JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Assessing Cognitive Load for Quantifying Swarming Wave Glider System Usability

Human Systems Conference 2020

Andre Douglas
Section Supervisor/Johns Hopkins University APL
PhD Candidate/George Washington University
Andre.douglas@jhuapl.edu

Melissa Carraway
Senior Professional Staff/Johns Hopkins University APL
Melissa.carraway@jhuapl.edu

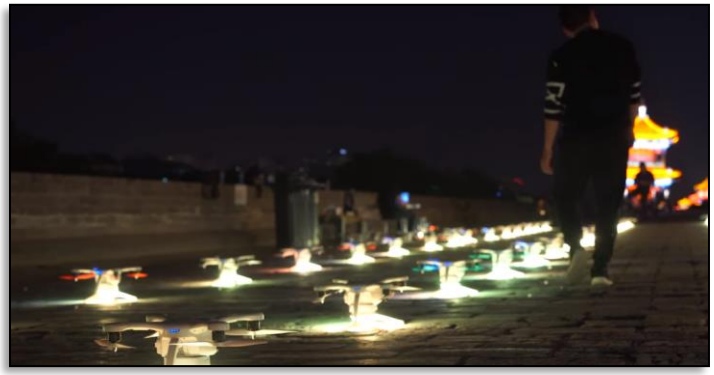
Dr Thomas Mazzuchi
Associate Professor and Department Chair/George Washington University
mazzu@gwu.edu

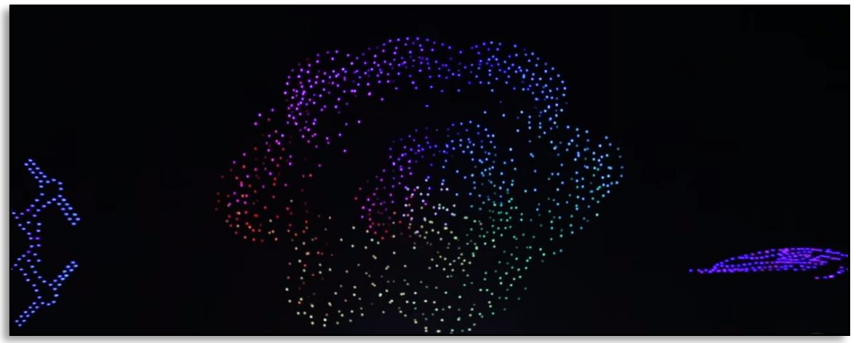
Dr. Sharham Sarkani
Associate Professor and Director/George Washington University
sarkani@gwu.edu

Agenda/Outline

- Intro: China's drone display
- Need for distributed swarming systems
- Real-time-strategy game StarCraft II
- Problem statement and research question
- Literature review
- Methodology
- Proposed experiment, simulation, equipment
- Wave glider operations and why this matters
- Conclusion
- Questions

China World Record Display of 1374 Drones

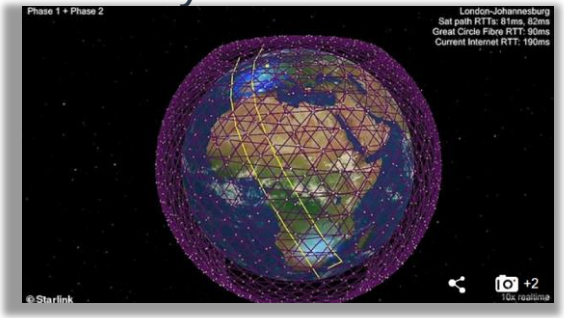




The Need for Distributed Systems

- Distributed unmanned systems have the potential to:
  - Reduce cost related to human operators
    - Safety systems
    - Life support systems
  - Increase flexibility, functionality, and reliability
  - Reduce threats to remote operators
  - Assist mankind in exploration beyond our limits

- Swarming intelligence is a promising approach for unmanned systems that can support various missions such as:
  - Intelligence, surveillance, and reconnaissance (ISR)
  - Space exploration
  - Search and rescue operations
  - Port security



