SCIENCE & TECHNOLOGY ORGANIZATION
CENTRE FOR MARITIME RESEARCH & EXPERIMENTATION

Robotics at CMRE: an overview

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Centre for Maritime Research and Experimentation (CMRE)

CMRE* is a world-class NATO scientific research and experimentation facility established in 1959, focussed on the maritime domain, located in La Spezia, Italy (employed about 143 people – 50 scientists)

CMRE conducts research in autonomous systems, ocean science, modelling and simulation, acoustics and other disciplines, focusing on disruptive and potentially game changing innovation:

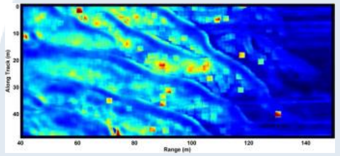
developing multi-robot, autonomous systems equipped with novel sensing technologies for effective and pervasive monitoring of the oceans

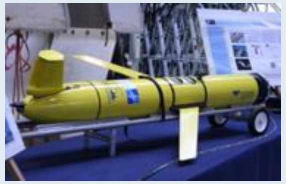
**Formerly the NATO Undersea Research Centre (NURC)*

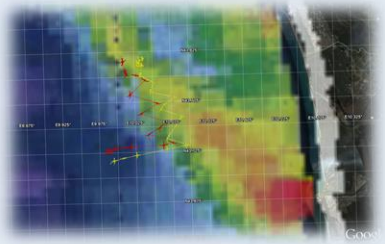
CMRE main programme areas

- **Autonomy for Anti-Submarine Warfare (A-ASW)**
- **Autonomous Naval Mine Countermeasures (ANMCM)**
- **Environmental Knowledge and Operational Effectiveness (EKOE)**
- **Decision Knowledge and Operational Effectiveness (DKOE)**
- **Maritime Unmanned Systems Enablers (MUSE)**
  - Multi-Domain Control System (MDCS) Working Group (STANAG 4817)
  - SCI-288/343 Autonomy in Communication-Limited Environments
  - JANUS: first digital underwater communications standard
  - Modeling & Simulations
- **Climate Change and Security**

