Autonomous Platforms in Persistent Littoral Undersea Surveillance: Scientific and Systems Engineering Challenges

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**AT A GLANCE**

**R&D Program**

- Ocean Acoustics – MCM, ASW, Acoustical Oceanography
- Sonars – Imaging, Mine, Ship
- Submarine Acoustic Systems – ACINT
- Arctic/Polar Science – Global Climate Change, SHEBA, SEARCH, SUBICEX
- Ocean Physics – Turbulent Mixing, Electromagnetic Sensing
- Satellite Remote Sensing - air/sea fluxes, aerosols, sea surface height, waves
- Medical Ultrasound - Acoustic Hemostasis, Imaging, High Intensity Focused Ultrasound, Lithotripsy

**R&D Budget**

- 46% Dev
- 54% Basic
- ONR 6.1
- NSF
- NASA
- NIH

- $43M FY04
- 62% Navy Derived

**Personnel**

- **Admin** 57
- **Ph.D.** 83
- **S&E's** 90
- **Tech Support** 10
- **Students** 48

- **300 Total**
Navy ASW CONOPs

- Near-term, leverage
  - Data collection/sharing
  - Collaborative real-time planning
  - Reachback support
  - Precision engagement

- Smart planning & precision execution in
  Hold at Risk and Secure Friendly Maneuver Area operations

- Far term, shift from “platform-intensive” to
  “sensor-rich” operations
  - Networks of sensors coupled to standoff weapons

Themes

Persistence
Pervasive Awareness

Speed & Operational Agility
Technological Agility
Background

- The Navy’s Hold-at-Risk ASW strategy requires operation in choke points, port areas, and open ocean areas.
  - Environments are harsh and changing
  - Required areas of coverage are large
  - Time frames of operational effectiveness are long (weeks to months)
  - Desired effectiveness is high with low risk to blue forces

- Current systems do not support this ASW strategy.
Undersea Persistent Surveillance

Provide accurate, persistent submarine surveillance in complex environments

Reduce the “detect-to-engage” timeline
Undersea Gliders for Navy Applications

- APL-UW Investigators:
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- Office of Naval Research
  - Tom Swean (sweant@onr.navy.mil)
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- Program sponsors: ONR, DARPA

- ONR RIMPAC04
- ONR TASWEX04
- Future Glider Technologies
  - ONR Xray flying wing glider
  - FutureGlider concept
- Role in Persistent Littoral Undersea Surveillance
RIMPAC June-July 2004
Acoustic effects of internal waves

Profiles 139-145

40-60m oscillations of thermocline

CASS Transmission Loss

Direct path

Target – 300m
Source/receiver – 7.6m

Bottom-bounce

Conv-Zone
TASWEX04
14 – 22 October SG017 Track

**SUCCESSES:**
- Research glider borrowed for Navy exercise
- JJVV & KKYY message auto-generation
- 100% data reliability despite typhoon
- Mixed layer depth pegged (70m deeper than model)
- Tide-induced internal wave effects Evaluated (and made a difference!)
- Seamless rendezvous with Bowditch

**CHALLENGES:**
- Glider data rate vs. model capabilities
Internal Waves on ECS Shelf
Profiles 95-114, 19 October ‘04

30-45m oscillations of thermocline
CASS Transmission Loss

Source = 7.6m

Receiver – surface

Receiver – 75m

Receiver – bottom

Sound Speed Profiles

Profiles 95-114

10dB at 5km

15dB at 10km

10dB at 5km

20dB at 15km

Target Depth = 0 M

Target Depth = 75 M

Target Depth = 99999 M
SG022 Double Bow-Tie Pattern (Dabob Bay)
SG022 Station-keeping (Dabob Bay)
Cumulative UW Glider Results

- 22 gliders built, 15 ordered
- 4 flying today: Hawaii, Washington Coast (1), Labrador Sea** (2)
- 8 Four-, 7 Five-, and 6 Six-month missions
  - April 05, SG022 & 023 finished 6+ month, ~600 dive, 3000+ km voyages - new record
- 2500 glider-days of operation
  (~75% of total by all gliders)
- Over 32,500 kilometers traveled through water
- 9 lost at sea, 1 recovered (SG004)
There is a Broad Glider Effort
A Snapshot of the Overall Glider Program
Global Deployment, (very) Remote Control
Undersea Glider Milestones

