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Collaborative AUVs for Survey and Search Missions – Update

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Outline of Presentation

- Introduction
- Autonomy for Marine Robots
- Principal Hardware
- Recent Autonomy Activities
- Current Work
- Concluding Remarks

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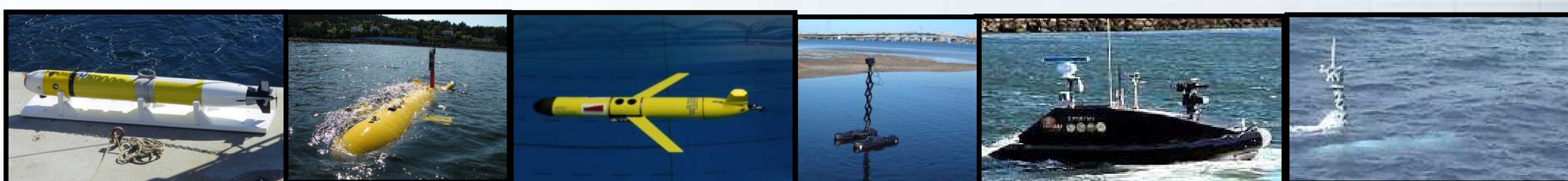
Naval Motivation

From the USN 2007 Unmanned Surface Vessel Master Plan:

"*The nation is faced, currently and for the foreseeable future, with a multitude of military challenges that are unlike any seen in recent history. The enemy is diverse, not easily recognizable, and operates in atypical ways. These asymmetric threats have the ability to do great harm to our maritime forces and infrastructure, and the Navy must have the ability to address and defeat them in support of national Defense objectives, while continuing to execute its traditional roles*"

