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# SET-UP AND STUDY OF A NETWORKED CONTROL SYSTEM

Anca-Mihaela Acreală[1], Vasile Comnac[1], Cristian Boldişor[1], Mihai Cernat[1], Robyn De Keyser[2]

[1]*Transilvania* University of Brasov, Faculty of Electrical Engineering and Computer Sciences

B-dul Eroilor 29, 500036 Brasov, Romania

{anca.acreala, comnac, cristian.boldisor, m.cernat}@unitbv.ro

[2]Ghent University, Department of Electrical Energy, Systems And Automation

Technologiepark Zwijnaarde 913, 9052 Zwijnaarde, Belgium, rdk@autoctrl.ugent.be

## Abstract

The technological progress and the continuous search of intelligent, low-cost and flexible control solutions lead today to the use of network communication in control systems. The performances of networked control are analyzed herein by considering a control system which performs the angular speed control of a Brushless DC motor using a PID controller. Ethernet technology is used for closed loop communication. Networked control system performances and communication issues are discussed. The results state the deficiencies brought by network communication in classical control strategies and therefore, the need of applying suitable methods which can properly cope with such challenges.

## 1. Introduction

Due to the technological progress the present control applications are increasingly richer in information. To handle this fact, recent solutions head to an intense interaction between communication, real-time and control systems implying distributed processing and high level logic. This new approach brings indisputable benefits: communication based on data packets, flexible and modular structure, simple and fast installation, considerable cost reduction, high-performance tools for diagnosis and maintenance.

Networked control systems (NCS) are suitable for various application fields such as: medicine, military applications, space exploration, industrial automation, process control in dangerous environments. The components of a NCS - control unit, process, actuators and sensors – communicate one with another by means of a network (Figure 1).

This communication assures the closed-loop control information flow. Network communication is done via data frames which encapsulate the control signal sent to the considered plant.

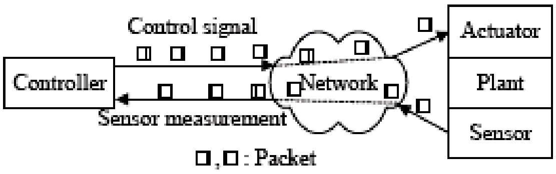


**Figure 1.** ***Direct structure of a NCS***

The system will respond by sending the sensor measurement to the controller [1], [2].

Each component of the NCS may act as a decision maker, making control as well as communication decisions.

The presence of a network brings constraints in the design of the control system, as information between the various decision makers must be exchanged according to the rules and dynamics of the network [3].

Aside the industrial network protocols (CAN, ProfiBus, ModBus), the general computer networks, Ethernet for example, became by their rapid progress major competitors for the control applications.

One major drawback regarding control performances is caused by the network specific variable time delays: the frame can arrive not necessarily in the same order, at variable times or possibly never [4].

Network delays can have several sources: system components waiting for network availability, the placement of the frame on the network, the propagation of the frame. Higher layer network protocols (TCP) may require retransmission if a packet contains an error. Therefore, when one or more packets are lost, the transmitter retransmits the lost packets. However, since a retransmitted packet usually has a long delay, the retransmitted control command packets are outdated by the time they arrive at the actuator [5]. This will lead to extended network delays which can severely affect the NCS [6].

The network delays might not have a significant effect over an open-loop system as for the cases which require feedback data across the network. In these applications the traditional control strategies which can deal with constant time delays might not be suitable.

## 2. Preconditions And Objectives

The network for the proposed NCS was selected by performing a multi-criteria analysis (*The synergetic fieldbus comparison chart*).

For this analysis, the selected possible solutions are the following protocols: Profibus, CAN, Ethernet and Modbus.

The considered criteria, in order of their priority are: network variable time delays, transmission speed, the costs of software implementation, monitoring and maintenance tools, the cost of hardware equipment, number of nodes per segment, maximum distance per segment, and difficulty of hardware installation.

The multi-criteria analysis concluded that one of the most convenient protocols, from the point of view of the considered criteria, is Ethernet. It assures a manageable network time delay, a very good transmission speed, very low costs, a multitude of network monitoring tools, moreover it is used worldwide and it is very easy to install.

The network collisions can cause non-controllable and variable time delays. These delays consist mainly from queuing delays and frame collision on the network. However, recent implementations of the Ethernet protocols reduce network collisions by adopting the prioritization of the messages.

Consequently, Ethernet was chosen to be further applied as a plausible NCS communication solution. Even if in this specific NCS the communication is strictly limited to the frames exchanged between the control unit and the process, network influences may definitely occur. The problems of variable time delays is depicted herein by analyzing the results of the proposed NCS.

## 3. Materials And Methods

The proposed NCS has the following components: a control unit (laptop), a motor drive board and a brushless DC motor (BLDC).

The closed loop information is exchanged between the control unit and the motor drive board via Ethernet. The motor drive is the interface that sends the commands to the actuator, gets the measurements from sensors and sends the feedback information (via Ethernet) to the controller.

A generic TCP packet-based protocol (TELNET) is utilized for communicating with the motor drive board. This provides a method to control the motor drive by exchanging closed-loop information, adjust its parameters (motor speed reference) and retrieve real-time performance data (Figure 2).

