Course Work Modules - Biomedical Engineering

Wearable Technology Laboratory

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1 Lab overview

The aim of this laboratory is to gain hands-on experience with an important biomedical signal that can be collected from wearable sensors: The electrocardiogram (ECG). You will learn how to acquire, pre-process and analyse various sensor-based measurements from clinically recorded data. The goal of this lab is to understand the role of signal conditioning, how to choose suitable parameters of signal processing algorithms, and the various technological methodologies biomedical engineers have to understand diseases from wearable sensor data.

Tip

It is recommended to follow the electronic/PDF version of this lab sheet to enable clickable embedded hyperlinks, depicted in blue.

2 Getting started

This laboratory will require a MATLAB vR2019b (or later, for example vR2024a) installation on your machine (The MathWorks, Natick, MA, USA). To download the latest version of MATLAB, visit the "How to get software" webpage at https://help.it.ox.ac.uk/sls/fulllist. Follow the instructions to download and install MATLAB using the licence-key provided by the Department of Engineering Science. More details on how to install MATLAB can be found at https://eng.ox.ac.uk/matlab/install. Ensure you have installed the signal processing toolbox (https://uk.mathworks.com/products/signal.html).

2.1 Downloading data

Once MATLAB is installed, you must download the data and accompanying code for the laboratory. The laboratory materials, scripts and data can be downloaded from: https://github.com/maurovm/cwm_laboratory_code. Download the lab files and unzip the content to your **own** MATLAB code directory (this is usually somewhere like: " `/user/code/CWM/`"). Type `userpath` into MATLAB's command window to find this. Next, run the `startup.m` file so that MATLAB can locate the data and code files. It is recommended that you keep all data in the "`data/`" and all code in the "`code/`" folders.

Tip

Remember to ensure that you use the correct `pathname` when loading your data, as this is the biggest troubleshooting problem students typically encounter.
See the official MATLAB documentation [a] for further useful information.

[a] https://uk.mathworks.com/help/matlab/matlab_env/what-is-the-matlab-search-path.html

3 The Electrocardiogram

The electrocardiogram (ECG) records the electrical activity generated by the heart as it undergoes depolarisation and repolarisation of the atria and ventricles. The electrical currents that are generated from this process propagate through the body. A typical ECG waveform is shown in figure 1.

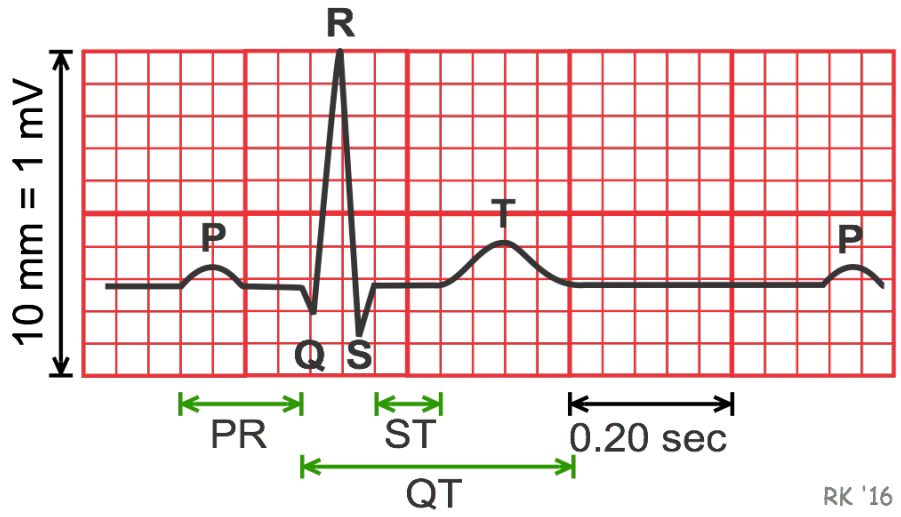

Figure 1: The typical ECG waveform. Image credit: http://www.cvphysiology.com/Arrhythmias/A009.htm.

3.1 Recording ECG

There are multiple different approaches to measure the ECG, with varying degrees of precision, viewpoint, and localisation by placing electrodes at different positions on the human body. The concept behind the ECG is based on Einthoven's triangle, an imaginary formation of three limb leads in an equilateral triangle with the heart at the centre, which forms a reference system to analyse ECG waveforms. There are three standard lead placements forming the *bipolar* standard limb leads: lead I,

an axis from left arm (+ electrode) to right arm (− electrode); lead II, axis goes from the right arm (−) to the left leg (+); and lead III, an axis from the left arm (−) to the left leg (+), as depicted in figure 2(a).

