
Physiological data analysis for educational technologies (SS18)
Instructors: François Bry and Yingding Wang
Presentation Date: 07. May 2018
Presented by Zhenhao Li
Agenda

- Introduction of Computed Stress
- Introduction of physiological and physical primary measures of computed stress
- Presenting other relevant information:
  - Motivation for stress research (Challenges & Applications)
  - Stress scale
  - Feature extraction techniques
  - Computational techniques for stress modeling
  - Future work in stress research
- Demo HR Feature: SDRR (standard deviation of RR Intervals)
Motivation for stress research
Problems and Challenges

Stress can overcome defense mechanism which has severe impacts on immune and cardiovascular systems [1]:

- More vulnerable to infections and incurable diseases
- Body's recovery process is slowed down

Further: Stress causes financial burdens on society [2]

Applications of stress research

- Improvement in personal, government and industry operations [1]:
- Increase in the robustness of military operations, law enforcements, athlete performance
- Improvement in designing games and education software, life support systems and commercial products.
- Improvement of learning and increase in work productivity [2]

Definition of stress
The term "stress" was introduced by Selye in 1936 [1]:

"The non-specific response of the body to any demand for change"

Characteristics (symptoms) of stress
Stress symptoms: Hormonal imbalances

- When under stress => increased stress hormones like cortisol
- Measurement done via invasive methods (e.g. taking blood, saliva or urine samples)
- Analysis takes time and requires qualified scientists [1-4]
- Not focus of this survey

Norepinephrine

Adrenaline

Stress symptoms: Physiological changes

- Measurement is non-invasive
- Physiological features require the use of tools that need to be attached to individuals to detect general fluctuations
- On the other hand, a physical feature can be seen by humans

- Brain activity
- Blood pressure
- Respiration
- Galvanic skin response
- Heart rate variability
Physical changes (stress symptoms)

- Measurement is non-invasive
- Physical features can be seen by humans
- However, sensors are still needed to obtain physical signals at sampling rates sufficient for data analysis and modelling

- Interaction
- Pupil dilation
- Voice
- Behavior
Computed stress
Computed stress

- Computed stress: “the stress computationally derived from instantaneous measures of stress symptoms obtained by non-invasive methods”
- Stress cannot only be compared across time but also across multiple individuals
- Statistically more reliable than individual reporting
Stress measurement
Overview of common physical and physiological measures to detect stress

Legend
- Physical Measure
- Physiological Measure

Physiological measures
Physiological measures - Background

Autonomic Nervous System (ANS)

- Sympathetic Nervous System (SNS) (arousing)
- Parasympathetic Nervous System (PNS) (calming)

SNS and PNS regulate:
- galvanic skin response
- heart rate variability
- brain waves

Physiological measures - Overview

1. Galvanic skin response
2. Heart rate variability
3. Brain activity
4. Other primary physiological measures
Galvanic skin response (GSR)

- Known as:
  - Skin conductance
  - Galvanic skin response (GSR)
  - Electrodermal activity response
- Reliable indicator of stress [1]
- Measurement of flow of electricity through the skin
- Stress => skin conductance is increased
- Electrodes are typically placed on the hand, first and middle fingers

Heart rate variability (HRV)

- Heart rate variability (HRV) detects: cardiovascular conditions [1] and ANS activities [2]
- Reliable and popular primary measure for stress
- Electrocardiogram (ECG) is highly sensitive to heartbeats and a superior measurement for HRV [3]
- ECG signals are periodic and have persistent features such as R–R intervals, a parameter to determine HRV
- Acute stress: causes the heart to contract with high force and increased frequency
- Chronic stress: the mass of the heart is increased to provide the body with greater response to stressors

Brain activity

- Methods for analyzing brain activity:
  - Functional magnetic resonance imaging (fMRI)
  - Positron emission tomography (PET)
  - Electroencephalography (EEG), most common due to high temporal resolution, low intrusive equipment and low cost
- EEG captures electrical signals produced by neural activity in the brain as waveforms
- The waveforms are characterized by frequency, amplitude, shape and sites of the scalp.
- EEG signals are categorized by frequency and each category represents some state for a person

