

An Experimental Result on System Identification over Networks using Delta-Sigma Transformation

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Abstract—In this paper, a method to system identification over networks using 1 bit delta-sigma transformation is proposed and the efficacy of the proposed method is verified based on experimental results. Accurate mathematical models are needed to achieve intelligent control with good performances in control engineering. It is easy to obtain those mathematical models if exact input-output data of a controlled object is available by applying system identification techniques. However it is difficult to obtain the exact input-output data over networks because the data is transformed from analog data into digital data. The proposed method provides a method to build mathematical models of controlled objects over networks.

Keywords-component; intelligent control; system identification, ARX models; computer networks;delta-sigma transformation

I. INTRODUCTION

Recently computer networks such as the Internet have spread quickly and widely. Some researches about control engineering have been focused on data transfers in computer networks and some congestion controllers have been proposed [1-3]. Congestion controllers play an important role in data transfers and the main role is to avoid congestion in the networks.

On the other hand, remote control problems are very interesting issues in control engineering and have discussed in many papers. In some researches, remote control problems are defined as Networked Control Systems (NCSs) [4][5]. In NCSs, dynamics of controlled objects are known exactly. But characteristics and performances of controlled objects are changing as time goes on. If the controlled objects have some failures, NCSs or remote control systems become unstable and unsafe. Thus it seems strongly required to estimate or observe dynamics of the controlled objects over networks.

In control engineering, system identification, which is one of black box modelings, is well known to build mathematical models of dynamical systems [6-10]. Some methods have been proposed as system identification techniques. In these methods, it is possible to build mathematical models of objects if input and output signals of objects are available. Thus system identification is very useful to build mathematical models of dynamical systems. But few researches have discussed about system identification concerning networks until now. We call this identification problem as system identification over networks.

In this paper, system identification over networks is considered. We try to establish a method to build mathematical models by using input and output data through networks. Our identification approach consists of modified delta-sigma transformation for quantization of data, decimation for cancellation of some noises and generation of special data for system identification.

This paper is organized as follows. In the section 2, an method to system identification over networks is proposed. In the section 3, developed experimental environment and experimental results are shown. Theoretical results are omitted and experimental results are mainly described

II. SYSTEM IDENTIFICATION USING 1 BIT DELTA SIGMA TRANSFORMATION

Here a procedure of system identification using 1 bit delta-sigma transformation is proposed. The proposed method consists of 1 bit delta sigma transformation with a feedback gain, decimation and system identification based on least squares method with ARX (Auto Regressive eXogeneous) models.

A. Delta-sigma transformation with a feedback gain

1 bit delta-sigma transformation is a method to transform continuous signals to 1 bit pulse signals. But usual 1 bit sigma-delta transformation has a problem. The problem is difficulty to deal with signals such that the maximum value of signals is more than 1. To overcome this problem, the following 1 bit sigma-delta transformation is proposed in this paper. The proposed 1 bit sigma-delta transformation is shown in Fig. 1.

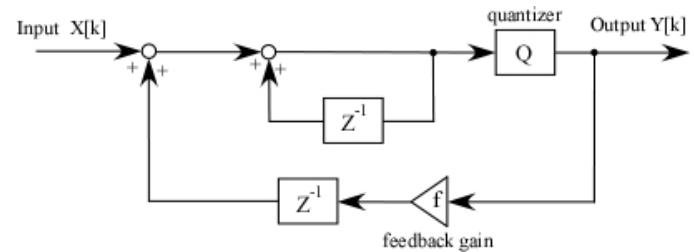


Figure 1. 1 bit delta-sigma transformation with a feedback.

In Fig. 1, an input signal is given as $X[k]$ at a step k and an output signal is given as $Y[k]$. z^{-1} denotes one delay operator.

f is a feedback gain. The input-output relationship of Fig. 1 is given by

$$Y[k] = X[k]f^{-1} + (1+Z^{-1})N_q[k],$$

where $N_q[k]$ is a quantization error at the step k . By using 1 bit delta-sigma transformation, the output signal is restricted as $-1 \leq Y[k] \leq 1$. Thus the following condition is satisfied.

$$-f \leq X[k] \leq f.$$

If $f > 1$, then the maximum value of input signal is more than 1.

B. An method to system identification over networks

Now a system identification method over networks is proposed based on the proposed delta-sigma transformation with a feedback gain. The procedure of the proposed method is shown in Fig. 2. Here we assume that input and output signals are available through networks.

In this proposed method, firstly input signals and output signals are obtained. We apply the following steps to input and output signals.

Step 1. Sampling: data sampling.

