Automated vehicles in Arctic marine research

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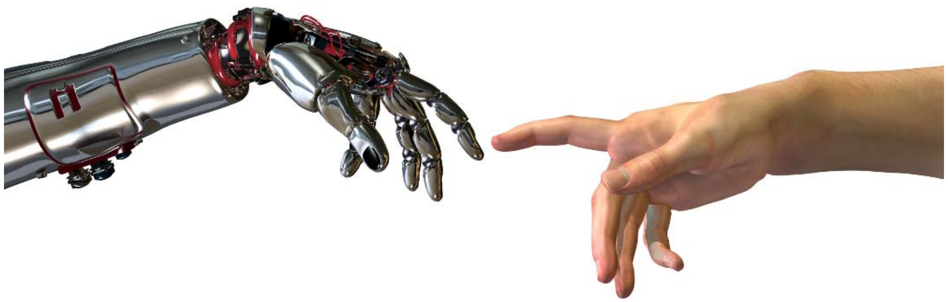
2015-06-03 Arctic Workshop, Scotland

Norwegian Centre of Excellence

AMOS

Content

- AMOS overview
- Integrated environmental mapping and monitoring
- Underwater platforms
- Unmanned aerial vehicles
- From automation to autonomy
- Field campaigns: mapping and monitoring of the ocean space



Acknowledgement:

Joint presentation with AMOS fellows and collaborators

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2013-2022
Centre for
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Ocean Space Industry

AMOS

Ocean Science

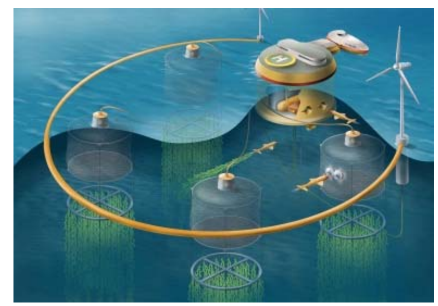
Marine mining

Shipping

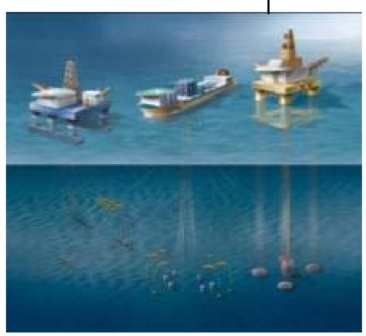
Fisheries

SUPER CLUSTER

Offshore renewable energy



Aquaculture and biological production



Oil & gas in deeper water…

…. and in Arctic areas

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Vision

- To establish a **world-leading research** centre on autonomous marine operations and systems

- **Fundamental knowledge** is created through multidisciplinary research
  - Marine hydrodynamics, marine structures, control and optimization, guidance, navigation, sensors, autonomy, marine biology, marine archeology

- **Cutting-edge interdisciplinary research** will provide the needed bridge to make autonomy a reality for ships and ocean structures, unmanned vehicles and marine operations

The Centre of Excellence (CoE) will contribute to improved international competitiveness of Norwegian industries as well as to safety and protection of the marine environment.

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Two Research Areas

- Autonomous unmanned vehicles and operations (underwater, sea surface, air)
  - 4 projects
- Smarter, safer and greener marine operations and systems
  - 5 projects

Enabling Technologies

- Information and communication technology
- Nano technology
- Bio technology
- Material technology
- Big data
- Integration of disciplines and technologies
- Multi-scale and distributed systems for sensing and actuation: Micro to macro (M2M)
- …..

Research for disruptive game changing technology beyond imagination…..

AMOS Facts and Figures

Personnel in 2015:

6 Key scientists/professors
6 Adjunct professor
9 Affiliated scientists/professors
2 Scientific advisors/professors
6 Post Docs/researchers
70 PhD candidates
2 administrative staff

Graduated PhDs:

5 PhDs graduated from associated AMOS projects (3 IMT and 2 ITK)

Partners and collaborators:

NTNU, Research Council of Norway, Statoil, DNV GL, MARINTEK, SINTEF Fisheries and Aquaculture, SINTEF ICT
14 International collaborators (Denmark, Sweden, Portugal, Italy, Croatia, USA, Australia, Ukraine)

Budget (10 years):

700+ MNOK (~85 MEUR)

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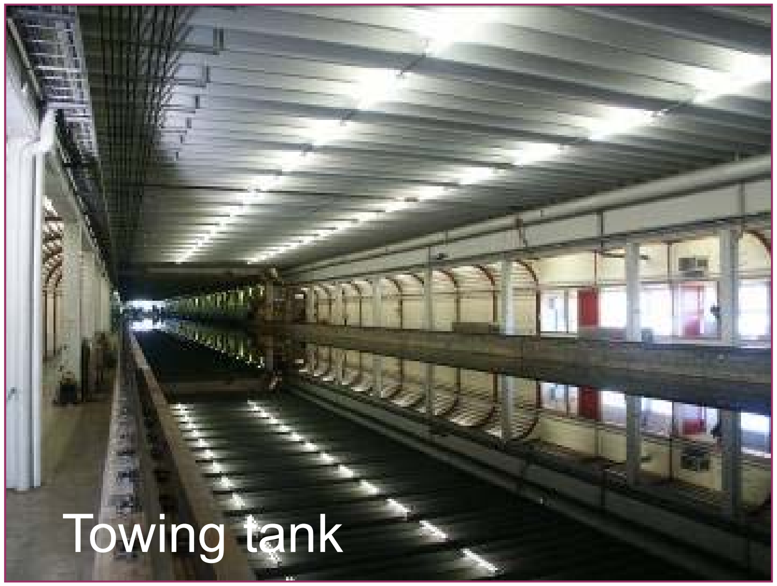
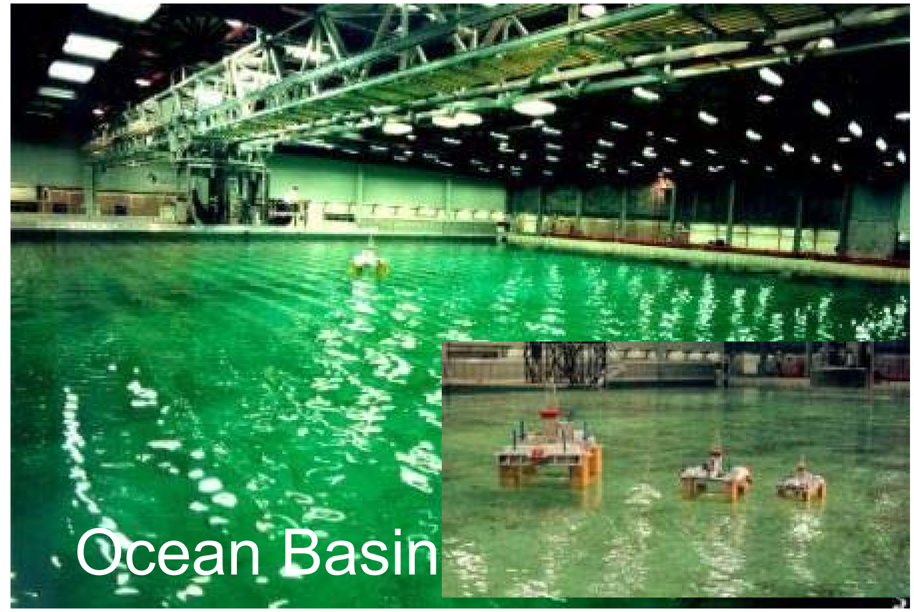
Hydrodynamic Laboratories

AMOS



Towing tank



Ocean Basin

Marine Cybernetics Laboratory

Research vessel "Gunnerus"

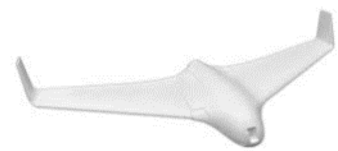
Other specialized experimental facilities (e.g. for sloshing tests)

NTNU Integrated technology platforms for ocean space research

Air (UAV-Lab):
- Penguin B fixed-wing (VLOS/EVLOS/BLOS)
- 3D Robotics hexa-copters (VLOS)
- Microdrone quadro-copter (VLOS)
- X8 fixed-wing (VLOS)

Photo: NTNU UAV-Lab

Photo: NTNU AUR-Lab



Sea surface:
RV Gunnerus
Unmanned ships

Water column and sea floor (AUR-Lab):
- ROV Minerva
- ROV 30k
- ROV SEABOTIX
- AUV Remus 100
- HUGIN HUS
- 2 new AUVs to be acquired

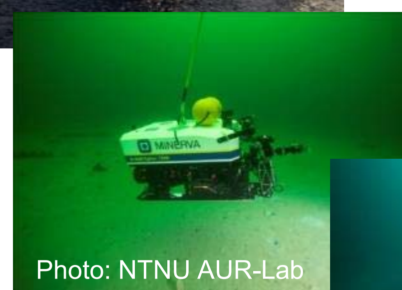


Photo: NTNU AUR-Lab

Photo: NTNU AUR-Lab

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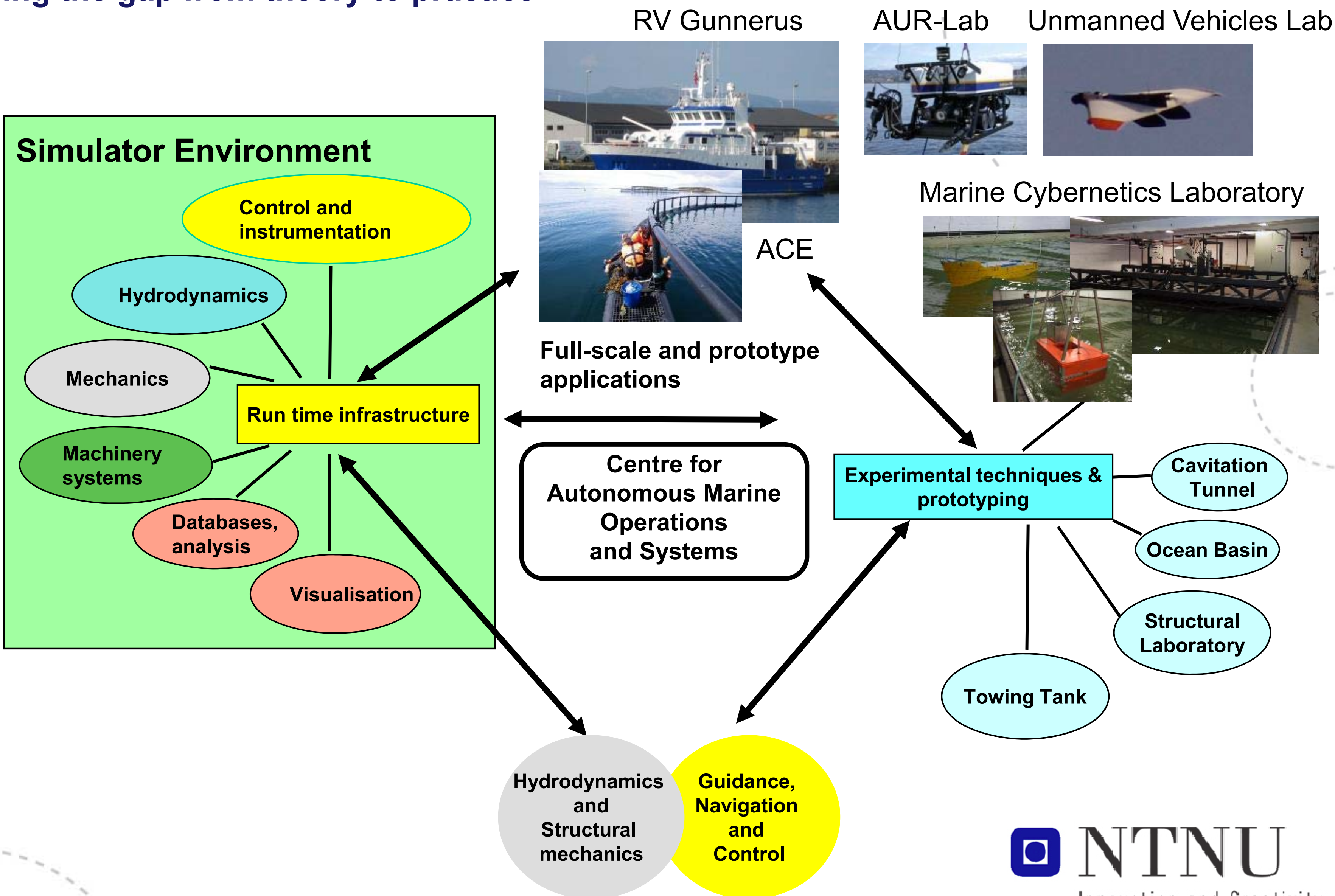
Theory – Simulation – Experiments – Operations

Bridging the gap from theory to practice



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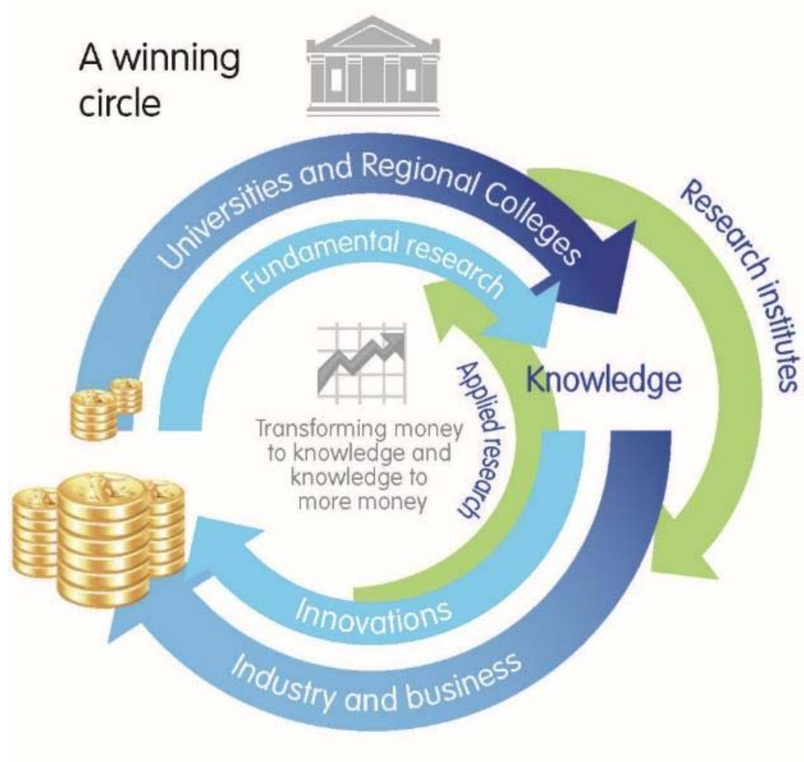
From research to innovations