<table>
<thead>
<tr>
<th>Wave Band</th>
<th>Frequency range (Hz)</th>
<th>Individual characteristic(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>13–30</td>
<td>Alertness or anxiety</td>
</tr>
<tr>
<td>Alpha</td>
<td>8–13</td>
<td>Relaxation</td>
</tr>
<tr>
<td>Theta</td>
<td>4–8</td>
<td>Dream sleep or phase between Consciousness and drowsiness</td>
</tr>
<tr>
<td>Delta</td>
<td>0.5–4</td>
<td>Coma or deep sleep</td>
</tr>
</tbody>
</table>

EEG wave band categories

Blood pressure (BP):
- Pressure exerted on the walls of blood vessels due to blood circulation
- Varies between a systolic (maximum) and a diastolic (minimum) pressure
- Increased BP => Increase in stress

Blood volume pulse (BVP):
- Amount of blood in a blood tissue during a certain time interval
- Measured by amount of light reflected by skin surface
- Decreased BVP => Increase in stress

Other primary physiological measures

- **Electromyogram (EMG):**
  - Shows electrical activity produced by active muscles
  - For stress detection, EMG electrodes have been placed on the trapezius muscle

- **Skin temperature (ST):**
  - Negatively correlated with stress
  - ST increased => stress decreases

- **Respiration:**
  - Rate and volume used to measure stress
  - Require individuals to wear a belt around their chest (intrusive)

---

Physical measures
Behavior, gesture and interaction

- Body language ( = body pose + body motion) can express stress states
- Detection using computer vision techniques with the purpose of understanding a visual environment
- More common: assessment done by human experts

Facial features

- Facial expressions:
  - Facial muscle movements have been used to determine stress
  - Increase in head and mouth movements => increase in stress
  - The human brain of a healthy individual has facial expression recognition detectors to determine symptoms of stress

- Eye gaze:
  - Eye gaze provides information on attention source and shows mental states of a person
  - Using eyes to focus on a particular object on a computer screen for a greater period of time and frequent focuses on the object are characteristics that correlate with stress levels
Facial features II

- Pupil dilation:
  - If an individual’s pupil diameter increases, the pupil dilates at a higher frequency => stressed (increasing mean values over a time period)
  - Both negative and positive stimuli can cause pupil diameters to increase
  - Interpolation techniques have been used to determine pupil diameters

- Blink rates:
  - Conflicting characteristics for stress detection in different experiment environments:
    - Higher frequency of blinks is detected when under stress (real driving experiments)
    - Lower frequency of blinks is detected when under stress (solving mathematical tasks on a PC)
  - Faster eye closure => higher stress level
Voice

- Stress in voice is defined as “observable variability in certain speech features due to a response to stressors” [1]

- Nonverbal components of voice reflect stress

- Stress indicated by:
  - Increases in range and rapid fluctuations in fundamental frequency
  - Increases in energy for high frequency voice components
  - Greater proportions of high frequency components

- Acoustic components in voice show that stress are caused by physiological changes that depict signs that the human body is responding to stress:

  - Micro-muscle tremors (MMT), caused by muscle tension, and voice stress analysis (VSA) reflect stress

  => Physiological and physical characteristics of stress are related.

Fusion of measures

- Combinations of sensors => better measure of stress
- Some examples of combination:
  - Facial expressions, eye movements, head movements, GSR, RTD and BVP [1]
  - GSR, BVP and HR => detect stress in video game players [2]
  - GSR, EMG, ECG and respiration => computer users [3]
  - ECG, GSR, EMG and respiration => car drivers [4]
- Combination of measures may be redundant
- => Finding optimal measure combination using mutual information measure and principal component analysis

Evaluation of primary measures for stress
# Empirical ranking of primary measures

