Proceeding Paper

Demystifying the Electrocardiogram—A Printed Circuit Board for Use in a Biomedical Electronics Laboratory †

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Abstract: The electrocardiogram is a widely used clinical diagnostic tool and is studied in biomedical engineering and electrophysiology courses. Modern electrocardiograms are complex, requiring some knowledge in many domains of engineering to comprehend their operation. This project develops an ECG laboratory for learners enrolled in biomedical electronics or biomedical instrumentation modules, who are exposed to a steep learning curve in electronics, intended to allow learners to uncover the fundamental processes of data capture, analysis, and presentation.

Keywords: electrocardiogram (ECG); biomedical engineering; active learning

1. Introduction

Biopotential amplifiers are ubiquitous in physiological measurement and clinical diagnostics, as in Sahin et al. [1], with the electrocardiogram (ECG) being the most widely used cardiac diagnostic tool, as in Mincholé et al. [2]. For undergraduate biomedical engineers, the electrocardiogram is widely used as an introduction to the numerous key concepts to be uncovered in the domain of electrophysiology.

Contemporary ECG designs make use of more modern and inherently complex hardware and software architectures such as (SOC, Embedded OS, and IoT applications) which capitalise on computational power to provide clinical interpretation. For our undergraduate learners, a laboratory practical was designed to compartmentalise concepts for learners to uncover.

The basic circuit from Sahin et al. [1] has been modified for usability within an undergraduate electronics laboratory and the circuit was produced as a printed circuit board (PCB). The ECG PCB is enclosed in an accessible enclosure designed and manufactured using an in-house additive manufacturing process.

2. Methods

2.1. Pedagogy

The workflow, as shown in Figure 1, exposes learners to discrete elements consisting of proprietary equipment, bespoke hardware, and a software tool. The laboratory experience is informed by a more progressive pedagogy, incorporating elements of socially mediated learning as in Vygotsky et al. [3], problem based learning as in Wood [4], and troubleshooting as in Bogart el al. [5]. The learners gain experience in the use of some typical biomedical test equipment, develop their skills in the gathering of data from a PCB, i.e., data acquisition, and process these data using some bespoke software application tools.
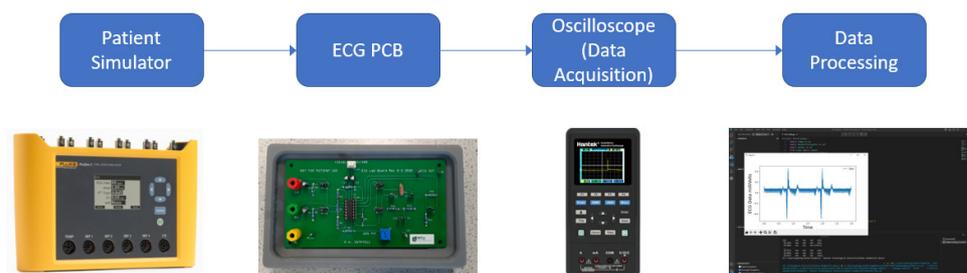
Figure 1. Workflow diagram.

2.2. Printed Circuit Board

A layout was chosen not for efficiency in terms of optimal PCB size, but to be visually similar to the ECG schematic. The layout needs to be of a size which will allow for the location of various banana plugs and numerous ground points. The common mode rejection rate (CMRR) potentiometer needs to be accessible and adjustable without the use of tools. Other modifications include banana plug connectors to attach LA, RA, and RL, and jumper connectors were included to allow the learners to bypass or disengage the two high-pass filters independently and the notch filter, which are both passive-type filters.

2.3. Enclosure Design

The ECG PCB is mounted in a 3D-printed tray to prolong the service life of the board, allow a more stable positioning of the PCB on the laboratory worktops, and elevate the bottom of the PCB to prevent inadvertent shorts or mechanical damage. The enclosure's design allows for easy storage of the ECG PCB.

