Engineering in Medicine and Biology (BIOM1010)
Laboratory: ECG Recording and QRS detection with LabChart

Background

This laboratory will provide you with a 'black box' introduction to electrocardiogram (ECG) acquisition and signal filtering and processing; by black box, it is meant that you will not focus on the inner workings of the hardware and software, but rather focus on the nature of the ECG signal, noise and interference which can occur during signal acquisition, and limitations of signal filtering in mitigating this artefact. You will also see how some simple techniques can be used to make a heart rate meter by detecting automatically the QRS complexes (the depolarisation of the heart ventricles) in the ECG.

In this laboratory we will use hardware and software made by ADInstruments. The hardware is called a PowerLab recording unit; this particular model is the PowerLab 26T. The software used to control this hardware unit is called LabChart, and is available on all of our laboratory computers. Documentation for both the PowerLab unit and the LabChart software are available on Moodle in PDF format, for your reference.

Set-up recording equipment

- Check that the PowerLab unit is switched on (check the power indicator light on the front panel, c.f. Figure 1) and is connected to the computer by a USB cable. Power should show blue. The status light will flash different patterns when the device is used.

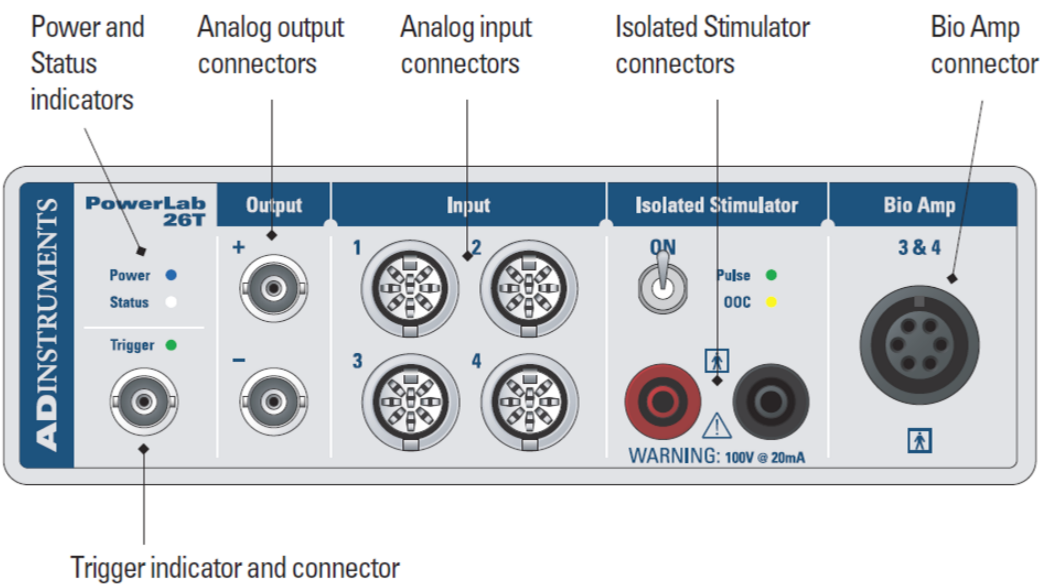


Figure 1. PowerLab 26T recording unit front panel.

- Connect the Bio Amp lead into the Bio Amp connector on the front panel of the PowerLab unit.

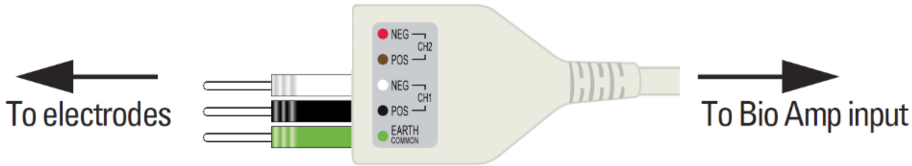


Figure 2. The Bio Amp cable yoke.

- Place three electrodes on the body in the Lead I position so that one ECG channel can be recorded.
    - Lead-I channel: POS of CH1 (black) from Bio Amp cable yoke to left shoulder electrode, NEG (white) to right shoulder electrode. We use the shoulder rather than the wrist.
    - Connect the green EARTH/COMMON input to an electrode on the bony part of the right hip.

