

Development of a Virtual Instrument for Control and Data Acquisition of a Cardiovascular Pulse Duplicator System Using LabVIEW™

by

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Category:

Biomedical

Products Used:

National Instruments 16-channel A/D board (AT-MIO-16E-10)

LabVIEW v5.1 software

The Challenge:

Develop a virtual instrument with top-level control structure and data acquisition capabilities for operating a cardiovascular pulse duplicator system. The virtual instrument must enable physicians, scientists, and engineers to easily control the system in real-time with active feedback of physiologically-equivalent cardiac parameters and waveform morphology.

The Solution:

Develop a communication link between desktop PC and cardiovascular pulse duplicator system via a programmable, multi-axis controller using a National Instruments 16-channel A/D board (model AT-MIO-16E-10) and LabVIEW virtual instrumentation software.

Abstract

Biomedical researchers at the Jewish Hospital Cardiothoracic Surgical Research Institute at the University of Louisville develop/investigate innovative surgical procedures and cardiac devices for the diagnosis and/or treatment of patients with heart disease. In support of this research focus, we have developed a cardiovascular pulse duplicator system for *in vitro* testing of these procedures and devices in a controlled environment under user-defined experimental conditions and physiological states. The cardiovascular pulse duplicator system is a research tool that simulates a beating heart by reproducing physiologically-equivalent cardiovascular pressures, flows, rates, and volumes in a feedback-controlled hydrodynamic flow loop. For example, the cardiovascular pulse duplicator can be programmed to beat with a user-defined profile at a fixed heart rate and stroke volume against a user-defined afterload. These experimental conditions cannot be easily controlled in an animal model. National Instruments hardware and LabVIEW software enabled us to develop the virtual instrument that provided a user-friendly interface with background handling of instruction set pre-processing, beat-by-beat data acquisition and processing, and ‘on-the-fly’ cardiovascular pulse generation.

System Description

The cardiovascular pulse duplicator (CPD) system is comprised of a PC-automated control system that drives a linear actuator coupled to a mock closed-flow loop (Figure 1). The hydrodynamic closed-flow loop parallels the physiologic cardiovascular system with analogous major components that include atrial and ventricular chambers and valves, venous storage reservoir, and tunable vasculature. Pressure or flow measurements within the closed-flow loop can be used as feedback control emulating baroreceptor response. A velocity-loop servo amplifier drives a screw-driven linear actuator that propels a bellows ported to the ventricle, which generates the desired pulsatile pressure. The input signal to the servo amplifier is produced by a programmable multi-axis controller (PMAC). Instruction sets and data are transferred between the PMAC and a host-PC via serial cable. The host-PC also houses a 16-channel A/D board (model: AT-MIO-16E-10, National Instruments, Austin, TX) for data acquisition enabling real-time monitoring and analysis of CPD parameters.



Figure 1: The LabVIEW-driven Cardiovascular Pulse Duplicator (CPD) system.

A user-interface was developed using the LabVIEW platform (Figure 2) to allow the CPD to be easily programmed and controlled to replicate a variety of cardiovascular parameters over a wide physiological range. User-controlled parameters include (1) heart rate, stroke volume, and/or cardiac output, (2) systolic/diastolic time ratio, (3) waveform profile (physiologic, sinusoidal, or sawtooth position and velocity), and (4) number of beats to be generated in an experimental trial. A status monitor displays all currently defined parameters. The CPD can be configured to use a flow (or pressure) measurement as a feedback control mechanism (i.e. baroreceptor). The mean flow (or pressure) is displayed real-time for beat-by-beat and moving average mean flows. Subsequently, user-selectable cardiac parameters (heart rate or stroke volume) can be adjusted 'on-the-fly' to compensate for differences between the user-defined and measured mean flows, which may be attributed to valvular reflux and/or changes in the vascular impedance of the closed-flow loop.

There are two tiers of software structure: one at the PMAC level (Delta Tau motion programming language) and one at the PC level (National Instruments LabVIEW 5.1). The motion programming code handles the lower-level movement functions of the CPD while the LabVIEW virtual instrumentation was used to develop a user-friendly interface control menu, handle feedback control, and provide data acquisition.

