Autonomous Swarms of High Speed Maneuvering Surface Vessels

Tyler Halpin-Chan[1], Varun Varahamurthy[1], Josh Vanderhook[2]

December 12, 2018

1 Naval Air Warfare Center
Weapons Division,
Point Mugu, CA

2 Jet Propulsion Laboratory
California Institute of Technology

Tyler Halpin-Chan
NAWCWD
805 989-5265
tyler.halpin-chan@navy.mil

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Outline

- Overview
- Method of Test
- Test Scenarios
- Results
- Conclusions

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Overview

- The Surface Targets Engineering Branch (STEB) has the world's largest USV (Unmanned Surface Vessel) fleet and developed the USV and the GUI (Graphical User Interface)
- The Jet Propulsion Laboratory (JPL) has developed the swarm algorithms for this project
- The HSMST as a USV has demonstrated its capabilities during the Phase I and II Demos of the CTEIP Swarm Autonomy Project
- The HSMST (High Speed Maneuverable Surface Target) has the network infrastructure to operate in a decentralized swarm
  - Local computations performed onboard the HSMST
  - Information shared between other participating HSMSTs

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Overview: Purpose

- HSMSTs
  - are used in large-scale demonstrations
  - represent asymmetric naval threats
- The CTEIP Swarm Autonomy Project desired to increase the number of boats one operator could control

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

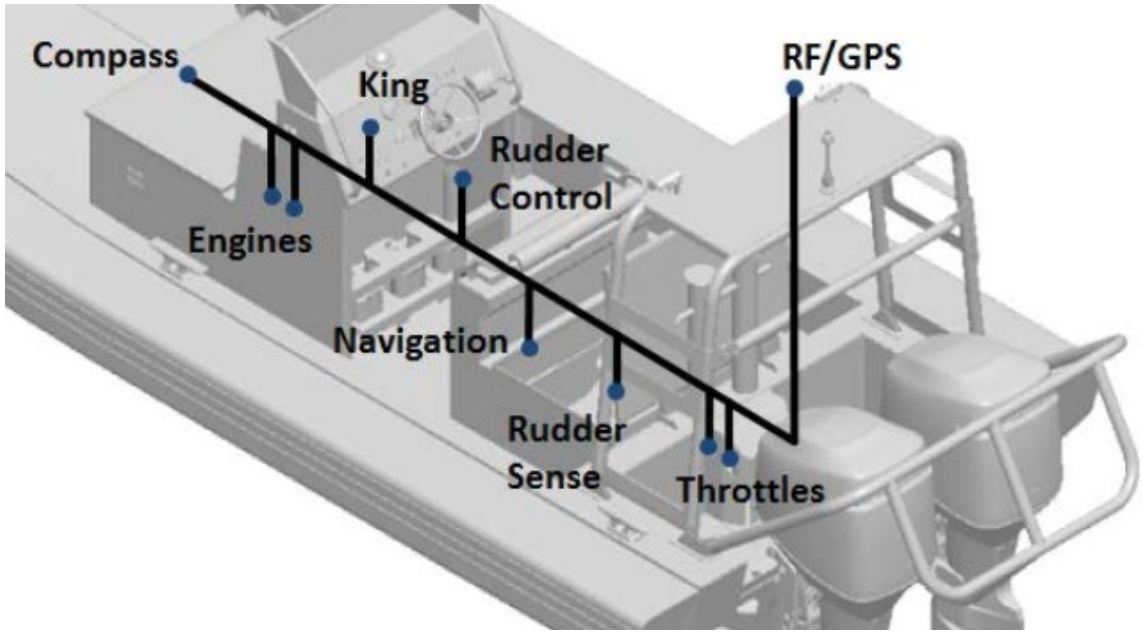
Overview: HSMST

Unique Features	**8m Aluminum deep vee**
	46+kt top speed
	Foam filled w/closed cell sponsons
	2x200hp outboard engines

