Research Article

CERTAIN INVESTIGATION OF REAL TIME NETWORKED CONTROL DC MOTOR USING SMITH PREDICTOR

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ABSTRACT : In this paper, DC motor is controlled by direct structure Networked Control System (NCS) with smith predictor control strategy. Mathematical model of DC motor is identified by empirical model building and estimated Round Trip Time Delay (RTT) is considered as time delay which is induced by network. Delay time which is induced in Networked DC motor is compensated with the smith predictor controller then the designed controller algorithm is comparatively analyzed with conventional PI controller. The simulation results are formulated for identified motor model with real time network. In addition to that the hardware fabrication of real time Networked DC motor has been developed and the results of both the simulation and hardware implementation are compared.

Keywords: DC Motor, Smith predictor, Round Trip Time Delay, Networked DC motor, Network based control.

INTRODUCTION

Nowadays many automation industries are replacing their conventional control into networked based control because of its extensive functionality, rapid development of low cost microprocessors and communication network technology. NCS is one of the newly established technologies in the modern industrial applications. NCSs are structures in which conventional feedback loop is connected in network through which information is exchanged with a limited bandwidth network between sensors, controllers and actuators [13]. In point-to-point communications, NCSs have great advantages, like minimizing wiring, system diagnosis, maintenance, and expandability [1]. On the other hand, the NCSs produce network delay, delays are generally recognized as a major adverse to control system, so enactment of NCS is often affects network delays as communication is between network and system [14].

In past few years several control techniques have been developed to compensate the effect of networked-induced delay. Tipsuwan and chow [2] proposed gain scheduling PI controller for NCS in order to compensate effect of time varying delay in Internet Protocol (IP) network. Lee et. Al. [3] proposed a NCS system with fuzzy logic controller (FLC) where the experimental results shows that fuzzy logic controller is more robust against time varying delay induced in the network. Tipsuwan and chow [4] present the survey paper in recent NCS control methodologies to stabilize the system due to delay concerns. Almutairi et.al. [5] developed FLC modulator to steady the networked PI control system and analyze its results. Fuzzy logic based NCS design like self-tuning fuzzy controller [6] and online adaptive fuzzy controller [7] using neural network to compensate uncertainty time delay induces in the network. Du peng et al. [8] proposed new smith algorithm to sweep predictive control for the purpose of compensating delays in wireless systems. More number of research work has been proposed for network delays using various structure of smith predictor controller approach [9], [10], [11], [12] and[15].

This work focuses design and an implementation of smith predictor control for real time direct structure network to control the DC motor in order to compensate effects of networked induced delay. Real-time User Datagram Protocol (UDP)/IP network is established using MATLAB real time windows target tool box. The performance of smith predictor has been validated by means of simulation and experimental results.

DIRECT STRUCTURE NCS

The direct structure NCS is mostly preferred, it comprises of a controller, sensors and as shown in Fig.1, actuators are connected through a shared network to accomplish closed loop control. For transmission across networks, the sensors and the control loops are enclosed using packet.

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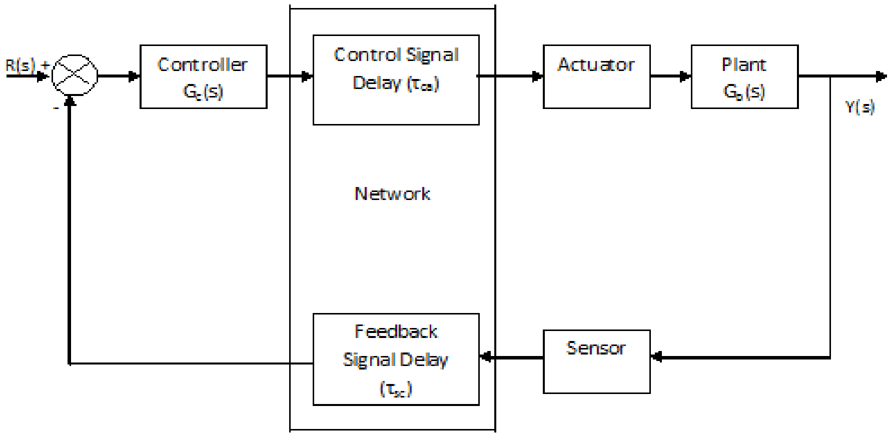

Fig.1 Direct structure NCS

The system which is shown above in Fig.1 shows that the data transfer from the host certain network delays can occur among controller and the distant system processing delay in the controller since they are working under a network. The delay between the controller and sensor is τ_{sc} and the delay across actuator and control τ_{ca} are two types of network delays in NCS, depending on the path of data transmission. The total network delay has been calculated as $\tau = \tau_{ca} + \tau_{sc} + \tau_d$ is greater than 1.

