INVESTIGATION OF WIRELESS NETWORKED CONTROL SYSTEM FOR A MULTI-LOOP PLANT

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***Abstract*— Wireless network has the potential in control systems because it reduces the amount of space and cost of laying wires and cables. However, wireless network has some limitations such as time delay and loss of data. This is because as the number of nodes increase, the time delay also increases. Similarly, when there are multiple loops trying to send signals at the same time within the same bandwidth, the signals only can be sent based on queue. Hence when the bandwidth is busy the signals have to be sent many times and this can cause loss of data. In order to investigate the effects of wireless network on the performance of two heat exchanger plants, several open-loop control systems have been modelled in from these plants. Transfer functions from each loop involved have been obtained through lab experiments and statistical modelling. PID tuning parameters are calculated and tuned for each loop using Ziegler-Nichols, Cohen-Coon or Skogestad tuning method. PI controllers are used for all loops in this project. Using the controller and plant parameters, the control system is recreated in Matlab TrueTime where data is transmitted over a wireless network. From Matlab TrueTime, the effects of using a wireless network in controlling a heat exchanger plant simulation are different in performance and stability of the plant. From the simulation, it can be observed that the time delay is the main factor considered. The performance of all controllers of all loops are affected by time delay in Wireless Networked Control Systems (WNCS). The rise time and the settling time are slower when simulated in Matlab TrueTime.**

Keywords—network delay; PID controllers; wireless networked control systems (WNCS)

I. INTRODUCTION

For data transmission in a process plant, the industry computer network has been in place for ease of implementation, cost reduction and also provide flexibility. Networked Control System (NCS) can be defined as the interchange of I/O data in a certain parts of a system through a common traffic. The major function of NCS is to collect live data through a suitable way of connection [1]. Wireless is one of the ways for the data to be transmitted in a closed control loop, known as Wireless Networked Control System (WNCS).

Advantages of having wireless network installed are it saves space, cost and also better in terms of safety. However, there are some limitations of wireless. They are time delay and loss of data. The time delay can occur from the sensor to the controller (τsc) and also from controller to the actuator (τca). It can cause the system to be slow and inefficient. When a data is being sent to a particular destination, it will send based on the queue in the network traffic. When the traffic is busy, the data has to be resent many times and loss of data can occur. Loss of data can cause degradation in controller performance.

One of the applications of WNCS is the NCS-iSpace (Intelligent Space). The task is the move the robot to reach the intended place chosen by the user via GUI (Graphical User Interface). The system covered by WNCS will look into the network delay at the image capturing and also from the command transfer from the controller to the robot. The wireless network is used to exchange data from the network camera to the user and also from the controller to the robot [2]. Another application involving WNCS is a Networked Control System Test Rig. The plant that will be controlled is a real servo control system. The networked control board and networked implementation board are connected via Intranet [2].

Smith Predictor is a controller that is designed for a system with time delay that result in an equivalent system with delay with time delay outside of the closed loop [3] while CMAC or also known as Cerebellar Model Articulation Controller is a controller that has variety of controlling method which are direct inverse moving control, feedforward control and feedback control [3]. When these two methods are applied in a closed loop plant, the PID control is reported to be more stable and has less affected disturbance by which the CMAC effect can make accelerate the response speed and the overshoot can be decrease because the PID control is the feedback control and the CMAC is the feedforward control [3].

In [4], a normalized PI and PID controllers are proposed for the systems with time delay. From the performance of the normalized PI controller that has been tested, it is shown that the bigger the phase margin, the better the performance of the controller. Similarly, the normalized PID controller with higher phase margin ($\pi/3$) will have a better performance compared to the controller with smaller phase margin ($\pi/4$) [4].

II. OBJECTIVES

The objectives of this project are to obtain multiple single input single output (SISO) control loops, to investigate the effect of wireless network induce time delay for multi-loop control and to improve or modify PID controller for the multi-loop systems.

III. METHODOLOGY

A. Experimental Data

Model experiment and simulation are made based on the heat exchanger plant and Drum-Heat Exchanger Process Pilot Plant. From the plant, three loops are determined which are level control loop (LIC340) and a cascade control loops that consists of temperature (TIC634) and flow (FIC631) control loops. The level control loop is based on the heat exchanger plant (Plant 6) while the cascade control loops of temperature and flow control loops are based on the Drum-Heat Exchanger Process Pilot Plant (Plant 5).

