Systems Modelling and Identification in CAN based Distributed Control Systems

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Abstract: Distributed control systems performance can be affected by the occurrence of jitter in the messages that carry relevant data such as sample and actuation variables. This jitter comes from the influence of messages from other sources and thus depends on factors such as the distribution of controller tasks and the medium access control used in the network. When a CAN- controller area network is considered, this jitter can be modelled as a random variable with a gamma distribution. In this paper a study of the influence of this specific type of jitter in system identification with recursive implementation is presented. The results are derived in an adverse situation when both sampling and actuation data suffer from jitter. It is shown that using a model that assumes fractional dead-time in the system leads to a much better parameter identification than when the problem is just ignored.

Keywords: CAN Distributed Control Systems, Jitter, System Modelling, Identification

Fieldbus based distributed systems [1] find wide dissemination in embedded control applications, e.g. real-time systems for the automotive and robotics fields. When periodic control variables are transmitted an average transmission period can be obtained but there are variations in the period due to the MAC (medium access control). This network-induced jitter may have a negative impact in control loops [2]. [3] and [4] address the problem, this last one also concerning CAN – Controller Area Network [13]. [5] points the need to further research on this topic and [6] and [7] also look at it in general real-time systems.

In this paper the influence in system identification performance of a particular type of jitter induced by the specific MAC of CAN is discussed and some simulation results are presented. The problem is addressed from two angles: in one the messages carrying sensor/actuator data are considered the ones with higher priority; in the other load messages used to simulate charge in the fieldbus are given a higher priority than the previous ones.

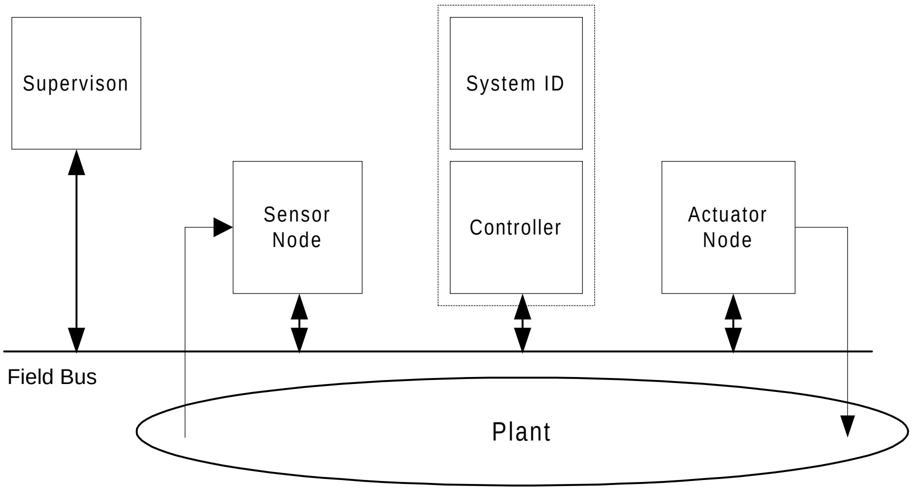

Figure 1 – Generic architecture of a distributed control system.

The occurrence of jitter depends on the architecture of the distributed control system. In figure 1 one example of the several control loops that may share the same communication infrastructure includes five blocks: the controller, the sensor, the actuator and the systems identification and the monitoring/supervision node which are optional.

The transmission of a periodic message carrying, e.g., sensor data acquired in specified instants with a constant sampling interval, may then be delayed by influence of a message being transmitted and of other messages waiting for the availability of the bus when these have higher priority from the MAC point of view. Figure 2 shows an example of the effect of unidentified messages in the one with sensor data.