Additionally there are three augmented *unipolar* limb leads which are single positive electrodes that are referenced against a combination of the other limb electrodes. These leads can be "augmented" or constructed from the bipolar leads, allowing us to use the same electrode placement as the *bipolar* form. The positive electrodes for these augmented leads are located on the left arm (aVL), the right arm (aVR), and the left leg (aVF), as shown in figure 2(d).

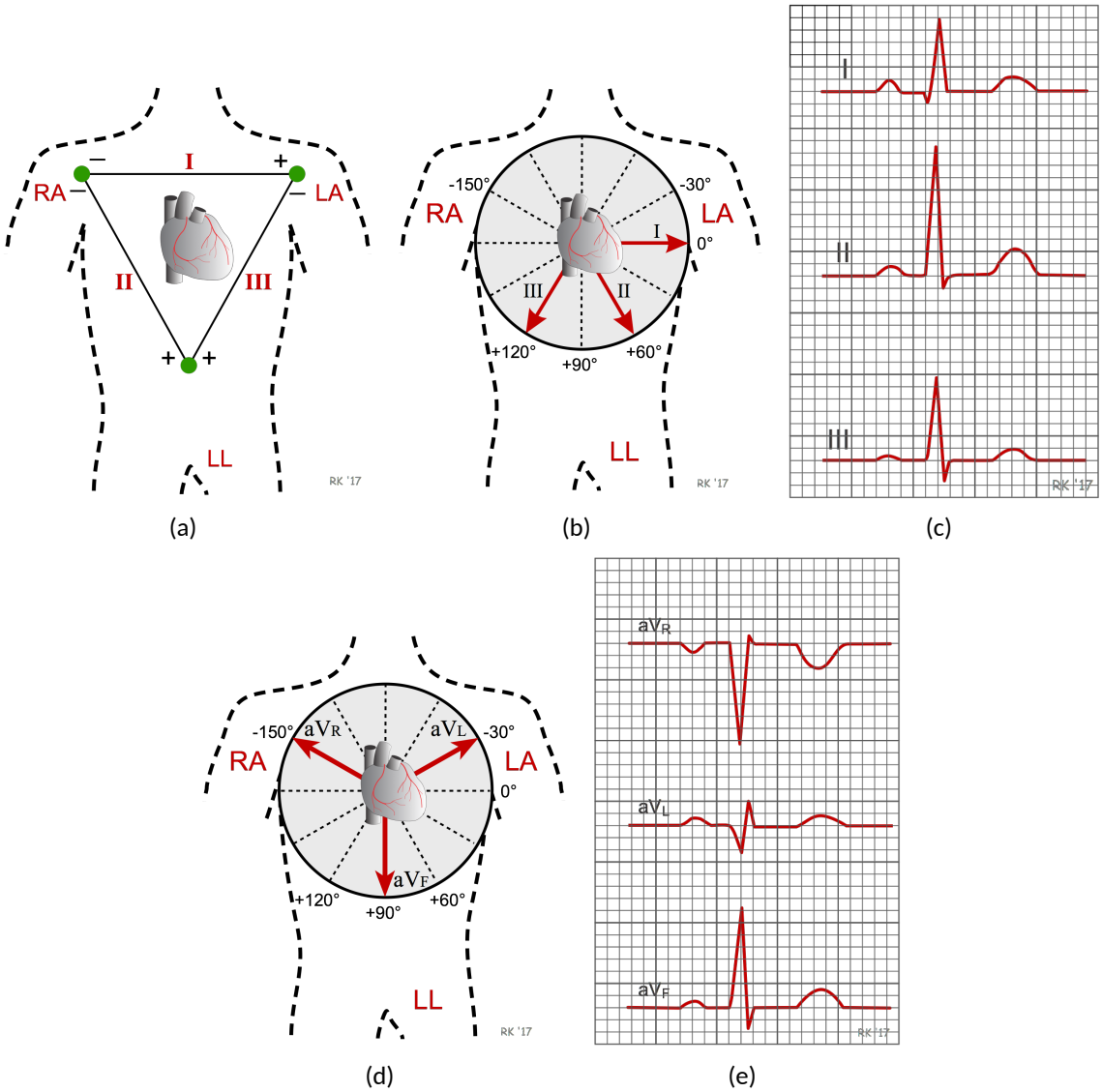

Figure 2: Electrode placement for (a) the standard *bipolar* 3-lead configuration and Einthoven's triangle construction. (b) *Bipolar* limb lead axis and (c) resulting ECG trace.(d) *Unipolar* augmented 3-lead axis and (e) resulting ECG trace.

