DYNAMIC DATA DRIVEN OPERATOR ERROR EARLY WARNING SYSTEM (OEWS)

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Outline

• DDDAS Background
• Overview and Motivation
• The Problem
• Our Approach
• Where are we today
• What needs to be done
• Summary
Why develop Error Early Warning System?

• Human operator error is the root cause of 80% (?) of major accidents
• Accident deaths and injury in the U.S.
  • 47,000 motor vehicle-related deaths / year
  • 13,000 deaths due to falls / year
• Cost of Workplace deaths and injuries
  • $48 billion / year
  • $780,000 / victim cost to society
Most Frequent Causes of Workplace Deaths and Injuries

**Injury**
- Overexertion
- Impact accidents
- Falls
- Bodily reaction to chemicals
- Compression
- Motor vehicle accidents
- Exposure to radiation/caustics
- Rubbing or abrasions
- Exposure to extreme temperatures

**Deaths**
- Motor-vehicle related
- Falls
- Electrical current
- Drowning
- Fire related
- Air transport related
- Poison
- Water transport related
- Other
Project Overview

• Project started in summer of 2014
• Goal of the research is to develop a dual reality DDDAS system for predicting and preventing operator error.
  • Develop a **body area network** to capture signals from biometric sensors
  • Analyze mental and physical states before, during, and after each cognitive activity in a **hebbian network**
  • Capture predicted mental and physical states of the operator is captured in the **avatar**
  • Evaluate the avatar’s actions in a **faster than real-time** simulation
  • If an error is predicted, **alert** the operator in the real world
Our DDDAS Approach

- **Measurement Model**
  - Measurement
  - Sensor Steering
- **Data Assimilation**
  - Observations
- **Simulation Model**
  - Dynamically estimated states
- **Wired Human Operator**
  - Body area network
  - Intervention
Equipment

• B-Alert X10 EEG Headset System (Advanced Brain Monitoring)
  • 9 channels of mid-line and lateral EEG sites
  • Bluetooth wireless signal transmission

• Shimmer3 GSR+ Unit (Shimmer)
  • 1 channel of GSR (measurement range from 10k to 4.7MΩ)
  • Bluetooth wireless signal transmission

• Tobii X60 Eye Tracker (Tobii Technology)
  • High tolerance for head movement
  • Run at 60 Hz data rate on Windows platform

http://www.shimmersensing.com
http://www.tobii.com
http://www.advancedbrainmonitoring.com
Experimental Setup

B-Alert X10 EEG headset

Computer-based Stroop test

Shimmer3 GSR+ unit

Tobii X60 eye tracker
Experimental Procedure

- Baseline (3 mins)
- 20 C. Questions
- 20 IC. Questions
- Rest (2 mins)
- 20 C. Questions
- 20 IC. Questions
- Rest (2 mins)
- 20 C. Questions
- 20 IC. Questions
- Survey (3 mins)

C: Congruent; IC: Incongruent
Preliminary Results – Workload

- Native English speakers (S004, S005, S007) had higher average workload when doing tests.
Preliminary Results – Engagement

- Lower engagement during rest sessions
- Higher engagement when getting familiar with the test and under considerable time pressure
Preliminary Results – GSR (Mental Stress)

- The arousal level fitted the difficulty level, and were similar to the change in engagement
Analysis of Raw Data

• Data from each subject is analyzed individually.

• Raw time histories from each of the nine electrodes are analyzed.
  • Data is pre-processed to remove artifacts such as eye-blinks and muscle movements.

• The approach to data analysis is to apply methods to...
  • ...investigate their effectiveness in a different data domain.
  • ...leverage control theory knowledge base in order to discover new ways of analyzing EEG data.

• Principal component analysis (PCA) and the least squares complex exponential parameter estimation algorithm are applied to the data.
**Principle Vector and Value Analysis**

- **Step 1:** Form data matrix from time histories of selected sensors.
  - EX: Assemble EEG data from one question of the Stroop test.

  \[
  \begin{bmatrix}
  F3(t1) & Fz(t1) & F4(t1) & \ldots & P4(t1) \\
  F3(t2) & Fz(t2) & F4(t2) & \ldots & P4(t2) \\
  \vdots & \vdots & \vdots & \ddots & \vdots \\
  F3(tn) & Fz(tn) & F4(tn) & \ldots & P4(tn)
  \end{bmatrix}
  \]

- **Q**=

- **Step 2:** Identify singular vectors and values.
  - \([v_L, SV, v_R]=\text{svd}(Q)\)

- **Step 3:** Look for changes in vectors and values to indicate changes in the decision making process.
Singular Values

• Singular values show the relative contribution of each component.