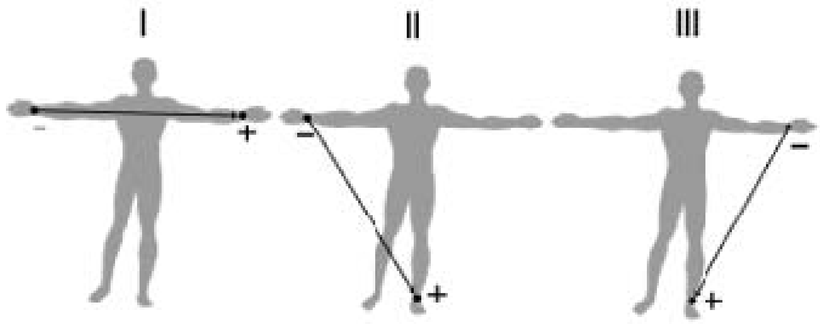
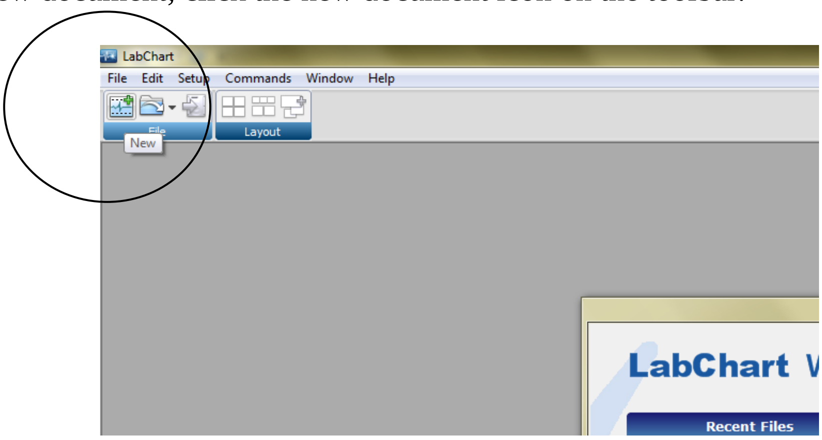


Figure 3. ECG Lead-I, Lead-II and Lead-III electrode placement configurations. The reference electrode (earth, common) is not shown in these diagrams. From: http://paramedicine101.blogspot.com.au/2009/09/electrocardiogram-part-ii.html

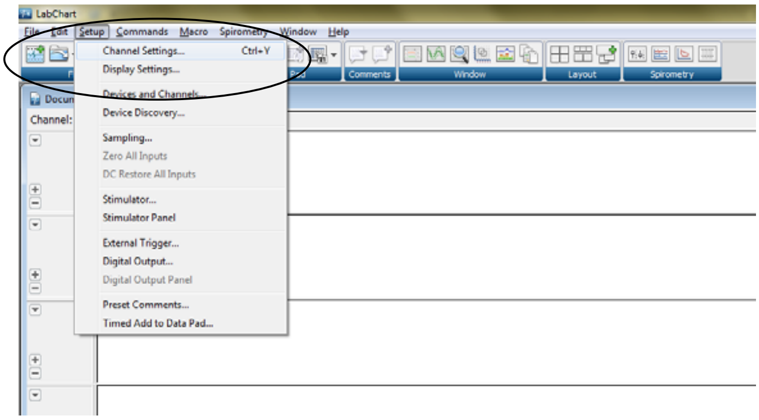
Specify channel properties

For a tutorial on LabChart, see the documentation PDF on Moodle.