Industry partners and collaborators

Universities and research institutes

Governmental agencies

New industry – company spinoffs



New method, product or process that are **valuable** and **taken in use**

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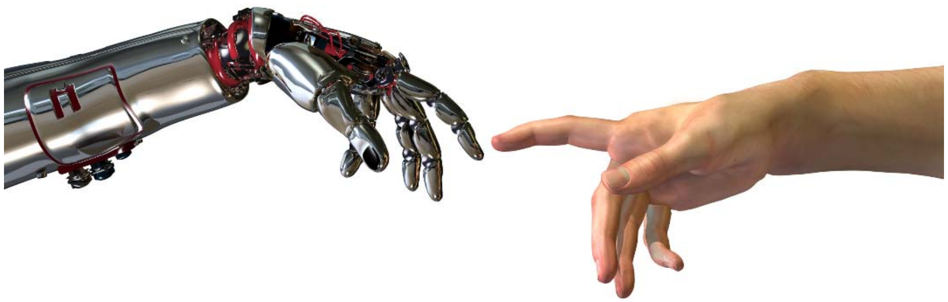

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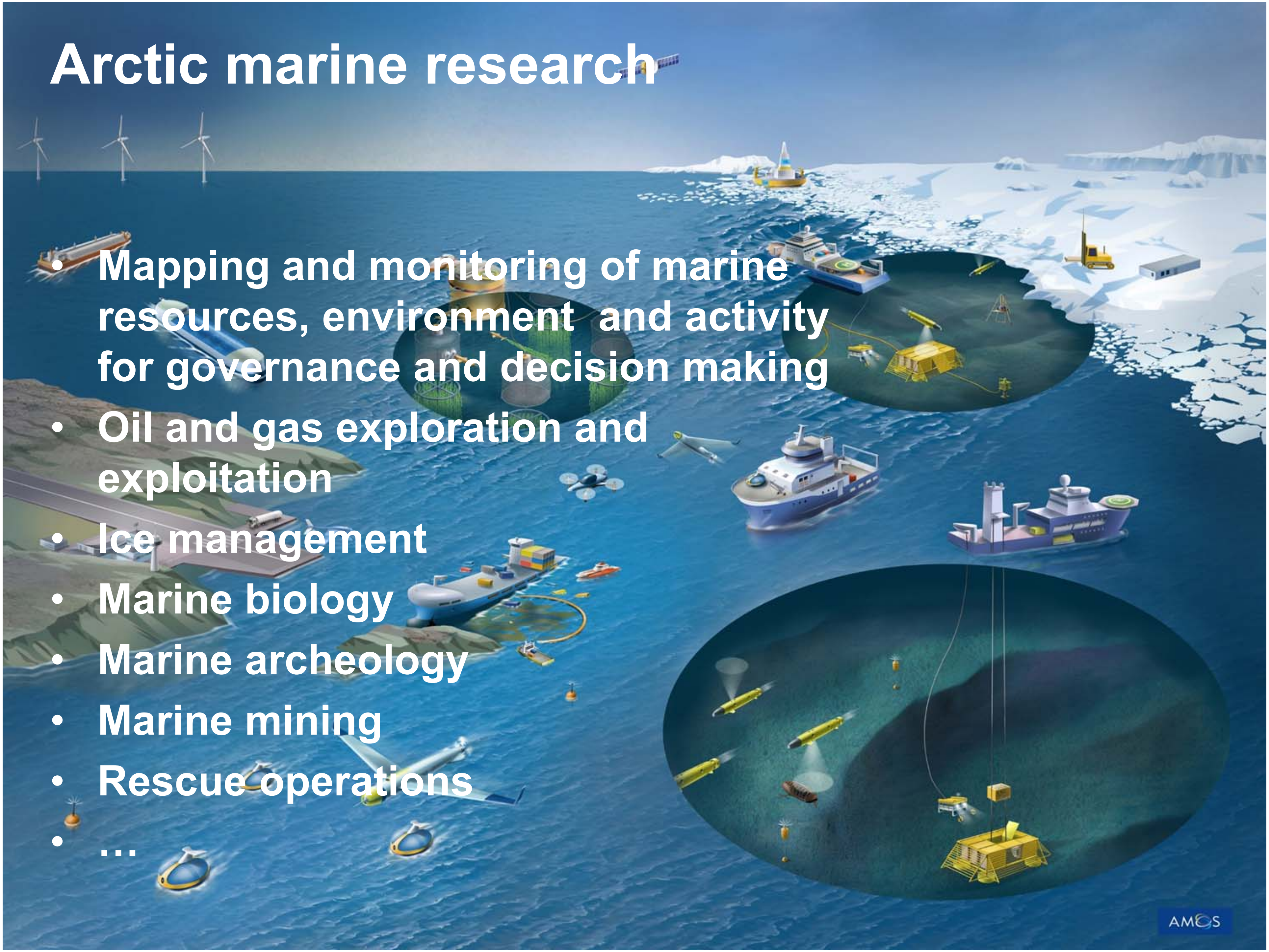
Arctic marine research



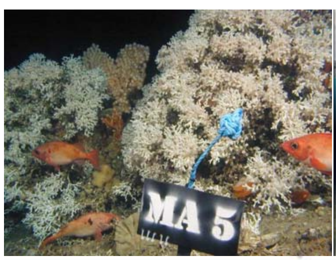
- Mapping and monitoring of marine resources, environment and activity for governance and decision making
- Oil and gas exploration and exploitation
- Ice management
- Marine biology
- Marine archeology
- Marine mining
- Rescue operations
- …

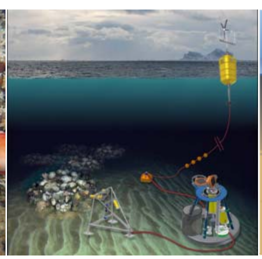

Contents lists available at ScienceDirect
Marine Pollution Bulletin
journal homepage: www.elsevier.com/locate/marpolbul

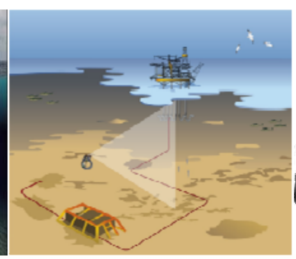
Integrated environmental mapping and monitoring, a methodological approach to optimise knowledge gathering and sampling strategy

I. Nilssen, Ø. Ødegård, A. J. Sørensen,
G. Johnsen, M. A. Moline, J. Berge

Statoil, NTNU, UNIS, University of Delaware, University of Tromsø





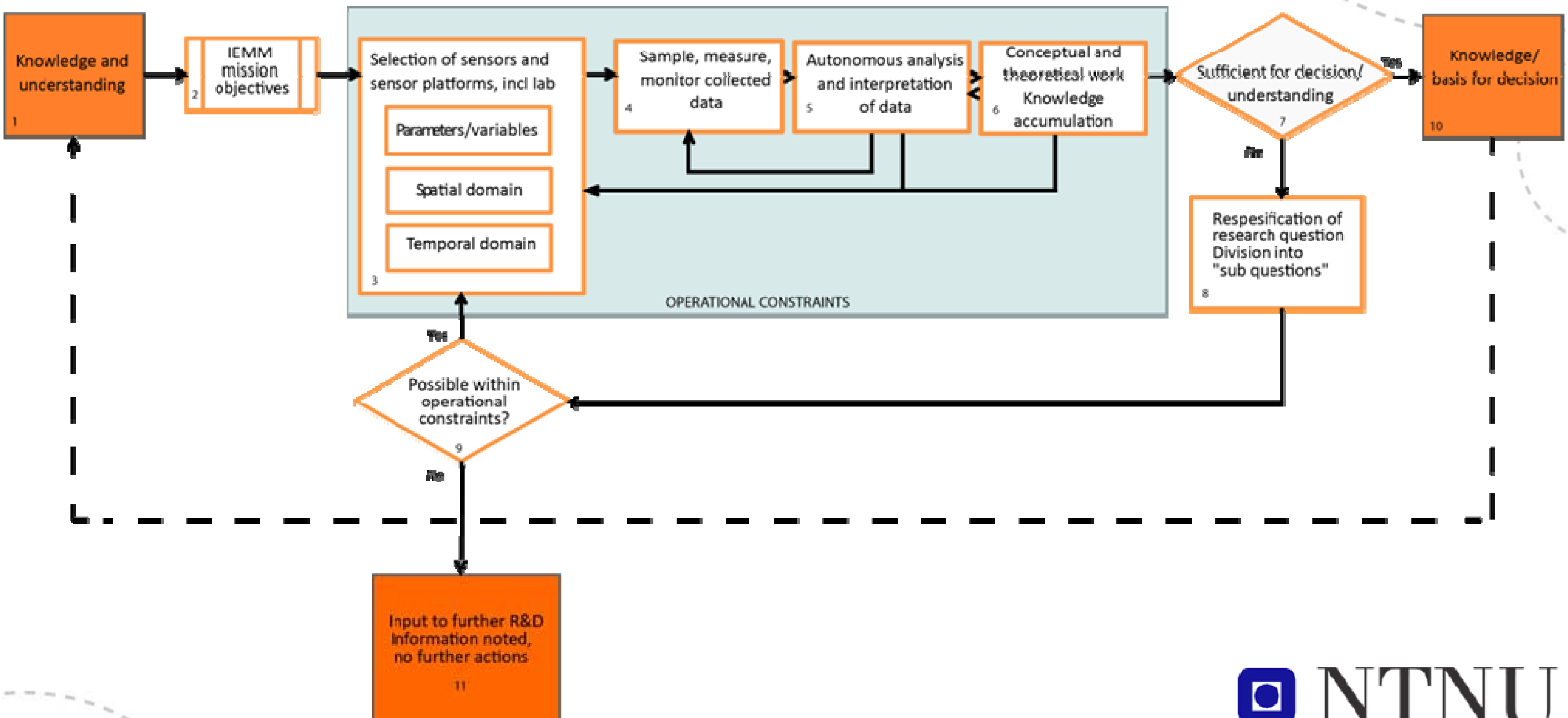


Introduction

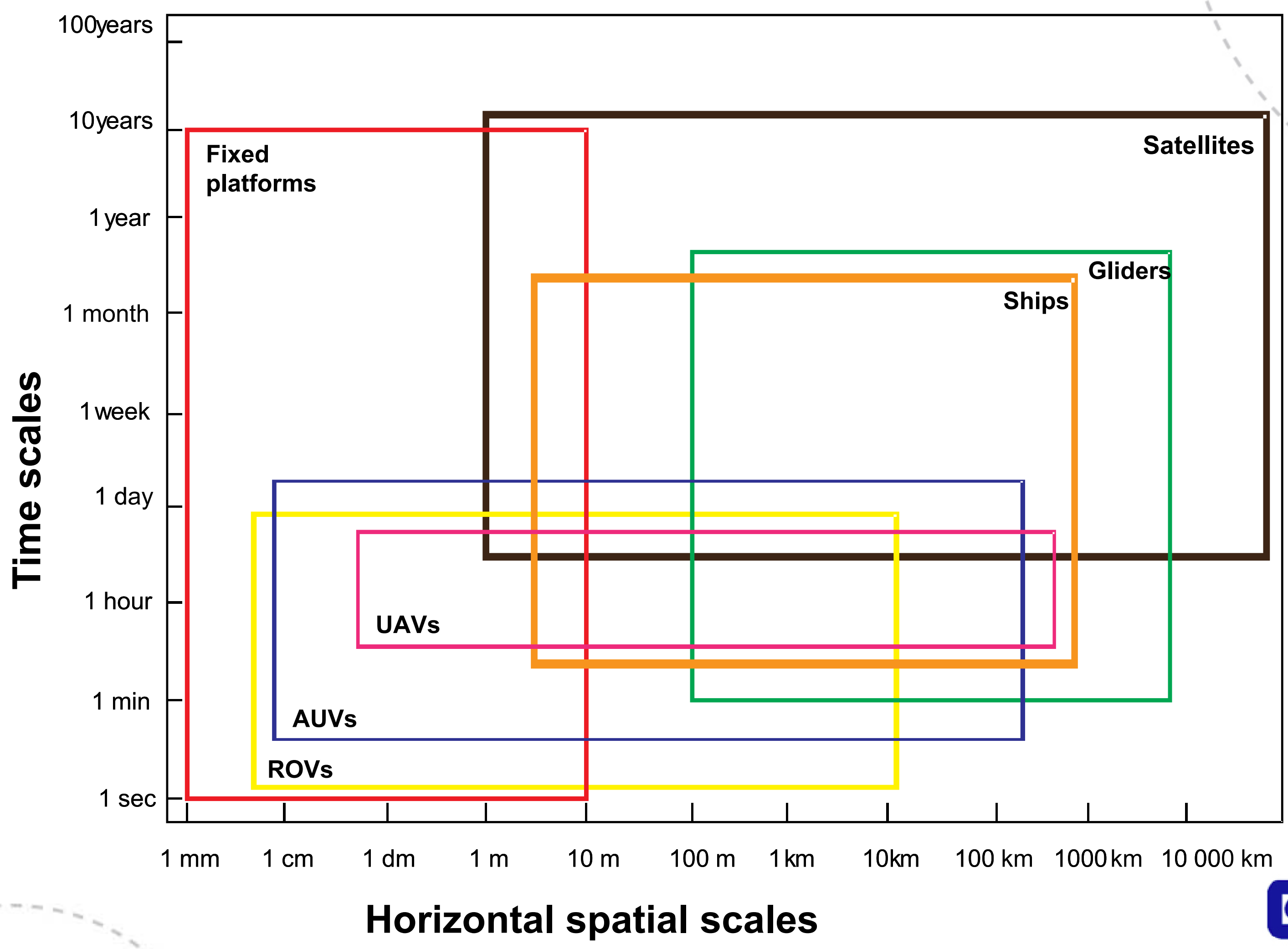
- Existing knowledge gaps, particularly in marine environments
- New technology has led to new opportunities for a holistic environmental mapping and monitoring
- New tools enable new methods
  - Approach adjusted to purpose and objects of interest
    - Spatial and temporal resolution
  - Advanced analysis
    - Autonomy and multivariate analysis

→ **Data available to decision maker in due time**

Integrated Environmental Mapping and Monitoring



Sensor platforms and their temporal and spatial resolution and coverage



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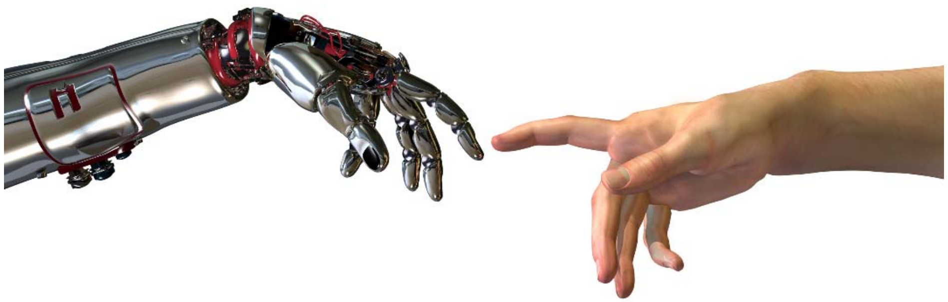

