

Teaching Virtual Instrumentation to Biomedical Engineering Students

Jonathon Toft-Nielsen¹, Jorge Bohórquez², Qian Shen³

Abstract – In order to address the growing importance of virtual instrumentation, our institution began offering a course entitled “LabView Applications in Biomedical Engineering”. The goal of this one credit course was to better prepare students for their engineering practice by developing skills in virtual instrumentation and the creation of biomedical device prototypes that involve real time physiological signal acquisition and processing. A hands-on methodology that fosters creativity and self-driven learning was developed for this course. Students are taught using a combination of traditional lectures interspersed with interactive examples, guided assignments, and self-driven problems. Cloud computing is used to afford students with 24/7 access to the software, and homework is assigned to help reinforce lessons outside of the classroom. The course culminates in a final project which tasks students with developing biomedical monitoring device (ECG, EEG or EMG) including all the functionalities of like devices.

Keywords: Virtual Instrumentation, Problem-Oriented Learning, Medical Signals, Engineering Education

INTRODUCTION

The Biomedical Engineering (BME) Department at the University of Miami has 14 primary faculty and approximately 200 undergraduates spread out among three concentrations: premedical, electrical and mechanical. The industrial advisory board of the BME department (after reviewing information gathered on recent graduates and the state of the industry) determined that our graduates would be better able to compete in the labor market if they given more exposure using modern computer tools for: 1) develop prototypes for real-time processing of physiological signals and 2) perform mechanical design and modeling. They advised the BME department to teach Pro-Engineer (or SolidWorks) to students in the mechanical concentration, and to teach LabVIEW, to the students in electrical concentration. Since BME industry is fertile ground for BME graduates and this dynamic industry requires more entrepreneurs generating new jobs [1], the craftsmanship and design skills will enable the BME graduates to capitalize on this opportunity and create a high and lasting impact in society.

Because of the nature of the Biomedical Engineering field, undergraduate studies in BME are necessarily broad. Yet, in order to impart the fundamental principles of engineering upon students, BME undergraduate curricula must also provide depth. During their studies, students are required to learn biology and physiology in addition to basic engineering science, which itself requires strong fundamentals in calculus, physics and chemistry [2]. As a result the curriculum is overcrowded (135 credits in four years, compared to 126/127 credits in Mechanical/Electrical Engineering). As new tools and concepts become important in the industries which students will enter, they must be incorporated into the curricula in such a way that they have a minimum credit impact.

¹ University of Miami, Department of Biomedical Engineering, P.O. Box 248294
Coral Gables, FL 33124, E-mail: j.toftnielsen@miami.edu

² University of Miami, Department of Biomedical Engineering, P.O. Box 248294
Coral Gables, FL 33124, E-mail: jbohorquez@miami.edu

³ Mount Sinai Medical Center, Wien Center for Alzheimer’s Disease, 4300 Alton Rd.,
Miami Beach, FL 33140, E-mail: qshen@msmc.com

Following the advice from the industrial advisory board, BME began offering a single credit course entitled “BME 507: LabView Applications in Biomedical Engineering” as a requirement for electrical concentration students. Additionally, the course was also open as a technical elective to students in the other concentrations, or to students in the graduate program.

In recent years, LabVIEW has become a prevalent tool in many engineering curriculums [3]. Initially the course was taught as a conventional lecture, where the different language tools and structures of the software were introduced in a systematic fashion, closely following the text book by Bishop [4]. While an excellent source book and teaching tool, the systematic method utilizing Bishop's book was not conducive given the limited credit allocation of the course and the varied background of the students enrolled. By the end of the initial semester, most students, while expressing an interest in the software had not reached a level of depth with the program to feel comfortable using it outside of the confines of structured exercises. It was necessary to efficiently teach a broad spectrum of concepts and foster confidence in the use of the program, all while maintaining a limited course credit impact and still meeting the expectations of a diverse student population. The proposed solution shifted the emphasis from a tool oriented discipline (like conventional engineering programs) to a more problem oriented discipline (like medicine) without compromising its engineering character (design and craftsmanship). This strategy has helped to grasp the attention and harness the motivation of both the pre-medical students, more sensitive to the clinical considerations, and the electrical and mechanical concentration students whom are more open to the technical details.