OEXs with towed hydrophone array



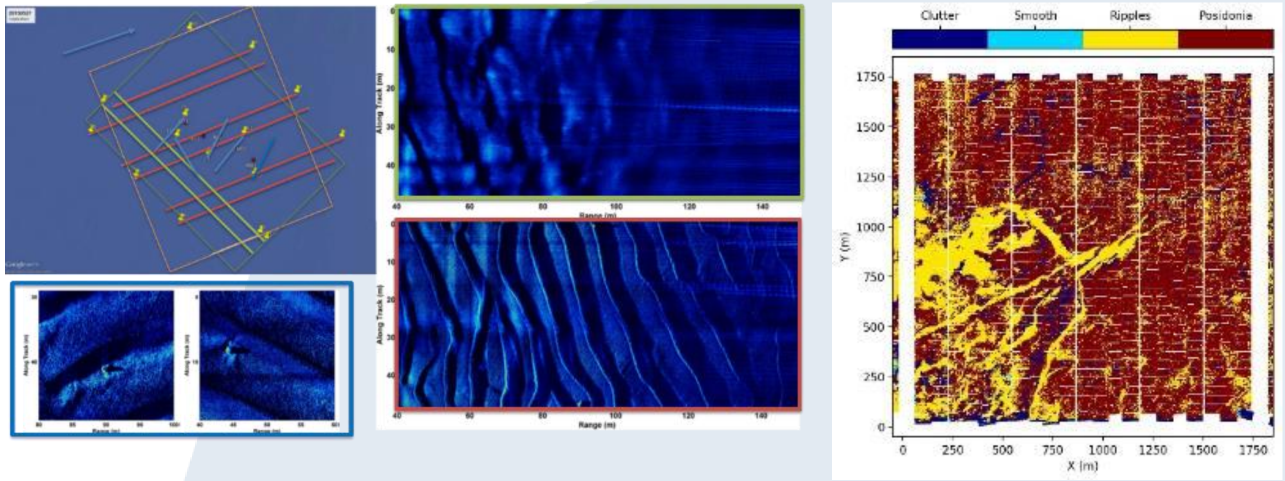


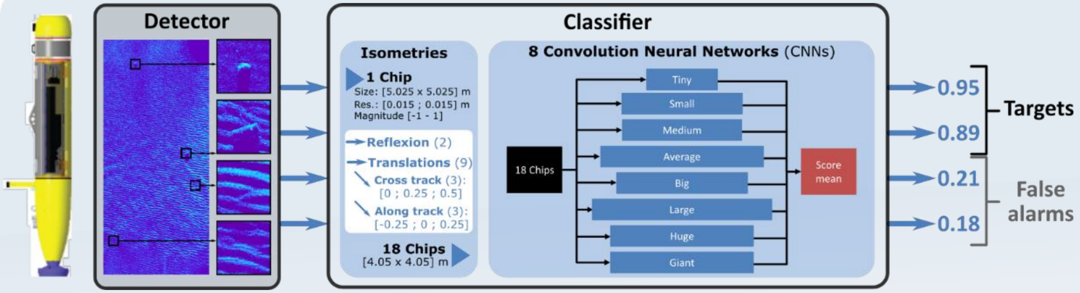


ANMCM
Autonomous Naval
Mine Countermeasures

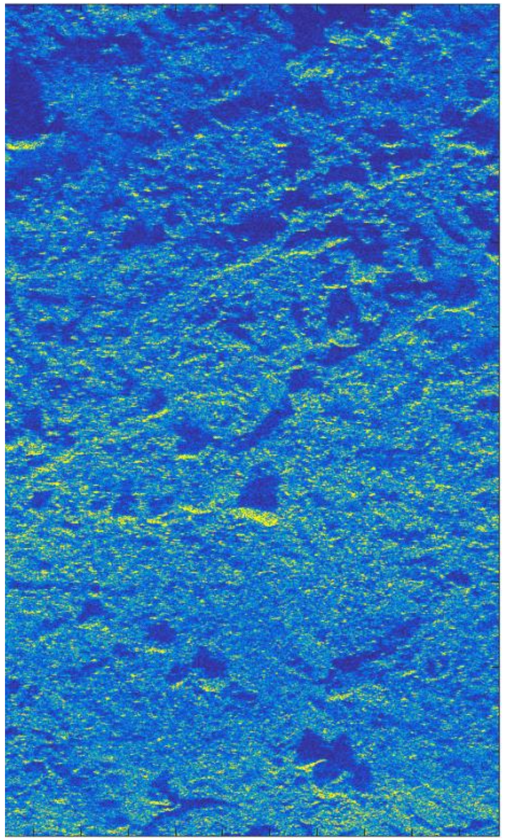
Autonomous Naval Mine Warfare

- Objectives: **Improve efficiency, effectiveness and overall performance to reduce risk**
- Focused currently on shallow water (10 – 100 MSW) environment, proud targets on seafloor
- Parallel activity on drifting mines localization and tracking
- Sensing including novel sensors, AI-based perception, decision making, and autonomy running in real time on sea-going interoperable platforms
- Autonomy as a *development multiplier*: increase quantity and quality of relevant data for future gains in entire system
- Interoperability and interchangeability as a *force multiplier* for greater robustness and resilience





