Clinical Application Driven Physiology in Biomedical Engineering Laboratory Course Education

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Abstract – **An innovative biomedical engineering (BME) laboratory course was developed to integrate wireless biotechnology with a hands on learning approach. In recent years the need for biomedical engineers in research and industry has increased dramatically. This requires novel strategies for training BME students in both engineering principles and clinical applications. BME students should be prepared with an appropriate skill set for real-world problems. BME education requires hands on learning with cutting edge technology to produce students ready to solve clinical problems in both research and industry. Including a wide range of BME clinical and rehabilitation applications increases student interest. A wide range of BME laboratories was designed to encompass both the basics of physiological signals and how to effectively utilize them in clinical applications. These clinical application interfaces are critical for students to understand how physiological signals may be manipulated to extract meaningful benefits for various medical disorders and rehabilitation needs. The biomedical engineering laboratory course presented in this paper was implemented and evaluated at several universities. Utilizing a virtual environment for practical applications bridges the gap between fundamentals and real world designs.**

Keywords – **Biomedical Engineering, Education, LabVIEW, Laboratory Course, Data Acquisition, Wireless**

I. INTRODUCTION

The demand for biomedical engineers in both industry and academia reflects the large social and economic impact the industry creates. The United States Department of Labor states that the number of biomedical engineering (BME) jobs will increase by 31.4% through 2010, more than double the average predicted rate in other fields [1]. Biomedical engineering plays an important role in affecting outcomes for medical disorders and rehabilitation needs. Therefore, BME education has a responsibility to effectively prepare students to approach and solve real world problems of an aging society.

In the early years of BME education it is important for freshman and sophomore BME students to create a connection that bridges the gap between theory and practice [2,3]. Students are not properly prepared to approach real-world applications until they understand how to apply basic fundamentals into practice. Additionally, utilizing the latest in biotechnology in a laboratory setting should improve students' experience and interest in biomedical engineering. Therefore, there is an increased need for hands-on learning centered on the latest industrial and research applications [2]. Once students understand how fundamentals engineering methodologies can be applied to solve wide-ranging health and rehabilitation needs, they will gain a better appreciation for theory. The National Science Foundation recently reported that engineering education should include "integrative laboratory experiences that promote inquiry, relevance, and hands-on experience" [4]. The Tulane BME study reported that students preferred to receive information visually (preferred by 88% of the

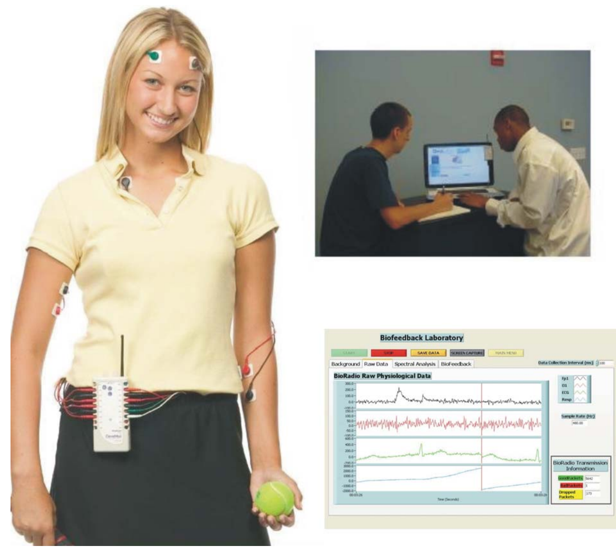

Fig. 1. The CleveLabs biomedical engineering laboratory system integrates wireless biotechnology for data acquisition with application-based software to optimize the student laboratory experience.

Table 1. The CleveLabs system provides a wide range of BME topics.