COURSE DESCRIPTION

Course Objectives

The overall objective of the BME507 course is to introduce and familiarize BMEs with virtual instrumentation and the LabVIEW software. The end goal is to provide students with the ability to develop a fully formed virtual instrument (VI), capable of acquiring, processing, displaying and storing real time bio-signals, by the end of the semester. The major challenge in teaching this course is to reach the level of sophistication set out in the goal in a 1-credit hour course, where students typically have zero familiarity with the LabVIEW software prior to enrolling in the course. Additionally, while the course is only a requirement for students in the electrical concentration, students from other concentrations, or from the graduate level often exhibit interest in learning the software and enroll. These students have varying familiarity with general programming concepts.

Course Strategy

The strategy adopted to teach BME507 involves three phases. Each class session is focused upon teaching a number of programming concepts or features of LabVIEW. Initially, the concept of the lecture is presented to the class via the white board or projector, similar to a “traditional” class lecture. Students are expected to take notes and are encouraged to ask questions during this phase. After the concepts have been introduced, the class moves into the second phase, which consists of a guided example. Here, students are exposed to the new material "in situ" so to speak, within a concrete application. During this phase, a predefined problem is developed and solved in the LabVIEW environment that illustrates the concepts and or LabVIEW features that have just been presented during the first phase of the class. The instructor's terminal is projected on screen for the whole class to see, as he moves through each step in solving the example. During this time, students follow along on their own terminals, developing the example simultaneously. Questions from students are encouraged, and if and when they arise, immediately expounded upon, so that the class as a whole might benefit from the addition insight. Upon completing the guided example (or examples), students are presented with a self-guided exercise which is also designed to reinforce the day's topics (a sample assignment is provided in Appendix 1). Typically, these self-guided exercises are posed in the form of a problem, which can be solved utilizing the tools the students have been exposed to during the day's session. During the self-guided phase, students work independently at their own terminals to develop a solution to the problem in the LabVIEW environment. Students are encouraged to come up with unique solutions to the problems, and the instructor is available for on demand, one-on-one help. While the instructors always have a particular solution in mind, a concerted effort is made to not stifle unique approaches to the problems that might be taken by the students. In providing guidance to the students, the instructor(s) will try and point out the flaws or faults in the students particular solution, rather than trying to steer the student back towards the “prescribed” method of solving the problem. In this way, the self-driven assignments provide the added benefit of helping to bolster the students problem solving and debugging skills. At the end of each class session, students are given a homework assignment to complete before the next class session in order to further reinforce the week's topics. Each student is

provided with access to the LabVIEW software via the University's Cloud (ViAComp) computing system so that they can complete the homework at their convenience.

Over the course of the semester, exercises and examples are designed in such a way that they build on each other from class to class, ever increasing in complexity. Students are taught to incorporate old exercises into new VIs as sub-VIs in later exercises and projects (the course material is designed to lend itself to this outward expansion). For instance, in an early exercise, students develop a VI which implements the conversion of Celsius to Fahrenheit. Later they incorporate this into a more complex VI which allows the user to select from a number of temperature scale conversions. These VIs ultimately are incorporated into a larger program which acquires real temperature values from the environment using a thermistor and allows the user to select from a number of different temperature scales to display that information.

COURSE CONTENT

Course Materials and Structure

Currently, the BME 507 class room is equipped with 8 student workstations and 1 instructor workstation. For any given semester, the enrollment is capped at 16 students (2 per workstation), but typical enrollment ranges between 5 and 12 students. Each workstation consists of a computer with the LabVIEW software and installed PCI 6024 acquisition board, a function generator, a PowerLab bio-amplifier, and a LabVIEW BNC-2120 interface box. Additionally, over the course students will utilize a number of hardware elements which will either send information to be processed by LabVIEW or be operated by signals coming from LabVIEW. Hardware includes:

- Thermistor and Thermocouple
- Photodiodes
- RED/GREEN/BLUE Light Emitting Diodes (RGB LEDs)
- Servo and stepper motors (See Appendix 1)

Creating VIs which can interact with a number of different types of hardware shows students the versatility and real world impact which virtual instrumentation can have, and lay the foundations for potential applications of the software in their academic or industrial futures.