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Overview: SeaCAN

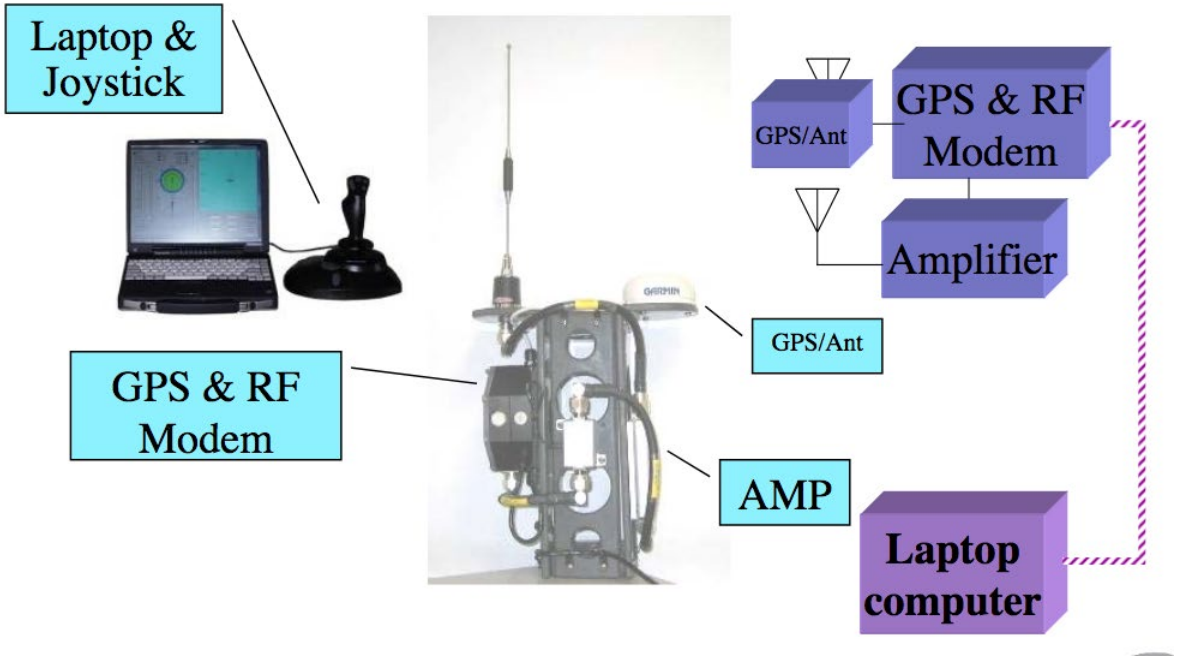
- SeaCAN (Sea Controller Area Network)
  - Uses the CAN bus to send a set of standardized messages between microcontrollers called nodes
  - Each node has a specific function, sometimes unique sensors
  - SeaCAN can be adapted to work on other surface vessel platforms
- HSMSTs share information with other boats in the swarm including
  - GPS location
  - Heading
  - Speed



Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Overview: PCCU

- PCCU (Portable Command and Control Unit)
  - Connects to SeaCAN via a RF link
  - Facilitates remote control of SeaCAN compatible surface vehicles
  - HSMSTs can be controlled by an on-board Operator, the PCCU, or Autonomy