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ROV Characteristics

- Deployed and operated from ship/floater
- Typical depth range: 0-6000 m.
- Many classes of ROVs:
    - Eyeball: Mini ROVs for inspection with depth limited to 100-300 m.
    - Observation class: Medium size ROVs for inspection and light intervention.
    - Work class: ROVs capable to do heavier intervention works.
- Recent developed ROV motion control systems provide high accuracy control

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ROV Characteristics

Pros:

- Sensors: high payload capacity
- High-resolution data for targeted area providing detailed seafloor mapping and sampling
- Umbilical gives unlimited electrical power and high bandwidth communication
- Manipulator arms for sampling and intervention
- Collection units (water masses and seafloor)

AMOS researchers have developed DP system, integration of control systems, navigation and payload sensors

Cons:

- Limited spatial range: usually < 1km transects lines. Spatial coverage/area usually lower than <100 m2
- Umbilical limits spatial coverage and is exposed to current loads/drag forces
- Expensive operation due to day rates of ships with DP systems and launch and recovery systems
- Costly ROV operation involving pilots, technicians and supervisors. Possible to increase efficiency by improved automation/control and autonomy.
- Weather window: Operation of ROV is sensitive to waves and current giving reduced availability

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Future ROVs

- Hybrid ROVs (I.e. WHOI, IFREMER)
  - AUV and ROV mode
- Permanently submerged ROVs with seafloor docking
  - No surface vessel

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AUV Characteristics

- May divide into:
  - o small AUVs (0-100 m depth)
  - o large AUVs (0-6000m).
- Deployed and operated from ship/floater/boats/shore
- Torpedo shaped survey AUV most used in mapping and monitoring
- Limited access to AUVs with DP (station keeping/hovering) capabilities
- Limited access to AUVs with manipulator capabilities doing light intervention and sampling

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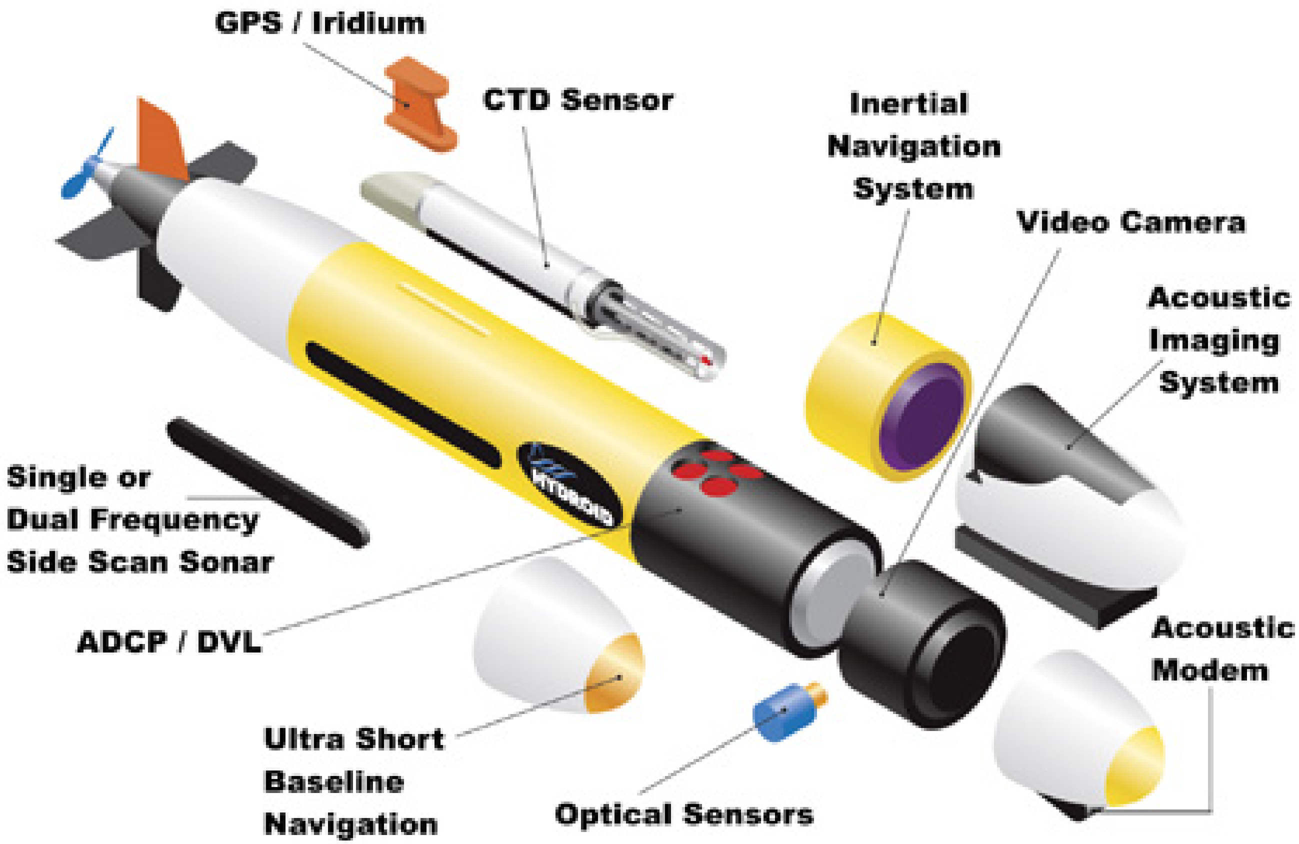
AUV REMUS 100



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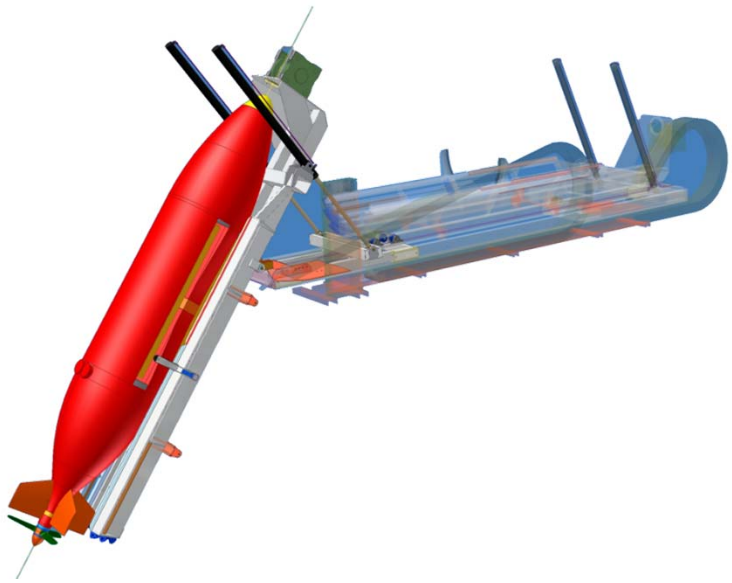
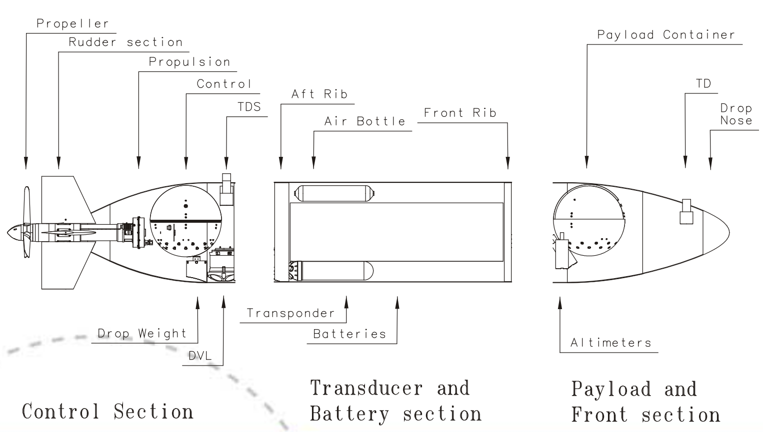
HUGIN HUS



- Modular design – centre section can be adapted to different sensor suites
- 10-30 hours endurance
- Speed 2-6 knots



AUV Characteristics

+ −

Pros:

- 3D (longitude, latitude and depth) mapping capabilities are unique
- High survey area coverage per time
- High spatial resolution data for large area providing detailed seafloor and water column mapping
- Avoid dependence on umbilical
- Less dependent on ship during operation
- Potential to take advantage of autonomy for planning – re-planning

AMOS researchers have carried out integrated research campaigns and developed integration of control systems and payload sensors, and DUNE integration of REMUS 100.

Cons:

- Risk of operation – loss of data and vehicle
- Limited on-line control and power supply.
- Today: Need for competence on AUV personnel
- Autonomy may be improved
- Possible limitations in operation due to ship traffic and risk for collision

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Future AUVs

- Under ice monitoring
- Intervention AUVs
- Automatic docking stations
- Improved autonomy with adaptive missions and onboard processing of payload data
- Cooperative control of multiple vehicles
- …

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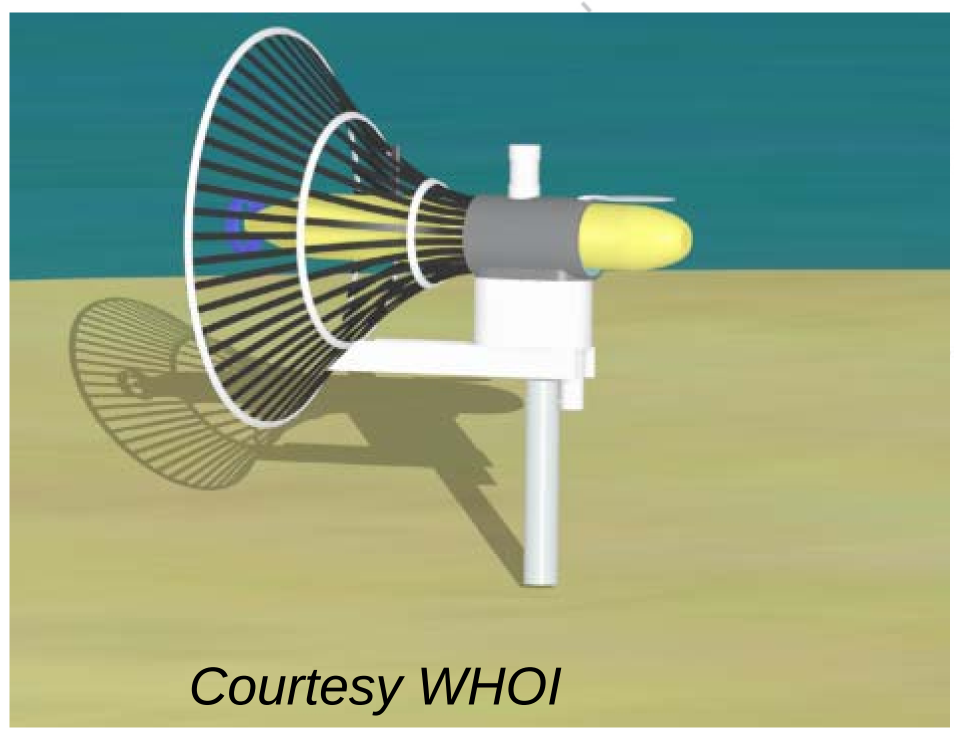
Underwater docking

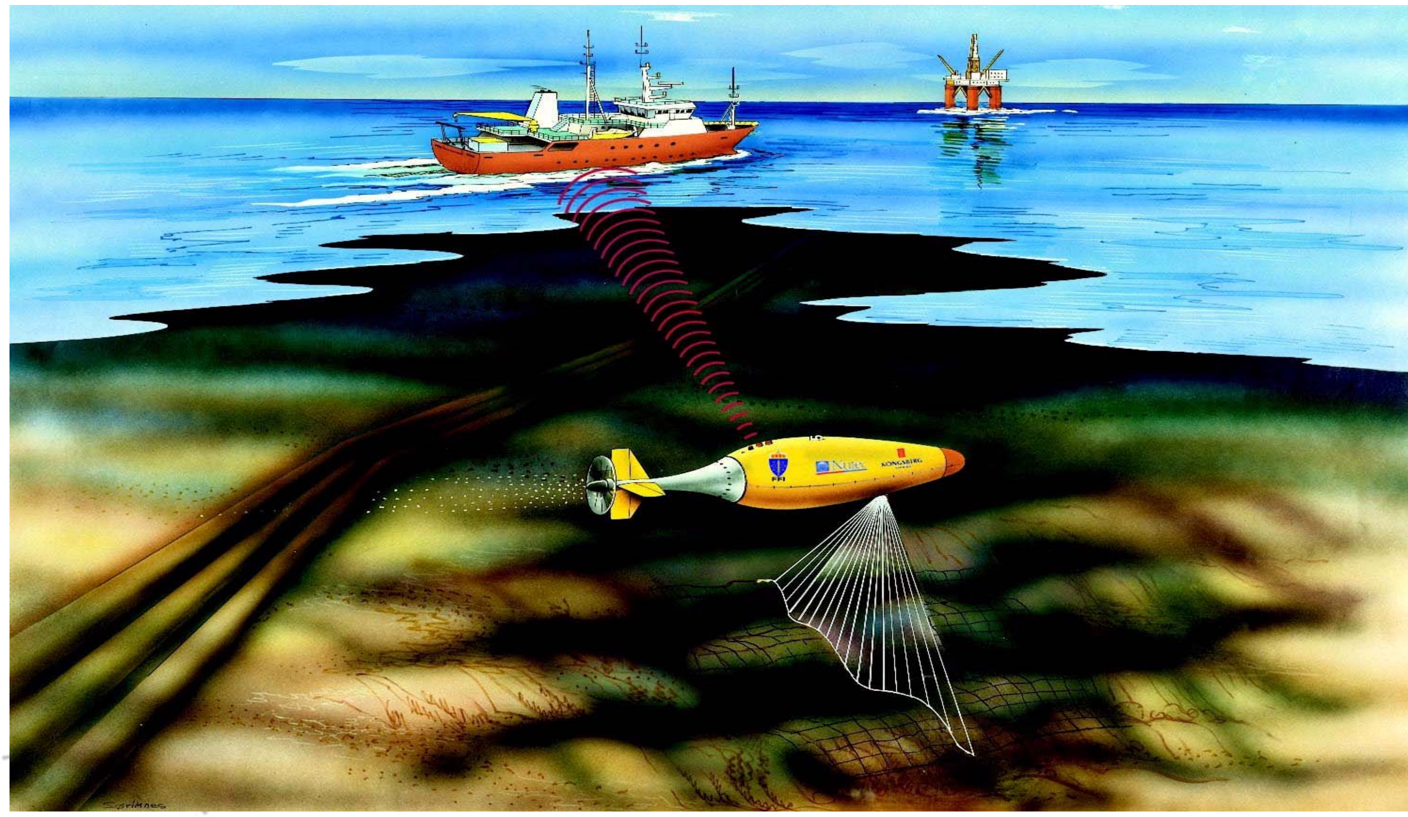
- Data transfer
- Power charging
- Types
  - Garage,
  - Stinger
  - Nose cone



Courtesy WHOI

Control objective

- Payload sensors are carried by a technology platform for collecting data
- The objective of the platform is to position the payload sensor in space and time



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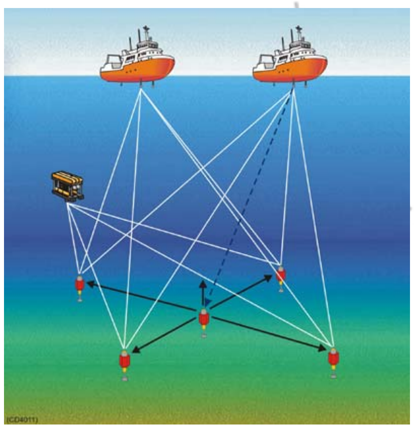
Navigation sensors for ROV and AUV

- Position:
  - GPS at surface for position fix
  - Acoustics
  - Optics (images, video, laser)
- Depth (pressure)
- Altitude and relative velocity to water or seafloor (Doppler Velocity Log)
- Orientations and accelerations, (Inertial Measurement Units)

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Payload sensors and tools

- Optical sensors
  - Video
  - Pin hole camera
  - Ecopuck (cDOM)
  - 0_2 sensor
  - Underwater Hyperspectral Imaging
- Acoustic sensors
  - Side scan sonar
  - Multi beam echo sounder
  - Sub bottom profiler
  - Acoustic Doppler Current Profiler (ADCP)
- Other sensors
  - Gas detectors
  - Magnetometers
  - CTD
  - ….