The general topics covered in the course are as follows:

- I. Labview Basis – The dual workspace, palettes, VIs, basic structures and data types, getting help and editing and debugging programs.
- II. SubVIs - How to design VIs so that they can easily be adapted to be used within larger VIs.
- III. Loops and Structures – (For Loops, While Loops Case structures, and Timed Loops)
- IV. Arrays, clusters, Charts and Graphs
- V. Data acquisition
- VI. Strings and File Input/Output
- VII. Plots, Data analysis and signal processing

The Final Project

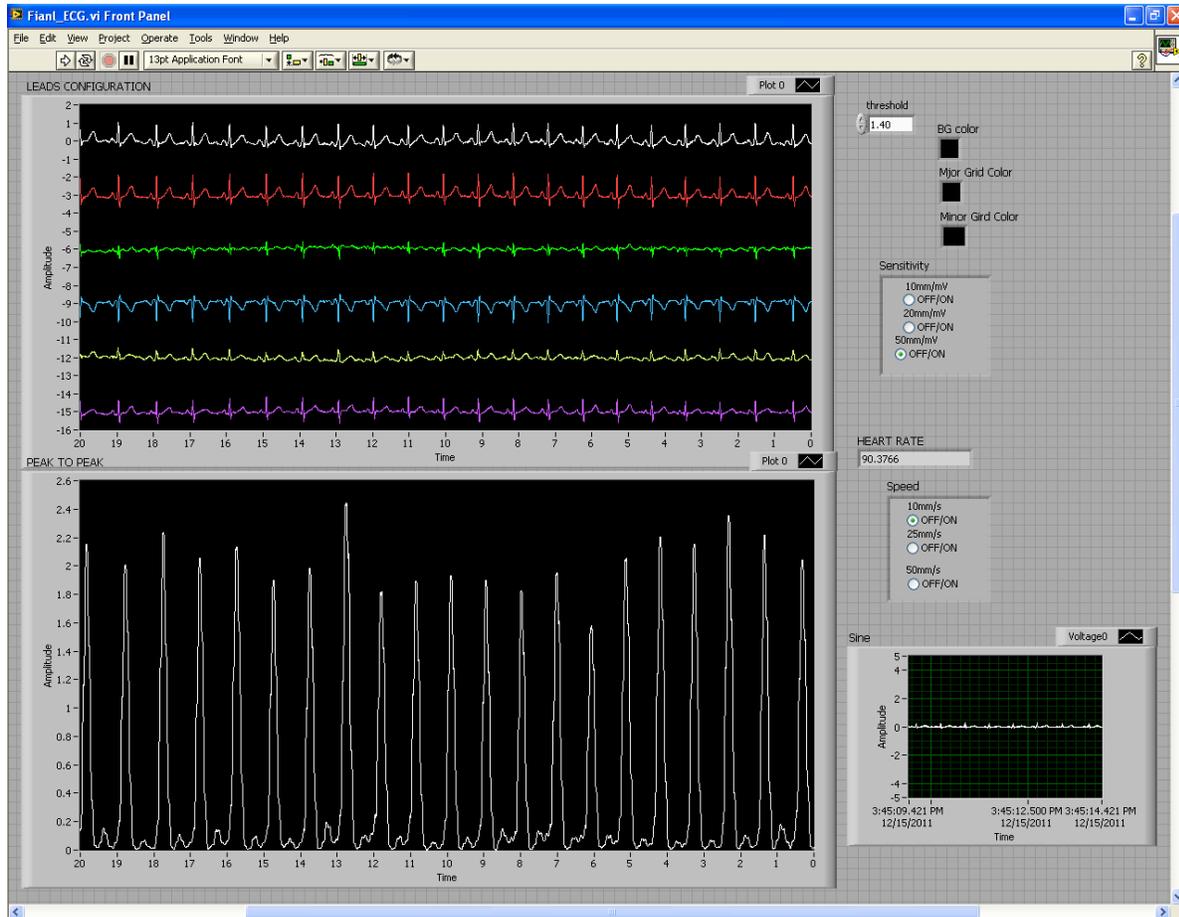
Towards the end of the semester, the assignments culminate in a final project, the design and implementation of a Virtual Bio-signal Monitoring system. Students are given three weeks to plan, develop and test the VI. The ultimate litmus of the project is when students acquire their own real-time bio-signals using their creation.

