

## Real-time Data Acquisition of Physiological Signals For an Instrumentation Course

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### Abstract

The United States Naval Academy offers an instrumentation course for non-electrical engineering majors, which takes advantage of the PC plug-in data acquisition (DAQ) boards and PC software (MATLAB). In this course, several lab exercises were developed for the undergraduate study of physiological signals. This includes electrocardiography (ECG) and electromyography (EMG) signals. With the advent of real-time data acquisition and signal processing technology, it is now much easier to develop instrumentation lab experiments for student use. The current hardware and software enables our students to achieve highly accurate measurements, perform time domain and frequency domain analysis, and store the data for subsequent use, analysis, and design. This paper discusses some of the methods developed for implementing these labs. We believe our techniques have greatly enhanced the ease of teaching and learning these important topics in instrumentation.

### 1. Introduction

This paper describes how student laboratories using data acquisition, measurement, and analysis of physiological signals has been integrated into an instrumentation course at the United States Naval Academy (USNA). T. Welch, et al., has successfully integrated the development of student laboratories using the real-time DAQ equipment into courses for electrical engineering majors at USNA<sup>1</sup>. This course is different in that, it is a senior elective for non-electrical engineering students and only requires a two-semester course in introduction to electrical engineering as a prerequisite. This course is entitled, *Fundamentals of Electronic Instrumentation*, and is taught for three hours of academic credit consisting of two hours of lecture and two hours of laboratories per week. However, this paper describes a new approach to teaching an instrumentation course, which emphasizes more lab time (three hours per week) and less lecture time. Thus, more time can be devoted to giving

students opportunity for hands-on experience in solving real engineering problems. This “more lab less lecture concept” does not degrade understanding of topics, because the student has completed a two-semester course in basic electrical engineering, and the ideas covered in this course extend upon basic principles already learned. This gives ample time for presenting new material, such as the overall data acquisition process, and an in depth discussion and demonstration on detailed analysis of all types of real world signals, such as those generated from a physiological source.

The data acquisition system used in this course is interfaced with MATLAB to facilitate further signal processing, analysis, and display of signals. Data acquisition combined with MATLAB is a convenient and powerful signal processing system that has been popular in many undergraduate electrical engineering programs throughout the country, and is ideal for use in an instrumentation course for non-electrical engineering majors.

## **2. Overview of DAQ Oriented Instrumentation Course:**

The impetus behind developing lessons that cover the data acquisition process using physiological signals originates from the idea that students are interested in real-time measurement of signals they can easily and accurately acquire, such as heart beat and muscle activity. It is also important point out that the technology and software are now available which make it possible to implement an inexpensive and easy-to-use DAQ system in the student laboratory. For example, one of the requirements of a data acquisition system capable of measuring biophysical signals, such as ECG and EMG, is to be low noise, high gain, and have a frequency response in the range of 1 Hz to 10 kHz range.

The students are each provided with a workstation that includes a personal computer, data acquisition system, software, such as Windows and MATLAB. The electronics workbench includes a proto-board for constructing circuits, power supplies, and measurement and signal generation devices, such as an oscilloscope, digital multi-meter and function generator. The course provides a comprehensive review of many topics covered in an instrumentation course such as filters, operational amplifiers, and digital systems, and includes lectures and assigned problems. This syllabus is expanded beyond the traditional instrumentation course into several lessons and labs that cover digital signal processing and real-time data acquisition. The syllabus includes the following objectives:

- I Introduction to instrumentation and analog signal conditioning
- II Operational amplifiers and instrumentation amplifiers
- III Introduction to digital signal conditioning
- IV Digital-to-analog converters, analog-to-digital converters, & frequency based converters.
- V Introduction to the data acquisition process
- VI Sensors (such as Silver/Silver-Chloride electrodes used in biophysical measurements)
- V Course projects in real-time data acquisition.

Each two-hour laboratory includes the following topics:

Lab 1 & 2	1 <sup>st</sup> order and second order Passive filters using MATLAB analysis techniques
Lab 3	Bridge circuits and transducers in data acquisition
Lab 4 & 5	Acoustic measurements-loudspeaker response and crossover networks
Lab 6	Instrumentation amplifier and bridge circuits
Lab 7	555 timer and servo motor position control
Lab 8	Introduction to data acquisition and MATLAB
Lab 9 & 10	Real-time data acquisition of physiological signals

In all of the above laboratories the students learn progressively more advanced plotting and analysis techniques in MATLAB. This approach assumes the student is not familiar with MATLAB in the beginning, but by the completion of all the labs, they are very proficient at composing sophisticated algorithms for data acquisition and analysis.

The laboratory experiments take the students step-by-step through the process of developing a complete measurement and analysis system for acquiring and analyzing data from several signal types in the audio range. The objectives for the data acquisition block of this instrumentation course are:

To become familiar with techniques used to perform real-time data acquisition, measurement and analysis of all types of time-varying data, to include voice, music, and physiological signals such as heart activity and skeletal muscle contraction.

To observe real-time data and develop diagnostic tools using computer algorithms and graphics interfacing.