The combination of the 6 *bipolar* and *unipolar* leads records electrical activity along a single plane, termed the frontal plane relative to the heart (see figure 3(a)). There are also six precordial, unipolar

chest leads which are often applied in rigorous clinical settings. These places six positive electrodes on the surface of the chest over different regions of the heart in order to record the electrical activity in a plane perpendicular to the frontal plane (see figure 3(b)).

Following your lecture notes, diagnostic information can be obtained from the ECG waveform by analysing the amplitude and relative timing of the various segments. ECG can be used for ambulatory monitoring, exercise and stress analysis or even for foetal ECG monitoring. Informative ECG features such as the heart rate, the timing of the PQRST complexes or heart rate variability (HRV).

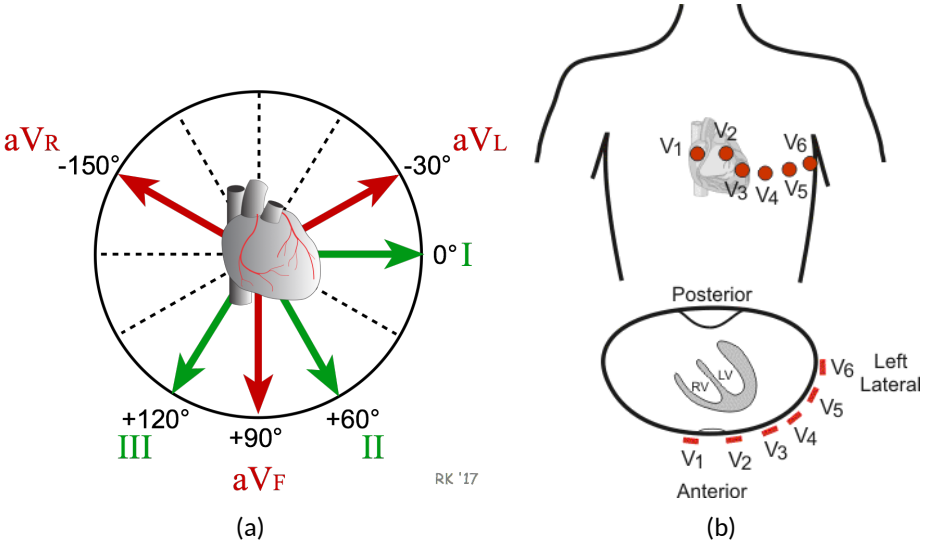

Figure 3: A full 12-lead ECG axis: (a) the combined *bipolar* and *unipolar* 6-axis ECG axis; (b) the ECG chest leads placement. Image credit: http://www.cvphysiology.com/Arrhythmias/A013c.htm.

3.2 Heart defects and diseases

As shown in the lecture slides, the heart beat rhythm is governed by pacemaker cells within the sinoatrial (SA) node which dictates the depolarisation and repolarisation of the atria and ventricles. Unfortunately, when this rhythm becomes irregular, too fast (tachycardia) or too slow (bradycardia), or the frequency of the atrial and ventricular beats are different, arrhythmias occur. Atrial fibrillation is one of the most common rhythm disturbances where this condition causes an irregular and often abnormally fast heart rate. Atrial fibrillation (AF) affects around 1 million people in the UK, affecting about 7 in 100 people aged over 65. Patients may describe an arrhythmia as a palpitation or fluttering sensation in the chest. Luckily, many arrhythmias can be treated with supression antiarrhythmic drugs. It is therefore critical to identify arrhythmias, such as AF, as early as possible so that patients can be provided with vital treatments. Other common heart defects and diseases include cardiac valve diseases, coronary artery diseases, hypertension and hypotension.

4 Section A: The Electrocardiogram

This section aims to introduce some standard approaches to analysing electrocardiogram (ECG) data. The example exercise uses clinical ECG data from the PTB Diagnostic ECG Database[1] in PhysioNet[2]. PhysioNet is a community resource and archive of digital recordings of physiologic signals, time series, and related data for use by the biomedical research community.

Figure 4: Examples of ECG waveforms available in the PTB Diagnostic ECG Database[1] in PhysioNet[2].