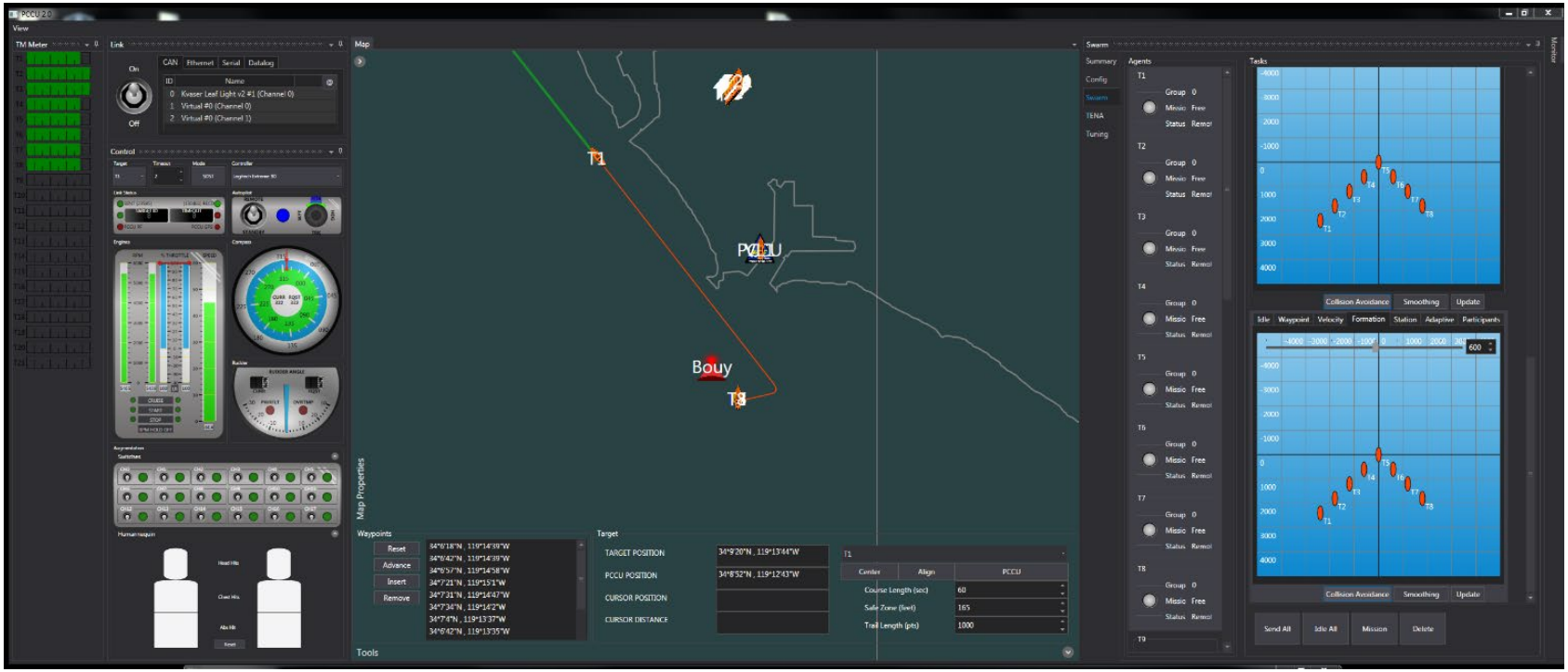


Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Overview: PCCU 2.0 GUI

- PCCU 2.0 GUI
  - is a reimplementation of the original, tried-and-tested PCCU 1.0. It features many of the same functions and interfaces that PCCU operators are already trained in.

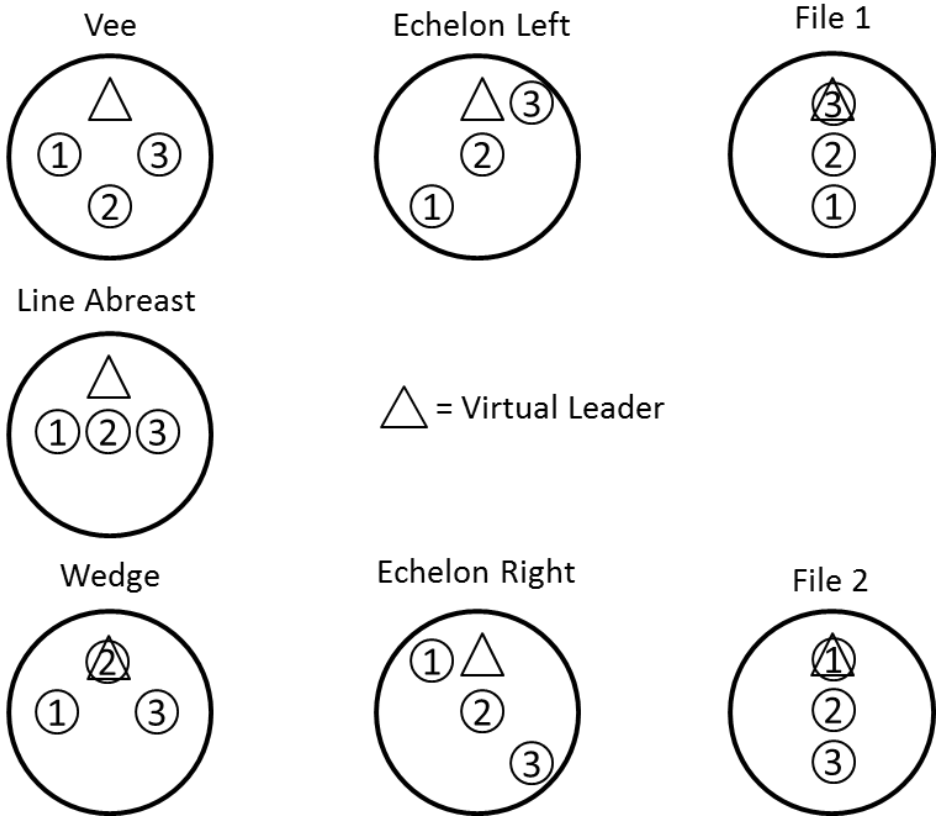
- PCCU 2.0 is written in C#/WPF, a more modern, secure, and maintainable framework allowing for rapid and secure development.



Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Overview: Formation Types

- Desired formation types include (but are not limited to) the following:
  - Vee
  - Line Abreast
  - Wedge
  - Echelon Left
  - Echelon Right
  - File



Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Overview: Algorithm

- JPL developed the autonomy algorithm for the HSMSTs
- Main outputs of the algorithm (per boat) are:
  - Desired Path
  - Preferred Controls
  - Safe Controls
- SeaCAN receives only the Safe Controls (Requested Speed and Heading) and executes that command

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Method of Test: Safety

- Similar to testing in the autonomous car industry, safety operators were required for initial tests of HSMST autonomy
- Safety operators were trained to
  - recognize abnormal autonomous behavior
  - communicate relevant information in short-hand over radio comms
  - stop the engines in case of emergency

- Other layers of safety included (but are not limited to)
  - PCCU operator “Idle All” command
  - HSMST telemetry timeouts
  - Safe zone radii around each boat

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

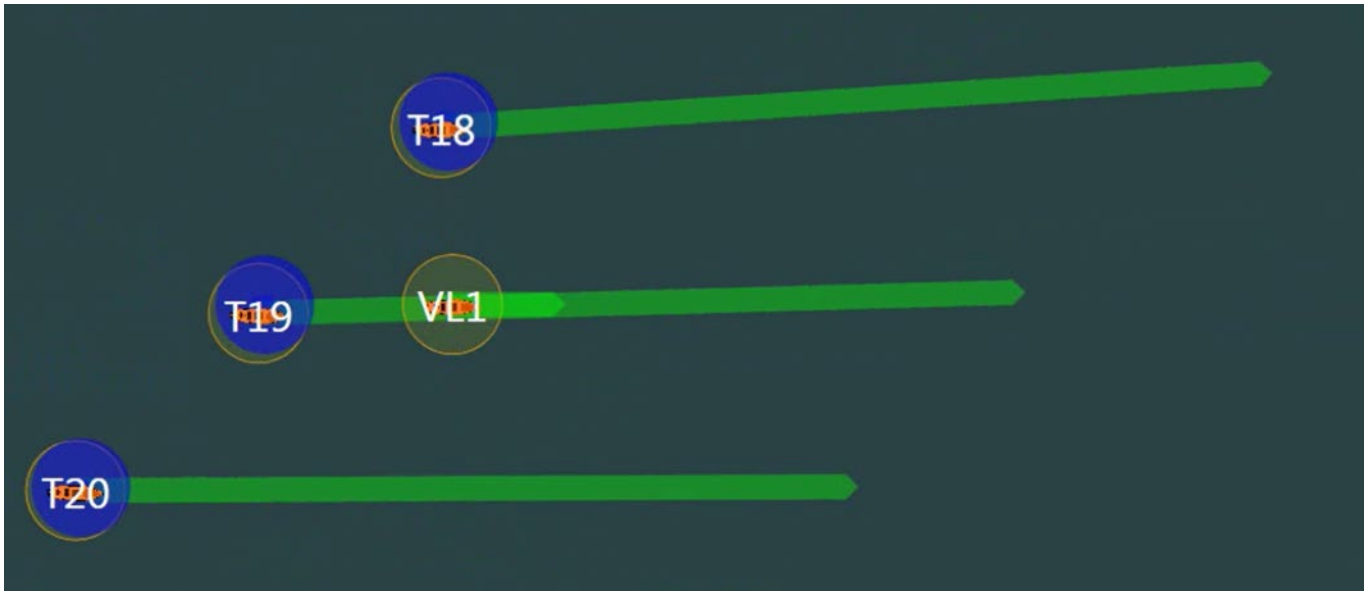
Method of Test: Ramp Up Procedures

- Ramp up procedures
  - Test scenarios designed to be completed at low, medium, high and mixed speeds
  - HSMSTs have a displacement and planing mode
  - Test in lower sea state before going to higher
  - Ramp up in complexity for boat operator understanding

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Method of Test: Virtual Leader

- The Virtual Leader (VL) concept was developed to
  - Make the transition from controlling 1 boat to a swarm easier
  - VL cannot be destroyed during a test
  - Reduces logic required for leader handoff



Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Test Scenarios

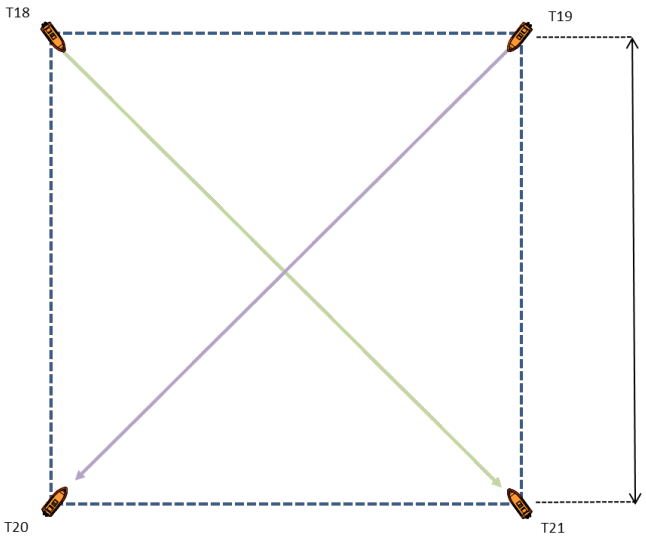
- Virtually infinite number of testable scenarios (i.e. formation switches)
- Different scenarios were developed to test discrete autonomous functions:
  - 3 & 4 Way Collision Avoidance
  - Formation commands
    - Arbitrary Start
    - Turning CW & CCW
    - Static/Adaptive Switching
    - Coordinated Weaving

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

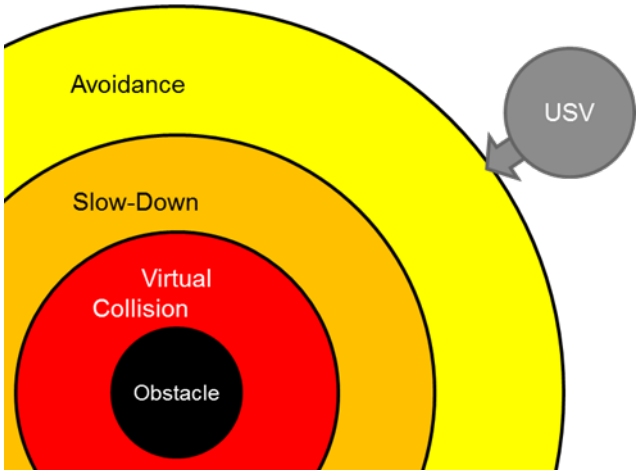
Test Scenarios: Collision Avoidance

- Collision Avoidance
  - Safe Zone Test
  - 3-Way Crossing
  - 4-Way Crossing

4-Way Crossing



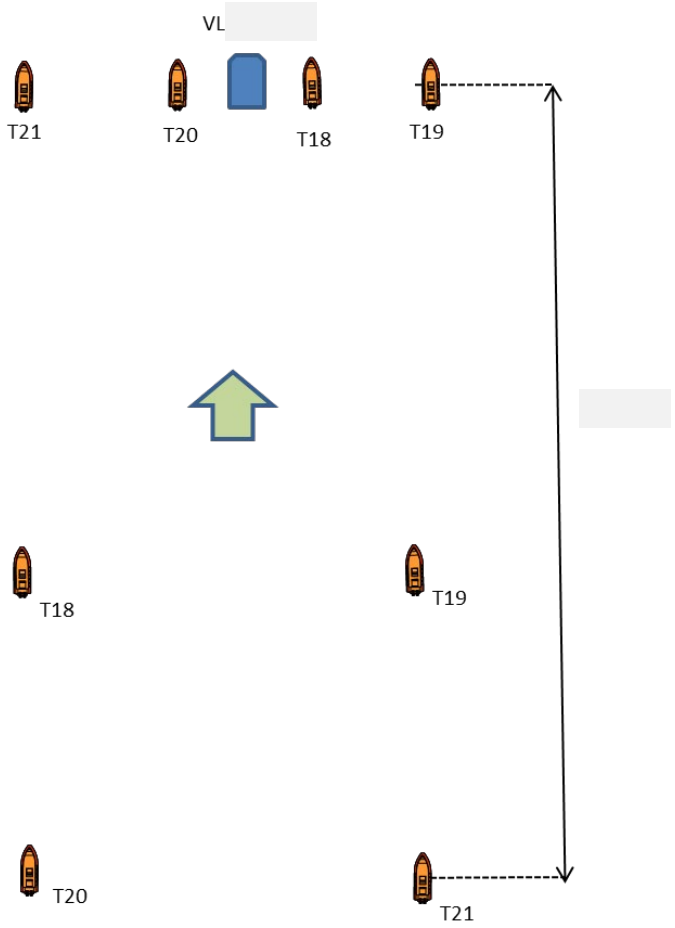
Safe Zone Test



Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Test Scenarios: Arbitrary Start

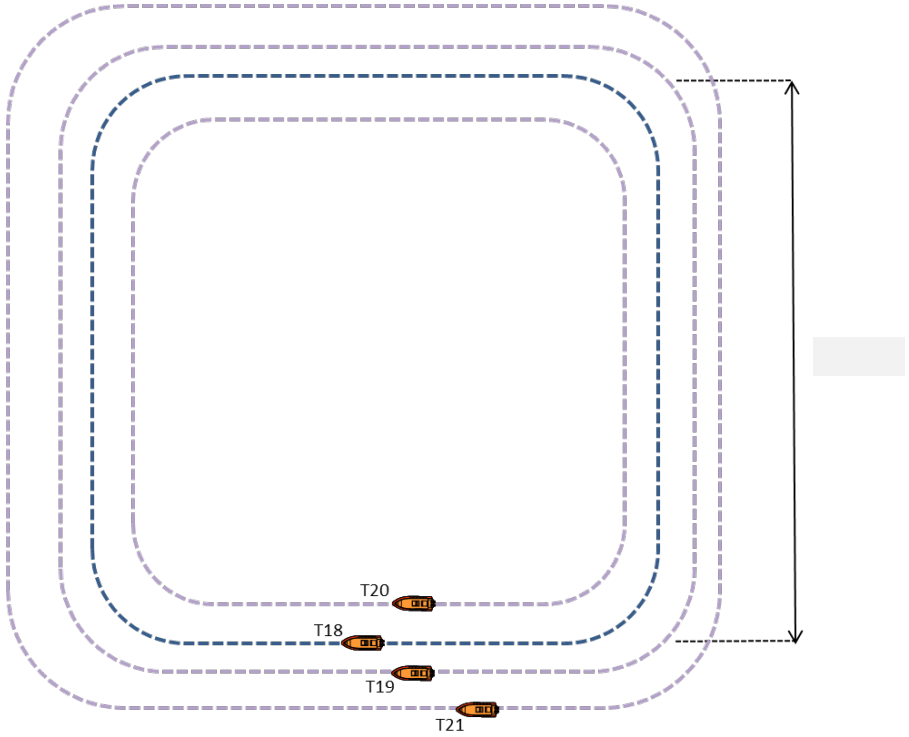
- Arbitrary Start into line abreast, wedge, vee, echelon left+right, and file



Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Test Scenarios: Turning CW & CCW

- Formation with 90 Degree Turns, CW & CCW
- Wedge causes CW & CCW to not be symmetrical

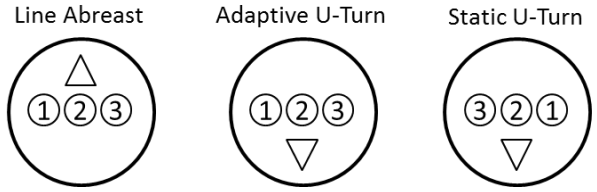


Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Test Scenarios: Formation Switches

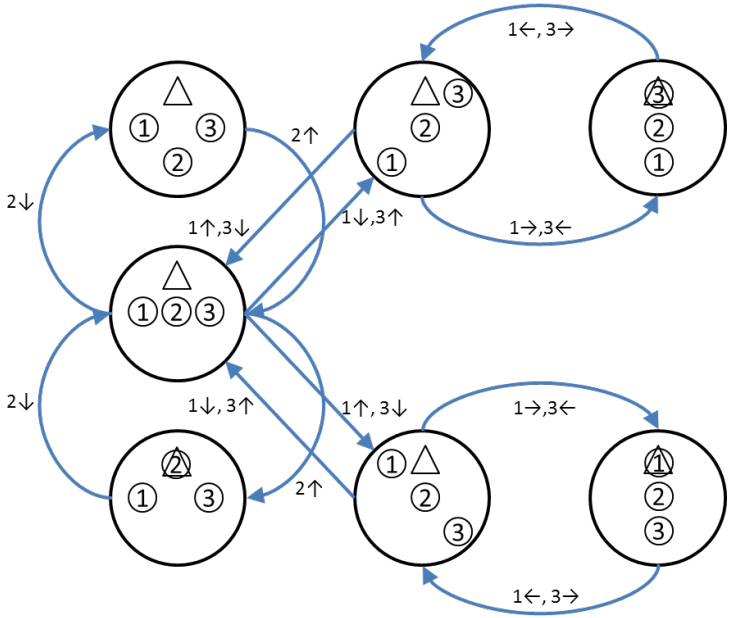
- Changing to Static and Adaptive Formations
- Adaptive formations can rank switch; Static are fixed rank

△ = Virtual Leader



- Formation switches no longer need to follow the Phase 1 Formation Switch Diagram
- Some formation switches were not known to JPL during development in order to test algorithm robustness

Phase 1 Formation Switch State Diagram

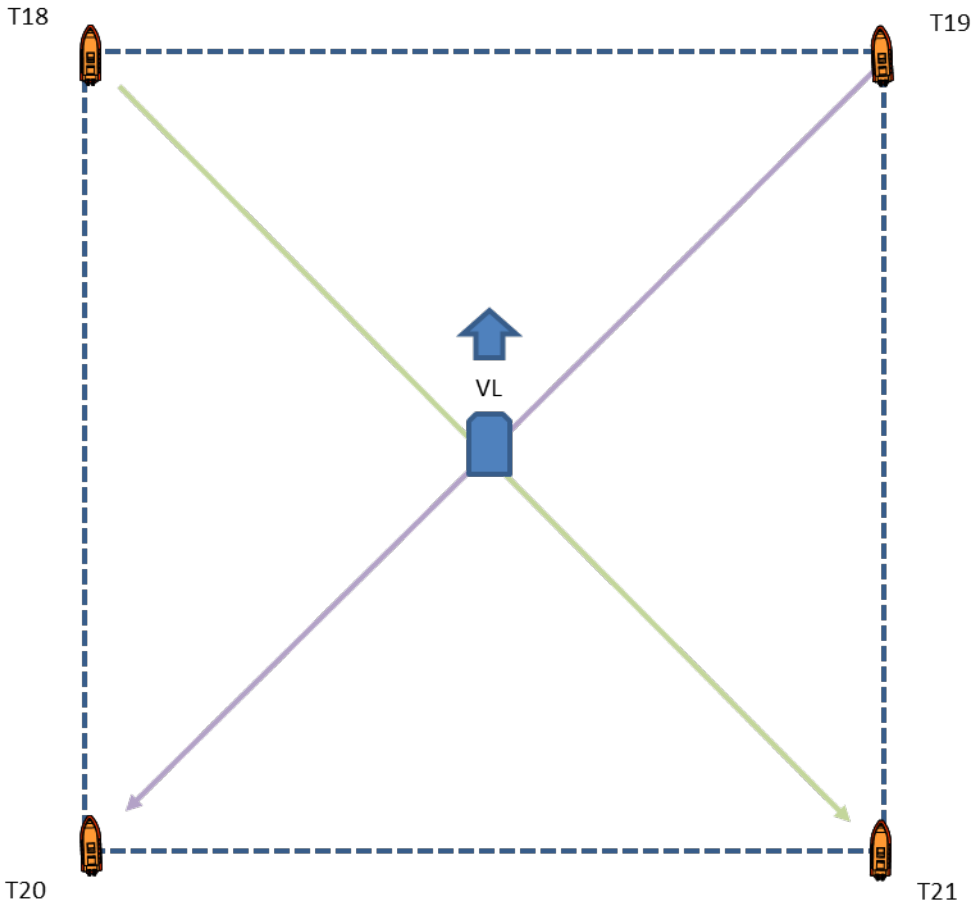


△ = Virtual Leader

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Test Scenarios: Hidden Formation

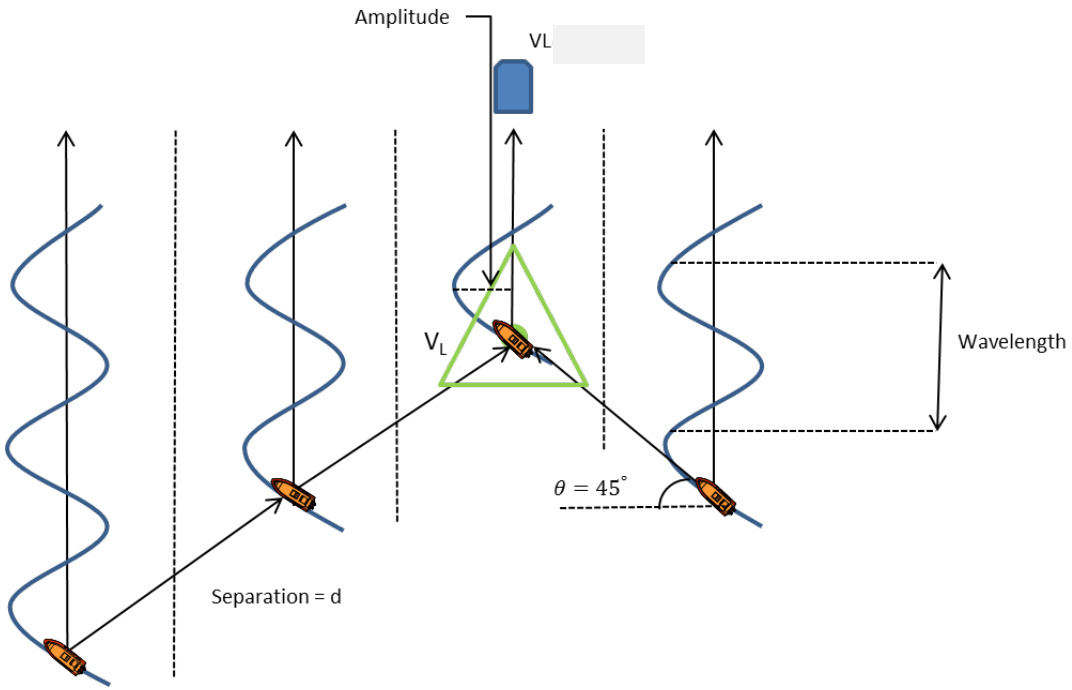
- Moving 4-Way Crossing



Approved for public release; distribution is unlimited. NAWCWD PR18-0260

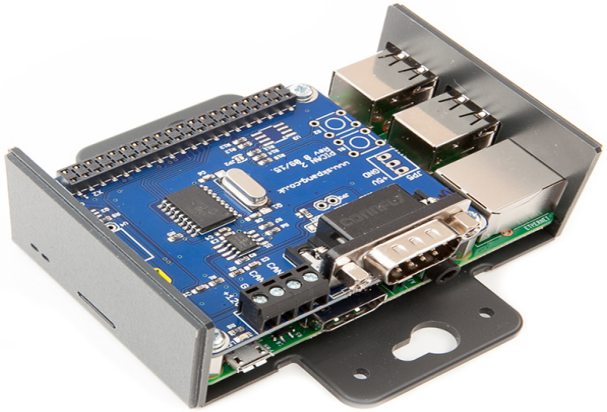
Test Scenarios: Formation Weave

- Coordinated Weaves in Wedge Formation

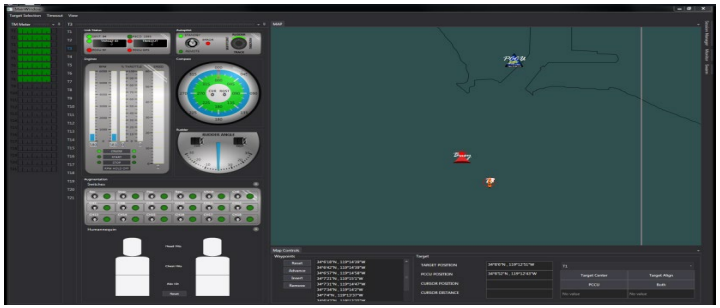


Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Results



- Raspberri Pi 3 chosen as the STT hardware
  - The Pi is a credit card sized computer (this particular variant costs $135)
  - JPL ported code to the Pi



- New PCCU 2.0 built from the ground up to improve GUI capability
  - Written in C# using WPF
  - Supports modern libraries and plugins
  - Improves operator situational awareness by supporting multi-monitor configurations

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Results: Video Summary

DISTRIBUTION STATEMENT A.
Approved for Public Release.
Distribution Unlimited.

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Conclusion

- All 38 test scenarios were completed at low, med, and high speeds (when applicable)
- No safety incidents
  - Safety precautions proved to be adequate
- One PCCU operator was used to conduct the entire week long test
- Demonstrated a method to test an autonomous sytem
- “Robustness” was determined by using hidden formations
- Provides target customers with high repeatability and precision

Approved for public release; distribution is unlimited. NAWCWD PR18-0260

Acknowledgements

- Algorithm development for collision avoidance and formation control occurred at the Jet Propulsion Laboratory, California Institute of Technology

- Project Management, GUI and HSMST firmware development was carried out by the STEB

- Supported in part by the U.S. Department of Defense, Test Resource Management Center, Test & Evaluation/Science and Technology (T&E/S&T) Program under NASA prime contract NNN12AA01C, Task Plan Number 81-103286.