The following steps are taken to enable the student to understand these objectives:

- (1) Introduction to MATLAB-students learn basic commands to generate and analyze simulated signals, such as sinusoidal signals and complex signals with and without noise.
- (2) Introduction to the fundamentals of electrical activity of the human heart and analysis of components of the cardiac cycle.
- (3) Introduction to fundamentals of electrical activity associated with human muscle movement (EMG), to include explanation of makeup of skeletal muscle, motor unit function, and source of EMG signals.
- (4) Analysis of real ECG and EMG data in the time domain and frequency domain, which includes development of methods for presentation of data and experimental results using MATLAB commands and graphics user interface (GUI) program. The student will examine the ECG components by measuring amplitudes (mV) and durations (msecs) of the cardiac

signal. The student will also examine similar features of muscle activity.

- (5) Familiarization of data acquisition system setup. Perform calibration, recording, and analysis of real-time sinusoidal signals such as ECG and transient signals contained in EMG.
- (6) Student design and construction of complete instrumentation measurement system for physiological signals, which includes data acquisition for measurement, and a graphics user interface for performing analysis and diagnostics.
- (7) Student demonstration of system and final reports based on experimental results.

### 3. The DAQ Experiments

#### 3.1 Equipment

The PC plug-in data acquisition (DAQ) board used for this course was the National Instruments 16 bit, 333 kSamples/sec, multi-function board. The PC software used was MATLAB, and BIOPAC shielded electrode cables (pinch connectors) and AG/AG-CL surface electrodes were used for sensing ECG and EMG signals.

#### 3.2 Experimental Procedures for ECG

**Setup:** Place electrodes on subject as shown in Figure (1), left medial surface just above ankle (Red lead), right medial surface just above ankle (Black lead), and right anterior forearm at the wrist (White lead).

**Recording:** Recordings can be taken in increments with subject in various positions to study effects of the heart rate, such as, lying down, sitting and relaxed, and immediately after exercising.

**Data Analysis:** Data was stored in a file in MATLAB for further signal conditioning and analysis. Comparisons were made between heart rate signals in various positions and conditions. The students include this information in their final report.

#### 3.3 Experimental Procedures for EMG

**Setup:** Place electrodes on subject as shown in Figure (3), anterior forearm at the wrist (Red lead), anterior forearm at the wrist (Black lead) approximately one inch from red lead, anterior forearm at elbow (White lead). Measurements are taken with subject in relaxed sitting position.

**Recording:** Recordings can be taken on right arm, and then left arm with subject in relaxed sitting position.

Data Analysis: Data was stored in a file in MATLAB for further signal conditioning and analysis. Comparisons were made between right arm and left arm muscle dynamics. The students include this information in their final report.

#### **4. Graphics display**

Waveforms can be observed directly using the data acquisition system for capturing the signal and a graphics user interface (GUI) to display the information in several formats. For instance, a display format for ECG measurement is shown in Figure (3). The GUI program includes time domain (top diagram) and frequency domain window displays, such as the power spectrum shown in the lower diagram. The GUI program can be customized for the user for selection of various filters, such as a low pass filter effect, which is demonstrated in the middle diagram, labeled “filtered ECG data. Also indicated automatically on the display is heart rate in beats per minute. The accuracy and real-time capability of the DAQ combined with the GUI yields an easily observed signal whose components can be analyzed.

Figure 4 shows the cardiac cycle segmented into different parts. The cardiac sequence begins with atrial depolarization (P wave), followed by ventricular depolarization (PQS wave), which corresponds to the start of ventricular contraction, and finally followed by ventricular repolarization (T wave), which signals the beginning of ventricular relaxation.

Using the data acquisition system described in this paper, the student can accurately measure the strengths of these pulses and intervals between these pulses. This can be a very useful tool to use for learning about activity heart and studying its function in considerable detail.

#### **5. Conclusions**

The instrumentation course was progressively taught, starting with students learning the most basic concepts of data acquisition then learning how to write robust computerized algorithms that interface with the DAQ system. Ultimately, the student is able to accurately observe and analyze real world data. This approach aids student retention of the complete data acquisition process. By introducing the concept of measuring and digitizing signals in real-time to the undergraduate engineering student, we immediately capture their interest and imagination, thus enabling them to apply their ideas and newly developed skills to developing their own exciting projects. This paper focused on using physiological signals in data acquisition, however, the application is not limited to measurement of biophysical signals. Many student laboratories and projects could be developed and easily implemented into a course at the basic electrical engineering level using the similar equipment and software.

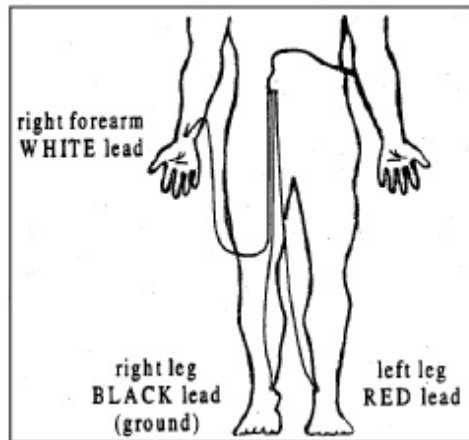


Figure 1. Placement of three electrodes for ECG measurement.