B. Statistical Modeling

After the results of the experiment have been obtained, statistical modeling is needed to obtain the transfer function. After a series of calculations, the value of Kp, τ and θ are obtained and thus the transfer function. The equations to obtain the values of Kp, τ, θ and also the transfer function are as below:

$$Kp = b/(1-a) \tag{1}$$

$$\tau = -\Delta t/(\ln a) \tag{2}$$

$$\theta = (\Gamma)(\Delta t) \tag{3}$$

$$Gp(s) = \frac{Kpe^{-\theta s}}{\tau s + 1} \tag{4}$$

C. PI/PID Tuning

The PID controller tuning is based on either Ziegler Nichols or Cohen-Coon. The level and temperature PID controller tuning are based on Ziegler Nichols while for flow is based on Cohen-Coon. Parameters are shown in Table 1.

D. Simulation

Simulation of the WNCS are conducted in this Matlab TrueTime. Using the PI/PID parameters determined from the experiments, it has been applied to study the effects of WNCS in a heat exchanger plant in terms of multiloop, time delay and loss probability. Wireless network setting are shown as Table 1.

Table 1 Wirelees Network Settings

Network Protocol	IEEE 802.11b/g (WLAN)
Pathlost	3.5
Data rate (bits/s)	800000
Minimum frame size (bits)	272
Loss probability	0 to 0.1

IV. RESULT AND DISCUSSION

A. Experimental

i. Level (LIC340)

The level controller is used to control the level of the water in the boiler, monitored by a level sensor LT340. Changes in the water level can be made by adjusting the opening of LCV340 which regulates the inlet the amount of water going into the boiler.

For LIC340, statistical modelling is not possible as the dead time has negative values. Hence only empirical modelling or process reaction curve [5] can be obtained from this loop. It can be said that the level has the fastest response compare to flow and temperature.

Hence the process reaction curve has been obtained from the graph of perturbation of MV from 70% to 90%. From process reaction curve, it can be concluded that the values of *Kp, τp,* and *θ* are 2.085, 2.03 and -0.66. The transfer function can be found in Table 2.

ii. Flow (FIC631) and Temperature (TIC643) Cascade Controller

FIC631 and TT634 are connected in cascade control scheme. Temperature TT634 monitors the outlet steam temperature from the heat exchanger, HE620. FIC631 monitors and control the flow of water going into the heat exchanger tube. To control the temperature, FV631 is used to adjust the amount flow going into the heat exchanger tube.

For FIC631, the perturbation of MV from 60% to 70% has been used for statistical and empirical modelling. From statistical modelling calculation, the findings are the value of *Kp, τp,* and *θ* are 0.069, 0.66 and 2.

Compared to FIC631 and LIC340, TIC634 has the slowest process response. The dead time also has a large value. It means that when the value of manipulated variable increases, the value of process variable increases slowly until it reaches steady-state.

From statistical modelling calculation for TIC634, the findings are the value of *Kp, τp,* and *θ* are 2.09, 5.41 and 0.27.

The transfer function for FIC631 and TIC634 can be found in Table 2.

B. PI/PID Tuning

Based on the calculations that have been made, the value of Kc, Ti and Td for every loop have been obtained. The result as in the Table 2.

Table 2 Three loops with its transfer functions, PID parameters and controller

Loops	Transfer Function	Controller Mode	PID Values
LIC340	$G(s)=\dfrac{2.085}{2.03s+1}$	PI	Kc = 0.9736211031 Ti = 1.44 Td = 0
FIC631	$G(s)=\dfrac{0.069e^{-2s}}{0.66s+1}$	PI	Kc = 6.51313515 Ti = 1.469387755 Td = 0
TIC634	$G(s)=\dfrac{2.09e^{-0.27s}}{5.41s+1}$	PI	Kc = 0.132 Ti = 0.98 Td = 0

