STUDENT WORKBOOK

QNET Myoelectric Trainer for NI ELVIS

Developed by Quanser

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Contents

1 INTRODUCTION

Electromyography, or EMG, involves acquiring and studying the electrical activity of muscles. The instrument used to measure the contraction of a muscles is called an electromyograph but the term EMG sensor is often used as well. An electromyograph measures the electric potential generated by muscle cells and this recorded voltage is called an electromyogram. EMG signals are of interest to the developers of prosthetic devices, such as artificial limbs, and this is called myoelectric prosthesis. EMG is also found in bio-instrumentation, as a clinical diagnostic tool to identify neuromuscular diseases, assisted control in aircrafts, and unvoiced speech recognition.

The QNET Myoelectric trainer shown in Figure 1.1 includes a two-electrode electromyograph with a grounding strap and a servo. The on-board processed EMG signal can be measured and the servo can be driven by the PWM. Through EMG signal processing and control, the clamp on the servo can be opened and closed through muscle contraction, similarly to myoelectric prosthesis.

Figure 1.1: QNET Myoelectric trainer (MYOELECTRIC)

There are three experiments: setup, signal processing, and EMG Control.

Topics Covered

- Signal Processing
- Zero-order hold (ZOH)
- Integral Control
- LabVIEW Programming

Prerequisites
In order to successfully carry out this laboratory, the user should be familiar with the following:

- Using LabVIEW®to program block diagrams and run VIs.

2 EMG SENSOR SETUP

2.1 Background

2.1.1 EMG Signals

The electromyogram acquired from the EMG is very qualitative. It depends greatly on how the sensor is placed, how close it is to the muscle, and what muscle is being measured. A typical EMG signal is shown in the first plot of Figure 2.1. As illustrated, EMG signals are very noisy and have a small amplitude, usually ranging around 5 mV. It can contain frequencies ranging from 10 Hz to 1 kHz.

To remove some of the noise, the electrodes on the QNET myoelectric trainer include a differential amplifier as well as a local band-pass filter. See Reference [14] for the common mode rejection ratio (CMRR) and filter specifications of the electromyograph. The EMG signal received from the instrument is isolated and amplified on the QNET myoelectric trainer circuit, as described in the *QNET Myoelectric User Manual* [1].

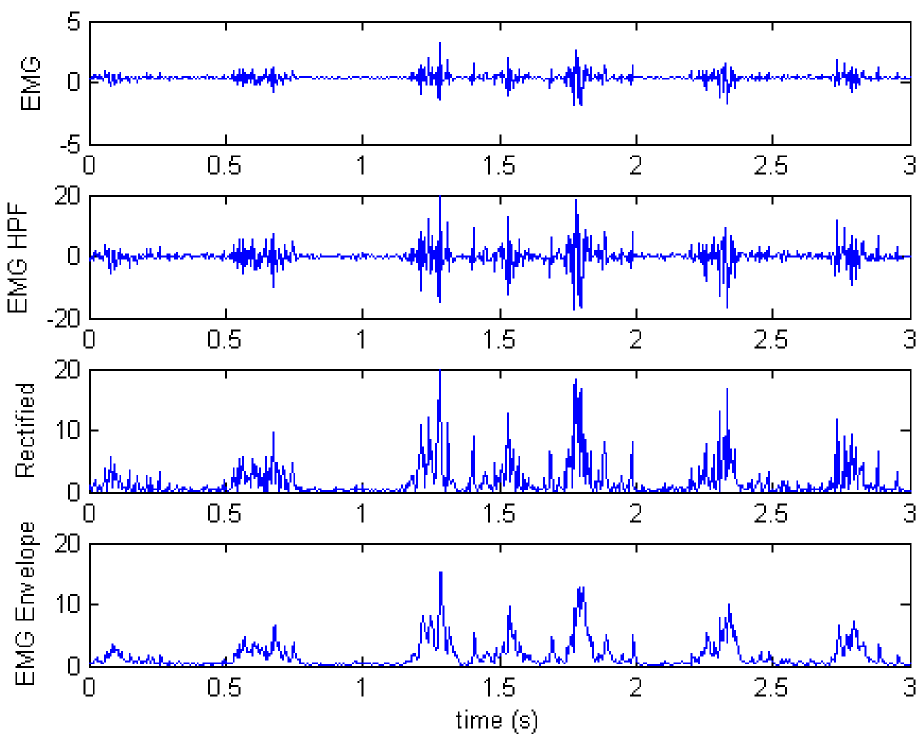


Figure 2.1: Measured and processed EMG signal

2.2 EMG Sensor Setup Virtual Instrument

The NI ELVISmx *Dynamic Signal Analyser*, shown in Figure 2.2, is used to verify that the EMG sensor has been properly setup.

