Secure Mission Control for Autonomous Underwater Swarms

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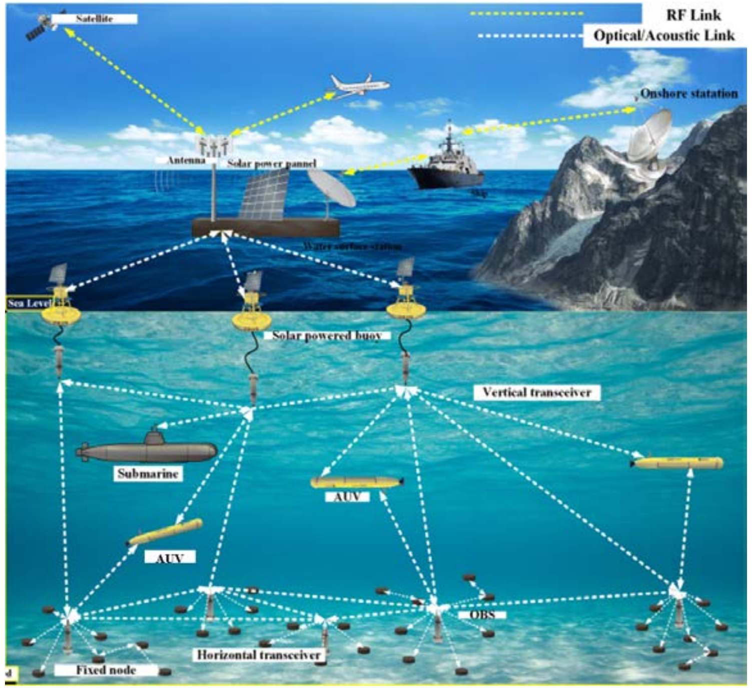
Goals for

Secure Mission Control for Autonomous Underwater Swarms: G1

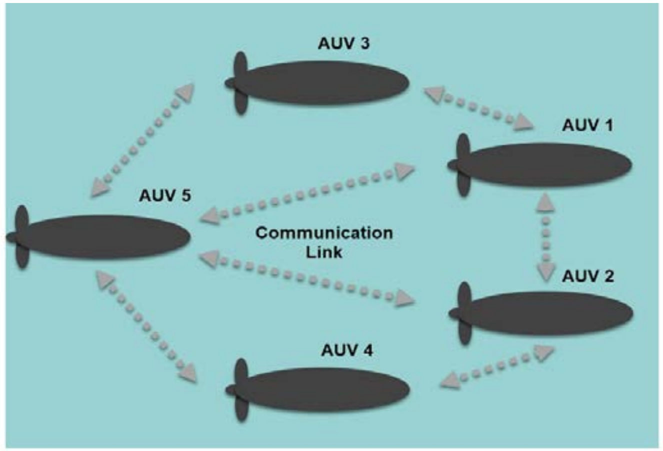
G1. Establish secure & resilient underwater communication channels for AUV by using underwater mobile ad hoc networks (uMANET).



Goals for

Secure Mission Control for Autonomous Underwater Swarms : G2

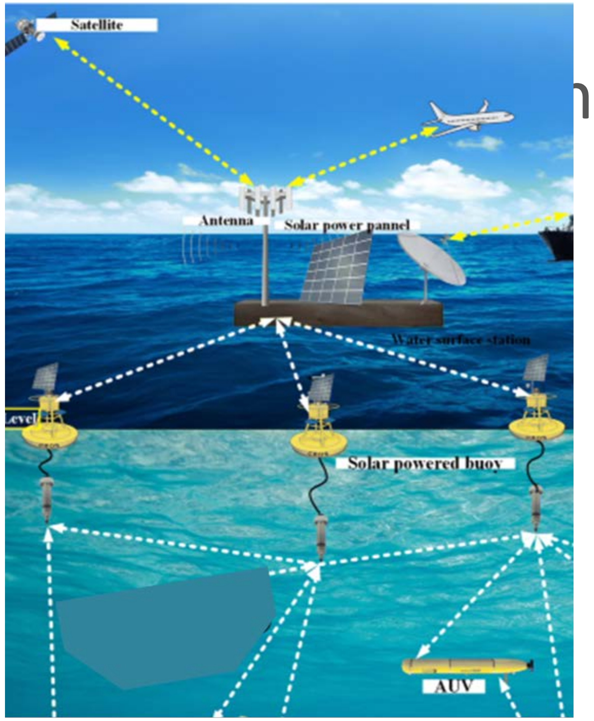
G2. Determine what formations or behaviors of a swarm should adopt for a given mission and design communication and protocols that effectively maintain the swarm in the desired formation.



Goals for

Secure Mission Control for Autonomous Underwater Swarms : G3

G3. Explore alternative methods by which a swarm can know its location with respect to a global grid (localization), and operate in an environment populated with moving obstacles.

