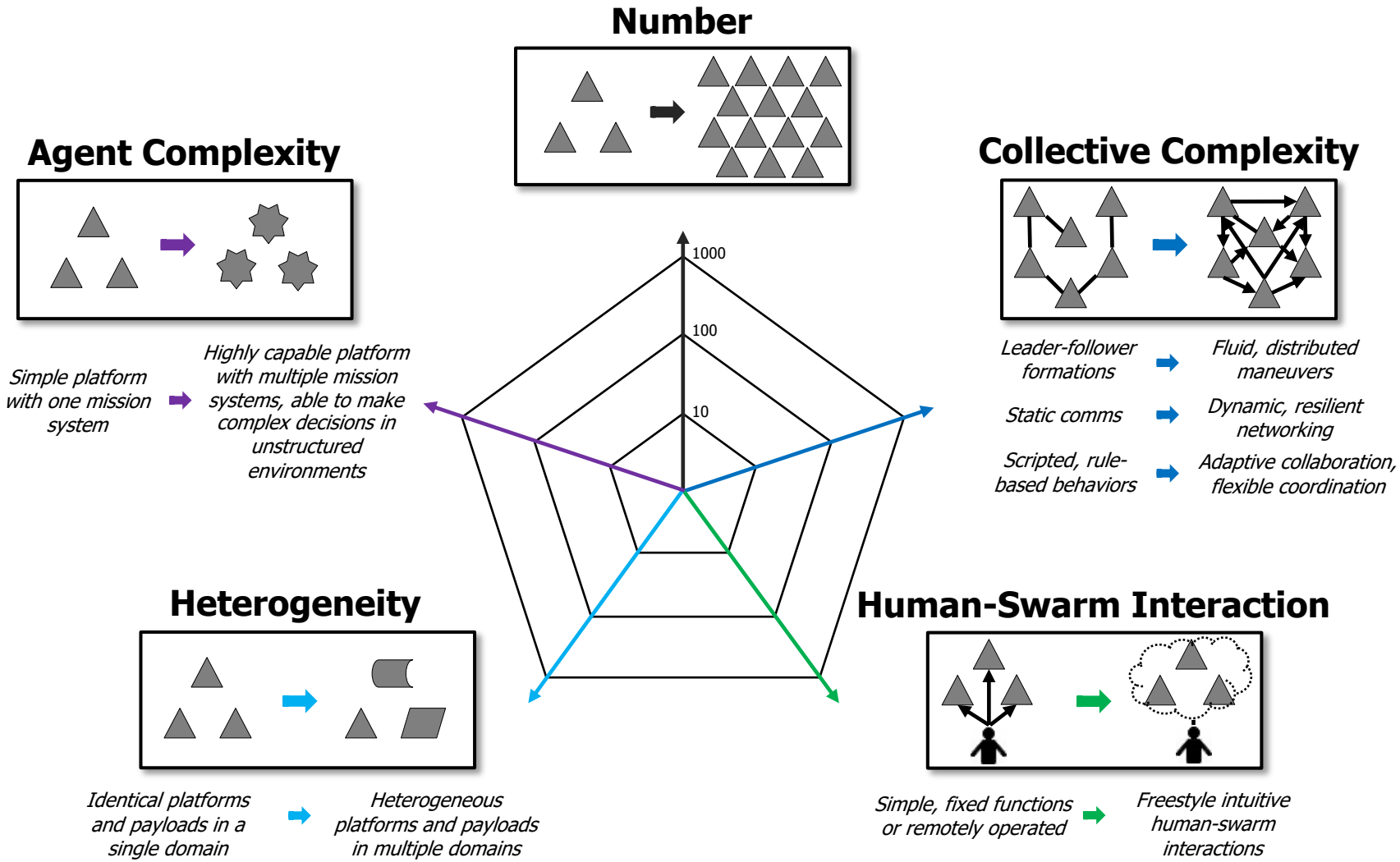
OFFensive Swarm-Enabled Tactics (OFFSET)

Dr. Timothy H. Chung
Program Manager
Tactical Technology Office
Defense Advanced Research Projects Agency