Details in CMRE reports

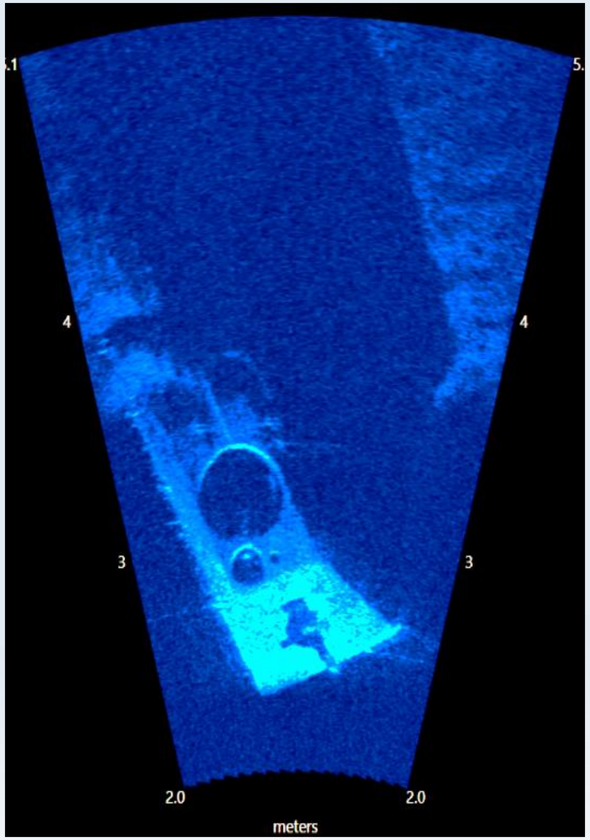


MUSCLE AUV

Prototype platform for wide area search

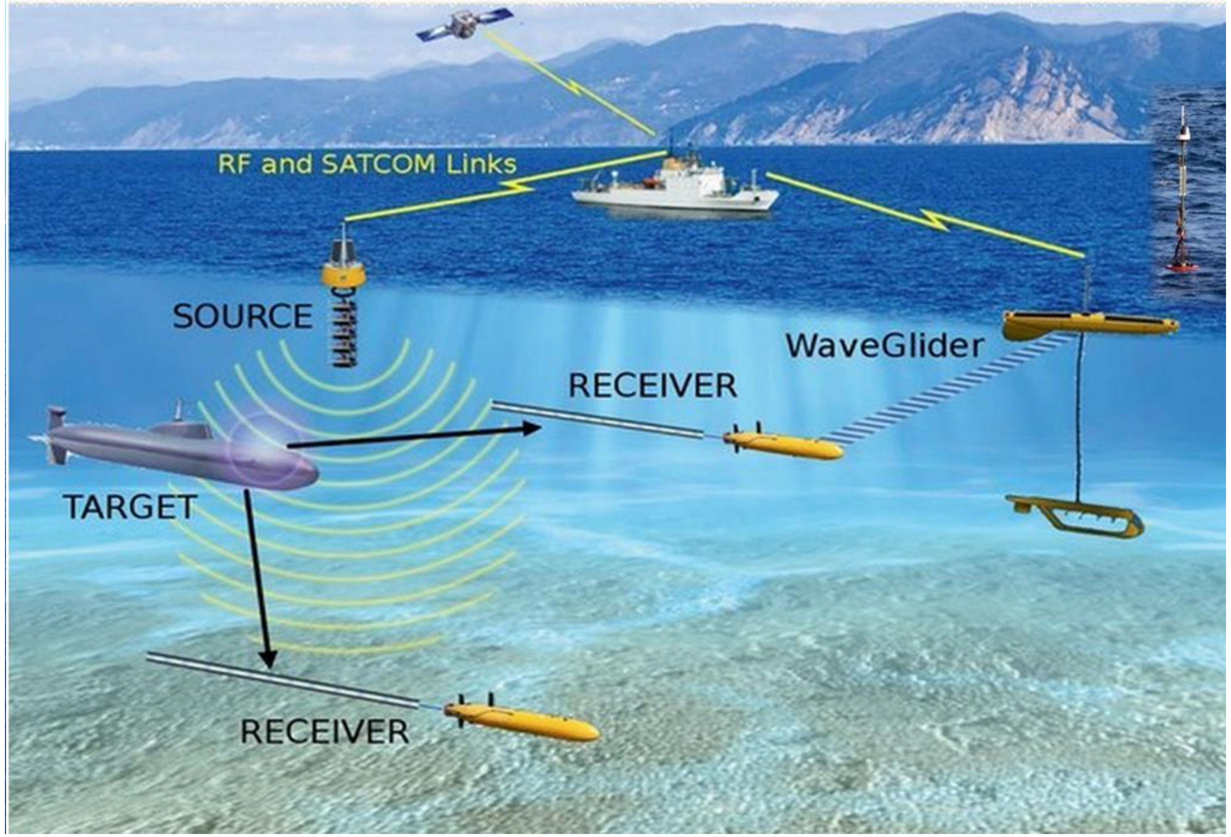
BIONDo AUV

Prototype platform for acoustic ID



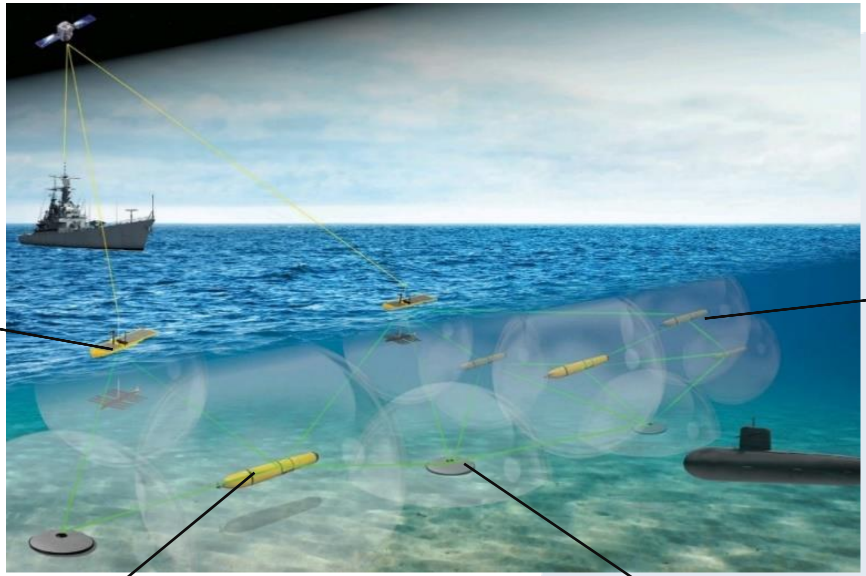
A-ASW
Autonomy for
Anti-Submarine Warfare

Active multi-static robotic network approach



- Based on **sensorised AUVs** acting as **autonomous mobile nodes** in a multistatic network.
- Multistatic sonar systems significantly increase ASW coverage and performance
- The network offers **scalability, redundancy**, **robustness** and **persistency**
- **Reduced costs** in respect of traditional means
- **Cooperative decision-making and data sharing/fusion** (range and bearing measurements) to increase the performance in the difficult shallow water sonar scenario

