

Control Performance Analysis of a CAN – Based Networked Control System: Active Suspension Study Case

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ABSTRACT

In this paper a performance analysis of a Networked Control System (NCS) based in Controller Area Network (CAN) is presented. The analysis is done considering three variables of CAN: baud rate, priority of message and network load. These parameters directly affect the network delay and in consequence the feedback control performance. An active suspension model is considered and extensive experimental results have been performed to demonstrate the influence of these parameters in the quality of control performance. An experimental system which includes a pedagogic scale model with real car components was exploited.

INTRODUCTION

The great advances obtained over the last years in the embedded systems field and network technology have given place to a new research field named Networked Control Systems (NCS). This term refers to a new type of system in which sensors, processes, actuators and controllers are interconnected over a network or a shared medium, Figure 1. This implies that the network becomes an element of the feedback control loop and, due to their limitations, the classic problems of the control theory (e.g. performance, stability and robustness) must be reevaluated, [1].

Several advantages are achieved by including the network as a part of the feedback loop. The first one is the reduction of the volume of wiring due to the fact that there are no more point-to-point connections. The second advantage refers to getting fewer potential points

of failure, increasing the system reliability. Third, the possibility of distributed control, increased capability for troubleshooting and maintenance, enhanced interchangeability and interoperability of devices, and improved reconfigurability of control systems, [2].

NCS research can be divided in two topics: network protocols and digital controller design. First topic refers to the analysis of different network protocols, considering their Quality of Service (QoS), to determine whether a protocol is suitable or not to be used in a NCS. This analysis tries to find a protocol that guarantees correct message transmission as well as a minimum network time delay, to assure an acceptable control performance. Second topic is about the digital controller design considering the network effects on the feedback loop.

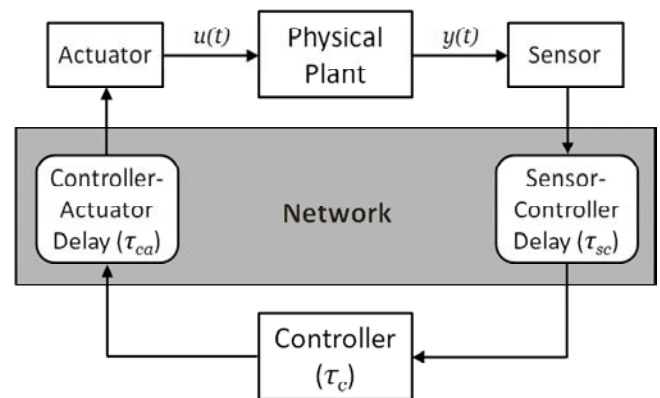


Figure 1. NCS with network-induced delays. τ_{sc} is the sensor to controller delay, τ_{ca} is the controller to actuator delay, and τ_c is the controller computational delay.

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Controller Area Network (CAN) is a network protocol proposed by Robert Bosch in the mid-80's to interconnect the different electronic control units (ECU) of automobiles. Its low cost, robustness and different mechanisms for error handling have made it so attractive. Today, it is the most used in the automotive industry and it can also be found in other areas such as manufacturing and biomedical devices, [3].

Even though there are motivating features in networked control systems; there are some drawbacks. The main contribution of this research is the development of an experimental platform for the implementation and evaluation of new generation of automotive control systems. Such experimental platform permits to evaluate the relevant parameters, which affect directly the communication delay, namely velocity of baud rate, network load and message priority. Interesting problems arise from the point of view of feedback control systems as stabilization, estimation and robustness.

STATE OF THE ART

A study of comparison among three of the most used protocols in industry is presented in [4]. The authors made an analysis, in two simulation cases and various conditions, of the network efficiency and time-delay of transmission of each of the protocols: Ethernet, DeviceNet (which is based in CAN) and ControlNet. This research concludes with the network conditions for which each protocol guarantees an acceptable QoS to be used in an NCS. Also, it presents a complete analysis of each component of the time-delay of transmission.

An analysis of the control performance of a PID in a NCS (based on Ethernet, DeviceNet and ControlNet) is made in [5]. A three-axis networked machining cell is controlled. To quantify the control performance, two criteria are used: the integral of time multiplied by absolute error and the integral of absolute error. An emphasis in the sampling rate selection is made and the simulation results present the trade-off between this selection and the network load.