The Need for Distributed Systems

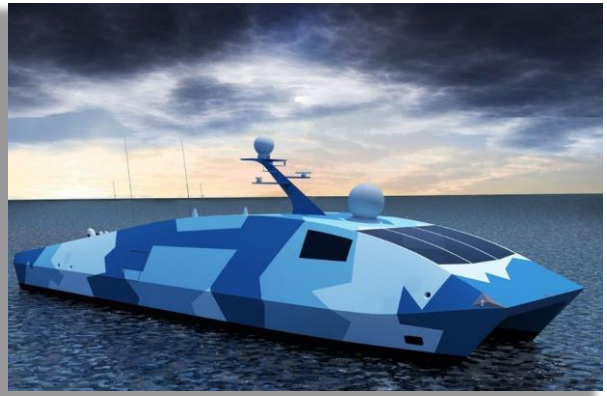
- Larger vehicles
- More extreme environments
- Ghost fleets
- Numerous heterogeneous agents

Nibbler UAV - Marines

Curiosity Rover - JPL

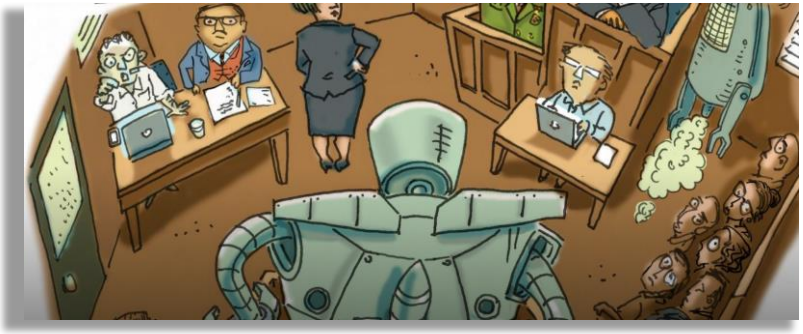
Sea Hunter - DARPA

Dragonfly - APL



NOMARS - DARPA

Where does the human fit and why?



- Most swarms utilized by the military will not require a human operator on board to reduce risk and improve safety
- Legal implications restrict autonomous unmanned systems from running fully autonomous
- Humans likely to participate in a remote supervisory capacity enabling them to take responsibility for critical decisions
- What might this look like?

StarCraft II: Real Time Strategy Game

- RTS games are already widely exercised today
- Players exhibit supervisory command and control to numerous units within an environment
- Requires complex strategy and situational awareness skills across multiple domains

StarCraft II Real Time Strategy Game

- Game enables ability to utilize heterogeneous or homogenous swarms to defeat enemies
- Players must balance task allocation efforts to win

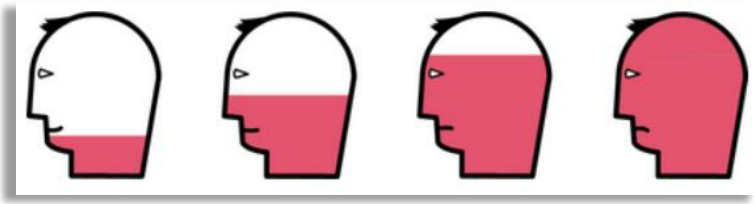
StarCraft II Real Time Strategy Game

- Tasks include:
  - Managing economic resources
  - Building
    - Basic units
    - Advance units
    - Tech upgrades
  - Collecting intelligence
  - Surveys

- Multiple players at once
- Three factions to choose from
- Various strategies for implementation
- AI players trained to beat humans: AlphaStar DeepMind