Step 2. 1 bit delta-sigma transformation with a feedback: quantization of data.

Step 3. Decimation: Cancelation of noises (quantization error).

Step 4. Gain f : Reconstruction of data.

Step 5. Input-Output data for system identification: Generation of data for system identification.

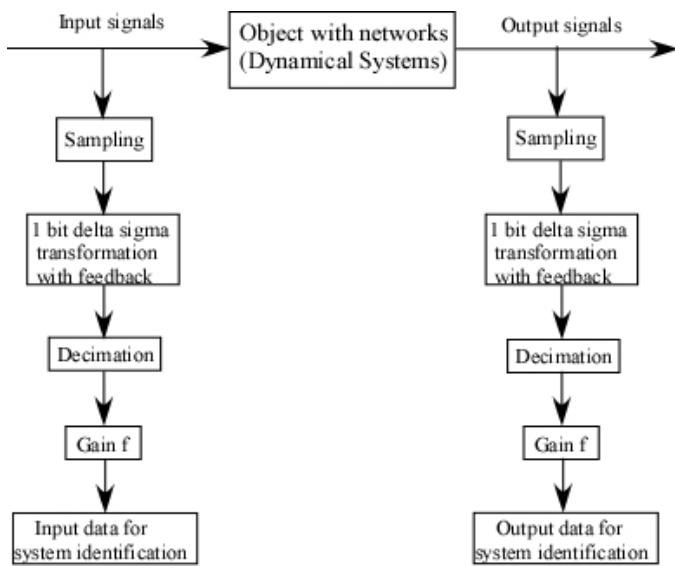


Figure 2. The procedure of the proposed method

Original input and output signals are modified to special data for system identification through step 1 to step 5. At step 5, system identification means least squares method with an ARX model. Here the feedback gain f is needed in step 2 and step 4. The feedback gain f is designed such that f is more than the maximum value of input signals.

Remark 1: It is able possible to build mathematical models of objects in Fig. 2 based on usual system identification method, for example least squares method with an ARX model. This is a method to build a mathematical model from input-output data directly. We call this method as direct method. (This is described in the next section.) But it seems highly possible that the accuracy of system identification becomes worse and inaccurate mathematical models are derived because usual system identification method does not consider some properties of networks by using direct method.

III. EXPERIMENTAL RESULTS

A. Settings of the experiment

The experimental environment is shown in Fig. 3. Fig. 3 shows two rooms connected with LAN (Local Area Network) cables. A computer to get input-output data, which is called as PC for system identification, is in the room 1. In the room 2, two computers are placed (Fig. 4). One computer is a router and another one is a sender/receiver computer of data from a DC motor, which is shown in Fig. 5. We call these computers as Router and Sender/Receiver PC respectively. DC motor is the object to identify dynamics as a mathematical model and the data of DC motor is sent to Sender/Receiver PC through RS-232C.

The network setting is given as follows,

- PC for system identification and the router are linked to a 10 Based-T LAN cable.
- Router and Sender/Receiver PC are linked to a 100 Base-T LAN cable.

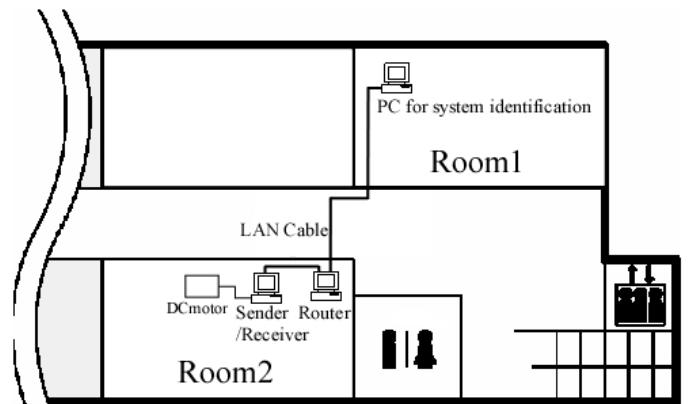


Figure 3. The experimental environment.



Figure 4. Router and Sender/Receiver PC.

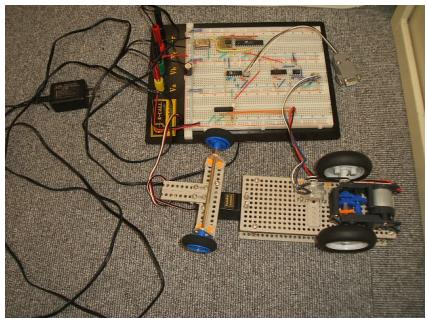


Figure 5. DC motor and I/O circuit.

