Petri Nets Applied for Modelling of Network Control System

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Abstract: This paper deals with Network control systems. There is presented problem of time delays in the network. Time delays, constant or even random can destabilize the system. Initialisations of individual elements influence on quality of regulation. Paper describes advantages and disadvantages of different initialisations and there are represented simulation results of with D-initialisation.

Keywords: Network control system, NCS, time delay, Coloured Petri nets, Initialisation

1 Introduction

Nowadays, analogue connections of elements in control systems are replaceable by communication network. Connecting sensors, controllers and actuators by control network allow us to use certificated components from information network. Control systems where sensors, controllers, actuators and other elements communicate by network are called network control systems (NCS).On the other side, the implementation of the network into control systems induce new problem as communication constrains, dependability of control quality on the network faults, asynchronous timing of elements [2].

This paper is organized as follows. First, in section 2, a brief review of the time delay in control systems are given. In section 3, there are describes Coloured Petri Nets (CPN) and *Design/CPN as* tool for modelling by CPN. A section 4 and 5 deals with initialisations of individual elements in NCS and there are presented result of simulation. The conclusion is presented in section 6.

2 Times Delays in Network Control Systems

Using network in NCS that is main reasons of time delays in control systems. These time delays can not only degrade performance of control system designed without considering of delays but also even destabilize the overall system [4]. For improvement quality properties of NCS there can be used intelligence sensors and actuator susceptible computation capabilities, ability to send and process timestamps and communication interface.

2.1 Reasons of Time Delays in NCS

Present control systems are still larger, so there is necessary to use communication networks to transfer messages between elemets. NCS are composite by many different elements, which cause different types of delay. Reason of time delays can be divided into four groups[1]:

- Delays caused by activity of individual NCS elements τ_A. There are delays related with activity of element as compute time of controllers, signal conversion in sensors and actuator and etc.
- Delays caused by asynchronism of clocks in NCS elements τ_B. Every element has a different internal clock influence of time delay in NCS.
- Network induced delays caused by MAC mechanism of communication media and parameters of network τ_C. Parameters of network are network protocol, time of data transfer, size of packet and etc.
- Delays caused by unpredictable network faults τ_D.

Total time delay in NCS is addition these four delays:

$$\tau_{TOTAL} = \tau_A + \tau_B + \tau_C + \tau_D \qquad (1)$$

For next we will concentrate on network induced delays.

2.2 Network Induced Delay

The character of network induces time delays that depend on the network protocol but also on a real implementation of NCS into real environment. This implementation brings other practical reasons for a NCS analysis.

Transfer of message between sensor and controller caused delays τ_k^{sc},which has a different characteristic than delay between the controller and the actuator τ_k^{ca}. Delay τ_k^{sc} is known in every discrete step *k*. This delay can be included to computing control signals by means of compensate τ_k^{sc}. Delay τ_k^{ca} from controller to actuator is known in the step *(k+1)* and can by compensate in the next step. Scheme of simple NCS is shown on Fig. 1 [4].

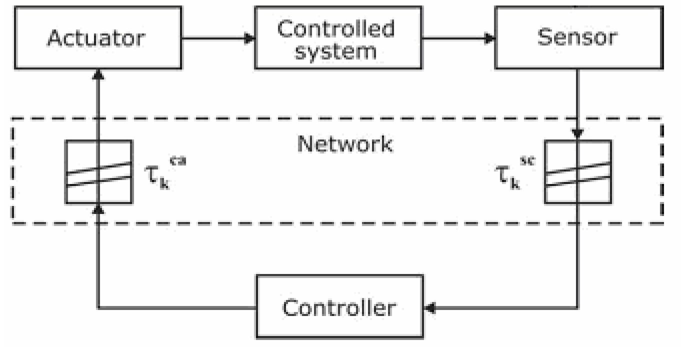

Figure 1
Scheme of NCS with network induced delays τ_{sc} and τ_{ca}.

In regard to delay duration, delays are divided into the following two groups:

- delays less or equal to sampling period $\tau <= T_s$
- delays greater than sampling period $\tau > T_s$,

where T_s is sampling period of the controlled system and τ represents network delay.

3 Modelling of NCS by Coloured Petri Nets

For analysis of NCS we must to handle modelling of simple NCS elements. Modelling of NCS requires tool, which provides modelling dynamic behaviour of systems, concurrency, assynchronism, creates hierarchic structure etc. Coloured Petri nets are fulfil these requiremets.

3.1 Coloured Petri Nets

CPN have much more modelling power and have better structuring facilities as types and modules. CPN are hierarchical because they contain facilities for representing a model as a hierarchical structure. CPN use basic data types that can be used for building composite data types.