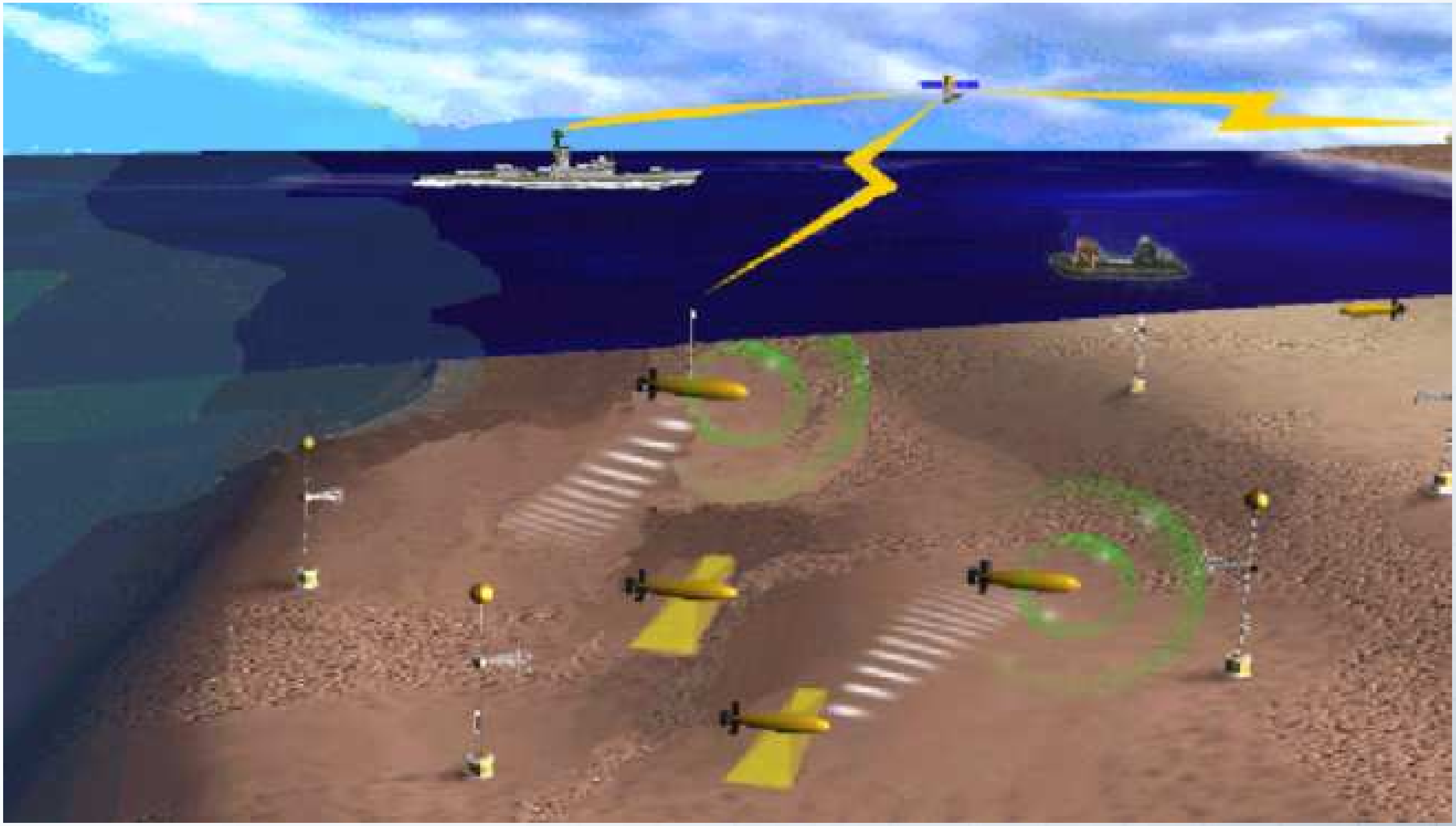
Naval Motivation

- unmanned systems have the potential and in some cases, demonstrated ability, to
  - reduce risk to manned forces
  - provide force multiplication necessary to complete complex missions
  - perform tasks that manned vehicles cannot (e.g. under ice)
  - economical (in most cases)
- in general, use robots / unmanned systems if the job is *dull*, *dirty*, or *dangerous*
- range of unmanned systems deployed or under consideration by the Navy is broad with airborne, sea surface, underwater, and ground applications
- emphasis today is on unmanned marine robots that work on or under the water surface



Objective

- long term vision for collaborative robots



Objective
Potential Impact Collaborative Robots

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- collaborative robotics is an integral part of the Future Combat System (FCS)
  - requires collaboration and intelligent command and control of heterogeneous robots of variety levels of autonomy and be able to act together in a cohesive manner
  - collaboration is a framework for robot teamwork and teamwork is required for optimal performance and impact demanded of FCS and forces
- vision is that robots under the water communicate with a robot that has in air communications which can facilitate collaboration between above water robots and assets

Autonomous Maritime Platform Military Missions

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- The U.S. Navy's 2004 UUV Master Plan identified 40 distinct UUV missions, prioritized categories are:
  1. intelligence, surveillance, and reconnaissance (ISR)
  2. mine Countermeasures (MCM)
  3. anti-submarine warfare (ASW)
  4. oceanographic data collection
  5. inspection / identification
  6. communications / navigation network node (CN3)
  7. payload delivery
  8. information operations
  9. time critical strike (TCS)
- DRDC has historical activity in 2 and 4 and starting up work in 1, and 3

Autonomy for Marine Robots - Onboard Autonomy Required

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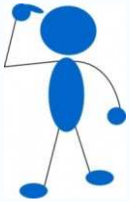

- intelligent on-board autonomy allows robots to operate long periods without operator intervention
  - have to address autonomy issues to achieve this
- require that the robot have some autonomy for decision-making or problem-solving to address unexpected vehicle or mission developments – this is paramount on long missions as the mission and robot will change
  - the behaviour-based subsumption control architecture that has been on robots is not sufficient;
  - relies on operator scripted missions a priori
  - no flexibility to adapt a mission in-situ based on changes in the ocean environment (as detected through on-board sensors or the robot itself
- mission autonomy – ability to adapt a mission to unanticipated conditions in the environment or in-situ intelligence exploited to better perform the mission, for e.g. in-situ environment measurements for better sonar images
- robot autonomy – increase robot fault tolerance so it adapts to unanticipated self events, for. e.g. a control fin jammed at an arbitrary deflection

On-Board Autonomy Required

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- autonomy ___especially___ important for marine robots given the environment (poor coms due to low bandwidth and high attenuation) as it increases TRL to 8 or better and can thus be deployed for naval operations
- minehunting, ASW, and under-ice autonomy of interest