Basically, the communication gives the possibility of setting a speed reference, to monitor the current and the angular speed of the brushless DC motor.

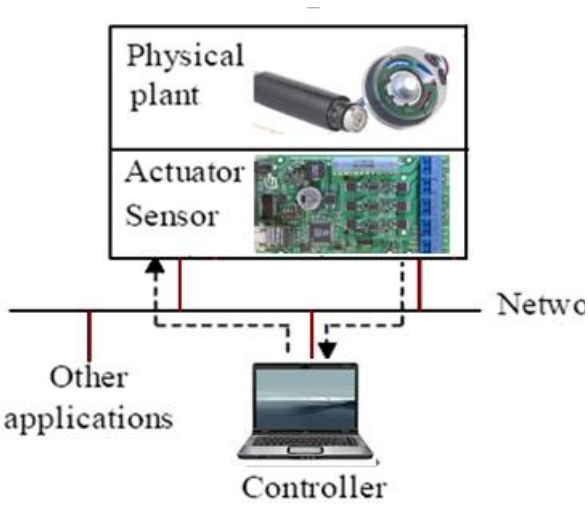


**Figure 2. Structure of the proposed control NCS**

In this particular case, the variable time delays can appear when sending the control signal (controller to actuator delay) or when sending back the system response (sensor to controller delay).

The control is performed by using a PI controller having the following values: $P = 131072$; $I = 1000$. The controller calculates the reference phase currents from the speed and torque requirements.

Once the communication is established between the control unit and the motor drive board, a real time communication flow analysis is required. To access and analyze the information flow between the control unit and the process during the real time control, a network monitoring tool (Wireshark) has been used. This tool "spies" the network traffic and provides the possibility to analyze the communication frames exchanged between the components of the NCS.

There are many problems related to the network approach that may occur during a real time control attempt. For example, during a BLDC motor control session, one of the frames is described by the monitoring tool as being a "malformed packet". This means that, for some reason (network collisions in the communication exchange process) the integrity of the frame was compromised. Obviously, in these situations, corrupted frames are not conclusive (Figure 3).

In real time systems, particularly control systems, delays or dropped packets may have a catastrophic effect and may cause instability. This fact shows the necessity of using special control strategies which can not be destabilized by network events such as the ones stated above [7].

## 4. RESULTS AND DISCUSSIONS

A graphical interface is available in order to keep track of the real time information (angular speed, current, power).

For a reference of 3000 rpm, the real-time NCS (Figure 4) gives good performances: the motor reaches its speed target in 0.8 seconds, acceptable for applications which do not need an extremely fast reaction. However, the overshoot of almost 30% is unacceptable even for the most tolerant control systems.

In order to have a base for a valid comparison, the same system was simulated in MATLAB/ SIMULINK environment [8]. The simulated process, having the same control scheme and using the same PI controller gave much better results (see the Statistics box, Figure 5). The numerical real-time data (angular speed, see green plot) were obtained by using a network monitor.

Even if the simulation of the system is not the object of this paper, it gives a hint that the PI controller has good performances.

The performance differences between the real control system and the simulation come from measurement errors, mathematical processing differences and mostly from the network influences (Figure 5).

Variable time delays usually perturb the expected control information flow and make the process reaction slower or not appropriate by degrading the performances and destabilizing the system.

All these characteristics of Ethernet communication, the performance degradation, the destabilization, lead to the clear fact that variable delays or the lack of frames cause an unstable behaviour for the classical control strategies.