Coloured Petri net is defined as a tuple [6]:

CPN=(Σ, P, T, A, N, C, G, E, I)

where

Σ is a finite set of non – empty types,

P is a finite set of places

T is a finite set of transitions

A is a finite set of arcs such as:

$P \cap T = P \cap A = T \cap A = \varnothing$

N is a node function. It is defined from A into $PxT \cup TxP$

C is a colour function. It is defined as $C{:}P \rightarrow \Sigma$

G is a guard function. It is defined from T into expressions such as:

$\forall t \in T : [Type(G(t)) = Bool \wedge Type(Var(G(t))) \subseteq \Sigma]$

E is an arc expression function. It is defined from A into expression such as:

$\forall a \in A : [Type(E(a)) = C(p(a))_{MS} \wedge Type(Var(G(t)) \subseteq \Sigma]$

where *p(a)* is a place of *N(a)*.

I is an initialisation function. It is defined from P into closed expression such as:

$\forall p \in P : [Type(I(p)) = C(p)_{MS}]$.

3.2 Design/CPN Software Tool

Design/CPN is an interactive computer tool for modeling and simulation by CPN. Design/CPN allows using of integer colorsets, list structures, probabilistic arcs, hierarchical composition, multi-color sets, generating of graph, etc.

- Design/CPN provides:
- An editor for creating and manipulating CPN
- Syntax checkers for validating CPN
- A simulator for executing CPN
- Interactive monitoring and debugging capabilities
- Animation and charging facilities for displaying simulation results
- Generating of OCC graphs – graphs of reachable state occurrence

These capabilities allow CPN models to be conveniently created, modified, organized, executed, debugged, examined and validated. Facilities for organizing a net into hierarchical modules are great advantage of Design/CPN [6].

4 Initialisation of Individual Elements of NCS

Initialisation of individual elements influence network traffic and namely influence NCS performance. The selection of initialisation is very important task of NCS design. Existing two basic initialisations of each NCS element connected to network are timing initialisation and event initialisation [3].

Timing initialisation is known, each element is initialises by internal clock. If elements use identical internal clocks, transfer of data by network time consumes, therefore total time delay is two sampling periods of elements of simple NCS. Next problem occurs with initialisation, when initialisations individual elements are time shifted and each element has different internal clock.

Reduction of time delay can be achieved by using event initialisation. In general, individual elements can be initialised by event as receiving of message over the network. This initialisation is knows as E-initialisation. E-initialisation is unsuitable for initialisation of sensor, because it has big effect to network traffic. For actuator and controller this initialisation is suitable, because E-initialisation occurs more optimal using of network.

Next case of event initialisation is D-initialisation element. D-initialisation activates element when change of measured variable is bigger as deadband. Deadband improves transfer possibilities of network unlike E-initialisation or T-initialisation. When the D-initialisation is applied in the actuator, it has not influence on network traffic[5]. Deadband in the actuator assure lower wear. Therefore D-initialisation is applied on output of controller, which affects using of actuator too. D-Initialisation of sensor reduces time delays on network. This initialisation influences on number of messages between sensor and controller, but influences number of messages between controller and actuator. In Table 1, there are combinations of initialisations, whose have effect to real applications of NCS.

Table 1 shows suitable initialisation on NCS

No.	Sensor	Delay	Control	Delay	Actuator
1.	T	τ^{sc}	T	τ^{ca}	T
2.	T	τ^{sc}	T	τ^{ca}	E
3.	T	τ^{sc}	E	τ^{ca}	T
4.	T	τ^{sc}	E	τ^{ca}	E
5.	T	τ^{sc}	D	τ^{ca}	T
6.	T	τ^{sc}	D	τ^{ca}	E
7.	D	τ^{sc}	T	τ^{ca}	T
8.	D	τ^{sc}	T	τ^{ca}	E
9.	D	τ^{sc}	E	τ^{ca}	T
10.	D	τ^{sc}	E	τ^{ca}	E
11.	D	τ^{sc}	D	τ^{ca}	T
12.	D	τ^{sc}	D	τ^{ca}	E

6 Simulation of NCS with D,T-initialisations

For evaluation of NCS behaviour There are considered parameters of regulation quality as [3]:

- T_{reg} - regulation time
- σ_{max} - maximum overshoot of controlled value, such that

$$\sigma_{max} = (y_{max} - y(\infty)) / y(\infty) * 100\% \qquad (2)$$

- T_d - deadtime at the beginning of step response characteristic caused by communication network.

For simulation was choosing cascade system of two connected tanks – control is level of water in second tank. Sensors, controllers and actuator are show on Fig. 2.

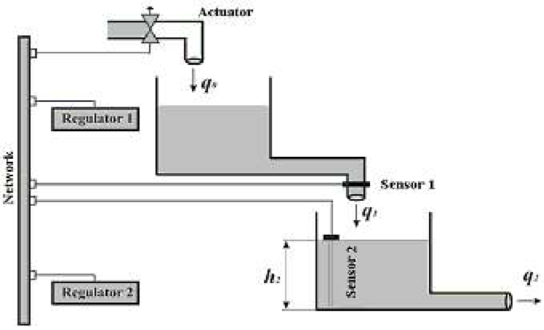

Figure 2
Scheme of cascade system of two realized by network.