<table>
<thead>
<tr>
<th>Rank</th>
<th>Primary measure</th>
<th>Physical or Physiological</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heart rate variability (HRV)</td>
<td>Physiological</td>
</tr>
<tr>
<td>2</td>
<td>Galvanic skin response (GSR)</td>
<td>Physiological</td>
</tr>
<tr>
<td>3</td>
<td>Electroencephalography (EEG)</td>
<td>Physiological</td>
</tr>
<tr>
<td>4</td>
<td>Pupil dilation (PD)</td>
<td>Physical</td>
</tr>
<tr>
<td>5</td>
<td>Voice</td>
<td>Physical</td>
</tr>
<tr>
<td>6</td>
<td>Eye gaze</td>
<td>Physical</td>
</tr>
<tr>
<td>7</td>
<td>Facial expression</td>
<td>Physical</td>
</tr>
<tr>
<td>8</td>
<td>Blood pressure (BP)</td>
<td>Physiological</td>
</tr>
<tr>
<td>9</td>
<td>Skin temperature (ST)</td>
<td>Physiological</td>
</tr>
<tr>
<td>10</td>
<td>Blood volume pulse (BVP)</td>
<td>Physiological</td>
</tr>
<tr>
<td>11</td>
<td>Eye blinks</td>
<td>Physical</td>
</tr>
<tr>
<td>12</td>
<td>Respiration</td>
<td>Physiological</td>
</tr>
<tr>
<td>13</td>
<td>Electromyography (EMG)</td>
<td>Physiological</td>
</tr>
</tbody>
</table>
Stress scale

- Binary:
  - Stressed
  - Not stressed

- 3 states:
  - High-Stress
  - Average
  - No-Stress

- Multiple categories:
  - Very Stressful
  - Stressful
  - Somewhat Stressful
  - OK
  - Somewhat Calm
  - Calm
  - Very Calm

- Continuous:
  - [0 - 100]
  - Higher = increase in stress levels
Feature extraction techniques
Feature extraction techniques

- Common to covert physiological signals from time domain to frequency domain
- Extracting features that are more apparent in the frequency domain for analysis
- Feature extraction techniques mentioned:
  - Fourier transformations (FT)
  - Wavelet transformations (WT)
  - Principal Component Analysis (PCA) for EEG feature extraction
  - Independent Component Analysis (ICA) for EEG feature extraction
Computational techniques for stress modeling
Recap: Computed stress

Symptom (e.g. HR)
Symptom (e.g. GSR)
Symptom (e.g. ECG)

stress model

Computed stress

How to build a stress model?
Techniques Overview

Input data

Naive Bayes

Decision Tree

Neural Net

RBF SVM

http://scikit-learn.org/stable/_images/sphx_glr_plot_classifier_comparison_001.png
Bayesian classification

- Predicts class membership probabilities for given samples
- Based on Bayes’ theorem
- Used to calculate posterior probabilities stress states
- Naive Bayesian classifiers used to classify stress (assuming independent classes)
- Bayesian belief networks or Bayesian Networks (BN) can be used when classes have dependencies
- Dynamic Bayesian Network (DBN) has been used to model stress (able to show how properties of stress vary over time)
Decision trees

- Based on a divide-and-conquer approach, flowchart like
- Each internal node represents some criteria or test to divide the input space into regions
- Each branch denotes an outcome of the test
- Each terminal node or leaf represents a target class
- Decision trees have been used to classify stress based on characteristics in:
  - physiological measures (e.g. EEG)
  - combinations of primary measures (e.g. combination of BVP, GSR, PD and ST)
- Potential problem: crisp splits for prediction
Artificial neural networks

- Inspired by biological neural networks
- Stress models based on ANN are at the early stages of research and have produced promising results
- ANN is better at recognizing stress than humans from voice recordings
- Following types of ANN have been used for stress classification:
  - Multi-layered perceptrons (multiple hidden layers)
  - Recurrent ANN (RANN): retains information of previous sample
- Parameterization (choose the number of hidden neurons and layers) is critical (usually obtained empirically)
Support vector machines (SVM)

- Classifies linear and non-linear primary measures
- SVM transforms training data to a higher dimension, in which a linear separating hyper-plane is determined by training samples, or support vectors, and margins
- An appropriate non-linear mapping can separate two classes of data with a hyper-plane (when data are transformed in sufficient high dimension)
- SVMs have been used to predict stress states using BVP, GSR, PD and ST data
Markov chains and hidden Markov models

- Markov chain
  - Simplest form of a Markov model
  - Models the state of a system with a random variable, which varies with time
  - State is dependent on prior states
  - Fully observable

- Hidden Markov model (HMM)
  - Partially observable (only the sequence of observations can be seen)
  - A double stochastic process with a Markov chain that has a finite number of states and a set of functions that corresponds to each state.
  - In stress research used in recognizing stressed speech

