An Unobtrusive System to Measure, Assess, and Predict Cognitive Workload in Real-World Environments

Keynote, BIOSTEC 2017

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23 February 2017
Porto, Portugal
Agenda

• Company background
  • Company overview
  • Human sensing projects overview

• Cognitive workload sensing
  • Why do we care?
  • Who cares?

• Methods
  • Custom sensing devices
  • Data handling
  • Information display

• Conclusions
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- Conclusions
Corporate Background

- Employee-Owned Small Business, Cambridge, MA, USA started in 1983
  - 150+ employees and associates
  - GSA Schedule for IT Services

- Bridging the gap between thought leaders in academia and systems developers/integrators
  - Long-term collaborative partner with world-class universities
  - Strong participation in professional societies/panels
  - Close relationships with several lead system integrators
Core Company Competencies

**Sensor Processing & Networking**
- Automatic target recognition (ATR) and tracking
- Automated analysis of security and surveillance imagery
- Network and software trustworthiness optimization
- Vision-based autonomous navigation
- Image and video enhancement

**Decision Management**
- Data mining, data/information fusion
  - Event detection and prediction
  - Situation analysis and threat assessment
  - Sensor/resource management
  - Course-of-action analysis
- Cyber security

**Socio-Cognitive Systems**
- **Sensor-based assessment of human physical and cognitive states**
- **Human behavior modeling for individuals, organizations, and societies**
- **Model-driven and model-backed assessment of complex situations**
- Tactical intelligence management and collection

**Human Effectiveness**
- Intuitive interfaces and operator support tools for complex systems
- Work analysis, design prototyping, and human-in-the-loop evaluation
- Skill modeling, intelligent tutoring, game- and simulation-based training
- Information visualization
Charles River bridges the gap between universities’ basic research and lead system integrators’ needs for mature technology.
## Powerful Productivity Tools

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Sherlock™</strong></td>
<td>Open, extensible software and hardware platform for rapid prototyping of solutions to collect, analyze, visualize, and reason about human physiological, neurological, and behavioral state</td>
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<tr>
<td><strong>VisionKit®</strong></td>
<td>A library of computer vision software components for developing object recognition, surveillance, video enhancement, and visual navigation systems</td>
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<tr>
<td><strong>BNet®</strong></td>
<td>Bayesian Belief Network development tool and accompanying software development kit</td>
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<td><strong>Connect™</strong></td>
<td>Social and Organization Network Analysis tool for domain-independent network analysis</td>
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<tr>
<td><strong>AgentWorks™</strong></td>
<td>Intelligent agent toolkit providing agent-based computational components and integrated system development, validation, and visualization environments</td>
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<tr>
<td><strong>Metronome™</strong></td>
<td>A plug-in based architecture and associated visual software components enabling developers of rich-client applications to create powerful, easy-to-use interfaces for high-availability and mission critical systems</td>
</tr>
<tr>
<td><strong>DRIVE™</strong></td>
<td>Toolkit to support rapid generation, reconfiguration, evaluation, and refinement of Information visualization content and format</td>
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<tr>
<td><strong>Figaro™</strong></td>
<td>A language and reasoning framework for probabilistic modeling and inference that provides the basis for many computational intelligence services such as data and information fusion, machine learning, forecasting, state estimation, and sensitivity analysis</td>
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<tr>
<td>Area</td>
<td>Project</td>
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<td>Cognitive Workload Assessment</td>
<td>ADAPTER II</td>
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<td>MEDIC II</td>
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<td></td>
<td>CAPT PICARD II</td>
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<td>SEAHAWK</td>
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<td>Condition Detection</td>
<td>SOMBA</td>
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<td>ADVISOR II</td>
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<td>READ-IT</td>
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<td>SERENE</td>
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The Need

1. Many work environments fraught with highly variable demands on cognitive workload
   - Fluctuation between cognitive overload and boredom
   - Detrimental to performance
Cognitive Assessment and Prediction to Promote Individualized Capability Augmentation and Reduce Decrement (CAPT PICARD)
The Need

2. Fast-paced, sometimes dangerous professions require personnel to be trained to perform duties automatically

- If skill still requires great effort, additional training is necessary
- Focus training to enhance learning
A System for Augmenting Training by Monitoring, Extracting, and Decoding Indicators of Cognitive Load (MEDIC)
The Need

3. Teams of individuals must focus on their own tasks, while maintaining awareness of teammates’ tasks
   • Optimize team performance
Adaptive Toolkit for the Assessment and Augmentation of Performance by Teams in Real Time (ADAPTER)
The Need

4. As new tools and systems are developed, their effect on cognitive workload must be assessed
   • Interaction should be intuitive; if additional workload is unacceptable, design must be adapted throughout developmental phases
   • Testing and evaluation in laboratory experiments
Cognitive Assessment and Prediction to Promote Individualized Capability Augmentation and Reduce Decrement (CAPT PICARD)
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Open, extensible software and hardware platform for rapid prototyping of solutions to collect, analyze, visualize, and reason about human physiological, neurological, and behavioral state

- COTS and custom sensors (patent pending)
- Data processing and analysis
- Classification of human states (e.g., cognitive load)
  - Statistical and probabilistic modeling techniques
- Prediction of performance
  - Machine-learning algorithms, hierarchical modeling
Custom Portable fNIRS Sensor

Mr. Filipe Silva, Biosignals PluX
fNIRS In Various Environments
Sensor Validation

- Simultaneous EEG/fNIRS data collection
- Compare attention/workload measures of both sensors

