Development of a Smartphone-based Pulse Oximeter with Adaptive SNR/Power Balancing

Tom Phelps, Haowei Jiang, and Drew A. Hall
University of California, San Diego

http://www.BioEE.ucsd.edu
Millions of people worldwide suffer from preventable diseases, but lack access to adequate healthcare equipment.

Pulse Oximetry

- Non-invasive measurement of peripheral oxygen saturation (SpO$_2$) and heart rate (HR)
- Commonly used to monitor:
  - Pregnancies (i.e., preeclampsia)
  - Chronic respiratory illnesses (i.e., COPD, asthma, CF) and pneumonia
  - Cardiovascular diseases
  - Sleep apnea
Clinical-grade

High accuracy due to advanced signal processing and (mostly) stationary patient

*Problem*: High cost (~$1k) and high power (~10W) → not portable

Portable

Lower accuracy at a modest cost ($40-$200)

*Problem*: Limited computational power, motion artifacts → not sensitive

**Challenge**: Achieving high accuracy at low cost
Mobile Phones

How can one tap into the mobile phone for mHealth devices?
Use the infrastructure in a mobile phone to realize a low cost (but high accuracy) portable pulse oximeter
Circuit Implementation

Current-mode LED Driver:
- Control $V_{\text{LED}} \rightarrow I_{\text{LED}} \rightarrow$ Light intensity
- AC-coupled to right audio channel
- $C_2$ filters out interference

Photoreceiver:
- Zero-bias photodiode $\rightarrow$ low dark current $\rightarrow$ save voltage headroom
- AC-coupled to mic. Channel
- Clamp diodes to protect mic input
Advanced Signal Processing

- Quality index assessment
- Motion artifact removal
- Powerline interference removal
- etc.

Signal processing entirely done on the phone! Easily updated, adaptive, and more computationally intensive algorithms possible.
Power and SNR Optimization

\[ Error = \sqrt{(HR_{\%Err}HR_\sigma)^2 + (SpO_2_{\%Err}SpO_{2,\sigma})^2} \]
Power and SNR Optimization

\[ \text{Error} = \sqrt{(HR_{\text{Err}} H R_\sigma)^2 + (SpO_2_{\text{Err}} SpO_2_\sigma)^2} \]
Measurement Results

**BE Biomedical PS-2110 Patient Simulator**

**Masimo RAD 87 used to collect true HR and SpO₂**

Despite low-cost and simplicity, HR accuracy < 1.8% and SpO₂ < 3.7%

<table>
<thead>
<tr>
<th></th>
<th>%Error Heart Rate</th>
<th>%Error SpO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subject</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>µ</td>
<td>µ</td>
<td>µ</td>
</tr>
<tr>
<td><strong>Gal. S6</strong></td>
<td>-6</td>
<td>5.3</td>
</tr>
<tr>
<td>Note 4</td>
<td>4.2</td>
<td>4.9</td>
</tr>
<tr>
<td>Note 3</td>
<td>3.2</td>
<td>3.4</td>
</tr>
<tr>
<td>LG V10</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>iOximeter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gal. S6</td>
<td>5.3</td>
<td>-1</td>
</tr>
<tr>
<td>Note 4</td>
<td>4.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Note 3</td>
<td>-3</td>
<td>-2</td>
</tr>
<tr>
<td>LG V10</td>
<td>-2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Despite low-cost and simplicity, HR accuracy < 1.8% and SpO₂ < 3.7%
Conclusion

- Developed a low-cost (BOM < $20) smartphone-based pulse oximeter
- Adaptive SNR and advanced signal processing techniques enabled by using the smartphone for all computation
Thanks!

Gabby Kang