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Evaluation of a Wireless ZigBee with PID Controller for Networked Control System Using True Time Toolbox**

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ABSTRACT

Wireless networked control system (WNCS) consists of control system and communication network system. The insertion of communication network in control systems has enormous advantages but on the other hand it brings several issues like network induced delays or packet dropouts that brings negative impact on the performance of the system and may lead to instability, the delay caused by wireless network transmission may have bad impacts on system, so we need to know the behavior of networked control systems to design better and optimum control that reduces the effect of delay. In this paper wireless networked control system is simulated using true time. True time is a Matlab/Simulink-based simulation toolbox which is used to design wireless network model of ZigBee, using PID control for DC motor system. The evaluation tests show that the PID controller cannot stabilize the system when the data rare of ZigBee network is 20kbps.

1 Introduction

Wireless network applies widely according to its advantages, such as no cabling, networking and maintaining convenient, easy to extend, etc. Wireless networked control system (WINCS) appears, which is based on all wireless channel communication. However, wireless network exists many shortages, such as limited bandwidth of wireless network causes random time delay, packet loss, interference, and competition problems of WINCS, so that all these overall factors must be considered to design a closed loop system [1] WNCS also are affected by signal attenuation, obstacles in the radio-path, reflections, propagation delays, and fading. Also, system delays (sensor/controller delay and controller/actuator delay) occur while data exchange on devices connected to the shared medium. In networked case, some packets suffer delays and may be lost during transmission or be discarded. To avoid this, it is important that the distance with neighbors, work channels, and capability of devices, among other features should be considered to get good network performance [2]. The issues of network control system are:

1. **Sampling and delay:** to transmit a continuous time signal across a network, the signal must be sampled, encoded in a digital format, and transmitted over the network, then the data must be decoded at the receiver side.

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2. **Packet dropout:** the possibility that data may be lost while in transit through the network. The packet dropouts result from transmission errors in physical network links (which is more common in wireless network than in wired networks) or from buffer overflows due to congestion. Reliable transmission protocols, such as TCP, guarantee the delivery of packets. However, these protocols are not appropriate for NCSs since the retransmission of old data is generally not very useful [3].

2 Controller Design

Proportional integral derivative (PID) controllers are common used controllers in the industrial control systems. PID controller consists of proportional, integral and derivative control actions. A PID controller calculates and corrects the error between the process response output and the desired input that adjusts the process rapidly. Figure 1 show schematic of the PID controller. The output of the controller or the manipulated variable is obtained by adding proportional P, integral I and derivative D components and their associated coefficient. Equation 1 indicates mathematical expression of the PID controller [4]:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + Kd\frac{de(t)}{dt} \qquad (1)$$

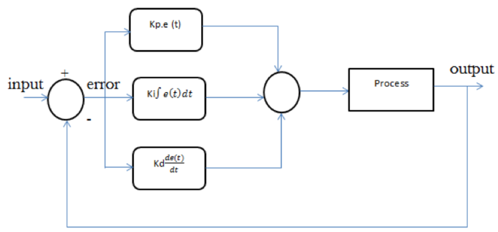

Figure 1. Schematic of PID controller

3 ZigBee Wireless Network

ZigBee is a high-level standard based on IEEE 802.15.4 that works in wireless personal area networks (WPAN). It defines the physical and medium access control layers of wireless networks. ZigBee is designed for low speed, because the channel bandwidth in the 2.4GHz is 250Kbps. A primary requirement of the IEEE 802.15.4 applications is the long battery life. When ZigBee is used for wireless networks, sensors and controllers don't need a large bandwidth due to the low latency and low power consumption with long battery life [2]. The optimum range of ZigBee is between 10-100m and data rate is between 20-250 kbps [5].

4 True Time Toolbox

True time is a Matlab/simulink-based simulator for control systems. True time eases co-simulation of controller task execution in real-time kernels, network transmissions, and continuous time transfer function. The kernel block simulates a real-time kernel executing tasks and interrupt handlers. The different kinds of network blocks allow node (kernel blocks) to communicate over simulated wired or wireless networks. The true time network block simulates medium access and packet transmission in a local area network. Six simple models of networks are supported: CSMA/CD (e.g. ethernet), CSMA/AMP (e.g. CAN), round Robin (e.g. token bus), FDMA, TDMA (e.g. TTP), and switched ethernet. The usage of the wireless network block is similar to the wired network and the same way as in work. Compute the path-loss of the radio signal, it has x and y inputs to specify the location of the nodes. Two network protocols are supported at this moment: IEEE 802.11b/g (WLAN) and IEEE 802.15.4 (ZigBee) [6]. The Figure 2 below show the true time blocks library version 2.