The PTB Diagnostic ECG database contains 549 records from 290 subjects (aged 17 to 87, mean 57.2; 209 men, mean age 55.5, and 81 women, mean age 61.6; ages were not recorded for 1 female and 14 male subjects). Each subject is represented by one to five records. Each record includes 15 simultaneously measured signals, including the conventional 12 leads (I, II, III, aV_R, aV_L, aV_F, V_1, V_2, V_3, V_4, V_5, V_6) together with the 3 Frank lead ECGs (V_x, V_y, V_z). Each signal is digitised at 1000 samples per second, with 16 bit resolution over a range of ±16.384mV. On special request to the

contributors of the database, recordings may be available at sampling rates up to 10kHz. A sample recording is shown in figure 4. More details on the PTB Diagnostic ECG database can be found at https://www.physionet.org/content/ptbdb/1.0.0.

The starting code for this laboratory session is found in the file "`section_A.m`" file inside the "`code/`" folder. We will use only one ECG recording "`s0016lre`" from one patient "`Patient001`" from the PTB Diagnostic ECG database. The ECG recording can be found inside the "`data/`" folder. The student is encouraged to download and try the code on any other record found at https://www.physionet.org/content/ptbdb/1.0.0.

4.1 Exercise 1: R-peak detection

In this exercise, we will detect the R-peaks of the provided sample ECG recording. We will use the "`rpeakdetect.m`" MATLAB script. The provided "`rpeakdetect`" function is based on the well-known QRS detected proposed by Pan, Hamilton and Tompkins[3, 4]. As explained during the lecture, this QRS detector has the following stages: i) Filtering the signal, ii) Derivation, iii) Squaring, iv) Integration, and finally v) Thresholding.

Note that the sample "`rpeakdetect`" function contains an error that the student is required to identify and provide a solution.
Tasks to perform:

1. Load the data into MATLAB;
2. Plot a suitable portion of ECG data from a normal subject, which depicts at least 2 heartbeats. Identify and label the PQRST points;
3. Detect the R peaks by fixing the error in the provided "`rpeakdetect`" function

4.1.1 Hints

- Using MATLAB's debugger will help you locate errors in scripts.

4.2 Exercise 2: Computing heart rate

Once the R peaks of the sample ECG signal were correctly located, the student needs to compute the heart rate (HR). The student needs to provide the reasoning used to compute HR.

4.2.1 Hints

- Heart rate can be computed instantaneously (beat to beat) or over a time period.

4.3 Exercise 3: Computing heart rate variability metrics

Heart rate is the number of heartbeats per minute. Heart rate variability (HRV) is the fluctuation in the time intervals between adjacent heartbeats. HRV indexes neurocardiac function and is generated by heart-brain interactions and dynamic non-linear autonomic nervous system (ANS) processes. HRV is an emergent property of interdependent regulatory systems which operate on different time scales to help us adapt to environmental and psychological challenges. HRV reflects regulation of autonomic balance, blood pressure, gas exchange, gut, heart, and vascular tone, which refers to the diameter of the blood vessels that regulate BP, and possibly facial muscles[5].

There are plenty of HRV metrics that have been proposed by the research community[5]. The most common are:

- SDNN or SDRR: Standard deviation of NN or RR intervals respectively[1].
- SDANN: Standard deviation of the average NN intervals for each 5 min segment of a 24h HRV recording.
- SDNN index (SDNNI): Mean of the standard deviations of all the NN intervals for each 5 min segment of a 24h HRV recording
- pNN50: Percentage of successive RR intervals that differ by more than 50 ms
- HR Max – HR Min: Average difference between the highest and lowest heart rates during each respiratory cycle
- RMSSD: Root mean square of successive RR interval differences

Tasks to perform:

1. The student has to compute two HRV metrics.
2. Justify choices and methods.

[1]NN-intervals refer to the intervals between normal R-peaks. During a measurement, artefacts may arise due to arrhythmic events or faulty sensors. This may lead to abnormal R-peaks, which may in turn distort the statistical measures. To ensure reliable and valid data, only normal R-peaks are selected. For this laboratory session, we will take RR-intervals and NN-intervals as synonymous.

Bibliography

[1] R. Bousseljot, D. Kreiseler, and A. Schnabel, “Nutzung der ekg-signaldatenbank cardiodat der ptb über das internet,” 1995.

[2] A. L. Goldberger, L. A. Amaral, L. Glass, J. M. Hausdorff, P. C. Ivanov, R. G. Mark, J. E. Mietus, G. B. Moody, C.-K. Peng, and H. E. Stanley, “Physiobank, physiotoolkit, and physionet: components of a new research resource for complex physiologic signals,” *circulation*, vol. 101, no. 23, pp. e215–e220, 2000.

[3] J. Pan and W. J. Tompkins, “A real-time qrs detection algorithm,” *IEEE transactions on biomedical engineering*, no. 3, pp. 230–236, 1985.

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