Briefing for the Naval Counter-Improvised Threat Knowledge Network

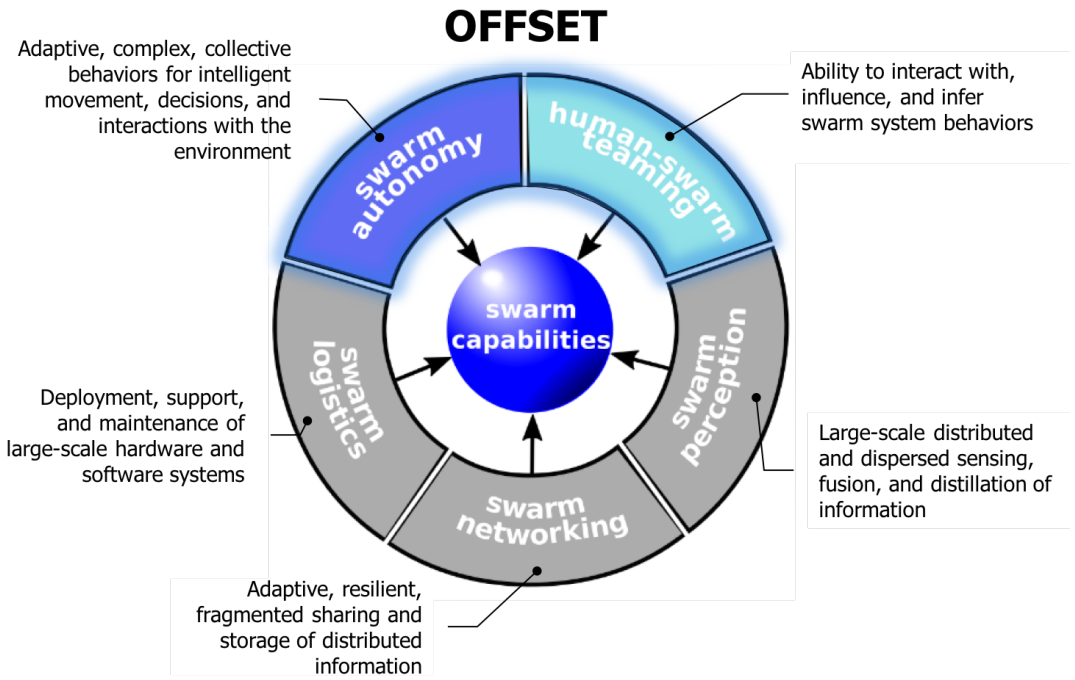
March 18, 2021

Why Are Swarms Hard: Complexity of Swarms

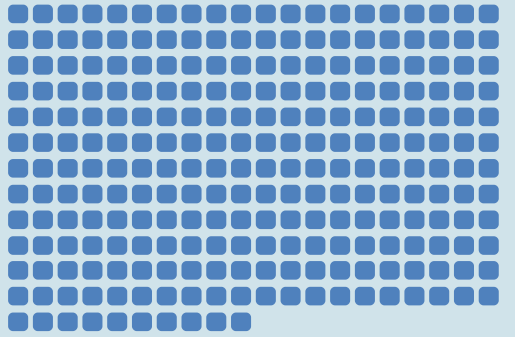


OFFensive Swarm-Enabled Tactics (OFFSET) Vision

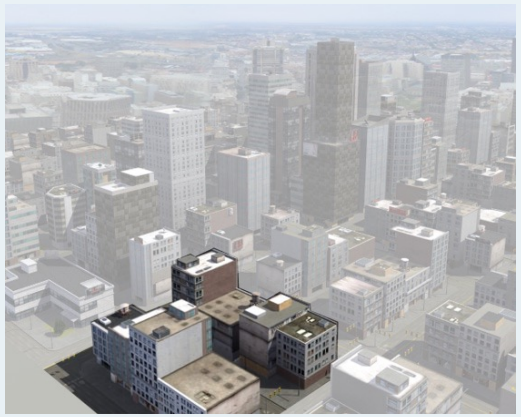
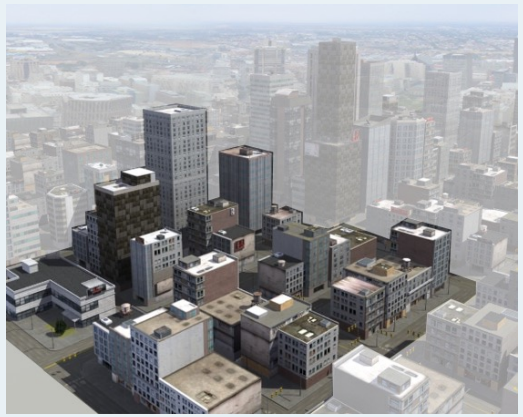
Discover innovative technologies to enable **large-scale teams of air and ground robots** to support **small-unit forces** operating in **complex urban environments**



Objective Capability
Seize key urban terrain

4-6 hours
Approx. 8 square city blocks


OFFSET Urban Mission-focused Approach

Vignette 1	Vignette 2	Objective Capability
Isolate an urban objective	**Conduct an urban raid**	**Seize key urban terrain**
		
15-30 minutes	1-2 hours	4-6 hours
Approx. 2 square city blocks	Approx. 4 square city blocks	Approx. 8 square city blocks

Introducing **OFFSET**: Swarms in Urban Environments

Highlights from recently completed OFFSET FX-4 @ Joint Base Lewis-McChord, Washington

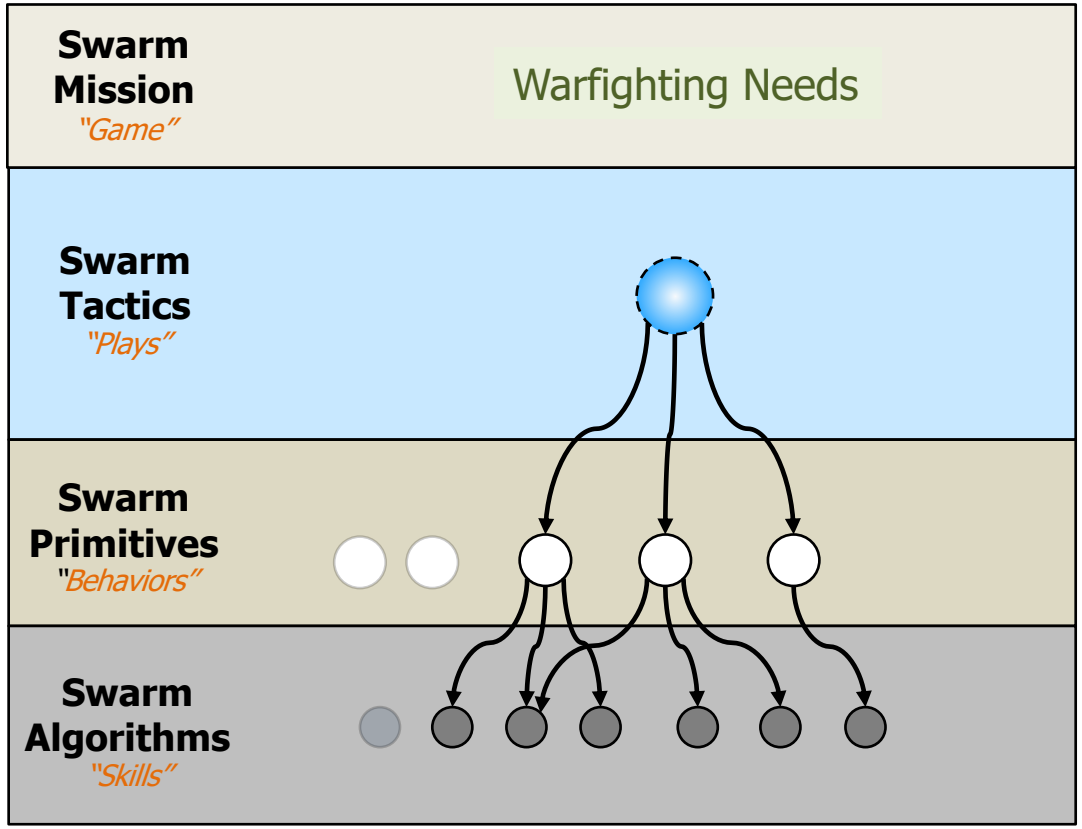
https://www.darpa.mil/news-events/2020-09-18

Accelerating Swarm Capabilities through **Swarm Tactics**

TACTICAL TECHNOLOGY OFFICE

Swarm Tactics | Swarm Systems Architectures | Scalable Swarm Simulators | Modular Swarm Testbeds