Light intervention

- Manipulators
- Grips
- …

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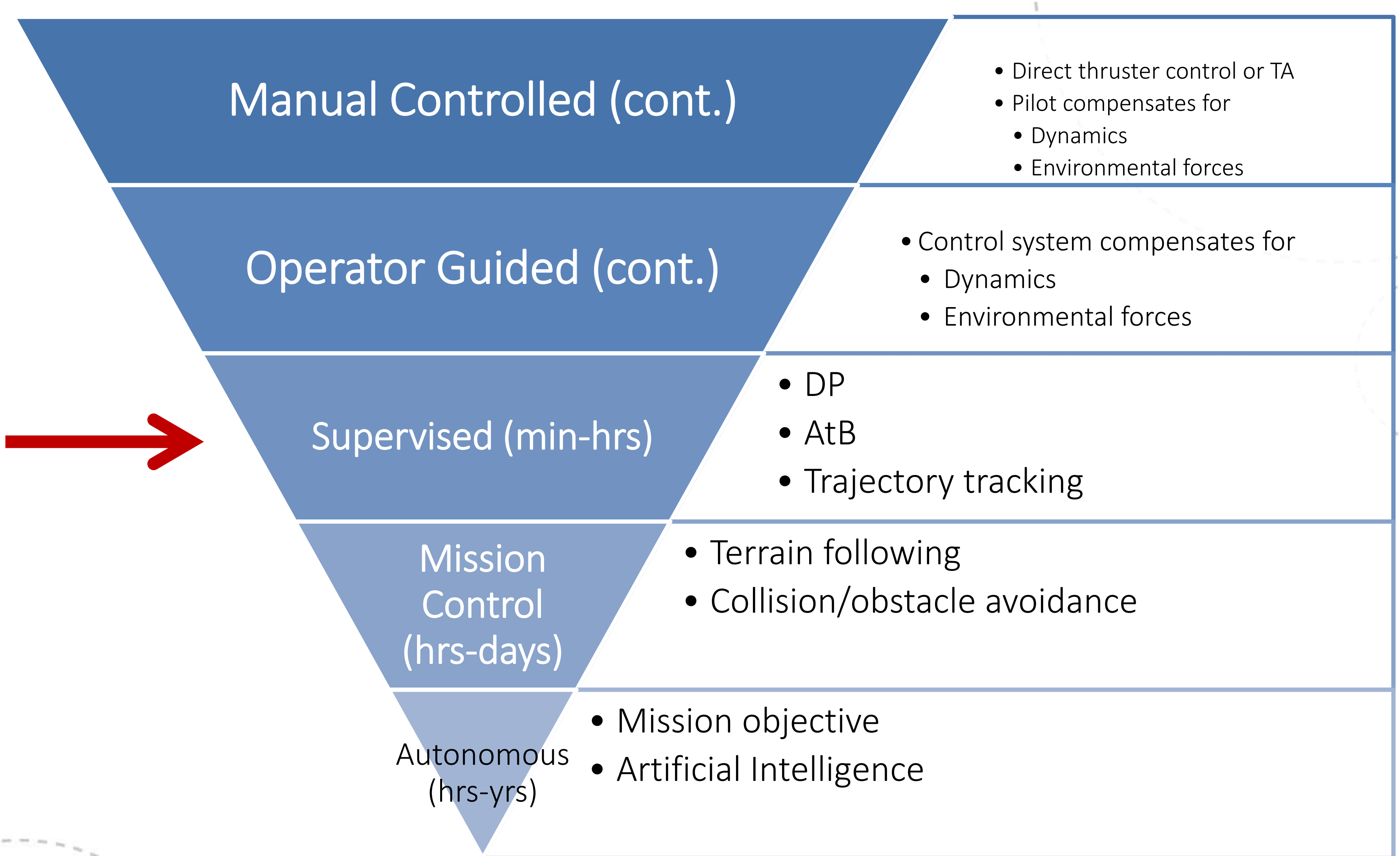
Level of Human Interaction/Autonomy



Guidance, Navigation and Control of ROV

GNC systems:

- Manual leavers
- Joystick system
- Dynamic Positioning Systems (DP)
- Autopilots and tracking systems

Increase performance

- Accuracy
- Consistency/repeatability
- Faster
- Safer

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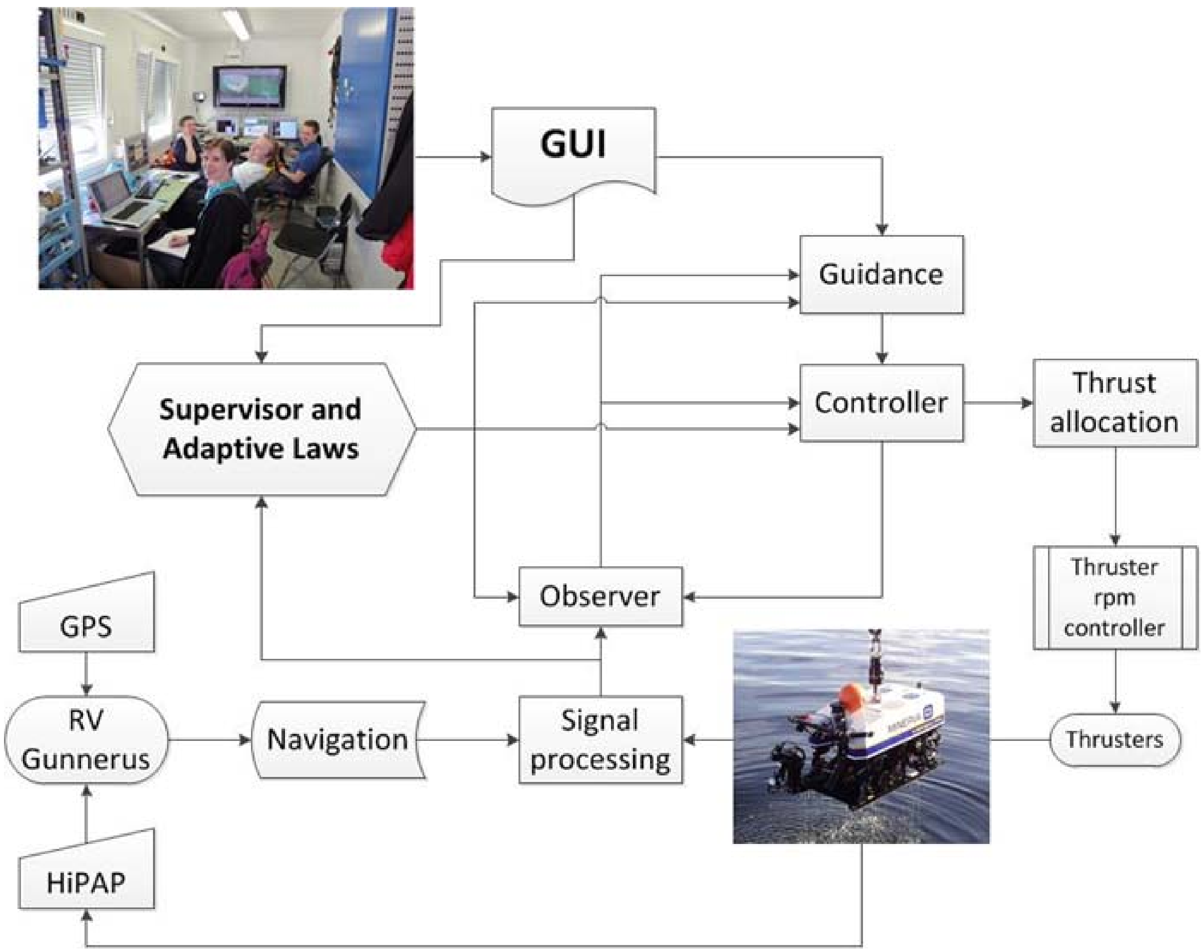
ROV DP SW Architecture



- Signal Processing
- Observer
- Controller
- Thrust Allocation
- Guidance System
- Supervisor
- GUI

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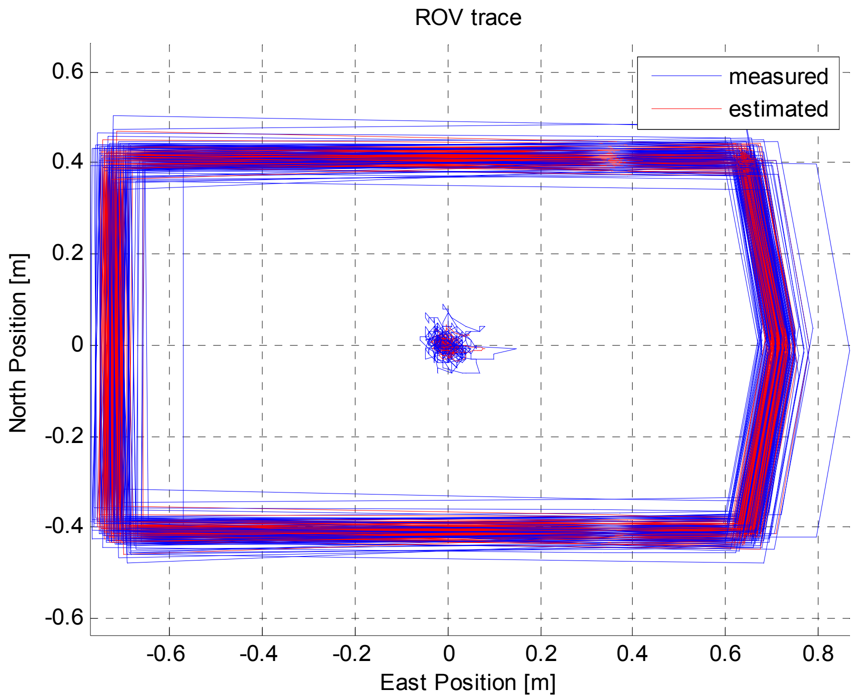
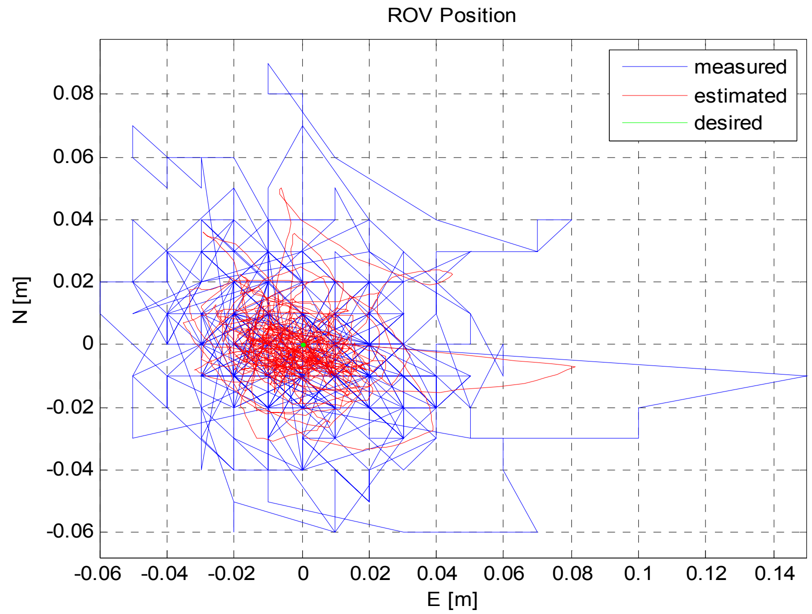
Heading and footprint during DP





