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Investigation of the Network Delay on Profibus-DP Based Network

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Introduction

The network based control systems have been developing continuously and their usage area increases in different fields. Especially, the usage of network control systems (NCS) increases quickly in the real time applications. The knowledges (reference input, system output, control input, etc.) are defined and the knowledge of the components (sensors, controllers, actuators, etc.) of control-induced system is changed or evaluated by using this network. One of the important problems of NCS is the delay of data transmission (sensor-controller, controller-actuator) between the units of NCS. This delay causes some data packages be spoiled or completely get lost. That is, the signals are weakened [1, 2]. The network – induced delay appears from two main parts as sensor-controller and controller-actuator. The control systems constructed without considering this delay have a low performance and reliability [3, 4]. Some suggestions are introduced on the network delays and the compensation methods in investigations [5-8].

But since specific properties (such as, to measure the values of components, being not possible in general and changing the components of the system with time) of NCS, these suggestions for the solutions are not sufficient. The network induced delay effects negatively on the stability of the system. That is another problem we must face. In this work, the mathematical model of the Profibus-DP based network system designed is obtained. The main concept of this work is the structure of the network. Especially the relation between the speed of data carried and network delay is examined. So the degree of the optimization for the system is exposed.

Network induced delay control systems (NDCS)

The network delay model of network induced system is seen in Fig. 1. Here τ_{ad} is the delay between the sensor-to-controller and τ_{di} is the delay between controller and actuator. By considering this design the generalized mathematical model of NDCS can be constructed. When we build this model we divide the NDCS into three parts as the controlled system (the Plant), the controller system (the Controller) and the network system which bounds these first two parts. That makes easier the system analysis [9]. The delay in the system can be divided in the following two groups [10].

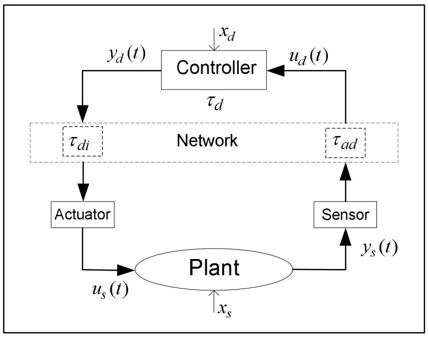

Fig. 1. The block diagram of network-induced delay

There is a network between the controller and the components of the area. This construction causes a delay between these two parts. The method of transmission and queue of the network paths are shown in Fig. 2. The most important factor in the environment of the network which effects the velocity of data transmission so the time, spent in the network, is the data used in transmission technology.

$$T_{as} = T_{af} + T_{ay} , \tag{1}$$

here T_{as} – the transmission time in the network medium, T_{ay} – the propagation time in the network medium, T_{af} – the structuring message time in the network medium. The size of the message, the data density and the distance between two points (the length of transmission line) are the main subjects of determining the duration of the time.

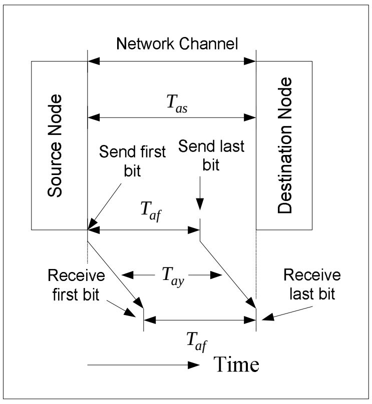

Fig 2. The time analysis in the network medium

The mathematical model

In the NCS by taking attention to the network delay and data transmission analyses the design of the mathematical model can be set up for the region, the controller and the network control system, respectively as follows [11].

The plant,

$$\dot{x}_s(t) = A_s x_s(t) + B_s u_s(t), \tag{2}$$

$$y_s(t) = C_s x_s(t). \tag{3}$$

Where, A_s, B_s *and* C_s are the convenient matrices of the parameters which effect the plant of the system.