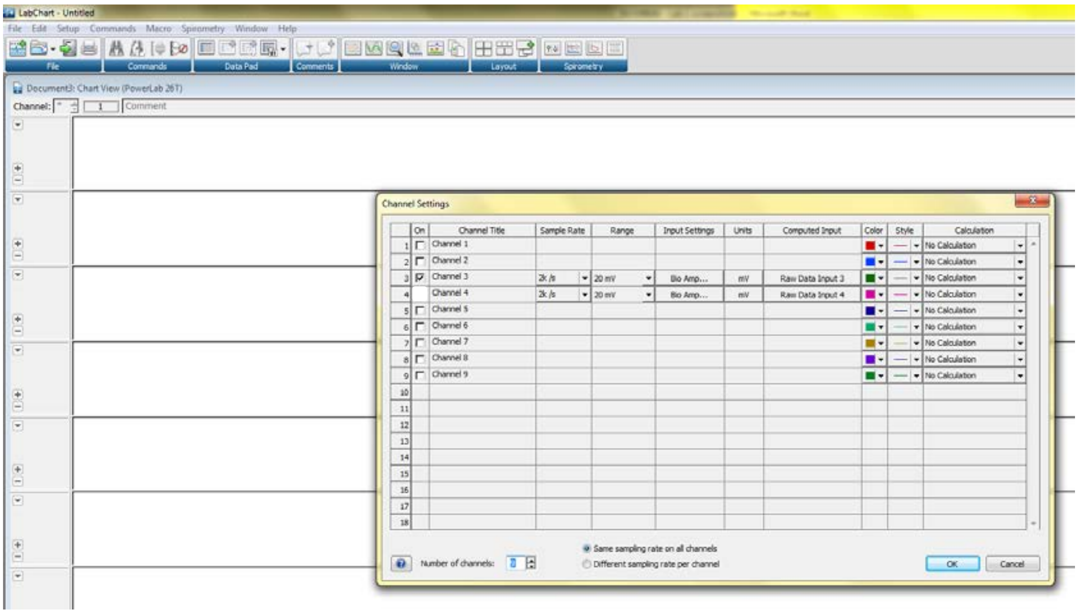
- Open the LabChart 7 program.
- Create a new document; click the new document icon on the toolbar.



- On the toolbar go to “Setup” → “Channel Settings…”

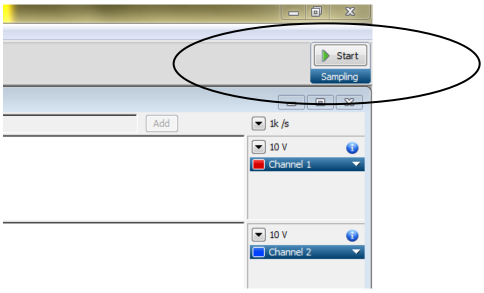


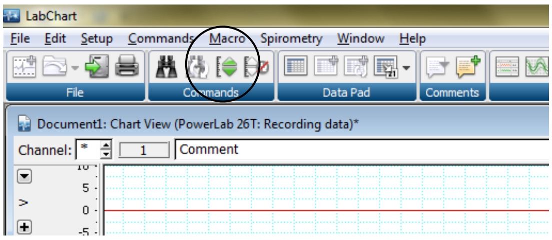
- Setup 9 channels:
    - Channels 1 and 2 have nothing connected to them, so these channels can be turned off.
    - Channels 3 will record the Lead-I ECG signal.
    - Channels 5 to 9 will be used to display some calculated signals (digital filter outputs) which are used to perform QRS detection.
- Set the sample rate to 2 kHz for Channel 3.



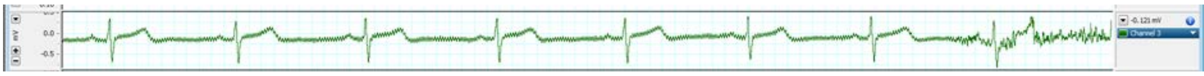
Record 'clean' ECG

- After you have setup the channels, click "Start" in the top right-hand corner of the screen to start the recording.





- In the “Commands” section of the toolbar, click the “Autoscale all channels” icon.
- You should now see an ECG trace on Channel 3, corresponding to Lead I.



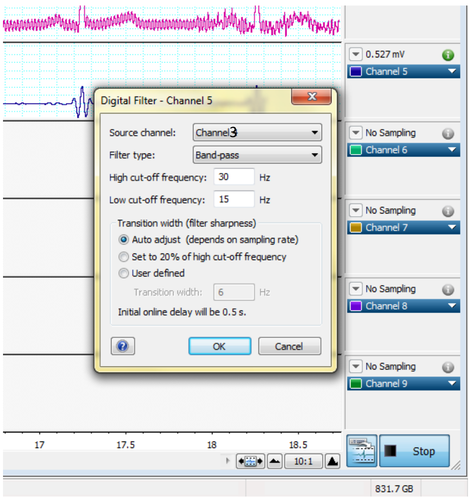
Create QRS detector

This task requires you to implement a number of filtering and arithmetic operations in cascade, applied to the Lead I ECG channel, in order to detect the R-waves and hence estimate both heart rate and an estimate of respiration.