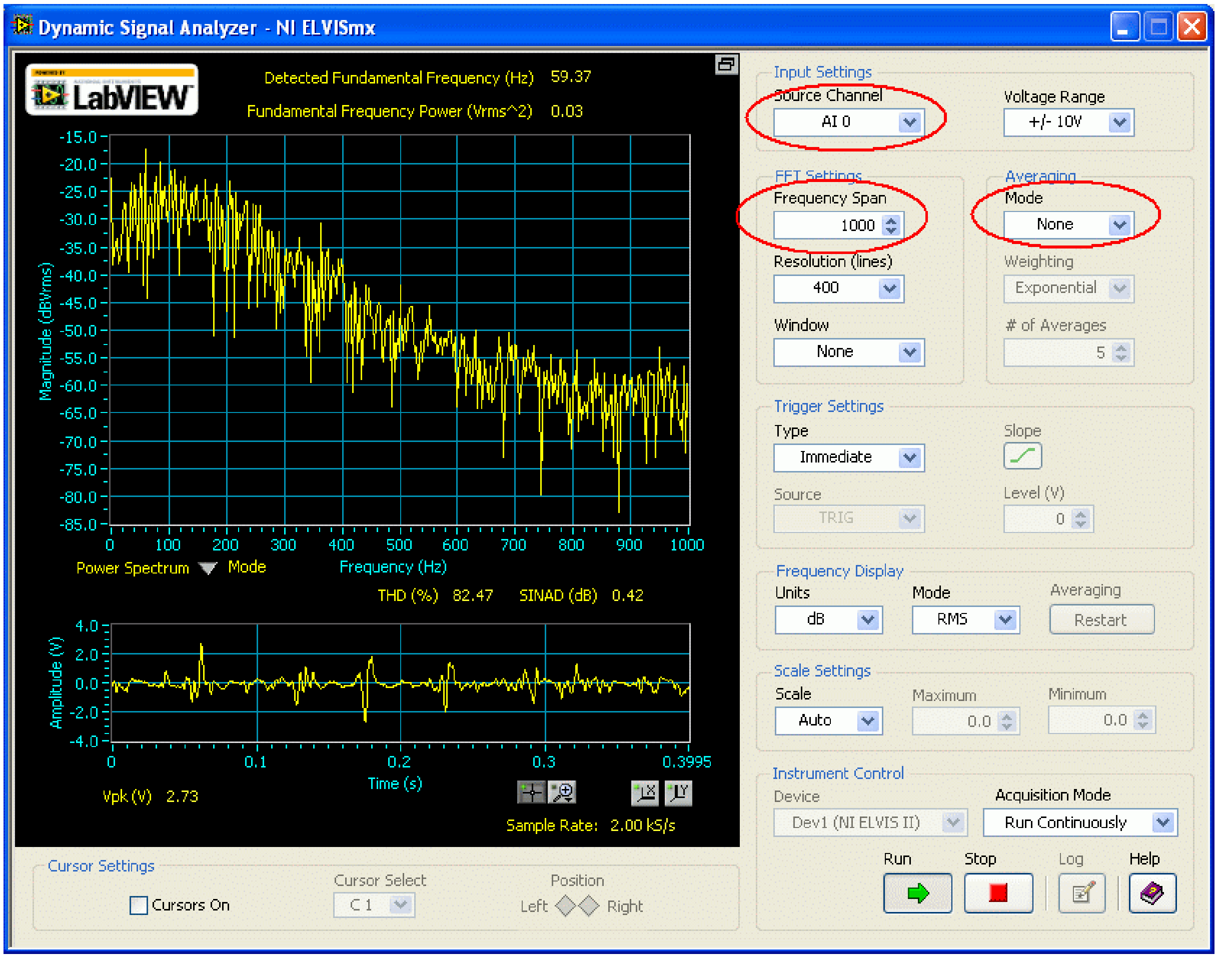


Figure 2.2: Setting up the Dynamic Signal Analyzer instrument

2.3 Lab 1: EMG Sensor Setup

1. Setup the QNET myoelectric trainer and power up the ELVIS, as described in the *QNET Myoelectric User Manual* [1].
2. Fasten the grounding strap on of your forearm, as illustrated in Figure 1.1. It should be snug to ensure the ground terminal is making contact with your skin.
3. Wrap the EMG electrode around the upper portion of your forearm, as shown in Figure 1.1. Ensure the electrodes on the EMG sensor are facing inside your arm (you should not see the metal probes). Position the electrodes such that they make contact with the the upper-inner muscle of your forearm.
4. Turn ON the *EMG Sensor* power switch (also, make sure there are batteries).
5. Run the *Dynamic Signal Analyzer* NI ELVISmx instrument. By default, this is located under *Start\All Programs\National Instruments\NI ELVISmx\Instruments*.

   For Traditional NI ELVIS Users: Go to *Start\All Programs\National Instruments\Traditional NI ELVIS \NI ELVIS Traditional* and then select *Dynamic Signal Analyzer* in the *ELVIS - Instrument Launcher*.
6. As shown in Figure 2.2, set the following in the *Dynamic Signal Analyzer* instrument:
   - *Source Channel* = *AI 0*
   - *Frequency Span* = 1000
   - *Averaging Mode* = *None*

7. Try to contract the muscles in your forearm and examine the voltage measured from the EMG sensor in the bottom scope called *Amplitude (V)*. As shown in Figure 2.2, the peak should exceed 2.0 V when the muscles are contracted. If not, then the EMG sensor has not been properly setup and you need to go through Steps 1 to 3 again.

   Note: If more problems are encountered then see the *Myoelectric Troubleshooting Guide* section in the *QNET Myoelectric User Manual* [1].

3 EMG SIGNAL PROCESSING

3.1 Background

3.1.1 EMG Signals

The signal acquired from the EMG sensor and amplified through the on-board QNET circuit is shown in the first two blocks of Figure 3.1. This signal is in the $\pm$ 10 V range but still includes a lot of noise. The signal must be processed further, using either an analog circuit or digitally through a PC, in order for it to be used. A signal processing method knows as linear envelope is used to do this. As illustrated in Figure 3.1, this involves rectifying the signal and passing it through a low-pass filter. A high-pass filter (HPF) may also be used to remove any low-frequency components. Choosing the filter cutoff frequency of the high-pass and low-pass filter is important.

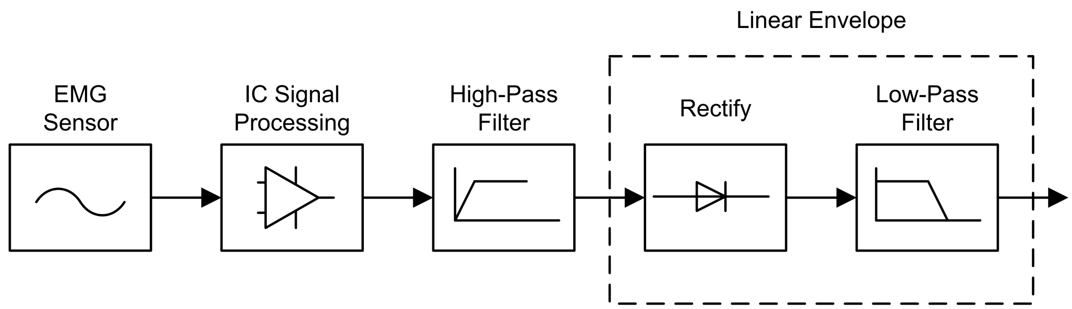


Figure 3.1: EMG signal processing

The result when the measured EMG signal is passed through a high-pass filter is shown in the second plot in Figure 2.1. For the QNET myoelectric, choose a low HPF cutoff (e.g. around 0.25 Hz) to ensure only the DC component is removed and the remainder of the signals are kept. Setting the cutoff too high can make the signal too noisy.

In order to take a "running average" of the EMG the signal is passed through a linear envelope. Rectifying the signal means taking its absolute value. In electronics, a full-wave rectifier circuit is used. As illustrated in the third plot in Figure 2.1, the obtained signal is always positive.

The low-pass filter makes the signal smooth and generates the "envelope" of the signal, as shown in the last plot of Figure 2.1. There is a tradeoff when setting its cutoff frequency. If the cutoff is too low, the envelop will be too slow. If its set too high, then the envelope will be less smooth. The resulting signal from the linear envelope can potentially be used to check for muscular failure, rehabilitation, myoelectric prosthesis, and so on.

3.2 EMG Signal Processing Virtual Instrument

The virtual instrument used to view EMG sensor measurements, and the output of the linear envelope is shown in Figure 4.3 and Figure 3.3.