Selectable BME Laboratory Course Sessions	
Engineering Basics	**Advanced Physiology**
BioRadio Introduction	Speech Recognition
Data Acquisition Basics	Polysomnography
Digital Signal Processing	Electrocardiography II
Statistical Analysis	EEG II
Image Processing	**Clinical Applications**
Post-Processing Toolbox	Biofeedback
Basic Physiology	Gait Pattern Recognition
Biopotential Basics	Environmental Controls
Electrocardiography I	Heart Rate Detection
Electroencephalography I	Alertness Detection
Electromyography	Motor Control
Electro-Oculography	Student Designed Lab
Respiration	

student sample) rather than verbally, focus on sensory information (55%) instead of intuitive information, process information actively (66%) instead of reflectively, and understand information globally (59%) rather than sequentially [5]. The course was designed to incorporate all of these learning preferences.

Table 1 shows the labs for the biomedical engineering laboratory course platform that successfully integrated engineering basics, basic physiology, advanced physiology, and real world clinical applications to better train and challenge biomedical engineering students. An innovative laboratory course was designed, developed, and implemented into the curriculum at a score of universities.

I. METHODS

A. CleveLabs Course Hardware

The BioRadio® 150 is a lightweight, wireless physiological monitor with eight programmable electrophysiology channels. It was selected as the hardware platform for the laboratory course (**Fig 1**). This hardware was developed for integration into the laboratory course system to maximize flexibility of different department focuses. Its small size saves laboratory space and allows any room with a computer to become a BME laboratory. Additionally, its wireless design removes cumbersome tethered leads and increases the flexibility of potential locations and applications. The subject worn unit includes eight channels of programmable physiological inputs. Each channel can be programmed for a particular input range, sampling rate, resolution, and AC or DC coupling so that many types of signals can be monitored with the same device. For example, potential input signals for each channel include, but are not limited to electrocardiography (ECG), electroencephalography (EEG), electromyography (EMG), and electro-oculography (EOG). In addition to the eight bioelectric signals, the hardware platform also integrates built in sensors for pulse oximetry, pressure based airflow, accelerometry, and a generic DC input. Various transducers such as respiratory effort belts and airflow thermistors can also be used as inputs. The subject worn unit amplifies, digitizes, and telemeters data to a computer located up to 200 feet from the subject. A computer unit connected to the student computer via a USB port receives the telemetered data. This hardware platform exposes students to state-of-the-art technology compared to traditional rack mounted amplifiers and filters.

B. CleveLabs BME Course User Interface Software

The BioRadio 150 hardware was interfaced to National Instrument's LabVIEW™ graphical user interface software through development of a BioRadio LabVIEW driver. The driver utilized a dynamically linked library to stream data from the computer serial port directly into LabVIEW. The LabVIEW programming language is a popular tool in BME education, research, and industry for data acquisition software and virtual lab system controls. Therefore, it provided a familiar environment for users to intuitively operate the course application software and also for designing their own laboratories (**Fig 2**). Virtual instruments facilitate problem solving and decision making [2]. Sub virtual instruments (VI's) were designed for integration into the windows based programming language for starting, reading data, and stopping. The sub VI's were used in the course application software as well as in example development libraries to support student designed software. In addition to the LabVIEW libraries, separate driver libraries were also created for use in the MATLAB® programming environment.

C. CleveLabs Curriculum

Wide-ranging laboratory topics were proposed to introduce students to several basic engineering principles, physiological basics, advanced physiology, and clinical applications (Table 1). Initial laboratory sessions introduce physiological mechanisms underlying the recorded signal, teach students how to acquire data from themselves, and demonstrate effective signal processing (**Fig 2**). Intermediate sessions introduce abnormal clinical signals

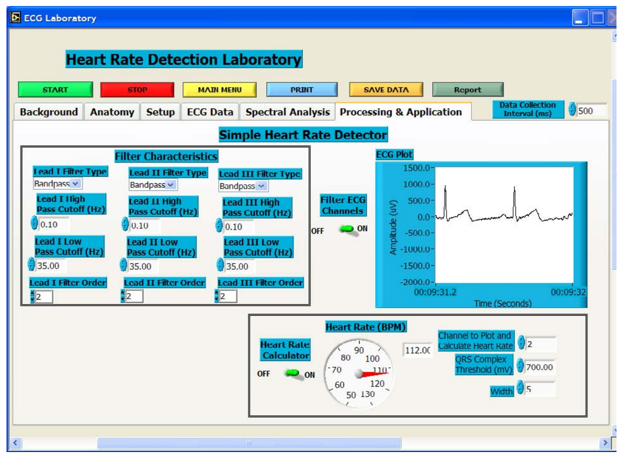

Fig. 2. Students processed their own ECG and developed real-time heart rate detection algorithms.