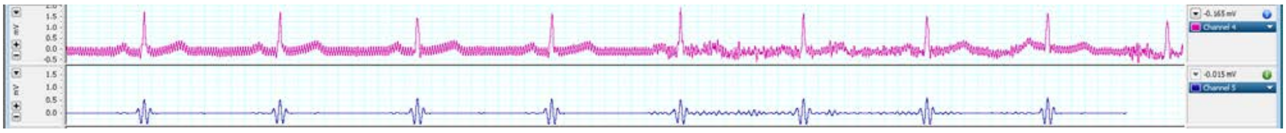
1) <u>Band-pass filter to accentuate QRS complex:</u>

A Fourier transform of a typical QRS complex would reveal that most of its energy lies approximately in the 15-30 Hz frequency range of the spectrum. You will band-pass filter the Lead I ECG in this range to accentuate this feature of the signal, and hopefully attenuate other morphologies (such as the P-wave and T-wave).

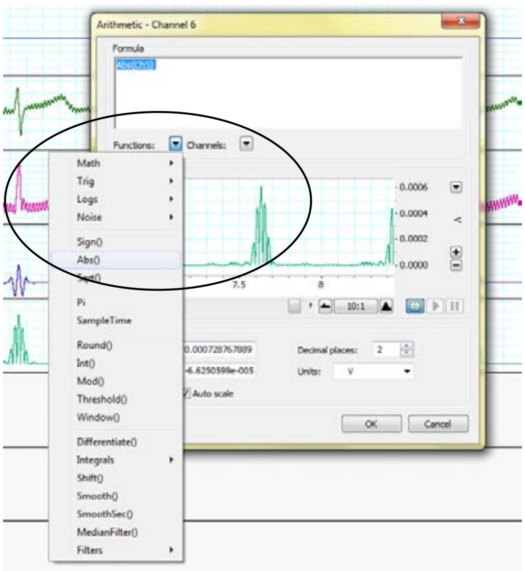
- On the right hand side of the window, choose the dropdown menu beside Channel 5.
- Select “Digital Filter…”
- Set the following parameters:
    - Source channel = Channel 3 (this should be your Lead I ECG);
    - Filter type = Band-pass;
    - High cut-off frequency = 30 Hz;
    - Low cut-off frequency = 15 Hz;
    - Transition width = Auto adjust.



- You should now see a trace similar to the lower trace shown below, which contains most of its energy around the times of the R-wave component of the heartbeat.

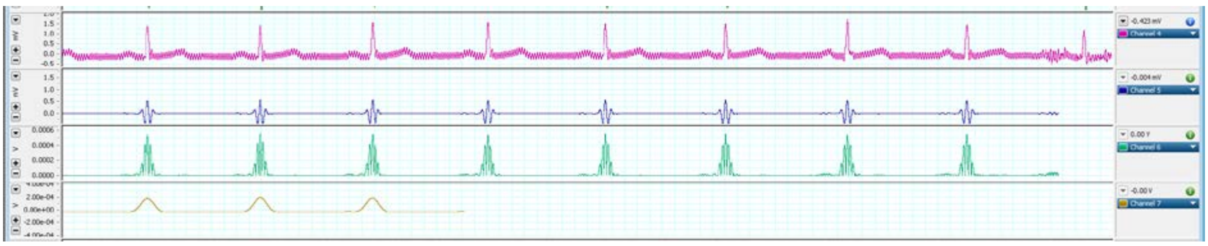


2) <u>Absolute value to make everything positive:</u>
- Similar to above, on the right hand side menu, choose the dropdown menu beside Channel 6.
- Select “Arithmetic…” → “Functions:” → “Abs()”.
- In the same menu choose “Channels…” → “Channel 5”.



- You should now see a signal on Channel 6, which is the absolute value of Channel 5.