1995
- Glider System Study
- Adaptive Sampling Experiments (Slocum, NJ)
- Webb Slocum Production
- AOSN Paper (Oceanography)

2001
- AOSN Glider Development (Slocum, Seaglider, Spray)
- AOSN-I
- AOSN Special Issue (IEEE/JOE)

2003
- AOSN-II
- Glider System Study
- AOSN-II Adaptive Sampling Experiments (Slocum, Spray; Monterey Bay)
- Deep Convection Experiments (Seaglider, Lab Sea)
- Coastal Current Experiments (Seaglider; CA, WA, AK Coasts)
- Bluefin Licenses Spray

2004
- NAVO WestPac Demo (Slocum, Philippine Sea)
- RIMPAC-04 Demo (Seaglider, Hawaii)
- TASWEX-04 Demo (Seaglider, East China Sea)

2005
- NAVO Demo (Spray, FL)
- CNMOC/NAVO Operational Gliders TTI

2006
- Advanced Glider Research

Color Key
- S&T Experimentation
- Publication
- Operational Experimentation
- Operational Transition
- Commercialization

TBC, 2004
ONR X-RAY Flying Wing Glider

- Funded by Office of Naval Research (Dr. Tom Swean)
- Collaboration with Marine Physical Laboratory, Scripps Institute of Oceanography (San Diego, CA)
- High efficiency blended wing/body concept
- Designed to operate in efficient Reynolds number regime
- High lift to drag ratio will permit long duration energy efficient operations
- Acoustic and EM sensors
- Navy interested in potential for long range, autonomous surveillance
Xray Glide Polar

Cruise speed: 5 kts
Wing span: 20 feet
L/D: 19.5
FutureGlider Concept

• Primary mission: Surveillance of far-forward, littoral areas
• Design goals
  – Low cost
  – Autonomous operations
  – Persistence
  – Stealth
  – Ease of launch/recovery (2 people, variety of platforms)
  – Over the horizon launch with rapid transit to operating area
  – Recoverable and reusable
FutureGlider: Booster/Glider
FutureGlider: Conformal Sensors
FutureGlider: Booster jettison
Multi-Institution Effort in Persistent Littoral Undersea Surveillance Network (PLUSNet)
PLUSNet Concept

- Unmanned Systems Approach to Distributed Sensor ASW Surveillance

- Use mature (enough) technologies to field a scalable system demonstration

- Environmentally and tactically adaptive, cable-free sensor network
  - Fixed sensor nodes
  - **Mobile** sensor nodes
    - Assess environment
    - Redeploy (adapt)
    - Directed as sensor "wolfpacks"
  - Autonomous processing
  - Nested communication structure
Defining Parameters

- Clandestine undersea surveillance for submarines in far-forward and/or contested waters of order $10^3 - 10^4$ square nautical miles, shallow and deep water, operating for months.

- Innovative technologies integrated into scalable systems.

- Systems at all scales that are deployable, affordable and effective for large area, persistent coverage.
Directional Sensitivity

Mobility, Persistence

Autonomy

Adaptability, Feedback

Cornerstones

Acoustic Vector Sensor Arrays
E-Field sensors

Acoustic and Ocean Models
Targeted Observations

Autonomous Underwater Vehicles
Acoustic modems

Autonomous DCL
Automated Tracking
Stages of Undersea Persistent Surveillance

Stage I
Adaptive Search
Maximize PD, Minimize PFA

Stage II
Adaptive DCL
Maximize Gain

Stage III
Adaptive Convergence
Maximize Intersect Probability

Ocean Nowcast / Forecast

Noise Statistics

Signal Cues

Target Glimpse

Target Lock

Neutralization
Environmental Assessment

- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize network cluster topology and fixed/mobile mix
Sensor Deployment

- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges..., finalize network cluster topology and fixed/mobile mix

- Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV’s enter semi-dormant state as temporarily fixed or drifting nodes
Reconfigure Network

