

# **2006-132: ELECTROCARDIOGRAM INSTRUCTION, CAPTURE AND ANALYSIS**

**Paul King, Vanderbilt University**

# Electrocardiogram Instruction, Capture and Analysis

## **Abstract**

This paper describes the conduct of an introductory freshman seminar titled Electrocardiogram Capture and Analysis, taught yearly since Fall 2000. The course covers the following topics: basic medical nomenclature, cardiac anatomy and normal cardiac rhythm, abnormalities of the heart, and basics of ekg analysis from the chart. Lectures and discussions include advanced topics in cardiology: electrical pacing, advanced diagnostic procedures, defibrillators (external and implantable), transmitter systems, Holter Monitors, databases, and future directions. Invited speakers typically include a cardiologist and a Medtronic field engineer, tours include a visit to a Human Patient Simulator and a Clinical Pharmacology research laboratory, and demonstrations involved use of a free commercial package on biological signals. The course further covers an overview of the following engineering topics: data capture techniques, sampling, and A/D conversion. The major computational experience for the students involves basic ekg rhythm analysis using Excel, using data collected from the students or (optionally) from an unknown subject. This is followed by a similar analysis using MATLAB (in parallel with a required freshman course in introductory engineering).

This course was originally intended to interest freshman students in the potential application of their engineering skills to real-life problems. It was similarly intended to assist in the retention of students during the initial semester of engineering classes. The course has had good student reviews, and seems to have achieved its goals.

This paper is intended to be of sufficient depth that the course may be replicated easily elsewhere.

## **Introduction**

The stated specific goals of this course include the introduction of the freshman student to data analysis techniques in electrocardiography, medical and engineering nomenclature, engineering & engineering applied to medicine, technologies involved in cardiology and electrocardiography, and societal ramifications of heart related research. A hidden agenda is the introduction of the student to realistic applications of some of the material co-taught in an introduction to engineering course, but with applications to their chosen area of interest. The course is one of several one-hour “modules” offered to entering students in order to potentially increase retention of freshman students.

The course, as offered, is scheduled for two hours a week. The students are informed that the class period will be one hour if the class consists of a lecture or in-class exercise. Facility visits are scheduled for two hours. The course has

been taught by the author five times since 2000, a second section has been taught by another faculty member four times in the same interval.

It is the purpose of the remainder of this paper to describe the normal lecture content, lab visits, optional exercises, and homework such that the course may be emulated elsewhere with a minimum of effort. The course web site may also be used as a reference.<sup>1</sup>

### **Normally scheduled lectures**

A portion of the first class is usefully used in allowing the students to introduce each other, discussing home towns, majors planned, unique events, and their reasons for taking this module. The remainder of the first class, and typically the entire next class is then used to give an overview of medical nomenclature, stressing the deconstruction of medical words in order to give the class the ability to understand terms especially relevant to cardiology. Chapter one of the text by Jacobson and Webster<sup>2</sup> or one of several web sites generally is an adequate introduction. A homework exercise related to this work is typically related to the “translation” of a series of medical terms, and the citing of one or two web references used in the homework.

Two articles from Natural History Magazine are then reviewed in the lectures session. These articles are titled “The Hidden Unity of Hearts” and “And the Beat Goes On”<sup>3</sup>. These two articles provide an excellent overview of the evolutionary history of hearts, and the different designs adopted by different vertebrates. A natural point now exists to begin discussion of living pumps in general (peristaltic, venous, and rhythmic/chambers) and heart function in general (O<sub>2</sub> and solute transport, heat transport, and force transport.) A brief foray into scaling (heart rate proportional to mass to the  $\frac{1}{4}$  power, heart size approximating .6% body weight (various references)) provides some interesting discussion points when comparing hummingbirds, mice, and elephants heart rates and sizes. The students are by this time ready for a discussion of the cell, the classification of cells into excitable and passive, the subclasses of nerve and muscle (excitable), and the subclasses of cardiac, smooth, and skeletal muscles.<sup>4</sup> With this discussion concluded, the students are introduced to electrocardiography and normal and abnormal rhythms and interpretation of the electrocardiogram<sup>5 6 7</sup>.