Controller,

$$\dot{x}_d(t) = A_d x_d(t) + B_d u_d(t), \tag{4}$$

$$y_d(t) = C_d x_d(t-\tau_d) + D_d u_d(t-\tau_d). \tag{5}$$

The following equalities can be written by paying attention the network delays of τ_{ad}, τ_{di} .

$$\begin{aligned} u_d(t) &= y_s(t-\tau_{ad}), \\ u_s(t) &= y_d(t-\tau_{di}). \end{aligned} \tag{6}$$

The network controller system, the region and the controller satisfy the following inequalities:

$$\begin{cases} 0 \le \tau_1 = \tau_{ad} \le \tau_{ad,\max} = \tau_{1,\max}, \\ 0 \le \tau_2 = \tau_{ad} + \tau_d \le \tau_{ad,\max} + \tau_{d,\max} = \tau_{2,\max}, \\ 0 \le \tau_3 = \tau_{di} + \tau_d \le \tau_{di,\max} + \tau_{d,\max} = \tau_{3,\max}. \end{cases} \tag{7}$$

In addition,

$$\dot{x}(t) = \begin{bmatrix} \dot{x}_s(t) \\ \dot{x}_d(t) \end{bmatrix} = \begin{bmatrix} A_s x_s(t) \\ A_d x_d(t) \end{bmatrix} + \begin{bmatrix} B_s u_s(t) \\ B_d u_d(t) \end{bmatrix} =$$

$$= \begin{bmatrix} A_s \\ A_d \end{bmatrix} x(t) + \begin{bmatrix} B_s \\ B_d \end{bmatrix} u(t) =$$

$$= \begin{bmatrix} A_s & 0 \\ 0 & A_d \end{bmatrix} \begin{bmatrix} x_s(t) \\ x_d(t) \end{bmatrix} + \begin{bmatrix} B_s & 0 \\ 0 & B_d \end{bmatrix} \begin{bmatrix} u_s(t) \\ u_d(t) \end{bmatrix}. \tag{8}$$

On the right hand side the second term can be rewritten considering the delays by using (6):

$$\begin{bmatrix} B_s & 0 \\ 0 & B_d \end{bmatrix} \begin{bmatrix} u_s(t) \\ u_d(t) \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ B_s C_s & 0 \end{bmatrix} \begin{bmatrix} x_s(t-\tau_1) \\ x_d(t-\tau_1) \end{bmatrix} +$$

$$+ \begin{bmatrix} B_s D_d C_s & 0 \\ 0 & 0 \end{bmatrix} x_s(t-\tau_2) + \begin{bmatrix} 0 & B_s C_s \\ 0 & 0 \end{bmatrix} x_s(t-\tau_3). \tag{9}$$

Furthermore, with $A = \begin{bmatrix} A_s & 0 \\ 0 & A_d \end{bmatrix}$, $A_1 = \begin{bmatrix} 0 & 0 \\ B_s C_s & 0 \end{bmatrix}$, $A_2 = \begin{bmatrix} B_s D_d C_s & 0 \\ 0 & 0 \end{bmatrix}$, $A_3 = \begin{bmatrix} 0 & B_s C_s \\ 0 & 0 \end{bmatrix}$ the system can be written as

$$\dot{x}(t) = Ax(t) + A_1 x(t-\tau_1) + A_2 x(t-\tau_2) + A_3 x(t-\tau_3), \tag{10}$$

$$y(t) = \begin{bmatrix} C_s & 0 \end{bmatrix} x(t). \tag{11}$$

Here, the equalities,

$$x(t) = \begin{bmatrix} x_s(t) & x_d(t) \end{bmatrix}^T \tag{12}$$

can be seen easily.

Analysis

In this work a network-based system is designed by using the architecture DP of the Profibus network protocol. In the designed system the network delay is performed with low level. This result can be explained as advantage of the architecture Profibus-DP of the other network protocol (Fig. 3) [12, 13].

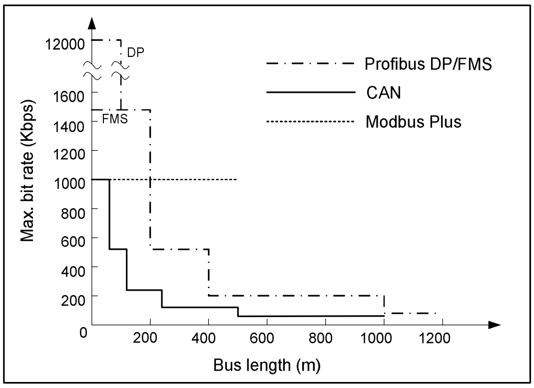

Fig. 3. Comparising of network protocols

The block diagram of Profibus-DP based network control system is given in the following Fig. 4. As it can be seen in this figure that data communication performed via Profibus-DP network backbone.

