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A New Approach for Scheduling of Networked Control System

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Abstract: In Network Control System (NCS), transfer of control data between sensor to controller and controller to actuator is done through a shared communication medium. The sharing of communication bandwidth will induce unavoidable data latency and might degrade the control performance. The performance of the control loops depends not only on the design of the control algorithms, but also on the scheduling of the shared network resource. A modified scheduling algorithm is proposed in this study to reduce communication delays and to maintain the stability of the system.

Key words: Network Control System (NCF), communication, performanse, MADB

INTRODUCTION

Over the past decade, major advancements in the area of communication and computer networks have made it possible to include communication in feedback in order to achieve real-time requirements (Feng-Li *et al*., 2006). This gave rise to a new paradigm in control system analysis and design, namely Networked Control Systems (NCS), wherein the control loops are closed through a real-time network. Such NCS have received increasing attentions in recent years because of their low cost, easy maintenance and reliability.

The use of networks as a media to interconnect the different components in an industrial control system is rapidly increasing. For example, in geographically distributed systems, the number and/or location of different sub systems to control make the use of single wires to interconnect the control system prohibitively expensive. In addition, the flexibility and ease of maintenance of a system using a network to transfer information is appealing. Systems designed in this manner allow for easy modification of the control system strategy by re-rooting signals, having redundant systems that can be activated automatically, when component failure occurs. And in general, they allow having a high level supervisor control over the entire plant.

Industrial applications include automobiles, intelligent vehicle systems, robotic systems, jacking systems for trains and process control systems, etc. However, the insertion of communication channel to control systems makes the analysis and design of the closed loop system complex (Shanbin *et al*., 2002). Conventional system theories with such assumptions as non-delayed sensing and determinism must be re-evaluated before they can be applied to NCS. Network-induced delays typically have negative effects on the NCS stability and performance.

In NCS, various delays with variable lengths occur due to sharing a common network medium (Feng-Li *et al*., 2002). These delays are dependent on the configurations of the network and the given system. Those make NCS unstable. Hence it is necessary to develop some methods to make these delays smaller and bounded, which are called scheduling methods for the NCS.

In feedback control systems, it is important that sampled data should be transmitted within a sampling period and stability of the system should be guaranteed in spite of the performance degradation (Zhang *et al*., 2001, Astrom and Wittenmark, 1977). This certain bound is called a Maximum Allowable Delay Bound (MADB).

NETWORK CONTROL SYSTEM

In the past, traditional control systems had a single centralized control unit, which controlled all other processes and devices (sensors and/or actuators).

It had various disadvantages like single point of failure, poor reliability, Poor performance and inability to support advanced distributed control scheme.

The solution currently adopted to address modern control problems is to distribute the processing functions of these systems over several physical nodes, each dedicated to a part of the control process and to a group of sensors/actuators. These nodes cooperate with each other, communicating through a shared physical channel, which forms a Networked Control System. These common-bus systems require less complex wiring reducing the setup and maintenance costs. At the same

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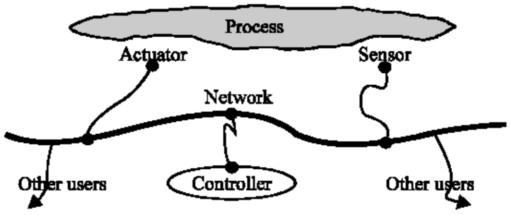

Fig. 1: Schematic diagram for an NCS

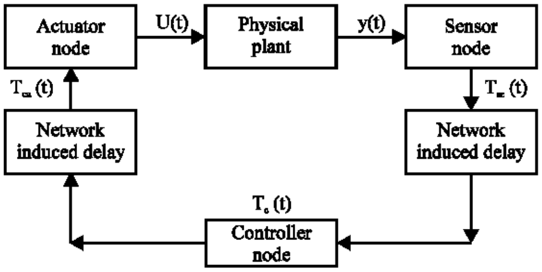

Fig. 2: Schematic of a feedback control system network-induced delays

time, they also reduce the possibility of a single fault affecting the whole system. Figure 1 shows the Schematic diagram for an NCS.

Networked Induced Delays are dependent on the configuration of the network and the given system (Shanbin *et al*., 2002). Delays in the NCS system consist of communication delay between sensors and controllers; τ_{sc}, communication delay between controllers and actuators; τ_{ca}, computation time in the controller; τ_c In practical applications, however, sensor-controller and controller-actuator delays are different and time varying at different networked devices due to the network transmission mechanism. Figure 2. Shows the schematic of a feedback control system with network-induced delays.