B. Local experiment

To show the efficacy of the proposed method, a local experiment is carried out. The local experiment means that Sender/Receiver PC and PC for system identification are removed and a mathematical model of DC motor is identified based on usual system identification approach directly. From this local experiment, the target mathematical model describing DC motor is obtained to compare the proposed method and another one in the next section.

First the following conditions are assumed in this experiment. These conditions seem adequate to apply a system identification technique to the object in this experiment.

Condition 1: Input signals for system identification are given as PRBSs (Pseudo Random Binary Signals) with $\pm 1.5V$.

Condition 2: The sampling period is 25ms.

Condition 3: Total time to apply input signals was 50s.

Fig. 6 shows the input signal to DC motor from 30s to 40s. This figure shows that this is a PRBS with $\pm 1.5V$. Fig. 7 shows the output signal from the object (DC motor). The output signal is the number of rotations of DC motor.

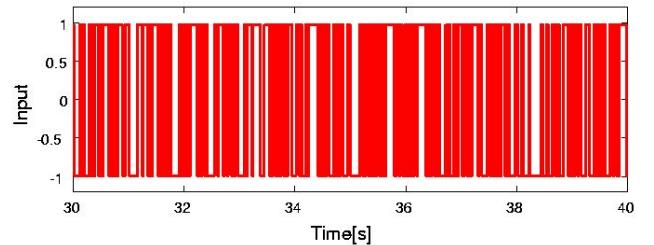


Figure 6. Input signal from 30s to 40s.

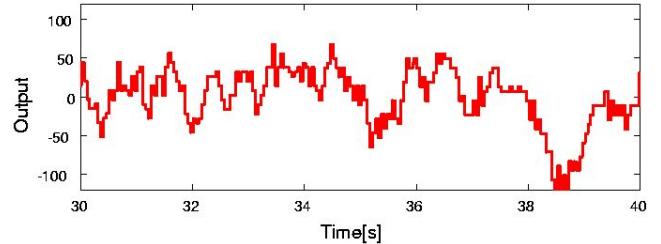


Figure 7. Output signal from 30s to 40s (local experiment).

By applying least squares method to input and output data in Fig. 6 and Fig. 7, a 2nd-order ARX model is derived. This method is a general system identification approach based on least squares method with an ARX model. Here the mathematical model is shown as a frequency response in Fig. 8.

In Fig. 8, the dotted line shows the frequency response of the DC motor from spectral analysis and the solid line shows the frequency response of the derived mathematical model (2nd-order ARX model). Fig. 9 shows the time response of the derived mathematical model for the PRBS applied to DC motor. It can be seen that the derived mathematical model has a high accuracy.

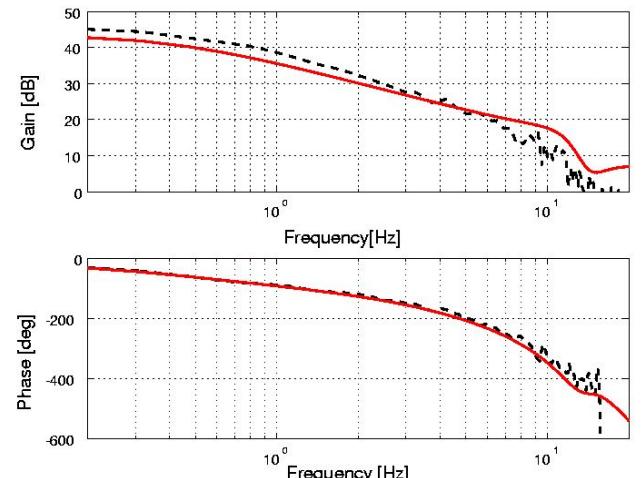


Figure 8. Frequency responses (local experiment: the dotted line is the frequency response from spectral analysis and the solid line is the frequency response of the derived 2nd-order ARX model).

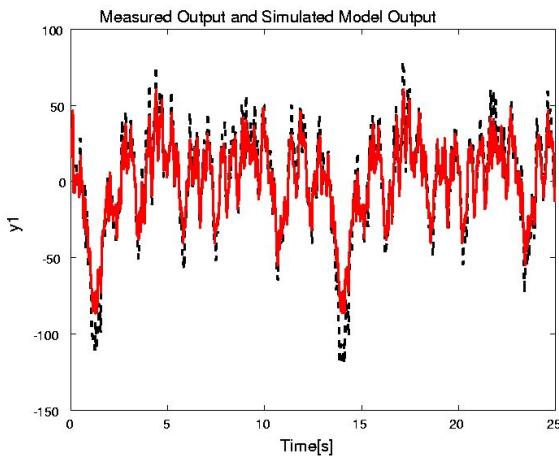


Figure 9. Time responses (local experiment: the dotted line is the output signal of DC motor and the solid line is the time response of the derived 2nd-order ARX model)).