Onboard Autonomy Framework

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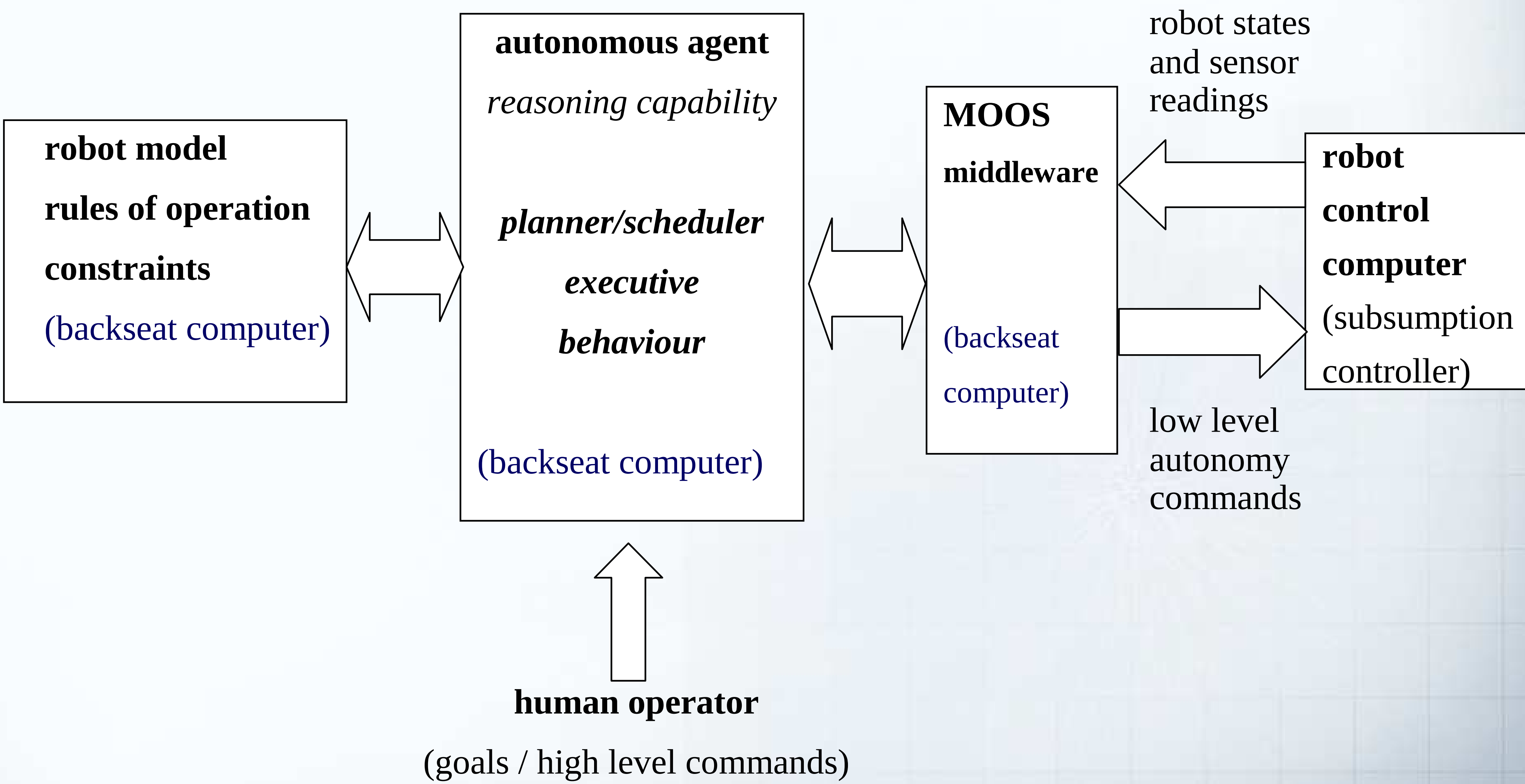

Onboard Autonomy Framework

- *planner / scheduler*: performs reasoning about the goals, breaks down goals into sub goals and generates flexible hierarchical plans
  - allows current plans to be interrupted for more urgent vehicle or mission business
  - goals can be abandoned and missions aborted via operator
  - if environmental conditions are such that expected mission goals are not achievable then the planner / scheduler drops goals based on a criteria (e.g. energy)
    - for e.g., ‘insufficient energy to survey far north section given currents now – drop this area from mission goals’
- *executive*: implements mission plans generated by the planner and tracks the states of their execution
- *behaviour*: stateless reactive behaviours

On-Board Automatic Target Recognition of Mines/IEDs

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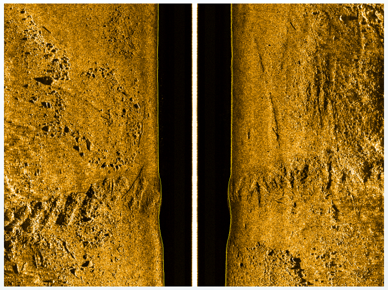
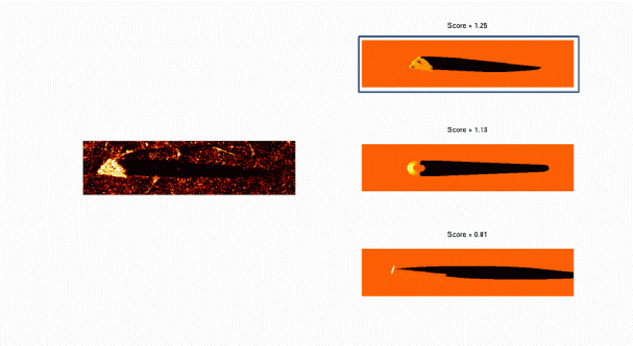
AUVs outfitted with side scan sonars with the following capabilities:

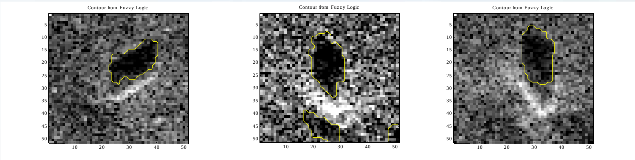


- single aspect (template matching)
- multi-aspect fusion
- change detection for images in areas of high clutter
- co-registration of images
- development of algorithms that intelligently task the AUV (POMDP, A*, inference, evolutionary algorithms, etc.)