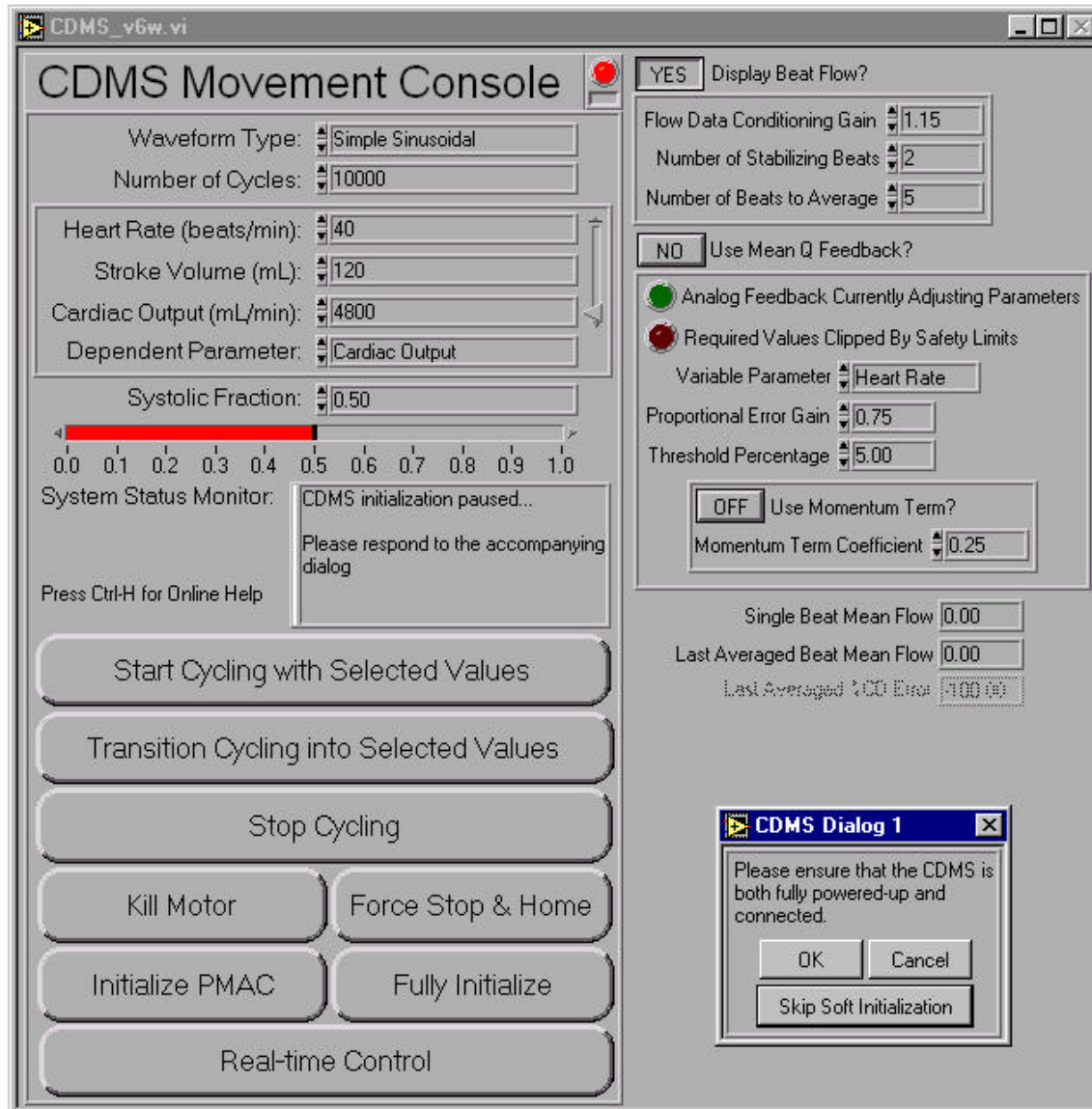


Figure 2: Front Panel of Virtual Instrument for operation and control of CPD.

Design Considerations

PMAC communication. The CPD virtual instrumentation developed in LabVIEW handles the user interface and communication with the PMAC. ASCII characters are transferred between the host-PC and PMAC via a serial cable. Through PC polling of the PMAC, the PC requests the initiation/termination of one of three motion programs and reads/writes values from/to memory locations in the PMAC. These motion programs serve the following functions: (1) hardware confirmation, (2) basic homing, and (3) generates waveform profile. Despite its relatively low bandwidth, serial cable communication was best suited for our application for noise isolation, device placement, and portability.

Waveform Profile. Without LabVIEW, we would be limited in our ability to program a variety of waveform arrays timely and efficiently. Specifically, the PMAC alone is incapable supporting the flow (or pressure) feedback control as it is unable to handle self-generation of a new array while simultaneously (1) managing controlled large-array (i.e. high-resolution) linear actuator movement with the current array and (2) maintaining enough open servo cycles for adequate status polling from the host-PC. LabVIEW virtual instrumentation allows the PC to generate and download the array to the CPD, permitting on-the-fly parameter changes necessary for a meaningful feedback mechanism.

Flow feedback control. Our LabVIEW program samples flow (or pressure) measurement(s) in the closed-flow loop. The program takes a moving average of n user-selectable beats and adjusts the stroke volume or heart rate of the linear actuator until the generated flow matches the measured flow. The tolerance level between programmed and measured flow is maintained by a percent error threshold algorithm defined by the user. The user also has control of the strength of the corrective signal as well as the use of a momentum term to reduce oscillation.

