SWARMs

Smart and Networking
Underwater Robots in Cooperation Meshes

SWARMs Newsletter #4 July 2018

SWARMs Final Demonstrations

The second, and final, set of SWARMs demonstrations took place at Trondheim fjord, in Norway, during the last week of June 2018. This final milestone event was preceded by multiple local testing involving different maritime robotic vehicles and support platforms, which were carried out since early May. These trials allowed the consortium to test and validate the final integrated version of SWARMs system.

Following a similar approach as adopted in previous SWARMs demonstration massive deployments, in Gran Canaria and at the Black Sea, the following planned missions were executed:

Main Mission: Plume Detection Mission

Mission 1: Detail Seabed Inspection

Mission 2: TNO High Speed Acoustic Link Demonstration

Mission 3: NAIAD Seabed Inspection

Simulated Missions:

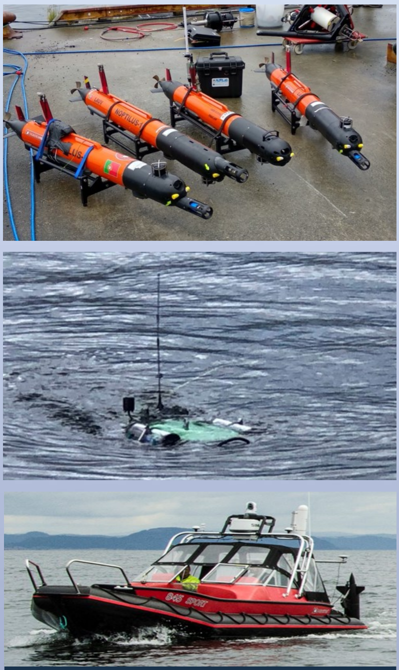
- Semi-autonomous Manipulation
- Plume Detection Mission
- Docking Maneuver

The objectives set for SWARMs second set of demonstrations were successfully achieved in Trondheim. The collaboration work performed by all partners allowed the validation of the technical developments carried out throughout the three years of the project.

The success obtained in exchanging data among the involved maritime robotic vehicles through the use of the developed SWARMs communication network and middleware, allowed to demonstrate the full integration of distinct robotic vehicles in the SWARMs system, specifically towards the considered Plume detection use case, which was at the core of the Main Mission.

The achieved hardware and software integration involved multiple heterogeneous technologies, e.g. based on RF and acoustics, as well as ROS and DDS, to allow seamless reliable data exchange in offshore missions, managed by the MMT and supported by vehicles' onboard autonomous and semi-autonomous capabilities.

SWARMs team at Trondheim, Norway



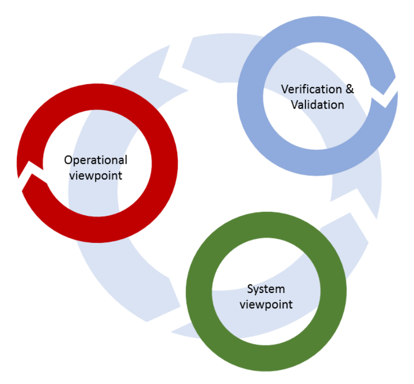
Vehicles used in the Final Demos

Further in this issue

- Verification and Validation
- Mission planning and supervision
- Environment data in SWARMs CAF
- Communication system V&V
- Robotic vehicles integration
- Semi-autonomous manipulation
- Simulation of 3D path planning

Verification and Validation

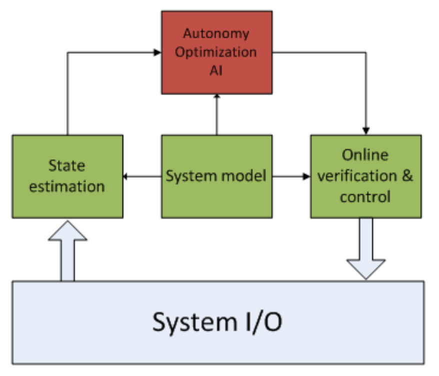
The SWARMs Methodology for development of autonomous systems consists of three viewpoints. The methodology is generic and have both been used in, and improved by the project. The operational viewpoint was important to ensure that all the partners had a common view on what was going to be developed. Verification and validation in SWARMs project have been an incremental process with several physical integration meetings and three demonstrators, one on each year of the project. In general, the challenge with verification of autonomous systems is the large number of outcomes.