Automatic Target Recognition

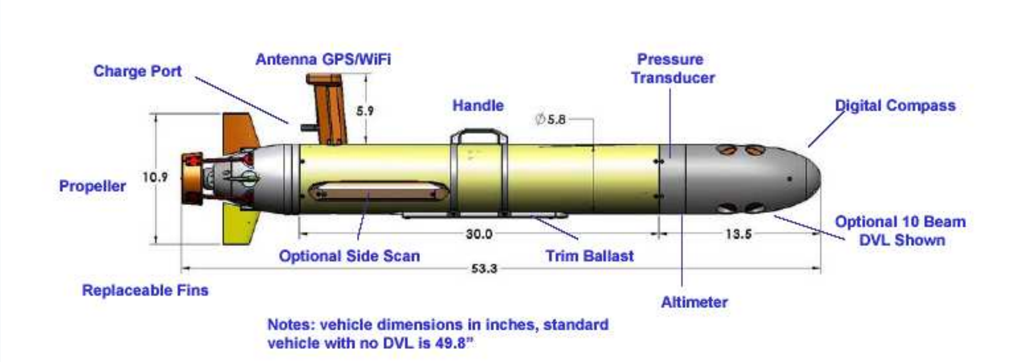
- designed to be flexible
  - a desktop based research system,
  - also a lightweight ATR system for use on low powered systems
- uses a component based architecture for easy integration of new processing components
  - data readers (XTF, 5kd, sdf, mst)
  - detection algorithms (Matched filter, Z-test, Speckle)
  - fusion algorithms
  - classifier (template based)
- output can either be a MAT file with targets, telemetry and mugshots, or a series of flat files with the same data.





IVER2 AUV – *Ludwig*

- VectorMap software for basic mission planning that interfaces to geo-referenced charts
- WiFi coms to command laptop (now a ruggedized Tuf Book)
- 6 beam Doppler Velocity Log with ADCP
- Imagenex Sportscan Side Scan Sonar (330 / 500 MHz)
- B/W and color low light camera and video camera (LED lights)
- extended hull section
- DGPS on surface
- WHOI Micro-modem
- X86 processor with 80 GB drive
- 600 Whrs energy, 1 – 4 knots speed; 2 knots endurance > 8 hours



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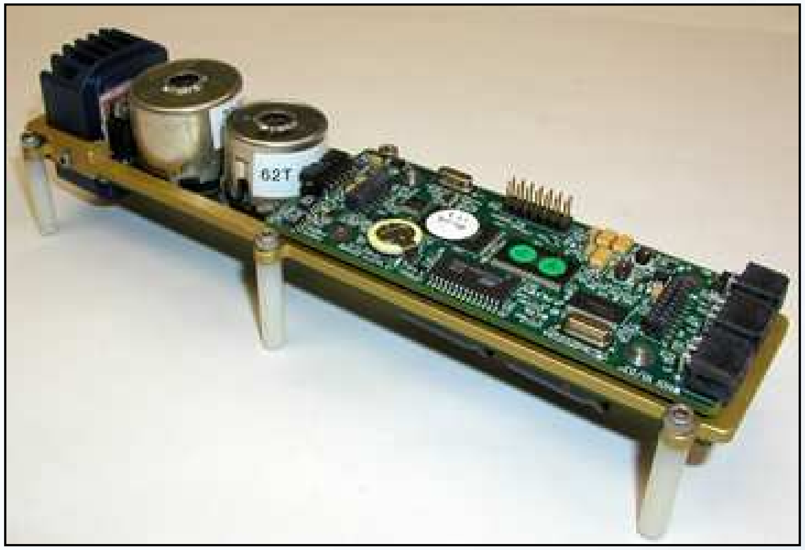
Acoustic Communications

- WHOI micromodem in the IVER2 for acoustic communications
- small footprint, low power (< 50 W), baud rates of 80 – 5400 bps
- topside deck (deck box) unit and towfish used to communicate with the IVER2 while underway

deckbox **dem**odulator



micro-**mod**em in IVER2

10 kHz towfish

2010 Summer of Autonomy - Activities

- visiting scientist, Dr. Donald Eickstedt (later joined by Scott Sideleau) from the Naval Undersea Warfare Center seconded at DRDC Atlantic to work with the Mine and Harbour Defence Group
- NUWC to lead and assist with implementation of autonomy on the new NRC / DRDC IVER2 – *Ludwig*
  - DRDC team: Mae Seto, Vince Myers, Warren Connors, Sean Spears, Owen Shuttleworth, Jonathan Hudson
- weekly / biweekly local in-water trials to test and validate, venues used:
  - DRDC Acoustic Calibration Barge – 30 x 17 m (out for the day)
    - barge is over 50 m of water with mud covered sea bed (sonar testing)
    - tools, marine equipment, radios, lab space, computer labs, phone lines, large moon pool with carriage, kitchen, washroom, and heated
    - RHIB support for launch / recovery, chase boat, etc.
    - on-site technicians

2010 Summer of Autonomy - Activities

- Fleet Diving Unit (Atlantic) hangar and jetty at Canadian Forces Base Shearwater (couple of hours at a time)
    - 15 m depth water – variable seabed
    - in-water RHIB (and driver) support for launch / recovery, chase boat, etc.
    - use of divers and ROVs if needed
    - use of barges off several jetties
    - access to FDU(A) hangar

- at the end (Sept 17th – 19th) collaborative AUV trial at Acoustic Calibration Barge to demonstrate successfully implemented capabilities