UNCLASSIFIED

Problem Statement

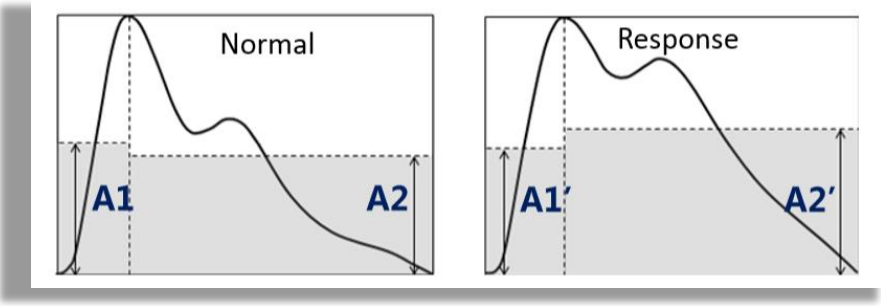


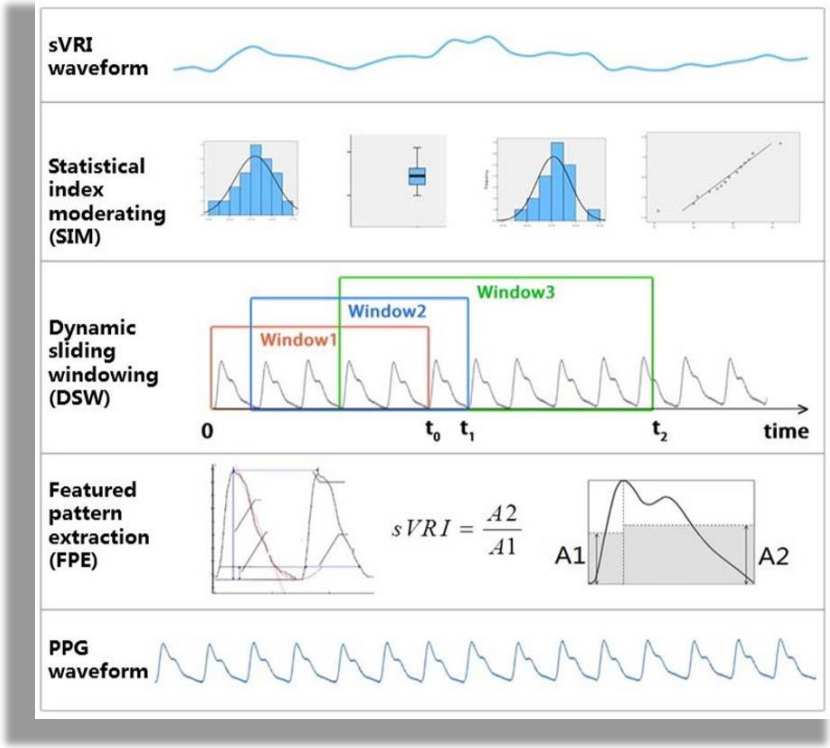
- While we have seen decades of research into swarming algorithm development, the community has lacked a thorough investigation of man-unmanned teaming system design performance.
- Research questions:
  - Which cognitive load metric is most accurate and meaningful?
  - How do we design a system such that its user maximizes performance?
  - How do we quantify task difficulty and understand how to compensate with automation?
  - How does cognitive load limits compare when experiencing different:
    - Swarm sizes
    - Task complexities
    - System disturbances
      - Cyber
      - Faults and failures
      - Environment
  - What is the right level of automation within teaming?

Literature Review on Cognitive Load

- Studies on measuring cognitive load have been done in the past to help us understand interactions between systems and tasking using various means:
  - Khawaja 2013 – Conducted a study to use non-invasive means (linguistics) to help measure cognitive load
    - Fire management studies using table top exercises
    - Team environment based on completing tasks
    - Audio recordings and surveys used to assess cognitive load
  - Evans 2016 – Conducted a study to use eye tracking metrics to assess cognitive load
    - Used real time strategy game for assessing players: Arcanium
    - Varied levels of autonomy in player's units to elicit varying performance
    - Measured eye fixation rate, run-time, and surveys to assess cognitive load
  - Zhang 2018 – Conducted a study to use pulse rate variability metrics to assess cognitive load
    - Used computer game to assess players performance: Plants vs. Zombies
    - Varied level of difficulty to understand cognitive load response
    - Used Photoplethysmogram (PPG) to measure and quantify cognitive load

