Acquisition Card NI USB-6009 in Automatic Control Laboratory Exercises

Hrvoje Benić, Mato Fruk, Goran Vujisić
Department of Electrical Engineering
The Polytechnic of Zagreb
Konavoska 2, Zagreb, Croatia
hbenic@tvz.hr, mato.fruk@tvz.hr, gvujisic@tvz.hr

ABSTRACT - This paper presents methods for collecting and processing data using the acquisition card NI USB-6009 and MATLAB's Data Acquisition Toolbox. It also enables analysis of control system elements and responses of closed loop systems. Results obtained by series of experiments are used as examples for further use in Automatic Control Laboratory Exercises. A detailed explanation of procedures can be used as a base for the preparation of further laboratory exercises. The paper covers topics of initial installation and various use of the acquisition card.

I. INTRODUCTION

This paper will show the necessary steps how to link acquisition card NI USB-6009 and Matlab. After these procedures various experiments and measurements will be presented how to use this device. There are some problems that occur for this type of acquisition card that can be minimized by certain methods and procedures that will be explained in the paper. Today's technology allows the collection and processing of data from many physical processes using acquisition cards and computers. That makes it easier to process data for analysis of control systems. The initial idea of this paper is to improve and simplify laboratory exercises. It will be further described and done in this paper. The paper will also describe how to use Data Acquisition Toolbox, which is located within Simulink, which is part of the Matlab.

II. DATA ACQUISITION

Data acquisition is the procedure of collecting information from the process. With analog instruments it is difficult to collect data. There is also a lot of problems such as noise, drift, instability and high energy consumption. In digital systems it is easier to control noise and they provide easy transfer and storage of data. Digital signal processing is virtually unlimited. It all makes digital systems better for data acquisition.

Measurement and acquisition system consists of three parts:
1. acquisition
2. analysis
3. data presentation.

Part that relates to the data acquisition is a card that connects to a PC. Here it is realized by:
1. connection
2. A/D conversion
3. signal processing.

The analysis part is performed by calculations such as filtering, spectral analysis, data formatting and statistics. Data formatting is necessary because different devices and instruments may require information in a different format. Third part of the system is a presentation, which provides displaying, saving and printing of results, data transferring between different applications and communications between systems and networks.

III: A/D CONVERSION

The tasks in this paper were processed with analog data and for that there are given basics of analog-digital conversion. A conversion process consists of three steps.

Fig. 1. The basic model of the conversion of the analog signal f(t) into a digital format that is shown a series of f[k]

The first step is carried out by the time discretization. With quantization level signal becomes a discrete value. In the final step there is performed coding of quantization level samples \( f(kT_s) \) or analog digital conversion. Each sample is associated with a corresponding binary number \( f[k] \). A/D symbol stands for unit for analog to digital signal conversion (coder). That unit makes digital signal in the third step of the conversion. In practice an electronic circuit performs operations from Fig 1. Some of the signals between the two steps don't exist in practice. That is why usually ADC (Analog Digital Converter) stands for analog to digital converter as a unit that makes operations from each of three steps of the conversion. Analog signal must be reconstructed after the digital signal processing.
That conversion takes place in two steps. In the first step impulses of samples were reconstructed based on digital data \( f[k] \). There is performed digital to analog conversion. This produces quantized level pulses \( f_T(kT) \). In the second step the analog form of the signal is being reconstructed \( f_r(t) \). It can be expected deviation of reconstructed analog signal \( f_r(t) \). This deviation is due to quantization errors. Corresponding analog signal is reconstructed by filtering samples.

IV. ACQUISITION CARD NI USB-6009

Acquisition card National Instruments USB-6009 allows data acquisition for mobile measurements, practice and lab measurements etc. It connects to the computer via the USB interface and that is a big advantage. The card is good for some complex measurements that can be seen at lab exercises.

A. SPECIFICATIONS

Acquisition card NI USB-6009 has 8 analog inputs, 2 analog outputs, 12 digital inputs/outputs and 32-bit counter. Maximum sample speed by each analog input is 48 Ks/s. Sample speed on analog outputs is 150 S/s and it can’t be changed. Analog inputs have 14-bit resolution and analog outputs have 12-bit resolution. USB interface allows better transferability and easier connecting with the PC. The external appearance of the card is shown in Fig. 2.