Transfer function of the NCS's is as follows:

$$\frac{Y(s)}{R(s)} = \frac{G_c(s)e^{-\tau_{ca}s}G_p(s)}{1 + e^{-\tau_{sc}s}G_c(s)e^{-\tau_{ca}s}G_p(s)} \qquad (1)$$

From (1), a time delay term in equation, which limits controller gain and as a consequence, the delay dominant system's control action is limited. When the system contains time delay, the closed loop performance will be degrade and even destabilize the stable loop due to the constraints imposed by time delays.

NCS SYSTEM ARCHITECTURE

Figure 2 portrays the design of a direct structure networked control system. The UDP/IP protocol was used to establish contact between the server and the client. The software and hardware configuration for UDP/IP protocol is done with the help of real time windows target tool box in MATLAB. The server and client node applications are implemented as simulink models and it has been run on real time operating system in external mode connection. The components used in building the direct structure NCS experiment are given as follows.

Client Node: It acts as closed loop control controller, in which the controller receiving speed measurement data via the network and it produces control signals after comparing it to the reference signal. These signals are compressed in packets and guided it to the server node through communication.

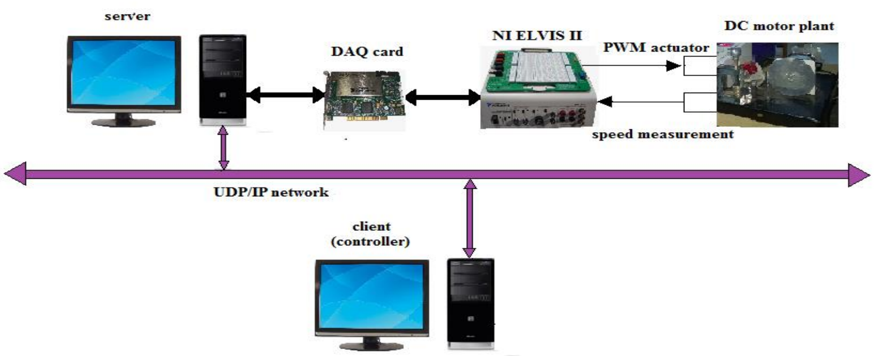

Fig. 2 Architecture of networked DC motor plant

Server Node: It acts as a gateway through which the measurement data has been collected from plant and frame the data as pocket then send it to the slave node (controller). In the same way Server Node collects the control data packet from the slave node and sends the control signal to the plant.

UDP/IP protocol: UDP/IP protocol is used for transmitting the information between client and server node across the network. The Internet protocol (IP) has the collection of network protocols that are used to connect on the internet, in which the User Datagram Protocol is the core member. UDP has no handshaking signals hence there is no possibility of retransmission. Because of these characteristics it is mostly used in real time applications.

PCI 6251 DAQ card: DAQ PCI 6251 is the PCI based on-board data acquisition hardware. It serves as a data acquisition device which contains ADC, DAC, digital I/O, internal clock and a timer. PCI 6251 DAQ card connected to the PCI slot on the computer mother board. PCI 6251 cannot be interfaced directly to the plant so NI ELVIS-II is used between the plant and the DAQ card. All data acquired from these NI ELVIS-II are then send to PCI 6251 DAQ card via data cable. The PCI-6251 DAQ card consist of ADC and DAC both having 16 bit resolution and the voltage ranges are -5 to +5v and -10 to +10v.

DC motor plant: DC motor is an electromechanical device in which electrical energy is converted into mechanical energy like motion and angular speed. The control signal which has been generated by the DAQ card to the DC motor is received through the PWM based actuator. The DC motor speed is measured using the encoder setup in which the pulse is generated based on the speed. The frequency of the pulse is converted into voltage with the help of frequency to voltage circuitry. The voltage range is (0-5) v and the corresponding DC motor Speed is (0-1500) rpm.

DC MOTOR MODEL IDENTIFICATION

This section briefly describes the DC motor model identification for design of controllers (PI Controller and smith predictor controller).The DC motor model is required for controller design and implementation so the identification and modeling of DC motor is obtained from the experimental setup as shown in Fig.3

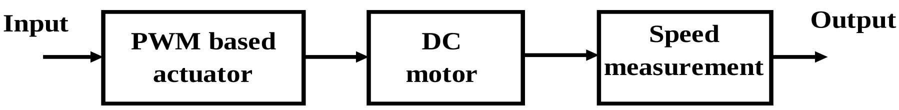

Fig.3 Setup for empirical model building

The open loop step response data is collected from the experimental setup and second order transfer function model is extracted from system identification tool in MATLAB and it is shown below (2).

$$\frac{\mathrm{Y(s)}}{\mathrm{R(s)}} = \frac{343.09}{0.154\,s^2 + 1.6436s + 1} \qquad (2)$$

The validation of the model and the real system are shown in Fig. 4. It shows, that the identified DC motor model approximately fits with the real model.