The modelled system is described by discrete state space. Discrete state space of first tank is as equals for sampling period $T_S = 1s$.

$$\begin{aligned} x(k+1) &= 0{,}7624\,x(k) + 0{,}8759\,u(k) \\ y(k) &= 0{,}2712\,x(k) \end{aligned} \tag{3}$$

Second tank is described by discrete state space for $T_S = 1s$ too.

$$\begin{aligned} x_2(k+1) &= 0{,}6965x_2(k) + 0{,}8391y_1(k) \\ y_2(k) &= 1{,}3333x_2(k) \end{aligned} \tag{4}$$

The mentioned NCS was modelled with using of DesignCPN software tool. Similar sensors and actuator were modelled. Gain of sensors is 1 and in sensors there is implemented D-initialisation. Gain of actuator is 1 and these elements anyway influence of transfer data. Controllers are realised as P-controllers where constants P for both controllers are 0.5.

Network is realised as individual Petri net. Data transferred by network has form:

("source","destination",data),status,timestamp)

All these elements of NCS are hierarchy connected. Data between individual elements are transferred by input/output places. Fig. 3 shows the model of the second tank and code segment that represents state-space of the tank by Petri nets. Models in DesignCPN were compared with models realised in Matlab. Each simulation of the NCS was realized with just one D-initialised element, where other NCS elements were T-initialised. D-initialisation is used for sensor1, sensor2 and controller1, whose output is connecting on actuator. Delays 1s are between sensor1 and controler1, sensor2 and controler2 and delay between controler1 and actuator. Deadbands for elements were design within 0-10% of measured variables. Level of water in the second tank was regulated and quality of regulation was compared with regulation without delay.

In Table 2, there are compared simulation results of control of cascade system by network and classical control. Here are presented three cases of initialisation elements describe in Table 1. Using network for control decreases the quality of control as it is represented in Table 2. Delay induced by network is 0.1s. Fig. 4 and Fig. 5 show water level of second tank vith different initialisation.

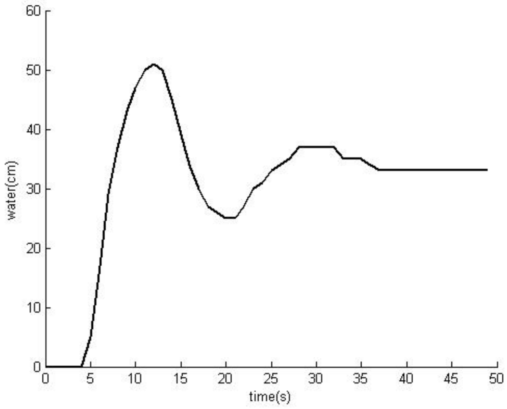

Figure 4
Level of second tank with initialisation case1.

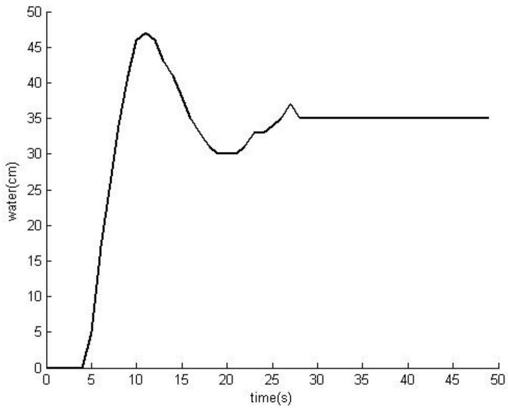

Figure 5
Level of second tank with initialisation case6.

Table 2 represent results obtained simulations. There are compared different initialisations. Next, there were evaluating parameters of regulation. Simulation cases have the same sampling, the same controlled system and the same controller.

Table 2 shows results of modelling

Initialisation	**Td [s]**	**T_{reg} [s]**	**σ_{max} [%]**
Classical	0	14	18,18
Case 1	3	37	38.24
Case 4	2	32	37.2
Case 6	2	28	34.2

Conclusions

Using network in NCS, it decrease quality of regulation. Number of network packet has big effect on quality of regulation. Deadbands in general decrease quality of control without network, but in NCS, where many nodes are connected to shared communication network can effectively reduce network congestion and continuously the improve control quality. Main influence on number of network packets has D-initialisation. D-initialisation together with E-initialisation improves quality of regulation by reduces delays. The biggest problem of D-initialisation is setting of deadbands. Simulations were realised for range deadband 0-10% of measured variable. In regard to quality of regulation, optimal setting of deadband is 5% from range of measured variable. From the simulation results the case initialisation is the most robust.

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