Activity-aware Mental Stress Detection Using Physiological Sensors

Master-Seminar ”Physiological data analysis for educational technologies”
(SS 2018)

Christian Sönnichsen
14. May 2018

Lehr- und Forschungseinheit für Programmier- und Modellierungssprachen
Institut für Informatik
Ludwig-Maximilians-Universität München
Introduction
• stress is a common problem in modern life
• continuous stress monitoring could help to intervene in case of too much distress
• there are many studies about mental stress detection, but only with rested participants
• it is impractical to ignore physical activity by developing an application for everyday use
• to solve this issue, physiological data of participants were measured by different activities with mental stressors
Background
Autonomic Nervous System

- Autonomic nervous system (ANS) is regulator of the body's physiological activities
- It is divided into three parts:
  - Sympathetic nervous system (SNS)
    * Mobilizes the body's resources under stress
  - Parasympathetic nervous system (PNS)
    * Relaxes the body
  - Enteric nervous system
    * Controls mechanical and chemical changes in the gut
Heart Rate Variability (HRV)

- the ability of an organism to change the frequency of heart rhythm spontaneously
- increases the adaptability
- defined by the fluctuations of RR intervals
- Electrocardiogram (ECG) shows the electrical activity generated by the heart

Figure 1: [Electrocardiogram sample]
Heart Rate Variability (HRV)

- standard activities like respiration normally cause a heart rate variability

*Figure 2*: ECG diagram with RR-interval at physiological respiration

- HRV analysis can be split into time-domain and spectral-domain parameters

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2https://courses.kcumb.edu/physio/ecg%20primer/normecgcalcs.htm
Time-Domain Parameters

- mean HR: mean heart rate (beats per minute)
- mean RR: mean heartbeat interval (ms)
- SDNN: standard deviation of the RR-interval
- RMSSD: root mean square of the difference between successive RR-intervals
- pNN50: the percentage of heartbeat intervals with a difference in successive heartbeat intervals greater than 50 ms
Spectral-Domain Parameters

- **LF (0.04-0.15 Hz):** a low-frequency component
  - reflects a mixture of SNS and PNS
  - associated with the baroreflex, regulating blood pressure
  - increased by mental and physical activity

- **HF (0.15-0.4Hz):** a high-frequency component
  - is linked to the PNS activity
  - associated with the respiratory sinus arrhythmia

- **LF/HF:** LF to HF ratio
  - balance of PNS and SNS activity
  - normal value 1.5 - 2.0, higher means excessive SNS activity

- **intensity of the spectral HRV parameters is shown by the Power Spectral Density (PSD)**
Spectral-Domain Parameters

**Figure 3:** HRV Frequency diagram of a performance-oriented manager

³https://www.autonomhealth.com/wp-content/uploads/2017/05/leistungsorientierter-Manager.png
Galvanic Skin Response (GSR)

- GSR measures the electrical resistance of the skin
- usually measured at hands or feet
- increasing skin conductance is caused by sweat secretion (mental, physical activity)
- sweat glands are controlled by the SNS

![GSR device on hand](https://www.tobiipro.com/imagevault/publishedmedia/x7n7u7za2ldr7guajibo/Fig_1_2Finger_electrodes.png)

**Figure 4:** GSR device on hand

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4https://www.tobiipro.com/imagevault/publishedmedia/x7n7u7za2ldr7guajibo/Fig_1_2Finger_electrodes.png
Galvanic Skin Response parameters

• three features to characterize startle response
  - total number of the startle responses
  - sum of the response magnitude
  - sum of the response duration

• mean of skin conductance level

• standard deviation of skin conductance level
Accelerometer

- mean value of three axial dimensions
- standard deviation of three axial dimensions
- energy of three axial dimensions
- correlation of each two axes

Figure 5: Sample accelerometer data

https://mcuoneclipse.files.wordpress.com/2013/08/accelerometer-graph.png
Basic Conditions
Basic Conditions

- 20 participants (7 women, 13 men)
- Three activities: sitting, standing, and walking
- Two measurements per activity
- One measurement 10 minutes

**Figure 6**: Experimental Conditions
Basic Conditions

- 3 sensors (ECG, GSR, Accelerometer) all from SHIMMER

**Figure 7:** Shimmer sensors: ECG, GSR, accelerometer

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*Activity-Aware Mental Stress Detection Using Physiological Sensors*
Basic Conditions