• In all three data sets, the first component contributes most strongly to the overall response.
  • Components 2-5 are the next most significant.
  • Components 6-9 contribute the least.
Singular Vectors

No timer
3 second timer
1.5 second timer

- Singular vectors 1, 4, and 5 show variation across the three data sets.
- It’s possible these variations are related to the change in the subject’s brain function due to the perceived stress caused by increasing time pressure.
Parameter Estimation
Least Squares Complex Exponential Algorithm

• STEP 1: Partition data by question
• STEP 2: Formulate impulse response function from signal time histories. Calculate auto-correlation
  • Form one-sided frequency spectrum
  • Form impulse response function, \( x(t) \)
• STEP 3: Form Toeplitz matrix of impulse response function

\[
T = \begin{bmatrix}
  x(t_1) & x(t_2) & \cdots & x(t_N) \\
  x(t_2) & x(t_1) & \cdots & x(t_{N-1}) \\
  \vdots & \vdots & \ddots & \vdots \\
  x(t_M) & x(t_{M+1}) & \cdots & x(t_{N+M-1})
\end{bmatrix}
\]

• STEP 4: Calculate coefficients of an autoregressive model

\[
S_{k=0}^N \{a_k \} (x(t_i)) = 0
\]

• STEP 5: Compare model output with experimental data to determine model error
Parameter Estimation Results

- The model is most accurate when time pressure is greatest.
  - For 26/40 questions presented with the shortest timer, model error is less than 12%.
- 85% of all data was modeled with less than 25% error.
- This model represents one-step-ahead prediction.
- Ongoing work is being conducted to improve the accuracy and predictive capability of the model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>4mer</th>
<th>3 second 4mer</th>
<th>1.5 second 4mer</th>
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<tbody>
<tr>
<td>No timer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 second</td>
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</table>
Next Step - 1
• Structured modeling of Human Errors
Next Step - 2

- Analyze outputs from each individual electrodes and sensors to develop biometric signatures of individuals, task categories and groups/segments.
Mental Arithmetic Study

Rest (3 mins)

No Timer

1st 10 Questions
2nd 10 Questions
3rd 10 Questions
Rest (2 mins)

1st 10 Questions
2nd 10 Questions
3rd 10 Questions

Survey (3 mins)

1st 2nd 3rd
Group 1 Easy Moderate Difficult
Group 2 Easy Difficult Moderate
Group 3 Moderate Easy Difficult
Group 4 Moderate Difficult Easy
Preliminary Results

- p-values (F-values) for treatments in the ANOVA (n = 10)

<table>
<thead>
<tr>
<th></th>
<th>Result</th>
<th>Pupil dilation (l)</th>
<th>Pupil dilation (r)</th>
<th>Stress</th>
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<tbody>
<tr>
<td>Difficulty level</td>
<td>0.000</td>
<td>0.023</td>
<td>0.003</td>
<td>0.919</td>
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<tr>
<td></td>
<td>(60.86)</td>
<td>(3.81)</td>
<td>(5.87)</td>
<td>(0.08)</td>
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<tr>
<td>Time pressure</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
<td>0.048</td>
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<td></td>
<td>(127.92)</td>
<td>(13.47)</td>
<td>(11.98)</td>
<td>(3.91)</td>
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<table>
<thead>
<tr>
<th></th>
<th>Workload</th>
<th>Engagement</th>
<th>Distraction</th>
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</thead>
<tbody>
<tr>
<td>Difficulty level</td>
<td>0.000</td>
<td>0.444</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td>(12.36)</td>
<td>(0.81)</td>
<td>(3.29)</td>
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<tr>
<td>Time pressure</td>
<td>0.407</td>
<td>0.103</td>
<td>0.122</td>
</tr>
<tr>
<td></td>
<td>(0.69)</td>
<td>(2.67)</td>
<td>(2.40)</td>
</tr>
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Preliminary Results

• ERN-Error Related Negativity
• Capture Stimulus Response in an Artificial Associative Matrix Memory in Avatar
Summary

• Prototyped a **body area network** to capture signals from biometric sensors

• Developed a preliminary models to analyze mental and physical states before, during, and after each cognitive activity in a **hebbian network**

• Preliminary models to predict mental and physical states of an operator

• Already exists
  • Simulate the avatar’s actions in a **faster than real-time** simulation
  • **Alert** the operator in the real world is an error is predicted