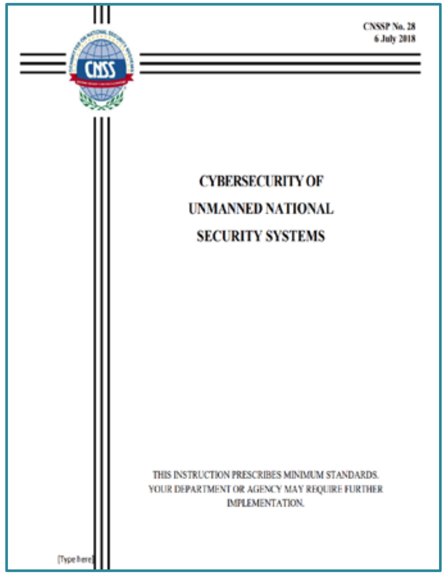


Goals for

Secure Mission Control for Autonomous Underwater Swarms : G4

G4. Security/resilience:

Compliance with the CNSSP-28 policy document: ‘*Cybersecurity of Unmanned National Security Systems*’ of the *Committee on National Security Systems*, for systems that operate in all physical domains and space, both remotely and autonomously.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CYBERSECURITY OF
UNMANNED NATIONAL
SECURITY SYSTEMS

THIS INSTRUCTION PRESCRIBES MINIMUM STANDARDS. YOUR DEPARTMENT OR AGENCY MAY REQUIRE FURTHER IMPLEMENTATION.

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Underwater Swarm Robotics

Contributions C1,C2

C1. A better understanding of the threat model for AUV swarms and of implementation vulnerabilities.

C2. Develop architectures and protocols for secure and resilient mission control of AUV swarms. This task focused on specific missions: primarily *Intelligence, Surveillance and Reconnaissance* (ISR) and *Mine Countermeasure Missions* (MCM).

Underwater Swarm Robotics
Contributions C3

C3. Investigate the challenges of securing AUV swarm formations.

We distinguish two types of algorithms used by under-water robots to act as a team: *formation* and *consensus*.

For these, the knowledge state of a robot at any time is shared with *some* (formation), or all (consensus) of the robots of a team.

This requires that the robots can communicate securely.

Underwater Swarm Robotics
Contributions, C4

C4. Investigate underwater communication channels, and design communication protocols that minimize transmitted data for formation and consensus control.

- Because of the high attenuation of underwater EM signals, *acoustic* (sonar) waves are preferable. However, we only get baud rates up to 10 kbs.
- *Optical* (laser) transmissions have much higher data rates, but significantly shorter ranges. E.g., with high power 450nm blue lasers we get data rates of 4.8 Gbs, but their range is only 5.4m. Furthermore, optical transmissions are strictly *line-of-site*, and are affected by the *turbidity* of the water.

Underwater Swarm Robotics
Contributions C4, cont.

- A possible solution is to use a *hybrid communication system* that enables the AUV of a swarm to maintain connectivity by using acoustic signals, while optical signals are used for communication.
- In our algorithms we use a dynamic underwater MANET (uMANET) with two modes of operation: sonar for formation and laser for communication.

Underwater Swarm Robotics
Contributions, C5

C5. Design secure and resilient uMANET protocols that maximize acquired sensor data for underwater consensus and formation control.

- The robotic devices monitor environmental events or conduct a specific mission.
- This requires the devices to co-operate as a team, and exchange acquired sensor data.

Underwater Swarm Robotics
Challenges, 1

1. Underwater swarm robotics is a complex field that combines a number of research areas, such as

   underwater propulsion/sensors/localization/communication/ swarm control (centralized/decentralized) and swarm intelligence (based on the collective behavior of self-organized systems),

to solve mission planning optimization algorithms.