During the fall 2010 course, the students developed a Virtual Electrocardiogram (ECG) capable of acquiring, analyzing and storing ECG data. The problem statement included the following specifications for the device:

- Sampling Rate: 240 samples/sec

- Acquire TWO real-time ECG signals from a subject: The standard Lead I and Lead II configurations.
- Data Processing: Notch filter.
- Using these signals, derive the other 4 standard Lead configurations: Lead III, augmented vector left (aVL), augmented vector right (aVR) and augmented vector foot (aVF).
- Provide an indicator that displays the instantaneous heart rate derived from the Lead I signal.
- Display all 6 ECG Lead configuration signals simultaneously.
- Provide user controls that allow for the adjustment of the time and voltage scales of the virtual display, as well as the ability to save a segment of ECG data to file.

Despite the complexity of the project, students are aided by the fact that assignments and lectures over the course of the semester have been specifically tailored to provide them with the basic concepts and skills they require for this project: Real-time acquisition and display of data, user defined controls on the virtual instrument, processing and filtering of real-time signals, etc. Over the course of the three weeks, students are afforded additional time in the classroom outside of the normal scheduled lecture times, and the instructors provide any additional support the students might require.



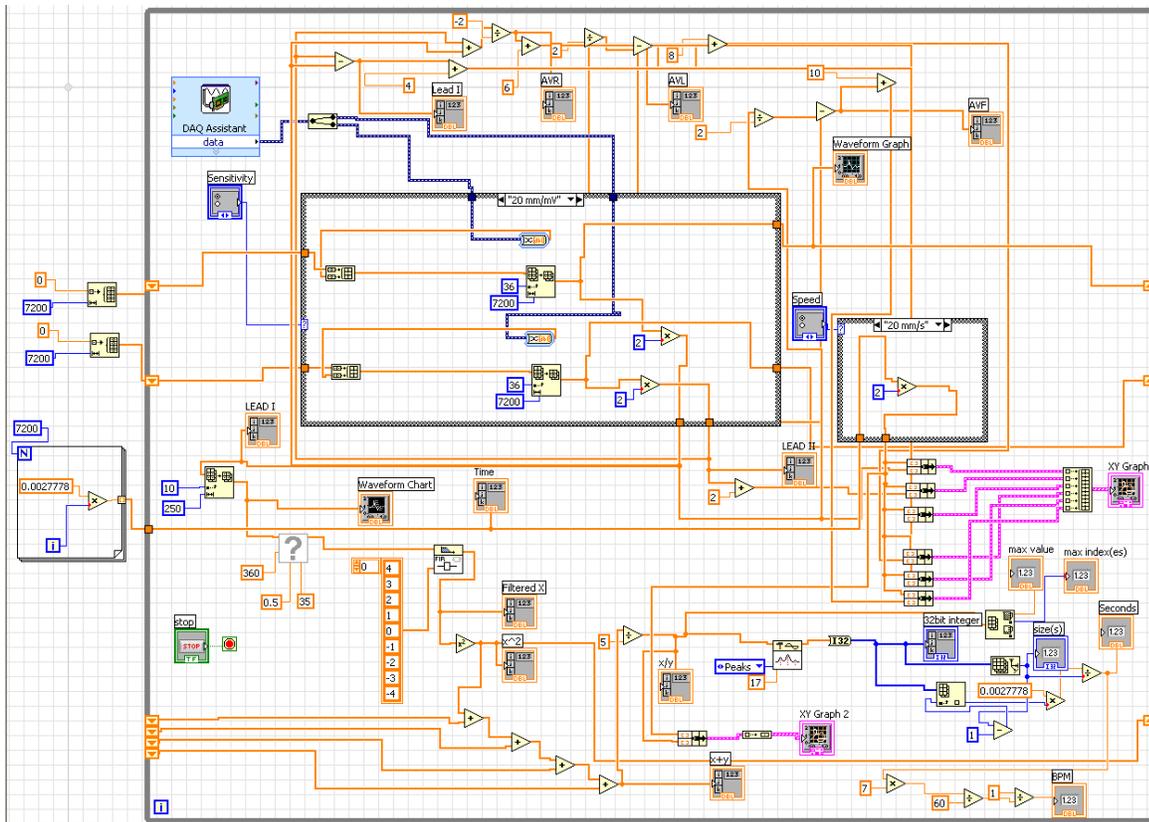


Figure 1. Student Front Panel and Block Diagram for the final project extracted from two different student projects.

COURSE ASSESSMENT

In addition to the standardized assessment forms utilized by the University, course specific assessment material has been developed by the instructors of BME507 to help improve further iterations of the course. These assessment materials involve a pre and post semester interviews with the students, as well as a post semester questionnaire with specific questions about the course content and implementation.

Standardized Class Surveys

At the end the semester the students are invited to fill out a three part, anonymous evaluation of the course. The first part asks for a quantitative evaluation of the instructor, the second deals with an evaluation of the fairness of the course grades, and in the third part, the students write candid comments about the course content, the instructor, and a general advice to new students. These candid responses provide valuable feedback for continuous improvement.

Additional Assessment

Beginning in the fall of 2011, instructors in this course expanded the assessment process by including a course specific questionnaire. This form includes seven free answer questions designed to extract more course specific feedback from students. Questions primarily focus on the structure of the course, and the teaching methods employed. Not only are students asked if the course was effective in meeting the objectives set out at the outset of the semester, but urges students to provide their thoughts on how the teaching approach used might be improved. Five students were enrolled in the fall 2011 semester and provided below are the questions posed and responses collected from students:

