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Design of Gain Scheduling PID Controller for Network Control System

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ABSTRACT
This paper presents the problems faced by the network control system and the design of a gain scheduling controller based on the network delay. The major problem faced by the network control system is network induced time delay which affects the stability and the performance of the network control system. The network delay is induced by the factor of different loading conditions between measurement and control of the network system. To face these variations of delay a delay dependent gain scheduling law is used. Based on these network delays, a delay dependent gain scheduling PID controller is designed. The gain scheduling controller which can able to cope with different loading condition based on the network induced delay. Different loading conditions are assumed by uniform random number which creates the data collusion in the network. The gain scheduling controller is designed by using the MATLAB TrueTime simulation toolbox.

KEYWORDS: Truetime kernel, network control system, gain scheduling, PID controller, RTT delay, network, execution time, scheduling policy.

INTRODUCTION

Network Control System (NCS) which is one of the distributive control systems is to implement the distributive control based on computer aided control and communication channel in the NCS may be shared with other nodes outside the control system. NCS where the control system components are closed via network (i.e., Carrier Sense Multiple Access/Collision Detection, Carrier Sense Multiple Access/Arbitration Message Priority, Round Robin, Frequency Division Multiple Access, Time Division Multiple Access, FlexRay, and Switched Ethernet). It introduces the concept of remotely control the process. The defining feature of an NCS is that information (reference input, plant output, control input, etc.) is exchanged using a network among control system components (sensors, controllers, actuators, etc). The functions performed by the NCS are acquisition (sensors), command (controllers), and communication (network) and control (actuators).

Collecting the real time data over the network via the distributed sensors is the research area. Two types of control system utilize the network field. One is shared network control system and another one is remote control system. Both the types are combined to form the Network Control System. In the NCS data are shared via the network and the process is controlled remotely. The NCS provides more flexibility in installation, maintenance, and troubleshooting. The information is transferred from sensor to controller, controller to actuator using shared network reduces the complexity of connections. The challenging problem in the NCS is delay effect, bandwidth allocation, and scheduling [3].The NCS can be designed in hierarchical structure or in direct structure depending on the application. The performance of the system will degrade due to the existence of the network delays regardless of the type of the network [2]. Random delays in the network are difficult to handle than the constant delays. It also affects the stability criteria of the NCS. The network has three types of delays. They are (1)

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propagation delay, (2) waiting time delay, and (3) frame time delay. By using the time delays RTT values are calculated [1]-[3].

The importance of NCS and its delay motivates the delay dependant controller, static state feedback integral control. This controller describes the modeling and the stability analysis NCS. This controller can react based on the delay values but it produces maximum peak overshoot error [4]. The stability conditions are derived by using the Lemma stability Theorem and the delta switched operator is designed but it makes the system into complex [7].

In the gain scheduling state feedback integral controller, the integral action is introduced to address the nonzero disturbance and the scheduling strategy but it has the lack of derivative action [4]. The PD controller can perform the control action under different loading conditions on an Ethernet network, the dual rate computation was also carried out and the stability is established in terms of probabilistic linear matrix inequalities. It also produces some offset error in the system output [5].

The problem of static output feedback control also induces the network induced time delays; therefore the robust stabilization is solved by the bilinear matrix inequalities [6]. Different methodologies to handle the network delays and the pocket dropout in NCS are explained but the methodologies have some lack of synchronization [1]. The cost control is another one problem faced by the NCS; predictive control scheme derived the conditions for the guaranteed cost control and the performance of the Networked control system and the delay is not considered [8].

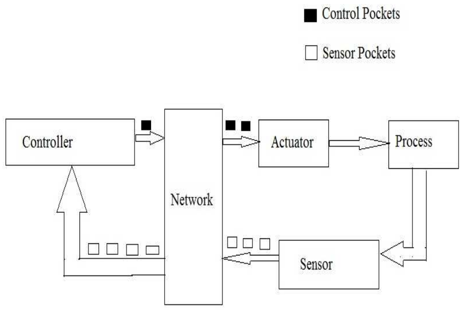

Fig. 1: NCS setup

In this paper focus on the problem of network delays which causes by the interrupts and the pocket collision. To detect the collision, Ethernet CSMA/CD (Carrier Sense Multiple Access/Collision Detection) type protocol is used as network which improves the performance of the network. Gain Scheduling laws are used to cope with different loading conditions. This paper also reduces the IAE, ITAE, ISE errors in the network which are compared with the PID controller. The basic NCS setup is shown in Fig. 1.