Example of HMM
Fuzzy techniques

- Fuzzy-based techniques, in particular fuzzy clustering have been used to measure stress.
- Fuzzy filters could be used to filter out uncertainties in physiological measures of stress.
- Data clusters by fuzzy can belong to multiple clusters (traditional clustering just one cluster) with different membership degrees.
- Each data element has a set of membership level values.
Evaluation of techniques for modelling stress
## Rankings of stress modelling techniques

<table>
<thead>
<tr>
<th>Rank</th>
<th>Modelling technique</th>
<th>Reported accuracy</th>
<th>Inputs for model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Support Vector Machines (SVM)</td>
<td>90.10% 79.3%</td>
<td>GSR, HR, PD, ST EMG, ECG, Respiration, GSR</td>
</tr>
<tr>
<td>2</td>
<td>Recurrent ANN (RANN)</td>
<td>MSE = 0.084</td>
<td>Voice</td>
</tr>
<tr>
<td>3</td>
<td>Adaptive neuro-fuzzy system (ANFS)</td>
<td>76.7%</td>
<td>EMG, ECG, Respiration, GSR</td>
</tr>
<tr>
<td>4</td>
<td>Artificial neuronal network (ANN)</td>
<td>82.7% [113] Not provided</td>
<td>EEG ECG</td>
</tr>
<tr>
<td>5</td>
<td>Hidden Markov Models (HMM)</td>
<td>Not provided</td>
<td>Voice</td>
</tr>
<tr>
<td>6</td>
<td>Decision tree</td>
<td>88.02%</td>
<td>GSR, HR, PD, ST</td>
</tr>
<tr>
<td>7</td>
<td>Naive Bayesian network</td>
<td>78.65%</td>
<td>GSR, HR, PD, ST</td>
</tr>
<tr>
<td>8</td>
<td>Fuzzy clustering</td>
<td>Not provided</td>
<td>HRV</td>
</tr>
</tbody>
</table>
Conclusion & Future Work
Conclusion

- Stress is a serious and growing issue with impacts on individuals and society
- Stress recognition, classification and prediction can solve the problem
- Stress research has many applications, incl. improving education, driving and work
- Stress cannot be directly measured but determined by its symptoms (primary measures)
- Computed Stress: take multiple symptoms of stress and choose a computational technique to model the stress, the output is the computed stress
Future Work

- Aligning multi-source signals:
  - Use of techniques such as dynamic time warping to find an optimal alignment
  - Investigating and modelling latencies for physiological and physical signals for fusion of primary measures for measuring stress

- Automated stress detection from behavior data

- Standard categorical labels for stress that following research can adopt

- Use of combinations of physical and physiological sensors extensively

- Clustering techniques can be included in the process for determining an optimal combination of primary measures.

- Use of Genetic programming (GP) techniques (already used for determining emotions)
Demo HR Feature: SDRR (standard deviation of RR Intervals)
SDRR - Standard deviation of RR Intervals

- SDRR: standard deviation of an interval between R peak and R peak of ECG (unit in time, e.g. milliseconds)
- Index of variation of heart rate
- RR-Interval: time between two heartbeats
- High SDRR = healthy state (indicates a stronger parasympathetic nervous system activation)
Math behind SDRR

- 1. mean (μ): \[ \frac{1}{N} \sum_{i=1}^{N} x_i \]

- 2. variance (σ²): \[ \frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2 \]

- 3. standard deviation (σ): \[ \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2} \]

- For RR-Interval: 60/bpm =>
  - MeanRR: \[ \frac{1}{N} \sum_{i=1}^{N} \frac{60}{x_i} \]
  - SDRR: \[ \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left( \frac{60}{x_i} - \mu \right)^2} \]
SDRR calculation in Python

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

def featureCalculation_SDRR(segment):
    """
    Takes a Segment of hrValues
    Transforms them to rrValues
    Calculates the standard deviation
    """
    return np.std(featureCalculation_RR(segment))
```
Demo: A really exciting and stressy day

The Coding Contest is uniting 50+ cities worldwide!
References

References

- U. Rajendra Acharya, et al., Heart rate variability: a review, Medical and Biological Engineering and Computing 44 (2006) 1031–1051
References


- http://scikit-learn.org/stable/_images/sphx_glr_plot_classifier_comparison_001.png