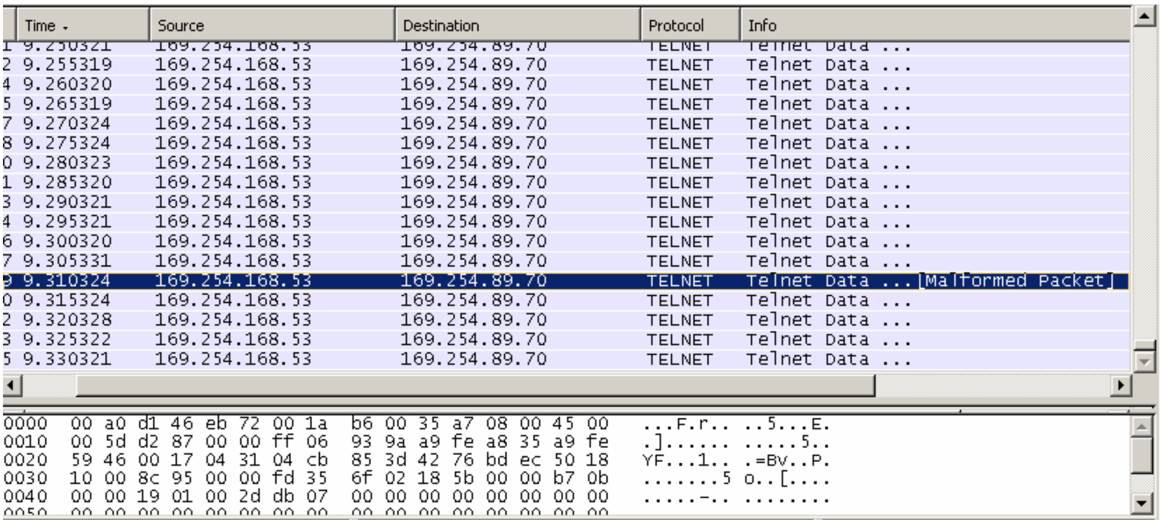


***Figure 3.*** **Wireshark capture: Malformed Packet**

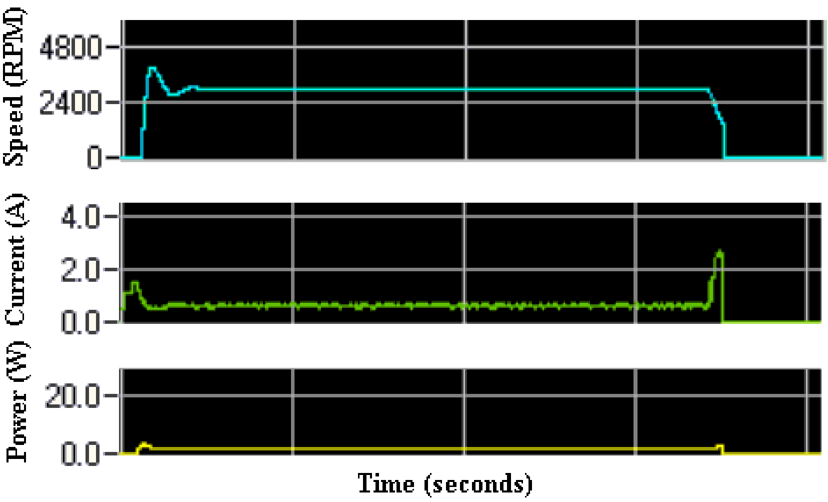


**Fig. 4. Real time NCS performances**

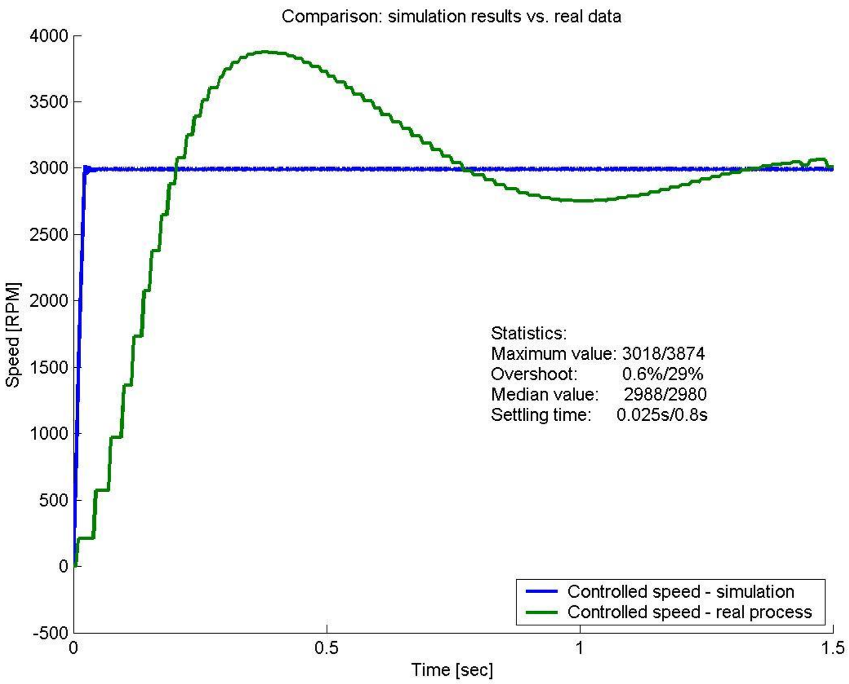


**Fig. 5. Performance comparison between the results of the NCS and the results of the MATLAB/Simulink simulation**

These performances have been obtained in a communication network in which the information change flow was not very loaded. This means that the network events (collisions, transmission delays) occurred rarely by comparison with a loaded, crowded network.

It can be concluded that these drawbacks imposed by network communication can be correctly coped-with only by using adaptable, predictable or even fuzzy-based control strategies which can robustly face these difficulties.

Other conceptual strategies are available, such as the playback buffering which will be considered in our future research.

The methodologies to control an NCS have to maintain the stability of the system in addition to controlling and maintaining the system performance as much as possible.

## 5. Conclusions

This paper treated a networked control problem, using a real-time control system in order to emphasize the occurring network difficulties.

Regardless of the structure or network used, the system performances of NCS will degrade due to the existence of network delays in the control loop. In the worst case of variable time delays, the NCS can be destabilized. These delays are hard to handle because there is no existing criterion to guarantee or assure the stability of a NCS.

Because of that, creating a network protocol-based application needs a lot of awareness regarding the feasibility and the reliability which can be provided by the selected control methodology. But all in all, the wide world spreading, the low cost solutions and the efforts to reduce frame collision make the Ethernet to be a valued solution in NCS research.

## 6. Acknowledgements

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