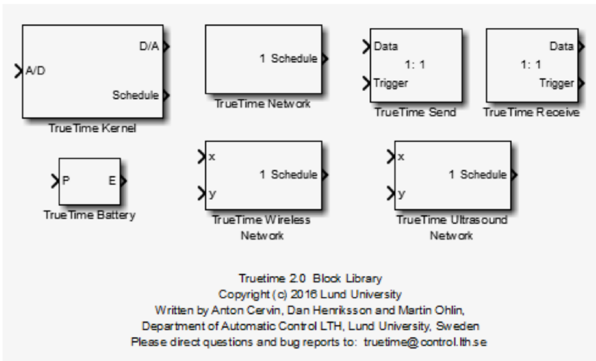

Figure 2. True time blocks library

4.1 Mathematical Model of the DC Motor

This paper contains WNCS which consists of DC motor controlled through a wireless ZigBee network using PID controller.

The model of DC motor system [6] is given by the following continuous-time transfer function:

$$G(s) = \frac{10.92e6}{s^2 + 6e3s + 3.67e6}$$

5 Implementation of Wireless Networked Control System

The insertion of the communication networks in the control loops make design of the NCS complicated because it imposes time delays in control loops, time delay phenomenon usually leads to severe degradation or instability of control systems performance [7]. PID controller can solve many control problems. However, conventional PID controller cannot be used with non-linear, multivariable, large time-delay. It must be an effective approach to design and develop various intelligent controllers or combine them in different forms to solve the delay problems of industrial process [1]. The sensor node is assumed to be time driven, the controller and actuator nodes are assumed to be event driven. At a fixed period, h, the sensor samples the process and sends the measurement sample over the network to the controller node. There the controller calculates a control signal and sends it over the network to the actuator node, where it is sequentially actuated [8]. Figure 3 show the structure of the proposed block diagram of WNCS [9].

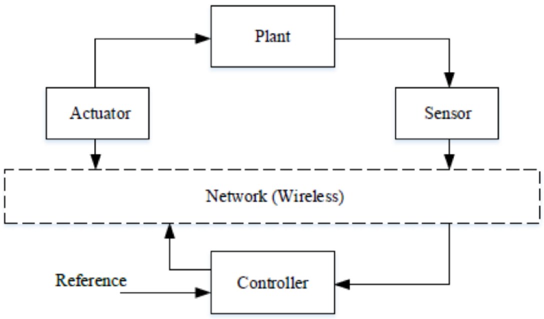

Figure 3. The proposed block diagram of WNCS

5.1 Simulation of PID Controller without Network

The model of only PID with plant is designed and result obtained, the parameters of PID is tuned using SISO design tool of Ziegler nickels tuning and refinement for parameters are made to get optimum results with no delay occurred in the system. The Figure 4 shows the output response of DC motor with PID controller

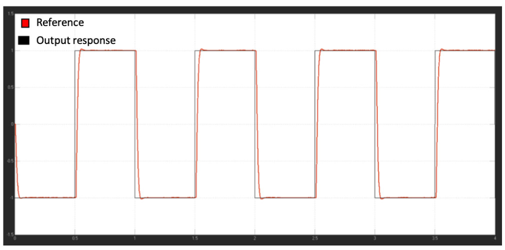

Figure 4. The output system response of for DC motor

5.2 Simulation of PID Controller with Network

The simulation in proposed model will suffer from delay caused by network that affect the performance of the system so the PID control will reduce the effect of delay and make the system stable, the proposed model is shown in Figure 5. In the [10] the data rate

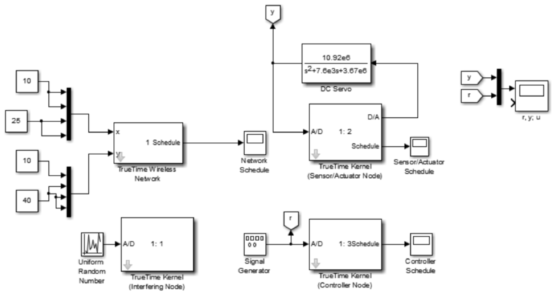

Figure 5. The model of wireless network control system

of ZigBee is 20kbps, 40kbps and 250kbps. These data rate of ZigBee is applied in the proposed model and the results obtained. The appropriate data rate for designed model is 250kbps as shown in Figure 6, then the data rate of 40kbps is applied and the output satisfied but with high overshoot as shown in Figure 7, but with data rate is 20kbps the output is never satisfied as shown in Figure 8. So the optimum data rate is chosen for our work is data rate of 250kbps. In figures below show the effect of testing and how degrade the performance of the system. In Figure 9 shows the result of packet dropout 1%, Figure 10 shows the result of packet dropout about 9%, and Figure 11 show the packet dropout about 25%, increasing the packet dropout will increase the degradation that effect the stability of the system.

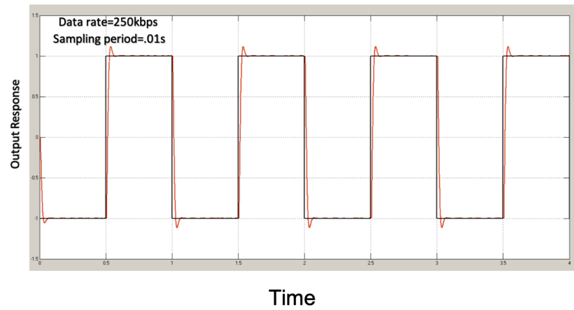

Figure 6. The output response DC motor with 250kbps data rate ZigBee network

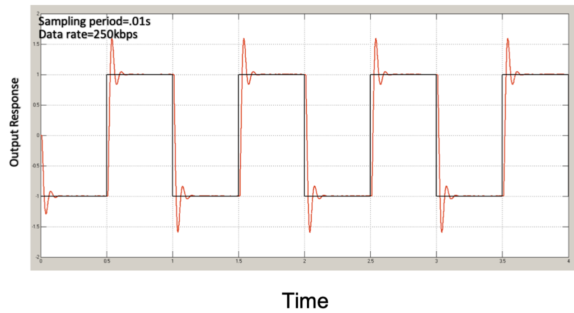

Figure 7. The output response DC motor with 40kbps data rate ZigBee network

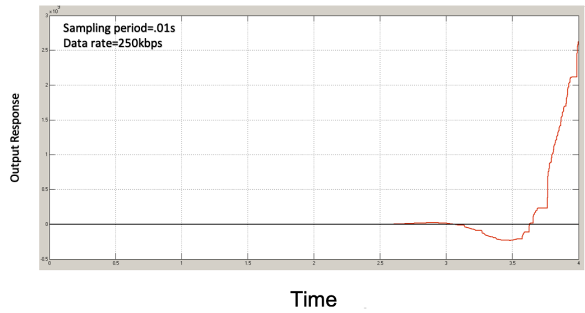

Figure 8. The output response DC motor with 20kbps data rate ZigBee network

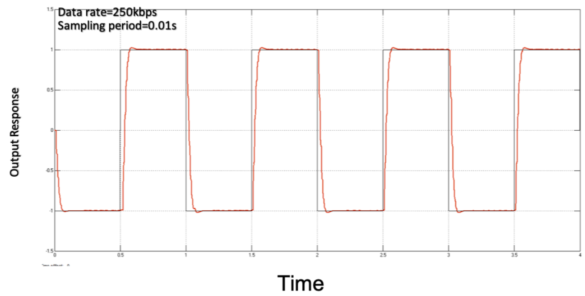

Figure 9. The output response DC motor with 1% packet dropout of ZigBee network

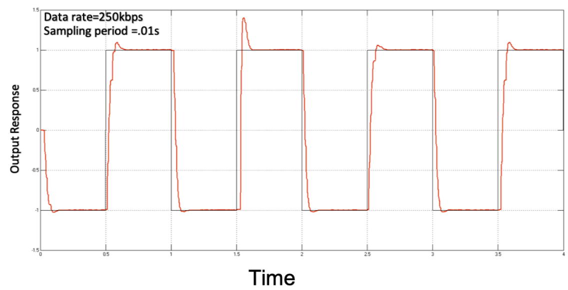

Figure 10. The output response DC motor with 9%packet dropout of ZigBee network

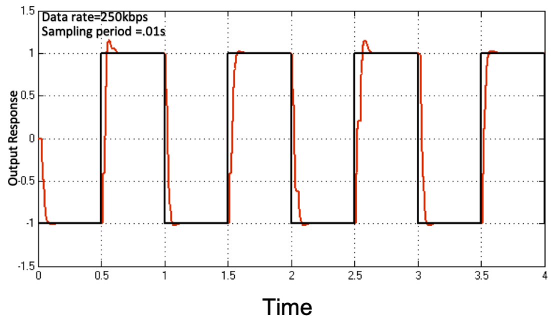

Figure 11. The output response DC motor with 9%packet dropout of ZigBee network after refinement of PID controller

We notice that PID controller performance will degrade the performance of the system when packet loss 25%, after refinement is made for PID controller parameters the output of DC motor is shown in Figure 12. In Figure 13 show the result of sampling period 0.01s then increasing sampling period in Figure 14 to 0.015s

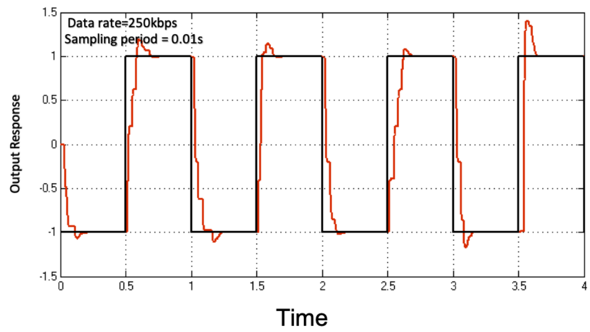

Figure 12. The output response DC motor with 25%packet dropout of ZigBee network

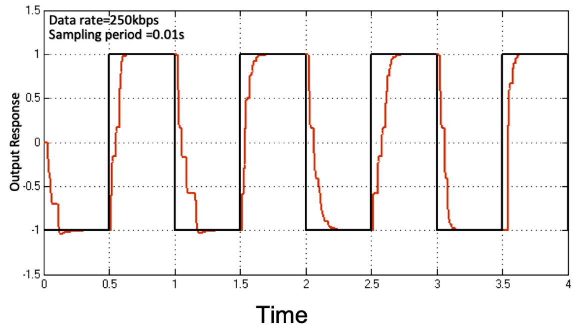

Figure 13. The output response DC motor with 25% packet dropout of ZigBee network after refinement of PID controller

and show the result, in Figure 15 sampling period is 0.001s and result is better comparing with result of other sampling periods, so with higher sampling period we observe better control of process value.

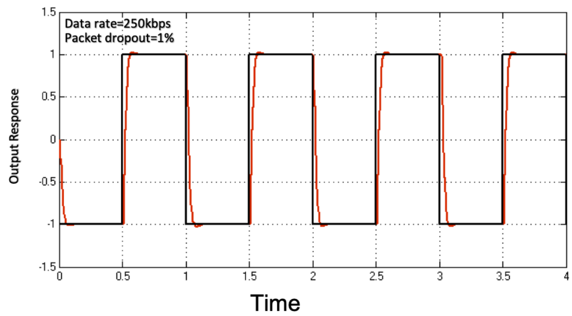

Figure 14. The output response DC motor with 0.01s sampling period of ZigBee network

Table 1.

Case	Packet Dropout			Sampling Period		
	0.01	0.09	0.25	0.01	0.15	0.025
Rise Time	0.502	0.525	0.55	0.55	0.59	0.6
Overshoot	1.12	1.12	1.6	1.03	1.002	1.03
Setting Time	0.5	5.6	0.56	0.625	0.7	0.65

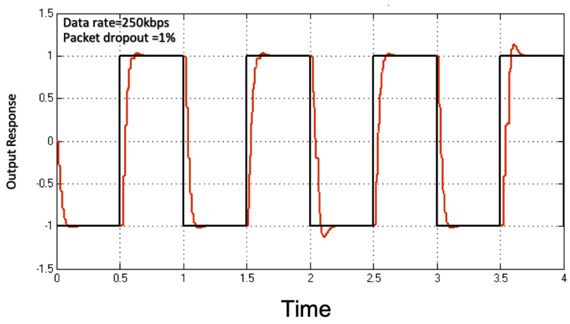

Figure 15. The output response DC motor with 0.015s sampling period of ZigBee network

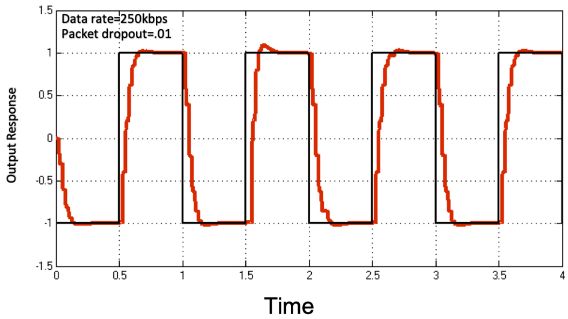

Figure 16. The output response DC motor with 0.025s sampling period of ZigBee network

6 Conclusion

In this paper, the simulation model of WNCS is designed in the true time toolbox. This model contains kernels blocks, which contain sensor/actuator node and control node, wireless network, which contains ZigBee network with appropriate parameters, and continuous-time transfer function. The problems of NCSs are investigated that are sampling period and packet dropout and design PID control to eliminate the impact of the network environment. The calculations of PID cases were tabulated for packet dropout and sampling period. The appropriate data rate is chosen for WNCS model.

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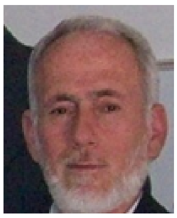

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