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- Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV’s enter semi-dormant state as temporarily fixed or drifting nodes

- Reconfigure mobile sensors nodes based on current tactical or environmental situation
Target Detection

- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize cluster topology and fixed/mobile mix

- Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV’s enter semi-dormant state as temporarily fixed or drifting nodes

- Reconfigure mobile sensors nodes based on current tactical or environmental situation

- Target initial detection communicated to network (ACOMMS or RF)
Wolfpack Response

- Environmental acoustic assessment – e.g., bathymetry, SVP, detection ranges…, finalize cluster topology and fixed/mobile mix

- Fixed and mobile sensor nodes launched from SSGN, LCS, USV and deploy for optimum surveillance coverage. AUV’s enter semi-dormant state as temporarily fixed or drifting nodes

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- Target initial detection communicated to network (ACOMMS or RF)

- Mobile asset "wolfpack" responds to detection to achieve weapon firing criteria DCL
Undersea Surveillance Seascape

ONR 31/32/33/35/NRL Team Efforts

Adaptive Sampling and Prediction Using Mobile Sensing Networks (ASAP)

Autonomous Wide Aperture Cluster for Surveillance (AWACS)

Undersea Persistent Surveillance (UPS)

Undersea Persistent Glider Patrol / Intervention (Sea Sentry)

Undersea Bottom-stationed Network Interdiction (CAATS)

Persistent Ocean Surveillance (POS)

Littoral Anti-Submarine Warfare (FNC)

Autonomous Operations (FNC)

Persistent Littoral Undersea Surveillance (PLUS) (INP)

Fixed surface nodes

Component technologies

Fixed bottom nodes

Adaptive path planning

Prototype system integration and testing

Trip wires, track and trail

Target interdiction with mobile sensors

Targeted observations

Cooperative behavior

Adaptive gain

Clutter/Noise suppression

Four dimensional target discrimination

Mobile sensor environmental adaptation

ONR

DARPA

NAVSEA

Italics: potential new program

Congressional Plus-ups

ONR/DARPA/NAVSEA SBIR efforts

PMS-403

PEO-LMW

Submarine T&T

Task Force ASW

PEO-IWS

Theater ASW BAA
Critical Mass Team Experience
Field Efforts

**FY05**
- Collaborative Vehicles (SACLANT)
- Liberdade / X-Ray

**FY06**
- ASAP MURI (Monterey Bay)
- SeaHorse / LCCA

**FY07**
- Final Demo ONR Acoustic Observatory – Systems Level Concept Demonstration (Ft. Lauderdale)
PLUSNet Steps Toward Future Systems Capabilities –

- Elimination of bottom cable enables rapid deployment and survivability of cueing system.
- Persistence through power saving sensing technology and intelligent AUV behaviors.
- Advanced communications technologies enable both remote control and autonomous operations.
- Autonomous, adaptive network control exploiting changes in tactical and environmental picture for improved DCL.
- Use of coordinated AUV wolfpack operation reduces need to send tactical platforms in harm’s way and increases likelihood of successful target prosecution.

A “System of Systems” Systems Engineering Approach
### Embedded Research and Systems Engineering Issues

- Shallow water environment
  - Acoustics
  - Oceanography
  - Modeling and Inversion
  - Performance prediction under uncertainty
- Environmental Adaptivity
  - Signal processing (including multiplatform, MFP, invariants)
  - Autonomous signal processing
  - Sensing and Network control
  - Acomms/channel capacity
  - Data fusion-Heterogeneous sensor data assimilation
- Sensor technology
  - Vector sensors
  - E-field sensors
  - Synthetic apertures
- AUV Technology
  - Intelligent behavior
  - Collaborative behavior
  - Quieting
  - Sensor integration
  - Power
  - Navigation approaches
  - Integrated sensing and control
Summary

- Distributed sensor field of networked unmanned fixed and mobile sensors for ASW surveillance

- Tactical and oceanographic environments sensed in real time, with sensor network reconfigured to improve target DCL

- Substantive research and systems engineering issues in this highly complex systems-of-systems effort must be addressed.