C. Experiment over networks

Next the experiment over the network is considered. Based on Fig. 3, input and output signals of DC motor were obtained over the computer network. Experimental conditions were same as the previous section.

Direct Method:

The input signal with PRBS is the same as Fig. 6. This input signal is sent from PC for system identification to Receiver/Sender PC through Router. Fig. 10 shows the output signal of DC motor, which is sent from Receiver/Sender PC to PC for system identification PC through Router. It can be seen that Fig. 7 and Fig. 10 are not same because of data transfer through the computer network.

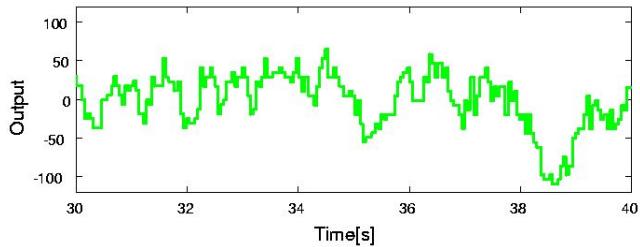


Figure 10. Output signal from 30[s] to 40[s] (the direct method).

Because input and output signals are obtained, a 2nd-order ARX model is derived by using the same system identification technique in the previous section, that is least squares method with an 2nd-order ARX model. We call this method as “direct method” because this is direct use of data. The result of the direct method is shown in Fig. 11 and Fig. 12, where solid lines are results of direct method and dotted lines are results of the local experiment. From Fig. 11, it can be seen that frequency responses are slightly different in high frequency domain. From Fig. 12, it is also obvious that time responses are different at some points with large amplitudes.

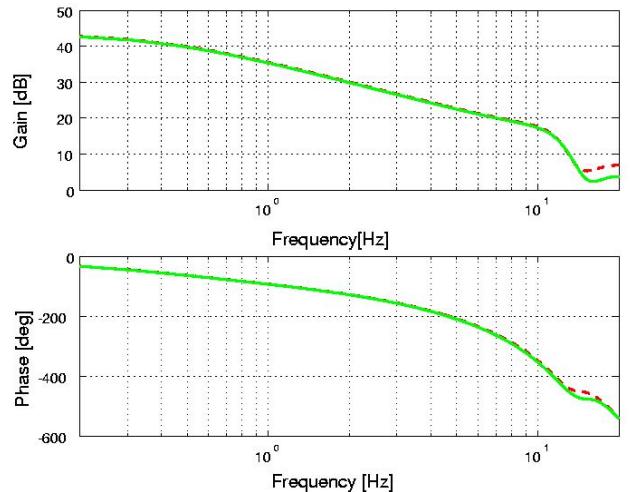


Figure 11. Frequency responses (the direct method: the solid line is the frequency response of the derived 2nd- order ARX model and the dotted line is the frequency response from the local experiment).

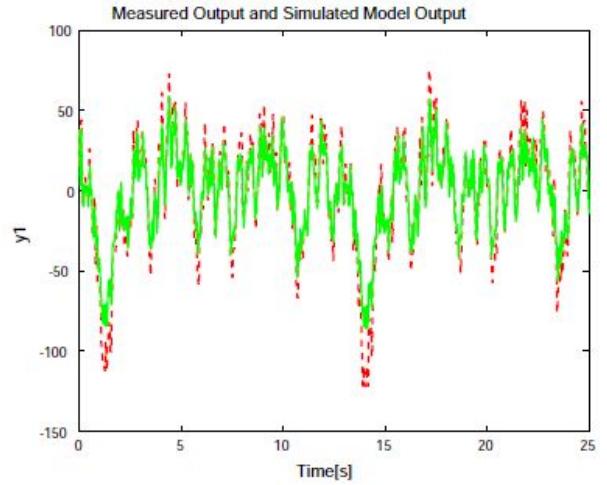


Figure 12. Time responses (the direct method: the solid line is the time response of the derived 2nd- order ARX model and the dotted line is the time response from the local experiment).

Proposed Method:

Now the proposed method is applied to input-output data to derive the mathematical model of DC motor over the computer network. For the proposed method, Fig. 13 and Fig. 14 show input and output signals after applying 1 bit delta-sigma transformation.