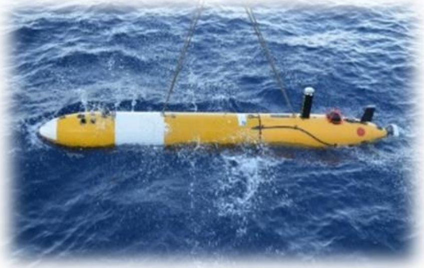
Cooperative Autonomous Passive Network



2x Wave-Glider sensorised and/or comms relay

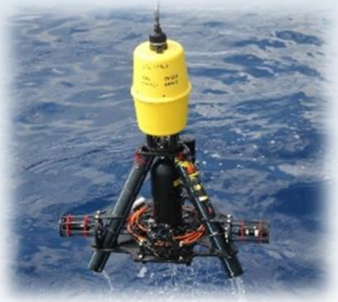
2x SLOCUM acoustic gliders

2x OEX-C with VESPA AVS array & ULAs

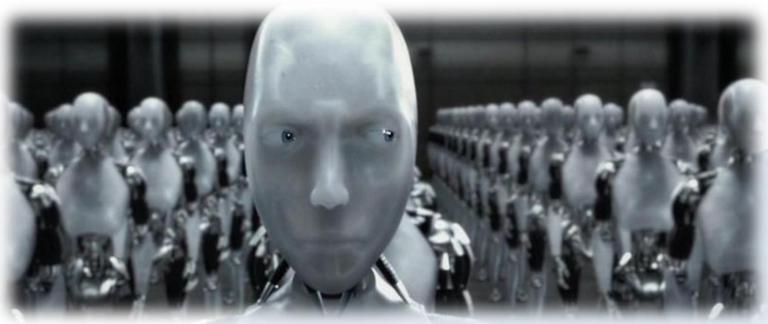


Top side on NRV Alliance

3x BONO
Bottom Nodes with a suite of acoustic and magnetic sensors

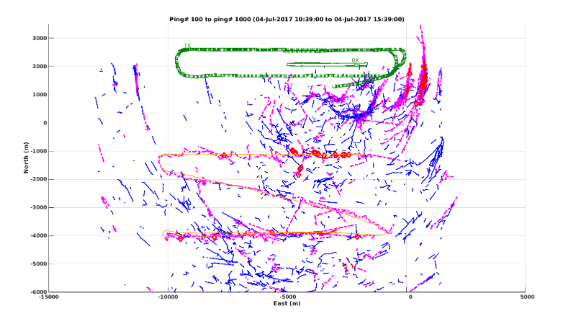


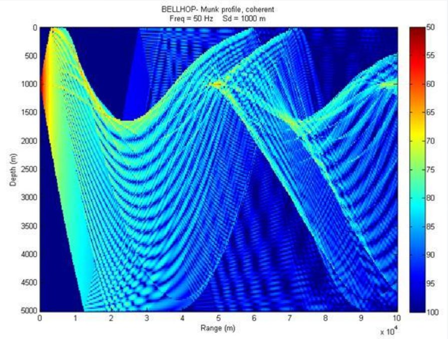
How to manage these complex multi-asset systems in real-world conditions?



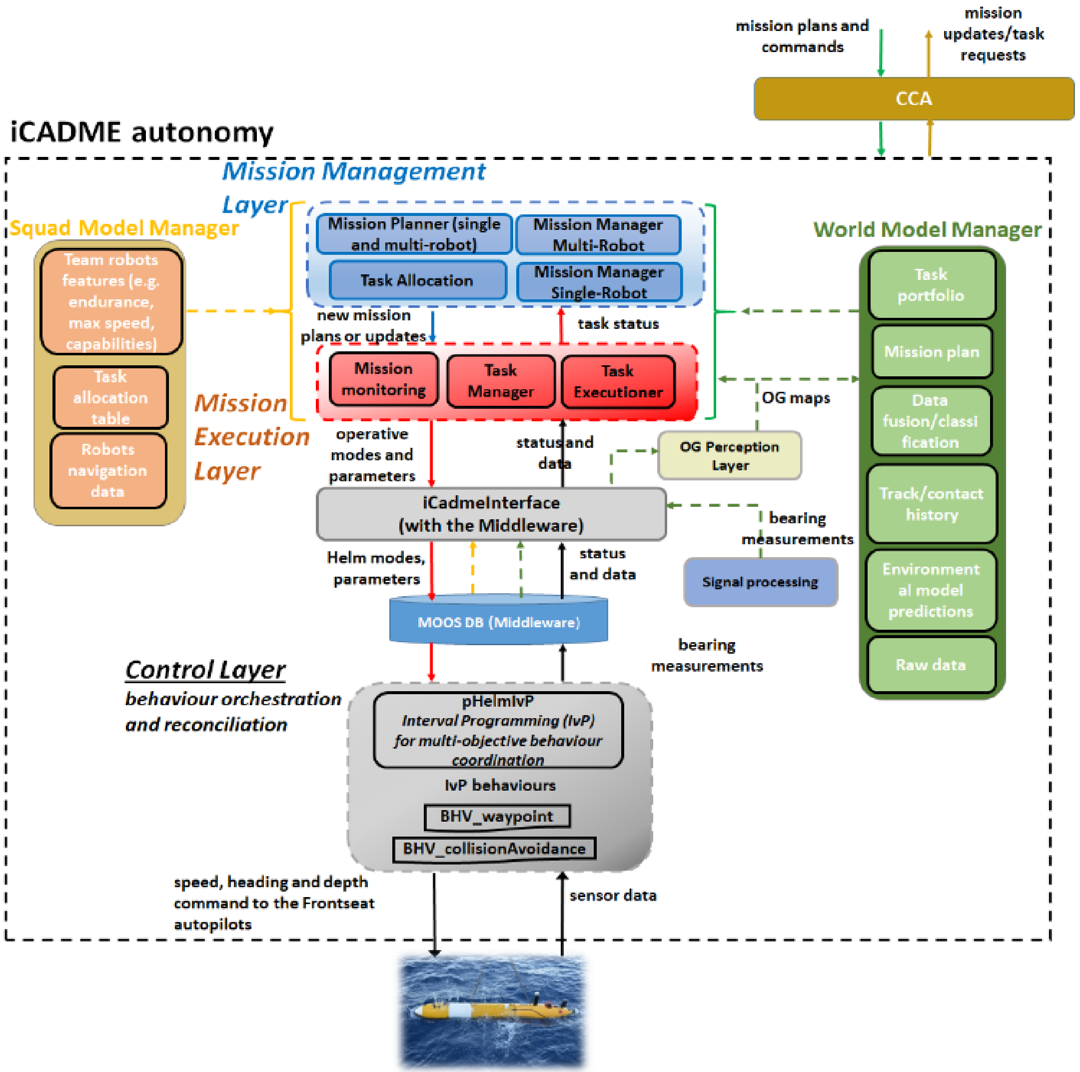
- Challenges in sensing
- Limitations in comms
- Impossibility to have a reliable link between C2 and robots

Autonomy and cooperation to control complex robotic networks and to increase mission performance





iCADME 2.0: a modular autonomy architecture for heterogeneous networks



iCADME autonomy Framework

Manages the on-board cooperative intelligence, making decisions on the robot behaviors and actions:

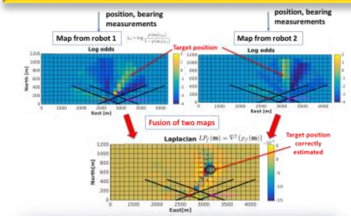
- Support to **cooperation** and advanced cooperative **autonomy**.
- Platform and middleware **agnostic**.
- **Modularity**, code re-usability.
- **Scalability** on heterogeneous assets.
- Ease to design complex autonomous missions by assembling **tasks** and **behaviours** from a CMRE portfolio.