SCHEDULING

The performance of NCS depends not only on the Control strategies, but also on the scheduling algorithm of network resources. It is more important to investigate the real-time schedule theory of the NCS under conditions, where the network resources are limited. Considering that NCS is a digital real-time control system, a controller has to collect message of controlled application from the sensor, then after processing the message, transfers to the actuator, which directly controls application according to the command.

In Maximum Urgency First (MUF) scheduling method, the task that has largest error will execute first. The priority of the task is dynamically allocated during the runtime depending on the error of the task at the instant.

While, designing a Networked Control System, both the effective network bandwidth and sensors sampling rates must be considered. The stability of NCS can be improved by reducing the network-induced delay, choosing the appropriate sampling period and Network scheduling method. Choices of the sampling period for each control loop not only affect the available control performance, but also affect the bandwidth utilization. Therefore, a tradeoff between bandwidth occupancy and control performance could be determined.

Let us consider the NCS with M control loops that share the network medium. The controller for each control loop is designed in advance without considering the effect of the network. Each control loop has two data transmitting nodes of sensor and controller, while the actuator node is not included because it does not transmit its data through the medium. Therefore, there are a total of N = 2M data transmitting nodes in the network. Let Ti, i = 1,2...M be the sampling periods of the M control loops of the NCSs and Ti≤Ti+1, ∀i. Assuming that Ti = kiT1 (Ki≥1), ∀ i>1, then

$$K_i \le \left[\frac{\varphi_i - (n_i + 1)T_1 + L}{2T_1}\right]$$

$$T_i < \left[\frac{\varphi_i - (n_i + 1)T_1 + L}{2}\right]$$

$$T_1 = \frac{\varphi_1 + L}{3}$$

where, ni is the number of cycle scheduling scheme and ϕi is the maximum allowable loop delay of control loop I

$$\phi_i \le \left[\frac{T_{i,rise}}{10}, \frac{T_{i,rise}}{4}\right]$$

where, Ti, rise is the rise time of the ith control loop. When the network parameters are fixed, the number of the maximum allowable transmission data in one base cycle that the network medium could provide is determined by

$$r = \left[\frac{T_1 - N\sigma}{L}\right]$$

where, L is the data transmission time and σ is the overhead.

If $r \geq N$, the network traffic is lightly loaded and the network provides data transmission for all N nodes. If $r<N$, it should be decided whether the designed NCSs are schedulable and if it does, how to schedule the data of every node.

Let U be the network utilization, which is defined as the fraction of time during which the network medium remains busy for data transmission. U is expressed as $\beta L/T1$, where β is expressed as

$$2\sum_{i=1}^{M}\frac{1}{K_i}$$

The scheduling method used here considerably increases the utilization of network resources as well as satisfies the performance requirement of each control loop in the NCS. Determination of data sampling time is important in the analysis of NCS. Overloaded Network traffic degrades the performance of the control system. Even, in the under loaded traffic, if the sampling periods of control loops are selected inappropriately, performance will be deteriorated.

DEAD BAND

The most effective way to improve Network Control Systems (NCSs) performance, is to reduce network traffic (Otanez and Tilbury, 2002). With a dead band defined on a node, the node does not broadcast a new message if the node signal is within the dead band. The implementation of dead bands is very promising since, nodes do not require knowledge of their environment and thus is better suited for reconfigurability.

The implementation of dead bands results in network traffic reduction while maintaining acceptable system performance. A node with a dead band compares the previous value it sent to the network, X sent, to the most recent value, X. if the absolute value of the difference between X and X sent is within the dead band then no update is sent to the network. As the size of the dead band increases, the number of messages transmitted by a node decreases.

SIMULATION

The NCS is assumed to have 2 control loops with 4 data transmitting nodes (2 controllers and 2 plants). Packetized data transmission time (L) and overhead are 1 and 0.1 μs. Bandwidth used is 80000 bits s^{-1}. Simulation is carried out using Matlab/Truetime. The DC motor taken for the simulation are:

$$G1(s) = (166.67S+166.67)/(S^2+12.5S)$$

$$G2(s) = (128.2S+128.2)/(S2+9.6S)$$

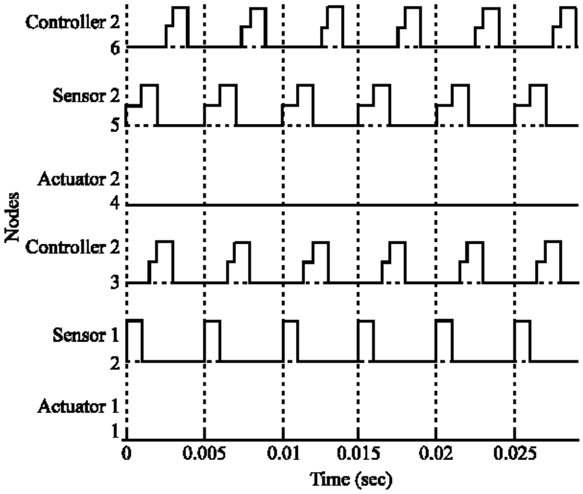

Fig. 3: Scheduling plot

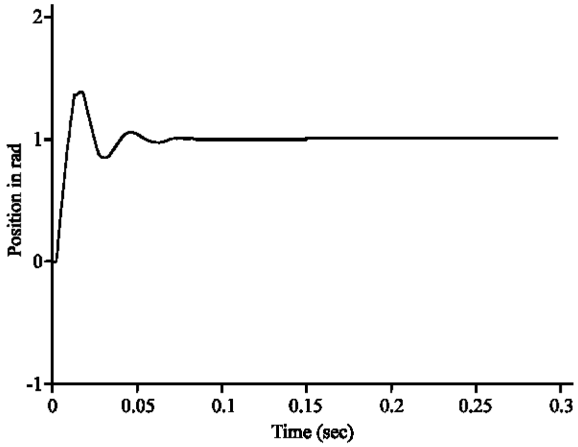

Fig. 4: System response of DC motor 1

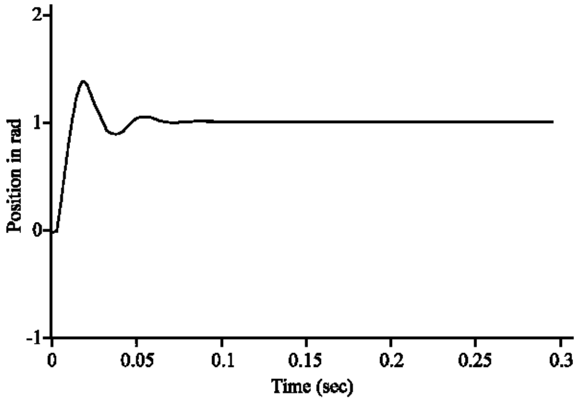

Fig. 5: System response of DC motor 2

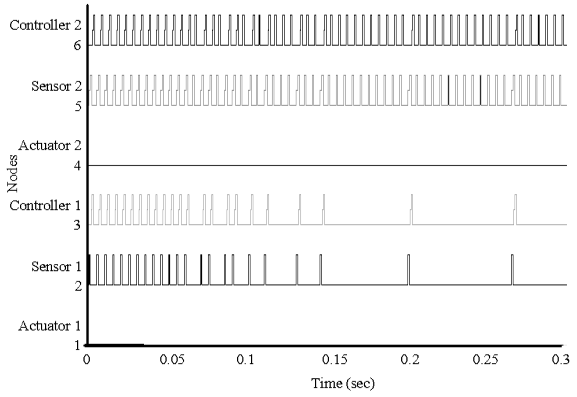

Fig. 6: Scheduling plot

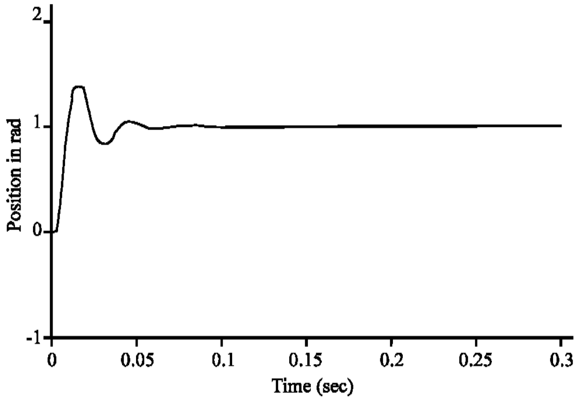

Fig. 7: System response of DC motor 1

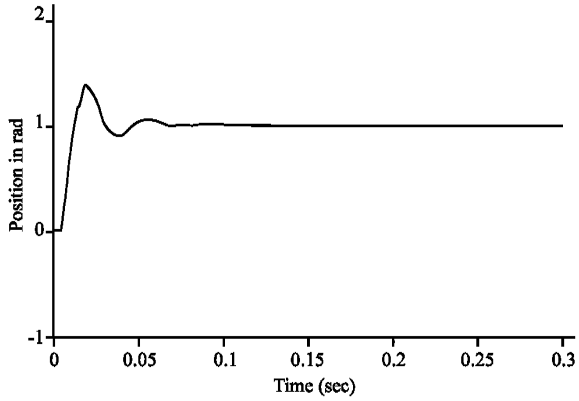

Fig. 8: System response of DC motor 2

Dc motor has one sensor to sense its position. The PID controllers are designed to control the position of the DC motors.