Description of Network Delays and Network Parameters:

The network control system has lot of problems along with it because of the uncertainties and the network delays. The network delay has great impact on the NCS stability and the performance. It always produces the negative effect on the NCS stability.

A. Network Delays:

The data pocket delay may be more harmful than the pocket loss. The network delays are classified into three types. They are,

1. Delay from the sensor to the controller, $T_{sc.}$
2. Delay from the controller to the actuator, $T_{ac.}$
3. Processing delay or Execution time, $T_{p.}$

Based on the delay values the total round trip time or the total time delay was calculated. The processing delay is also classified into three types (i.e., processing delay at Sensor level (t_s), Actuator level (t_a), Controller level (t_c).).

$$T_p = t_s + t_a + t_c \quad (1)$$

The total time delay is the addition of sensor to controller delay, controller to actuator delay, processing delay.

$$RTT = T_{sc} + T_{ac} + T_p \quad (2)$$

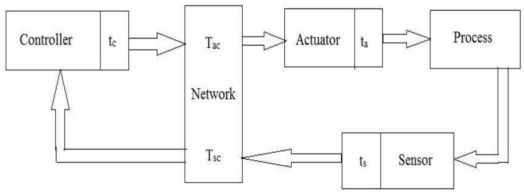

Fig. 2: NCS with delay

The network control system with delay is shown in Fig. 2. These delays are induced by the interference or interrupts in the network. Random disturbance highly will affect the stability than the constant disturbance. A uniform random number is added to induce the time delays in the network.

B. Network Parameters:

Ethernet CSMA/CD is used to connect the local side and the remote side of the network control system. The remote side of the NCS consists of controller and the local side of NCS consists of sensor, actuator, and process. Here the process is controlled remotely. When two or more networks are waiting for the network/cable, the collision will occur. Different loading conditions also induce the collision in the network. The induced time delay will be produced because of the network collision.

When collision occurs, the sender will wait for a time which is defined as (3),

$$T_{wait} = \text{Minimum Frame Size / Data rate} * R \tag{3}$$

Where,

$$R = \text{rand}\,(0, 2^k - 1) \tag{4}$$

R is the discrete uniform distribution and k is the number of collision.

Description Of Gspid Controller:

To improve the stability and the performance a delay dependent controller (GSPID) is proposed. GSPID stands for Gain Scheduling Proportional Integral and Derivative controller.

$$U = P + I + D \tag{5}$$

Where,

$$P = K_p * (r-y) \tag{6}$$

$$I = I.\ old + K_i * T_i * (r-y) \tag{7}$$

$$D = -K_d * d(r-y)/dt \tag{8}$$

Algorithm for the Gain Scheduling PID, Actuator and Sensor are given below,

C. Algorithms:

1) GSPID Controller Algorithm:

Step 1: receive the measurement from sensor.
Step 2: calculate the RTT values from (2).
Step 3: compute the PID parameters from (5).
Step 4: obtain the signal (U) to the actuator.
Step 5: send signal (U) to actuator.

2) Sensor and Actuator Algorithm:

Step 1: receive the control action from the controller.
Step 2: obtain the processing delay at controller t_c and the controller to actuator delay T_{ca}.
Step 3: wait for the execution time of actuator t_a.
Step 4: after reaching t_a, sensor starts to send the signal to the controller.

True Time Simulation and Result:

For delay compensation algorithm and scheduling algorithm of NCS, TrueTime is an ideal platform. It has four main components such as TrueTime Kernel, TrueTime Network, TrueTime Wireless Network, and TrueTime Battery. The TrueTime modules can be connected with the common simulink modules in MatLab.

The network module of the TrueTime simulates receiving and sending of pockets in accordance with the network module selected. The network module can provide six kinds modes and network parameters, such as network nodes, transmission rate and medium control protocol and so on. The MAC includes CSMA/CD, CSMA/AMP, Round Robin, FDMA, TDMA, and Switched Ethernet.

