REMOTE PHOTOPLETHYSMOGRAPHY USING NONLINEAR MODE DECOMPOSITION

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Goal: Improve HeartRate detection success by applying a recently proposed signal decomposition method (NMD) on PPG signal which is extracted from human face region.

Problem:
- Due to being weak in power, PPG signals are affected by noise.
- The measured PPG signal includes not only blood volume pulse but also respiratory wave, illumination change, rigid and non-rigid head motion. Thus, it needs to be separated.

Proposed Solution:
- We have applied Nonlinear Mode Decomposition (NMD) method to decompose the PPG signal into nonlinear modes to separate blood volume pulse.
- PureDL dataset has been used.
- The face regions, thus, ROI (Region-of-Interest) have been extracted by Viola-Jones face detector.

NONLINEAR MODE DECOMPOSITION

- A recently proposed signal decomposition method, which separates a signal into its physically meaningful oscillations, while removing noise.
  \[ q(t) = \sum a_i \phi_i(t) + \epsilon(t) \]
  \[ c(t) = q(t) \cdot \epsilon(t) = \epsilon(t) \sum \phi_i(t) \phi_i(t) + \epsilon(t) \]
- Steps:
  1. Extract the fundamental harmonic of an NM from the TFR representation
  2. Find all possible harmonics of the fundamental harmonic
  3. Select the true harmonics of the same NM
  4. Build the nonlinear mode from fundamental and true harmonics, subtract it from the signal and repeat
  5. Stop when the residual signal meets noise criteria
- Features:
  - NMD is extremely noise-robust
  - The parameters of the algorithm are adaptively chosen
  - Returns physically meaningful even though non-sinusoidal waveform.

Example Signal:
\[ s(t) = (10 - 0.035 \sin(2\pi t/3)) + 10 \cos(2\pi t) + 0.5 \eta(t) \]
\[ \phi_i(t) = 10 \eta(t), \]
\[ \psi_i(t) = 14 \eta(t) + 2 \eta(t) \cos(2\pi t) \]
\[ \eta(t) = \text{random signal} \]

ALGORITHM

The Viola-Jones face detector extracts the location and the size of face region.
- The ROI is constructed as the %80 in width and %100 in height of the Viola-Jones face box.
- The R, G, B color components are normalized with respect to intensity:
  \[ r(t) = \frac{R(t)}{R(t) + G(t) + B(t)} \]
  \[ g(t) = \frac{G(t)}{R(t) + G(t) + B(t)} \]
  \[ b(t) = \frac{B(t)}{R(t) + G(t) + B(t)} \]
- 30 second signal is normalized \[ G = \frac{\| r(t) \|_2^2}{\sigma} \]
- In NMD method, only the G signal is used, while in ICA method, all three signals are used.
- The mode is selected based on the criteria:
  \[ i = \arg \max_{1 \leq i \leq 10} \left( |G_i| - \text{median}(|G_i|) \right) \]
  where \( G_i \) is the power spectrum of mode \( i \)
  - The frequency with the highest power in the selected mode is the HR frequency estimate
  \[ HR_{bpm} = HR \times 60 \]
  \[ |HR_{bpm}(i) - HR_{bpm}(i-1)| < 12, \text{ the frequency with next highest frequency is selected.} \]

RESULTS

<table>
<thead>
<tr>
<th>SETUP</th>
<th>NMD-HR</th>
<th>ICA [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talking</td>
<td>17.31</td>
<td>24.41</td>
</tr>
<tr>
<td>Slow Translation</td>
<td>15.21</td>
<td>23.27</td>
</tr>
<tr>
<td>Fast Translation</td>
<td>2.34</td>
<td>3.90</td>
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<tr>
<td>Slow Rotation</td>
<td>5.10</td>
<td>25.86</td>
</tr>
<tr>
<td>Median Rotation</td>
<td>11.55</td>
<td>26.46</td>
</tr>
</tbody>
</table>

Experimental results of the proposed NMD-HR method and the ICA based method. The absolute mean error and the standard deviation of the estimation errors are given in beats per minute.

- The «Talking» setup has the highest average mean error 17.41, 40.10 respectively.
- The NMD signal decomposition method performs better than ICA method in most of the cases.

Experimental results of the proposed NMD-HR method and the ICA based method in terms of RMSE.