- 2 stressors:
  - Stoop Test
  - Montreal Imaging Stress Task

Figure 8: Stressors: Stroop Test, Montreal Imaging Stress Task

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7 Activity-Aware Mental Stress Detection Using Physiological Sensors
Data Analysis
Data Analysis

- 6 datasets (60 minutes) per participant divided in 60-second windows
- each window is one feature vector $\Rightarrow$ 60 feature vectors
- normalization of all features

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{1-9}$ ECG</td>
<td>Mean RR, Std RR, Mean HR, Std HR, RMSSD, pNN50, LF, HF, LF/HF ratio</td>
</tr>
<tr>
<td>$f_{10-14}$ GSR</td>
<td>Mean SCL, Std SCL, Total magnitude, Duration, and Number of startle responses</td>
</tr>
<tr>
<td>$f_{15-26}$ Accel</td>
<td>Mean of X, Y and Z axis, Standard deviation of X, Y, and Z axis, Energy of X, Y, and Z axis, Correlation coefficient of XY, YZ, and ZX</td>
</tr>
</tbody>
</table>

**Figure 9**: Feature Vector
Figure 10: Sample RR interval data
Figure 11: Sample GSR data
Stress Classification

- WEKA machine learning engine used
  - Java
  - integrated classifiers
- used classifiers:
  - J48 Decision Tree
  - Bayesian Network
  - Support Vector Machine
Stress Classification

- K-means algorithm to label automatically the type of activity

**Figure 12:** Activity classes derived from accelerometer data by K-means algorithm
Experiments
• two Experiments:
  1. Cross Validation with Different Feature Combinations
     - four feature combinations
     - investigate how different feature combinations affect stress classification
  2. Between-subjects Experiment
     - investigate if classifier generalizes across participants by train the classifier
Results
Cross Validation with Different Feature Combinations

- 4 combinations: all and for 3 other combinations exclude one feature
- 10-fold cross validation
- Best classification is obtained by decision tree
- Decision tree uses the accelerometer data as test conditions close to the root
- Accelerometer data helps to increase the classification accuracy

**Figure 13:** Accuracy of the three classifiers using different feature combinations
Between-subjects Experiment

- selected randomly a subset of subjects to train classifier
- test of the classifier with the remainder
- repeated 10 times and calculated average accuracy
- SVM classifier with the highest accuracy

Figure 14: Accuracy of the three classifiers using different feature combinations
Comparison of HRV and GSR Parameters

- mean RR interval decreases in all of the three mental task segments
- mean HR increases
- this proves the efficacy of HRV data distinguishing mental stress across the three physical activities

<table>
<thead>
<tr>
<th>HRV Parameters</th>
<th>Sit Base</th>
<th>Sit Stress</th>
<th>Stand Base</th>
<th>Stand Stress</th>
<th>Walk Base</th>
<th>Walk Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean RR (ms)</td>
<td>887.59</td>
<td>814.752</td>
<td>722.43</td>
<td>586.03</td>
<td>562.94</td>
<td></td>
</tr>
<tr>
<td>Std RR (ms)</td>
<td>70.88</td>
<td>85.39</td>
<td>82.44</td>
<td>68.35</td>
<td>92.47</td>
<td>98.94</td>
</tr>
<tr>
<td>Mean HR (bmp)</td>
<td>69.53</td>
<td>75.59</td>
<td>82.84</td>
<td>85.66</td>
<td>107.09</td>
<td>110.79</td>
</tr>
<tr>
<td>Std HR (bmp)</td>
<td>5.54</td>
<td>7.56</td>
<td>8.00</td>
<td>9.50</td>
<td>18.98</td>
<td>16.21</td>
</tr>
<tr>
<td>pNN50 (%)</td>
<td>19.54</td>
<td>15.69</td>
<td>12.09</td>
<td>11.38</td>
<td>4.49</td>
<td>4.23</td>
</tr>
<tr>
<td>LF (%)</td>
<td>7.04</td>
<td>8.45</td>
<td>7.49</td>
<td>7.77</td>
<td>9.43</td>
<td>9.45</td>
</tr>
<tr>
<td>HF (%)</td>
<td>6.25</td>
<td>6.51</td>
<td>6.33</td>
<td>6.73</td>
<td>13.95</td>
<td>15.64</td>
</tr>
<tr>
<td>LH Ratio</td>
<td>1.34</td>
<td>1.51</td>
<td>1.45</td>
<td>1.48</td>
<td>0.67</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Figure 15: HRV data in 6 conditions
Comparison of HRV and GSR Parameters