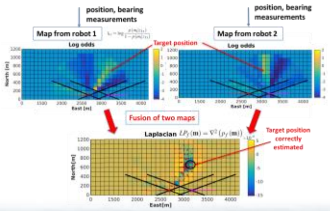
Real Use case 1:
REPMUS21 TD localizing a sub in a distress experiment

NRV Alliance C2 and data fusion node

iCADME Autonomy

iCADME Autonomy



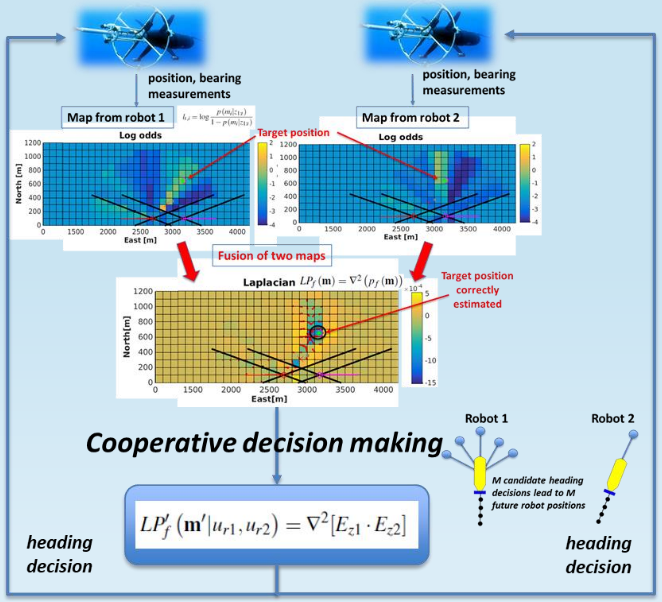


Nav, bearing contact messages

Topside Commands

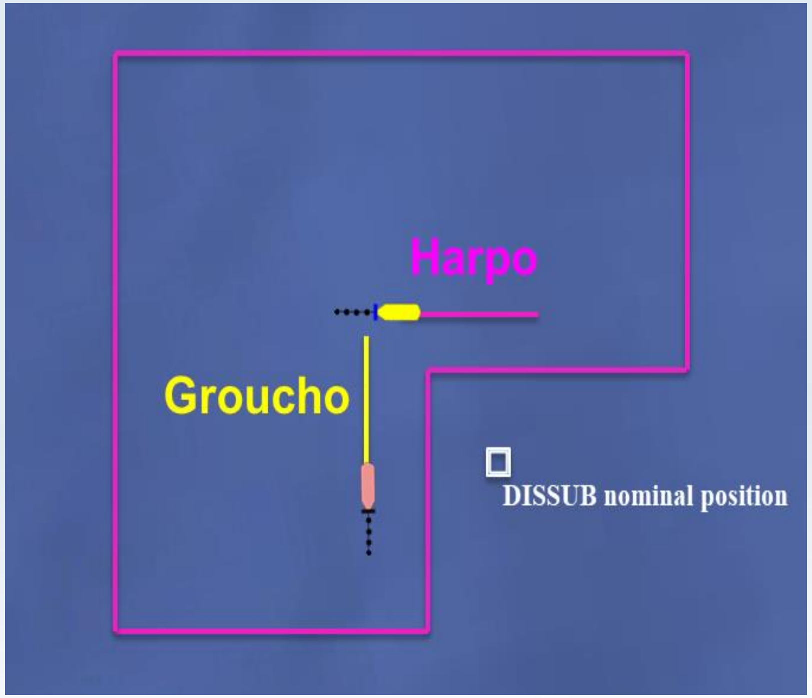
Occupancy Grid framework for cooperative autonomy

- Data fusion and target localization
- Guide the area survey
- Basis for cooperative decision-making