Dr. Elena Festa, Brown University
Synchronized Annotation Tool

MEDIC II - bbracken

Scenario Name: Bethany Test

Start Time: 09:57:02 09/29/2016

Duration (minutes):

Workload Rating Interval (Min) (min... 0 45 90 135 180 225 270 300

Workload Rating Interval (Max) (m... 10

Interval Time Out Limit (minutes): 2

Rating Time Out Limit (minutes): 1

Subject Role

No content in table

Save Cancel

Mr. Alex Negri
Synchronized Annotation Tool

Mr. David Koelle
Data Fusion

ActiveMQ

OSVR

Mr. Scott Irvin
Estimating Cognitive Workload

Ms. Noa Palmon
Cognitive Assessment and Prediction to Promote Individualized Capability Augmentation and Reduce Decrement (CAPT PICARD)
Pilot Study: Estimating Cognitive Workload

Two Variable CIM

Three Variable CIM

Time (seconds)
Assessing Cognitive Overload and Boredom

- Baseline Rest
- Cognitive Task Battery
  - N-back (3 levels)
  - Digit Symbol Substitution
  - Psychomotor Vigilance
  - NASA Multi-Attribute Task Battery (3 levels)
- Boredom Induction
  - Peg Turning Task
- Repeat Cognitive Task Battery
- Post Rest

Dr. Elena Festa, Brown University
Assessing Cognitive Overload and Boredom

- NASA’s multi-attribute task battery (MATB)
Assessing Cognitive Overload and Boredom

- Boredom induction (Mackey et al., 2014)
  - Peg turning
A System for Augmenting Training by Monitoring, Extracting, and Decoding Indicators of Cognitive Load (MEDIC)
Assessing Cognitive Overload During Physical Activity

- Baseline
- Word list learning
- Balance ball
- 20 Questions
- Puzzle
- Hot Potato
- Logic problems
- Moving Boxes
- Word list recall
- Team jump rope

- 19 teams completed (excluding pilot data and drop-outs) for a total of 57 participants

Dr. Polemnia Amazeen, Arizona State University
Data Processing During Motion

Dr. Seth Elkin-Frankston

Participant 1 Helmet Device
Participant 2 Helmet Device
Participant 3 Helmet Device
Data Processing During Motion

Dr. Seth Elkin-Frankston
Data Processing During Motion

Participant 1 Helmet Device
Participant 2 Helmet Device
Participant 3 Helmet Device

Dr. Seth Elkin-Frankston
Data Processing During Motion

Dr. Seth Elkin-Frankston

Participant 1 Helmet Device
Participant 2 Helmet Device
Participant 3 Helmet Device
Estimating Cognitive Workload During Physical Activity

- Will insert medic modeled data here if we get it done
Estimating Cognitive Workload During Physical Activity

- Teams of medical students and faculty members
- High-fidelity medical simulations
- Will update with appropriate data collection statistics (include the data we collected if we can use it, if not estimate when collection will start)

Dr. Matt Weinger, Vanderbilt Medical School

Dr. Arna Banerjee, Vanderbilt Medical School
Adaptive Toolkit for the Assessment and Augmentation of Performance by Teams in Real Time (ADAPTER)
Team-Specific Cognitive Workload Metrics

- Teams of three unmanned aerial vehicle (UAV) task:
  - Air Vehicle Operator (avo) flies the UAV
  - Payload Operator (plo) takes photos of targets
  - Data exploitation, mission planning, and communications operator (dempc) uses a map to plan the UAV route and coordinates with the other teammates

Dr. Nancy Cooke, Arizona State University
Team-Specific Cognitive Workload Metrics

- Measures of importance are task dependent
- Inter-subject correlation for blood oxygenation significant predictor of team performance ($R^2 = .08, p < .05$)
- But ONLY for the team leader

Dr. Jorge Barraza, Claremont Graduate University
Cognitive Assessment and Prediction to Promote Individualized Capability Augmentation and Reduce Decrement (CAPT PICARD)
Predicting Cognitive Workload and Performance

- Design and train classifiers to predict shape of cognitive workload curve (and thus predict when performance will decay) several time steps (seconds or minutes) in advance
  1. Design classifiers to distinguish between groups (bored vs. baseline) and between tasks (e.g., easy, medium, hard)
  2. Curve estimation based on initial portion of curve to predict upcoming decrements
Curve Estimation

Mr. Scott Irvin
Information Display

MEDIC - After Action Review

Monday February 03, 2014

Logged in as: User 1

Exit

Timeline

Team Dynamics
Task Allocation
Cognitive Workload
Stress

Alpha Company

Soldier 5 Lead Medic

Soldier 12

New Note

Title: Procedure observation

Time: 0135

Did a great job switching rolls when asked to bag the patient rather than run for supplies

Save Note

Save Review

Will change this to real UI screen shots when DK sends
Information Display
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Generalization of Results

- We believe this approach is widely applicable across domains
- Currently researching commercial applications:
  - Marketing
  - Finance
  - Education
  - Gaming
  - Psychiatric monitoring (e.g., children with ADHD)
- Always looking for collaboration opportunities!
Acknowledgements

- This work was supported by:
  - NASA contract number NNX16CJ08C
    - Data modeling/interpretation, cognitive workload/performance prediction
  - Army contract number W81XWH-14-C-0018
    - Sensor R&D, data processing, information display
  - Air force contract number FA8650-14-C-6579
    - Sensor R&D

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

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