When the message are read in or sent out, the network module executes the task. After the completion of the message transmission, the message will be stored in the buffer at the destination node and it will inform the destination by the form of interrupts.

The TrueTime Kernel module can be used to simulate nodes of networked control system, such as sensors, controllers and actuators etc. It has flexible real-time kernel, A/D and D/A converters, network sending and receiving interfaces, external interrupting channels and multi-task scheduling and monitoring output interfaces, where the output of dispatchers and monitors are used to display the distribution conditions of public resources (CPU, monitor, network) in the simulation process.

The kernel module can execute the task according to the scheduling algorithm. It has four scheduling algorithm such as fixed priority (prioFP), rate monotonic (prioRM), deadline monotonic (prioDM), and earliest deadline first (prioEDF).

D. TrueTime Simulation:

To show the effectiveness of the proposed system, consider a DC motor transfer function as the process and the stability is compared with the conventional PID controller.

In the simulation, networked controller is time driven. At each sampling period, it calculates the control signals with the most recent sensor packet available. After the calculation, the new control signals and the timestamp of the used plant state are encapsulated into a packet and sent to the actuator via the network. The timestamp will ensure the actuator in selecting the appropriate control signal to control the plant. The sensor task is a time-base mode of operation, i.e. sensor will sense the plant every 0.1 sec directly from A/D input port. The actuator task is responsible of doing D/A conversion of control signal to actuate the plant with the new received value. The actuator task is an event-based mode of operation, i.e. an interrupt is set to listen to network interface for any receiving controller packet. The simulation is shown in Fig. 3.

The parameters of network such as type of network, data rate, execution time, pocket size and the number of nodes are listed in Table 1.

Table 1:

Item	Network Parameter	Value
1	Type of Network	Ethernet CSMA/CD
2	Data rate	10Mbps
3	Pocket Size	72Kbps
4	Number of Nodes	3
5	Execution time	5ms

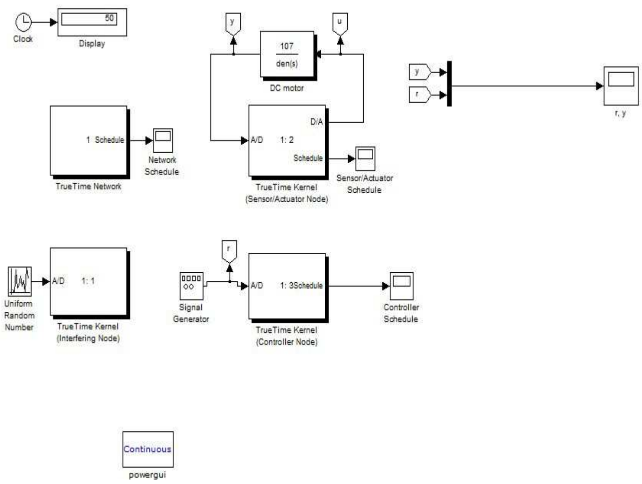

Fig. 3: Simulation

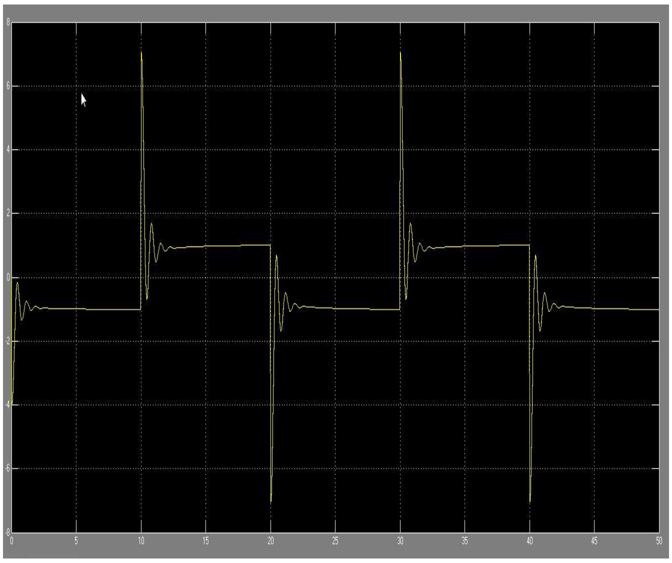

Fig. 4: GSPID Controller output

E. Result of TrueTime Simulation:

Fig 4 and Fig 5 shows the controller output and the process output respectively. Fig 6 shows the total delay values (i.e., RTT values).