In Fig. 5, the network-induced delay of 7.724 ms is the elapsed time of the transfer of the signal from a network tied module to CPU and transmission to another module after being processed till the operation done there. The values of network-induced delay involve detector-controller delay (τ_{ad}) and controller-processor delay (τ_{di}). Therefore these values show the network-induced delay for twice.

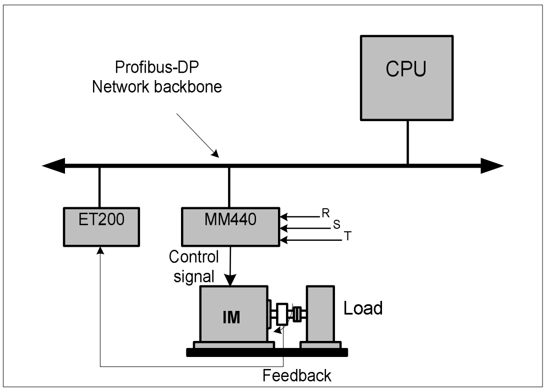

Fig. 4. The block diagram of the designed control system

Network backbone is used for either detector or processor thus, network-induce delay is assumed approximately the same for both. And so, as you see in Fig. 5, network-induce delay comes out as (7.724/2).

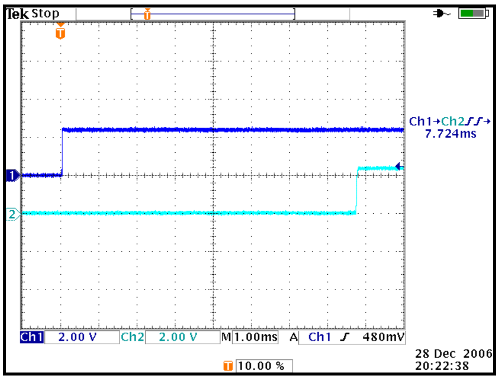

Fig. 5. Network-induced delay ($\tau_{ad} + \tau_{di} = 7.724$ ms)

In Fig. 6 and Fig. 7 network-induce delays occur in network medium which has a different data traffic are given.

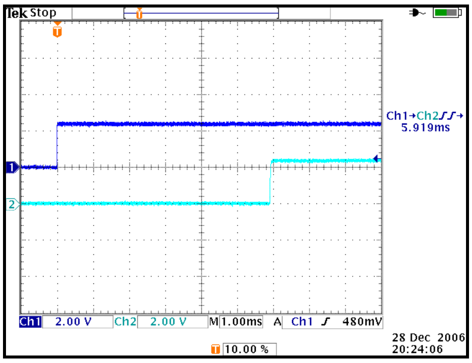

Fig. 6. Network-induced delay ($\tau_{ad} + \tau_{di} = 5.919$ ms)

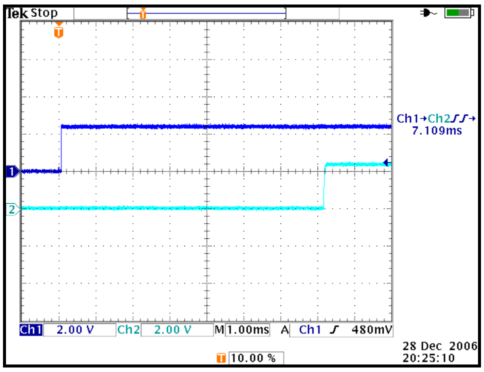

Fig. 7. Network-induced delay ($\tau_{ad} + \tau_{di} = 7.109$ ms)

In Fig. 8 you can see two individual output traffics which are controlled by a single control signal. The time lag between the outputs that is controlled by control signal is 6,669 ms and this delay ($\tau_{ad} + \tau_{di}$) contains two network-induce delays. It is supposed that the outputs obtained in Fig. 7 occur at the same time but when the output signals are magnified in the diagram, the delays between two outputs can be seen in degree of “µs” or “ns” and this delay is the data handling time of the module where the output signals are obtained. Therefore we can say that even it is on a small scale, each hardware in the network inevitably add additional period on network delay.

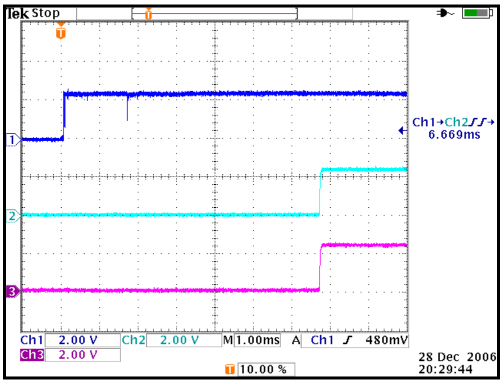

Fig. 8. Network-induced delay ($\tau_{ad} + \tau_{di} = 6.669$ ms)

Process time of two different concurrently sent control signals for the same module and the delay between two outputs can be seen between Fig. 9 and Fig. 10.