OFFSET Focus



NORTHROP GRUMMAN

OFFSET RISE

Rapid Integration Swarm Ecosystem
(RISE)

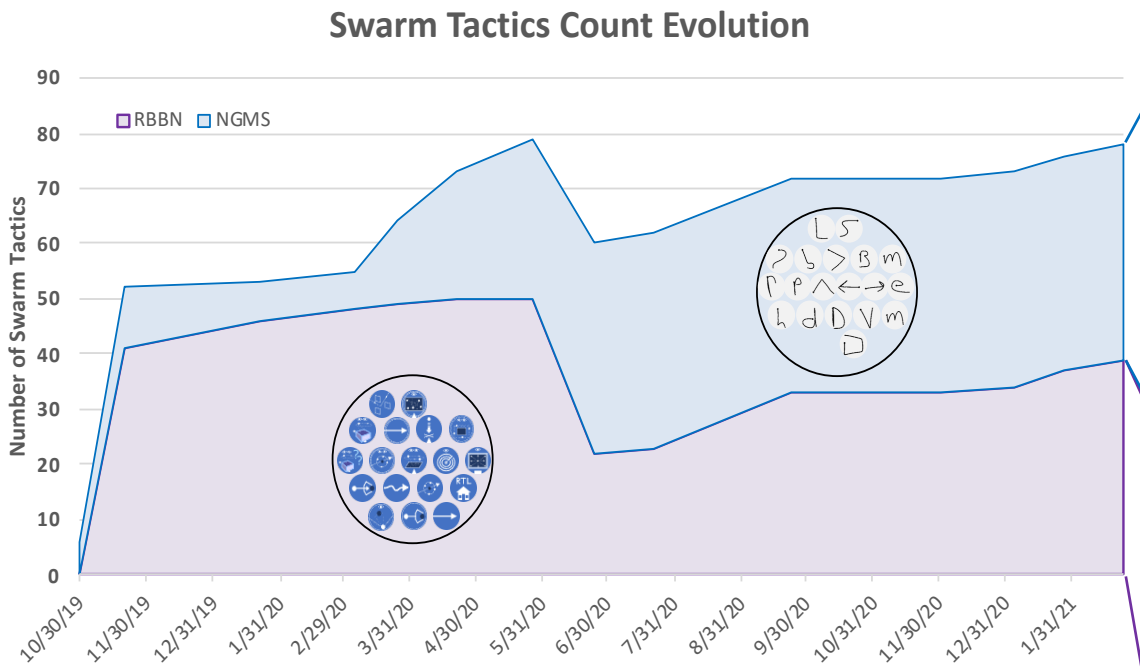
OFFSET Swarm Systems Integrators

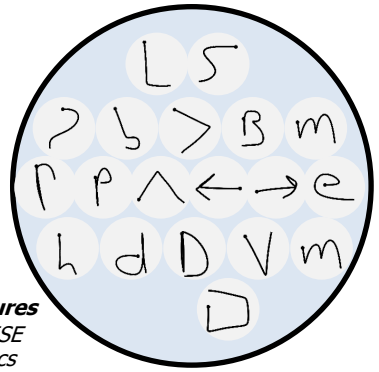
Raytheon BBN

Command and Control of Aggregate Swarm Tactics
(CCAST)

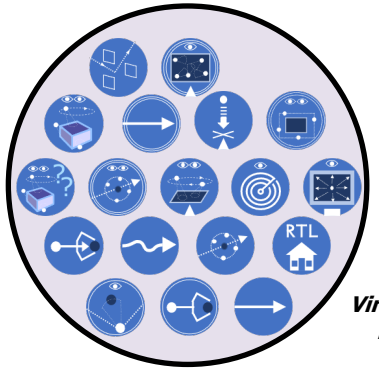
OFFSET Impact: Software Repository of swarm tactics code, user tutorials, and developer documentation

Swarm Tactics Exchange: Repositories of Swarm Software





Sketch gestures *for NGMS RISE swarm tactics*



Virtual reality icons *for RBBN CCAST swarm tactics*

RISE *Swarm Tactics Exchange*

- Examine Objective
- Follow Route
- Hold Position
- Hover Above Current Location
- Inward Scan
- Move To
- Multi-agent inward scan
- Overhead scan
- Ring around POI
- UAV Test POI
- RADAR scan for ST-MTRI
- Safe Land
- Sector split leader follower
- Platform test
- Building scan
- Waypoint navigation/POI
- Tornado scan
- Hover
- Ring around POI
- Overhead Scan
- Multi-agent inward scan
- Examine Object
- Safe Land
- Outdoor to indoor transition
- Indoor exploration
- Artifact handler
- Artifact secure
- Building perimeter scan
- Outdoor exploration
- GPS to indoor explore
- GPS to indoor non-explore
- Indoor ramp traversal
- Leader follower (follower)
- Leader follower (leader)
- Platform Test
- Approach area
- Breach Building
- Waypoint Navigation/POI
- Approach target area leader follower

CCAST *Swarm Tactics Exchange*

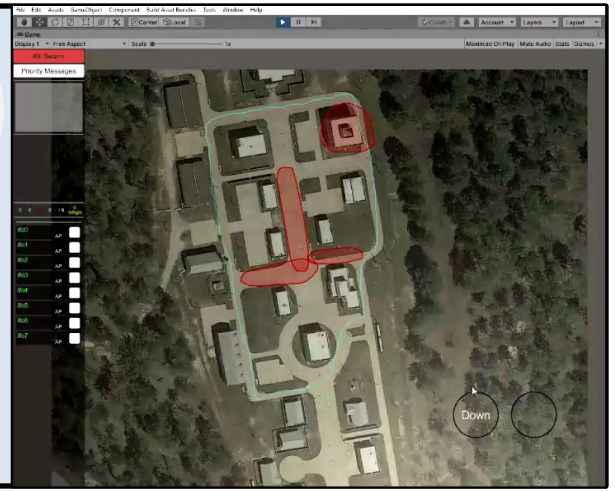
- Add To Replacements
- Amass
- April Tag Scan
- Area Survey
- Cordon Area
  Cordon Building
- Explore
- Explore Building
- Flock To LLA
- Follow Object
- Gather Ground Imagery
- Go To
- Go To – Complex
- Interact
- Interact Go To
- Join Quick Reaction Force
- Land In Area
- Land In Place
- Look At
- Maintain Proximity to AT
- Patrol
- Process Obstacles
- Proximity
- Relieve agent
- Rendezvous at Point
- Report Objects
- Return To Launch
- Revive at Medic
- Route Nav
- Split
- Stage In Area
- Stop
- Stop/Estop
- Surveil Ground
- Surveil Object
- Surveil Area
- Transition To Region
- Watch Entry Points in Zone
- Designate Quick Reaction Force

