

Applicability of Internet-based Distributed Control System

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Abstract: The rapid development of distributed control systems has caused the necessity of knowledge and understanding of communication network in a process of a dynamic system modelling and controller synthesis. A lot of work has been done to determine the suitability of dedicated networks for data transmission in control systems. This paper is an approach in the problem of control of a remote system over the Internet. The work is an attempt to model and simulate a transmission network characteristics, taking into account the delay introduced by the network. Additionally, the experiment was conducted on a real network to determine the applicability of the Internet in distributed control systems.

Keywords: distributed control system, network based control system

Many modern automation systems are designed as distributed control systems. Distributed Control System (DCS) might use dedicated telecommunication network (LonWorks, CAN, ProfiBus) or commonly used network (Ethernet, Internet). There are several advantages of distributed control system, like a reduction in wires and power requirements, flexibility of operations, ease of maintenance, diagnostics and monitoring [7]. However, a communication network in the feedback loop generates two major problems: an unpredictable delay and packet losses. These problems threaten the stability of the entire automation system and have a significant impact on the dynamics and the behaviour of the system. That is why methods of the control system design need the knowledge about the properties of telecommunication networks. The aim of Internet-based distributed control system is direct network control, insensitive to the inherent Internet time delay [2].

1. Dynamic model of distributed control system

Let us consider the following continuous-time linear system with communication delay (1).

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t - \tau^{ca}) \\ u(t) = -K_p x(t - \tau^{sc} - \tau^c) \end{cases} \quad (1)$$

$$x(t) \in \mathbb{R}^n \quad u(t) \in \mathbb{R}^1$$

The linear state-feedback controller has a constant gain K_p . A communication network connects the sensor-controller nodes and the controller-actuator nodes. The overview of distributed control system over network is depicted in Fig. 1 The structure and utilization of the network affect the sensor-to-controller delay (τ^{sc}) and controller-to-actuator delay (τ^{ca}). The delay of the control signal

computation is denoted by τ^c and it is not dependent on the telecommunication network (Fig. 2).

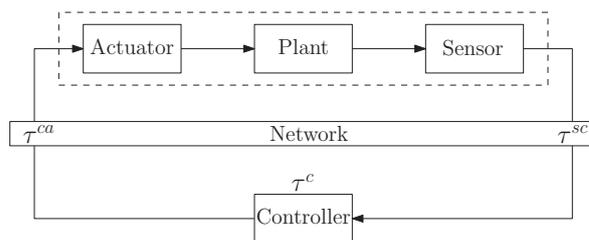


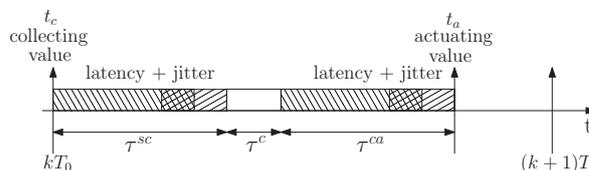
Fig. 1. The model of a distributed control system
Rys. 1. Model układu sterowania rozproszonego

The closed-loop system, obtained with proportional controller is described in (2).

$$\begin{aligned} \dot{x}(t) &= Ax(t) - BK_p x(t - \tau(t)) \\ \tau(t) &= \tau^{sc}(t) - \tau^c - \tau^{ca}(t) \end{aligned} \quad (2)$$

The discretization of continuous time-delay system is given in (4), where T_0 is the sampling time. The extended state space leads to transform representation (1) and (2) into finite-dimension system. An extension of state space model is shown in (8). This model can be used for simplification of the controller synthesis [4]. The closed-loop system equations are valid for the condition (3). Otherwise, the actuator operates in the open-loop mode [5].

$$0 \leq \tau(k) \leq T_0 \quad (3)$$



$$\tau(k) = t_a(k) - t_c(k) = \tau^{sc} + \tau^c + \tau^{ca}$$

Fig. 2. Timing relationships in the model of a distributed control system [7]

Rys. 2. Zależności czasowe w modelu sterowania rozproszonego [7]

The block structure of the discrete time-delay system is shown in Fig. 3.

$$\begin{aligned} x[(k+1)T_0] &= \Phi_0 x(kT_0) + \Gamma_0(\tau)u(kT_0) \\ &+ \Gamma_1(\tau)u[(k-1)T_0] \end{aligned} \quad (4)$$

For the second simulation experiment, the average delay time has been calculated based on a statistical analysis of the network connection (Fig. 8) and it equals 160 ms. The control line is disconnected from the process at a random instant. This part of the model simulates open-loop mode of system operation, as a result of buffering effect (when the assumption (3) is not fulfilled). The simulation performance results of the closed-loop control are shown in Fig. 9.

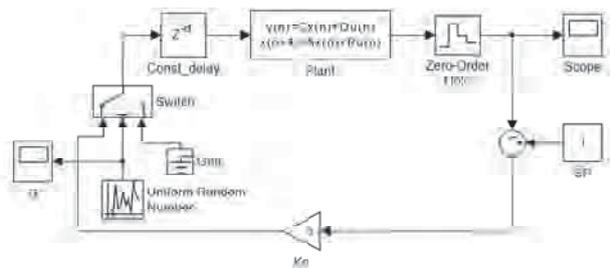


Fig. 5. The MATLAB/Simulink model [1]
 Rys. 5. Model systemu w programie MATLAB/Simulink [1]

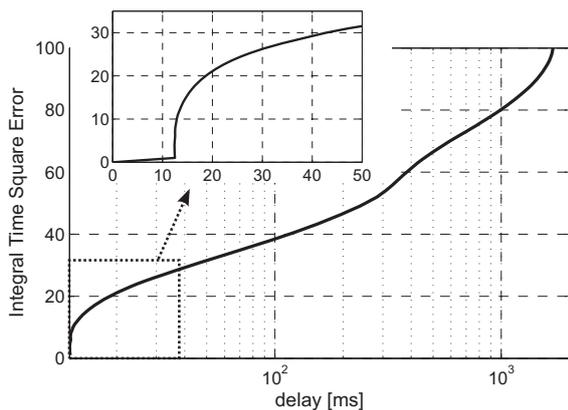


Fig. 6. Effect of propagation delay on the quality of control
 Rys. 6. Wpływ opóźnienia sygnału na wartość wskaźnika jakości sterowania

3.2. Control system via Internet

The network delays in the distributed control system can be either determined or random. The delay variation between a host A in Kraków (Poland) and a host B in Raleigh (USA) is shown in Fig. 7. The Network time delay histogram is presented in Fig. 8. As can be seen, a minimal signal propagation time between locations is 138 ms.

To evaluate the feasibility of the Internet medium for distributed control purposes, a dedicated client/server Java program was written. The server side (host B) emulates the discrete-time dynamic system (10). The client side (host A) connects to the server using the 6780 TCP port, receives the process value and transmits the control signal. If the signal propagation time exceeds the sampling time limit ($\tau \geq T_0$), the packet is rejected and the actuator uses the last valid control value. Real time clocks on the host A and the host B have been synchronized by the

Network Time Protocol (NTP). Fig. 9 shows the evolution of the process value, obtained with a MATLAB/Simulink simulation and with a real-network experiment. As can be seen, the time-delay equals around 150 ms. There is a good degree of accuracy between the simulation and real-network

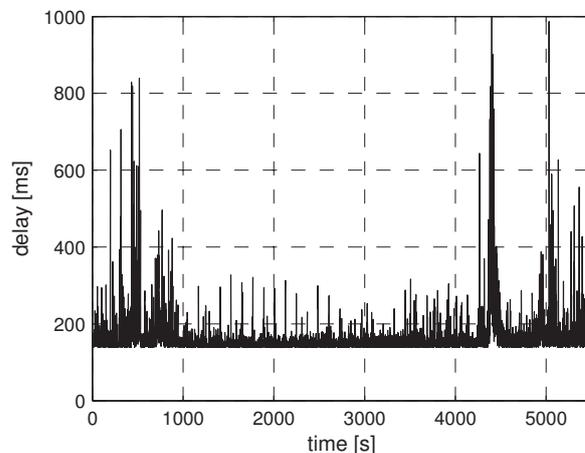


Fig. 7. The evolution of the network delay between a host A in Kraków and a host B in Raleigh
 Rys. 7. Zmiana opóźnienia sieciowego połączenia pomiędzy serwerami w Krakowie i Raleigh

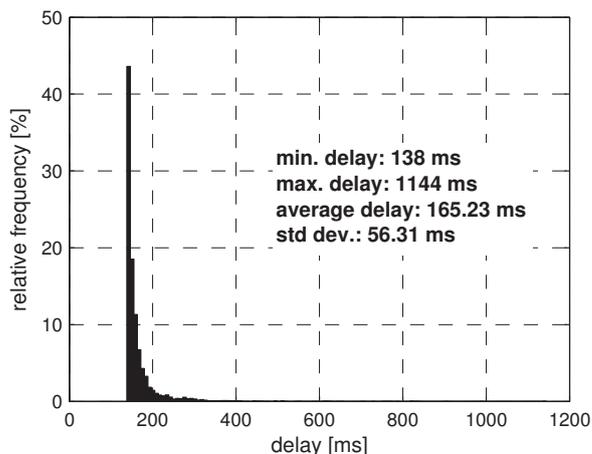


Fig. 8. The histogram of the network delay
 Rys. 8. Histogram opóźnienia sieciowego

experiment results. Some of the packets have been rejected due to too long propagation time (7.3 %). However the impact of network gives weak effect, due to the relation between average delay time and model dynamics.

4. Conclusions

In the following paper it was shown that control system for a gradually changing, structurally stable process can be distributed over a very long distance. Analysis was conducted, based on simulation results and real-world experiments. The study leads to the conclusion that Internet can be used as a medium for transmission of control and process signals. The application of the TCP protocol reduces the chance of a packet loss while it increases slightly the closed-loop delay.

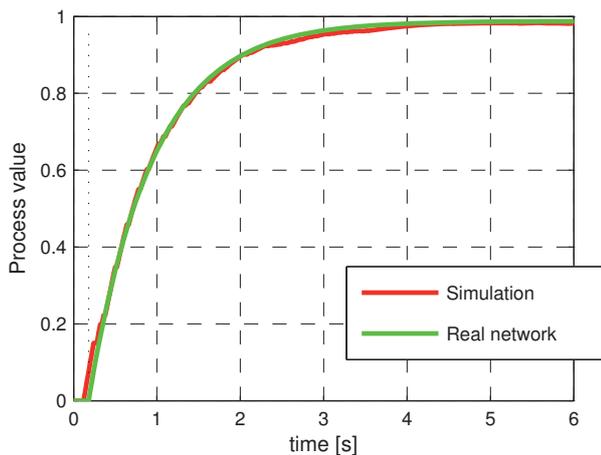


Fig. 9. The simulation and the real network results for the distributed control system

Rys. 9. Wyniki symulacyjne oraz wyniki eksperymentu sieciowego dla systemu sterowania rozproszonego

Bibliography

1. Hasan M. S., Harding C., Yu H., Griffiths A., *Modeling Delay and Packet Drop in Networked Control Systems Using Network Simulator NS2*, International Journal of Automation and Computing, vol. 2, 187–194, 2005.
2. Han K-H., Kim S., Kim Y.-J., Kim J.-H., *Implementation of Internet-Based Personal Robot with Internet Control Architecture* Proceedings of the 2001 IEEE International Conference on Robotics & Automation, 217–222, 2001.
3. Mastellone S., Abdallah C. T., *Networked Control Systems and Communication networks: Integrated Model and Stability Analysis*, Proceedings of the 16th IFAC World Congress, 2005.
4. Grega W., *Metody i algorytmy sterowania cyfrowego w układach scentralizowanych i rozproszonych*, Wydawnictwa Naukowo-Dydaktyczne AGH, 2004.
5. Grega W., Rosół M., *Distributed Control Using GPRS Wireless Network*, 11th IEEE International Conference on Methods and Models in Automation and Robotics, 2005.
6. Fei T., Hong W. C., *Modeling and Real Time Control of Internet-Distributed Control System*, 28th Annual Conference of the IEEE Industrial Electronics Society, 2002.
7. Samaranyake L., *Distributed Control of Electric Drives via Ethernet*, PhD dissertation, Royal Institute of Technology Stockholm, 2003.

8. RFC 768 – *User Datagram Protocol*, J. Postel, 1980.
9. RFC 675 – *Specification of Internet Transmission Control Program*, V. Cerf et al., 1974.
10. RFC 1122 – *Requirements for Internet Hosts – Communication Layers*, R. Braden, 1989. ■

Aspekty sterowania rozproszonego i analiza możliwości sterowania odległymi systemami poprzez Internet

Streszczenie: Gwałtowny rozwój rozproszonych systemów sterowania spowodował, że w procesie modelowania systemów dynamicznych oraz syntezy regulatorów konieczna okazuje się wiedza i zrozumienie działania sieci przesyłu danych. Wiele badań zostało poświęconych określeniu przydatności dedykowanych sieci umożliwiających przesył danych w układach sterowania. Niniejsza praca stanowi próbę przybliżenia problemu sterowania odległymi systemami poprzez Internet. Praca zawiera próbę zamodelowania właściwości sieci transmisyjnej i przeprowadzenia symulacji z uwzględnieniem opóźnienia wprowadzonego przez sieć. Ponadto został przeprowadzony eksperyment na rzeczywistej sieci, mający na celu określenie przydatności sieci Internet w systemach sterowania rozproszonego.

Słowa kluczowe: sterowanie rozproszone, sterowanie poprzez Internet, rozszerzona przestrzeń stanu

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