cRIO-BASED WIRE SCANNER MOTION CONTROL*

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Abstract

The Compact Reconfigurable Input/Output (cRIO) hardware manufactured by National Instruments (NI) is evaluated as a wire scanner motion controller. This particular configuration utilizes a NI cRIO-9074 system combined with various C-series modules for wire scanner motion control I/O. Programs for this system have been written in LabVIEW and a majority of the motion-control functionality has been programmed into the cRIO's FPGA in order to provide the fastest motion control processing possible with cRIO. The purpose of this improved motion control being necessary for convergence to a wire scanner movement design goal of a 1-mm move within 8.3 ms. Additional topics of interest include, cRIO-based resolver-to-digital conversion and closed-loop, stepper-based motion control.

INTRODUCTION

National Instrument's cRIO hardware has been evaluated as a candidate for LANSCE's planned upgrade of its wire scanner motion control systems. The wire scanners that are presently used by LANSCE (Los Alamos Neutron Science Center) operate in open-loop with constant velocity profiles [1]. Furthermore, the systems used presently assume that the steps provided to the actuator motors will be achieved. Unfortunately, flaws, such as mechanical wear, reduce the possibility that the wire scanner will be driven to the desired measurement location. With technology such as cRIO, there now exists the possibility of developing a custom motion control system for closed-loop, stepper motor-based, wire scanner motion control. The benefit of a close-loop system is its ability to counter the effects of mechanical wear in order to guarantee the desired position of measurement.

HARDWARE DESCRIPTION

Wire Scanner Actuator

At the core of the system is a LEDA (Low Energy Demonstration Accelerator) wire scanner actuator. This actuator is the latest wire scanner design at the LANSCE facility and its mechanical operation is more or less typical of most wire scanners used at LANSCE. The LEDA wire scanner utilizes a stepper motor to turn a leadscrew resulting in a linear translation of the wire scanner fork. The movement of the fork positions a wire that is used to probe the LANSCE accelerator's particle beam. The data collected by the wire is used to generate a transverse beam profile.

*Work supported by the United States Department of Energy.

E-AC Stepper Motor Driver

Manufactured by Parker, the stepper motor driver is an AC-line powered device capable of powering a single Parker OS22B, or equivalent, stepper motor. The cRIO's interface to this drive consists of simple step, direction and diagnostics I/O.

NI cRIO

National Instrument's cRIO hardware has many benefits for developing a customized motion control system. Among these benefits is the ability to program a miniaturized computer with a real-time operating system as well as the ability to program an onboard FPGA that interfaces to various analog and digital input-output modules. Five such modules that were utilized for this project include:

- NI 9401 digital I/O module for control of the E-AC stepper motor driver.
- NI 9411 digital input module for encoder signal acquisition.
- NI 9422 digital input module for limit switch signal input.
- NI 9215 analog input module for resolver signal acquisition.
- NI 9422 analog output module for resolver excitation signal generation.

SOFTWARE DESCRIPTION

NI cRIO-9074 Onboard Computer Program Description

In its present form, the cRIO's computer consists of a program used to record and display motion performance of wire scanner moves. The user has control over various closed-loop control parameters as well as position and whether or not to enable trajectory generation.

Additional NI software called SoftMotion, has been installed into the cRIO system. SoftMotion's software trajectory generator controls the stepper-motor's angular velocity, acceleration, and position through its generation of waypoints for the motion controller to follow.

NI cRIO-9074 FPGA Program Description

Although the cRIO's "Real Time" computer is very capable, an important design goal for the new wire scanner control system is to offload as much of the motion control processing onto the cRIO's FPGA as possible. The primary reason for this is that it frees the onboard computer from having to operate in close cooperation with the FPGA while a move is underway, thus permitting the computer to dedicate itself to other tasks (e.g. wire scanner signal analysis and EPICS interface management). Furthermore, FPGA-based motion control may reduce the gap between a design goal of a 1-mm move in 8.3 ms and what is practically achievable.

