Efficient Sensing in Biosystems

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Event-Based Readout in Lab-on-CMOS: Spike Processing

Introduction

Sampling bio-potential data yields a large amount of data, however, the actual information content of the signals is much sparser than the data being collected.

- Transient waveforms require high sampling rates: 40 kSamples/s × 16 bits/Sample × 32 channels → 154 MB/min
- Spike information is quite sparse: < 100 spikes/s × 32 channels → < 3.75 kB/min

Instead of reading out the raw data by itself, we may match the asynchronous signal source with an event-driven readout.

- This requires local spike detection capability
- Bandwidth requirements are reduced by a factor of 1000

System Overview

The system is an active micro-electrode array

- Array of sensor pixels
- Pixel: Electrode pair, bioamplifier, spike detection circuit, and Address Event Representation (AER) interface
- Bioamplifier: Operational Transconductance Amplifier (OTA): \( A_v \times C_{in}/C_{out} = 46 \, \text{dB}, \, C_{in} \times 20 \, \text{pF}, \, C_{out} \times 100 \, \text{fF}, \, \text{Passband: 280 mHz to 8.1 kHz} \)
- Spike Detector: Nonlinear Energy Operator (NEO) algorithm
- AER: Asynchronous readout with full handshaking or autonomous self-timing operation

AER Protocol

- Spike detector triggers event generator
- Row and column arbitration controls address generation
- Single spatial address per spike event

Bandwidth Reduction Factor (BRF)

With typical data acquisition scheme: 40 kSamples/s × 16 bits/Sample × 1 384 b = 80 kB/s

With asynchronous readout:

- 50 AP/s × 8 b/AP × 1 384 b = 50 B/s

\( \text{per channel in a 16 channel system} \)

Experimental Verification

Computational accuracy of NEO circuit measured by providing a 1 kHz spike train with amplitudes of 850 µV (attenuated from 12.7 mV).

Numerical

Signal

Raw

Spike

Experimental Output

Receiver operating characteristic showing detection rate (DR) vs. false positive rate (FPR). Spike amplitudes of 55 – 900 µV (10 – 100 mV un-attenuated).

With input spikes at 390 µV:

- 76% DR vs. 5% FFR
- 100% DR vs. 14% FFR

Statistical Bandwidth Reduction: Compressed EEG Sensing

Introduction

The study of brain diseases such as schizophrenia has traditionally been performed using laboratory-based EEG and MEG devices. Wireless mobile sensing platforms can be a valuable tool in studying EEG patterns:

- Recording responses that are uncontrolled (e.g. hallucinations)
- Facilitates patient comfort

Problem:

- Battery lifetime: system should run continuously throughout the day

Proposed Solution:

- Compress EEG signals prior to data transmission in a computationally-simple manner

Low Cost Mobile EEG

Built from commercial-of-the-shelf components and facilitates on-board compressive sensing.

- Biopotential ADC: TI ADS1299
- High performance microcontroller: Atmel SAM G55
- Up to 7 EEG channels and one audio envelope channel
- Up to 500 samples/s
- Bluetooth connectivity
- Low cost ($200)

Compressed Sensing

Compressive sensing (CS) is a technique of compressing acquired signals in real-time and in a low-power manner.

- Move bulk of computational effort in compression away from the battery-powered wireless node to a base station.
- Compression algorithm is designed to be simple (i.e. made of a few elementary operations)
- Decompression algorithm is inherently non-linear and usually more time- and energy-consuming.

Rakeness CS

Statistical tuning of the CS algorithm to the EEG signals of interest, resulting in implicit signal filtering

- Matched features are enhanced
- Other sources like noise are attenuated

Environmental Noise Shaping

Tune Rakeness CS algorithm to filter out 60 Hz environmental noise

Sensor Noise Shaping

Unwanted sensor motion filtered

Power Measurements

Power consumption of the mobile EEG system was measured as a function of the compression ratio and number of EEG channels being recorded.

- Diminishing returns as compression ratio is increased
- AFE contributes most to increase in power consumption as more channels are added (58% increase in consumption vs. 13% increase)
- Microcontroller processing cost was negligible compared to overhead

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