Table1. BME507 Student Assessment Questions and Answers

| Question | Comments |
|---|--|
| <p>“Do you feel the objectives set out in the course syllabus were met? If not, which were not met? Are there any topics you feel should be added or omitted?”</p> | <ul style="list-style-type: none"> • “All of the objectives set out in the syllabus were met over the course of the semester. I feel the class could be better if it were to meet twice a week instead of once a week. One thing I would like to see added to the syllabus is how industry uses Labview. • “Yeah, I think the objectives were well met. I don’t see how to improve it. I like the open-endedness of the class. I’m an independent worker so essentially learning on my own while the instructor provides a framework and support when needed is my format of choice.” • “Yes. Ran on schedule. I don’t feel like anything was omitted.” • “I can’t think of anything that wasn’t covered...” • “Yes, all topics were covered. I would have liked to implement sub-VIs more often, because we did it so few times that I do not feel familiar with using them. Everything else was implemented well and commonly.” |
| <p>“Briefly describe your experience with programming in general prior to taking this course”</p> | <ul style="list-style-type: none"> • “Basic programming using Matlab. C++ with logic.” • “Intermediate experience with Matlab, beginner experience with C++ and no experience with Labview.” • “I had minimal experience with programming, C++ and Matlab.” • “C++, Java, Matlab, P-Spice” • “A lot of Matlab, basics of C++” |
| <p>“How do you feel the approach taken in this class differed from your experience learning other programming software/languages? Do you feel the more problem oriented approach adopted for this course aided or abetted your learning, and what would you list as the pros and cons of the different teaching styles you have experienced?”</p> | <ul style="list-style-type: none"> • “The class size was smaller so we had much more personal assistance and learning. Since the class isn’t heavily lecture based, we got the opportunity to figure it out ourselves and make mistakes that might not have been covered, so we get a better understanding of the formatting and limitations of Labview.” • “More hands on, but aided. I like this style.” • “Since the class was a small group, the learning experience was a more personal, one-on-one learning experience, which was great because I needed all the help I could get. Also, the problem oriented approach adopted for the course guided me to better learn Labview. The only problem I had was, since the instructor was helping each of use one at a time, some of us had more questions than others and it took some time before you can get help with your problem. It would be better if the instructor can spend more time in general teaching the class basic concepts that would be needed for the new assignment and from there help out each student.” • “It was a lot of individual and personal instruction, whereas in other programming courses, the professor lectured to the entire class and we asked few questions. The problem oriented approach was better than teaching a lot of theory for multiple classes. I prefer to learn by doing problems, and fell that we |