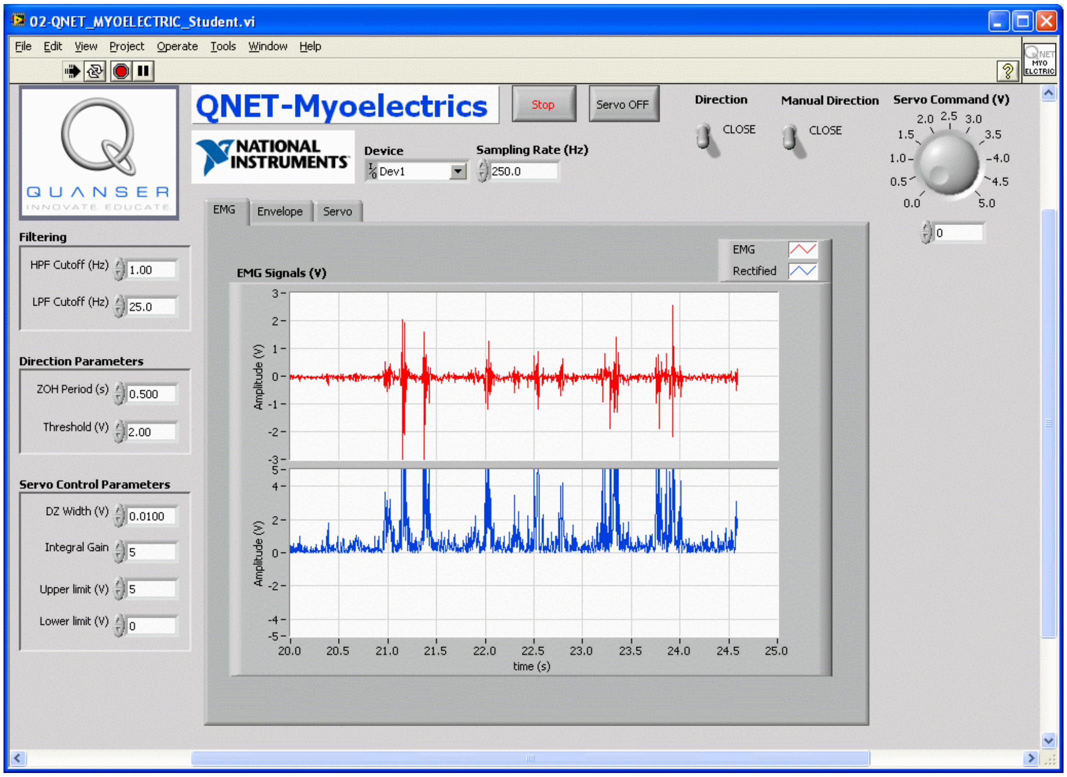


Figure 3.2: QNET Myoelectric VI: EMG Signal tab

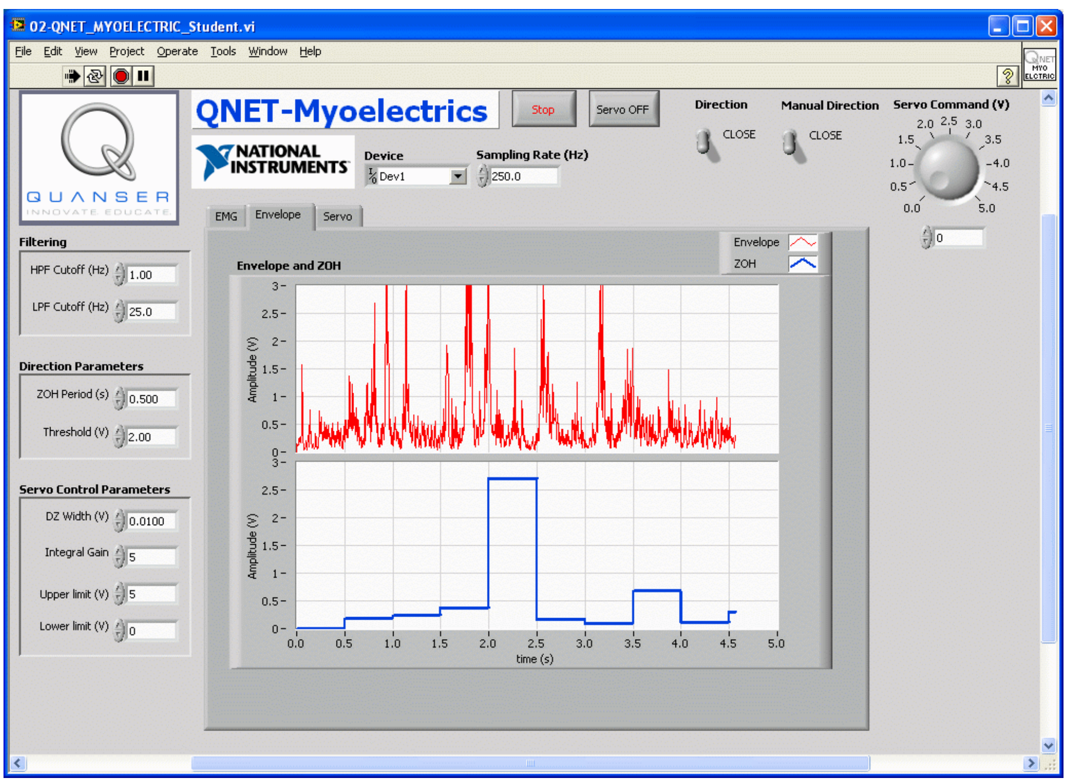


Figure 3.3: QNET Myoelectric VI: Envelope and ZOH tab

3.3 Lab 1: Signal Analysis

1. Go through the steps in Section 2.3 to ensure the EMG sensor is working properly and that you have the *Dynamic Signal Analyzer* instrument up and running.
2. Take a screen capture, similar to Figure 2.2, of when the forearm muscles are contracted.
   Hint: To do this, select the instrument window and press on the *ALT* and *PRTSCN* keys and the image will be saved on the clipboard.
3. Relax the muscle in your forearm and take a second screen capture.
4. Comment on the difference between the power spectrum response when the muscles are contracted and relaxed. Enter the absolute peak voltage of the measured EMG signal (i.e. large positive or negative value attained) and the frequency range where the power spectrum amplitude is above -40 dB.
5. If completed, click on the *Stop* button and close the *Dynamic Signal Analyzer* instrument.

3.4 Lab 2: Linear Envelope

1. Go through the steps in Section 2.3 to ensure the EMG sensor is working properly.
2. Open the QNET_MYOELECTRIC_Student.vi as shown in Section 5.2. **Make sure the correct *Device* is chosen.**
3. Run the VI.
4. Select the *EMG* tab, as shown in Figure 4.3. The top plot in the *EMG Signal (V)* scope is the measured EMG signal (after on-board signal processing) and the bottom plot is the high-pass filtered and rectified signal.
5. Adjust the high-pass filter cutoff frequency, *HPF Cutoff*, such that the rectified signal has less noise. As a guideline, the peaks of the rectified signal should not be much more than double the peaks of the EMG signal. Attach a capture of the response.
6. Select the *Envelope* tab, as shown in Figure 3.3, the top plot is the linear envelope of the EMG signal and the bottom plot is the zero-order hold of the envelope.
7. Adjust the low-pass filter cutoff frequency, *LPF Cutoff*, so the envelope is smoother. What happens when the cutoff is set too low? Summarize the tradeoff and attach the envelope response.
8. Click on the *Stop* button to stop running the VI.

4 EMG CONTROL

4.1 Background

4.1.1 Myoelectric Control

In this section, the EMG envelope signal is used in the control algorithm shown in Figure 4.1 to open and close the clamp on the servo. The servo is driven by the on-board PWM amplifier.

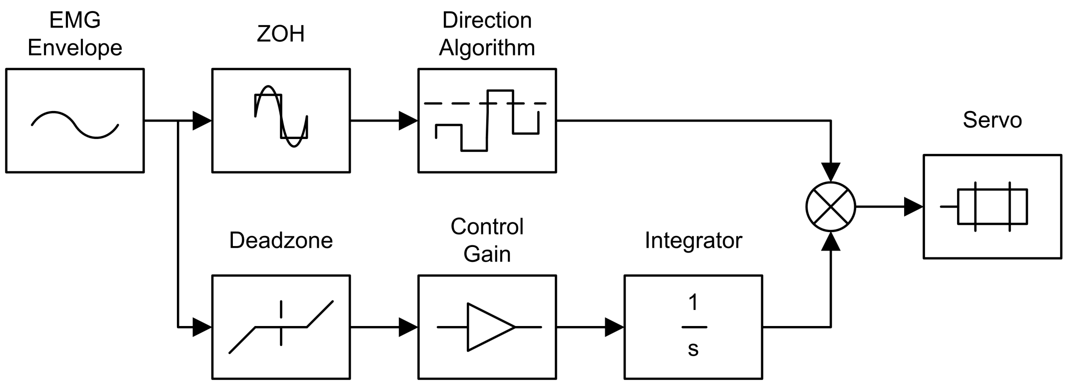


Figure 4.1: Myoelectric servo control algorithm

In order to open/close the clamps at different positions, this task-based control system has two parts: direction control and position control.

Servo Direction Control

The direction algorithm uses the EMG envelope signal to choose when to open or close the clamps and is illustrated in the top portion of Figure 4.1. To change the direction of the servo, i.e. from open to close or close to open, the signal must exceed a set threshold value for a certain time. Thus when the muscle is contracted more than usual, it should trigger a direction change. For example, if the signal is above the pre-defined threshold value of 0.5 V for at least 0.1 seconds then the servo direction should change.

Zero-order hold (ZOH) is typically used to reconstruct digital signals. It holds its input signal for a specified sampling period. The equation is defined as

$$y(t) = \begin{cases} u(t_i), & t - t_i < 0 \text{ and } t_i - t \leq 0 \\ u(t_k), & t_k - t \leq 0 \text{ and } t - t_{k+1} < 0 \end{cases}$$

where t is the current simulation time, t_i is the initial simulation time. For $k = 0, 1, 2, ...$ and the ZOH sampling time T_s,

$$t_k = t_i + kT_s.$$

Figure 4.2 shows how the EMG envelope in sampled when passed through a ZOH with a sampling period of 0.1 seconds. If the ZOH signal exceeds a specified threshold, then the current servo direction is reversed.