Methodology



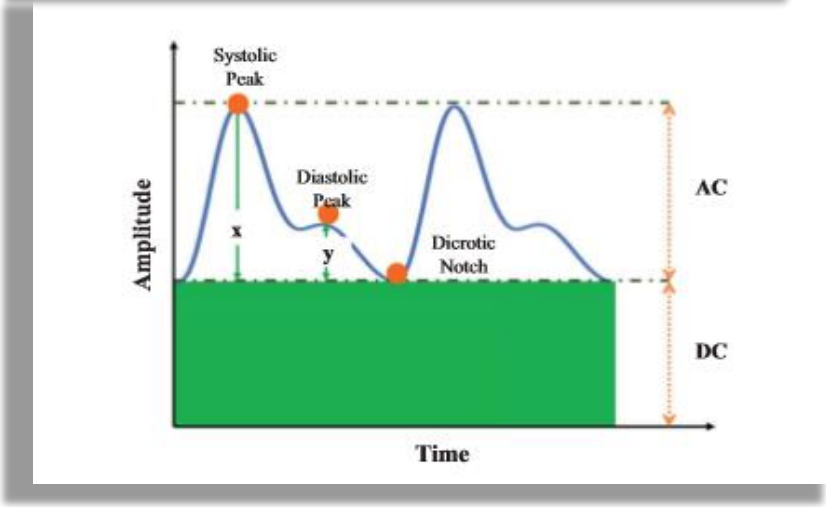


- sVRI (Stressed Induced Vascular Response Index):
  - Measures the average amplitude for A1 and A2, then computes ratio

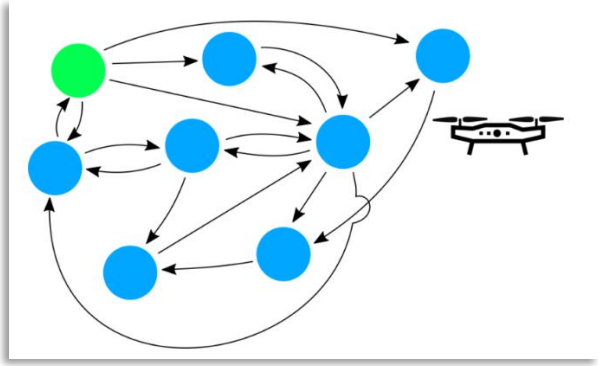
- Algorithm Framework (Bottom Up)
  - Statistical Index moderating:
    - Assesses the normality of the data
  - Dynamic Sliding Window
    - Enlarges the data range for smoothing out calculated index
  - Featured Pattern Extraction
    - Appropriately identifies features for algorithm processing

Methodology

- Choose simulation or exercise for participants to use for assessing cognitive load using swarms:
  - Agent based simulation of Wave Glider system
  - StarCraft II environment
  - Other simplified RTS game
- Assess Cognitive load using non invasive measures:
  - PPG with appropriate indexes (primary indicator)
  - Eye tracking
  - Surveys NASA task loading index
- Data analysis
  - ANOVA
- Determine which parts of the system design and interaction result in near the “red line” of cognitive limits



Experiment Proposal



- Test subjects
  - Age range
  - Experience level
  - Normalize rest state
- Behavior Executions within Missions
  - Localization
  - Payload execution
  - Navigation through environment
  - Fault injection
  - Objective change in missions
- Test environment
  - Constant conditions
  - Similar timeframe
  - Minimal disturbances

Experiment Goal

- Understand what supervisory control and decision making require the most cognitive load
- Understand what tasks and durations cause human complacency in a supervisory control man-unmanned teaming situation
- Determine which displays impact cognitive load during supervisory control
- Use results to help design autonomy to be adjustable based on cognitive load levels
- Identify overload points in supervisory control
- Understand how usable this system is

Wave Glider System

- Unmanned Surface Vehicles used to remotely monitor maritime environments
- Piloted by operators around the world using Iridium

Wave Glider

Conclusions

- Experimentation and results can be used to influence design of swarming unmanned system interfaces
- There is a growing need for this type of integration as the demand for larger swarming systems evolve with increasing capability and size
- Metrics can be defined to help with this process, then used to develop a full model for understanding the feedback loop for adjusting system level autonomy for teaming
- Measuring cognitive load in real time can also give feedback to designers that users cannot always do verbally

References:

- 1. Behrisch M, Blumenschein M, Kim NW, et al. Quality metrics for information visualization. *Computer Graphics Forum*. 2018;37(3):625-662. https://onlinelibrary.wiley.com/doi/abs/10.1111/cgf.13446. doi: 10.1111/cgf.13446.
- 2. Yang S, Ferris TK. Cognitive efficiency in Human–Machine systems: Metrics of display effectiveness for supporting multitask performance. *Journal of Cognitive Engineering and Decision Making*. 2018;12(2):153-169. https://journals.sagepub.com/doi/full/10.1177/1555343417712464. doi: 10.1177/1555343417712464.
- 3. Zhang X, Lyu Y, Hu X, Hu Z, Shi Y, Yin H. Evaluating photoplethysmogram as a real-time cognitive load assessment during game playing. *International Journal of Human-Computer Interaction*. 2018;34(8):695-706. http://www.tandfonline.com/doi/abs/10.1080/10447318.2018.1461763. doi: 10.1080/10447318.2018.1461763.
- 4. Khawaja MA, Chen F, Marcus N. Measuring cognitive load using linguistic features: Implications for usability evaluation and adaptive interaction design. *International Journal of Human-Computer Interaction*. 2014;30(5):343-368. http://www.tandfonline.com/doi/abs/10.1080/10447318.2013.860579. doi: 10.1080/10447318.2013.860579.
- 5. Evans DC, Fendley M. A multi-measure approach for connecting cognitive workload and automation. *International Journal of Human - Computer Studies*. 2017;97:182-189. https://www.sciencedirect.com/science/article/pii/S1071581916300623. doi: 10.1016/j.ijhcs.2016.05.008.
- DoD Directive 3000.09, Autonomy in Weapons Systems, 2012
- 2018 International Panel on the Regulation of Autonomous Weapons (iPRAW) concluding report.
- https://deepmind.com/blog/article/alphastar-mastering-real-time-strategy-game-starcraft-ii
- https://www.hrw.org/report/2015/04/09/mind-gap/lack-accountability-killer-robots

References: Images

- https://starcraft.fandom.com/wiki/Korhal_City_(map)?file=KorhalCity_SC2-HotS_Art1.jpg
- https://www.ldatschool.ca/working-memory-and-cognitive-load/
- https://medium.com/design-signals/cognitive-psychology-in-ux-minimising-the-cognitive-load-d97ad8e3115b
- https://www.dailymail.co.uk/sciencetech/article-7577107/SpaceX-files-30-000-Starlink-satellites-approved-12-000.html
- https://www.clickorlando.com/news/local/2020/01/02/first-launch-of-2020-spacex-starlink-liftoff-moves-to-monday/
- https://www.unmannedsystemstechnology.com/technical-article/torpedo-run-developments-in-torpedo-shaped-autonomous-underwater-vehicles/
- https://www.embention.com/news/drone-swarm-performance-and-applications/
- https://news.northropgrumman.com/news/releases/northrop-grumman-utilizes-dozens-of-unmanned-vehicles-to-deliver-unique-performance-in-darpa-swarm-test
- http://www.neelabell.com/online-learning-2/avoiding-cognitive-load-meltdown-in-moodle/
- https://www.techrepublic.com/article/15-ways-to-combat-cognitive-overload/

References: Images

- https://thebittheories.com/data-analysis-and-statistical-inference-a-quick-guide-part-2-anova-87441c5018e5
- http://mavlab.tudelft.nl/how-the-google-sorting-algorithm-helps-us-develop-swarms-of-drones/
- https://verhaert.com/ai-technology-to-measure-absolute-blood-pressure/
- https://www.brainsigns.com/en/science/s2/technologies/eyetracker
- https://dotesports.com/starcraft/news/the-best-starcraft-2-player-in-the-world-may-not-be-korean
- https://www.liquid-robotics.com/wave-glider/software/
- https://singularityhub.com/2017/02/09/why-the-best-innovators-ask-the-most-beautiful-questions/
- https://www.seti.org/research/Planetary-Exploration
- https://en.wikipedia.org/wiki/Dragonfly_(spacecraft)#/media/File:NASA_Dragonfly_mission_to_Titan.jpg
- https://www.defensenews.com/naval/2020/01/10/does-the-us-navy-have-its-robot-warship-concept-all-wrong/
- https://defensesystems.com/articles/2017/05/08/marinecorpprint.aspx

???Questions???

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY