Continuous Inference of Psychological Stress from Sensory Measurements Collected in the Natural Environment

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Outline

- Motivation and Background

- Stress model development (lab data)
  - Physiological stress model
  - Perceived stress model

- Model evaluation on field data

- Conclusions and Future Work
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Negative Effects of Stress on Health

- Excessive stress adversely affects
  - Body
  - Mind

- Over long time it increases risk of
  - Physical illness: cancer, cardiovascular health
  - Mental illness: depression, anxiety disorder

- Strong motivation to study stress
  - Measure continuously, in natural environment

- Need robust methods for measuring stress
Measuring Stress in the Field

- **Self-reports have been used for a long time**
  - Questionnaires or surveys
  - Measure perceived stress

- **Strengths and limitations**
  - Capture detailed information
  - Discrete sampling
  - Burden to participant

- **Need an **automated** approach for **continuous** stress measurement in the field**
The Quest for Automated Stress Measure

- Predicting psychological state from physiology
  - William James – pioneering work (1880)
  - John Cacioppo and others – revitalized interest (1990)

- Many emotion and stress prediction studies
  - Identified stress and emotion markers (Heart rate, skin conductance)
  - Mostly in controlled settings

- Few studies in uncontrolled environments
  - Either no validated stressors, no lab session to train models, not able to account for confounders, or tried to match self-reports directly
Challenges of Stress Study in Field

1. **Need an unobtrusively wearable sensor system**
   - Collect multiple sensor modalities
   - Provide scientifically valid data

2. **Control for confounding factors**
   - Activity, change in posture, food, all affect physiological measurements

3. **Account for between-person differences**

4. **Unavailability of ground truth in the field**
   - Self-reports are one source of ground truth
In the AutoSense Project

- We developed a new wearable sensor suite
- Conducted scientific user study with validated stress protocol
  - 21 participants, 2 hour lab study, 2 day field study
    - Protocol designed by behavioral scientists
    - Stressors used are validated and known to produce stress
    - Self-reports designed by expert behavioral scientist
    - Participants wore AutoSense for in lab and for two days in field

- Developed new stress models to measure
  - Physiological response to stress
    - To measure adverse physiological effects of stress
  - Perception of stress in mind
    - To derive a continuous rating of perceived stress
AutoSense Wearable Sensor Suite

- Respiration Band
- ECG Electrodes
- Temperature Probe

ECG, Respiration, GSR, accelerometer, Ambient & skin temp.
Alcohol, accelerometer, PPG, in arm band

Self-reports

Android G1 Cell Phone

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AutoSense Wearable Sensor Suite

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Self-reports

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Lab Study – Stress Protocol

- **2 hour lab session**
  - Subjects exposed to three types of stressors
    - Public speaking – psychosocial stress
    - Mental arithmetic – mental load
    - Cold pressor – physical stress

- **Physiological signals recorded at all times**
  - Using AutoSense
  - Also, collected self-reported stress rating 14 times
Self-Report Measures of Stress

- Self-report questions related to affective state

<table>
<thead>
<tr>
<th>Question</th>
<th>Possible Answer</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheerful?</td>
<td>YES yes no NO</td>
<td>3 2 1 0</td>
</tr>
<tr>
<td>Happy?</td>
<td>YES yes no NO</td>
<td>3 2 1 0</td>
</tr>
<tr>
<td>Frustrated/Angry?</td>
<td>YES yes no NO</td>
<td>0 1 2 3</td>
</tr>
<tr>
<td>Nervous/Stressed?</td>
<td>YES yes no NO</td>
<td>0 1 2 3</td>
</tr>
<tr>
<td>Sad?</td>
<td>YES yes no NO</td>
<td>0 1 2 3</td>
</tr>
</tbody>
</table>

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Overview of Model Development

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Impact of lab stressors on ECG measure

- Selected 1 minute intervals from each period
- Removed outliers from RR intervals
- Computed 35 features
  - Normalized features
Identified 22 Features from Respiration

**Basic Features**
- Inhalation Duration
- Exhalation Duration
- Respiration Duration
- Insp./Exp. Ratio
- Stretch
- Breathing Rate
- Minute Ventilation

**Statistical Features**
- Mean
- Median
- 80th Percentile
- Quartile Deviation

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Computed 13 Features from ECG

**Basic Features**
- RR Intervals
  - RSA

**Statistical Features**
- Variance
- Power in low/medium/high frequency bands
- Ratio of low frequency/high power
- Mean
- Median
- 80th Percentile
- Quartile Deviation

[ECG Signal Diagram]

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Feature and Classifier Selection

- Used Weka for Training
  - Evaluated Decision Tree, DT with Adaboost, and Support Vector Machine
  - Using 10-fold cross validation, and training/test data

- Classification results using 35 features

<table>
<thead>
<tr>
<th>J48 Decision Tree</th>
<th>J48 with Adaboost</th>
<th>SVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>87.67%</td>
<td>90.17%</td>
<td>89.17%</td>
</tr>
</tbody>
</table>

- After feature selection, 13 features
  - 8 Respiration, 5 ECG
Classification Accuracy on Lab Data

Features:
- Selected (S)
- All (A)
- RIP (R)
- ECG (E)

Stressors:
- All
- Instruction
- Speaking
- Mental Arithmetic (Standing)
- Mental Arithmetic (Seated)
- Cold Pressor

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Perceived Stress Model

- **Want to relate physiological classifier to self-report**
  - Predict what the person would have responded

- **Self-report rating**
  - Five answers mapped to real value
  - Average of 5 numerical codes

<table>
<thead>
<tr>
<th>Answer</th>
<th>Value (-)</th>
<th>Value (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>no</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>yes</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>YES</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
Using a Hidden Markov Model

- Use a binary Hidden Markov Model
  
  \( s_t \in \{0,1\} \) is perceived stress

  \[ \pi_t = P[s_t = 1 \mid x_1, \ldots, x_t] \] is perceived stress value

- To reduce number of parameters we approximate \( \pi_t \) by

  \[ \hat{\pi}_t = \alpha \hat{\pi}_{t-1} + \beta x_t \]

  \( \alpha, \beta \) person-dependent parameters
Evaluation of the Model (on Lab Data)

- Correlation of accumulation model and self-report rating

- 21 Participants

- Median correlation
  - 0.72

- Values of ρ<0.5
  - Not significant

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- **Conclusions and Future Work**
Field Study Protocol

- **Participants wore AutoSense continuously, for 2 days**
  - Going about their life (home, school, etc.)
  - Except at night

- **Field self-reports**
  - Participants responded to self-reports 20+ times each day
  - Same questions about affect state as in the lab
    - Additional context information

- **Additional behaviors automatically collected**
  - Speaking, from respiration patterns
  - Physical activity, from accelerometer
Realities of Natural Environment

- Data eliminated
  - 37% affected by activity
  - 30% poor quality
- Less than 4 min consecutive data
- 4 subjects missing data or self-report
Realities of Natural Environment

- Evaluation is on average stress level over both days
Evaluation of the Model (Field)

- Compared average stress ratings over both days
- Accumulation model versus self-report
- Linear interpolation

![Graph showing the correlation between perceived stress and self-reported stress with R=0.71]
Conclusions and Future Work

- The long-standing question on whether stress can be measured automatically in the field has now been answered
  - The focus can now shift from “Whether” to “How Well?”
  - Three additional user studies (with 50+ subjects) in progress for additional refinement and validation of stress model

- New apps can now be developed for monitoring of stress and to help reduce stress in daily life
  - For example, to select a less stressful route for driving

- Mediators of stress can now be investigated in the field
  - For example, relationship between stress, smoking, drinking, physical activity, entertainment, etc.