E2corder (Esophageal ECG recorder) – Filter Design

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Many patients suffer from short and rare-occurring episodes of heart rhythm disturbances (paroxysmal arrhythmias) that may have serious consequences such as stroke, loss of consciousness, or sudden cardiac arrest. Diagnostics rely on long-term electrocardiogram (ECG) conventionally using skin electrodes. The diagnostic yield increases with recording time and signal quality.

Background

In contrast to skin electrodes, the esophageal approach grants optimal electro-mechanical characteristics. Difficulties of recording long-term esophageal ECG emerge from the *baseline wander* (BLW), that arises from esophageal peristaltic, respiration and cardiac motion. The low-frequency BLW overlaps with ECG's bandwidth and makes linear analog filtering inapplicable.

Methods

To extend the limited recording time, ADC resolution and memory size have to be reduced. This can be achieved by subtracting the digitally estimated and stored BLW prior to sampling with the *analog-to-digital converter* (ADC) feedback. Different methods using Simulink were simulated and the most promising model has been implemented on a specially built low-power evaluation board. To validate the simulations in real-time, measurements with surface and esophageal ECGs and synthetic signals were performed.

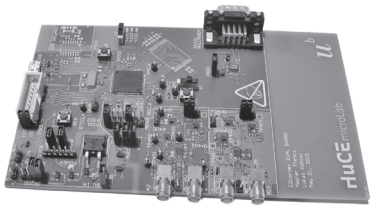
Results

All concepts with digital filters (FIR, IIR, etc.) introduce a group delay that has to be compensated by a predictor (e.g. a LMS filter) for online processing. The predictor comes with high computational effort that cannot be handled by a low-power system. Another simple method called bang-bang removes the baseline wander by offset subtraction and can be imagined as the ADC range that follows the BLW. The evaluated method allows to use an ADC with fewer bits without driving the system into the range limits and additional data to be stored. The acquired signals show that the bang-bang principle is practically feasible in vivo while resting, breathing, eating, liquid ingestion, coughing and sneezing.

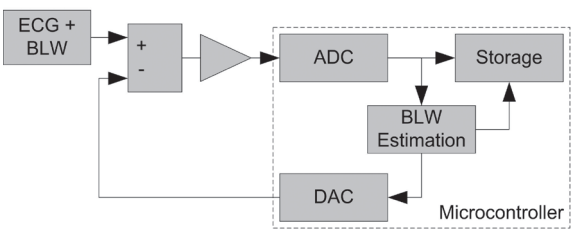
Discussion and Outlook

The relative ECG-spike resolution for a 1 mV peak is increased from 5.8 bit to 7.3 bit with the bang-bang method. It has to be mentioned, however, that oversampling is necessary and that the signal-to-noise ratio cannot be improved. The bang-bang method can be applied to many other signals and to almost any bio-signal suffering from baseline wander, such as surface ECG, electromyography (EMG), electrooculography (EOG) or electro-encephalography (EEG) signals.

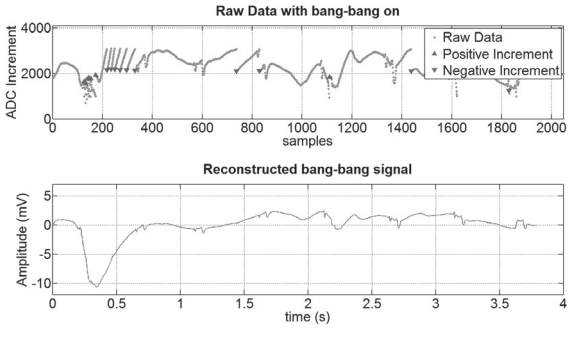
Lukas Kohler



Our self-developed, application dedicated, low-power experimentation board containing microcontroller, flash, two analog ECG amplifiers and USB 2.0 interface.



Functional block diagram of the baseline wander suppression used to subtract BLW prior sampling.



Human esophageal ECG during liquid ingestion sampled with the bang-bang method (top) and the reconstructed signal (bottom). The signal shows a superposition of esophageal peristaltic wave, mechanical motion and the ECG.