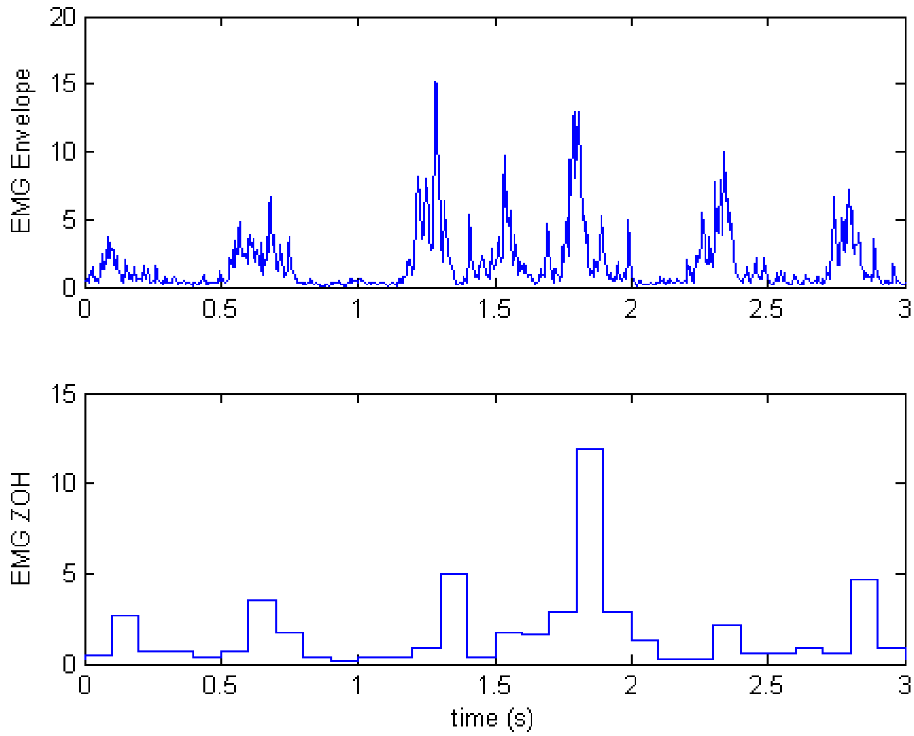


Figure 4.2: Zero-order hold of EMG envelope

The direction function is then

$$dir = \begin{cases} 1, & \epsilon < y_{\text{env}}(t) \\ -1, & y_{\text{env}}(t) \leq \epsilon \end{cases} \tag{4.1}$$

where ϵ is the threshold and $y_{\text{env}}(t)$ is the envelope of the EMG signal.

Servo Position Control

The position of the servo/clamp is proportional to the voltage fed to the PWM amplifier that drives it (i.e. no feedback design required). As shown in Figure 4.1, a dead zone is used to remove any small amplitude signals from the EMG envelope that may cause the servo to move from minor muscle contractions. Basically this prevents the servo from drifting when the muscles are at rest.

As shown in Figure 4.1, the envelope of the EMG signal is amplified by a control gain and passed through an integrator. This generates a voltage that controls the position of the servo. The gain has to be tuned according to the EMG signal. Saturation limits on the integrator ensure the clamp does not close or open passed its limits. The voltage command to the servo can be defined as

$$u(t) = \begin{cases} V_{\text{high}}, & V_{\text{high}} < u \\ V_{\text{low}}, & u < V_{\text{low}} \\ \dfrac{dir\, k_i\, y_{\text{env}}}{s}, & \text{otherwise} \end{cases}$$

were the upper integrator saturation is V_{high}, the lower integrator limit is V_{low}, the integral gain is k_i, the EMG envelope signal is $y_{\text{env}}(t)$, and the dir function is defined in Equation 4.1.

4.2 EMG Control Virtual Instrument

The virtual instrument used to configure the ZOH, and control the servo position is shown in Figure 4.3 and Figure 4.4.

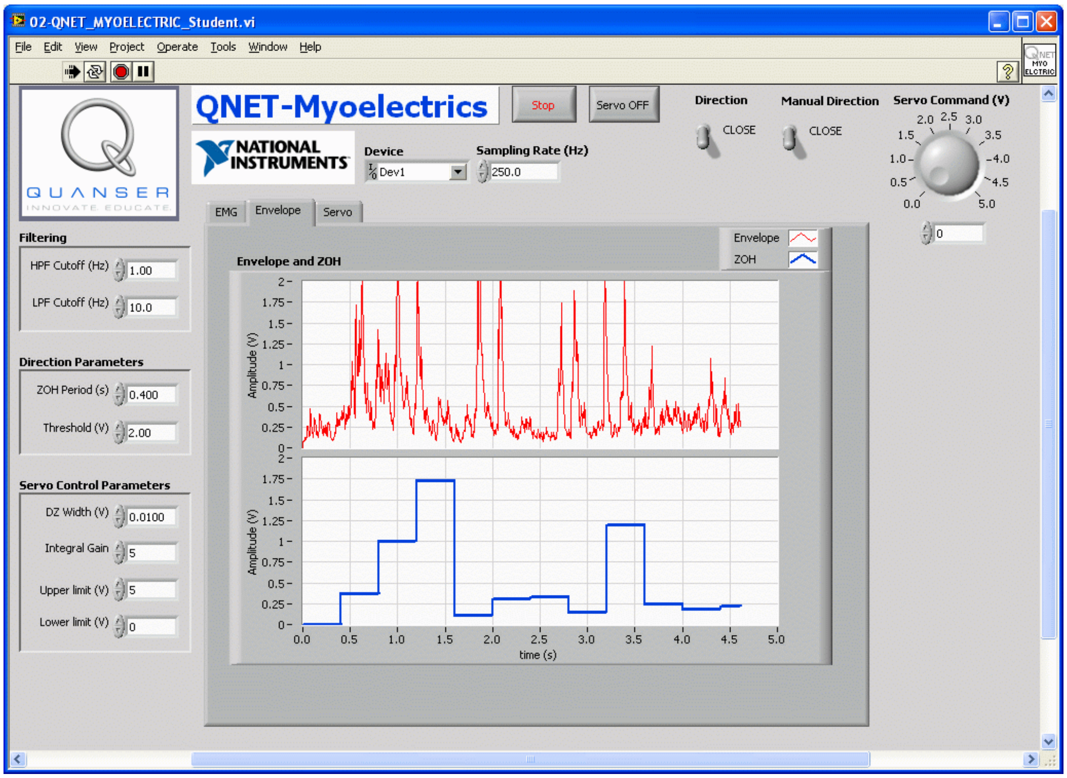


Figure 4.3: QNET Myoelectric VI: Configure the ZOH

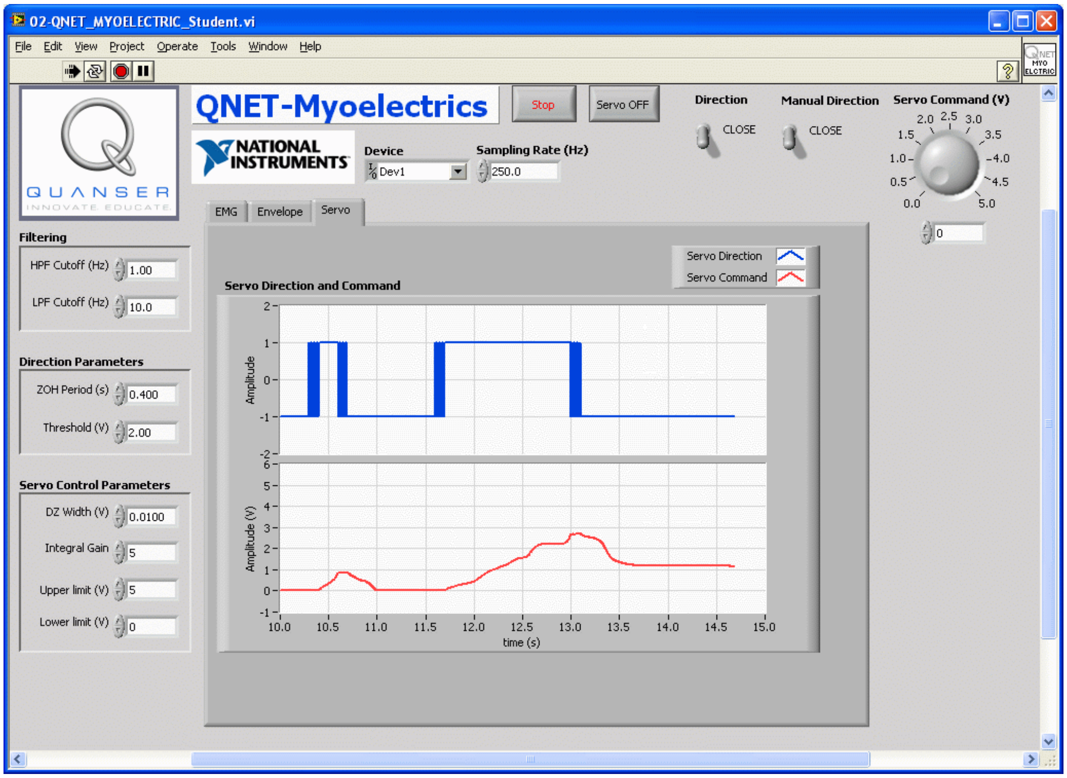


Figure 4.4: QNET Myoelectric VI: Servo tab

4.3 Lab 1: Servo Direction Change

1. Make sure you have gone through the exercises in Section 3.4. The EMG envelope should be configured for a smooth response.