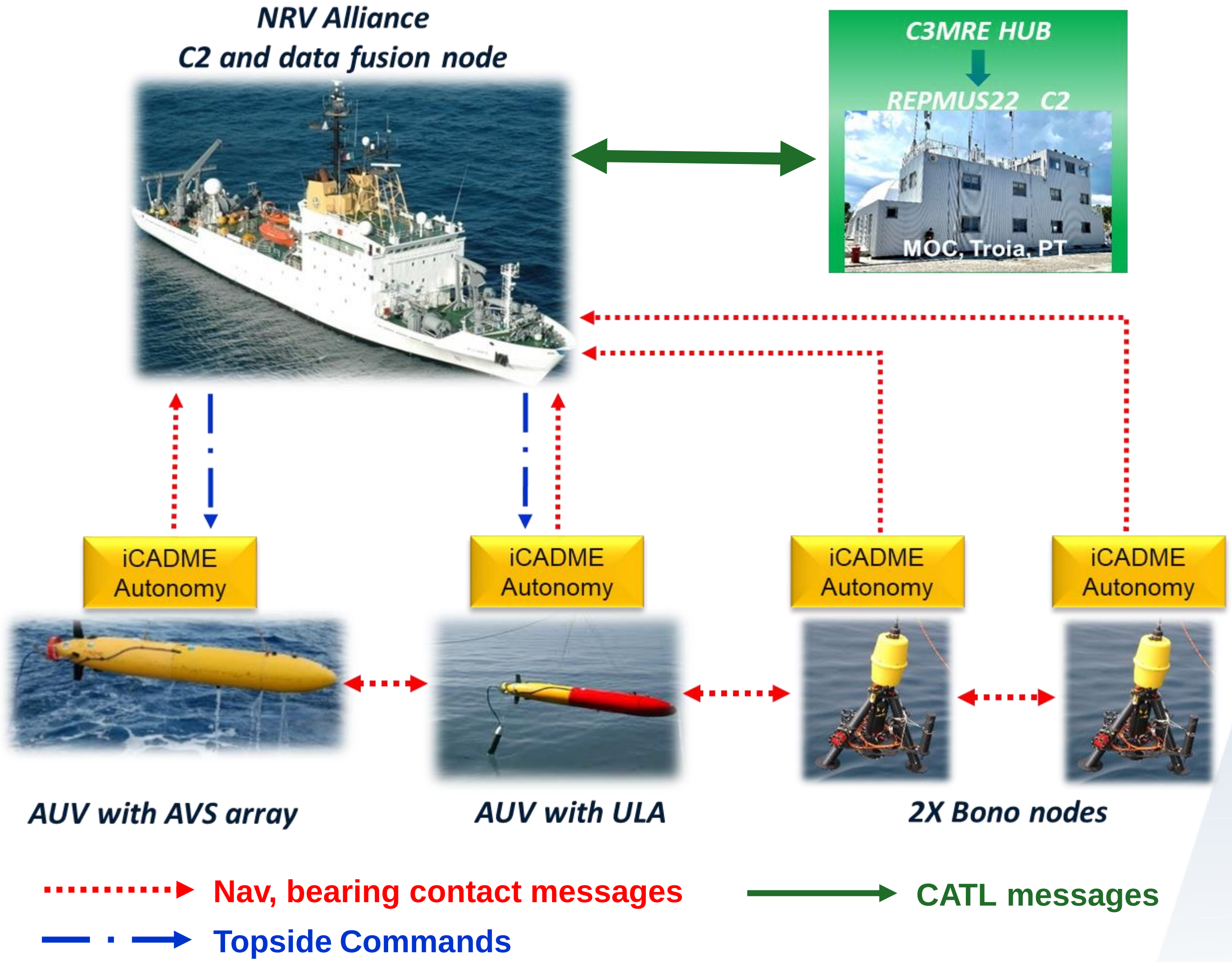


$$LP'_f(\mathbf{m}'|u_{r1}, u_{r2}) = \nabla^2[E_{z1} \cdot E_{z2}]$$

Details in [Ferri et al. 2020 a, Ferri et al. ICRA 2023]



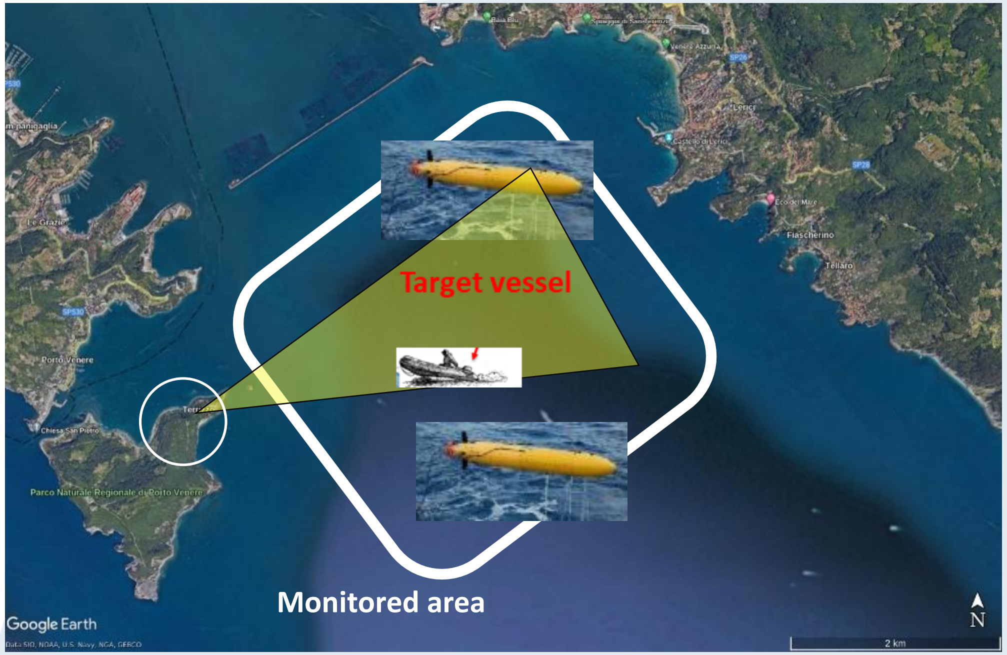
Real Use case 2:
REPMUS22-DYMS22 - heterogeneous autonomous robotic network



- Heterogeneous network composed of both **Fixed** and **Mobile** nodes
- The framework enables **real-time data fusion** for target localisation
- **iCADME** autonomy architecture controlled **multi-task**, cooperative robot missions
- **Cooperative** robot navigation cooperative adaptation: Autonomous real-time spatial reconfiguration of the network benefits mission performance (e.g. target localization and tracking)
- Network **fully integrated** with the MOC (REPMUS command and control centre) via CATL messages (protocol for interoperability of autonomies **developed by the** NATO SCI-343 panel)

Real Use case 3: INFORE network for maritime situational awareness (MSA)