![Fig. 2 Acquisition card NI USB-6009](image)

Maximum voltage that can be connected to analog inputs is from -20 V to 20 V (card specifications says -10 V to 10 V, but in practice -20 to 20 V can be connected). Analog outputs voltage is from 0 to 5 V and it can’t be changed. The card connects with PC via USB interface. At digital inputs it can be connected voltage from 0 to 5 V and at digital outputs it gives 5 V. The card also has a counter that gives voltage from 0 to 5 V and maximum frequency of 5 MHz.

The card also has a green control LED that switches on when the card is connected to a PC via USB interface. If LED is not switched on card is not connected properly or it is malfunctioned. If it flashes that means that the card is in function.

Conductors merge with inputs and outputs with screw fittings connections that are at sides of the card. Analog inputs and outputs were used in measurements.

![Fig. 3 Colloaction of screw fittings connections](image)

B. CARD INSTALATION

At the beginning of using the card it is necessary to install a driver that is obtained on a CD with the card. Program Measurement & Automation Explorer needs to be installed. Measurement & Automation Explorer is used to test the card, reset it and adjust its characteristics.

V. FUNCTIONAL TESTING OF NI USB-6009

A. USE OF PROGRAMMING PACKAGE MATLAB

Work with acquisition card NI USB-6009 is possible with 32-bit programm package Matlab and its library Simulink. Inside of Simulink there is a toolbox called Data Acquisition Toolbox which reads the card and makes possible to use its inputs and outputs in schemes inside of Simulink. That makes measurement easier because it enables to work with data inside of program.

Data Acquisition Toolbox takes place inside of Simulink library. Simulink library takes place inside of Matlab.

B. THE INITIAL MEASUREMENT

The first task was to observe the signal delay when processing data inside the card. Sinusoidal frequency 1 Hz was selected for the test signal. It was obtained from the function generator and it was brought to analog input and observed with 2-channel digital oscilloscope on analog input and output of the card. The model is made inside Simulink with usage of Data Acquisition Toolbox and it is very simple. Input and output parameters are set within the model. The window in which the parameters are set opens by double-clicking on the
input block. It is possible to select the input that will be used, sampling frequency, input voltage range, mode and whether there is used one or more cards. Modes are asynchronous and synchronous. The difference is that the asynchronous mode is FIFO (First In, First Out), or the card sends data out in the order that it receives and synchronous mode is such that all data are processed within the card and then it is sent to the output. The difference between these two modes is observed in larger models and affects the duration of the simulation. Asynchronous mode is faster. Output parameters that can be set are: output that we want to use and how many cards we want to use. Output voltage range is from 0 to 5 V and it can't be changed.

![Fig. 4 Linking Up](image)

The measurement signal on the analog input was sampled with the frequency of 500 S/s. Sample frequency is one of the factors that affects on data processing speed and the duration of the simulation. Sampling frequency at analog output is 150 S/s and it can't be changed as mentioned before.

Measured result is that sinusoidal frequency at the output of the card has delay of approximately 136 ms. Reason for that is data processing inside of the card that requires A/D conversion on the input of the card and D/A conversion at the output. Another reason is time that is necessary for acquisition and data processing that is given by a Simulink model. The result of this measurement is shown in fig 6.

![Fig. 5 Simulink model](image)

C. TEST RESULTS FROM THE INITIAL MEASUREMENT

Given results were obtained with repeated measurements. The test signal obtained from function generator was now rectangular with the frequency of 1 Hz and 10 Hz. Digital oscilloscope Velleman PCSU1000 which is connected to the computer was used. Given results show that card has delay in range of 120-140 ms which confirms result that was given in initial measurement.

VI. RECORDING AND PROCESSING TIME RESPONSES OF SECOND ORDER ELEMENTS

A. ESTIMATION OF THE TRANSFER FUNCTION OF PT₂ ELEMENT

Double RC circuit is second order element. It is described by differential equation of the second order. It has two time constants and two energy storages. Energy storages are its two capacitors.

![Fig. 7 Double RC circuit](image)

The purpose of this experiment is to examine the possibilities of card. Tool SIT (System Identification Toolbox) is used in this experiment. SIT is used in a way that it compares the given time response with some known response inside SIT and it determines in which percentage they match with each other. SIT automatically determines system parameters (gain, time constants, dead time and transfer function).