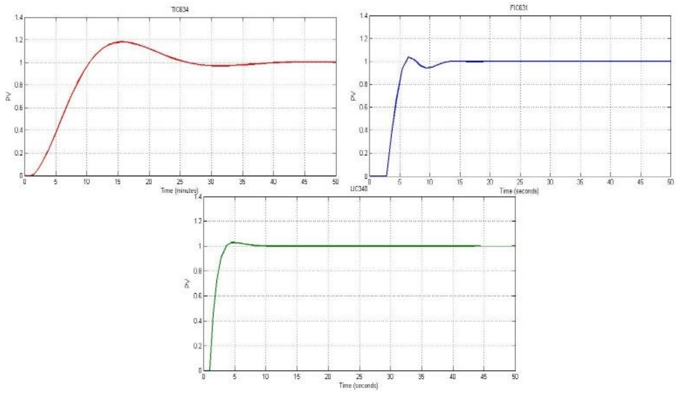

Figure 1 Graphs of Three Loops with PI Control Modes

From Figure 1, it can be seen that the controller performance of TIC634 has slight overshoot but eventually reach steady state. For FIC631, it has a small overshoot and reach steady state very fast compared to TIC634. For LIC340, it rises perfectly and fast. However, it has some offset of 0.1.

C. WNCS Simulation using TrueTime

i. 4.3.1 WNCS with no network delay

a) Flow (FIC631)

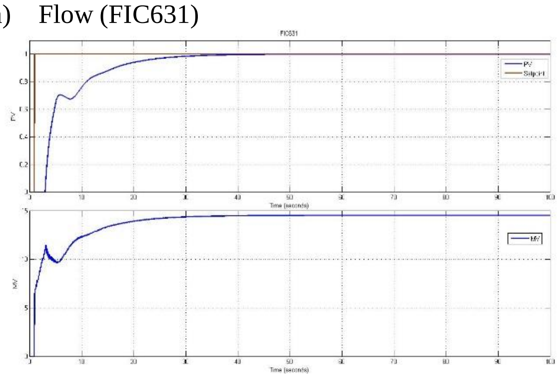

Figure 2 Graph of FIC631 simulated in WNCS TrueTime

The rise time of FIC631 in TrueTime simulation is slower compared to the normal PID simulation which takes around 35 seconds. However there is no overshoot in this simulation. The steady state time for flow also takes a longer time (35s) compared to normal PID simulation (13s). The effect of wireless can be seen clearly in this loop.

b) Level (LIC340)

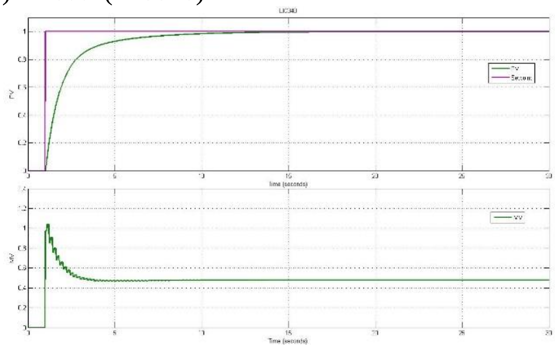

Figure 3 Graph of LIC340 simulated in WNCS TrueTime

The rise time of LIC340 in TrueTime simulation is also slower compared to the normal PID simulation which takes around 13 seconds. However there is no overshoot in this simulation. The steady state time for level also takes a longer time (13s) compared to normal PID simulation (8s). The effect of wireless can be seen clearly in this loop. Compared to FIC631, LIC340 process is faster in terms of rise time and settling time.

c) Temperature (TIC634)

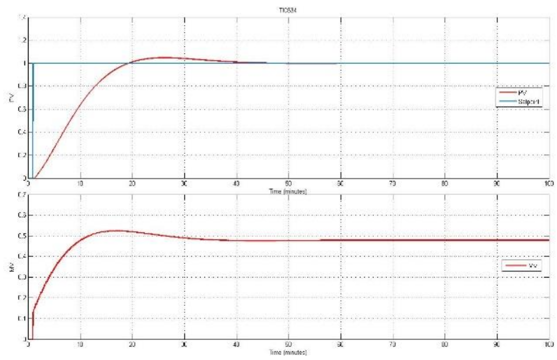

Figure 4 Graph of TIC634 simulated in WNCS TrueTime

The rise time of TIC634 in TrueTime simulation is also slower compared to the normal PID simulation which takes around 20 minutes. However the overshoot in this simulation is less compared to normal PID simulation. The settling time for temperature also takes a longer time (41m) compared to normal PID simulation (39 minutes). The effect of wireless can also be seen clearly in this loop. Compared to FIC631 and LIC340, TIC634 process is the slowest in terms of rise time and settling time.