2. Open the QNET_MYOELECTRIC_Student.vi as shown in Section 5.2. **Make sure the correct *Device* is chosen.**

3. Run the VI.

4. Select the *Envelope* tab. As illustrated Figure 4.3, the bottom plot shows the zero-order hold (ZOH) of the envelope.

5. Adjust the sampling period of the zero-order hold, *ZOH Period*, so the output signal is responsive enough to the peaks of the envelope. You need to restart the VI in order for the new ZOH period to take effect. When tuning the period, keep in mind that the ZOH signal will be used to change the direction of the servo when it exceeds a user-defined value. Attach a capture of the response and record the ZOH period used.
■ **Caution: Make sure the ZOH period is an integer multiple of the VI sampling interval.** For instance, by default the VI has a sampling rate of 250 Hz, so the ZOH period must be a multiple of 0.004 seconds (e.g. 0.18, 0.26). Otherwise, an error will be prompted saying "The discrete step size must be an integer multiple of the step size".

6. Click on the Stop button to stop running the VI.

7. Go into the block diagram of the QNET_MYOELECTRIC_Student.vi and find the area that is depicted in Figure 4.5, below. Change the block diagram such that the servo direction, i.e. the *Direction* indicator, changes when the output from the ZOH block exceeds the value in the *Threshold (V)* control. Use the case structure and remove the constant Boolean values (they are just place holders so the VI can be compiled and ran). Copy and paste this section of the block diagram and attach it.

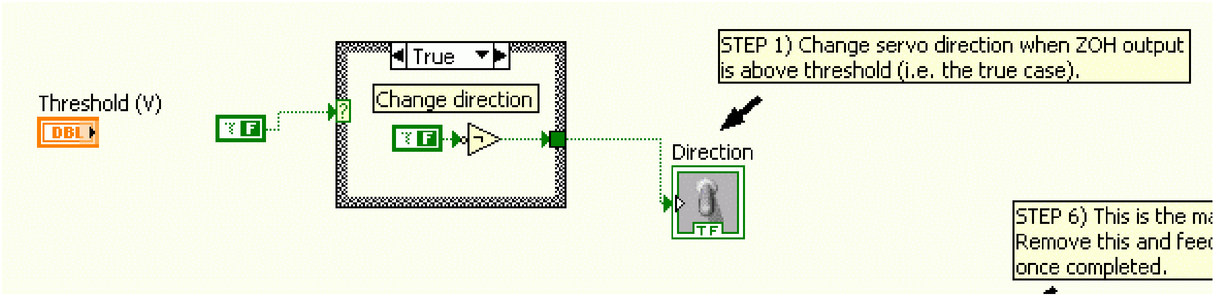
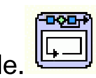


Figure 4.5: Add code to change servo direction when ZOH output exceeds threshold value

Hint: Use the memory VI from the LabVIEW Simulation Module. 

8. Run the VI and verify that the direction is working. The top plot in the *Servo* tab shows the direction of the servo. The clamps on the servo should be **open** when it's -1 (FALSE), and **closed** when it's 1 (TRUE).
9. Capture and attach sample ZOH and the *Direction* responses (from the *Envelope* and *Servo* tabs). Record the ZOH period and threshold used for this test as well.
10. Click on the *Stop* button to stop running the VI.

4.4 Lab 2: Servo Position Control

1. Make sure you have gone through the exercises in Section 3.4. The EMG envelope should be configured for a smooth response.
2. Open the QNET_MYOELECTRIC_Student.vi as shown in Section 5.2. **Make sure the correct *Device* is chosen.**
3. Run the VI.
4. The *Servo Command (V)* control is directly connected to the D/A#0 that drives the PWM amplifier connected to the servo. Vary the *Servo Command (V)* knob in the VI and examine its affect on the actual servo position. Describe how the voltage affect the position of the servo clamps.
5. Click on the *Stop* button to stop running the VI.
6. Open the block diagram and find the section shown in Figure 4.6, below. Connect the output of the zero-order hold signal to a dead zone. Use *DZ Width (V)* control to specify the width of the dead zone function. Attach a copy of your code.

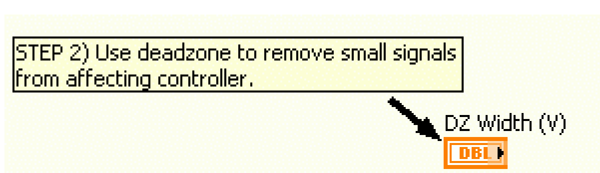


Figure 4.6: Wire ZOH output to dead zone

7. Find the section in the block diagram shown in Figure 4.7. Multiply the dead zone output by the *Integral Gain* control. This signal is basically the servo command rate that will later be fed to an integrator. If the direction is TRUE (i.e. positive) then the clamps should close. If the direction is FALSE (i.e. negative) then the clamps should be open. Add this logic to the code and attach an image of the block diagram.

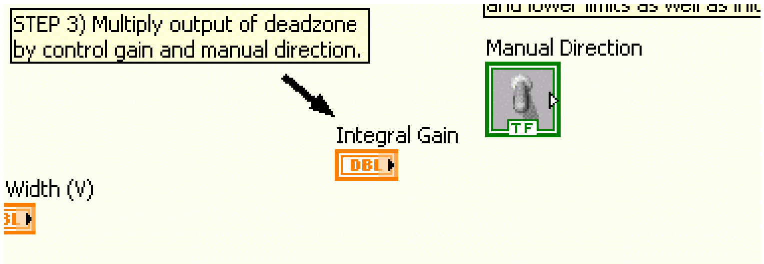


Figure 4.7: Multiply dead zone output by control gain and manual direction

8. Go to the block diagram section shown in Figure 4.8. Add an integrator and connect the signal from 7 into its input. Make sure to setup the lower and upper saturation limits of the integrator with the *Upper limit (V)* and *Lower limit (V)* controls. The initial condition should also be wired to the *Lower limit (V)*. Attach an image of your block diagram.

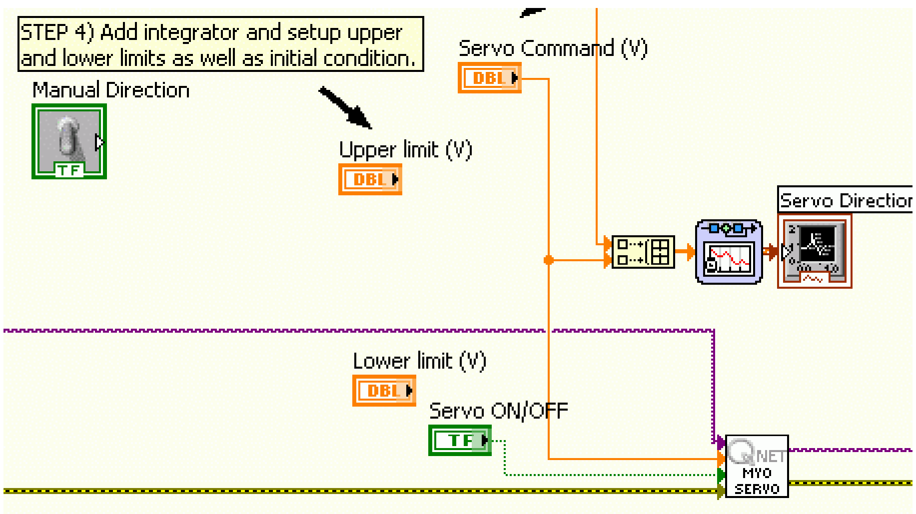


Figure 4.8: Add an integrator

9. Disconnect the *Servo Command (V)* control and wire the integrator output instead as shown in Figure 4.9. This should be connected to the *Servo Direction* and *Command* chart (second input of cluster) and the *Servo (V)* terminal on the *QNET_MYOELECTRIC_Servo_Write* sub-VI. Also, make sure the direction from the *Manual Direction* control is plotted on the *Servo Direction* and *Command* chart (first input of cluster). Attach an image of the block diagram.