2.4. Peripherals

The biosignal source is a patient simulator and not the students themselves, as neither the ECG PCB nor the bench top power supplies are ISO/IEC 60601-1-12:2014/Amd 1:2020-compliant [6]. The use of a patient simulator also removes the requirement for teaching students basic skills such as skin preparation and lead placement, and the requirement for consent and data management practices. The oscilloscope used here also functions as digital multi-meter and a function generator. The students will use sin waveforms for analysing filter performance, instrumentation amplifier gain, and adjusting the CMRR.

2.5. Software

The capture and processing of the data requires manual steps using a prepared MSExcel worksheet and a Pan–Tomkins QRS detection algorithm with graphing functions from Luis et al. [7].

3. Results

A patient simulator is used as a biopotential source, with lead placement limited to the Einthoven three-lead placement system. The output of the ECG PCB is captured on a PC using an oscilloscope and PC-based software. The data are captured as a csv file. These data are pre-processed by the learners in MS Excel and graphically depicted to review the morphology. The data are then subject to a Pan–Tomkins [8] QRS detection algorithm using Python. The ECG PCB produces an ECG trace, shown in Figure 2, that has typical ECG morphology characteristics, and QRS detection is possible with correlation between the patient simulators heart rate and the heart rate identified by the QRS detector. Various circuit functionalities are tested by the learners such as removal of the low-pass filter, notch filter, and high-pass filter, as well as altering RV1 to introduce a DC offset.

The patient simulator is configured with various heart rates and compared with the QRS detector output. The patient simulator is configured with various ECG artifacts and arrhythmias.
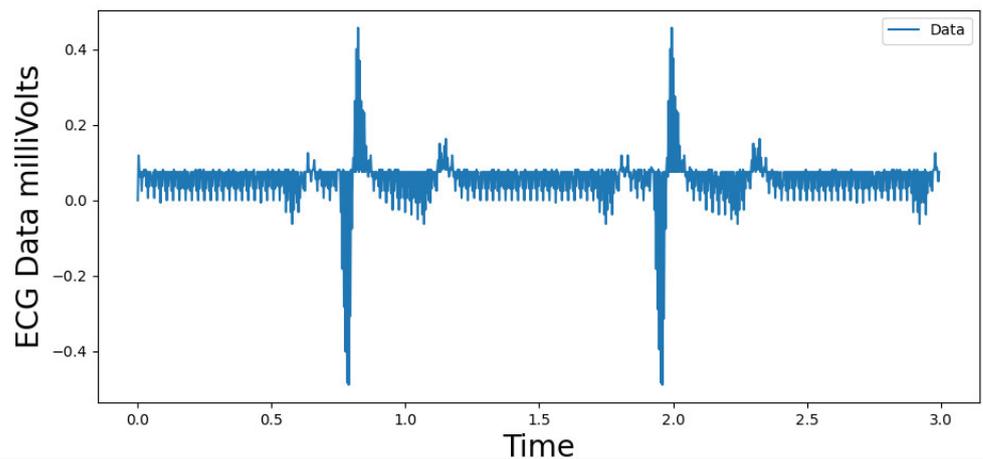
Figure 2. ECG trace processed by QRS detector.

4. Discussion

Other universities have developed much more involved course structures, where an ECG circuit is designed by students within a defined problem space as in Yiu et al. [9] and García et al. [10]. The objective of this project is to provide learners with a functioning and accessible ECG device where various diagnostic and performance verification procedures can be performed, without the requirement for learners to spend time designing or building the circuit; thus, learners can explore the fundamental concepts of ECG. While the aim of this project was to develop a laboratory practical, future work will include capturing learners' experience of this laboratory practical using qualitative analysis and data gathered from focus group interviews, similar to the work of Bogart et al. [5] and a research publication in review by this author.

5. Conclusions

The ECG PCB allows students who are learning about the ECG as a clinical diagnostic tool an opportunity to demystify the building blocks of ECG by engaging in fundamental cause-and-effect-type laboratory sessions. The learners are provided with a basic ECG and some software resources to process the data they capture. Whilst this paper provides some background details on the successful design and implementation of the ECG PCB, further qualitative analysis in the form of focus groups will be conducted to gather feedback from students on their experience of using the ECG PCB and to determine their depth of knowledge regarding this fundamental piece of clinical diagnostic biomedical technology.

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