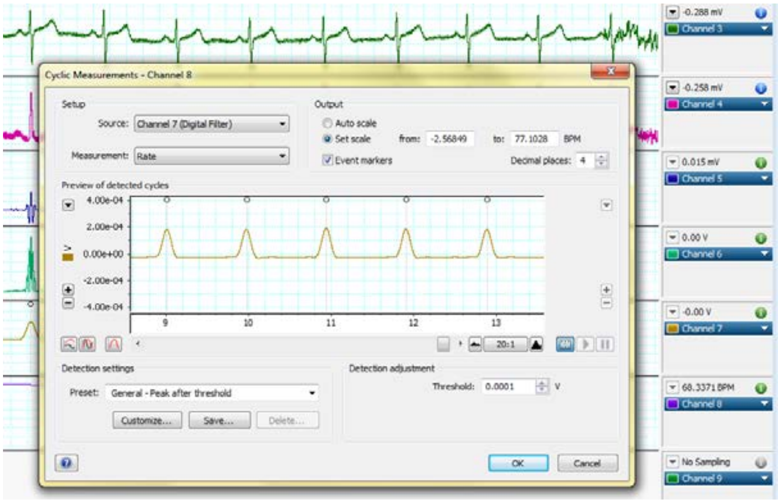
3) <u>Band-pass filter to smooth absolute value and remove baseline drift due to interference:</u>
- Similar to task 1) above, on Channel 7, create a filtered version of Channel 6, using a band-pass filter with a pass-band between 0.5 Hz and 5 Hz.
  - o These frequencies are chosen as the range of frequencies over which we expect the heart rate to normally vary; from 30 beats per minute (BPM) to 300 BPM.
- You should see a trace similar to the bottom signal shown in the figure below.
  - o The signal may be delayed in appearing, due to the digital filtering process.



4) <u>Apply threshold to detect peaks:</u>
- On Channel 8 you are going to show a graph of the estimated heart rate.

4a. *<u>Display heart rate:</u>*

- To estimate the heart rate we must detect the R-waves by applying a threshold to the signal in Channel 7.
- From the dropdown menu to the right of Channel 8, choose “Cyclic Measurements…”, and use the following settings:
    - Source = Channel 7.
    - Measurement = Rate;
    - Output = Auto scale;
    - Tick the “Event markers” checkbox;
    - Detection settings → Preset → General – Peak after threshold;
    - Detection adjustment → Threshold: 0.0001 V;
        - Note the threshold level may vary, depending on the size of your ECG signal and the quality of the ECG electrodes.
    - Set horizontal scaling to 20:1.



- You should now see a trace representing an estimate of the heart rate which updates every time a new peak is detected in Channel 7.
- If you breathe deeply, or hold your breath, you should see the heart rate change. There are several feedback systems which cause respiration to modulate heart rate, including baroreceptors (for blood pressure sensing), chemoreceptors (for blood oxygen and CO_2 levels) and neural control by the autonomic nervous system as well as influences on venous return by the pressure in the pleural cavity. Specifically, what do you see happen to the heart rate when you breathe in deeply.

Introduce 50 Hz interference

- Grab a 50 Hz mains cable (the insulation on the outside of the cable!) with your hand.
    - How does this affect the ECG signals?
    - Does it seem to affect the signal on Channel 7, used to detect the QRS complexes?
- Turn on a digital mains (50 Hz) notch filter on Channel 4 and observe how it affects the signal.

Introduce movement artefact

Movement artefact is one of the most difficult aspects of an ECG to control. When the interface between the electrode/electrolyte and skin changes, or when the skin is stretched, very large artefacts may corrupt the signal.

- Generate some artefact on the Lead I ECG signal by tapping the electrode on your left hip with your finger, or by moving or rubbing the electrode slowly.
    - How does this affect the signal?
    - Does it seem to affect the signal on Channel 7, used to detect the QRS complexes?
- You can also generate artefact by muscle contraction. So squeeze the muscles in your arms and chest as tightly as you can.

Export to Matlab and Filter

Try exporting and saving two files (of at least 30 seconds each) to then import into Matlab (one with 50 Hz noise and the other with as little 50 Hz noise as you can manage). You can mark the regions to export on the LabChart. In Matlab perform a power spectrum analysis on the data, to determine the frequency components of the signals. The MATLAB `pwelch` command can be used for this task (if the frequency resolution is too poor then increase the window size). Plot the power spectrum. The signal and noise components of the recorded wave should be present. The function prototype is:

```
[pxx,f] = pwelch(x,[],[],[],fs);
plot(f,10*log10(pxx));
xlabel('Frequency (Hz)')
ylabel('Magnitude (dB)')
```

`x` is the ECG signal being analysed and `fs` is the sample rate of 2 kHz. You can also look at the other parameters of `pwelch` using the Matlab help function. For example, try the following settings `window = hamming(2000);` `noverlap=1000; nfft=2^16;`

As a reality check the signal corrupted with 50 Hz noise should have a large peak at 50 Hz when you plot the frequency spectrum.