Ludwig, NUWC, and DRDC at Acoustic Calibration Barge

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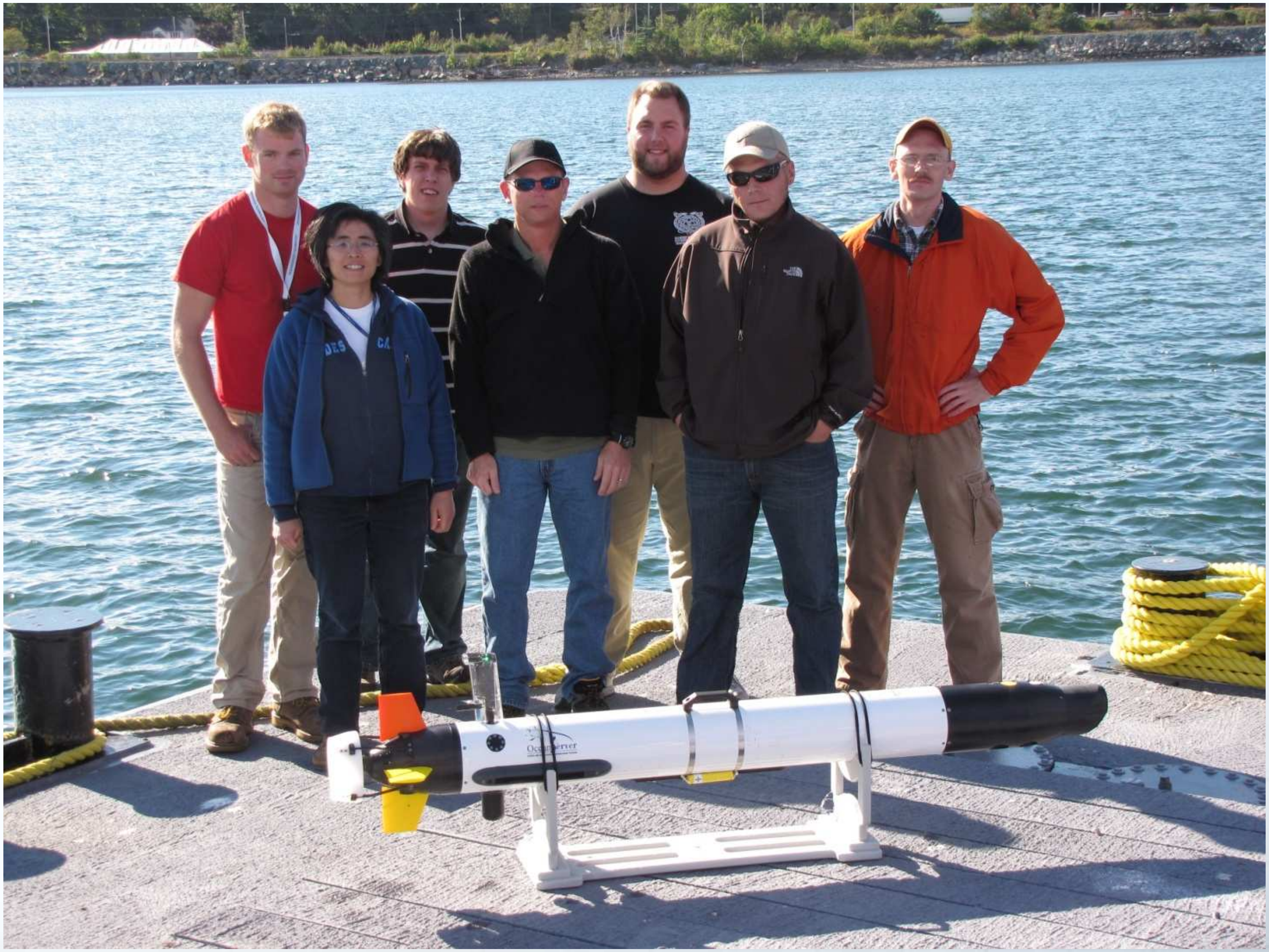
- at conclusion of collaborative CAN / USA trial (Sept 18, 2010)



2010 Summer of Autonomy - Capabilities Developed

- payload autonomy on the NRC / DRDC IVER2
  – install and test MOOS-IvP autonomy software on the payload / back seat driver computer
  – successfully demonstrated through in-water trial

- acoustic communications on *Ludwig*
  – installed MOOS software (*pAcomshandler*) implementing acoustic coms
  – successful communications between *Ludwig* and topside modem unit demonstrated during several in-water trials
  – able to track underwater position of *Ludwig* via acoustic updates
  – ability to abort a mission via an acoustic message
  – ability to start payload autonomy missions via acoustic coms

2010 Summer of Autonomy - Capabilities Developed

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- adaptive collaborative AUV mission
  - successfully implemented and demonstrated in-water between *Ludwig* and a vehicle simulation running on topside computer
  - goal was for two vehicles to orbit a target location and for the vehicles to establish and maintain a specific angle (aspect) between them with respect to the target
    - multi-aspect target sensing application
    - demonstrates advanced capabilities of NRC / DRDC's autonomy architecture on-board *Ludwig*