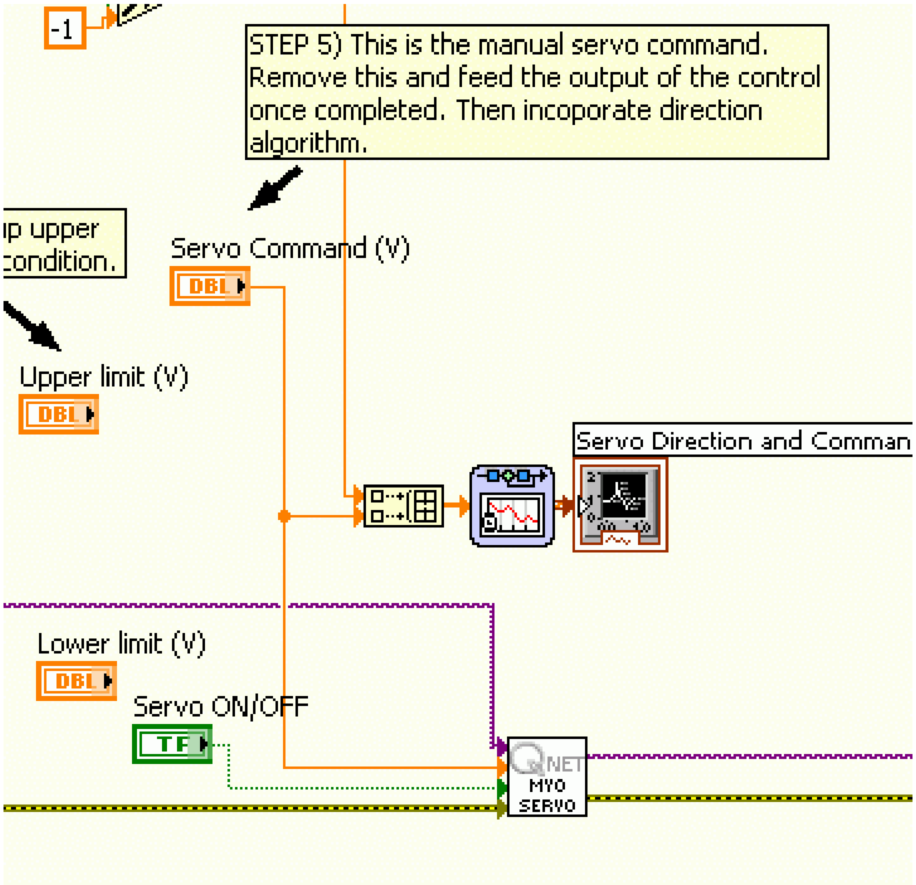


Figure 4.9: Disconnect manual servo command and use output of integrator

10. Run the QNET_MYOELECTRIC_Student.vi.
11. Press on the *Servo OFF* button to enable the servo. When the button is bright green and reads "Servo ON", then you can feed voltage to the PWM and drive the servo.
12. Test the servo position control with the manual direction switch. On start-up the servo clamps are closed, so to open them make sure the *Manual Direction* control is set to True (i.e. open clamps) and contract your forearm. The servo command is based on the EMG envelope. So you will have to tune the integral gain such that the clamp position moves at a reasonable rate. You may also have to change the dead zone width to avoid the clamps from moving when the muscle is relaxed. Attach a representative response of the *Servo Direction* and *Command* that shows the clamps opening fully and closing.
13. Click on the *Stop* button to stop running the VI.

4.5 Lab 3: Full Servo Control

1. Make sure you have gone through the exercises in Section 4.3 and Section 4.4.
2. Open the QNET_MYOELECTRIC_Student.vi as shown in Section 5.2.
3. Open the VI block diagram.
4. Combine the direction algorithm designed in Section 4.3 with the servo position regulation made in Section 4.4. Attach an image of the block diagram.
5. **Make sure the correct *Device* is chosen.**

6. Run the VI.
7. Press on the S*ervo OFF* button to enable the servo. The button should be bright green and read "Servo ON".
8. Test out the full servo control. You may have to tune the envelope and control parameters. Once you can easily open and close the position of the clamps using your muscles, record the parameters.

Parameters	Value	Units
HPF Cutoff		Hz
LPF Cutoff		Hz
ZOH Period		s
Threshold		V
DZ Width		V
Integral Gain		
Upper Limit		V
Lower Limit		V

Table 4.1: QNET myoelectric trainer filter and control parameters

9. Record the response when using the full servo control to open and close the clamps. Give the results from both the *Envelop* and *ZOH* scope and the *Servo Direction* and *Command* scope. Based on your test results, could the system be used to control a myoelectric prosthesis?
10. Click on the *Stop* button to stop running the VI.

5 SYSTEM REQUIREMENTS

Required Hardware

- NI ELVIS II
- Quanser QNET Myoelectric Trainer. See QNET MYOELECTRIC User Manual [1].

Required Software

- NI LabVIEW®2011 or later
- NI DAQmx 9.3.5 or later
- NI LabVIEW Control Design and Simulation Module 2011 or later
- *ELVIS II Users*: ELVISmx 4.3 or later (installed from ELVIS II CD).

■ **Caution: If these are not all installed then the VI will not be able to run!** Please make sure all the software and hardware components are installed. If an issue arises, then see the troubleshooting section in the QNET MYOELECTRIC User Manual [1].

5.1 Overview of Files

File Name	Description
QNET MYOELECTRIC User Manual.pdf	This manual describes the hardware of the QNET Myoelectric trainer system and how to setup the system on the ELVIS.
QNET MYOELECTRIC Lab Workbook (Student).pdf	This laboratory guide contains pre-lab questions and lab experiments demonstrating how to design and implement controllers on the QNET MYOELECTRIC system LabVIEW®.
QNET_MYOELECTRIC_Student.vi	Control position of servo clamp using EMG sensor.

Table 5.1: Files supplied with the QNET MYOELECTRIC Laboratory.

5.2 Myoelectric VI

This VI can be used to view the EMG sensor measurements and the output of the linear envelope. Further, the envelope parameters can be changed on-the-fly and the position of the clamps on the servo can be controlled manually using the *Manual Direction* and *Servo Command* controls. This VI can also be used to design an algorithm to control the position of the clamps from the EMG sensor. Table 5.2 lists and describes the main elements of the QNET-MYOELECTRIC Student virtual instrument user interface. Every element is uniquely identified through an ID number and located in Figure 5.1, Figure 5.2, and Figure 5.3.