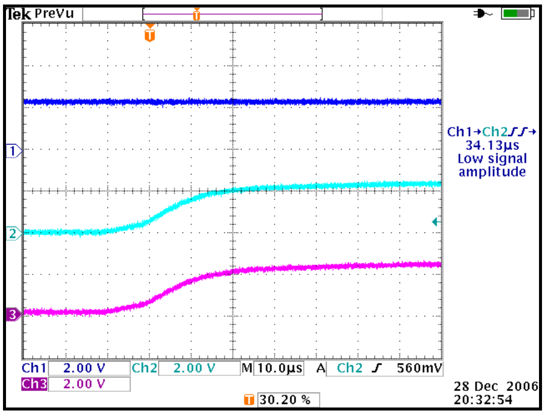

Fig. 9. The delay between two outputs in the same module (34.13 µs)

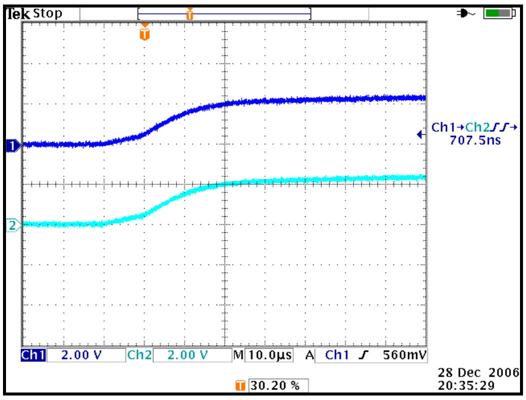

Fig. 10. The delay between two outputs in the same module (707.5 ns)

Conclusions

In the mathematical module of NDCS, the most important problems are network length, network traffic and ‘network-induce delay’ varies depending on hardware properties. Network protocol that is used in network based automation systems and has a substantial effect, persistently can not cover the requirements of stabilized working environments and depends on too many variables thus, entails difficulties of formation of the mathematical model. It affects many features from network speed to performance. Profibus-DP network structure that is used in the design made a substantial effect in minimization of network delay by means of its high data transfer speed. On the contrary, experimental analysis of the designs states that the network delay does not stand firm. This circumstance affects system performance in a negative way.

Experimental analysis of Profibus-DP based network control systems prove that network delay, data processing time of modules, evaluation of data by processor and formation of control signals varies as a consequent of the network structure. And so, the performance of the prediction systems is influenced adversely. Furthermore, it is a significant factor for the determination of control methods of the designed systems.

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The mathematical model of the network-induced delay control systems (NDCS) is given. Also the role of the NDCS’s components such as controller, sensor and network environment on the network-induced delay are included in the mathematical model of the system. The network delay is investigated on Profibus-DP based network application and experimental results obtained are presented graphically. The experimental results obtained show that the network induced delay is randomly changed according to the network protocol of the network induced delay and other devices (controller, sensor and actuators). Ill. 10, bibl. 13 (in English; summaries in English, Russian and Lithuanian).

Ц. Илмаз, О. Гиурдал, Г. Г. Сайан. Анализ задержки в сети, основанной на «Profibus-DP» // Электроника и электротехника. – Каунас: Технология, 2008. – № 7(87). – С. 23–26.

Представляется математическая модель анализа сетей, в которой учитываются органы управления, преобразоватепи и окружающая среда. Найдено выражение, позволяющее определить величину задержки сети. Экспериментальные результаты получены на основе применения «Profibus-DP» и представлены в виде графиков. Ил. 10, библ. 13 (на английском языке; рефераты на английском, русском и литовском яз.).

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Pateiktas matematinis tinklo sukelto vėlinimo kontrolės sistemų (TVKS) modelis. Matematiniame sistemos modelyje atsižvelgta į TVKS komponentų, tokių kaip valdiklis, jutiklis ir tinklo aplinka, įtaką tinklo vėlinimui. Vėlinimas tiriamas „Profibus-DP“ pagrindu veikiančiame tinkle, gauti eksperimentiniai rezultatai vaizduojami grafiškai. Il. 10, bibl. 13 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).