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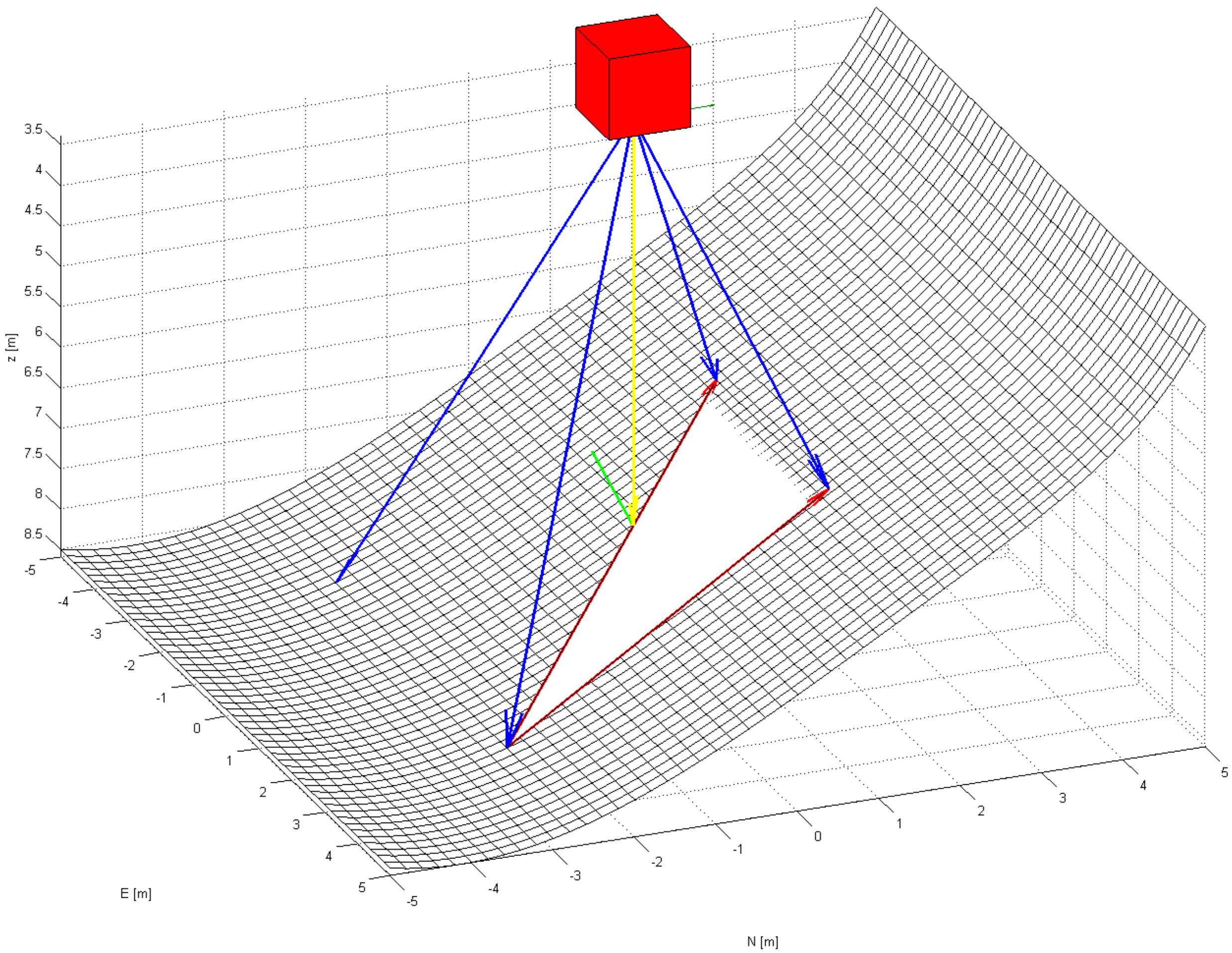
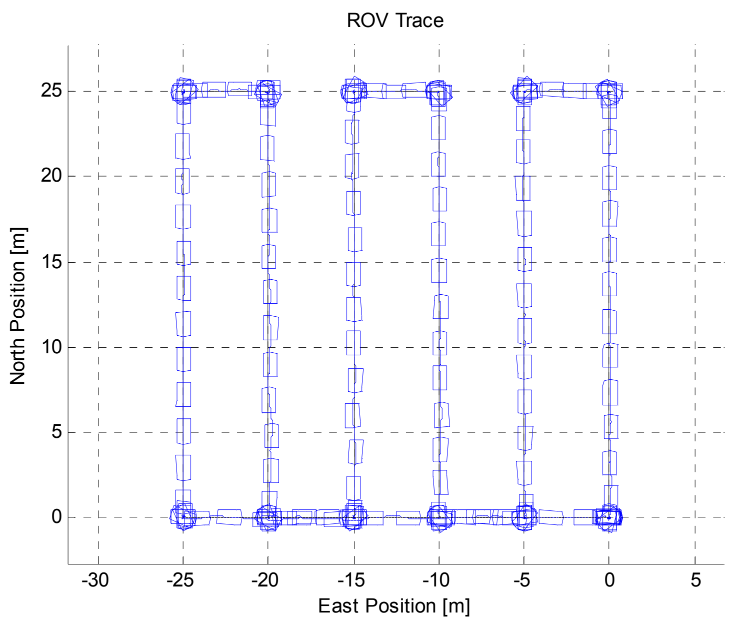
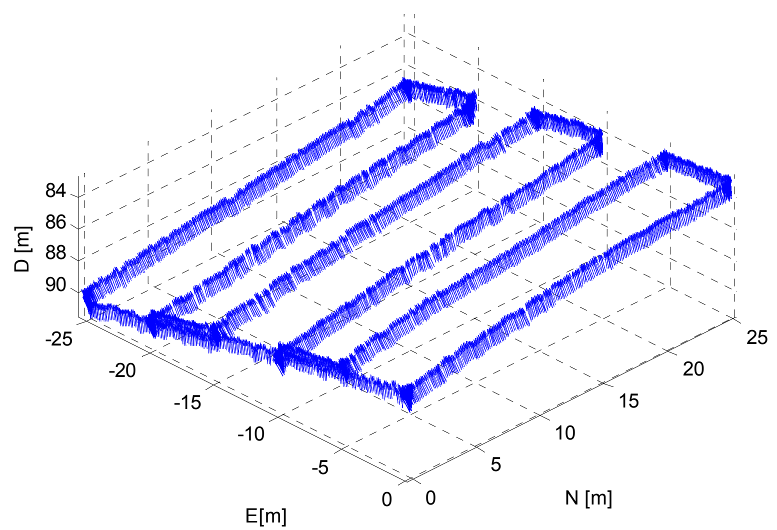
Use of DVL for altitude control



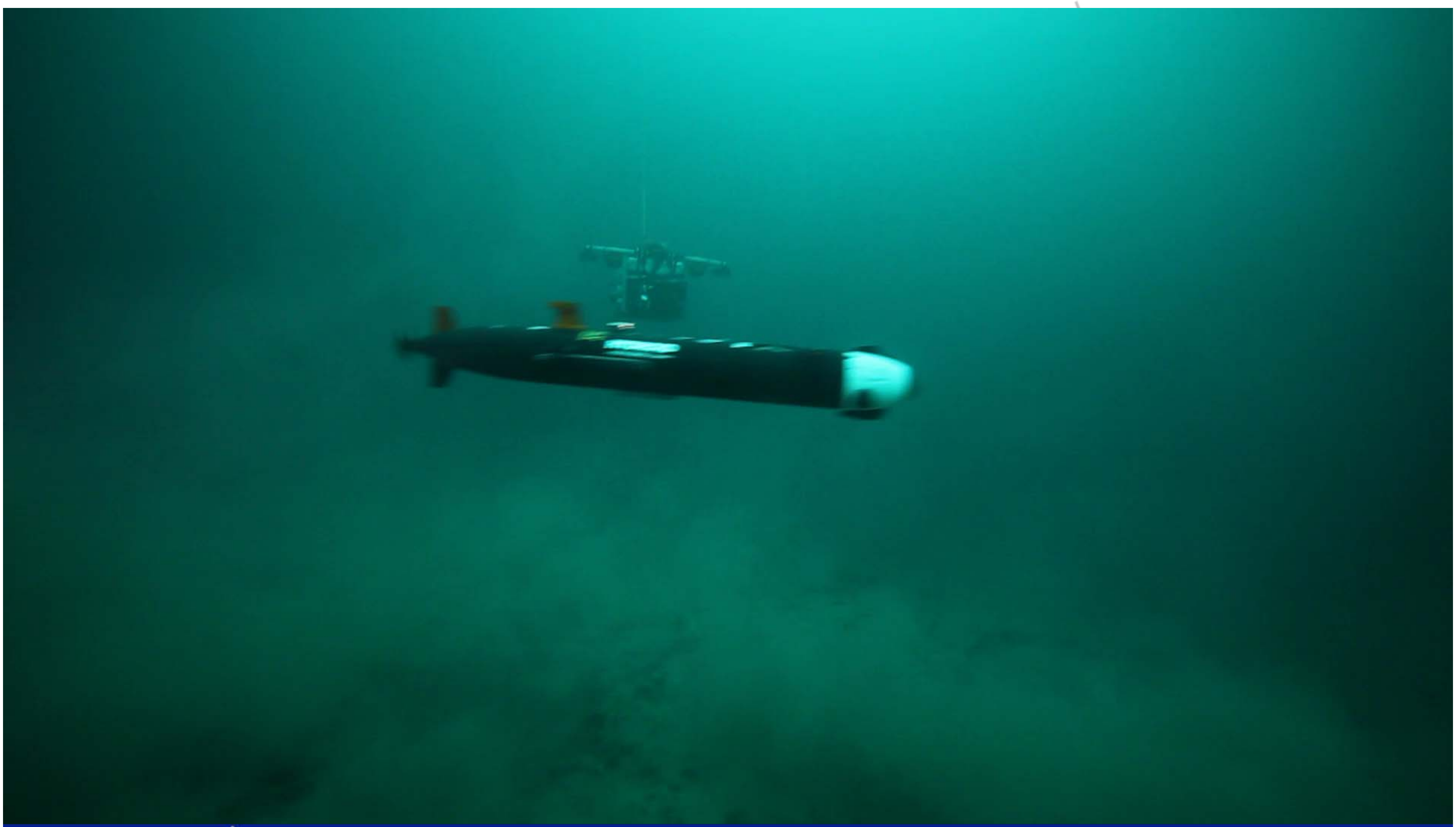
Altitude Estimation and Control

Lawnmower pattern with snapshots of ROV outline





AUV REMUS 100 and ROV Minerva



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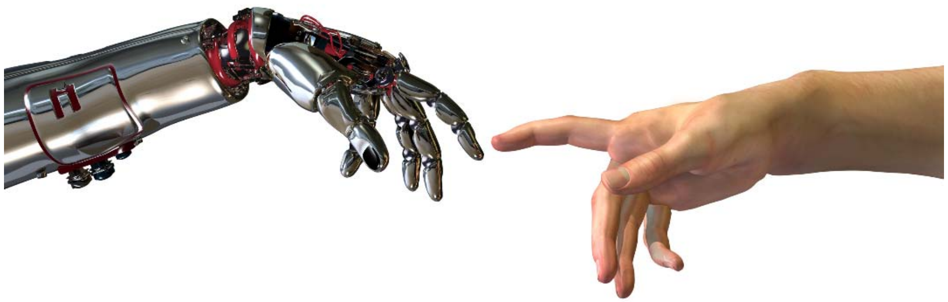

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http://www.itk.ntnu.no/english/lab/unmanned

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Unmanned Aerial Vehicle (UAV) Laboratory and Research

Professors Tor A. Johansen and Thor I. Fossen
Department of Engineering Cybernetics

AMOS

Main Goals

We intend to enable autonomous marine operations with Unmanned Aerial Systems (UAS)

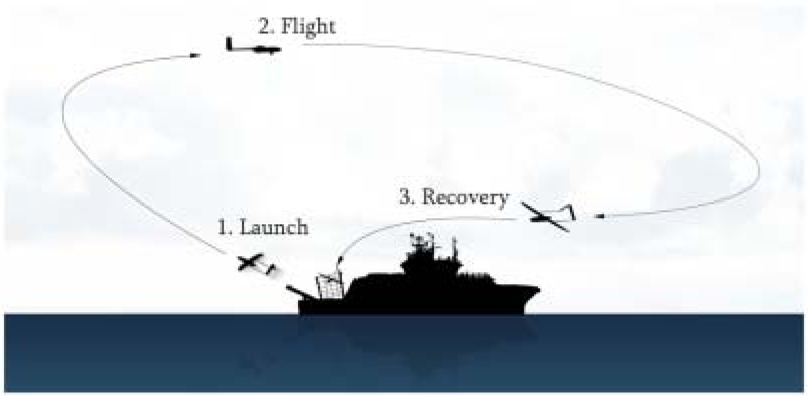
- Fault-tolerant control, navigation and communication for BLOS operations
- Harsh environment; *anti-icing systems*
- Autonomous ship-based *launch* and *recovery*
- Onboard intelligence – cannot assume high-quality communication:
  Real-time image and sensor data analysis, remote sensing, search and tracking
- Delay-tolerant communication relaying and networking;
  Heterogeneous multi-vehicle BLOS operations
- UAS-assisted deployment and recovery of sensor nodes and other assets

We also use Eggemoen and Ørland

Agdenes Airfield

Launch and Recovery Systems

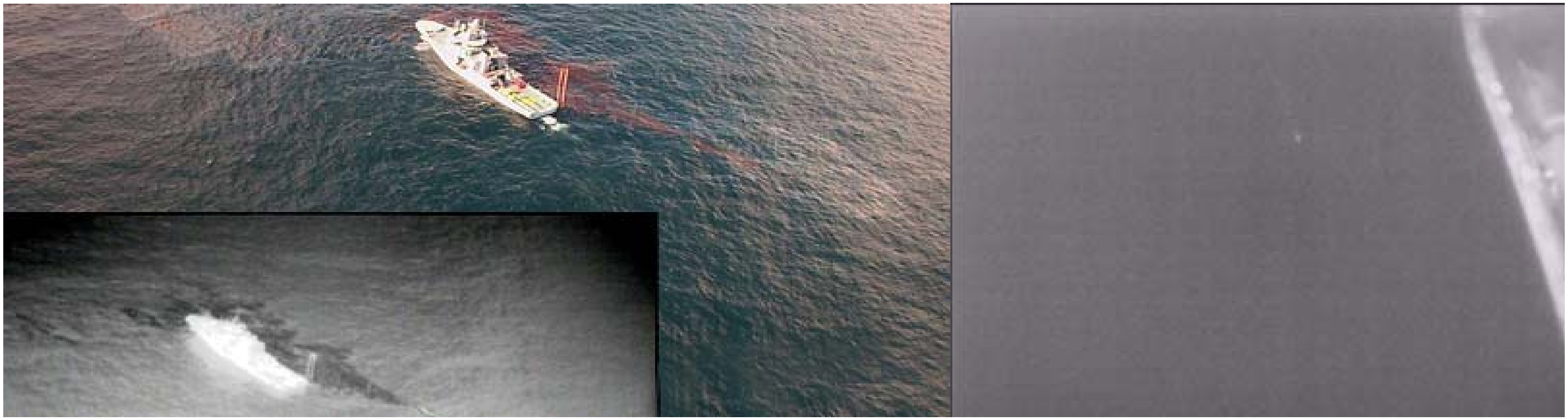
- Conventional take-off and landing on airfields
- Catapult and automatic landing in net onboard the NTNU ship Gunnerus



Five Focused Main Research Areas

1. Smart UAV remote sensing payloads –
   Autonomous detection, classification and tracking of objects and distributed features
2. UAV payloads for deployment and recovery, e.g. of ground/floating sensor nodes from UAV
3. Multi-vehicle networking – mobile sensor network
4. Fault-tolerant and robust UAV guidance and navigation
5. Enabling ship-based UAV operations in remote and harsh conditions

1. Smart Payloads - Autonomous Detection and Tracking of Objects and Features



Reduce the need for high-capacity payload datalink and human analysis by onboard intelligence and autonomy

- Real-time onboard machine vision and remote sensing
- Mission planning for search based on optimization
- Distributed features such as oil spills and sea ice