Swarm Tactics: **Spotlights**

Overhead Scan

```
parameters = [
  Altitude
  Cell Size
  Agent Count]
```

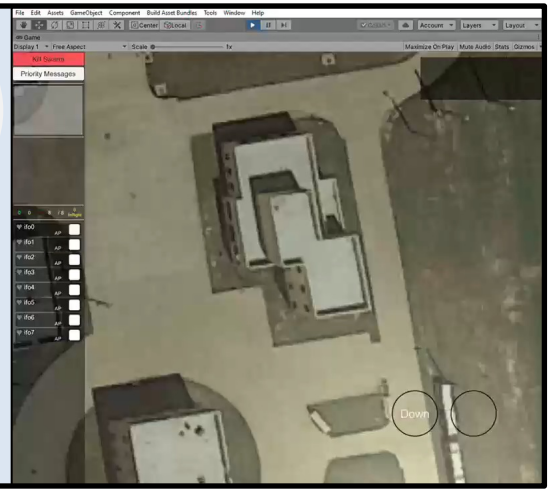
Description: Fly UAVs over area to find artifacts



Multiagent Inward Scan

```
parameters = [
  Starting Altitude
  Level Count
  Distance Between Levels
  Agent Count
  Outward]
```

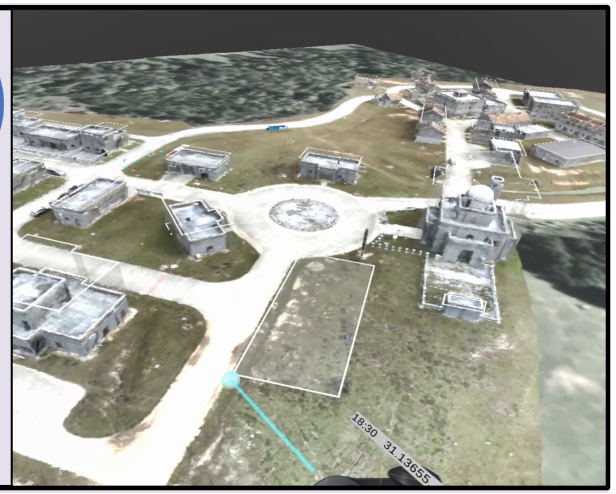
Description: Use multiple UAV agents to scan enclosed area specified by path stroke.



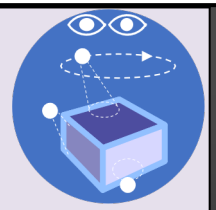
Surveil Area

```
parameters = [
  Polygon
  Agent(s)
  Concluding Action]
```

Description: Command wildcard agent(s) to travel to user input area

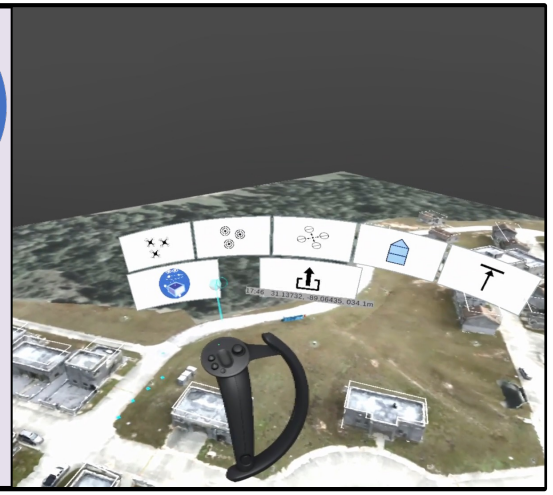


Surveil Object



```
parameters = [
  Building (spatial
    database)
  Agent(s)
  Concluding Action]
```

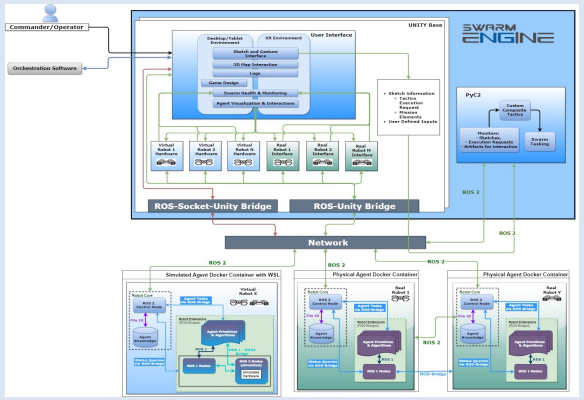
Description: Command agent(s) to travel to and surveil an object in the spatial database

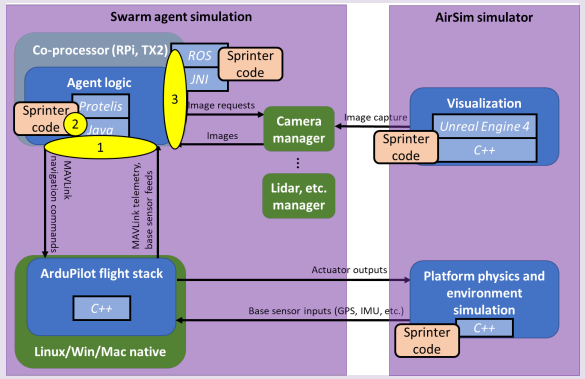


Swarm tactics-enabling **Swarm Systems Architectures**

Swarm Tactics	Swarm Systems Architectures	Scalable Swarm Simulators	Modular Swarm Testbeds

NORTHROP GRUMMAN





Raytheon BBN

Swarm Tactics
"Plays"

Swarm Primitives
"Behaviors"

Swarm Algorithms
"Skills"

Fact 1: real-world missions requires *composability*
Different approaches, different assumptions, different context

Fact 2: adopting new innovation requires *flexibility*
Novel ideas don't come in just one shape and size (or interface)