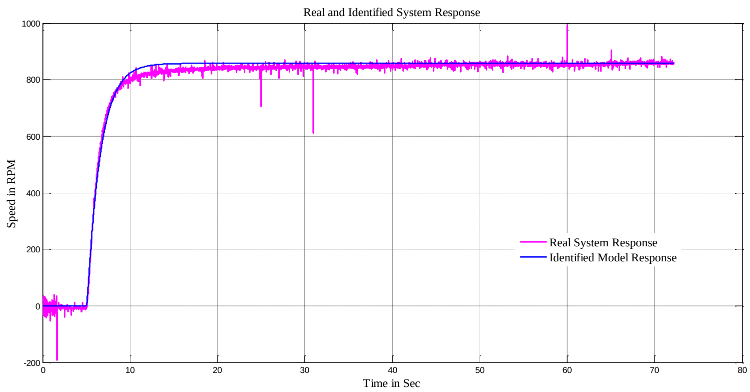

Fig.4 validation of the real system and identified model

CONTROLLER DESIGN

This section describes the design procedure of Strategy using a PI controller and a Smith predictor controller.

PI Controller design: Because of its structural simplicity, the proportional-integral controller is most generally proposed controller configuration in many industrial systems. The PI controller is a conventional feedback controller that uses a weighted sum of errors and the integral of the value to control the plant. The PI controller is mathematically denoted as:

$$G_C(s) = K_P + \frac{K_i}{S} \qquad (3)$$

K_p and K_i are the controller parameters where these two parameters are called controller design or tuning parameters, It is obtained by the IMC based tuning method formula [9]. The designed PI controller gain values are K_p =0.02913 & K_i =0.04163 for closed loop time constant τ_c= 0.2.

Smith predictor controller design: Figure 5 shows the smith predictor structure. It consists of model Gm(s), actual process GP(s) to be monitored, and the actual control loop's expected RTT delay. It provides a simulated environment in which the loop delay is compensated for using the plant model and assumed delay. The NCS's actual feedback loop is the outer loop, which includes a regular PI controller Gc (s). The inner loop is a virtual loop consisting of process models Gm(s), which was obtained using the device identification method and has an approximate RTT delay ofτ_{est}. The loop outputs are deducted in order to withdraw delay effect in control loop.

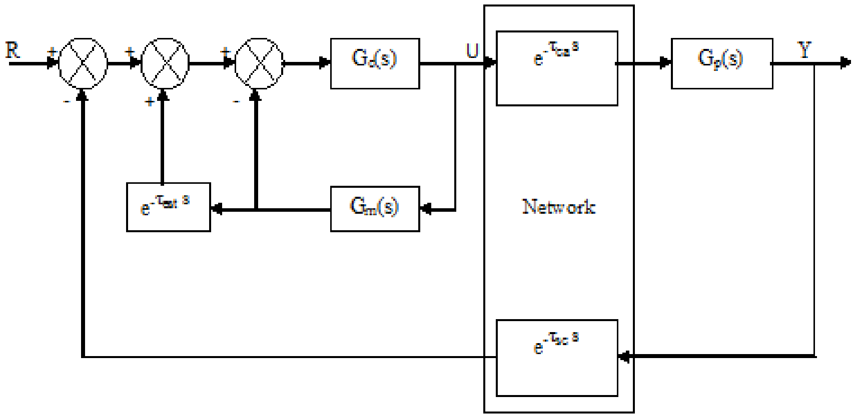

Fig.5 Smith predictor controller structure in NCS

The transfer function of the closed loop system is given by,

$$\frac{Y(s)}{R(s)} = \frac{G_c(s)e^{-\tau_{ca}s}G_p(s)}{(1 + G_c(s)G_m(s) + \left(e^{-\tau_{sc}s}G_c(s)e^{-\tau_{ca}s}G_p(s) - G_c(s)G_m(s)e^{-\tau_{est}s}\right)} \quad (4)$$

The results of network-induced delay were included, as seen in (4). Its effect can degrade system performance and few information, contribute to instability of the system. As a result, it is important to reduce negative outcomes via achieving condition (5).

$$\left(e^{-\tau_{ca}s}G_p(s) - G_c(s)G_m(s)e^{-\tau_{est}s}\right) \approx 0(5)$$

Equation (5) is satisfied if and only if the predicted model closely matches original system, i.e. $(G_m(s)\,G_p(s))$. The expected delay and the actual delay in communication are the same, i.e., est= ca+ sc+waiting delay, then (4) can be reduced to

$$\frac{Y(s)}{R(s)} = \frac{G_c(s)e^{\tau ca(s)}G_p(s)}{1 + G_c(s)G_m(s)} \qquad (6)$$

As a result, compensator of predictor eliminates the delay from the equation, permitting for an rise in gain as shown in the equation (6).