Safety. We developed safety and hardware configuration confirmation routines to prevent injury to person or equipment. The first safety concern was with the linear actuator, which has a force rating of 224 pounds (996 N). During 'start-up' and initialization of the *Interface Menu*, the user is prompted to identify desired software and hardware configuration. Hardware and software confirmation routines that verify the PMAC is performing properly are run and monitored during the confirmation progress for error codes using LabVIEW sub-VI's. Since the PMAC handles low-level movement, error and warning conditions are not usually apparent to the user without a special terminal interface. Our LabVIEW program notifies the user of unsafe operation and automatically invokes an appropriate solution -- (1) "killing" the linear actuator, (2) re-closing the servo loop, or (3) homing the system after a safety limit trigger.

Application

Recently, our CPD system was used to test a new theory for calculating flow through prosthetic heart valves using the pressure differential. Our Interface Menu developed using LabVIEW enabled investigators to successfully complete their experiments in a safe, efficient, and controlled environment. Investigators were able to generate physiologically-equivalent pressures and flows over a wide range of heart rates and stroke volumes (Figure 3).

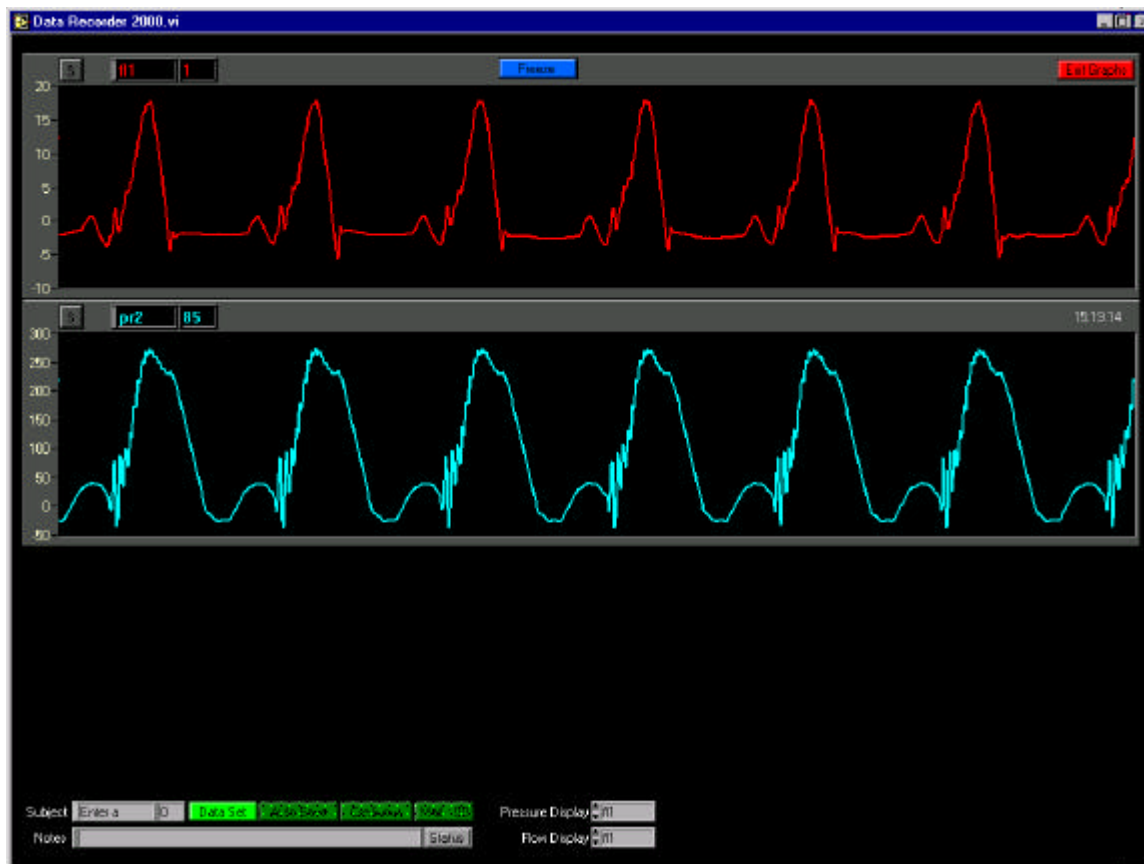


Figure 3: Sample aortic flow (red) and left ventricular pressure (blue) waveforms generated by the CPD.

Conclusion

We developed a cardiovascular pulse duplicator system for *in vitro* developing/testing innovative surgical procedures and cardiac devices for the diagnosis and treatment of heart disease. The software communication and control structures that support the electro-mechanical components of this system can be quite complex. In order to

facilitate the operation of this sophisticated device by researchers and physicians, we developed a user-friendly Interface Menu for high-level control using LabVIEW and a National Instruments 16-channel A/D board. In this approach, we were able to successfully interface with our programmable multi-axis controller and signal conditioners, significantly improving the ease of operation. In light of these factors, coupled with the integrative qualities of virtual instrumentation and the effective G coding format, we recognize National Instruments as an excellent choice for our application.