Underwater Swarm Robotics
Challenges, 2,3,4

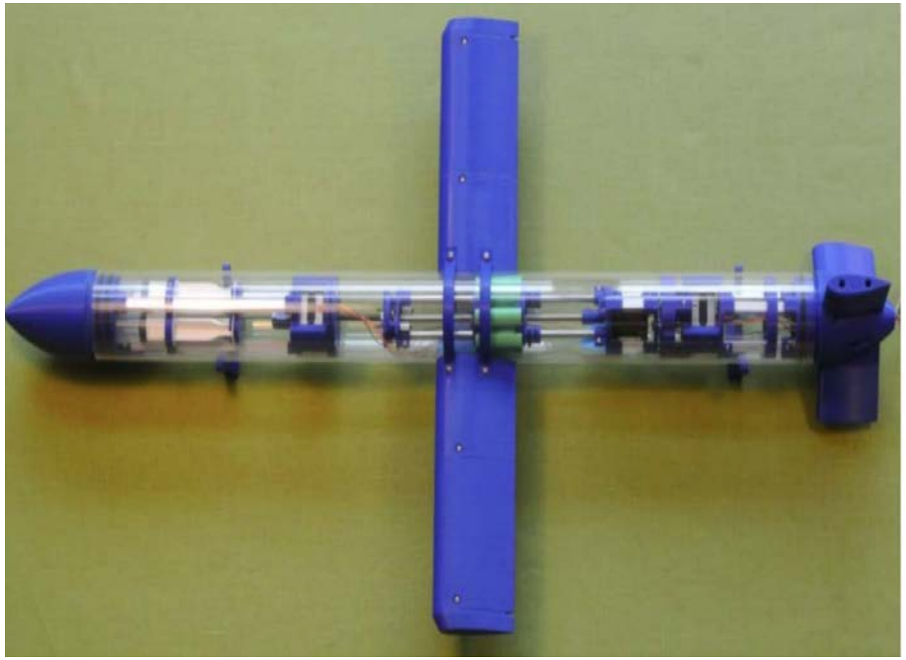
2. Swarm algorithms are often based on the behavior of animals (e.g., the Particle Swarm Optimization (PSO) can be visualized as the behavior of a flock of birds) and minimize the required communication between interacting parties to achieve a specific objective.
3. Whether, or to what extent, any of these algorithms may apply to the needs of Navy missions involving UAV swarms has yet to be determined.
4. What is certain is that new algorithms need to be devised for UAV motion control and decision-making.

Underwater Swarm Robotics
Challenges, 5,6

5. In particular, AUV should implement self-organizing controllers that adapt to the environment (e.g., by using Neural Networks for learning and Self Organizing Maps for control).
6. These are particularly challenging because of the
   - low cost requirement for the AUV, and the
   - security/resiliency requirements.

Underwater Swarm Robotics

A low-cost open source AUV for testing and research



Testing equipment:

- A low-cost underwater glider for research ($1,000, 1.2m long, 1.2kg, capable of 50hrs continuous operation.

 (the Hackaday 2017 Prize Winner)

Underwater Swarm Robotics

Mine Countermeasure Missions

- **For mine detection countermeasures**, we use a swarm of low-cost AUV's to sweep the search area.
- A basic line-sweep guarantees the absence of overlapping tracks. This can be extended by using a PSO (Particle Swarm Optimization) algorithm.
- A further extension allows for searches that cross the same location multiple times, in case the target is missed or is trying to evade detection. The goal is for all areas to be covered the same number of time (on average).
- Examples of AUV swarms in a regular tessellation formation for linear and circular sweeps are shown below.

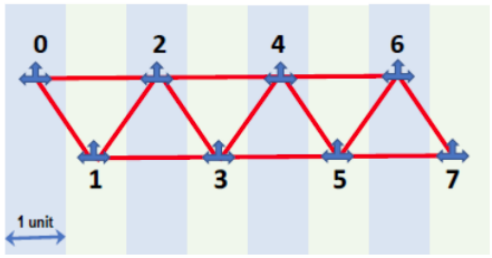


Figure 1: A regular tessellation formation of 8 UAV: each AUV only needs to check its distance from 2 nearest neighbors.

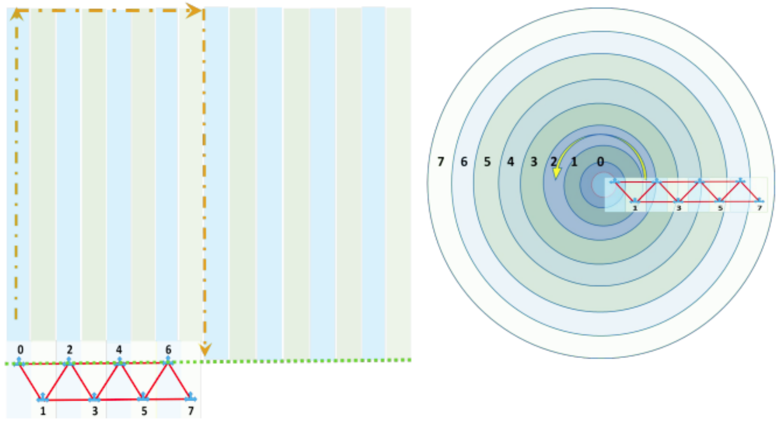


Figure 2: An AUV swarms in a regular tessellation formation for linear and circular sweeps.

Underwater
Swarm Robotics
Current Research

1. **Design uMANET protocols that maximize acquired sensor data** for underwater consensus and formation controlled protocols.
   This requires the robotic devices to co-operate as a team, and exchange acquired sensor data that depends on the sensor types and the elapsed time from the previous sensing.
   We design uMANETs for specific mission tasks, that are secure and resilient (prevent swarm breakup and restore connectivity) based on earlier work for VANETS and MANETs.

Underwater Swarm Robotics
Current Research

2. **Provide hands-on learning experiences** based on software in the loop testing (SITL) for students and cyber faculty.
3. **Designing SITL tools to test implementations, and modifying protocols to achieve specific performance goals** provides students with essential hands-on learning experiences in understanding the subtleties of protecting robotic systems and resources.

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Thanks!