F. Comparison between PID and GSPID controller:

ITAE (Integral Time Absolute Error), MO (Maximum Overshoot, and MU (Maximum Undershoot) values are reduced in the GSPID controller than the PID controller. Comparison between the PID and GSPID controller is shown in Table 2.

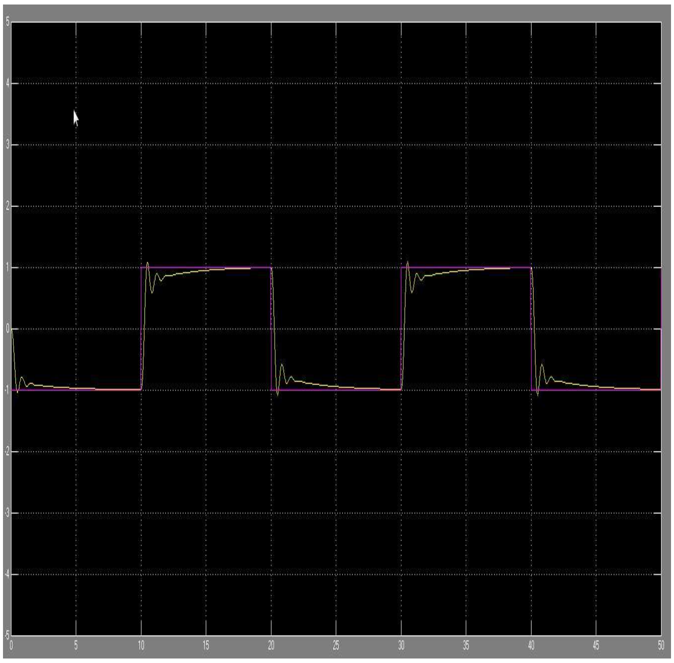

Fig. 5: Process output for GSPID Controller

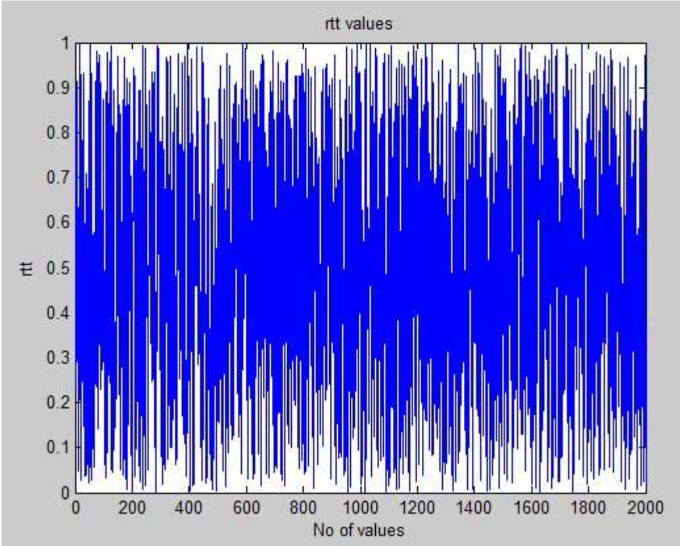

Fig. 6: RTT Values

Table 2:

Criteria/controller	PID	GSPID
ITAE	4.639×10^3	1.325×10^3
MO	4.226	1.0781
MU	-5.537	-1.0369

Conclusion:

A delay dependant Gain Scheduling PID controller is designed for the network control system. The delay values are calculated by using the gain scheduling laws. Ethernet CSMA/CD is considered as network. The network setup considers two different sides: the remote one (controller) and the local one (plant, sensor and actuator). The network is assumed to be shared with other nodes generating a randomly-varying load on it by adding the disturbance randomly. The controller design is simulated using MATLAB TRUETIME Toolbox. The error is reduced and the stable output is produced even the disturbance is present in the network.

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