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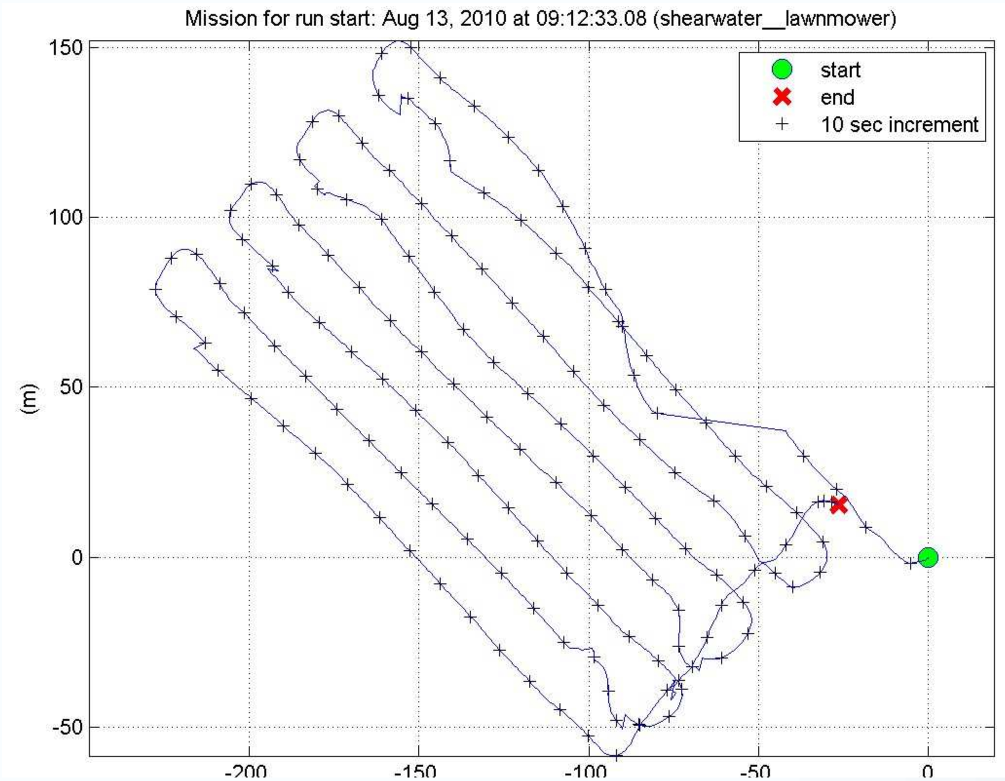
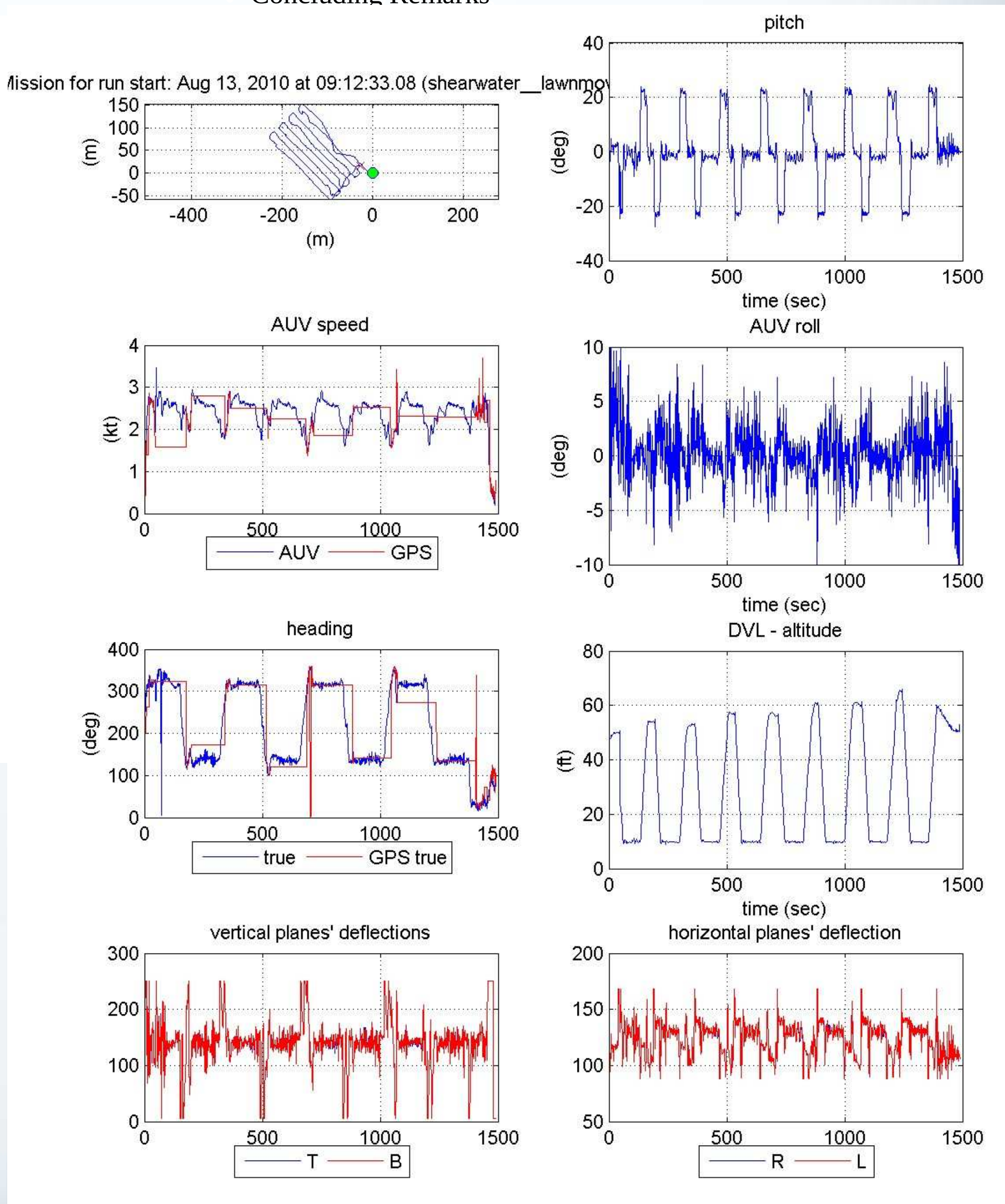
Sample Missions





