is shown in Figure 1. The instrument console contains the electronic flow, level, temperature controllers and electrical switchgear. It is connected to the process equipment by several cable assemblies. The process equipment consists of a water tank, water circulating pump, electrical water heater, two vessels, two electrically positioned control valves and a heat exchanger. In process control simulator, twelve manual valves are available for different process experiment loops. In the simulator, temperature measurement and control can be made at four different points which are first tank, heater output, second tank input and output. The system developed for transferring data between the computer and the panel. Data transfer is achieved wirelessly by using the two antenna are found in the laboratory connected to the computer and outside connected to the process simulator. Control valves outputs are connected to the modules, the necessary calibrations are made. The water is pumped via the electrical heater into the reactor up to a certain level. The water then flows back to the sump tank via the cooler. Heat is fed to the water by the heater and residual heat removed by the cooler so as to return the sump tank water temperature to a suitable base level. Heater which is connected on-line to the computer is used as a manipulated variable [8].

III. TEMPERATURE CONTROL LOOP AND METHODS

The water is pumped via the electrical heater into vessels V1 and V2 in series, thus simulating a reactor vessel with considerable thermal mass. The water then flows back to the sump tank via the cooler. Heat is input to the water by the heater and residual heat removed by the cooler so as to return the sump tank water temperature to a suitable base level. Four thermocouples (T1 - T4) monitor the temperature at different points around the circuit. A selector switch is provided so that any one of the temperatures T2, T3 or T4 can be input to the temperature controller as the process variable. T2 is located at the outlet from the heater and thus provides minimum process response time while T3 and T4 are positioned after V1 and V2 respectively and thus allow the study of systems with greater response times. The selected thermocouple signal is fed into the Eurotherm 3 term temperature controller, the output from which controls the power fed to the heater via two thyristor unit controlling 2 legs of a balanced 3 phase star connected load. The base water temperature is measured by 'T1 at the outlet from the pump. The controller input (process variable), controller output signal and all process temperatures can be recorded on the SCADA package. By varying the temperature difference between the control set point and base temperature, the effect of varying system load can be demonstrated [8].
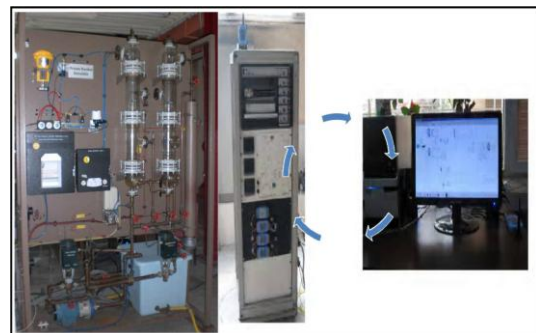

Fig. 1 Experimental system: Process simulator, control panel and computer on-line connected to simulator with wireless technology
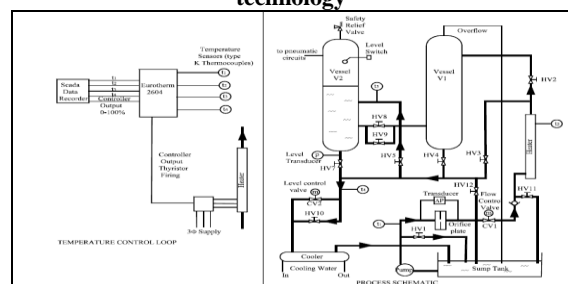

Fig. 2 Temperature control loop and experimental flow chart

First, the steady-state experiments were performed. The fluid flow is obtained by running the pump when the liquid level control valve is opened at a certain level. The cooling water is opened after liquid level is fixed. The heater output temperature is expected to become at steady-state while % heating capacity is on. The temperature is monitored when system has become at steady-state condition. To obtain the desired temperature in the face of set point change, the Matlab-Simulink program for GPC block shown in Figure 3 is used.
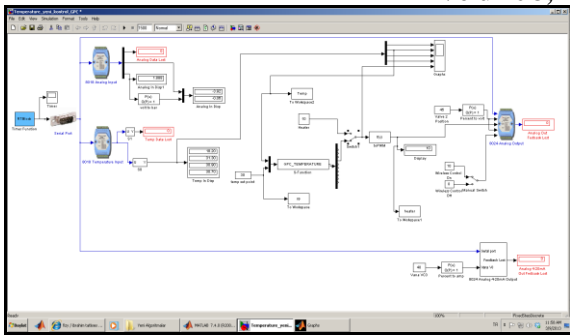
Fig. 3 Matlab/Simulink program for temperature control

