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
Past DDDAS Projects

Homeland Security

National Security
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
<table>
<thead>
<tr>
<th>Injury</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overexertion</td>
<td>Motor-vehicle related</td>
</tr>
<tr>
<td>Impact accidents</td>
<td>Falls</td>
</tr>
<tr>
<td>Falls</td>
<td>Electrical current</td>
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<tr>
<td>Bodily reaction to chemicals</td>
<td>Drowning</td>
</tr>
<tr>
<td>Compression</td>
<td>Fire related</td>
</tr>
<tr>
<td>Motor vehicle accidents</td>
<td>Air transport related</td>
</tr>
<tr>
<td>Exposure to radiation/caustics</td>
<td>Poison</td>
</tr>
<tr>
<td>Rubbing or abrasions</td>
<td>Water transport related</td>
</tr>
<tr>
<td>Exposure to extreme temperatures</td>
<td>Other</td>
</tr>
</tbody>
</table>
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

Diagram:
- **Measurement Model**
  - Measurement
  - Sensor Steering
  - Observations

- **Data Assimilation**
  - Dynamically estimated states
  - Measurement Steering

- **Simulation Model**
  - Intervention

- **Sensors**
  - Wired Human Operator
    - Body area network

- **Measurement Steering**
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 Galvanic Skin Response (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
Experimental Setup

- B-Alert X10 EEG headset
- Shimmer3 GSR+ unit
- Computer-based Stroop test
- Tobii X60 eye tracker
NeuroSky

- NeuroSky is a non-invasive EEG that connects the user to iOS and Android platforms, and transfers all signal information through Bluetooth as opposed to radio.

- The EEG outputs for this setup are controlled primarily by variations in brain-state. In order to achieve a specific level of EEG the user may be prompted to relax or improve focus, thus altering the specific output of brain energy and ultimately changing the level of expressed EEG signals.
Data Analysis to Assess Decision Making

GOALS:

• Identify different phases of the decision making process.
  • For the Stroop test, the “simple” model of decision making according to [1] applies.
    • Sense, categorize, respond.
    • Beware of complacency, entrained thinking, desire to make complex problems simple, etc.

• Identify “modes” of the decision making process.
  • Are certain parts of the brain more active at different points in the decision making process?

• Identify trends as a function of number of questions answered.
  • Is stress, fatigue, complacency, etc. reflected by changes in the “modes” of the measured data?

Experimental Setup

C: congruent; IC: incongruent
Results showed on the screen for 0.5s for each question
Experimental Setup

Stroop Test

Math Test

32 / 4 - 6 - 1 = 1
Correct!
Overview - Engagement

Baseline
Test - w/o timer, congruent
Test - w/o timer, incongruent
Rest sec 1
Test - 3s timer, congruent
Test - 3s timer, incongruent
Rest sec 2
Test - 2.5s timer, congruent
Test - 2.5s timer, incongruent

S001
S002
S003
P001
P002
Overview - Workload

Baseline
Test - w/o timer, congruent
Test - w/o timer, incongruent
Rest sec 1
Test - 3s timer, congruent
Test - 3s timer, incongruent
Rest sec 2
Test - 2.5s timer, congruent
Test - 2.5s timer, incongruent
Recovery

S001
S002
S003
P001
P002
Overview – GSR (Mental Stress)
Data Analysis to Assess Decision Making

APPROACH

• Extract principal vectors and values to determine trends for selected combinations of data channels.

• Build Toeplitz matrices to extract eigenvalues and eigenvectors from time histories.

• Use autoregressive models to predict future performance.

• Assess correlation between identified “modes” and trends in standard metrics (workload, attention, etc.).

• Identify which sensors (or combination of sensors) can isolate the “modes” first.
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.

\[
\begin{bmatrix}
F_3(t_1) & F_z(t_1) & F_4(t_1) & \ldots & P_4(t_1) \\
F_3(t_2) & F_z(t_2) & F_4(t_2) & \ldots & P_4(t_2) \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
F_3(t_n) & F_z(t_n) & F_4(t_n) & \ldots & P_4(t_n)
\end{bmatrix}
\]

• 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.
Principle Vector and Value Analysis

• EXAMPLE:

For this subject, the 2nd and 3rd right singular vectors distinguish the timed question sets (red and green) from the untimed question set (blue).

Blue = Set 1 (no timer) Green = Set 2 (3 sec timer) Red = Set 3 (1. sec timer)
Analysis of Toeplitz Matrices

• STEP 1: Formulate impulse response function from signal time histories.
  • Calculate auto-correlation.
  • Form one-sided frequency spectrum.
  • Form impulse response function, \( x(t) \).

• STEP 2: Form Toeplitz matrix of impulse response functions.

\[
\begin{bmatrix}
x(t1) & x(t2) & x(t3) & \ldots & x(tN) \\
x(t2) & x(t3) & x(t4) & \ldots & x(tN+1) \\ & & & \ddots & \ddots \\ & & & & x(tM) & x(tM+1) & x(tM+2) & \ldots & x(tN+M-1)
\end{bmatrix}
\]

• T=

• STEP 3: Calculate coefficients of an autoregressive model

• STEP 4: Compare model output with experimental data to understand how brain activity can be predicted.
Analysis of Toeplitz Matrices

- **EXAMPLE:**
  - Toeplitz matrices formed from impulse response functions
  - For this subject, the one-step-ahead prediction model works best for Set 3, when the subject is under the most stress.

*Distribution of mean of residual error* and *Distribution of std in residual error* graphs are shown, with the x-axis representing the mean error and standard deviation of error, respectively, and the y-axis showing the number of occurrences.
What can we say at the group level?

All questions

3 seconds before the questions the subject made an error
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.
Next step - 3

• 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