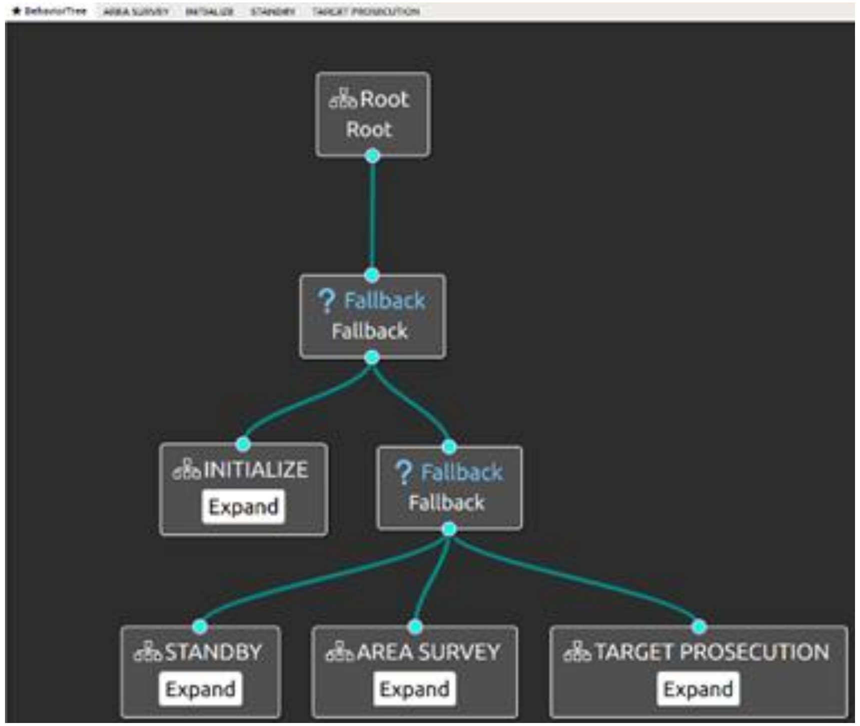
- Use case: A coastal area needs constant surveillance and improved MSA.
- Autonomous Underwater vehicles are deployed in the area as silent agents
- INFORE system **detects a vessel** with AIS off and entering a protected area
- The hybrid robotic network **cooperatively and autonomously acts to detect** and track the target
- Data related to target detections are sent to the INFORE system, that is capable of **data fusion** and **complex event detection**: e.g. fishing
- UAV is sent on site to identify and classify the vessel



C2 area is set up with:

- x 2 OEX-C AUVs with ULAs
- 1 Parrot ANAFI 4k UAV.
- Thermal camera.
- Satellite data

iCADME 2.0: using Behavior Trees for mission planning and execution



BT the multi-task mission executed at sea during MEDASWAN23

From Finite State-Machine (FSM) to Behavior Trees (BT) for mission planning and execution

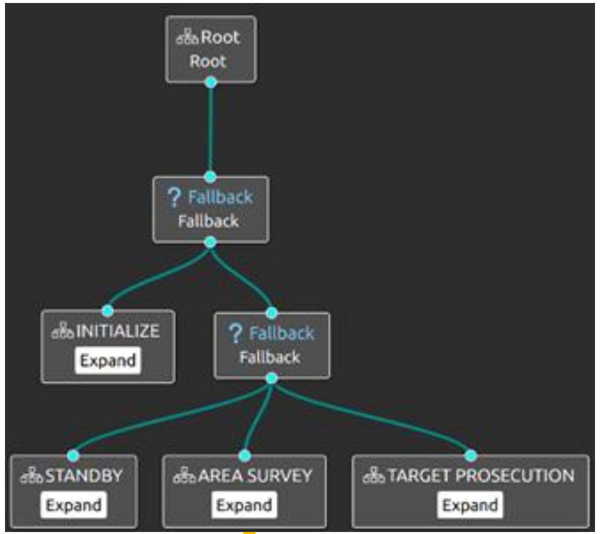
Why BTs are preferable to FSMs?

- **Maintainability**: transitions in BT are defined by the structure. Nodes can be designed **independently** from each other.
- **Scalability**: when a BT has many nodes, it can be **decomposed** into small sub-trees saving the **readability** of the graphical model.
- **Reusability**: due to the independence of nodes in BT, the subtrees are also independent. This allows the reuse of nodes or subtrees among trees or projects.

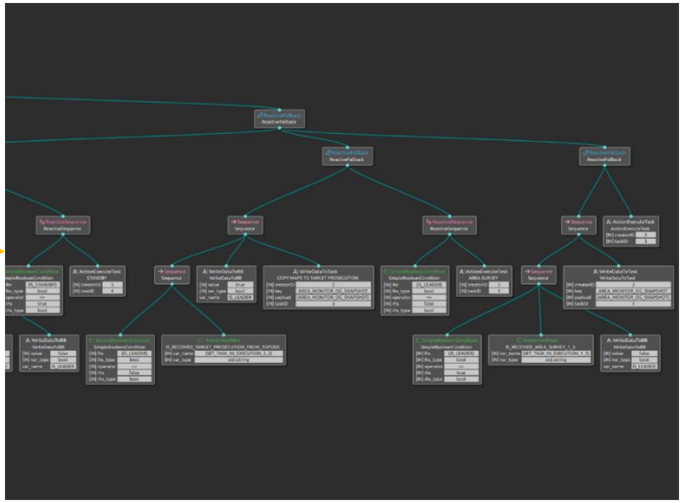
These features of modularity and reactivity open new horizons in terms of mission creation (also using graphical tools) and planning, facility of code re-use among different missions and testing.