SWARMs Methodology viewpoints

Challenge 1
Large number of outcomes – Online verification and control

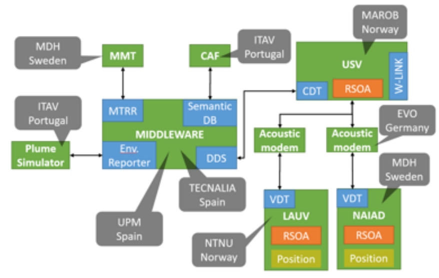
One method of solving the large or infinite number of outcomes for an autonomous algorithm is to use online verification with an easy to verify model of the system, supervising certain parameters. The LAUVs used for the final demonstration in the fjord of Trondheim are equipped with such simple models from the manufacturer. The LAUV will for example autonomously abort a mission if the mission lasts longer than a preconfigured time. The vehicle will also abort the mission if it dives deeper or faster than preconfigured limits. In the figure the difficult to verify autonomous algorithm is illustrated in read, while the easy to verify state estimator, the system model and the online verification and control algorithm are illustrated in green.



Online verification and control

Challenge 2
Spread across Europe – Virtual integration & simulation lab

SWARMs software (SW) components were made by different partners across Europe as illustrated in the figure. The partners listed are the partners appointed responsible for serving the system integration. Several other partners participated in SW development. In addition to physical meetings, the Internet was used for virtual integration. A simulation lab was set up in Trondheim, with remote access, in order to provide confidence in the system before testing offshore.



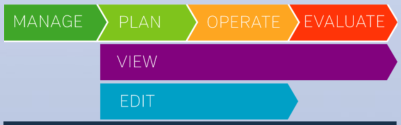
SWARMs SW integration

Challenge 3
SW in TRL7 Environment – Simulation & small increments

SW was developed towards TRL4-5. Trondheim fjord, where the demonstrations took place, is large and deep. This implies a large risk of loosing equipment worth hundreds thousand EURO. Key factors for addressing this: 1) upfront integration activities; 2) always simulate the mission before deploying vehicles; 3) do small steps during the offshore mission, starting with simple operations with one vehicle and add one functionality at a time; 4) having an experienced mission leader, building a strong operational team of SWARMs partners supervising the operation.

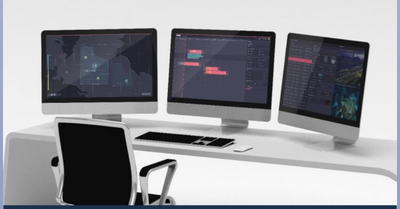
GUI Guidelines

Guidelines for development of graphical user interface (GUI) have been made as part of the methodology. The guidelines were used for implementation of the Mission Management Tool (MMT). The operational work flow, architecture, layout, as well as detailed use of color graphics and icons were developed for SWARMs and similar projects. The workflow is illustrated below.



SWARMs GUI development

The considered three screen SWARMs Command and Control Station (CCS) is illustrated below, consisting of an actor manager screen, a timeline screen and a map screen. Detailed information is normally hidden to the operator, and are available via few clicks.



SWARMs three screen CCS

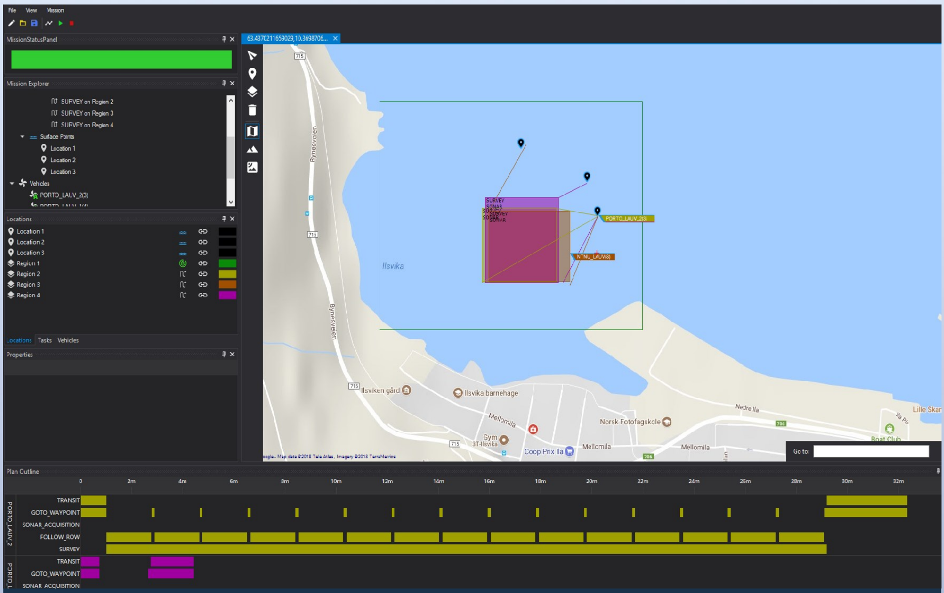
More on simulators

Different kinds of simulators have been developed in SWARMs. A Gazebo-based simulator was used for visualization and demonstration of functionalities that time did not allow to demonstrate offshore. Also, a plume simulator was used in the main mission demonstration, allowing optimizing mission area.