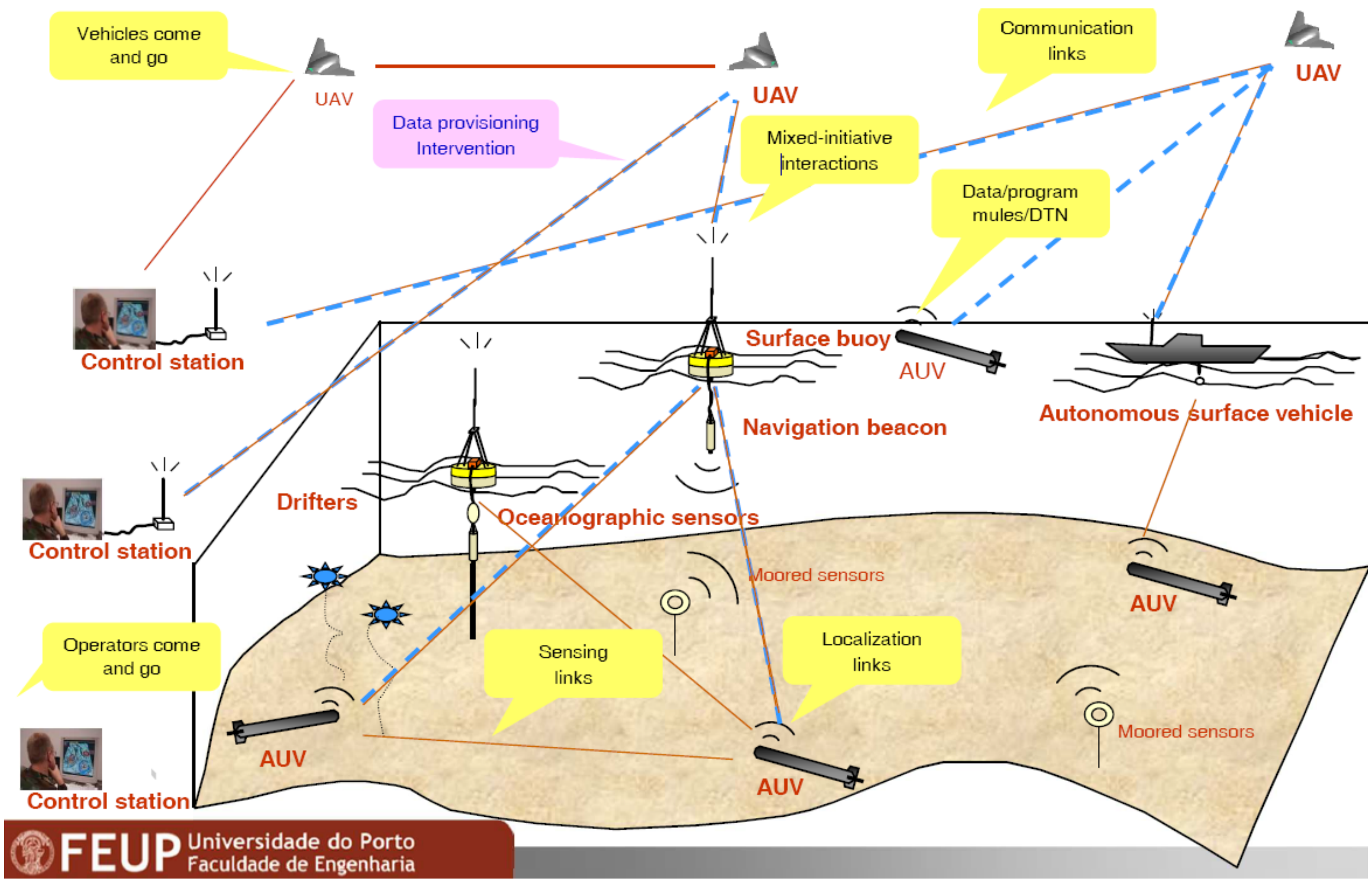
2. Deployment and Recovery Payloads

Deployment and recovery of ground/floating sensor nodes or other objects from UAVs

- Modular and smart floating sensor nodes
- Multi-rotor and fixed-wing UAV payloads for precision deployment and recovery of small objects (e.g. in-situ sensors)
- Data acquisition from buoys, AUVs and other floating assets with insitu sensors using UAVs

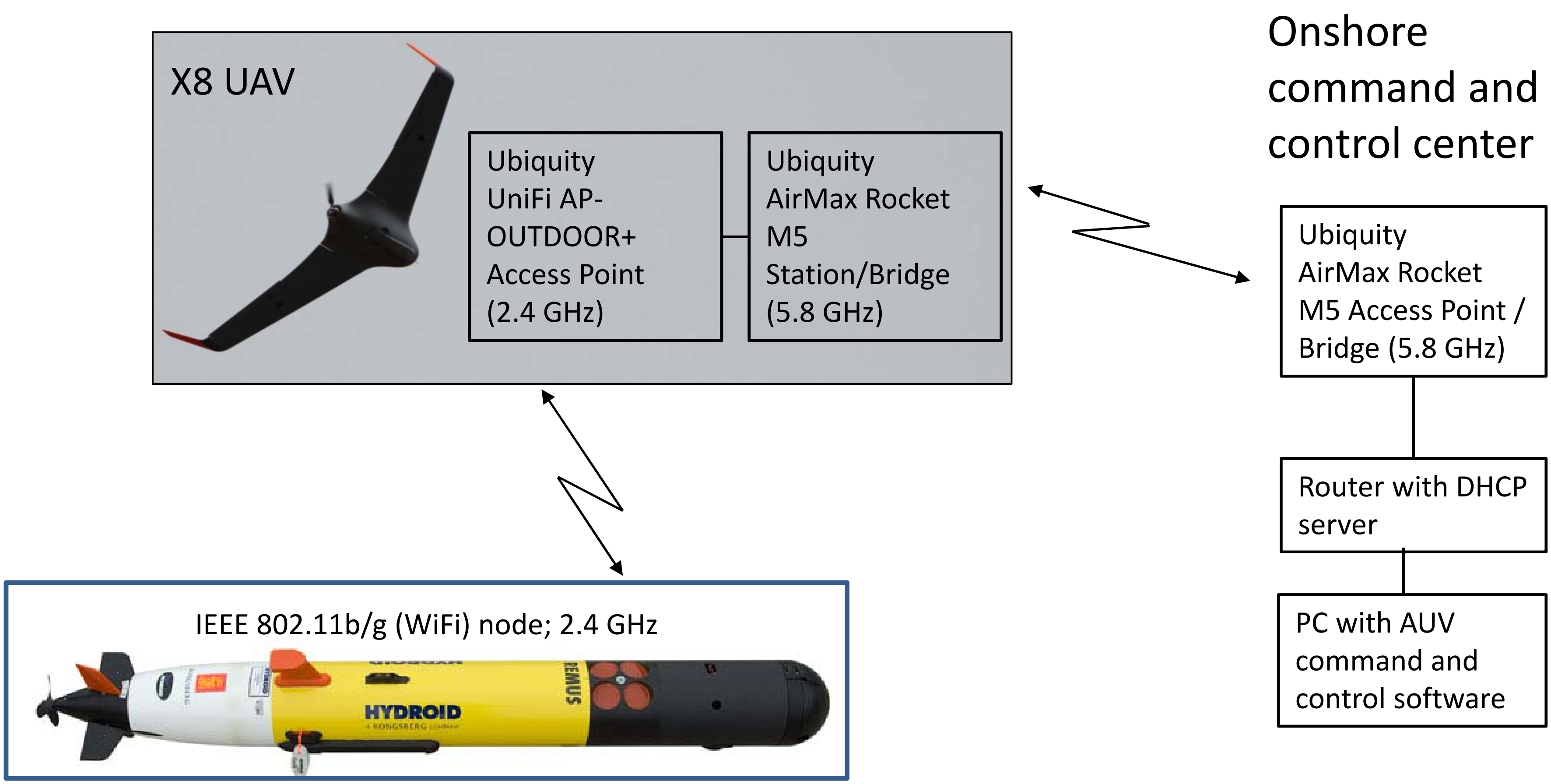
3. Multi-Vehicle Networking

- Inter-operability with aerial, surface and underwater sensor systems and vehicles
- Delay-tolerant and ad.hoc. networking (radio and acoustic)
- System integration with DUNE/NEPTUS middleware
- Onboard mission planning and re-planning (T-REX, from MBARI)



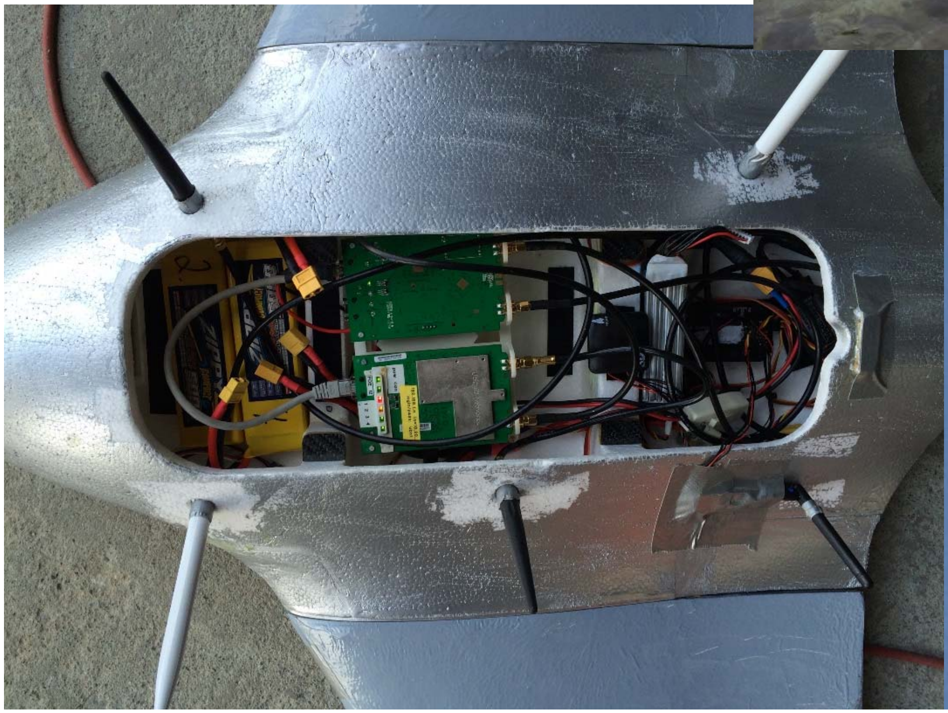
Networked operation with aerial, surface and underwater vehicles

Example: UAV for communication relaying



Remus 100 AUV (Autonomous Underwater Vehicle)

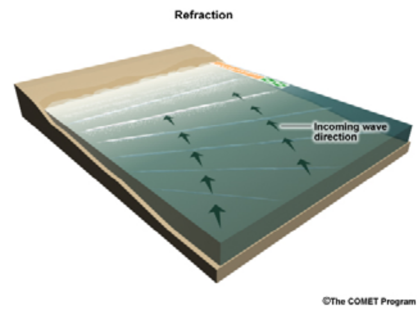
Field tests at Hopavågen, Norway



4. Fault-Tolerant and Robust UAV Guidance and Navigation

Accurate, redundant and robust low-cost global navigation solutions, when GNSS or compass is degraded:

- Visual odometry and optical flow as an alternative to magnetometer and inertial navigation aiding
- Visual navigation at sea (wave direction and horizon from online image processing)



- MEMS-based inertial navigation for fault detection, north seeking and dead reckoning:
  - Integrated with GNSS
  - Integrated with mathematical vehicle model
  - Integrated with camera-based systems
  - Other combinations

5. Enabling Ship-Based UAV Operations in Remote and Harsh Conditions

Launch and recovery of fixed-wing UAVs from moving ships

- Low-cost autonomous ship-based net recovery systems for fixed-wing UAVs based on RTK/DPGS and local navigation
- Advanced recovery net for UAVs (joint research with Maritime Robotics)
- Low-speed recovery of UAVs with moving ship rendevouz

Inflight anti-icing and de-icing systems for small UAVs

- Fault-detection and identification for early warning; identification of icing (versus faults related to airspeed sensor, engine/fuel system, servos, etc.)
- Inflight anti-icing and de-icing based on conductive coating (electric power); smart power control system design
- Fault-tolerant flight control in degraded conditions

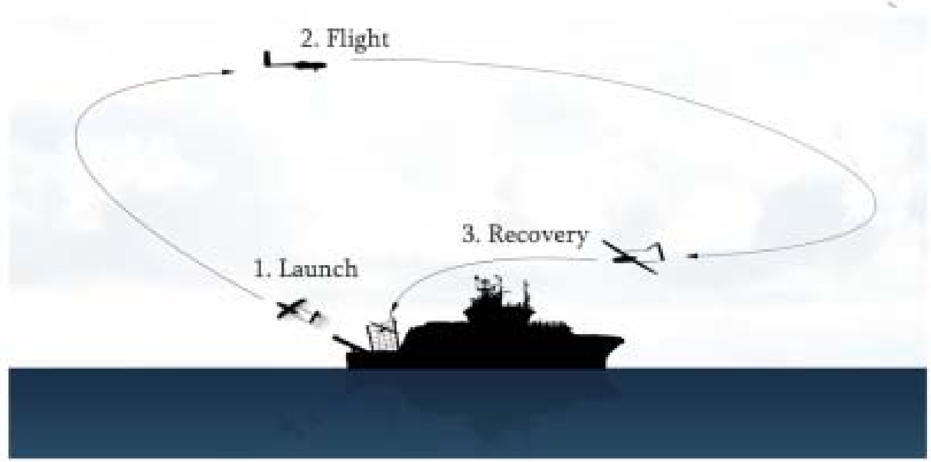
Long-distance radio communication and networking

- Phased array antennas
- Robust heterogeneous radio communication and network technologies

X8 Catapult Launch in Extreme Wind

Autonomous UAV Recovery and Rendezvous on Moving Ships

Optimal approach trajectory taking into consideration turbulence, and movement of ship, UAV and wind. Model the approach trajectory and control as hybrid automata where the transitions may be due to environmental model change (steady airflow away from the vessel, surface wind shear near the water surface, and wind shear and turbulence from the vessel) or due to controller decisions (change control mode, deploy flaps, abort, etc.)