The FPGA code can be divided into 7 subunits:

- E-AC driver control interface.
- Actuator limit- switch monitor.
- Optical encoder position counter.
- Proportional-derivative control loop.
- Resolver-to-digital converter.
- 10 kHz sine wave generator for resolver excitation.
- Position sampling buffer for taking a time-sampled record of actuator movement.

Since the primarily interest of this investigation is the performance of the motion control system, an optical encoder was utilized as the wire scanner position feedback device due to its improved sensor bandwidth and resolution over resolver feedback [2].

Closed-Loop Control Algorithm

At the core of the FPGA's motion control program is the Proportional-Derivative (PD) controller [3]. As is typical of a closed-loop controller, the difference between the desired location and the measured position is taken as input to the controller. This difference (or error) is then fed into the discrete-time PD controller (integral control inherently exists within the system due to the nature of the encoder pulse acquisition program of the FPGA). The derivative error is then multiplied by an operator-specified constant we referred to as 'Kd' while the proportional error response is simply the multiplication of the position error with a constant we referred to as 'Kp.' The two error responses are then added together and used to vary the step pulse rate to the E-AC stepper driver, therefore affecting the rate of rotation of the wire scanner's stepper motor. In regard to proportional error response, this technique has the affect of reducing the actuator speed as it approaches the desired position.

MOTION TESTS AND RESULTS

In order to evaluate the performance of the closed-loop motion control system, we tested two types of moves; a 1-mm move and larger, 50-mm move. Furthermore, both of these move types were evaluated using a simple step response input and a SoftMotion-generated trajectory. The controller gains (Kp and Kd) were chosen to achieve a high-speed response and were unchanged for all moves. Plot samples were acquired by the FPGA using its position sampling buffer program.

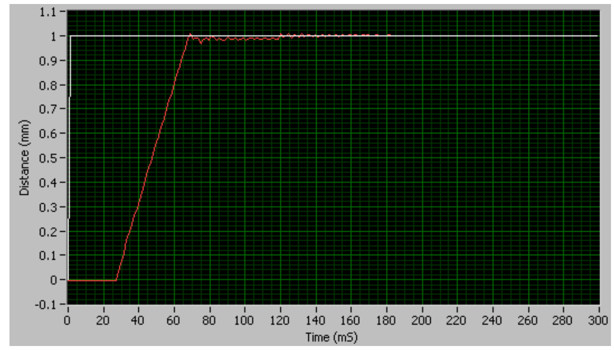

Figure 1: Closed-loop step response, 1mm move. Setpoint is white, measured position is red.

The result for a 1-mm move is shown in figure 1. For this move, a desired position (indicated by the white line) of 1-mm was immediately applied to the cRIO controller. The red line indicates the measured position of the actuator as the controller directs the actuator to the desired position. This result indicates that, for a 1-mm move, the controller is capable of driving the actuator to the desired position within about 80 ms.

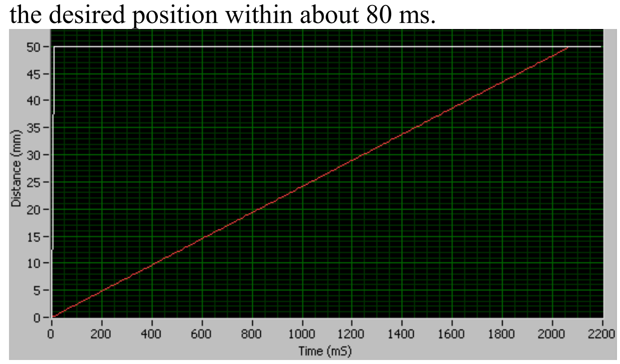

Figure 2: Closed-loop step response, 50-mm move. Setpoint is white, measured position is red.

Similarly, figure 2 depicts the step-response of the closed-loop system to a desired position of 50-mm being immediately applied to the controller. This result shows that the closed-loop system was able to attain the desired position within 2.2 seconds.