The experiment measurement was made in a way that the double RC circuit was connected with card.
Input voltage of the double RC circuit is program designed step which is connected to the analog output of the card. Output voltage of the double RC circuit is brought to the analog input of the card and it is observed on program oscilloscope.

Sampling frequency at the analog input is 40000 S/s and at the analog output it is 150 S/s. Input voltage of the double RC circuit are two program designed steps which starts in different moments. At Fig. 8 it is evident that given response matches with assumed in 98.68%.

Obtained accuracy is satisfying. Obtained time constants are almost equal to the time constants obtained by habitual classic procedure. That all means that the card is good for measurements like in this experiment and that it can be used for laboratory exercises of this type.

B. ESTIMATION OF THE TRANSFER FUNCTION OF PT₂S ELEMENT

Serial RLC circuit is the element of second order. It has two energy stores and two time constants. It is described by differential equation of second order. Its energy stores are capacitor and coil.

The purpose of this experiment also is to examine the possibilities of card. The experiment measurement is made in the same way as last one. SIT (System Identification Toolbox) is also used. The expected response of the system is damped oscillatory response. The difference compared to the previous experiment is that the frequency of sampling analog input is set on 10000 S/s. Obtained system response is shown on Fig. 11.

System response is like it was expected. SIT is used in a further process of identifying the parameters of system as in the previous measurement.

Obtained accuracy is 96.49%. That is also good result like in previous measurement. Conclusion of this test is that card is suitable for this type of measurement in laboratory exercises.
VII. CONCLUSION

After various tests of NI USB-6009 work potentials with use of Matlab conclusion is that the card is good for laboratory exercises. Plenty of measurements performed on laboratory exercises in subject Automatic control can be simplified by using the card and Matlab. It is useful that the students familiarize themselves with the data acquisition and virtual instrumentation because that is present and the future and it is is likely for them to encounter some kind of data acquisition in their profession after they graduate.

While the card was tested some conclusions about possible improvements were made. Following pro and cons:

Disadvantages:
1. Card with use of Data Acquisition Toolbox works only on 32-bit Matlab
2. The voltage at the analog outputs of the card is limited to the range of 0-5 V, and can not be changed.
3. Sample frequency at analog outputs is 150 S/s and can not be changed.
4. Maximum sample frequency at the analog inputs (48 kS/s) can be achieved using only one analog input. Maximum sampling frequency is reduced if used multiple inputs simultaneously.
5. It often happens that Matlab simulation stops working and that Matlab blocks if the card is not previously reseted inside Measurement & Automation Explorer.
6. The card has a signal latency which is not fixed.
7. Card does not work in real-time mode.
8. Simulation time and real time of process are not the same. Eg. for simulation time 10 s process usually will not last 10 s. The time required for the implementation of the simulation depends on many factors, including the complexity of the model and the step size inside Solver.
9. Card has a problem with noise and drift while receiving and processing analog data.

Benefits:
1. Connecting to a computer via the USB interface.
2. Easy to work in a graphical environment (Data acquisition toolbox).
3. Small dimensions.
4. No additional power supply of the card is needed.
5. Using the card reduces the necessary equipment to perform laboratory exercises.
6. The card “remembers” the last voltage state in which it found itself.
7. Simulation time inside of Simulink can be set on unlimited in a way that instead of numerical value for end of the simulation enters inf
8. Using the Rate transition block.

![Rate Transition](image)

Fig. 13 Rate Transition Block

The Rate transition block is inside of Simulink library (Simulink ➔ Signal attributes ➔ Rate transition) and it is used for changing sample frequency to its divisor. (Eg. 1000 S/s u 100 S/s). The purpose of this is that signal at analog input can be sampled on a given frequency, and within the simulation can be viewed only parts of the signal (Eg. if at input is 1000 S/s it is possible for some part of the simulation later to put 100 S/s and watch every tenth sample of the input signal). It makes possible that in simulation every block needs not to have same sample frequency and it is possible to work with fixed discretization step.

Possible improvements:
1. Work with 64-bit Matlab.
2. Possibility of changing range of output voltage at analog outputs.
3. Possibility of changing sample frequency at analog.
4. Troubleshooting blocking simulation.

BIBLIOGRAPHY