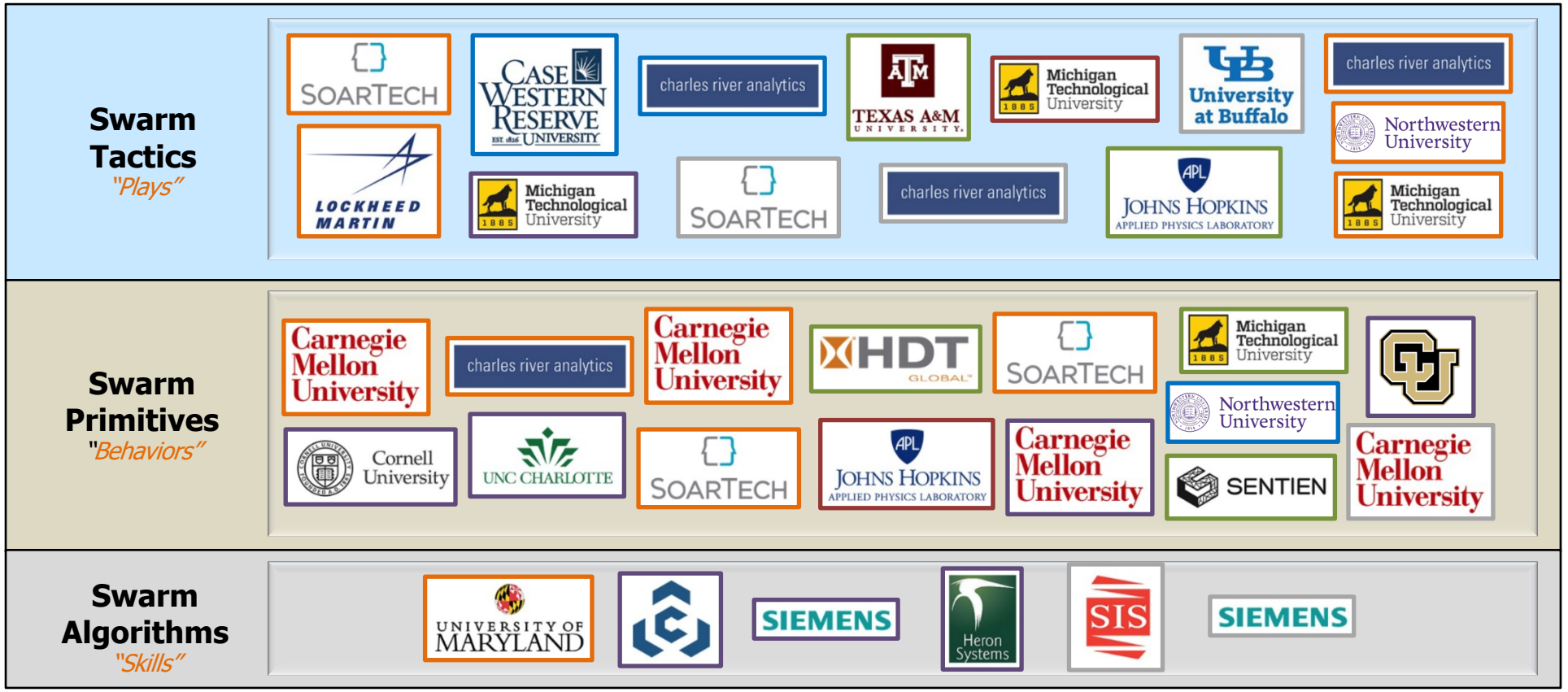
OFFSET relies on **composable** and **flexible swarm autonomy**
swarm tactics | *swarm primitives* | *swarm algorithms*

OFFSET Impact: Swarm Sprinter-exercised *design patterns* for how to contribute novel swarm tech through flexible architecture interfaces

Swarm Systems Architectures: **Layers of Swarm Autonomy**

TACTICAL TECHNOLOGY OFFICE

"Open architecture" means open to **diverse and flexible pathways** for integrating novel technologies



35 Swarm Sprinter efforts across five Swarm Sprints

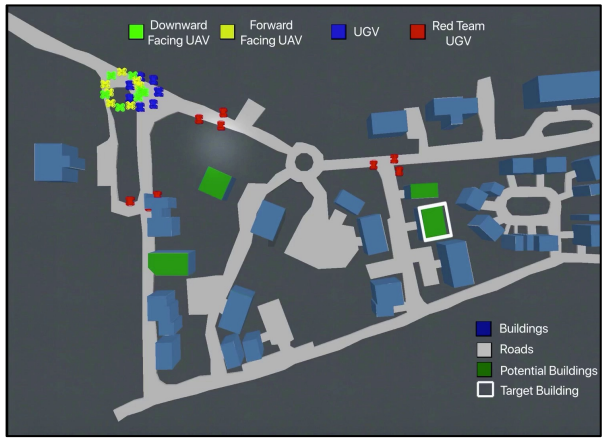
Swarm Sprint Thrust Areas:
Swarm Tactics Swarm Autonomy
Human-Swarm Teaming Virtual Environment
Physical Testbed Applications of AI

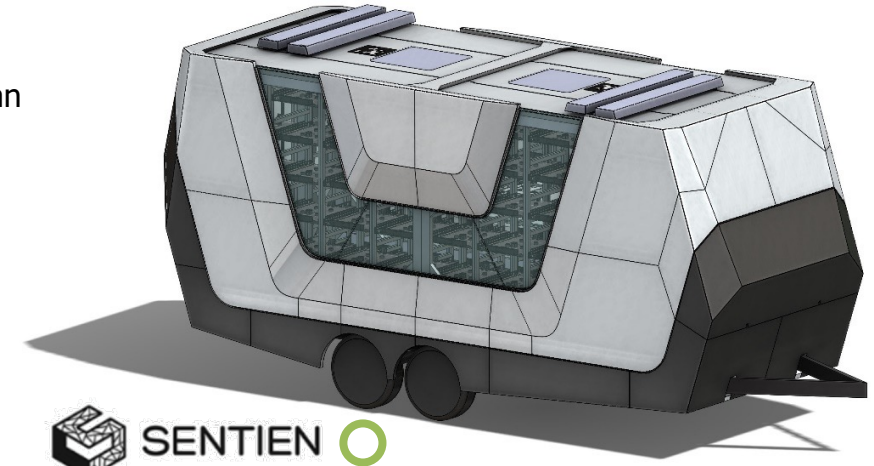
Swarm Sprinters: **Spotlights**

Swarm Sprint Thrust Areas:
Swarm Tactics | Swarm Autonomy | Human-Swarm Teaming
Virtual Environment | Physical Testbed | Applications of AI