Another analysis of the control performance of a PID in a NCS is made in [6]. A comparison is made for two protocols: Ethernet and Switched Ethernet. The process controlled is a servomotor and the study is only made varying the network load. The control performance of the PID is quantified with the overshoot and the time of stabilization in closed-loop. The best results achieved are those for switched ethernet due to its high determinism even for high network loads.

A study of performance of CAN in a city-bus application is presented in [7]. A model of the network protocol is made for its physical layer, transfer and object sub-layers according to the specification made in [8]. Ten ECU are simulated with different priorities of message,

an 8-byte length of data field and a 250 kbit/s baud rate. The performance of the protocol is quantified by three parameters: time-delay of transmission, network load and message retransmission. For the proposed conditions, the maximum time-delay found was 2.5 ms, which was marked in [7] as lower than the specified by SAE J1939, thus concluding that CAN is suitable for real-control time.

Different methods to reduce the jitter (i.e. variability of time-delay of transmission) in CAN have been presented, [9, 10]. In [9], a procedure based in reducing the stuffing bits was used, while in [10] it was proposed a method based in genetic algorithms. It has been stated [11] that the future in the network protocols analysis for NCS is based in looking for techniques that improve the QoS of the existing protocols, like [9] and [10].

CONTROLLER AREA NETWORK

Figure 1 shows the general structure of a NCS, where $y(t)$ and $u(t)$ are the output and input of the physical plant respectively. These signals are corrupt by noise and time delays because of transmission among the components of the control system. This time delay could be constant or time varying, determinist or stochastic, and affects negatively the control system performance. In the worst case, it could cause instability. Other problem is the possibility of loss of information or reception of erroneous data. This effect is common on those NCS implemented with a network protocol with a poor or null error detector system. The appearance of bottlenecks is another network effect very common on those situations with high network loads and an inadequate baud rate. This effect also exists when the computer elements (e.g. CPU, micro-controller) do not have the enough computational power to achieve the time and design requirements.

The magnitude of the effects described above depends on the QoS of the network protocol used. This parameter tells how well a network protocol does its work: transmitting information from one node to another. It depends mainly on two factors: speed and network bandwidth, and time-delay and jitter of transmission.

CAN is a network protocol developed by Bosch in the mid-80s with the initial purpose of interconnecting the different ECU among the automobiles. It is a serial broadcast protocol with the following characteristics: baud rate of up to 1 Mbit/s, message priority, guarantee of latency times, configuration flexibility, multicast reception with time synchronization, error detection system and automatic retransmission of erroneous messages.

One of the most important characteristics of CAN is its message routing. In this protocol, the message is named by an identifier. This does not indicate the address of the

destination but the meaning of the data. Thus, due to the broadcast characteristic, each node can utilize the information received whether its meaning is relevant to it or not.

CAN is a CSMA / CD + AMP protocol (i.e. carrier sense multiple access with collision detection and arbitration on the message priority). This means that each node must wait the bus to get idle to begin transmission and the collisions are solved by a method based on priority. This priority is in the message identifier and works like this: when two nodes are competing to use the bus, the dominant bits (i.e. in CAN those with a logic '0') prevailed over the recessive (i.e. in CAN those with a logic '1'); thus, when a node detects that has lost the arbitration, it stops transmitting and waits until the bus gets idle again. Based on this, the priority of the message decreases as the value of the identifier grows (i.e. those identifiers with low values have high priority).

The time-delay of transmission in a NCS based in CAN depends on several parameters, but the most important are: baud rate, message priority, and network load.

EXPERIMENTAL SET UP

The pedagogic scale model Full CAN X3 is a training aid unit with real components of the Peugeot 807, Figure 2. It is composed of twelve modules: Built – In System Interface (BSI), Built – In Supply Module (BSM), air conditioning, passenger door, driver door, front lights, back lights, dashboard, radio, AFIL (Lane Departure Warning System for the abbreviation in French), tow module and alarm. These modules are interconnected in three CAN networks: an intersystem network whose baud rate is 500 kbit/s, a chassis network, and a comfort one, both with a baud rate of 125 kbit/s, [7].