- mission at Fleet Diving Unit

Current Work

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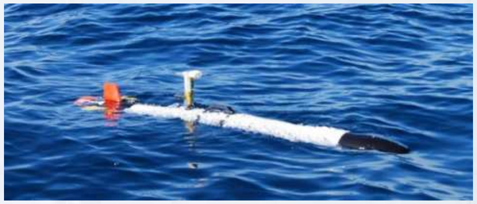
- mine warfare autonomy
  - implement a MOOS module that uses a partially observable Markov decision process (POMDP) for doing automated multi-aspect target recognition with side-scan sonar (Myers)
  - implementing MOOs module to test the use of inference in collaborative AUV missions when the acoustic coms is sparse or non-existent (Seto)
  - waiting for in-water tests



- sonar / automatic target recognition tools integration
  - DRDC automated target recognition modules successfully ported to MOOS
  - working on side scan sonar (Imagenex) integration with the payload computer – delayed by delivery of a connector

Current Work
New Hardware

Ludwig

- IMU being purchased and MOOS code developed to integrate it
- 600 MHz radio being purchase
- acoustic pinger and emergency float

Wolfgang

- scheduled for early Dec 2010 delivery)
- mostly same features as *Ludwig* except no cameras or Imagenex side scan sonar
- MarineSonics Side Scan Sonar (800 MHz / 1.5 GHz)
- 600 MHz radio

Improved Underway Navigation

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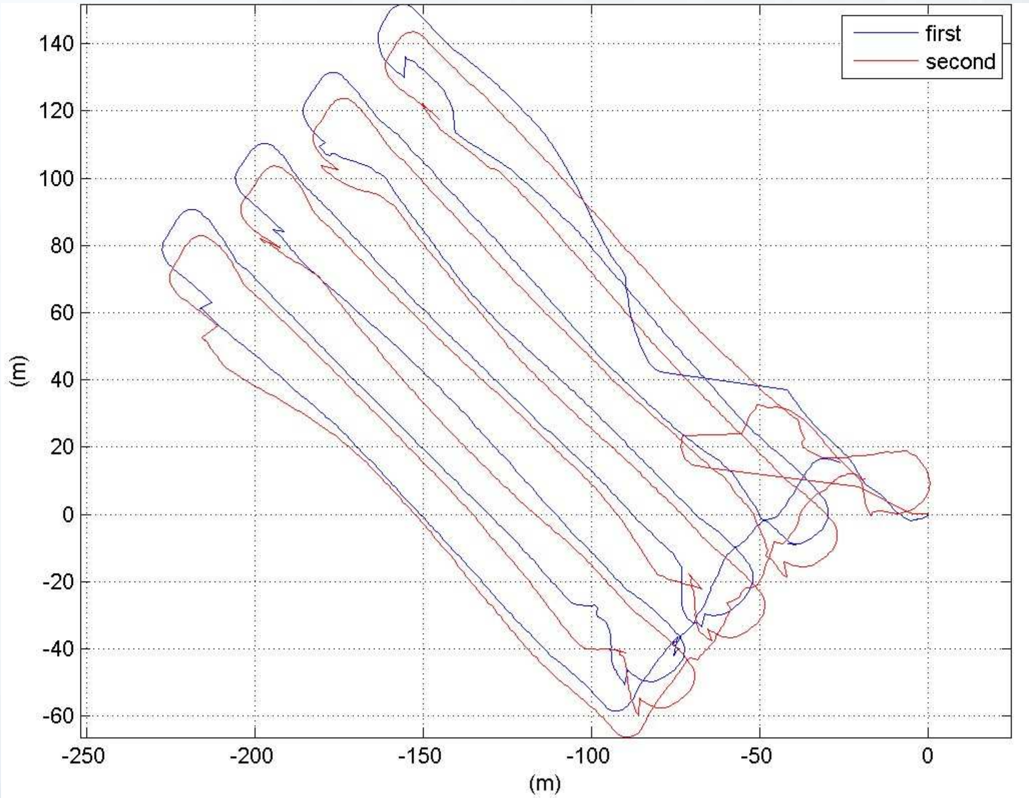
- IMU needed to improve navigation – onboard magnetic compass is affected in the presence of other ships
- IMU almost sourced; work underway to integrate into MOOS
- generally interested in improved underway navigation through a fusion of sensors
  - comparison between 2 identical missions using dead-reckoning;
  - proximity of large ship changed between 2 missions