| | |
|---|--|
| | <p>learned Labview better because of that.</p> <ul style="list-style-type: none"> • “While I appreciate the format of the class and think I learned a lot in a short time, I would also like a more formal set of course documents (even though there was some) that way I have more to go back to” |
| <p>Describe your experience using Labview via the Cloud. How important do you rate having access to the software at your convenience? How did Cloud access to Labview help or hinder you over the course of the semester?</p> | <ul style="list-style-type: none"> • “It was helpful only for assignments in the beginning of the course that did not require the DAQ. Once we started implementing the DAQ into our programs, I rarely used Labview via the cloud. Perhaps, if more homework prior to coming to class was assigned, then cloud would be more useful.” • “It’s very important to me to use Labview via the Cloud. It’s accessible from anywhere besides the library. I can practice at home. And the saving files on the cloud is very convenient. But the lab computers aren’t able to connect to the cloud and don’t run the same version of the software. When we have to implement a real signal (DAQ) from outer device connected to the lab computer, the Cloud Labview isn’t able to be used.” • “It was great using Labview through the cloud at the beginning of the semester when we are just starting out. But once we started building VIs that required the use of the DAQ, it became difficult to use Labview via the cloud because the cloud can’t connect with the DAQ. However, overall, it helped out having Labview at my convenience in the beginning but not when we needed to use the DAQ” • “It makes me sad. The Cloud logs out fairly common (every 15 -30 minutes or so). Convenience was very important. It helped my course”. • “Labview worked fine on the Cloud, but like all my experiences with cloud computing, it fell short of having the program yourself. Cloud access was convenient, but if we ever ran into an error or problem outside of class, we would have no immediate assistance from the instructor.” |
| <p>“How would you rate your familiarity with the software after this course? Do you feel you would be capable of “scaling” the concepts you learned to apply them to more complex or seemingly unrelated problems in the future?”</p> | <ul style="list-style-type: none"> • “I feel like I can now do most of the tasks I would need to in Labview. However, as with all introductory programming courses, full mastery is not within my grasp. I probably could do a more complex problem in labview now. It would definitely take longer though.” • “Im familiar enough that I can teach myself more complex functions.” • “In a scale of 1 to 5, 5 being an expert, I would rate my familiarity with Labview a 3. I still feel I need more practice using Labview and applying the concepts to more complex or seemingly unrelated problems in the future would take me some time to figure out. • “Yes, I am glad we had intense and focused experiences with basic concepts, such as loops, signal manipulation, and data acquisition. I prefer to use the same ideas multiple times rather than to slightly touch upon particular topics.” • “I feel real familiar now. I really like the graphic programming |

| | |
|--|---|
| | instead of just writing lines and lines and lines of code.” |
| “Would you be inclined to use Labview in the future, either in your senior design project in some capacity, a hobby project, or some other application?” | <ul style="list-style-type: none"> • “Yes! I am planning to use Labview in my senior design project for an ultrasound transducer acquisition project. I like Labview and will prefer to use it over Matlab for real time experiments.” • “Yes, I would be inclined to use Labview for a hobby project to have more practice.” • “I would definitely use labview again even if only for a hobby if I had access to the software and hardware” • “Sure” • “I actually bought myself the student version of Labview since the Cloud was frustrating me.” |
| Please provide us with any other comments about how to improve any aspect of the course (i.e. content, structure, approach, etc.) | <ul style="list-style-type: none"> • “The only thing I could suggest is maybe another day on which we could come to the lab for assistance, maybe if we contact the TA in advance to ask him/her to be there. Since I only worked on the projects while in the lab for the latter half of the semester.” • “No comment. Don’t cancel the class! I feel labview will be very useful in the future in my field, more so than C++.” • “Update the Labview software in the lab, and fix or replace some of the computers in the lab.” • “One thing that could be improved is to lecture to the whole class more in depth at the beginning, before we start programming. This is because most of us had the same questions to ask the professor, and many times I felt like time could be better utilized if the professor answered particular student questions to the whole class. Some homework would help us to be better prepared for the projects. We could come into class with greater knowledge of how to set up the programs.” • [student did not respond to this question] |