University at Buffalo

ENHANCE: Evolving Neural Architectures with Human Augmented Novelty for Complex Environments





SENTIEN

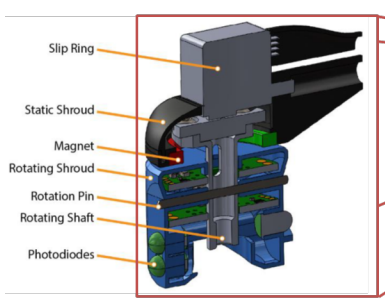
HiveXL: automated 80-drone launch, recovery, charging, and transport

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

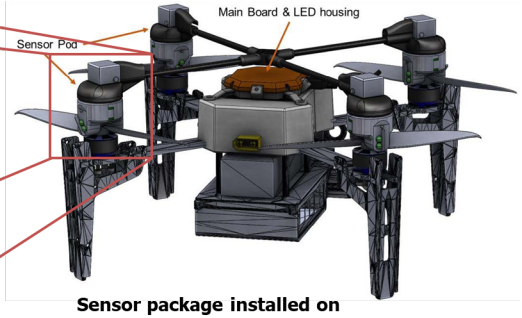
ACCIPITER: Aerobatic Control and Collaboration for Improved Performance In Tactical Evasion and Reconnaissance

HDT GLOBAL

Rotor Mounted Bearing+Elevation Sensor



CAD Rendering and cross section of sensor pod



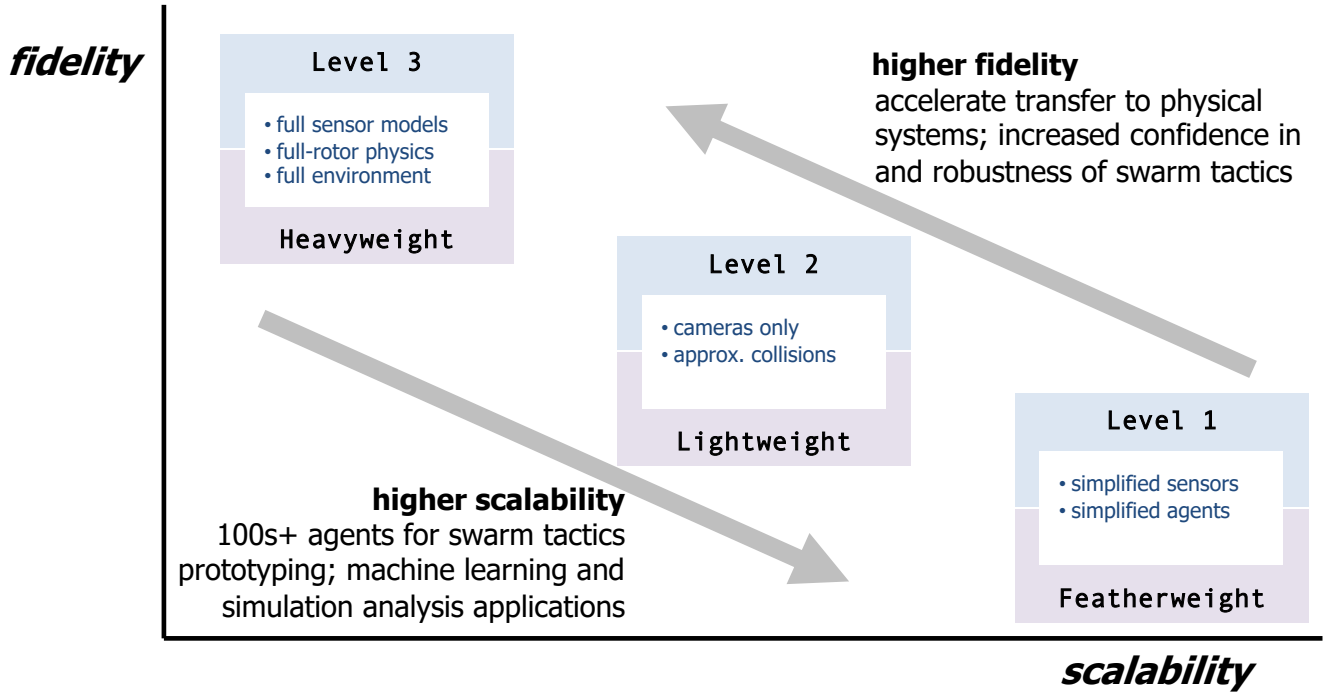
Sensor package installed on OFFSET testbed platform (IFO-S)

Swarm Sprint 1 | **Swarm Sprint 2** | **Swarm Sprint 3** | **Swarm Sprint 4** | **Swarm Sprint 5**

Swarm tactics-enabling **Scalable Swarm Simulators**

TACTICAL TECHNOLOGY OFFICE

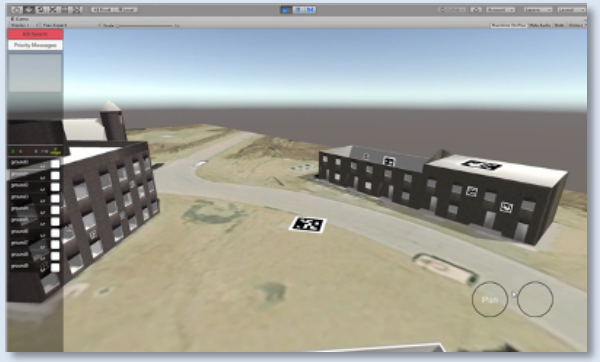
Swarm Tactics | Swarm Systems Architectures | Scalable Swarm Simulators | Modular Swarm Testbeds



higher fidelity
accelerate transfer to physical systems; increased confidence in and robustness of swarm tactics

higher scalability
100s+ agents for swarm tactics prototyping; machine learning and simulation analysis applications

NORTHROP GRUMMAN



OFFSET Virtual Environments

Raytheon BBN

OFFSET Impact: Two extensible virtual environments for integrated autonomous systems simulation + development + testing