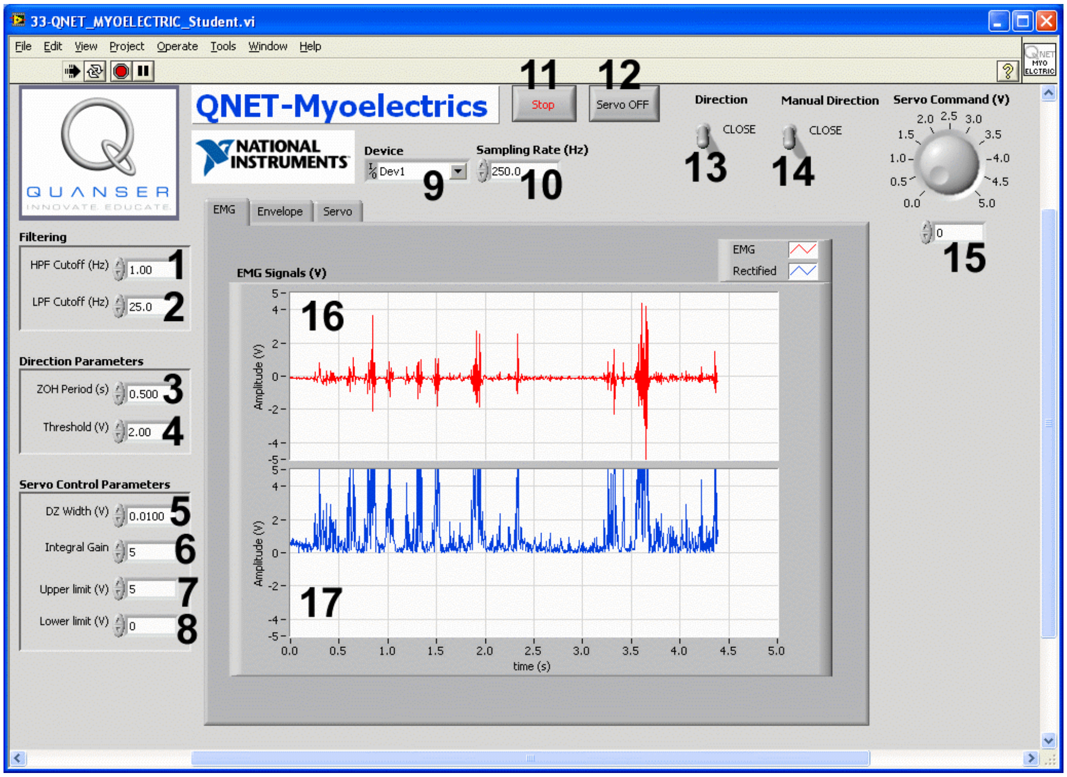


Figure 5.1: QNET Myoelectric Student VI

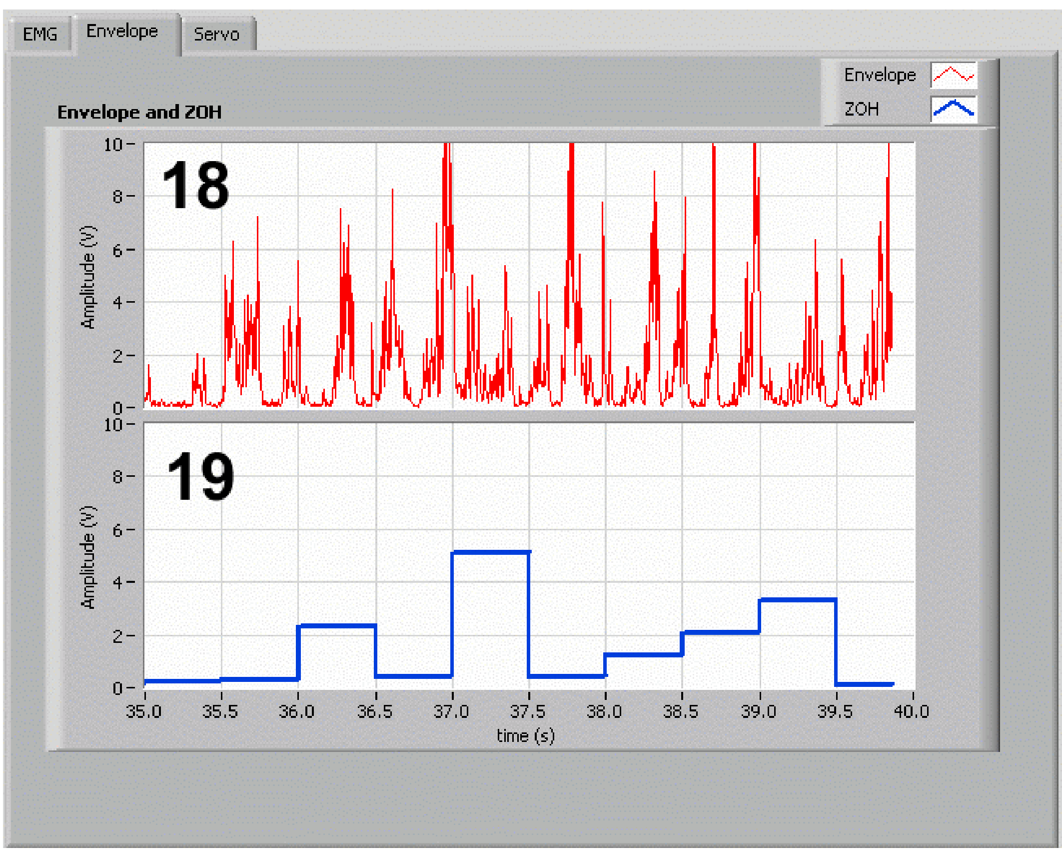


Figure 5.2: NET Myoelectric VI: Envelope tab

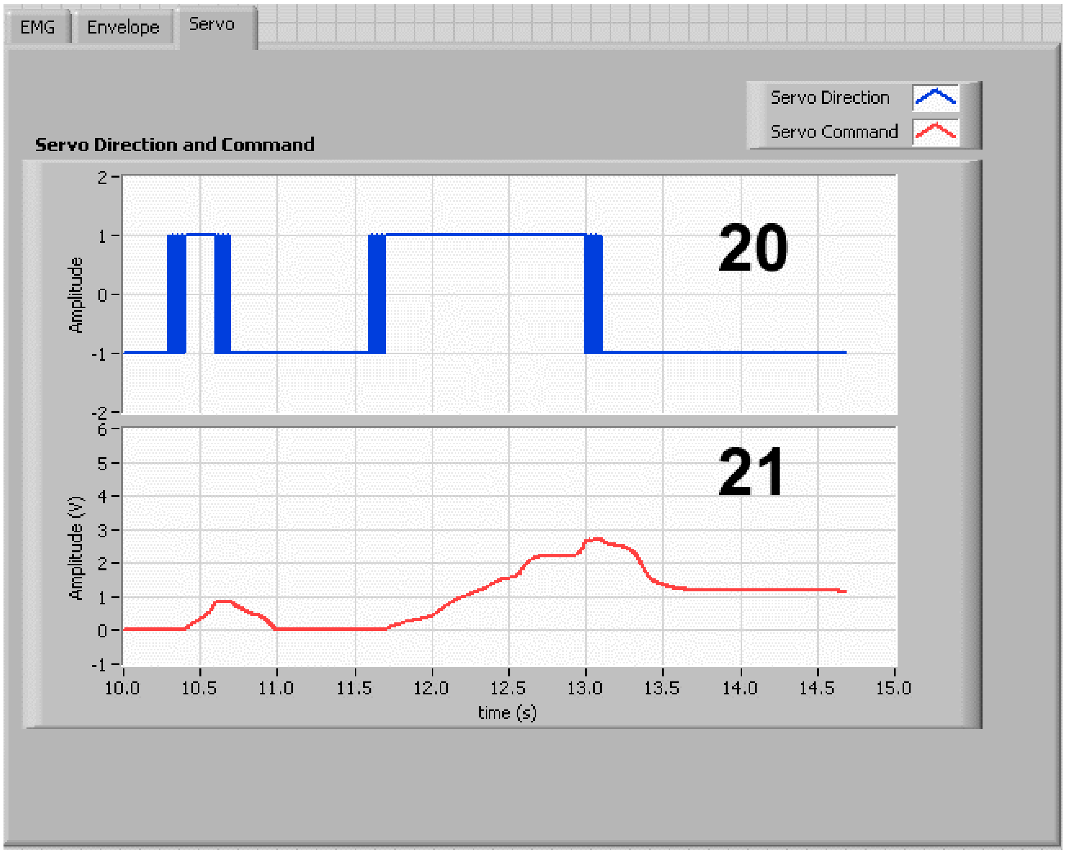


Figure 5.3: QNET Myoelectric VI: Servo tab

ID #	Label	Symb	Description	Unit
1	HPF Cutoff Frequency		High-pass filter cutoff frequency	Hz
2	LPF Cutoff Frequency		Linear envelope low-pass filter cutoff frequency	Hz
3	ZOH Period	T_s	Sampling period of the zero-order hold function	s
4	Threshold	ϵ	Value that ZOH signal has to exceed to change servo control direction	V
5	DZ Width		Width of dead zone function	V
6	Integral Gain	k_i	Integral gain used in servo position control	V/V
7	Upper limit		Maximum output value of integrator	V
8	Lower limit		Minimum output value of integrator	V
9	Device	K	Select the NI DAQ device	V
10	Sampling Rate	τ	Sets the sampling rate of the Hz	
11	Stop		Stops the LabVIEW VI from running	
12	Servo OFF		Press down to enable servo command	
13	Direction	dir	Indicates the direction of the servo control	
14	Manual Direction		Used to manually control the direction of the servo	
15	Servo Command	ω_m	Controls position of servo directly	V
16	Scope: EMG Signals (V)	y	Measured EMG signal	V
17	Scope: EMG Signals (V)	$\|y\|$	Rectified EMG signal	V
18	Scope: Envelope and ZOH	y_{env}	Linear envelope of EMG	V/s
19	Scope: Envelope and ZOH		Zero-order hold of envelope	V/s
20	Scope: Servo Direction and Command	dir	Servo control direction (clamps open = -1, clamps close = 1)	
21	Scope: Servo Direction and Command	u	Servo position command	V

Table 5.2: Components of QNET MYOELECTRIC VI

6 LAB REPORT

This laboratory contains three groups of experiments, namely,

1. EMG Sensor Setup,
2. EMG Signal Processing, and
3. EMG Control.

For each experiment, follow the outline corresponding to that experiment to build the *content* of your report. Also, in Section 6.4 you can find some basic tips for the *format* of your report.

6.1 Template for Content (EMG Sensor Setup)

I. PROCEDURE

1. *Finding Resistance*
    - Briefly describe the main goal of the experiment.
    - Briefly describe the experimental procedure in Step 7 in Section 2.3.

6.2 Template for Content (EMG Signal Processing)

I. PROCEDURE

1. *Signal Analysis*
   - Briefly describe the main goal of the experiment.
   - Briefly describe the experiment procedure in Step 4 in Section 3.3.
2. *Linear Envelope*
   - Briefly describe the main goal of the experiment.
   - Briefly describe the experiment procedure in Step 5 in Section 3.4.

II. RESULTS
Do not interpret or analyze the data in this section. Just provide the results.

1. Envelope response from step 7 in Section 3.4.

III. ANALYSIS
Provide details of your calculations (methods used) for analysis for each of the following:

1. What is the difference betwen the power spectrum responses in Step 4 of Section 3.3?
2. High-pass filter cutoff frequency adjustments that were made in Step 5 of Section 3.4.
3. Low-pass filter cutoff frequency adjustments and observations in Step 7 of Section 3.4

6.3 Template for Content (EMG Control)

I. PROCEDURE

1. *Servo Direction Change*
    - Briefly describe the main goal of the experiment.
    - Briefly describe the experimental procedure in Step 7 in Section 4.3.
2. *Servo Position Control*
    - Briefly describe the main goal of the experiment.
    - Briefly describe the experimental procedure in Step 4 in Section 4.4.
3. *Full Servo Control*
    - Briefly describe the main goal of this experiment.