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Automatic Net Landing

UAV Applications: The Arctic

- Surveillance for ice and marine mammals in seismic operations
- Supplement to satellite remote sensors, ship radars etc. using UAVs with EO/IR/laser/SAR sensors
  - Monitoring of iceberg and sea ice treats to offshore structures and marine operations
  - Monitoring of ice treats along North-East ship route to Asia
- Climate and polar research
- Search and rescue
- Situation awareness in marine/offshore operations

Example application: Ice surveillance to support shipping and offshore operations in the Arctic

UAV in the Arctic

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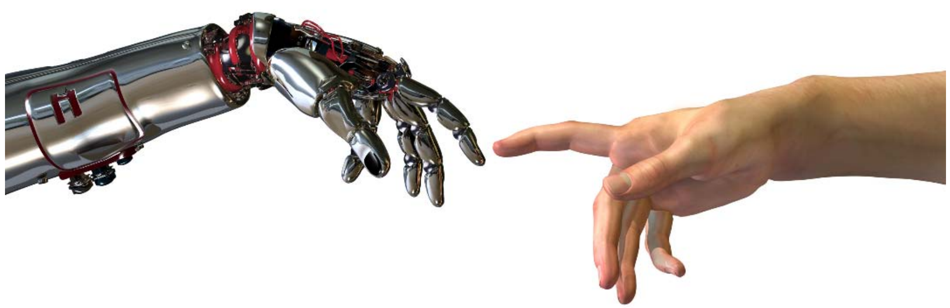
MANAGING RISK
DNV

Content

- AMOS overview
- Integrated environmental mapping and monitoring
- Underwater platforms
- Unmanned aerial vehicles
- From automation to autonomy
- Field campaigns: mapping and monitoring of the ocean space



Acknowledgement:

Joint presentation with AMOS fellows and collaborators

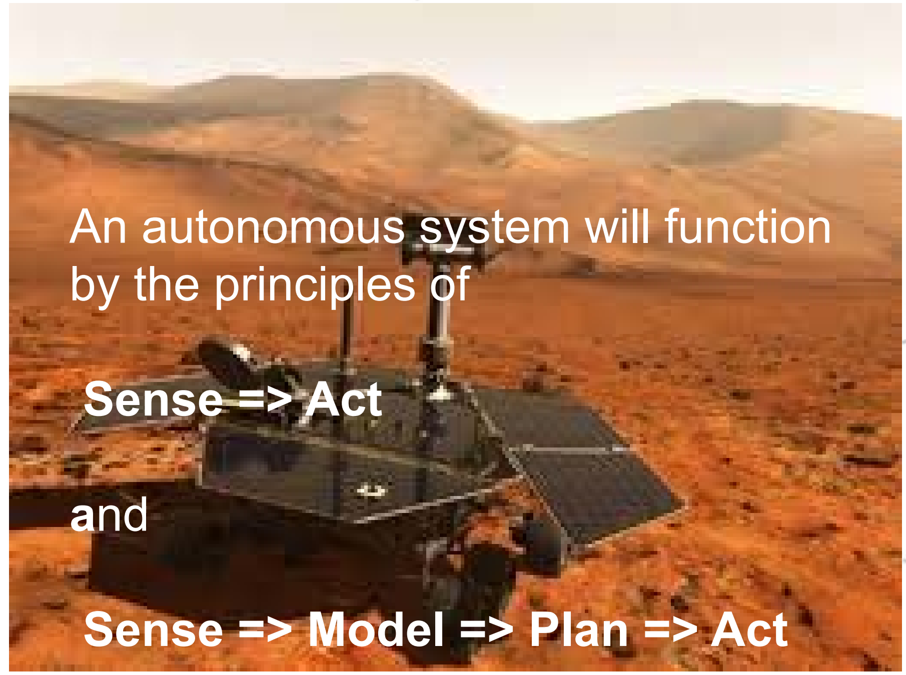
Automatic versus Autonomous

Automatic systems

- Can perform well-defined tasks without human intervention

Autonomous systems

- Designed to perform complex tasks well under significant uncertainties in the system and unstructured environment
- Are highly dependable and must be able to handle external events and internal faults including reconfiguration, planning and re-planning
- Should be able to learn, adapt and improve
- Add extra layer between their measurements and actions which enable them to model and plan their actions, hence <u>making deliberate choices</u>



Simply speaking:
Autonomous systems have more intelligent and adaptive functionality that allows them to perform when automatic systems might fail due to more or less unexpected internal or external events

Why autonomy?

AMOS

More intelligent systems that depend less on human operators

Unique (or cheaper) solution when no (or limited) communication is available (bandwidth, remoteness)

Unmanned systems may be smaller, lighter, cheaper and safer to deploy and operate

Qualified operators may be a shortage

Mandatory for new functions

Enables complex functionality; provides fault tolerance and robustness

Enables operations in complex, harsh and remote environment (Dull/Dirty/Dangerous Operations)

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Levels of autonomy as defined by the Uninhabited Combat Air Vehicle Program

Level 1 (Manual Operation)
- The human operator directs and controls all mission functions.
- The vehicle still flies autonomously.

Level 2 (Management by Consent)
- The system automatically recommends actions for selected functions.
- The system prompts the operator at key points for information or decisions.
- Many of today's autonomous vehicles operate at this level.

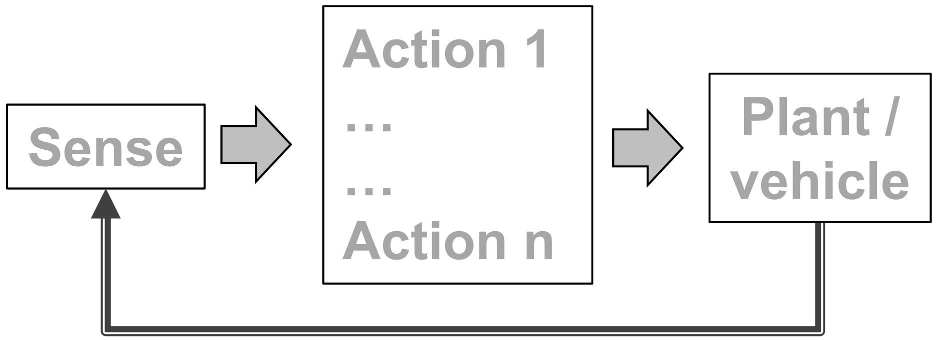
Level 3 (Management by Exception)
- The system automatically executes mission-related functions when response times are too short for operator intervention.
- The operator is alerted to function progress.
- The operator may override or alter parameters and cancel or redirect actions within defined time lines.
- Exceptions are brought to the operator's attention for decisions.

Level 4 (Fully Autonomous)
- The system automatically executes mission-related functions when response times are too short for operator intervention.
- The operator is alerted to function progress.

Autonomous Vehicles in Support of Naval Operations, http://www.nap.edu/catalog/11379.html

Reactive control systems

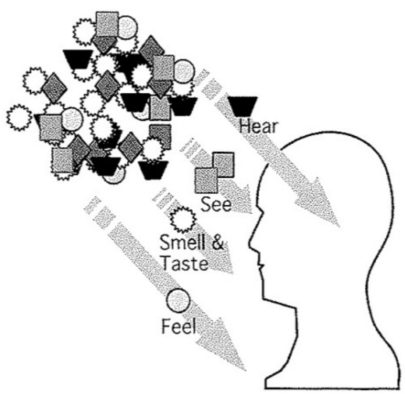
- Current systems are very good at solving precisely defined problems, where carefully designed algorithms precisely define the relationship between measurements ("sense") and actions 1,…,n ("act")
- Current systems are reactive, and have preprogrammed a direct relationships of the type "sense => act"
- Examples of reactive systems include:
  - Autopilots, LOS
  - Dynamic positioning (DP) systems
  - Contingency handling: anti collision, alarms systems, …

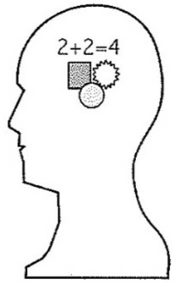


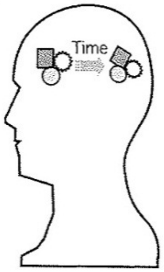
Situation awareness

- Being aware of what is happening around you and understanding what this information means to you now and in the future
- The formal definition breaks down into three separate levels:
  - Level 1: **Perception** of the elements in the environment
  - Level 2: **Comprehension** of the current situation
  - Level 3: **Projection** of the future situation
- To be implemented in appropriate system models

Designing for Situation Awareness. An Approach to User-Centered Design. Endsley, Bolte, Jones







Courtesy Kongsberg Maritime

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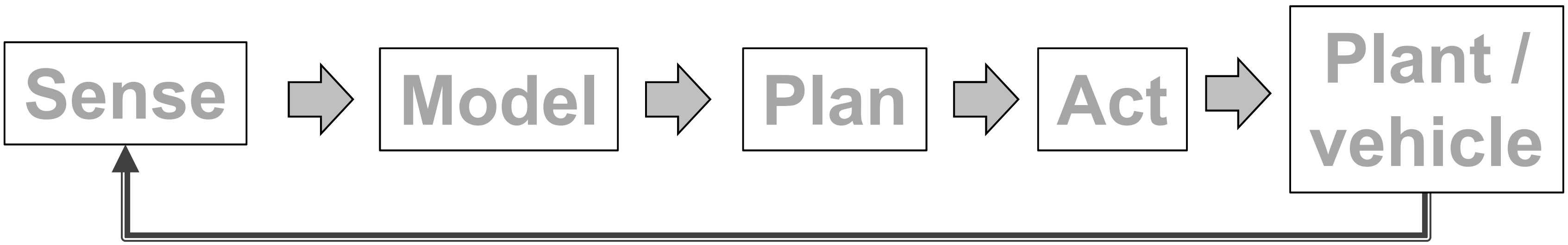
Deliberative control architecture

Going from reactive to proactive systems of the type:
“Sense => Model => Plan => Act"

Learning by model updates and accumulation of knowledge

- Situation awareness
- Learning by sensing and observing
- Learning by doing
- Human-in-the-loop



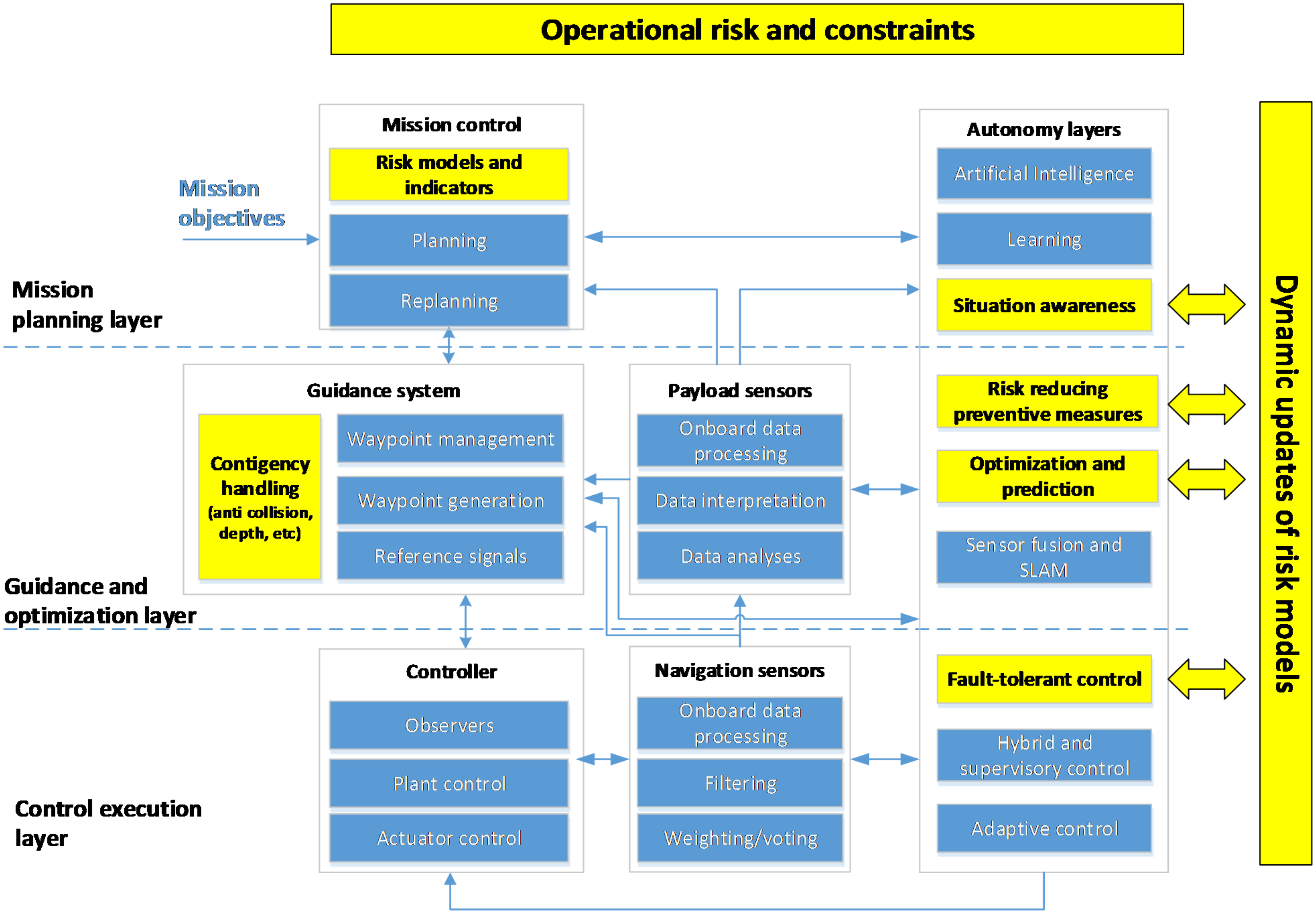
Combining reactive and deliberative control

Mission planner level: Mission objective is defined and the mission is planned. Subject to contingency handling, any input from payload sensor data analysis and any other input from the autonomy layer, the mission may be re-planned.

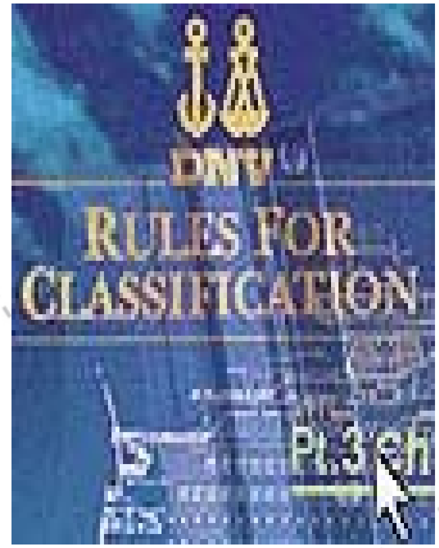
Guidance and optimization *level* handles waypoints and references commands to the controller.

Control execution level: at this level the plant control and actuator control takes place

Control architecture for autonomous underwater vehicles



More challenges…..



