Smart Energy Body Area Sensor Networks For Pregnancy Monitoring (SEBAN)
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Introduction
With current systems regular monitoring to reduce complications during pregnancy generates extremely high costs and is an unbearable load to the healthcare system. The aim of SEBAN is to generate knowledge on non-invasive, reliable, and comfortable techniques for mobile fetal monitoring applications. To this end a prototype fetal health monitor is created which is as energy-efficient as possible, resulting in a device capable of operating throughout pregnancy. The basic idea is built-in intelligence at the Front-end to reduce power consumed by wireless communication.

Signal Properties

<table>
<thead>
<tr>
<th>Signals to be detected</th>
<th>Amplitude</th>
<th>Freq. range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal ECG (mECG)</td>
<td>0.5 mV</td>
<td>0.5 ~ 50 Hz</td>
</tr>
<tr>
<td>Fetal ECG (fECG)</td>
<td>0.05 mV</td>
<td>1 ~ 70 Hz</td>
</tr>
<tr>
<td>Electrohysterogram (EHG)</td>
<td>0.5 mV</td>
<td>0.1 ~ 1 Hz</td>
</tr>
</tbody>
</table>

Front-end system architecture

- **AMP**: Amplifier
- **ADC**: Analog-to-Digital Converter
- **Detailed Architecture**: Low noise, low power, high CMRR instrumentation amplifier + Speed/Resolution reconfigurable ADC
- **Motion Artifacts**: Low frequency servo loop for motional artifacts removal
- **Electrode offset**: DC servo loop for EO removal

Power optimization

- **System level**: Highly duty-cycled
  - Space domain: Choose the electrodes with the best SNR and turn off the others
  - With built-in intelligence in the Frontend
- **Circuit level**: Co-design of front-end amplifier and ADC
  - Minimize ADC power consumption exploiting prior knowledge on signal properties

Operation scenarios

Further power reduction possible
- **During pregnancy**: Low duty-cycle operation during periods with high SNR e.g. sleep, reduces power consumption.
- **During delivery**: Continuous monitoring during labor for fast intervention. High power consumption acceptable because of imminent delivery and end of product use.

Operation throughout pregnancy on one battery feasible

Traditional way:
Sending raw data Energy is dominated by wireless

Proposed way:
Limited distributed signal processing ability at Front-end reduces energy used by communication

Maternal and Fetal ECG extraction

- **Amplitude of IECG is small compared to noise**
- **Main interference consists of mECG, electrode motion artifacts, and power line interference**
- **Exact estimate of mECG needed for removal Abdominal ECG signal**

Uterine activity detection

- **Estimate intra uterine pressure (IUP) as well as strength, interval and duration of contractions**
- **Prediction of preterm delivery based on uterine activity**

Fetal health estimate

- **Fetal heart rate (fHR) variability and ST analysis**
- **Response of the fHR to stress to contractions**
- **Estimation of labor onset based on IUP and EHG propagation velocity**

Power optimization

- **Reduce computational complexity in order to allow for power reduction**
- **Selective activity and SNR signal usage**
- **Task off-loading to dedicated hardware, e.g. Filtering, SNR estimation, artifact removal**

Operation throughout pregnancy on one battery feasible