Optimal User Attention Allocation in a Multi-tasking Environment

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What are we trying to do?

- Human operator in a supervisory role can become a bottleneck in a multi-tasking environment

Human Supervisory Control (HSC): operator only intermittently interacts via an automated agent, receiving feedback and providing commands to a controlled process or task environment (Sheridan 1992)

- Improve human effectiveness by guiding attention at multiple levels of decision making

RESCHU: http://www.mit.edu/~yalesong/new/project.html

Cummings et. al. 2010

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Why?

Network centric operations
- Increased use of unmanned systems
- Increased autonomy to invert human to machine ratio

=> Operators will increasingly play a supervisory role

Challenges (Cummings et. al. 2010)
- Information overload
- Appropriate levels of automation
- Adaptive automation
- Attention allocation
- Distributed decision making
- Supervised monitoring of operators
- Decision biases
- Trust/reliability

Real time assessment of pilot cognitive-affective state through psychophysiological measures for adaptive dynamic function allocation (augmented cognition)

Optimal allocation strategy for set of dynamic tasks to balance time constraints with relative importance of tasks (stopping rules, primary task interruption)
Operator Supervisory Role

Manned Unmanned Teaming Missions:
Level 4 control of multiple autonomous UAS simultaneously with manageable workload
- Improve SA, survivability, and lethality

Supervisory Controller for Optimal Role Allocation for Cueing of Human Operators (SCORCH): ICB/Army funded

<table>
<thead>
<tr>
<th>Operator Tasks*</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception</td>
<td>Target search/classification in UAV/ownship imagery</td>
</tr>
<tr>
<td>Payload Control</td>
<td>UAV/ownship sensor</td>
</tr>
<tr>
<td>Communication</td>
<td>Response to chat/voice messages</td>
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<td>Monitoring</td>
<td>Mission progress, UAV/ownship health/status</td>
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</table>

*Cognitive task analysis to systematically decide human and machine role/task allocation

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Search Attention Allocation (AA) Aide: Motivation

Hypothesis:
- Humans have difficulty administering their fixation and overall search times in challenging search tasks: missed detection, poor efficiency
- Dynamics of human information acquisition and eye-position data can be used to estimate probability that all information has been acquired => recommend search termination or exploration=>enhance human effectiveness

Challenges:
- Need task specific tractable models capturing dynamics of information acquisition
- Integration with real time eye tracking data
- Robustness
Search AA Aide: Concept

Instructions

Engage in Target Search

**Time Spent:** To avoid rush or excessive time due to mind wandering

**Eye Movement:** User fatigued (miss targets), accidentally skips part of scene

**Exploration:** Avoid fixation at same regions
Search AA Aide: Data for Psychophysics Studies

➢ Task:
  ▪ Detect target (person) and classify target as armed or not

➢ Stimuli:
  ▪ Slowly varying videos (generated in Army Lab simulation environment)
  ▪ 50% images contain a target, 50% of the target-present images contain a person with a weapon
  ▪ Different frame offsets to vary target position for multiple trials
Search AA Aide: Free Viewing Experiment

11 Observers
~2000 trials/obs
Search AA Aide: Forced Fixation Experiment

13 Observers
~4000 trials/obs

Use these curves and sequence of fixations and saccades to characterize how well image has been explored?

Detectability Map
Signal Detection Theory: Transform in $d'$ space

$$d' = Z(HR) - Z(FAR)$$

Compute detectability map per saccade (assumed independent) and add in $d'$ space

$$(d'_{c})^{p} = \sum_{i=1}^{N} (d'_{i})^{p}$$
Search AA Aide: Incorporate Zoom/Clutter Effects

- High Zoom Level
- Medium Zoom Level
- Low Zoom Level
Search AA Aide: Clutter Metrics

- Feature Congestion: Rosenholtz et al. (2005, 2007)
- Subband Entropy: Rosenholtz et al. (2007); Simoncelli & Freeman (1995)

Search AA Aide: Incorporate Zoom/Clutter Effects

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Clutter Map

Detectability Map

Clutter \times (1 - \text{Detectability Map})

Feedback to user where to explore
Real Time Eye Tracking Data

Observer Input

Move On

General Satisfaction?

Yes

Show Next Image

No

Pr(PC_{max} - PC_t) > \epsilon_T > \theta_T
Pr(PC_{max} - PC_e) > \epsilon_e > \theta_e
Pr(PC_{max} - PC_D) > \epsilon_d > \theta_d

If Spacebar was Hit?

500ms Delay
Search AA Aide: Experiments

Goal: Accomplish as many search tasks (given max 15sec/task) as possible in 20min without compromising detection performance

- 2 practice sessions (w/wo aide)
- 4 test sessions (2 w aide/2 w/o aide)

Stimuli: Video imagery at different clutter/zoom

Apparatus: EyeLink1000 eye tracker (500Hz)

Data collection: User decisions, search times, aide trigger time, etc.

Preliminary results: 10 participants

# search tasks completed:

- No Aide = 47
- With Aide = 55

Improved user search efficiency!