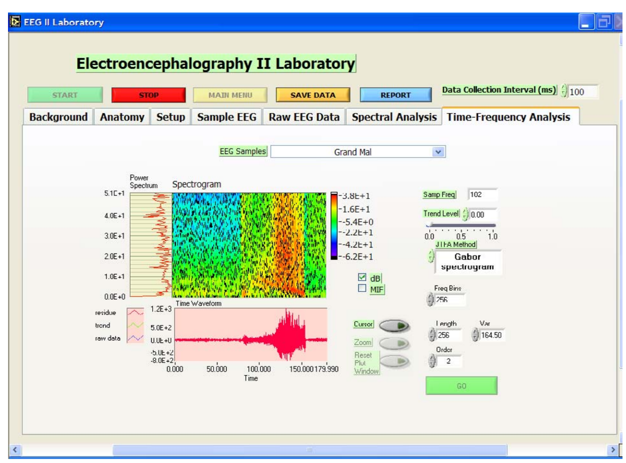

Fig. 3. Abnormal databases are presented for a variety of clinical disorders including brain function shown above. Students utilize time-frequency analysis methods to extract features.

(**Fig 3**). Later sessions apply the signal in a clinical application (**Figs 4 and 5**). Each laboratory incorporates detailed setup instructions and user-friendly features for saving, analyzing, and reporting results. Students process and analyze signals both in real-time and offline. The laboratory course minimizes overhead time associated with hardware setup, equipment troubleshooting, and data management, while maximizing the time spent critically analyzing and applying data. Finally, the course integrates learning styles shown effective for most BME students including active, sensing, visual, and global learning [5].

D. CleveLabs Course Integration

The CleveLabs system has been implemented at many universities including the University of Southern California, the University of Toronto, Case Western Reserve University, and Lake Forest College (LFC). Laboratory course materials include the wireless BioRadio physiological signal acquisition system, student and teacher edition laboratory chapters, disposables, software, electrodes, and several transducers. Accessories include gold cup electrodes, snap electrodes, cotton swabs, skin prep, and snap leads. Professors, teaching assistants, and students from the initial users provided feedback after completing laboratories. This feedback was used to upgrade future revisions of the developed laboratory course. Feedback included ease of use, technical problems, curriculum advisement, and students' subjective experience with the laboratory course.

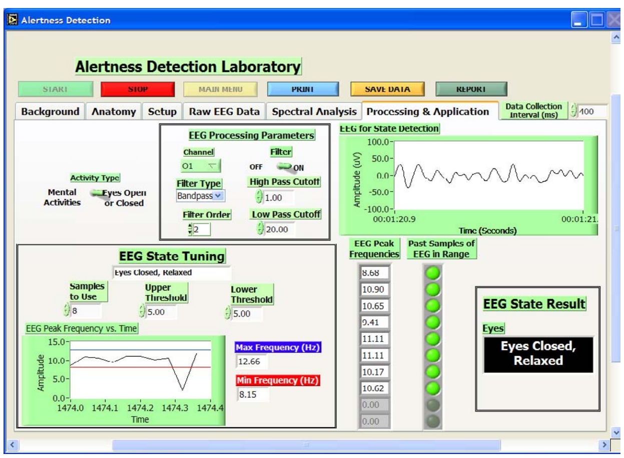

Fig. 4. Students collected and processed their own EEG and developed state detection algorithms.