    - Briefly describe the experimental procedure in Step 4 in Section 4.5.

II. RESULTS
Do not interpret or analyze the data in this section. Just provide the results.

1. Envelope and ZOH response from 5 in Section 4.3.
2. Direction change code from Step 7 in Section 4.3.
3. ZOH and *Direction* response from 9 in Section 4.3.
4. Dead zone code from Step 6 in Section 4.4.
5. Integral gain code from Step 7 in Section 4.4.
6. Integrator code from Step 8 in Section 4.4.
7. Servo position control code from Step 9 in Section 4.4.
8. *Servo Direction* and *Command* response from 12 in Section 4.4.
9. Complete servo control code from Step 4 in Section 4.5.
10. Sample *Envelope*, *ZOH*, *Servo Direction* and *Command* responses from 9 in Section 4.5.

III. ANALYSIS
Provide details of your calculations (methods used) for analysis for each of the following:

1. ZOH sampling period adjustments made in Step 5 in Section 4.3.
2. Description of the behaviour of the servo clamps in Step 4 in Section 4.4.
3. Servo direction and command adjustments in Step 12 in Section 4.4.
4. Envelope and servo control parameters from Step 8 in Section 4.5.

IV. CONCLUSIONS
Interpret your results to arrive at logical conclusions for the following:

1. Analysis of the complete control algorithm in Step 9 in Section 4.5.

6.4 Tips for Report Format

PROFESSIONAL APPEARANCE

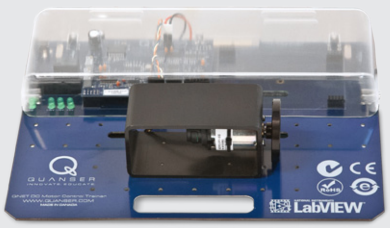
- Has cover page with all necessary details (title, course, student name(s), etc.)
- Each of the required sections is completed (Procedure, Results, Analysis and Conclusions).
- Typed.
- All grammar/spelling correct.
- Report layout is neat.
- Does not exceed specified maximum page limit, if any.
- Pages are numbered.
- Equations are consecutively numbered.
- Figures are numbered, axes have labels, each figure has a descriptive caption.
- Tables are numbered, they include labels, each table has a descriptive caption.
- Data are presented in a useful format (graphs, numerical, table, charts, diagrams).
- No hand drawn sketches/diagrams.
- References are cited using correct format.

REFERENCES

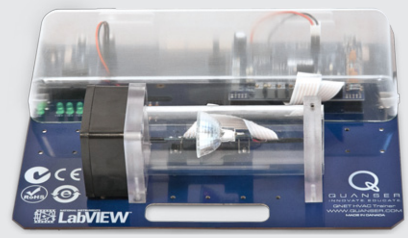
[1] Quanser Inc. *QNET Myoelectric Control Trainer User Manual*, 2011.

Six QNET Trainers to teach introductory controls using NI ELVIS

QNET DC Motor Control Trainer
teaches fundamentals of DC motor control

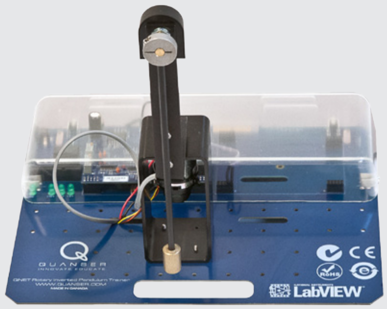


QNET HVAC Trainer
teaches temperature (process) control



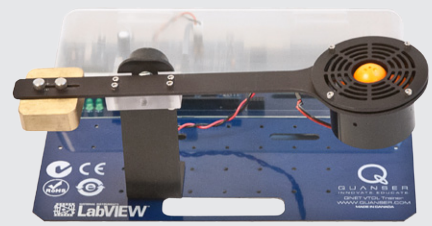
QNET Mechatronic Sensors Trainer
teaches functions of 10 different sensors

QNET Rotary Inverted Pendulum Trainer
teaches classic pendulum control experiment



QNET Myoelectric Trainer
teaches control using principles of electromyography (EMG)

QNET VTOL Trainer
teaches basic flight dynamics and control



Quanser QNET Trainers are plug-in boards for NI ELVIS to teach introductory controls in undergraduate labs. Together they deliver added choice and cost-effective teaching solutions to engineering educators. All six QNET Trainers are offered with comprehensive, ABET*-aligned course materials that have been developed to enhance the student learning experience.

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*ABET Inc., is the recognized accreditor for college and university programs in applied science, computing, engineering, and technology. Among the most respected accreditation organizations in the U.S., ABET has provided leadership and quality assurance in higher education for over 75 years.