Students have by this time seen a number of electrocardiogram waveforms, but have not (necessarily) seen a real-time electrocardiogram. One complete class is devoted at this time to data capture, where (optionally) each student collects his or her own ekg. An introduction to sample rates and A/D conversion precedes the actual data collection. The equipment used for this involves their own laptop (required of all students), and Logger Pro software, a controller device (Vernier Lab Pro), and the Vernier EKG sensor.<sup>8</sup> This inexpensive system allows the students to view in real time their own, and others' electrocardiograms. (Laptops are run on battery power, as are the Vernier devices, thus no electrical hazard exists.) This system allows for the viewing of a single lead EKG, typically we use Lead III in order to get a normally large and

clean signal with minimal embarrassment to the students. Students are instructed to obtain 30 seconds worth of data at a sample rate of 100 samples per second. Students further assist each other in data collection; starting the data collection steps for each other so that movement artifacts do not appear in their own data collection. Once data collection is done, each student cuts and pastes his/her data into an Excel spreadsheet for further analysis in the next class period. Homework typically consists of plotting out a section of the data (10 seconds), estimating heart rate, and discussing the waveform.

Generally, the next available class period is used to do some primitive analysis of the electrocardiogram by demonstrating some elementary techniques for R-wave (and therefore heart rate) detection. Students, as a class, are led through a series of steps to analyze their data. The data is first differentiated and plotted alongside the original waveform. Two point and four point derivatives are discussed; generally the students opt for a two point derivative for their analyses. A discussion of the value of the derivative (removal of baseline offset and some low frequency wander) ensues. Students are led to a discussion of different techniques for R-wave recognition (amplitude analysis, shape analysis, derivative trigger, etc.) With the overlay of the raw and differentiated electrocardiogram analysis, the students are shown the usefulness of a derivative trigger value. Typically this is set at 0.6 times the maximum negative derivative in the data set. A typical setup to plot the trigger data involves an equation of the form  $=IF(B2<-1.4,1,0)*IF(B2<B3,1,0)$ , where (in this case) -1.4 was the trigger value and the array B is the slope of the electrocardiogram data (which is typically placed in column A). The effect of the first term is to place a one in any cell element where the slope data exceeds the trigger value, otherwise a zero is placed. The second term further requires that this slope data point be more negative than the next, which tends to decrease the number of "double hits" on the slope trigger. If all goes well, the trigger data set, when overlaid on the original EKG and EKG slope data only triggers when the maximal downslope on each QRS complex is "seen". Student then turn in their work, noting the value of this exercise, commenting on the usefulness of the derivative trigger technique, and estimating the average heart rate by using the number of "hits" on the downslope data. It is left as an exercise to come up with a better technique for triggering on QRS complexes.

The above exercise is repeated at the end of the term, by which time the class has had experience in another freshman class using MATLAB. This time, the class uses a prewritten MATLAB program<sup>9</sup> to analyze the data. Results are obtained much quicker and the class can come to appreciate the value of their use of Excel vs. MATLAB.

Two classes are generally demonstration classes. One class consists of a discussion of other biomedical waveforms (EMG, EOG, EEG, etc.) and simulation of data collection methods used. (A CD for this class must now be requested as an on-line demo is now no longer available.<sup>10</sup>) A second full class period typically involves a lecture and demonstration of anesthesia techniques

using a sponsored web site.<sup>11</sup> The importance of cardiac monitoring techniques is once again related to this course. A homework exercise typically requires the students to use one of the other simulators at this site (ACLS, Critical Care, Sedation, Bioterrorism, etc.) and to report on the use and usefulness of the simulation.

Two classes generally involve guest speakers. One class typically involves an appearance by a local Medtronic Technical Field Engineer (one of our graduates) who discusses the entire field of cardiac pacing and defibrillation devices and their development and use. Another class generally discusses, with a cardiologist, the areas of research currently being pursued by Physicians and PhDs working in Cardiology.

### **Normally Scheduled Field Trips**

We have been fortunate every year to be able to utilize a local rehabilitation facility to obtain a treadmill exercise stress test on a volunteer student. The test consists of the standard graded increase in slope and rate of the treadmill, a complete data set is generated for the study. The exercise physiologist who conducts the study gives a brief introductory lecture, conducts the study, and reviews the collected data for the class. Replotting the data and analyzing the data is a homework exercise for all but the volunteer<sup>12</sup>. This is an excellent exercise physiology introduction.