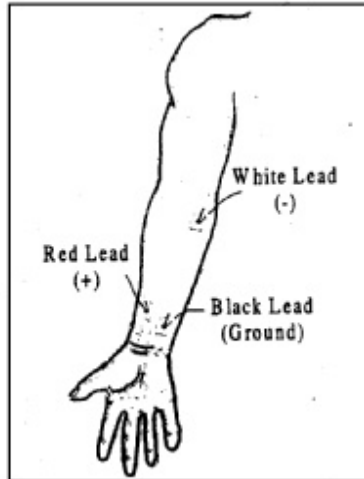


Figure 2. Placement of leads for EMG measurement.

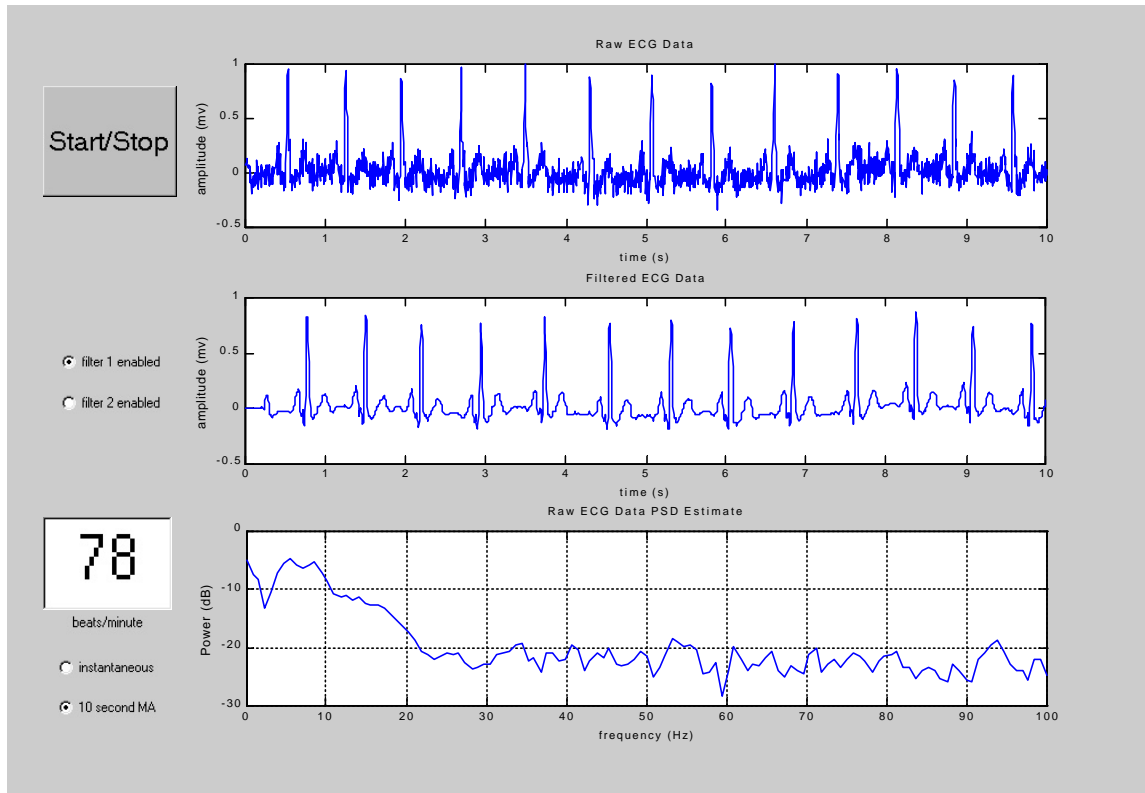


Figure 3. MATLAB Graphics User Interface (GUI) for ECG measurement and analysis.

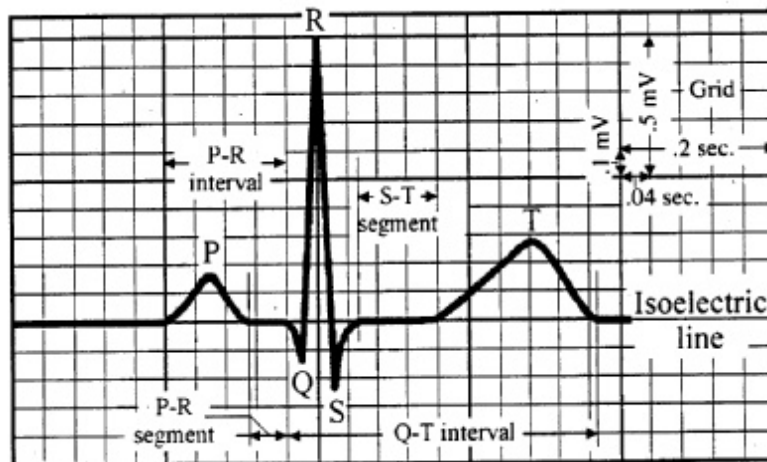


Figure 4. Different components of the cardiac signal.

## Bibliography

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