<table>
<thead>
<tr>
<th></th>
<th>Hit Rate</th>
<th>Median Search Time (target present)</th>
<th>Median Search Time (target absent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Clutter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Aide</td>
<td>88%</td>
<td>3.5s</td>
<td>4.3s</td>
</tr>
<tr>
<td>With Aide</td>
<td>94%</td>
<td>2.9s</td>
<td>3.3s</td>
</tr>
<tr>
<td>Medium Clutter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Aide</td>
<td>97%</td>
<td>2.1s</td>
<td>3.6s</td>
</tr>
<tr>
<td>With Aide</td>
<td>97%</td>
<td>1.9s</td>
<td>2.8s</td>
</tr>
<tr>
<td>Low Clutter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Aide</td>
<td>96%</td>
<td>2.4s</td>
<td>2.6s</td>
</tr>
<tr>
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<td>99%</td>
<td>1.8s</td>
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### Multiple Task Attention Allocation (AA) Aide: Motivation

**Operator Tasks**

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- Piloting: Ownship co-pilot tasks
- Perception: Target search/classification
- Payload Control: UAV/ownship sensor control
- Communication: Response to chat/voice messages
- Monitoring: Mission progress, UAV/ownship health/status

**Operator Tasks**

- **Examples**
  - Piloting: Ownship co-pilot tasks
  - Perception: Target search/classification
  - Payload Control: UAV/ownship sensor control
  - Communication: Response to chat/voice messages
  - Monitoring: Mission progress, UAV/ownship health/status

**Problem**

Random task arrival

**Abstraction**

Estimate of task start time available

**User recommendation:**
- Drop/process task
- Task processing time
- Rest period

Multiple Task AA Aide: Problem Formulation

Objective: Max cumulative reward $R$ over horizon

Decision variables:
- Task order: $x$
- Task time: $d$
- Rest time: $r$

Multi-Task Attention Allocator: Receding Horizon Optimization

MILP

$$\max_x \sum_j \sum_i R_j x_j^i$$

s.t $\sum_i x_j^i \leq 1 \forall i$, $\sum_i x_j^i \leq 1 \forall j$,

$c_{i-1} + \sum_j s_j x_j^i \leq c_i \forall i$

$\sum_j (s_j + d_j) x_j^i \leq c_i \forall i$

$c_i \leq T_H \forall i$

Variations (lead to MINLP): incorporate
- Error rates, and task time as decision variables

$$\max_{x,d} \sum_j \sum_i R_j p_e(d_j) x_j^i$$

- Utilization constraints, and rest time as decision variables

$$u(d,r,u_0) = (1 - (1 - u_0) e^{-\frac{d}{\tau}}) e^{-\frac{r}{\tau}}, \quad u_m \leq u \leq u_M$$

- Penalty on task waiting time

$$\max_x \sum_j \sum_i R_j (1 - \frac{\sum_i x_j^i c_i - (s_j + d_j)}{s_j + d_j}) x_j^i$$

- Switching costs, relook,..
## Multiple Task AA Aide: Test Bed

### Task Based Control (New RESCHU*)

High level Supervisory Control
- Monitors vehicle exposure and chooses acceptable damage level
- Prompts automation (A* with threat avoidance) to replan
- Accepts all / individual plans
- Processes visual search tasks

### Timeline – text-based

<table>
<thead>
<tr>
<th>Task</th>
<th>Remove Schedule</th>
<th>Proposed Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>06:30</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>06:15</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>01:30</td>
<td></td>
</tr>
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</table>

### Text-based schedule comparison

### Maximum vehicle damage level shown

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Multiple Task AA Aide: Implementation

State-machines based architecture to synchronize user engagement, attention allocator, optimizer and multi-UAV mission planner

Receding horizon optimization to account for uncertainty in operator behavior

Multiple Task AA Aide: Numerical Studies

- Fixed total mission time (10 min)
- Receding horizon optimization (4 tasks per horizon window)
- Different attention allocation policies:
  - Greedy: High reward first
  - Optimal: Maximize cumulative reward (reward increases if tasks remain unprocessed over a horizon)
- Random parameters
  - Service times (log-normal, from previous studies)
  - Reward (uniform)

Improved human-machine system performance
Robustness in Attention Allocation

Characterization of uncertainty in human models: certainty equivalent approach may not be satisfactory
- Tractable robust/stochastic optimization techniques
- Online adaptation
- Extensions for human teams

(Bertuccelli & Cummings, CDC, 2011; Peters & Bertuccelli, ACC 2016; Peters & Bertuccelli, AIAA J. of Aerospace Inf. Sys. 2016 (Under Review))
Conclusions

Summary: Attention allocation aide to enhance human effectiveness in a supervisory control setting

Ongoing/Future Work

- Adaptation to SCORCH operational context: moving imagery, impact of computer vision algorithms and secondary tasks, real time implementation
- Detrimental operator state detection and changing level of automation
- Robustness to user uncertainties/variability
- Joint optimization of human machine teams*
- Trust/reliability

Back Up
Incorporate Effect of Image Zoom and Clutter

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Incorporate Effect of Image Zoom and Clutter