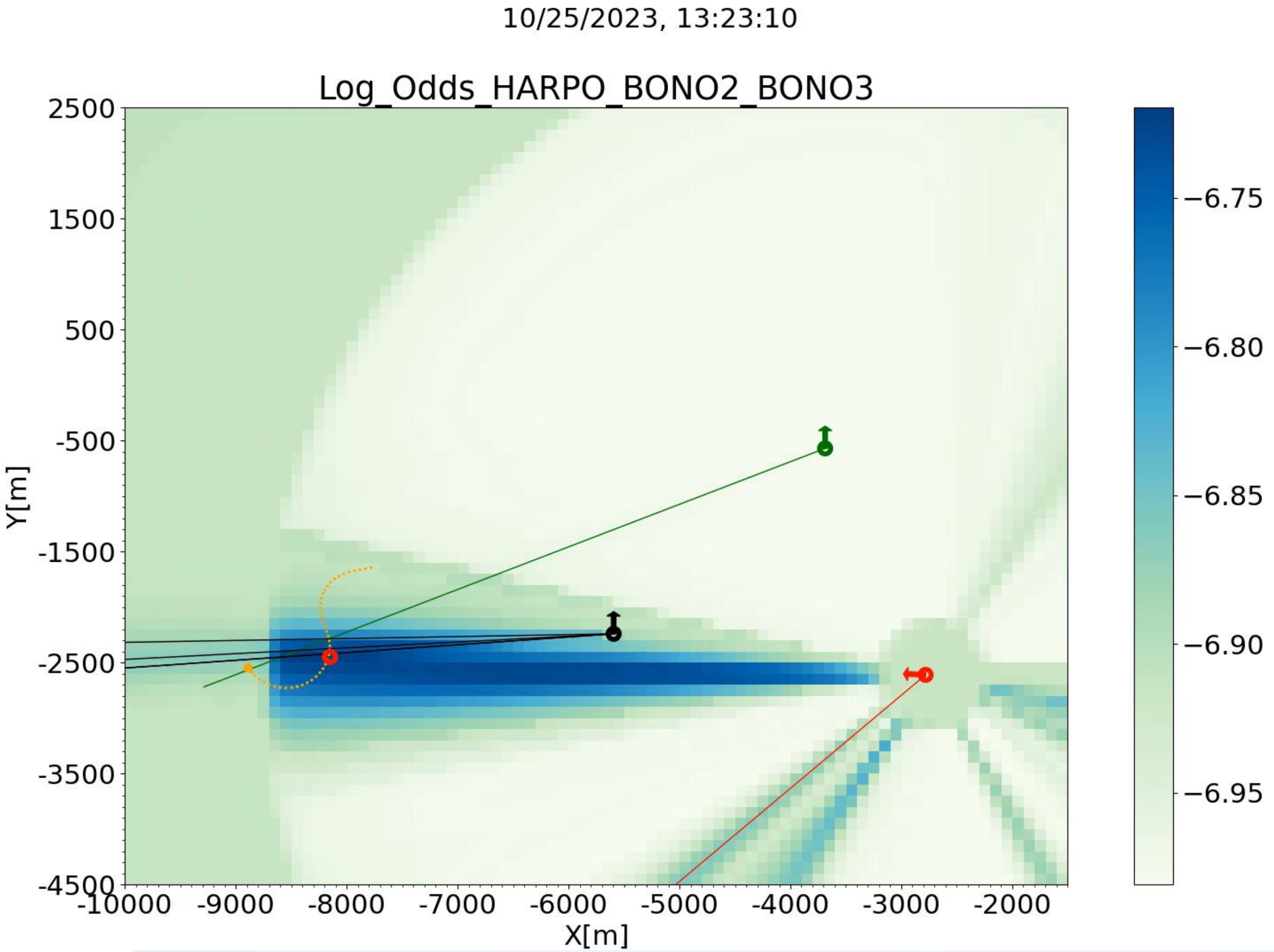
This supports the mission designers in expanding or combining existing missions to create complex multi-task missions even at real-time.

A BT-managed, multi-task, multi-robot, cooperative mission



BT design of a **multi-task**, **multi-robot** mission, based on cooperative autonomy and **real-time data fusion**





Execution of the designed mission at sea during MEDASWAN23 in real time: results on board Harpo fusing BONO2 and BONO3 as remote nodes

Robotics Competitions at CMRE since 2010

2010

Student Autonomous Underwater Challenge- Europe (SAUC-E)

- **Marine** domain
- **Realistic** underwater competition, set in a real sea water basin
- Targeting students

2015

euRathlon Grand Challenge

- First world's competition with **cooperative land, marine and aerial robots**
- Inspired by Fukushima disaster
- Held at Piombino power plant

2017

European Robotics League (ERL)

- **Land**, **marine** and **aerial** domains
- Held at Piombino power plant

2019

ERL Emergency (2018-2019)

- **Marine** and land domains
- Harbour disaster @CMRE basin

2022/2023

RAMI Competition

- **Marine** domain
- Focus on **Inspection & Maintenance**
- @CMRE basin

Conclusions

- MUS **revolution** is happening
- **Autonomy, AI**, data fusion and **network of robotic nodes** as drivers to increase MUS performance
- Demonstrated at sea the **effectiveness** of cooperative autonomy solutions as key to overcome environmental challenges and manage **multi-task missions**
- Ongoing work at CMRE on the use of environment model to support **decision-making**
- Proposed paradigm results **usable** in **real-world** applications
- Effective autonomous systems that work in **real-world** applications, require architectures that are modular, extensible and scalable
- MUS **liability, classification, standardisation, safety,** and **security** need to be defined (ongoing work at CMRE starting from a WaveGlider case study)

Thanks for your kind attention!

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