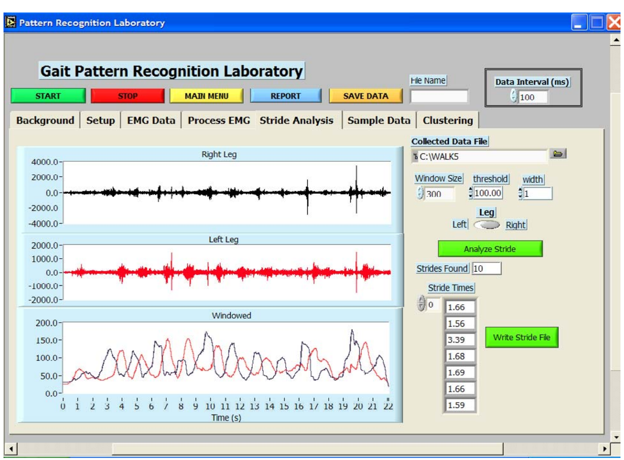

Fig. 5. Students processed their own EMG and developed algorithms to detect gait parameters and relate them to different neurological disorders.

III. RESULTS

A wide range of laboratory topics was implemented (Table 1). In this way, the course could be approached in a sequential manner or individual labs could be selected and implemented based on a particular department's research focus. Clinical setup movies were integrated into each lab to illustrate electrode or sensor setup, real-time displays of raw and processed signals in the time and frequency domains (Fig 2), a signal processing toolbox, examples of abnormal clinical phenomena, a practical application, and a user-friendly student database for saving and reporting results.

Basic sessions introduced the BioRadio 150, application software environment, biopotential fundamentals, and statistical analysis. For example, students complete a basic data acquisition and signal processing laboratory. A 10Hz square wave is generated by an included test pack and displayed in real-time. In software, students then add varying frequency and amplitude noise. Filtering algorithms are then explored to remove the noise.

Advanced laboratories expanded students understanding as examples of abnormal clinical data were presented for several disorders. For example, in the advanced EEG II lab a database of abnormal clinical EEG signals are included and can be analyzed in time, frequency, or joint time-frequency domains (Fig. 3).

Finally, several practical applications provided a comprehensive understanding of how to effectively use signals in medical or rehabilitation environments. For example, students not only learn the basics of a standard three-lead electrocardiograph (ECG), but also explore algorithm development and pitfalls of calculating heart rate from the ECG (Fig. 2). In another lab students record electroencephalography (EEG) and develop algorithms for sleep state and alertness detection (Fig. 4). In another example, the basic origins of electromyography (EMG) are explored, and the basic force-EMG relationship is developed. Furthermore, students will explore how to process and construct algorithms that use EMG to calculate gait parameters and detect neurological disease (Fig. 5). Other applications include using EMG for pattern recognition and the electro-oculogram (EOG) as an input for computer cursor control.

Positive feedback was obtained after the course was integrated into the curriculum at several universities. "Students really enjoyed being able to move around while monitoring themselves." The modular format provided course flexibility. Additional flexibility was achieved by using the BioRadio 150 drivers for third party software development to create new labs.

IV. DISCUSSION

Undergraduate BME programs are one of the fastest growing programs in the world; this requires innovative tools to properly train BME students for real world clinical problems. Exposing BME students to biomedical basics and practical applications of physiology better prepares them for research and industry.

The developed lab course incorporated learning styles shown to work best for BME students including active, sensing, visual, and global learning styles [5]. Active learning is employed since students are able to process information while completing a lab activity. Visual learning is utilized with the scrolling real-time data displays. The hands-on experience with cutting edge technology promotes sensory learning. Finally, global learning is incorporated as students understand the big picture in the terms of real world applications.

By requiring students to design detection and control algorithms they gain experience in problem solving and troubleshooting. Utilizing a flexible, familiar software interface such as LabVIEW promotes understanding of how skills developed now can be applied to unique problems later. This bridges the gap between theory and practice. The programming skills better prepare students for demands of industry where efficiency and cost effectiveness can increase with virtual instruments.

The CleveLabs system was easily customized to fit department needs. Using the developed driver interfaces, professors and students can develop their own real-time lab sessions. CleveLabs provides students with both a basic understanding of engineering principles and physiology, as well as knowledge of how these principles fit into the big picture of clinical and rehabilitation needs.

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