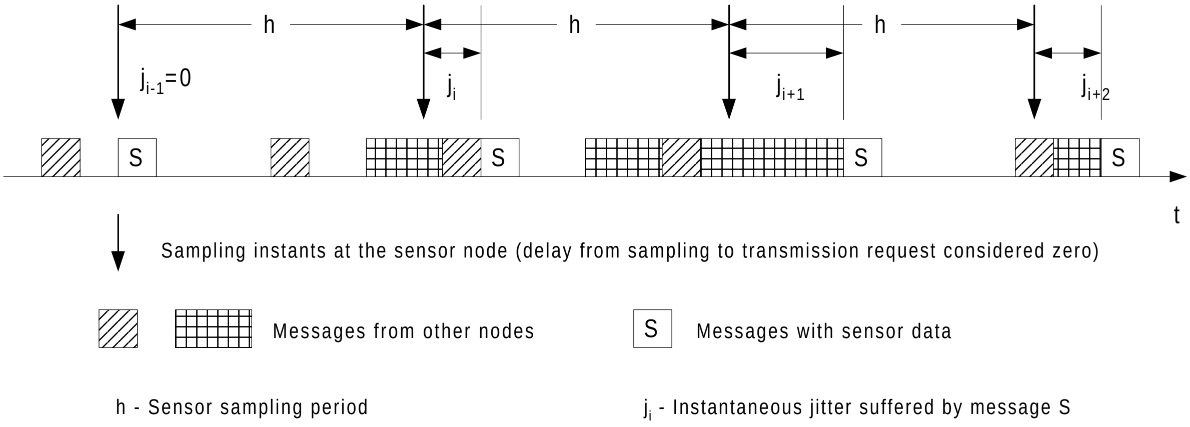

Figure 2 – Network-Induced jitter.

Factors such as the MAC, the priority of the messages, the message scheduling algorithm, initial phasing, affect the jitter value. In CAN it is possible to obtain a measure of the jitter from a suitable representation of the messages delay as a random variable. A set of experiments [8] consisting on sending the messages over a CAN network and measuring the messages delay with other messages acting as load (based on the PSA benchmark[9]) were done. Two different cases were considered, one with messages IDs higher than load messages IDs (load has then a higher priority) and other with messages having lower IDs. Figures 3 and 4 present examples of the histograms of message delays obtained experimentally. To these graphs, the p.d.f. of a Gamma r.v. with identical mean and variance were superposed.

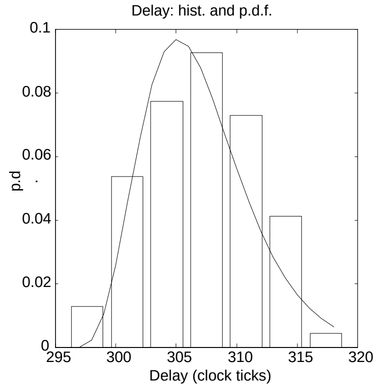

Figure 3 – Histogram and gamma p.d.f. (Load = 10%, low)

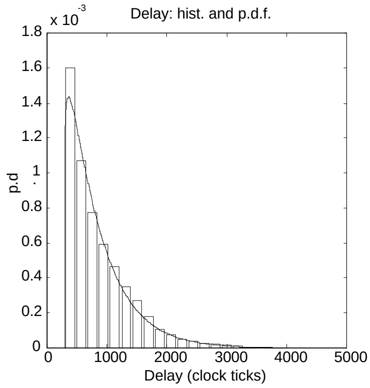

Figure 5 – Histogram and gamma p.d.f. (Load = 85%, high)

The experimental results show that, under very different working conditions, message delays in CAN can be represented by means of a Gamma distribution.

The effect of jitter can be viewed as a perturbation that introduces a variable delay in the reading of the samples and in the actuation signal sent to the plant. The existence of one or both of the situations depends on the distributed control system architecture (read-in and read-out jitter [3]).

In figure 6 a block diagram of a system with read-out jitter is presented. The discrete signal *u(k)* is the input of a Zero-order-Hold (ZOH) which generates the continuous signal *u(t)* which suffers a delay, τ, before it is output to the plant. This delay is a random variable and thus, jitter will be present in the $u(t-\tau)$ signal.

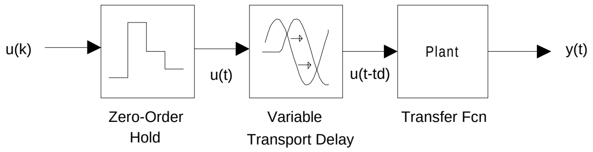

Figure 6 – Diagram of a system with read-out jitter.

Figure 7 now represents a block diagram of a system with read-in jitter.