DISCUSSION AND IMPROVEMENT OPPORTUNITIES

Assessment has shown that the objectives set out for this course have been achieved to a satisfactory level. The problem oriented methodology adopted similar to the one described by See [5] and Meyer [6] is effective at familiarizing and motivating students to use advanced tools in virtual instrumentation. Many students have gone on to use LabVIEW in their senior design projects and other applications. Despite this, there is always room for improvement.

Access to the software through the universities cloud enabled students to have exposure and access to the software at all times. However, there were limitations due to the inability to test acquisition hardware while using the cloud. One potential improvement would be to ensure that the cloud and lab computers were both running the same version on LabVIEW. Also, by using serial communication acquisition devices in the future, the students will be able to interact with hardware while using the cloud.

Students have also indicated that they would like more exposure to the software, more than is allowable in its current 1 credit form. One potential solution would be to follow the example set out in [6], and incorporate LabVIEW into a core instrumentation or measurements course.

REFERENCES

- [1] Jen-Shih Lee, *Biomedical Engineering Entrepreneurship*, World Scientific, Singapore, 2010
- [2] David J. Beebe, *Teaching Hands-on Biomedical Instrumentation*, Proceedings from the 1996 Annual Conference of the American Society of Engineering Education
- [3] Nesimi Ertugrul, N. *Towards virtual laboratories: A survey of LabVIEW-Based teaching/learning tools and future trends*, Int. J. Eng. Education 16, 3, 171–180. 2000.
- [4] Robert H. Bishop, *LabView 7 Express*, Prentice Hall, Upper Saddle River, NJ, 2006
- [5] Alex See, *Challenging computer-based projects for a Mechatronics course: Teaching and learning through projects employing virtual instrumentation*, Computer Applications in Engineering Education, Volume 14, Issue 3, pp: 222-242, 2006
- [6] George Meyer, “*An Improved Instrumentation and Controls Course for Agricultural and Biological Engineering*”, proceedings of the 2009 Midwest Section Conference of the American Society of Engineering Education

Jonathon A. Toft-Nielsen

Jonathon Toft-Nielsen is a PhD candidate in Biomedical Engineering at the University of Miami. He received his undergraduate and Master’s degrees in Electrical Engineering from the University of Miami as well. His research interests include medical instrumentation, neural engineering and vision research.

Jorge E. Bohórquez

Dr. Bohórquez is an Assistant Professor of Professional Practice of Biomedical Engineering, College of Engineering. He received his undergraduate degrees in Electrical Engineering and Physics from Los Andes University, Bogotá, Colombia and his PhD degree from the National Institute of Applied Science (INSA), Lyon, France. His research interests are engineering education and neural engineering applied to audiology, neurology and anesthesia monitoring.

Qian Shen

Dr. Shen is a research associate in Wien Center for Alzheimer’s Disease, Mount Sinai Medical Center. She received her PhD degree in Biomedical Engineering from University of Miami, Miami, USA. Her research interests include medical signal and image processing, pattern recognition and engineering education.

Appendix 1
 Example of a Laboratory Guideline
 University of Miami
 BME 507 – Labview applications to BME - Fall 2011