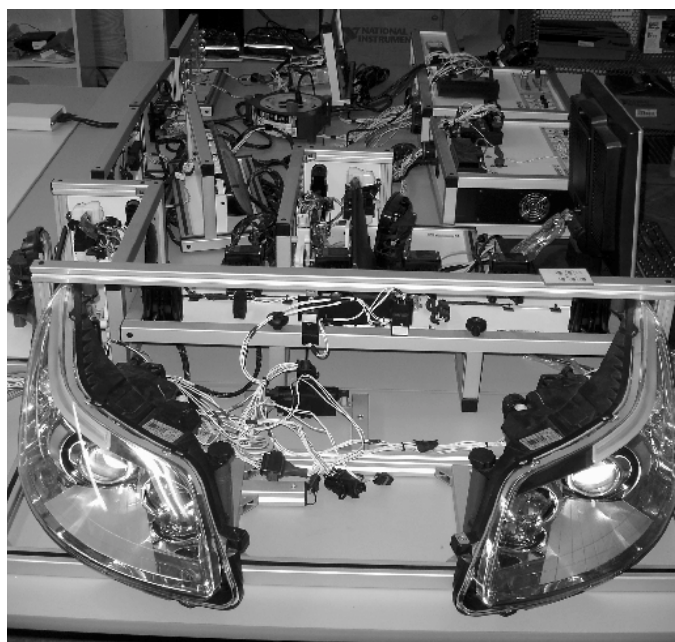


Figure 2. Frontal view of the Scale Model Full CAN X3.

The experimental application is shown in Figure 3. The process and the controller reside in different nodes and CAN is the used network protocol.

In order to evaluate the control performance at different conditions, the process and the controller are connected to a real network environment. (i.e. an automobile).

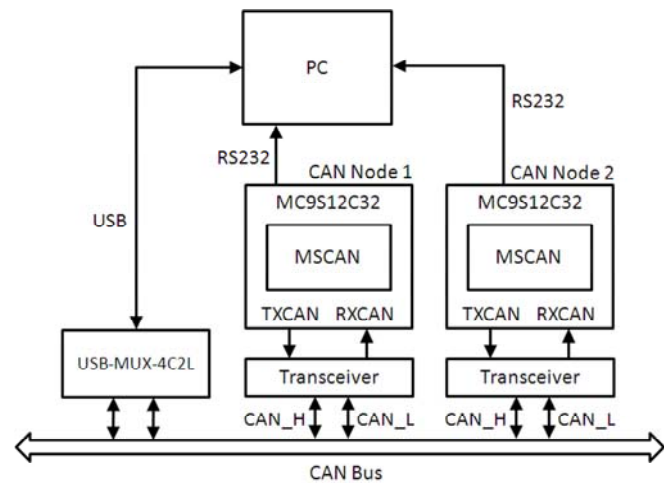


Figure 3. Data acquisition based on a PC, an EXXOTest[®] USB-MUX-4C2L module, and Freescale[™] semiconductor MC9S12C32 micro-controller. CAN_H and CAN_L are the two signal lines of the bus, and TXCAN and RXCAN are the transmission and reception lines, respectively.

Based on Figure 4, three CAN nodes were developed: process, controller and load generator. Each CAN node is composed of a PC and the USB MUX 4C2L. This one is a module that allows a PC to connect to a CAN bus. For each node a software application was developed according to its specific function.

Using the *process node*, the user can specify the system model based on a state space representation. Every sample time, this node sends the value of all the state variables. As input, this node receives the control signal from the controller node.

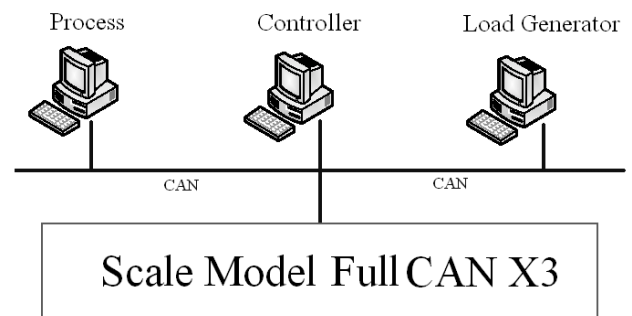


Figure 4. General structure of the experimental setup.