Next, two tests were taken to evaluate the motion controller's ability to follow the trajectories created by the SoftMotion trajectory generator (white lines). As is shown by figure 2, the controller managed to follow the trajectory, albeit a slight oscillatory behaviour is evident about the commanded position. For this move, the system was able to achieve the final position within 140 ms.

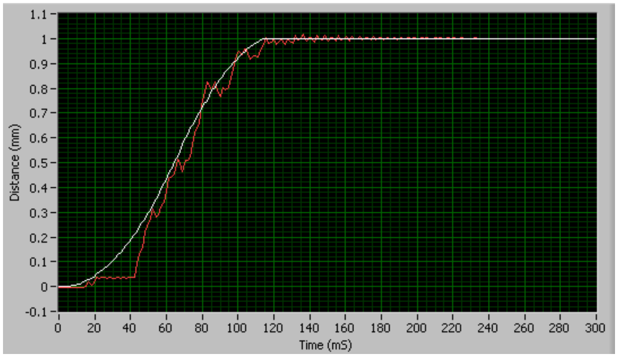

Figure 3: SoftMotion trajectory following, 1mm move. Setpoint is white, measured position is red.

Finally, figure 4 depicts a SoftMotion trajectory generator-based 50-mm move. For this larger move, the system was able to match the trajectory quite well, attaining the desired position within 2.5 s, about 0.3 s longer than the 50-mm step-response test of figure 2.

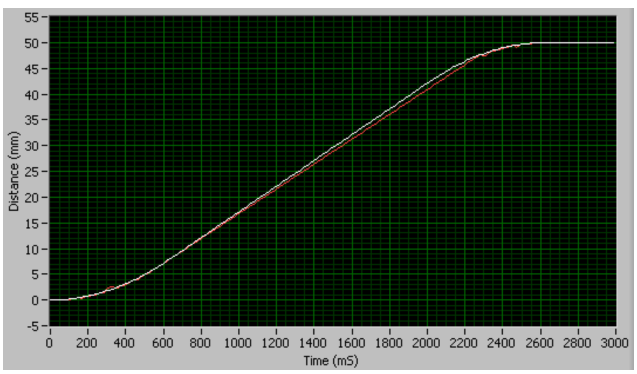

Figure 4: SoftMotion trajectory following, 50mm move. Setpoint is white, measured position is red.

RESOLVER TO DIGITAL CONVERSION

Resolver-to-digital converter code was developed for the cRIO's FPGA using the techniques described by Staebler [4]. This technique involved generating a 10-kHz sine wave from the cRIO system in order to "excite" the resolver. The method for generating the resolver excitation frequency initially involved programming the numerical samples of one cycle of a sine wave into a look-up table on the FPGA. In order to generate the sine wave, the FPGA sends the sample sequence to the NI 9422 module, where it is output as a voltage. This voltage is transmitted to the resolver's rotor, where the signal induces 10-kHz sine waves onto the resolver's stator windings. The stator sine waves are then read by the cRIO's FPGA through the NI 9215 A/D converter module. In order to obtain the best signal-to-noise ratio of the returning sine waves, the FPGA samples the sine waves at their peak. The ability to perform this action is due to the fact that the FPGA created the sine wave that is transmitted to the resolver, thus allowing the FPGA to predict when the return peaks should occur. Sampling the peaks results in two values for every cycle of the transmitted sine wave. These samples are input into a CORDIC (COrdinate Rotation DIgital Computer) "ATAN2" function programmed into the FPGA. The resulting output value is a π-normalized motor shaft angle. This shaft angle is later scaled to degrees.

We were unable to compare the results of this R/D converter to a precision reference, but angular measurement stability appeared to be accurate to within 0.1 degrees.

CONCLUSIONS

National Instrument's cRIO system has proven to be an exceptional technology for use as a wire scanner motion control system. Of major significance is the ability of the cRIO's FPGA to handle the processing requirements of a closed-loop motion controller, encoder counter, resolver-to-digital converter, resolver excitation frequency generator, and position data acquisition device. Furthermore, NI tools for cRIO such as SoftMotion, provide an easy to implement, trajectory generation algorithm.

REFERENCES

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