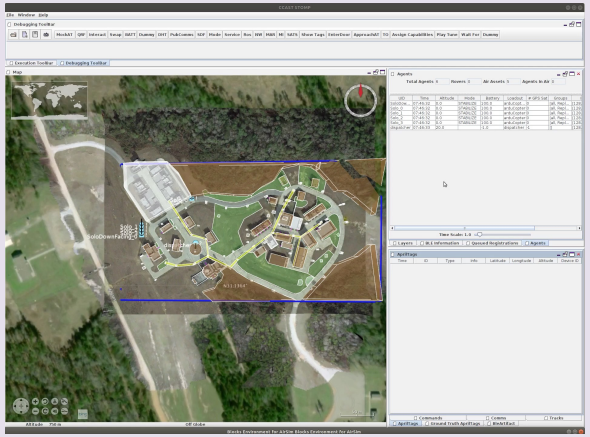
Scalable Swarm Simulators: **Spotlights**

Large-scale swarm mission scenario play

Temporal coverage sensor modeling

Multi-host swarm tactic execution

Variable faster-than-real-time simulation



Field test swarm mission rehearsal

Multi-robot environment interactions

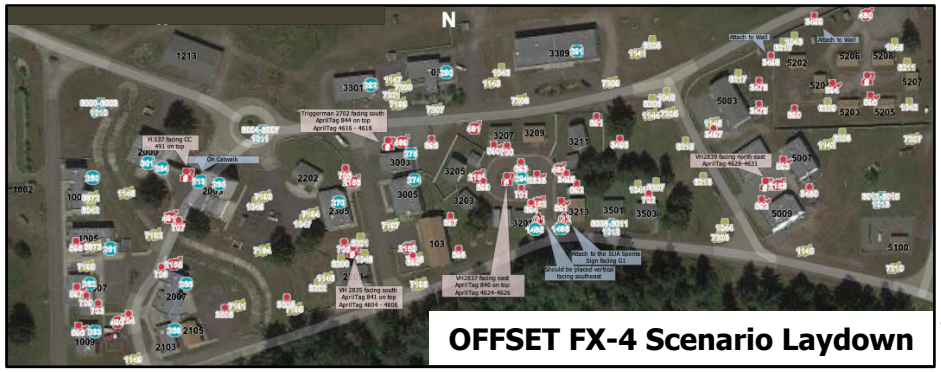
Swarm tactics-enabling **Modular Swarm Testbed**

Swarm Tactics	Swarm Systems Architectures	Scalable Swarm Simulators	Modular Swarm Testbeds

Modular Swarm Testbeds: **Agile Swarm Experimentation**

TACTICAL TECHNOLOGY OFFICE

1. Design scenario for offensive urban operations

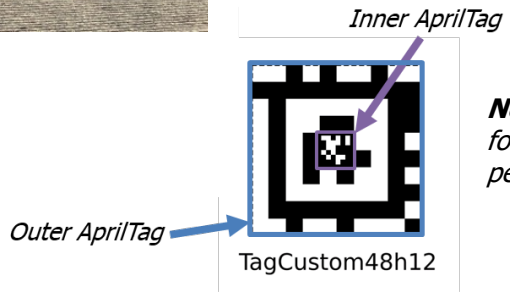


Joint Base Lewis-McChord "Leschi Town" CACTF

2. Rapidly instrument large-scale urban test sites

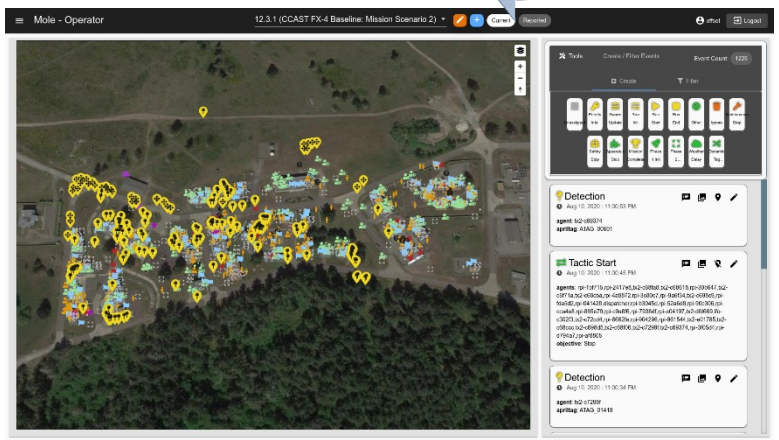
FX-4 Infrastructure Measures

- **5300+ meters** of Ethernet
- **600 meters** of optical fiber
- **811** Unique AprilTags
- **83** Raspberry Pi Nodes
- **26** network switches
- **14** USG team members



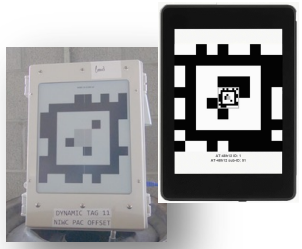
Nested AprilTags *for multi-scale perception*

3. Orchestrate and capture real-time assessments of "Swarm Under Test"



Screenshot of networked orchestration software frontend (a.k.a. Mole)

Dynamic AprilTags*: E-ink screens for evolving scenarios*



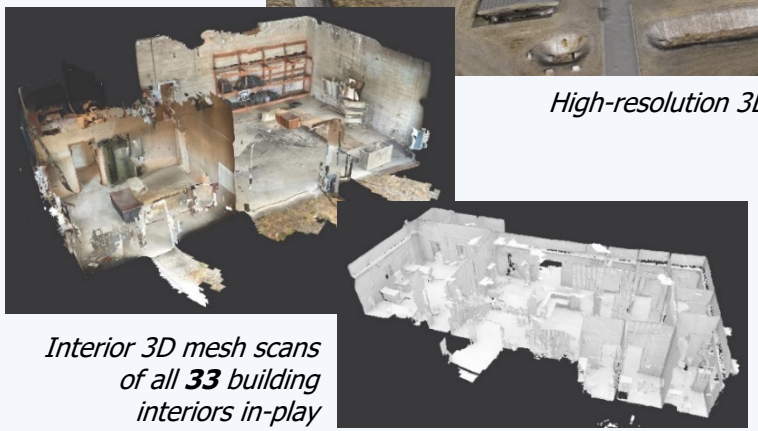
Program Schedule, by Vignette and Scope

Operational Context		Vignette 1	Vignette 2	Vignette 3		
	Representative Mission	Isolate an urban objective	Conduct an urban raid	Seize key urban terrain		
	Mission Duration	15-30 minutes	1-2 hours	4-6 hours		
	Area of Operations	Approx. 2 square city blocks	Approx. 4 square city blocks	Approx. 8 square city blocks		
	Swarm Size	50	100	250		
FX	**Experiment**	FX-1	FX-2	FX-3	FX-4	FX-5	FX-6
	Date	Oct 22-25, 2018	June 5-13, 2019	Dec 7-19, 2019	Aug 1-12, 2020	Jan 2021	Jun 27-Jul 14, 2021
	Location	 Camp Roberts	 Fort Benning	 Camp Shelby	 Joint Base Lewis-McChord	**Cancelled** Camp Shelby	 Joint Base Lewis-McChord