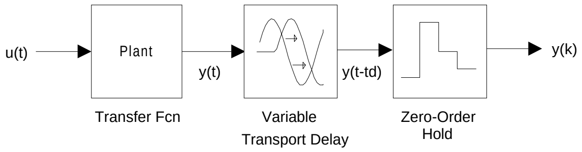

Figure 7 – Diagram of a system with read-in jitter.

Two situations can then be considered when one proceeds to the identification of a system with jitter. The first one is just ignoring it. The second is to try to take it in consideration in the system model. In this last case, a possible model for a SISO system could be:

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t-\tau)$$
$$y(t) = x(t)$$

where τ is the variable delay which can obviously be considered as a dead time. As in most distributed systems it is possible to bound this dead time and if this bound is the sampling period value ($h > \tau$), then the discrete model can be [10]:

$$y(kh+h) = \Phi y(kh) + \Gamma_0 u(kh) + \Gamma_1 u(kh-h)$$

where:

$$\Phi = e^{Ah}$$
$$\Gamma_0 = \int_0^{h-\tau} e^{As} ds B$$
$$\Gamma_1 = e^{A(h-\tau)} \int_0^{\tau} e^{As} ds B$$

The discrete transfer function is:

$$G(q) = \begin{bmatrix} 1 & 0 \end{bmatrix} (qI - \Phi)^{-1} \left(\Gamma_0 + \Gamma_1 q^{-1} \right)$$

This last equation represents the discrete model of a system with fractional dead time which has now a new zero that doesn't exist when τ is zero. It is also clear that Γ_0 and Γ_1 values are dependent on τ.

In order to study the validity of this model in CAN based distributed control systems, a simulation using four common control systems $\left(G(s)=\frac{1}{s+1},\frac{1}{s},\frac{1}{s^2}\text{ and }\frac{1}{s(s+1)}\right)$ was carried on. For each of them a recursive system identification procedure based on the least squares method with a fixed forgetting factor [11] was tested using either the simple model and the one with fractional dead-time. In the simulation the systems were affected by read-in and read-out jitter taken from the experiments described above.

Figures 8 and 9 show some results of the identification tests for those systems. There, it is shown the square residuals (estimation errors) average for the two type of models in function of the fieldbus load (from 5% to 95%). The ***** line corresponds to the more complex model (the one with fractional dead time) and the **o** line to the simple model.

