Experimental data acquisition and processing system for ECG signals

Levy G. S. Galvão

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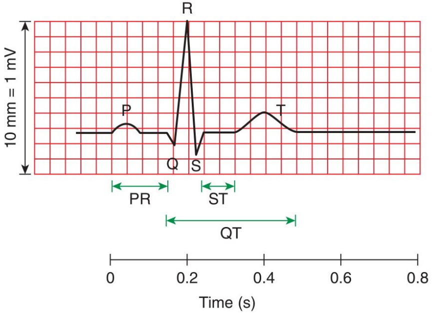
Initial studies: bibliographic research

1. Importance of an electrocardiograph (ECG) instrument;
2. Electrical and physical characteristics of an ECG signal;
3. Distortions associated with the ECG;
4. Consolidated data acquisition systems for ECG;
5. User interface with the ECG instrument;

Figura: Normal waveform pattern of cardiac signal obtained in ECG. Source: [Khandpur, 2019].



Initial studies: system specification

1. Amplitude:
   - ECG signal with $1\,\mathrm{mV}$ peak-to-peak [Khandpur, 2019];
   - Combined distortions with $\approx 10\,\mu\mathrm{V}$ peak-to-peak [Khandpur, 1987];
   - **Solution:** preamplifier gain of 500 [Khandpur, 2019] and CMRR $> +100\mathrm{dB}$ [Khandpur, 2019, Khandpur, 2005]
2. Frequency range:
   - Typical range 0.05 to $150\,\mathrm{Hz}$ and sampling rate of 300 samples/s;
   - **Solution:** used sampling rate of 500 samples/s;
3. Quantization:
   - 16-bit or 24-bit ADC [Khandpur, 2019];
   - **Solution:** available 12-bit ADC;
4. Typical use of bipolar leads arrangement [Khandpur, 2019];

Initial studies: distortions specifications

1. Power-line interference:
   - Frequency of $50/60\,\mathrm{Hz}$;
   - **Solution:** analog Notch filter;
2. Baseline wanders and muscle contraction:
   - Range of $0.05\,\mathrm{Hz}$ [Khandpur, 2019, Murugappan, 2014] to $0.5\,\mathrm{Hz}$ [Sahin, 2020];
   - **Solution:** analog high-pass filter;
3. Electromagnetic interference:
   - Higher frequencies (RF);
   - **Solution:** analog low-pass filter;
4. AWGN and aliasing:
   - Across all frequency range;
   - **Solution:** analog low-pass filter and digital moving average filter;

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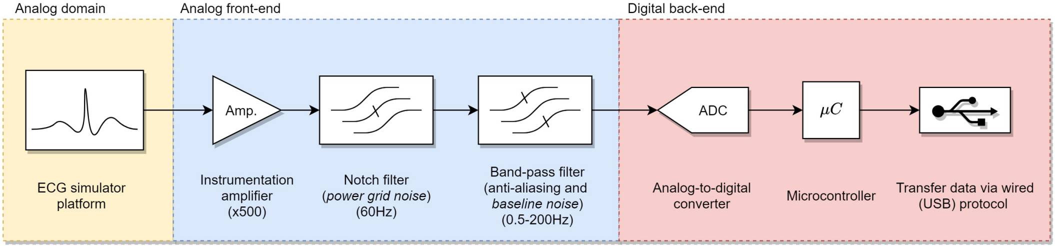
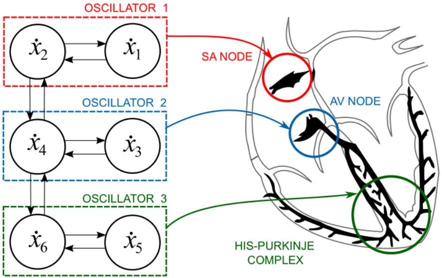
System overview



System overview

- ECG simulator embedded in an ESP32 microcontroller dev-kit outputting via a built-in 8-bit DAC using the [Quiroz, 2019] model;
- Analog front-end simulated via software in LTSpice;
- ECG DAQ embedded in another ESP32 dev-kit with:
  - Built-in 12-bit ADC;
  - Two cores;
  - USB interface with Python plotter client;
  - DSP for heart rate computation and pathology analysis;

Figura: Diagram relating the cardiac natural pacemakers to non linear variables. Source: [Quiroz, 2019].