For the NCSs, T1, ki and r are determined. The sampling periods of the loops are determined as $T_1 = 5$ ms and $T_2 = 5$ ms. The Network Utilization is 80%. Initially, NCS is simulated without introducing dead band. Figure 3-5 shows the Scheduling plot and System responses of DC motor 1 and DC motor 2, respectively.

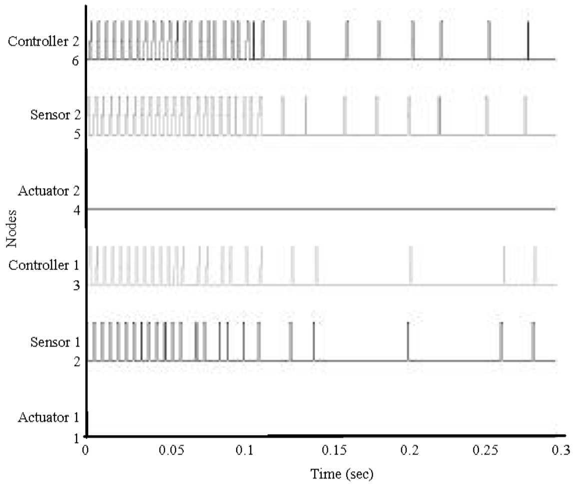

Fig. 9: Scheduling plot

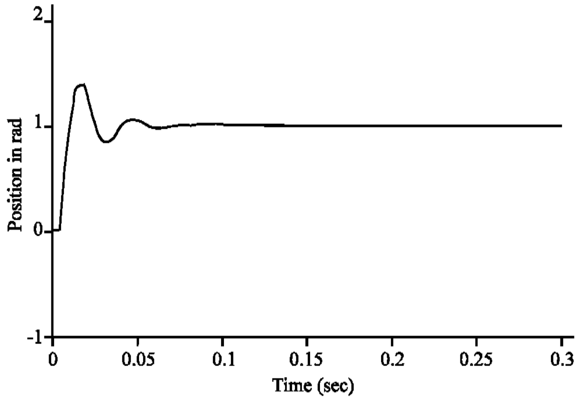

Fig. 10: System response of DC motor 1

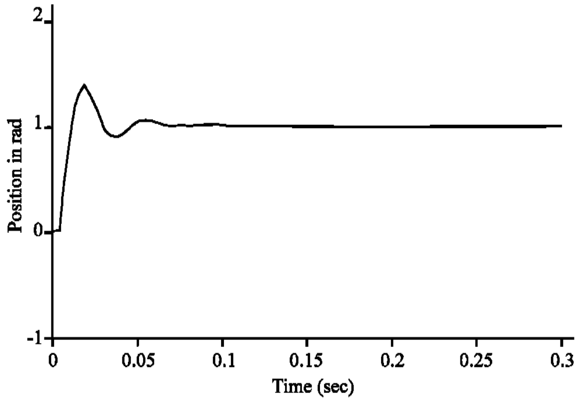

Fig. 11: System response of DC motor 2

Table 1: Impact of dead band on network usage

Dead band	Commuication %	Reduction in communication
-	80	-
Sensor 1	56	24
Sensor 1 and 2	36.6	43.4

Then, NCS is simulated by introducing dead band on the sensor of DC motor1 and then on the sensors of both the DC motors.

Figure 6-8 shows the Scheduling plot and responses of DC motors, when a dead band is introduced in the sensor of DC motor1. Figure 9-11 shows the Scheduling plot and responses of DC motors, when a dead band is introduced in the sensor of DC motor1 and 2. Sensor utilizes 20% of bandwidth, but after introducing dead band, sensor 1 utilizes only 8% and sensor 2 utilizes 10.3% (Table 1).

CONCLUSION

The Scheduling and effectiveness of dead band in reducing the communication was investigated. It was shown that the system with dead bands maintains the same stability properties as the original system. The dead band introduced here reduces the network traffic significantly.

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