- Legal considerations
- Social acceptance
- Employment issues
- Safety barriers and risk management
- Big data
- Standards, rules and regulations to follow pacing the race of the computerized world with ICT everywhere
- Effective test and verification methods must be developed and taken in use

Need for standards and class regulations

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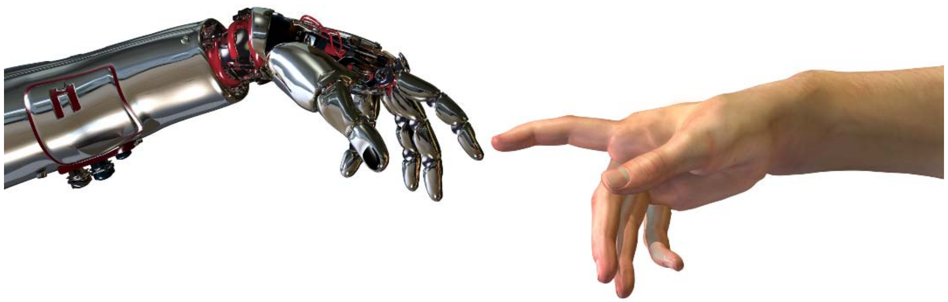

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Exploring the Ocean Space

AUR-Lab & FFI 2013 December cruise

FFI Forsvarets forskningsinstitutt

Norwegian Defence Research Establishment

NTNU

AUR-Lab

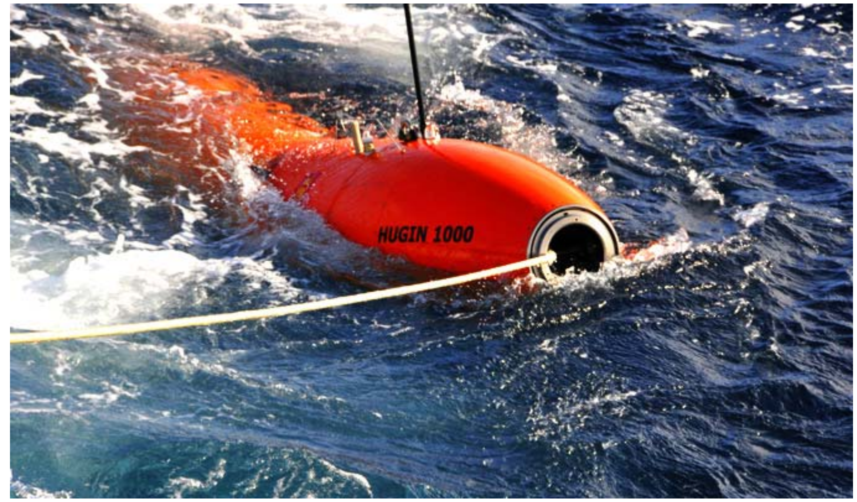
NTNU Research Vessel Gunnerus

NTNU's research vessel, R/V Gunnerus, was put into operation in spring 2006. The ship is fitted with a dynamic positioning system and a HiPAP 500 unit, optimal for ROV operations and the positioning of any deployed equipment.

The vessel is arranged with wet lab, dry lab and a computer lab in addition to a large aft deck.

Accommodation comprise three double berth scientific personnel cabins and three single berth crew cabins. The large mess hall functions as a lecture room for 25 people.

FFI HUGIN HUS



The HUGIN system was developed in a collaborative effort by FFI and Kongsberg Maritime, and is used by the offshore survey industry for detailed seabed mapping and data acquisition, and by navies for mine counter measures (MCM) and intelligence, surveillance and reconnaissance (ISR).

HUGIN HUS is 0.75 m diameter, 5.3 m long and weighs 980 kg

HUGIN HUS was especially designed as a scientific AUV, and primary sensors for this survey were HiSAS 1030 Synthetic Aperture Sonar, a Sub Bottom Echosounder and a B/W Still Camera (nadir)

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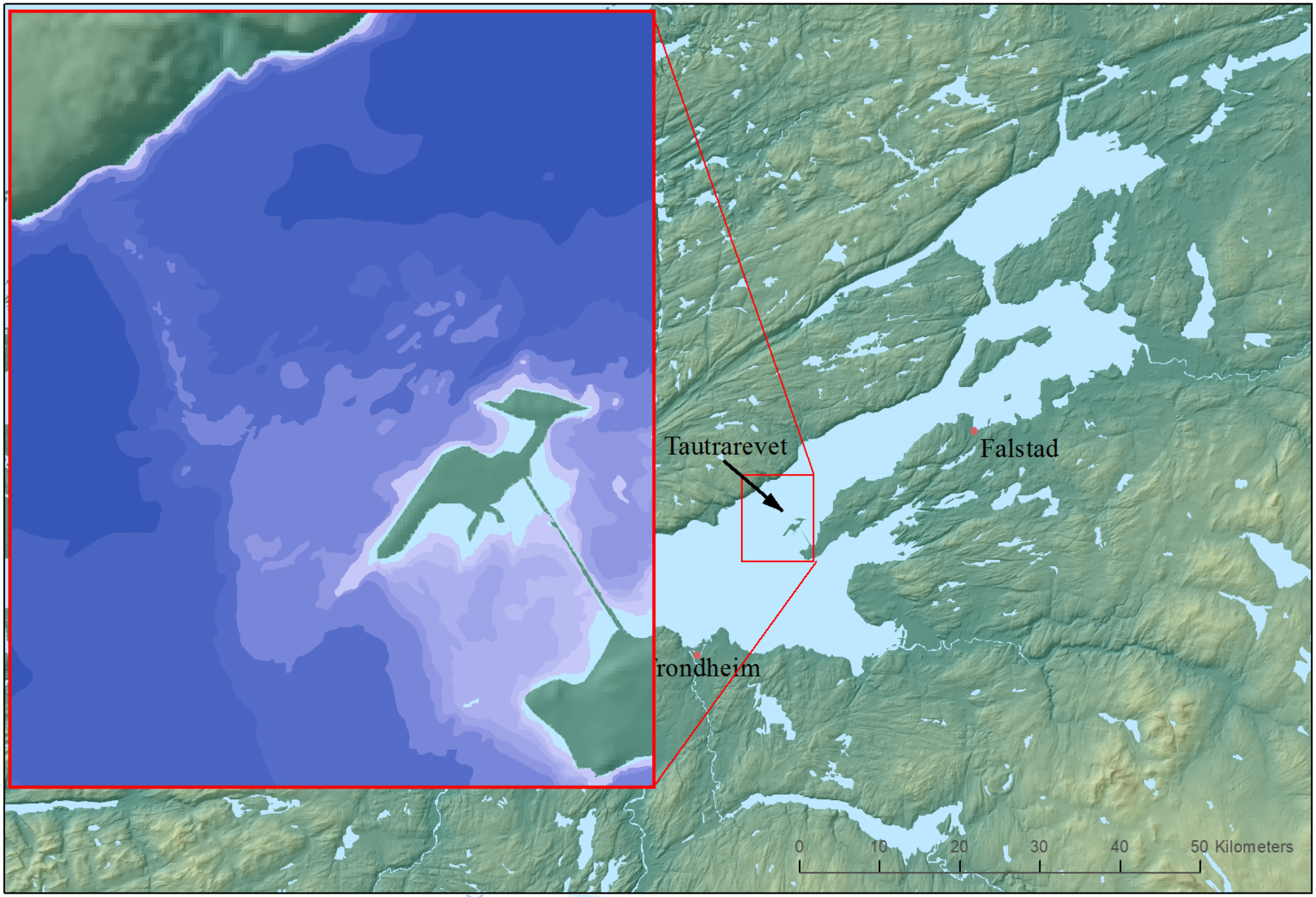

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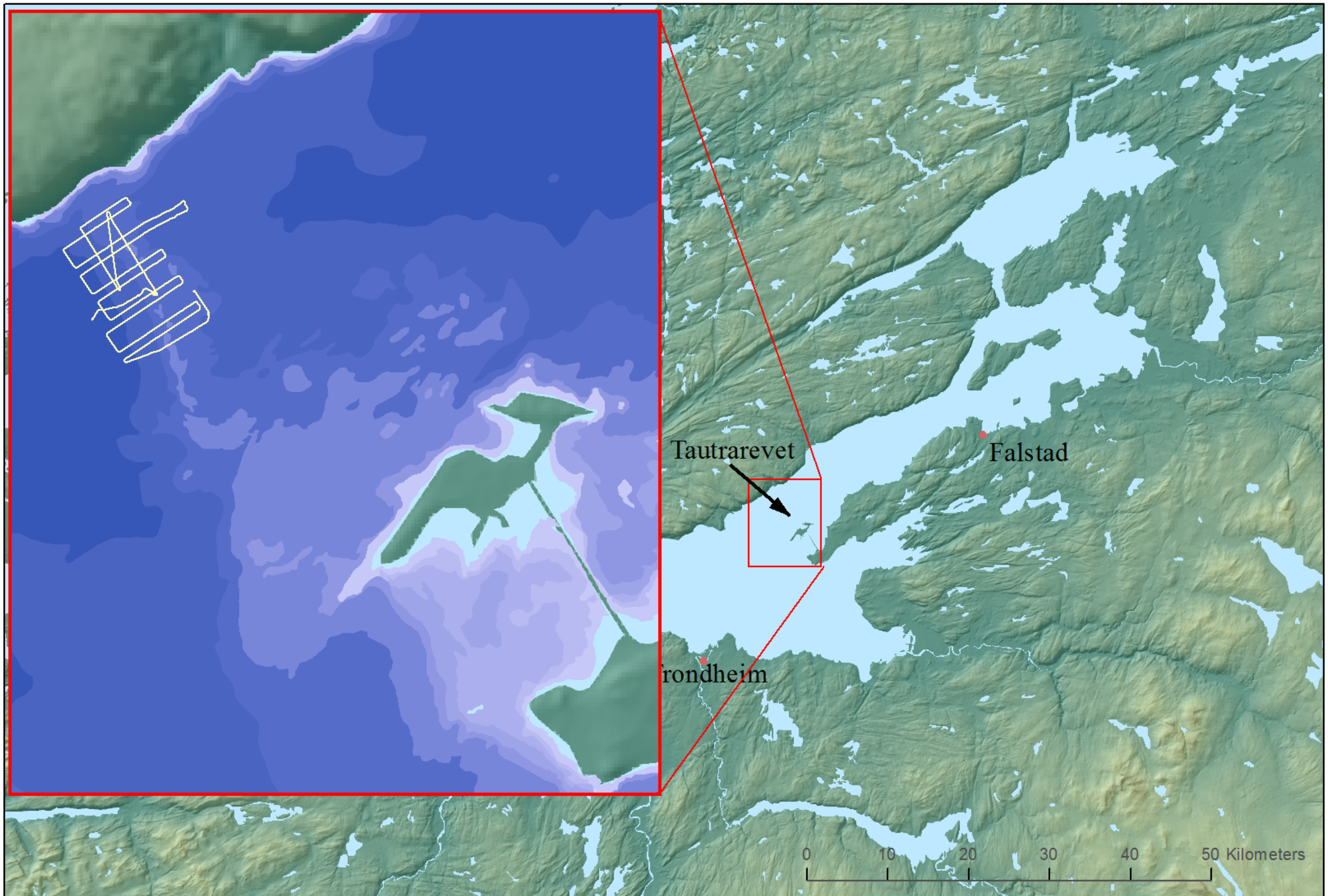

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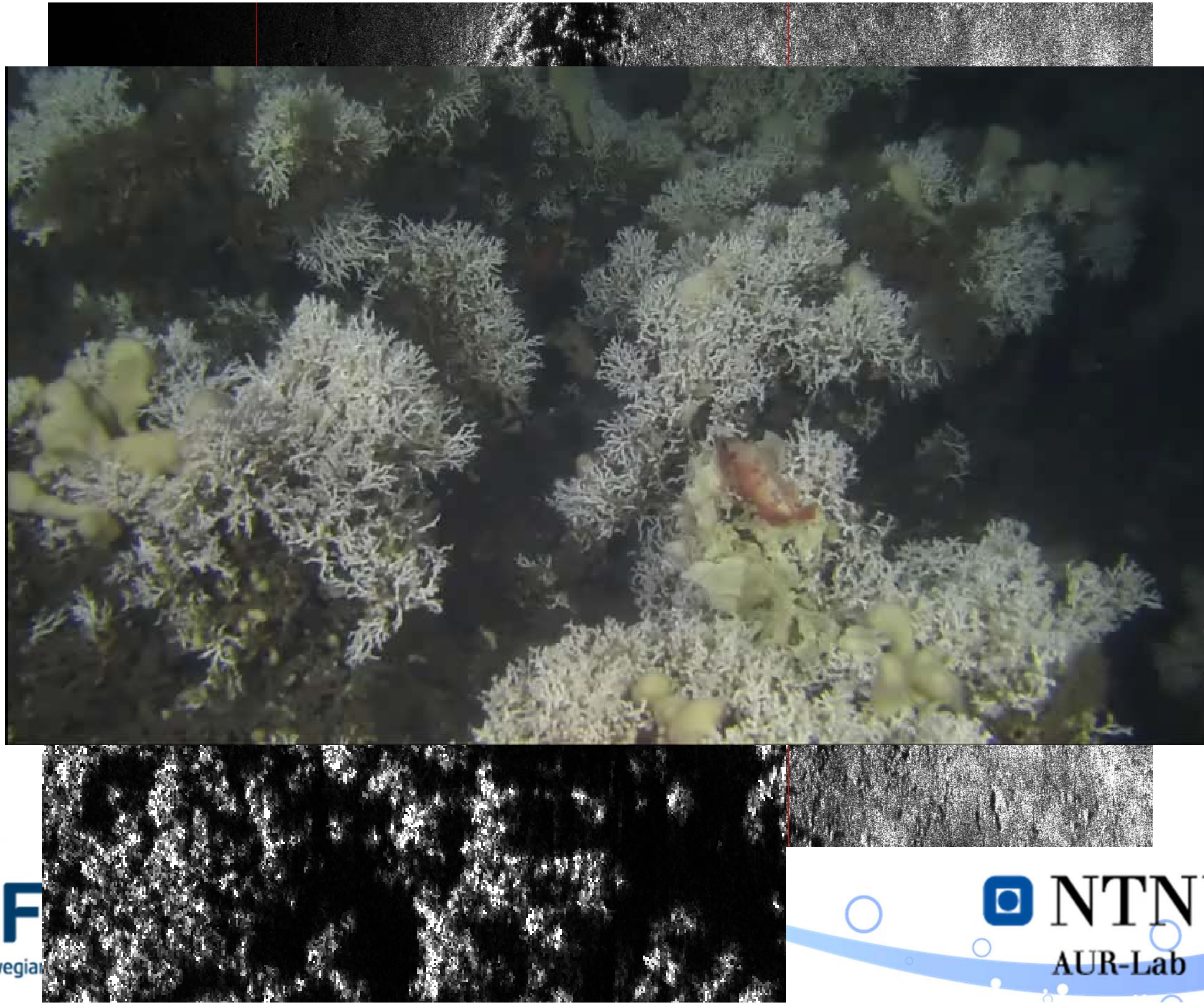

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Photomosaic recorded by ROV

Tautra, Trondheim Fjord