Concluding Remarks

- level of intelligent autonomy on DRDC AUVs increased dramatically as a result of work over the last 1.5 years
  - use of MOOS-IvP as the middleware
  - capability of controlling a mission by directly tasking the backseat computer while AUVs are in the water
  - ability to collaborate between AUVS
- successful collaborative AUV trial between DRDC and NUWC
- hardware upgrades underway for first IVER2 and procurement of 2nd IVER2 is well underway
- work underway for mission autonomy that allows in-situ decision-making and mission-planning on-board the AUV

Questions?

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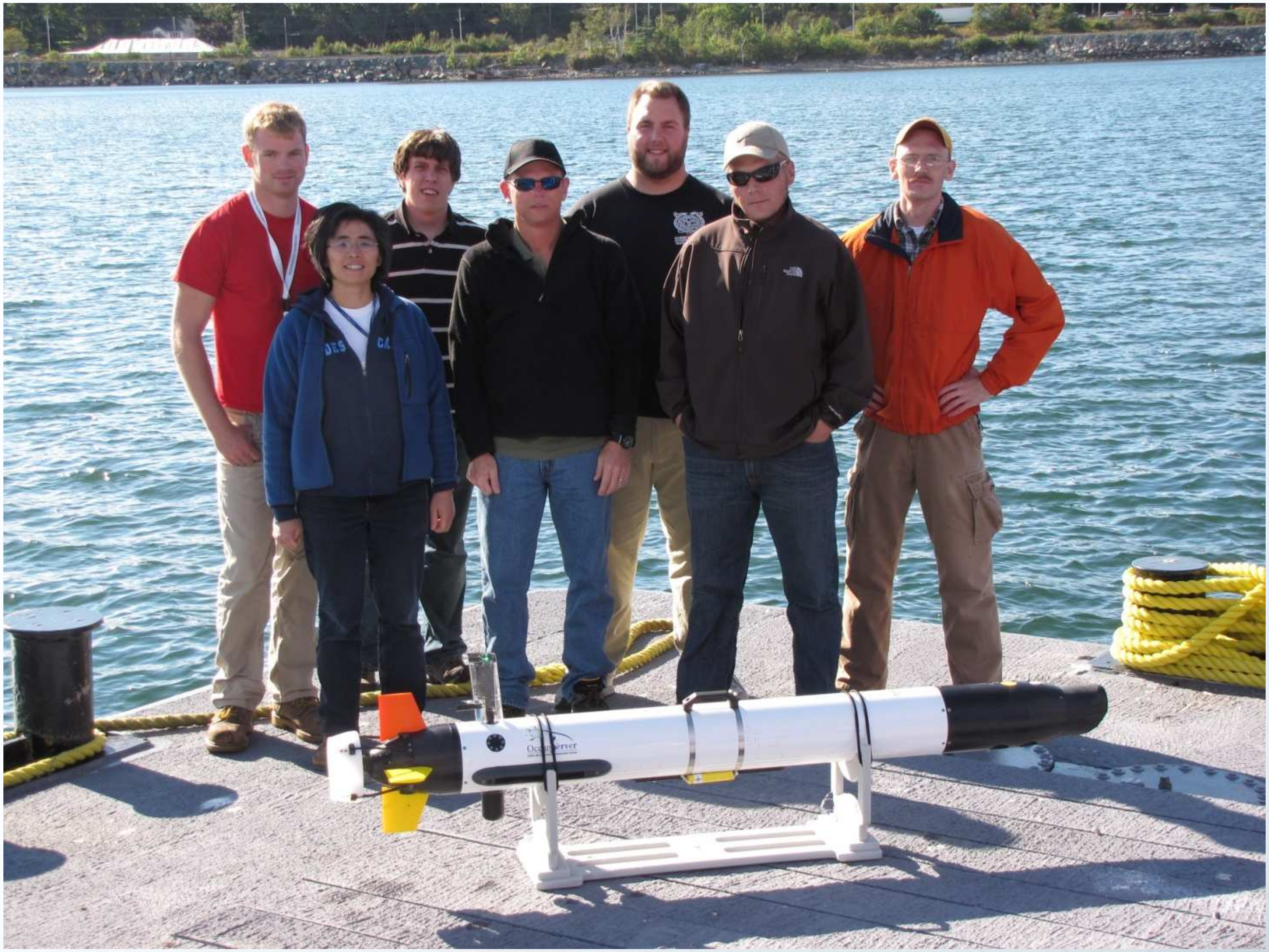

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