ii. 4.3.2 WNCS with induce network delay

The simulations are extended to introduce the network delay into the simulation. There are two delays situated in the simulation which are τ_{ca} and τ_{sc}. The variation of values of τ_{ca} and τ_{sc} are shown in the table below:

Table 3 Values of network delays with loops

Loops	Values of τ_{ca} (seconds)	Values of τ_{sc} (seconds)
FIC631	0.5	0.5
	2	2
LIC340	0.5	0.5
	2	2
TIC634	1	1
	4	4

a) τ_{ca} Delay

The performance of the variations of τ_{ca} can be observed in the table below:

Table 4 Performance of the Variations of τ_{ca} on three loops

Loops	τ_{ca}	Performance
FIC631	0.5	No difference
	2	Faster rise time and settling time
LIC340	0.5	Faster rise time and settling time
	2	The controller becomes unstable
TIC634	1	No difference
	4	Faster rise time but slower settling time

b) τ_{sc} Delay

The performance of the variations of τ_{sc} can be observed in the table below:

Table 5 Performance of the Variations of τsc on three loops

Loops	τ_{sc}	Performance
FIC631	0.5	No difference
	2	Faster rise time and settling time
LIC340	0.5	Faster rise time and settling time
	2	The controller becomes unstable
TIC634	1	No difference
	4	Faster rise time but slower settling time

iii. 4.3.3 WNCS with loss probability

The loss probability is this simulation is varied from 5% to 10% (0.05-0.1). It can be concluded that the amount of 10% loss of data does not have much effect towards the performance of the controller. The simulation can be further investigated by increasing the loss probability.

iv. 4.3.4 WNCS with Multi-loop Plant

The graphs of three loops are shown as:

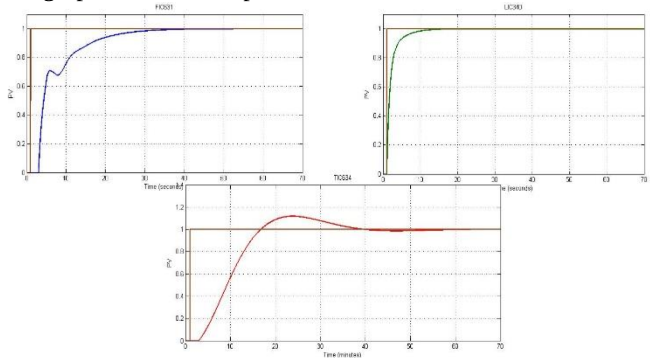

Figure 5 Graph of Multi-loops simulated in WNCS TrueTime

From the graph, it can be concluded that the WNCS has not much difference in multi-loop compared to single loop simulation. The settling time for FIC631 is 35 seconds while for LIC340 is 12 seconds and TIC634 is 41 minutes. The simulation can be further investigated by adding delays to the simulation to see the behavior of the controllers.

V. Conclusion and Recommendation

The project is mainly to investigate the effect of wireless network induce time delay for multi-loop control and improve or modify PID controller for the multi-loop systems. The transfer functions for all the loops can be found by statistical or empirical modelling. PID tuning shows that FIC631 and TIC634 are using PI-controllers while LIC340 only uses P-controller. The simulation of wireless networked control system (WNCS) have been made in Matlab TrueTime and it shows that WNCS has an effect towards the controller in terms of time delay and loss of data as the time taken to reach steady state is longer than usual. For LIC340, WNCS has caused the controller to be unstable when the time delay is two times than the sampling time while for FIC631 and TIC634, the rise time and the settling time take longer time compared to the normal PID simulation. So adjustments have been made to the controllers to investigate the effect of WNCS to the controllers. Through literature review, it can be seen that most of the researches have been proposed modifications on the PI and PID controller in order to overcome the time delay and loss of data.

For future work, there are some recommendations that can be made to the project. Other types of controller such as Smith-Predictor can be used to replace the PID controller as Smith-Predictor can shift the time delay outside the closed-loop. Besides that, other parameters of the wireless network can be changed to investigate the performance of the controllers such as the wireless protocol, the path distance, disturbance and also the computational delay. Path distance also can be a major factor as the longer the distance, the longer time taken for the data to be transmitted.

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