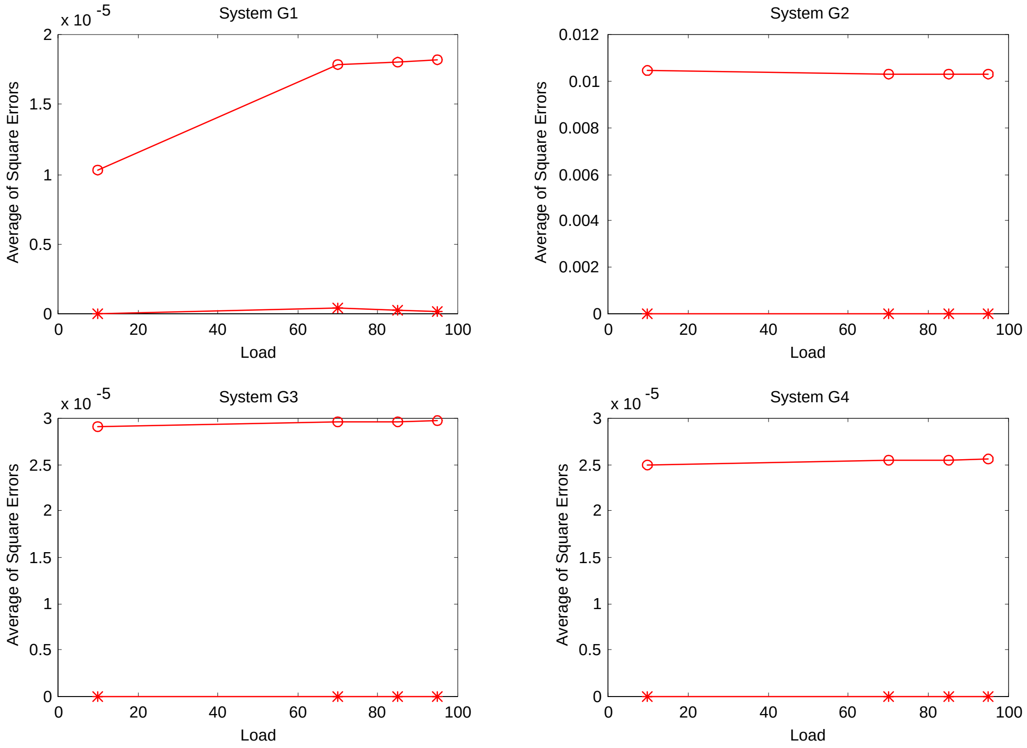

Figure 8 – Square Average of the Residuals versus the load (RLS-FF=0.98) – Low Address

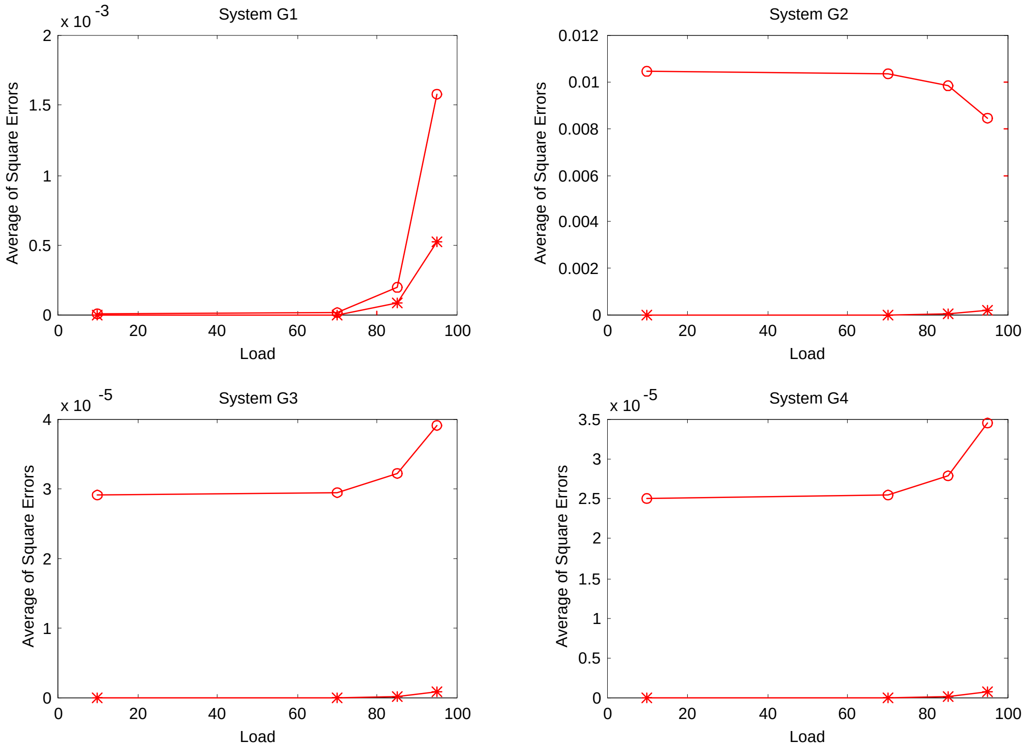

Figure 9 – Square Average of the Residuals versus the load (RLS-FF=0.98) – High Address

When jitter is not taken into account, the model identification is poor when compared with the one that considers it as a fractional dead time. Values range from an improvement of 2.3 times (G1 system with 85% load and low message priority) to an improvement of 7700 times (G2 system with 70% load and low message priority). Also, the more complex model shows in most situations some immunity to the influence of high transmission loads, independently of the priorities chosen for the relevant messages.

Some problems occurring from this work are still under investigation. One of them is the study of the influence of the forgetting factor in the identification performance under jitter conditions. Some specific techniques such as the directional forgetting factor [12] are also to be analysed in this situation. Also, it should be pointed that further work must be done in order to evaluate the impact of the identification improvement in the closed loop behaviour of, for example, adaptive controllers.

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