- total duration was calculated by accumulating the total elapsed time of the responses in the window
- total magnitude was measured by summing up the difference of the onset and the peak of each startle response in window
- GSR data illustrates an obvious increase from baseline to stressed state
- but standard deviation does not show a significant change
- GSR features are relatively independent of the physical activities

![GSR data in 6 conditions](image)

**Figure 16:** GSR data in 6 conditions

<table>
<thead>
<tr>
<th>GSR Parameters</th>
<th>Sit Base</th>
<th>Sit Stress</th>
<th>Stand Base</th>
<th>Stand Stress</th>
<th>Walk Base</th>
<th>Walk Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total duration(second)</td>
<td>3.17</td>
<td>14.30</td>
<td>4.16</td>
<td>13.15</td>
<td>13.72</td>
<td>16.32</td>
</tr>
<tr>
<td>Total magnitude(μSiemens)</td>
<td>0.79</td>
<td>2.04</td>
<td>0.75</td>
<td>3.32</td>
<td>1.69</td>
<td>1.97</td>
</tr>
<tr>
<td>Total occurrence</td>
<td>1.09</td>
<td>6.58</td>
<td>3.13</td>
<td>6.37</td>
<td>5.63</td>
<td>7.47</td>
</tr>
<tr>
<td>Mean GSR(μSiemens)</td>
<td>4.69</td>
<td>4.83</td>
<td>6.19</td>
<td>6.97</td>
<td>6.42</td>
<td>7.22</td>
</tr>
<tr>
<td>Std GSR(μSiemens)</td>
<td>0.62</td>
<td>0.53</td>
<td>0.62</td>
<td>0.71</td>
<td>0.63</td>
<td>0.52</td>
</tr>
</tbody>
</table>
Conclusion and Future Work
• including physical activity in mental stress measuring could improve the every day monitoring
• decision tree classifier has best performance in the conducted experiments
• stress monitoring applications should rely on personalized data
• next experiment with more participants, more activity types and longer recording time
Demo HR Feature: Mean of RR Intervals
Mean of RR Intervals

- the mean of all RR intervals over a certain period
- inverse of mean HR

Figure 17: Sample of Mean RR

\[ \text{Average RR interval} = \frac{650\text{ms}}{92\text{bpm}} \]

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• mean: \( \frac{1}{N} \sum_{i=1}^{N} x_i \)

• \( x_i \) in bpm \( \Rightarrow \) mean RR: \( \frac{1}{N} \sum_{i=1}^{N} \frac{60}{x_i} \)
calculation for segments of 15 minutes

```python
def featureCalculation_RR(segment):
    """
    Takes a Segment of hrValues
    Transforms them to rrValues
    """
    return [60/hrValue for hrValue in segment]

def featureCalculation_meanRR(segment):
    """
    Takes a Segment of hrValues
    Transforms them to rrValues
    Calculates the mean value
    """
    return np.mean(featureCalculation_RR(segment))
```

**Figure 18:** Calculate mean RR in Python
Sun FT., Kuo C., Cheng HT., Buthpitiya S., Collins P., Griss M. 2012 Activity-Aware Mental Stress Detection Using Physiological Sensors

Clemens Breitenbach 2003 Die gesundheitliche Lebensqualität und das kardiovaskuläre Regulationsverhalten. Eine Pilotstudie bei diabetischer autonomer Neuropathie

Erich Styger
https://mcuoneclipse.files.wordpress.com/2013/08/accelerometer-graph.png

Prashant Gupta https://towardsdatascience.com/decision-trees-in-machine-learning-641b9c4e8052

https://www.openml.org/a/estimation-procedures/1
References

- https://www.autonomhealth.com/blog/grundlagen-der-herzfrequenzvariabilitaet/
- http://www.hrv24.de/HRV-Interpretation.htm
- https://www.overleaf.com/latex/templates/metropolis-beamer-theme/qzyvdrntfmr#.WvV1xEOsbIU
- https://imotions.com/blog/heart-rate-variability/
References

http://versuch.file2.wcms.tudresden.de/w/index.php/Hautleitfhhigkeit_(EDA)


https://stila.pms.ifi.lmu.de/