RTT delay estimation: A clock signal is sent through the network to calculate the delay in the NCS loop. In each time sample across the network, the $\tau_{est}$is considered as the modification among transmitted and received clock signals. The average estimated delay after the delay estimation procedure is 0.33sec, which is much longer than the sample period of 0.01sec.

SIMULATION AND EXPERIMENTAL RESULTS OF NCS

Various simulation and trials are piloted to investigate NCS control performance for designed controllers.

Simulation results: With the support of MATLAB simulink and the real-time windows target tool box. The sampling time has been set to 0.01 seconds. The device response obtained without the use of a network environment using the PI controller is shown in Fig.6. With a settling time of 1.4 seconds and a peak overshoot of 2.77 percent, this response meets the controller's design requirements.

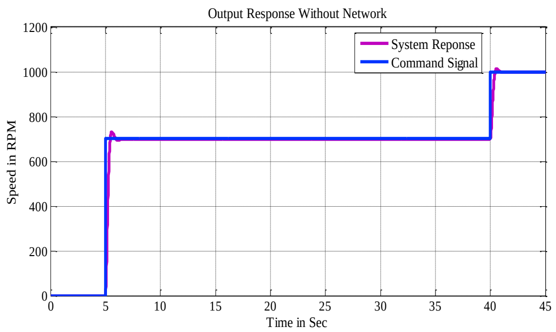

Fig.6DC motor response with PI controller

The Fig.7shows that the system response obtained using PI controller with network environment. The PID controller proposed in unstable in NCS due to the time constant in the model which is less dominant compared to the delay time induced in the network between two PC.

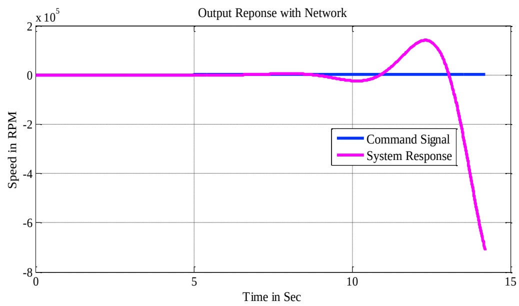

Fig.7 PI controller response to a networked DC motor

The Fig.8shows the system response obtained using smith predictor controller using controller with network environment. In this case instability of PI controller is stabilized by using smith predictor controller and performance is improved as settling time of 2.77 sec and peak overshoot as 23.53%. The estimated RTT delay between two PC is 0.33 sec.

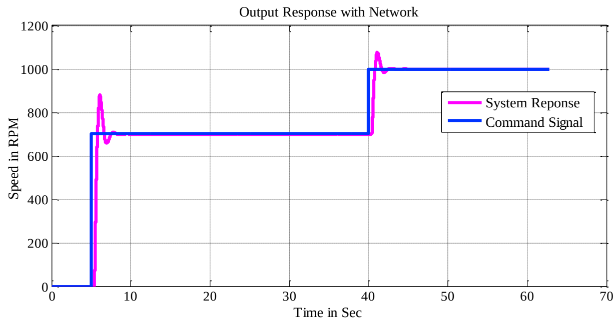

Fig.8 Response of networked DC motor with Smith Predictor Controller

Experimental Result: The experimental setup for the NCS DC motor control is shown in Fig.9.

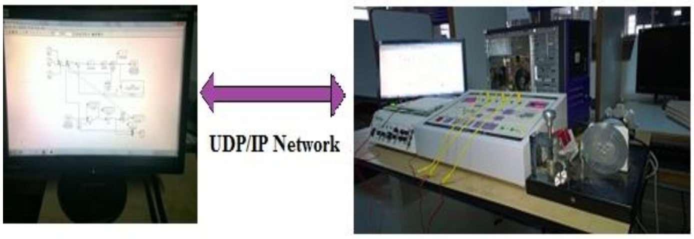

Fig.9 Networked DC motor hardware configuration

The experimental results is obtained by using without a network, a PI controller environment is depicted in Fig.10. This response shows the settling time of 2.8 sec and peak overshoot as 17.64%.