(Ongoing) OFFSET Lessons Learned

OFFSET Urban Scenario Reference Dataset

High-resolution 3D photogrammetric mesh



*Interior 3D mesh scans of all **33** building interiors in-play*

*Exterior building scan videos (by drone) for all **40** buildings in-play*

Scenario walkthrough videos (outdoor/indoor) of entire test range

What has OFFSET created?

- Library of collaborative autonomy software
- Swarm virtual environments as bridge to real-world
- Unique swarm datasets

What are (actionable) OFFSET lessons learned?

- Define point-of-departure swarm autonomy capabilities
- Seek applications needing high + fast "swarm power"

What comes next after OFFSET?

- Urban maneuver-capable platforms
  - **Still** need agile and adaptable robotic systems
- Swarm logistics enablers
  - On-the-move and/or federated swarm deployment
  - Swarm replenishment, recharge, and recovery technologies
- Counter swarm/autonomy

www.darpa.mil

OFFSET@darpa.mil

www.darpa.mil/work-with-us/offensive-swarm-enabled-tactics

Physical Testbed: **Northrop Grumman Swarm Agents**

TACTICAL TECHNOLOGY OFFICE

Uvify IFO-S

Specification Overview

- PX4 Flight Stack
- NVIDIA Jetson Nano
- Intel RealSense D435
- GPS with Helical Antenna
- CSI/MIPI Camera
- TFMini LiDAR
- Rajant DX2

Capabilities

- Collision Avoidance
  - Static and dynamic
- Scanning Tactics
- Waypoint Navigation
  - Follow Route Tactic
  - POI
  - Hover/Loiter
- Camera Feed & AprilTag Detection – forward & downward
- Depth sensing via RealSense and TFMini LIDAR

AION R1 w. TX2 (ATX)

Specification Overview

- ArduRover Flight Stack
- NVIDIA TX2
- Intel RealSense D435/D415
- Here2 GPS
- Embedded Wheel Encoder
- RPLiDAR
- Rajant ES1

Capabilities

- Collision Avoidance
  - Static and dynamic
- Scanning Tactics
  - Area Scan
- Waypoint Navigation
- Depth sensing via RealSense and RPLiDAR
- Indoor Capabilities
  - Building Breaching Tactic
  - SLAM
  - GPS-denied capable
- Camera Feed & AprilTag Detection

AION VTOL

Specification Overview

- ArduPilot Flight Stack
- NVIDIA Jetson Nano
- Here2 GPS
- Downward CSI/MIPI Camera
- Rajant Dual Band mini radio

Capabilities

- Overhead Scan and SA
- Waypoint Navigation
  - Follow Route Tactic
  - POI
  - Hover/Loiter
- Downward Camera Feed & AprilTag Detection

Physical Testbed: **Raytheon BBN Swarm Agents (1of2)**

3DR Solo

Specification Overview

- Electro Optical camera – Pi Camera v2
- FCC-approved radios
- Custom expansion board
- Raspberry Pi 3B+ co-processor
- Raspberry Pi Cam (down EO sensor
- USB LTE modem

Capabilities

- Surveil Building
  - Watch points
  - Path planning
  - Identify points of ingress/interest
- Surveil Area
- AprilTag Detection – forward or downward
- Flock
- Rendezvous
- Battery Swap

AION R1 w. TX2 (ATX)

Specification Overview

- ArduRover Control Software
- Nvidia Jetson TX2 co-processor
- Intel RealSense D435 (forward EO sensor)
- Backward-facing webcam
- 2D spinning lidar
- USB LTE modem

Capabilities

- Explore Building
  - Enter building
- Cordon Area
  - Distribute in circle
- Cordon Building
- Depth sensing via RPLiDAR
- Join Quick Reaction Force
- AprilTag Detection
- Rendezvous

Uvify IFO-S

Specification Overview

- PX4 Flight Control Software
- Nvidia Jetson Nano
- Intel RealSense D435 (forward EO sensor)
- Raspberry Pi Cam (downfacing EO sensor)
- USB LTE modem

Capabilities

- Surveil Building
  - Watch points
  - Path planning
  - Identify points of ingress/interest
- Surveil Area
- Flock
- Move to target point
- Rendezvous
- Maintain Proximity
- Depth sensing via RealSense

Physical Testbed: **Raytheon BBN Swarm Agents (1of2)**

TACTICAL TECHNOLOGY OFFICE

Modal AI VOXL m500

Specification Overview

- VOXL Flight Deck with PX4
- GPS/Compass
- PWM breakout board
- Stereo image sensor
- Tracking image sensor
- 4K image sensor

Capabilities

- Surveil Building
  - Watch points
  - Path planning
  - Identify points of ingress/interest
- Surveil Area
- AprilTag Detection – forward or downward
- Flock
- Rendezvous
- Battery Swap

mRo Nano Talon EVO

Specification Overview

- ArduRover Control Software
- Nvidia Jetson TX2 co-processor
- Intel RealSense D435 (forward EO sensor)
- Backward-facing webcam
- 2D spinning lidar
- USB LTE modem

Capabilities

- Combat Air Patrol
- Surveil Building
  - Watch points
  - Path planning
  - Identify points of ingress/interest
- Explore
- AprilTag Detection

JHU Custom Fixed Wings

Specification Overview

- mRo Control Zero F7
- Intel NUC
- Ardupilot/ACCIPITER
- Basler Dart (EO Camera)
- RFD900U telemetry radio

Capabilities

- Multi-Agent Fixed-Wing Building Scan
- Multi-Agent Fixed-Wing Aerobatic Decoy