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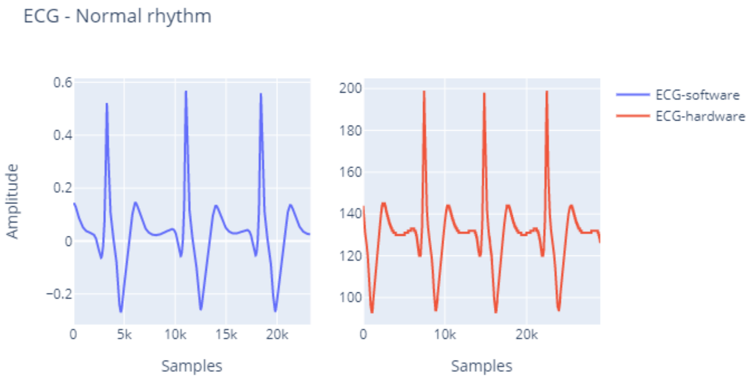
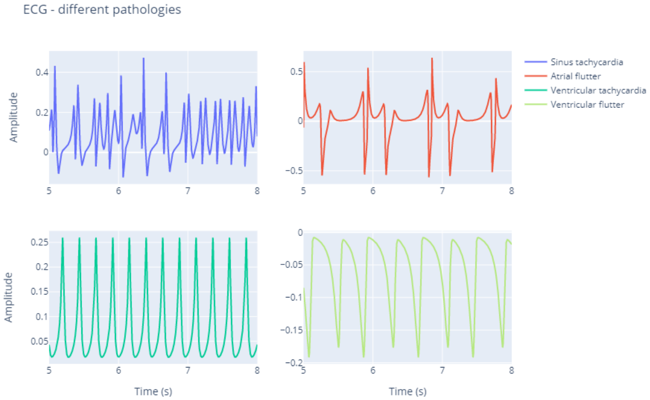
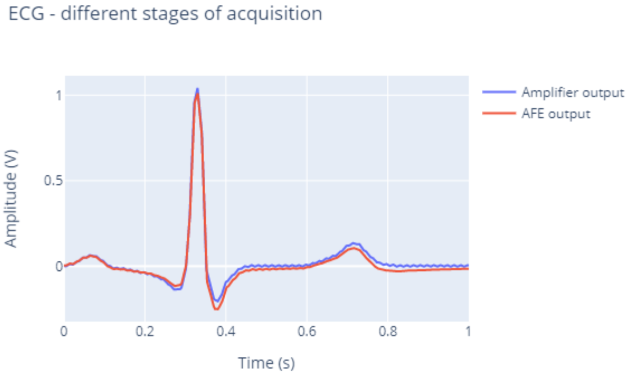
ECG simulator in 32-bit software vs. 8-bit DAC hardware



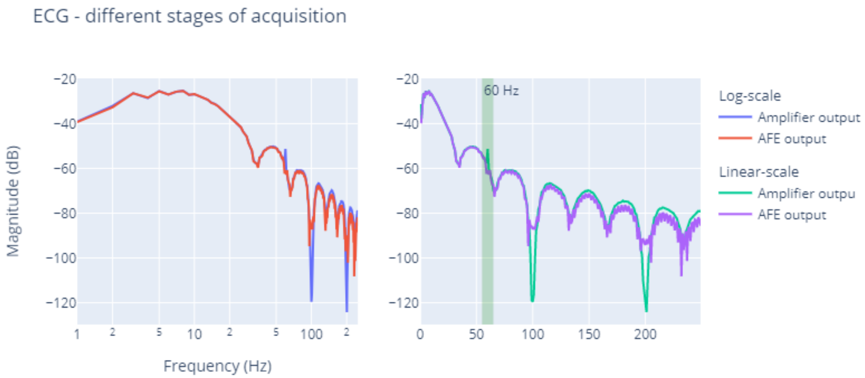
ECG simulator for multiples pathology configurations