IV. RESULTS AND DISCUSSION

Performance of the GPC depends on the choice of tuning parameters (minimum costing horizon, N_1; maximum costing horizon, N_2; control costing horizon, Nu; control weighting, λ). λ values are bigger than 1.0 not suitable because of oscillatory behaviour of the response results shown in Figure 4 and Figure 5.. Suitable values of these parameters were taken as $N_1=1$, $N_2=2.0$ and 4.0, $Nu=1$ and λ is varied in order to obtain the best results shown in Figure 6-9. The efficiency of the GPC algorithm was observed by calculating the performance criteria such as the integral of the square of the error (ISE) and the integral of the absolute value of the error (IAE) from experimental results and the performance comparison is given in Table 1 and Table 2 respectively.
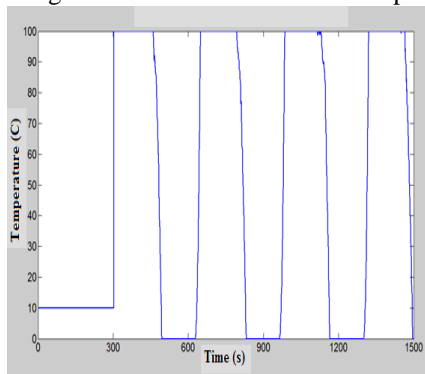

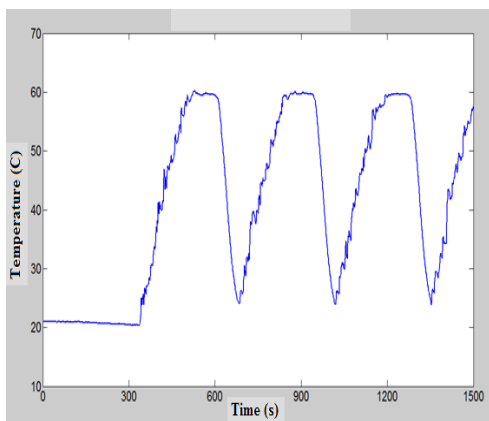**Fig. 4 Heater capacity changes for λ values are bigger than 1.0**

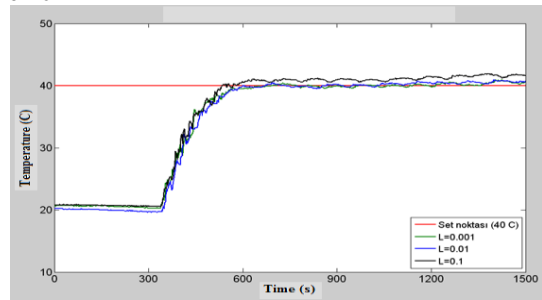**Fig. 5 Temperature changes for λ values are bigger than 1.0**

Fig. 6 Temperature changes for $N_U=1$, $N_2=2$ and $\lambda=0.001$, 0.01, 0.1
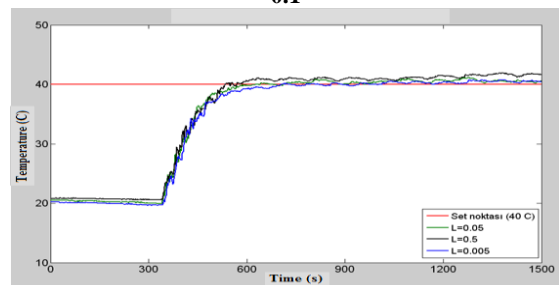