Each year a visit to a METI Human Patient Simulator has been a part of this course. This simulator gives realistic responses to drugs and gasses introduced, and is a good simulator to introduce the students to intubation techniques. Students are expected to do a brief literature review (web) on the use of simulators in medicine.

### **Optional Lectures and Visits**

Until this year, one lab visit was to a research facility which uses mice to test drugs. Cardiac data is collected real-time via implanted radio transmitters. The students were shown the laboratory and one mouse being tested, and had the ability to ask questions of the researchers. A homework exercise was to read some of the “people for the ethical treatment of animals” (PETA) literature on their web site<sup>13</sup> and to discuss this information vs. what was seen and discussed in the laboratory. (Note – this has been dropped only because the laboratory has been moved to a too-small facility.)

Another occasional laboratory visit included a class visit to our Clinical Research Facility on campus, where the class met with the director of Biomedical Informatics. He gave a lecture and tour of the facility and its equipment.

A one time visit to a Medtronic touring van which allowed demonstration (simulation) of the placement of cardiac catheters for internal cardiac monitoring for pacing and shock therapy was a fantastic learning experience for the few students who had a chance to use the simulator.

## Evaluation and Conclusions

Evaluation of students each term has been strictly through a fairly light homework load. Attendance and interest remained high throughout the term, no final exam or term paper appeared necessary. Student written evaluations of the course were consistently high, no changes were suggested. An example evaluation in 2005 read “*I enjoyed all of our visits to the patient simulator, Medtronic Lab, and Dayani Center. I also enjoyed how the class was not difficult. It was a seminar and it achieved its purpose w/o being too labor intensive.*”

This course is one of several one hour freshman seminars offered at the Vanderbilt University Engineering School. It is estimated by an associate dean that the introduction of our seminar series is likely the one item that increased our freshman retention rate by 4% since their onset. This section, and the one taught by another faculty member, have had sufficient enrollment to make two sections every year but one. A minor variation of this class has also been taught at a local high school by the second faculty member.

It is hoped that the above course description will be implemented at other universities. The course structure is a fairly good one, giving the interested freshman a reasonable introduction to the field of biomedical signal processing in a fairly non-threatening manner. The course has been of value in validating the remainder of the freshman experience.

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<sup>1</sup> <http://vubme.vuse.vanderbilt.edu/King/ekg2000.htm>

<sup>2</sup> Jacobson, B., and Webster, J. G., *Medicine and Clinical Engineering*, Englewood Cliffs, Prentice Hall, 1977.

<sup>3</sup> Natural History Magazine, April 2000, Volume 109, Number 3, pages 56-65.

<sup>4</sup> This material is equivalent to an overview of Chapters 2, 3, 17, 18, 19, 22, 23 and 24 of Berne, R. M., Levy, M.N., *Physiology, Third Edition*, St. Louis, Mosby, 1993.

<sup>5</sup> Pages 387-395 of Berne & Levy (above)

<sup>6</sup> Dubin, D, *Rapid Interpretation of EKG's*, Tampa, Florida, Cover Publishing, 1979 (and more recent.)

<sup>7</sup> Davis, D., *How to Quickly and Accurately Master ECG Interpretation*, Philadelphia, J.P.Lippincott Co., 1992.

<sup>8</sup> For prices and more information, see <http://www.vernier.com>. ECG electrodes may be obtained from Vernier also, or from ConMed Corp., Utica NY.

<sup>9</sup> [http://vubme.vuse.vanderbilt.edu/King/ekg\\_hw5.htm](http://vubme.vuse.vanderbilt.edu/King/ekg_hw5.htm)

<sup>10</sup> See [http://www.biopac.com/bsl\\_frdemo.htm](http://www.biopac.com/bsl_frdemo.htm)

<sup>11</sup> <http://www.anesoft.com/>

<sup>12</sup> See [http://vubme.vuse.vanderbilt.edu/King/ekg\\_hmwk\\_3\\_2002.htm](http://vubme.vuse.vanderbilt.edu/King/ekg_hmwk_3_2002.htm)

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<sup>13</sup> <http://www.peta.org/>