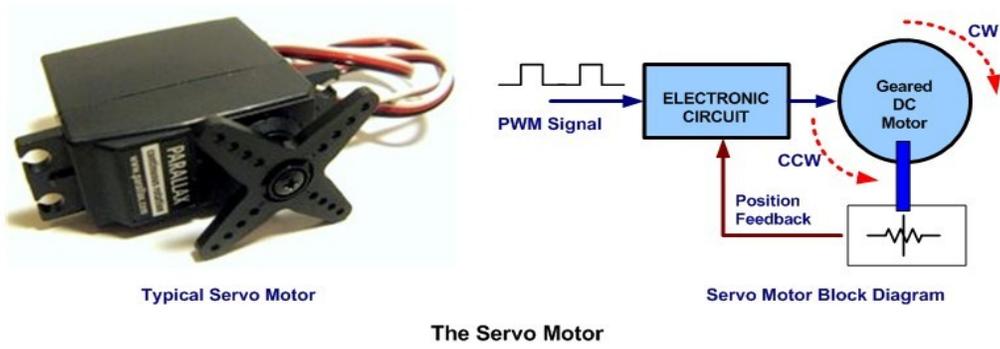


Image from www.ermirco.com/blog

Objective

Create a VI that drives a servo motor. Servo operation is based on pulse width modulation. The standard servo has 3 control lines. One (black or brown) is the ground line, connected to a DC ground source. The second (red) is the source, a DC value typically between 4 and 6 V. The third line (white or orange) is the control line. The control line receives a signal as shown below. Depending on the condition of the signal on the control line, the servo arm will move to the particular position and stay there.

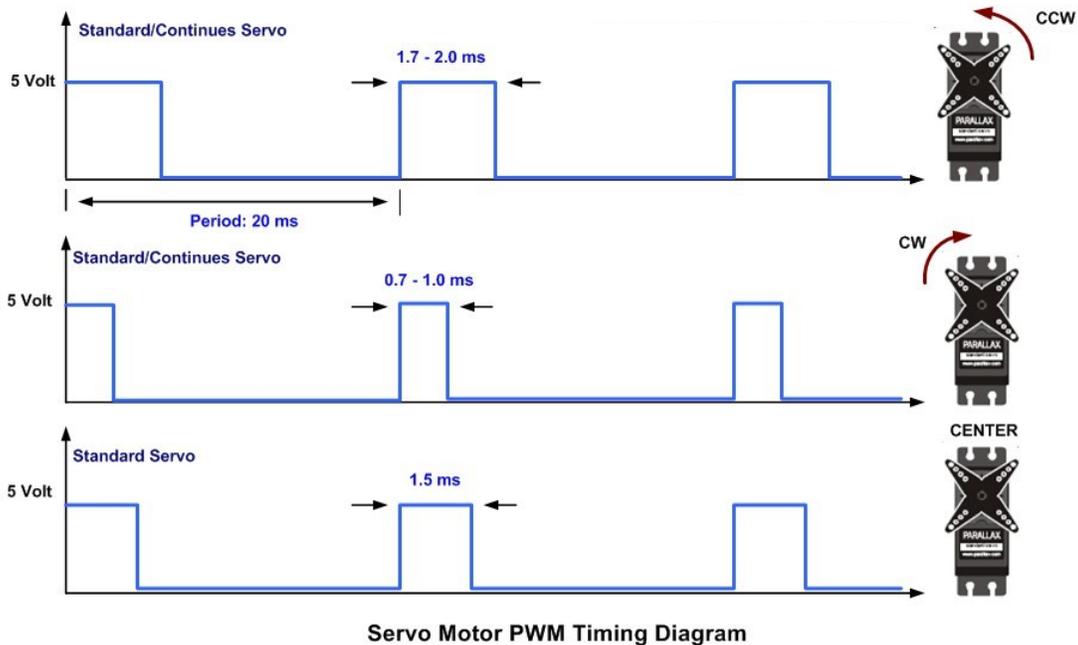


Image from www.ermirco.com/blog

Specifications

1. The servo will be configured via software to be moved between the two extremes that the servo arm can move (you can think of it as an "OPEN" and "CLOSED" state).

2. Your VI must generate and output the control line signal, and must switch between the “OPEN” and “CLOSED” state signals. Your VI must include 3 separate modes of operation, which will dictate the condition for changes on the control line.
 - a. Software: A user controlled switch on the Front Panel causes the servo to open and close.
 - b. Timed control: The servo opens and closes on its own based on a user defined time schedule (i.e. – 3 seconds open, 3 seconds closed).
 - c. External control: The servo opens and closes based upon the signal received from an external sensor (photodiode).