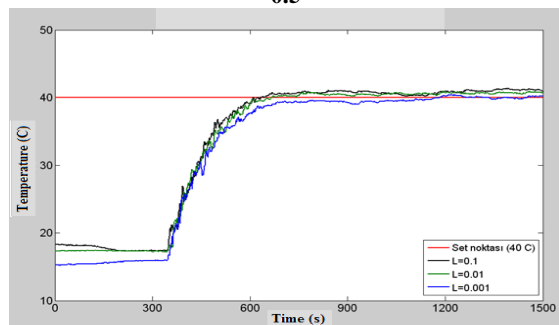**Fig. 7 Temperature changes for $N_U=1$, $N_2=2$ and $\lambda=0.005$, 0.05, 0.5**

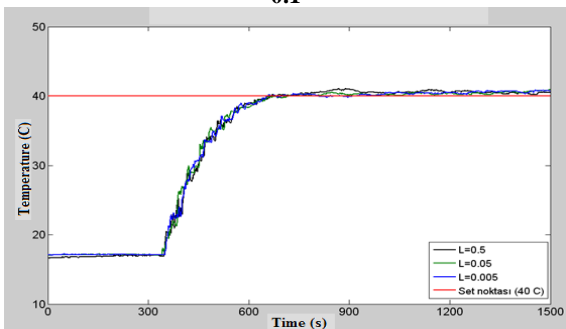**Fig. 8 Temperature changes for $N_U=1$, $N_2=4$ and $\lambda=0.001$, 0.01, 0.1**

Fig. 9 Temperature changes for $N_U=1$, $N_2=4$ and $\lambda=0.005$, 0.05, 0.5

Table 1. Calculated ISE values for Tset=40 °C

	Nu=1, N_2=2	Nu=1, N_2=4
λ =0.001	14319,62	14844,85
λ =0.005	14452,90	16957,10
λ =0.01	13406,04	14595,94
λ =0.05	15408,40	15837,30
λ =0.1	16729,95	16888,92
λ =0.5	17617,56	17595,54

Table 2. Calculated IAE values for Tset=40 °C

	Nu=1, N2=2	Nu=1, N2=4
λ =0.001	1603,00	1853,90
λ =0.005	1698,20	1926,50
λ =0.01	1586,20	1638,80
λ =0.05	1647,30	1719,40
λ =0.1	1875,40	2097,40
λ =0.5	2332,60	2519,30

V. LINEAR SYSTEM IDENTIFICATION RESULTS

Linear system identification was applied for GPC algorithm to temperature control of the process control simulator. ARMAX model was used for the linear black box model. The System Identification Toolbox in MATLAB was applied to estimate of the linear model.

$$y(t) - 1.355\,y(t-1) + 0.4527\,y(t-2) = 0.0766u(t) - 0.0334u(t-1)$$
$$+0.0074u(t-2) + e(t) - 0.2618e(t-1) - 0.0742e(t-2)$$

Fig. 10 shows the results of the experimental data and ARMAX model for a positive step change on the heater and the temperature increases as expect at this effect.
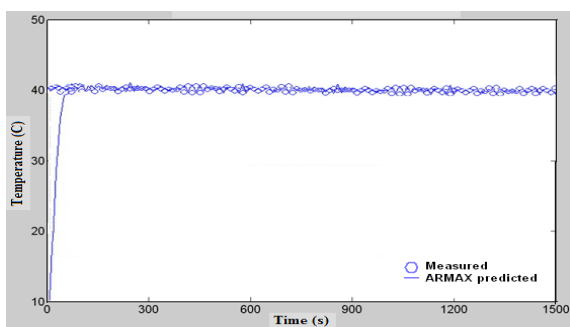

Fig. 10 Step change response of experimental and ARMAX predicted model for heater output temperature

VI. CONCLUSION

A GPC algorithm was utilized to experimentally wireless temperature control in a process control simulator. The experimental GPC comes to the set point much quickly. The experimental GPC results with different λ are compared by observing the temperature profiles and calculated ISE, IAE values compared for efficiency of the GPC algorithm. When the λ value increases, the ISE value also increases and oscillation of the response increases. λ values which are bigger than 1.0 not suitable because of oscillatory behaviour of the response. The best wireless temperature control is provided with λ =0.01 value which ISE and IAE values smaller than other λ values. The wireless temperature GPC was applied to the system successfully. Because of the good results of wireless temperature control experiments this technique can be proposed for the industrial processes. Wireless measurement and control applications will be pervasive in the future.

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