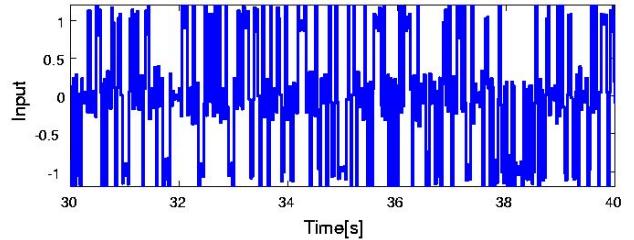


Figure 13. Input signal from 30s to 40s (the proposed method).

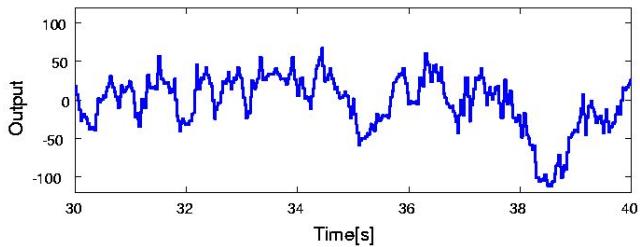


Figure 14. Output signal from 30s to 40s (the proposed method).

By using input-output data in Fig. 13 and Fig. 14, the mathematical model, which is a 2nd-order ARX model, is derived as Fig. 15 based on the proposed method. The solid line denotes the frequency response of the proposed method. The dotted line denotes the frequency response of the local experiment. Comparing Fig. 11 and Fig. 15, it can be concluded that the result of the proposed method is better than that of the direct method because of good matching in high frequency domain. Fig. 16 shows the time response based on the proposed method. Moreover it also can be seen that the fitting of signals becomes better than that in Fig. 11.

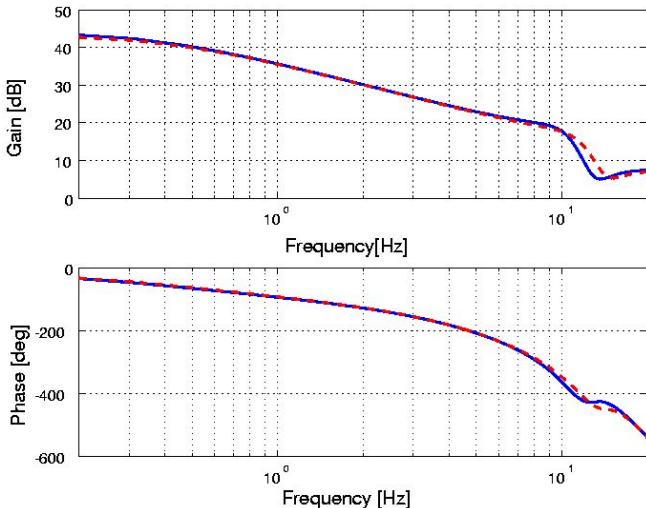


Figure 15. Frequency responses (the proposed method: the solid line is the frequency response of the derived 2nd- order ARX model and the dotted line is the frequency response from the direct method).

IV. CONCLUSIONS

In this paper, a problem to build the mathematical model over computer networks has been considered and a method has been proposed based on modified delta-sigma transformation. Simulation results have been omitted but experimental results have been shown. From experimental results, it has been

verified that the proposed method is effective for system identification over computer networks.

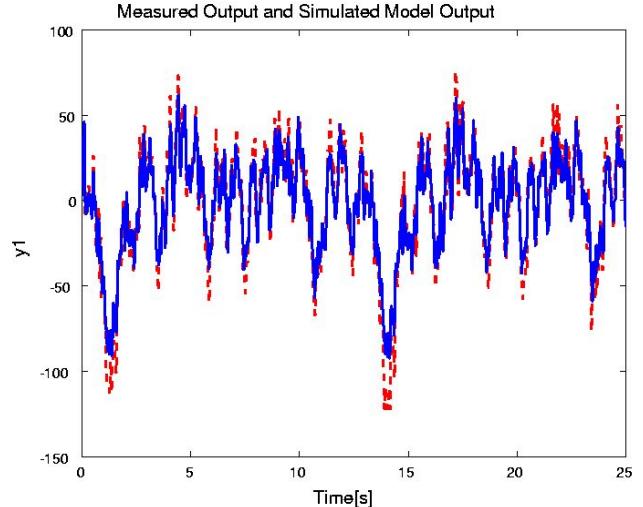


Figure 16. Time responses (the proposed method the solid line is the time response of the derived 2nd- order ARX model and the dotted line is the time response from the direct method).

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