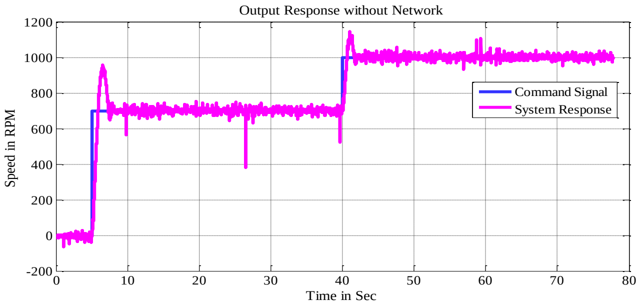

Fig.10 DC motor response using a PI controller

The Fig.11 shows the experimental results obtained using PI controller with network environment. This experimental result indicates the instability of the PI controller used in NCS.

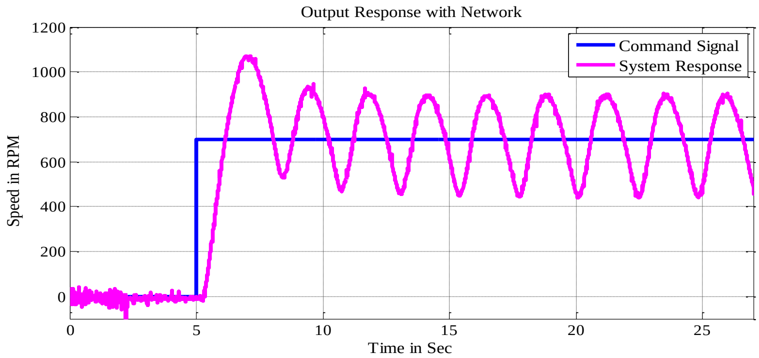

Fig.11 PI controller response to a networked DC motor

The Fig.12shows the experimental results using smith predictor controller with network environment. In this case instability of PI controller is stabilized by using smith predictor controller and performance is improved with the settling time of 4.1 sec and peak overshoot as 24.65%.

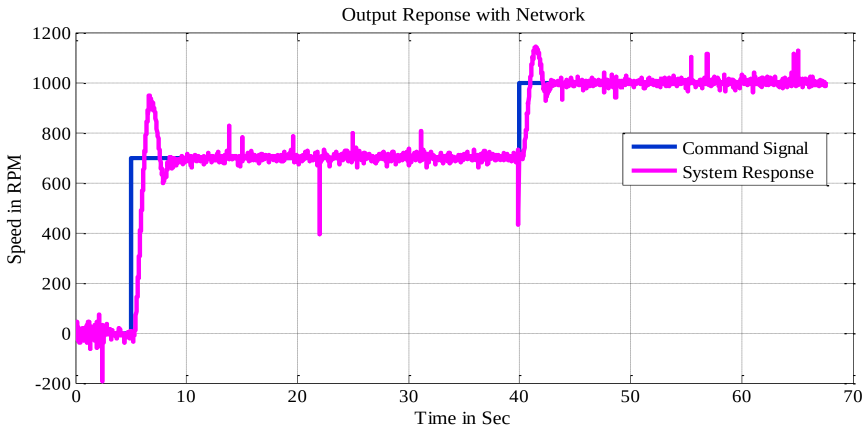

Fig.12 Response of networked DC motor with Smith Predictor Controller

According to the simulation and experimental findings, that the smith predictor controller ensures better control performance in the NCS. The performance index of the experiment is much larger than simulation because uncertainty of identified DC motor system as shown in Table.1.

Table.1 Performance Index Comparison

CONCLUSION

Performance Index	**PID Control (without Network)**		**PID Control (with Network)**		**Smith predictor controller (with network)**	
	Peak overshoot (%)	**Settling Time (sec)**	**Peak overshoot (%)**	**Settling Time (sec)**	**Peak overshoot (%)**	**Settling Time (sec)**
Simulation Results	2.77	1.4	unstable		17.64	2.8
Experimental Results	23.53	2.8	unstable		24.65	4

The smith predictor controller is used to solve the problem of the NCS with constant delay is discussed, and tested on a simultaneously using networked DC motor drive. This design, however, necessitates a precise mathematical model of the process as well as an accurate estimate of the total network delay. Results of simulations and experiments are compared, in which smith predictor controller performed better than the PI controller. In the future, a method for balancing simulation execution on the master and slave nodes will be developed. This research can also be used to build a filtered adaptive smith predictor for varying delay NCS and to minimize noise effect on the output response.

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