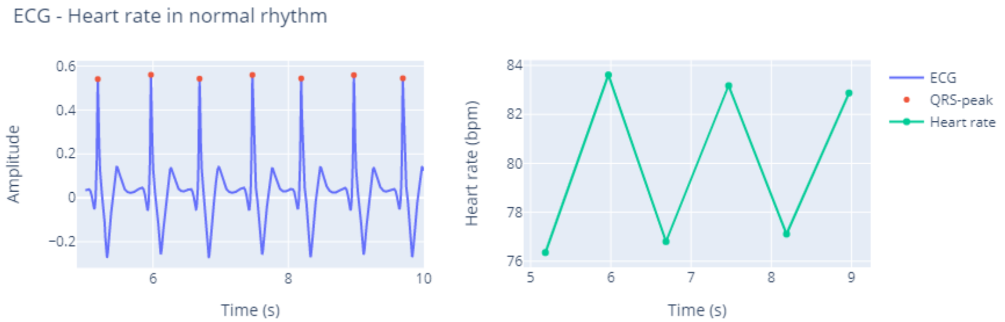
Analog front-end nodes in time domain



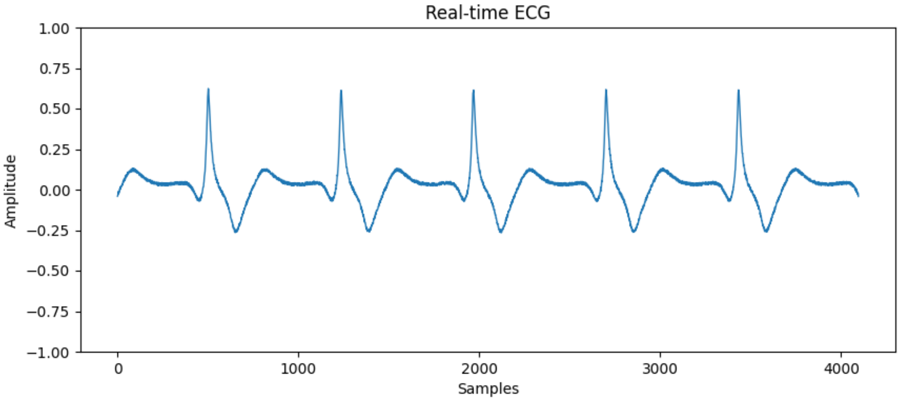
Analog front-end nodes in frequency domain



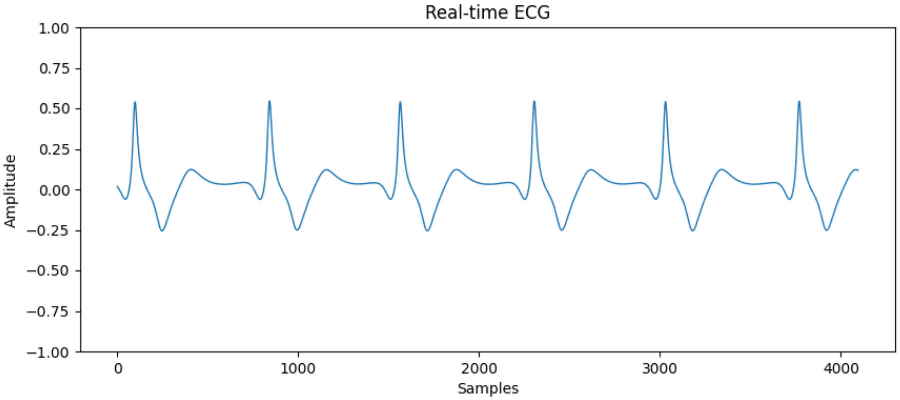
Heart rate analysis in software



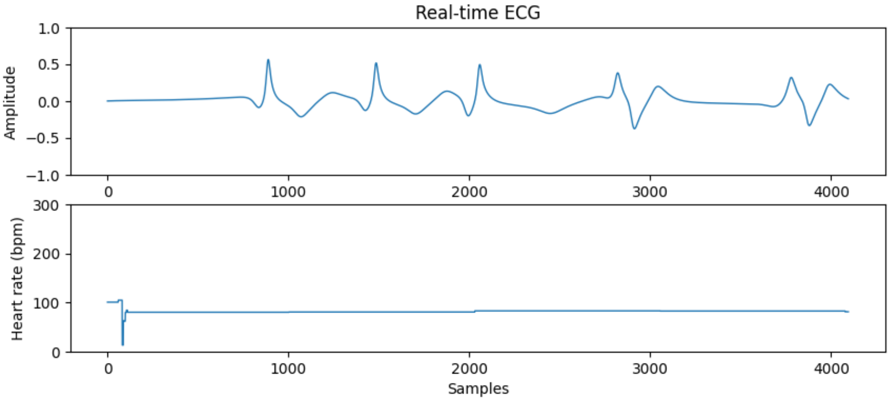
Visualization in Python USB client: noisy ECG



Visualization in Python USB client: filtered ECG



Visualization in Python USB client: ECG + heart rate



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Next steps

- Implement the ECG simulator with a better DAC;
- Implement the analog front-end in hardware and validate the wave forms in each node with oscilloscopes;
- Use an external ADC with higher bit resolution and conditioning circuit to address its input to the ADC linear region;
- Transmit the data via wireless protocol via internet;
- Test new topologies for the analog front-end, such as: multistage amplifiers, higher order filters etc.;
- Further enhance the DAQ DSP section;

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