Realistic vehicle simulators were used during V&V activities. Also, an advanced acoustic modem simulator was used, allowing full scale SWARMs integration testing setups, as illustrated here in the figure on the left.

Mission planning & supervision

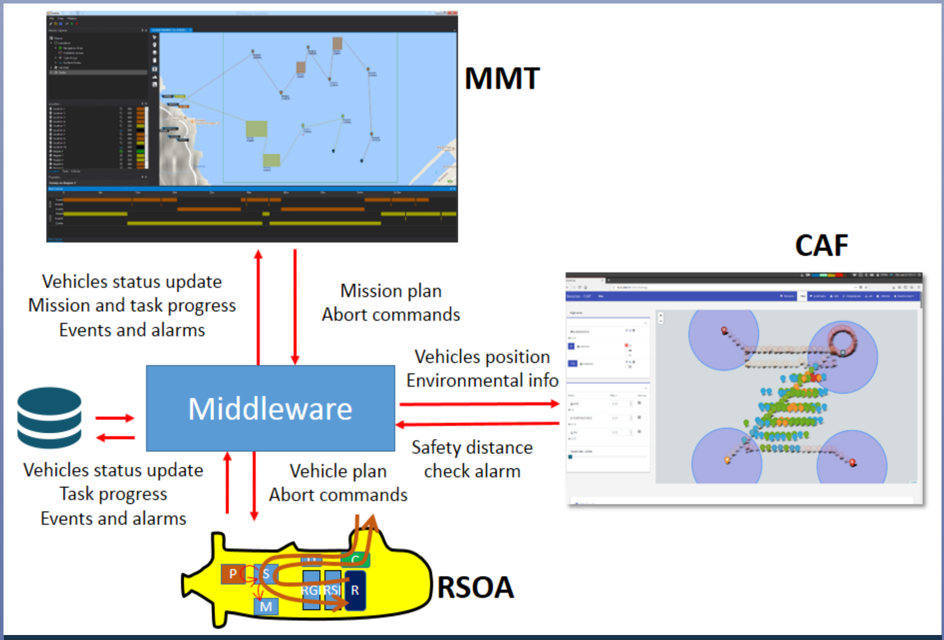
SWARMs Mission Management Tool (MMT) provides the operator with a GUI and algorithms for mission definition, (re)planning and execution; progress monitoring and supervision of tasks and vehicle status; and mission abort in case of alarms.



SWARMs Mission Management Tool

A DDS based semantic middleware ensures the communication and coordination of the swarm of maritime and underwater robotic vehicles, regardless of type, manufacturer and capabilities, when executing mission tasks defined by the MMT.

The MMT sends the mission plan to the middleware, which forwards the tasks to the appropriate vehicles. Besides, the middleware receives from each vehicle its status update, the progress of the tasks and events or alarms indicating abnormal behaviour. This information is communicated to the MMT and is displayed to the CCS operator. The middleware is also invoked by SWARMs Context Awareness Framework (CAF) to store and retrieve environmental data.



Coordination of maritime robotic vehicles via SWARMs DDS-based semantic middleware

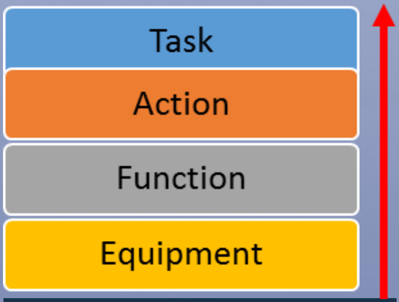
Mission Planners

High level planners assign vehicles to sorted tasks optimizing overall time of the mission and taking into account vehicles' capabilities and battery status.

- Constraint Programming Temporal Planner (CPTP)
- Genetic Mission Planner (GMP)
- Harmony Search Planner (HSP)
- 15-Puzzle

Event Reporter

Reports any event or abnormal behaviour at different functional levels. The lowest level is the equipment level, indicating that some equipment (SONAR, IMU, etc.) raised an alarm. The function level corresponds to atomic (propulsion, direction, localisation) or complex functions (navigation). The action level corresponds to robot capabilities (FOLLOW ROW, GOTO WAYPOINT). Finally, the most complex actions are gathered in the task level (INSPECT, TRANSIT, SURVEY, PICK_UP). A low level event propagates up in the functional architecture.



Event functional architecture

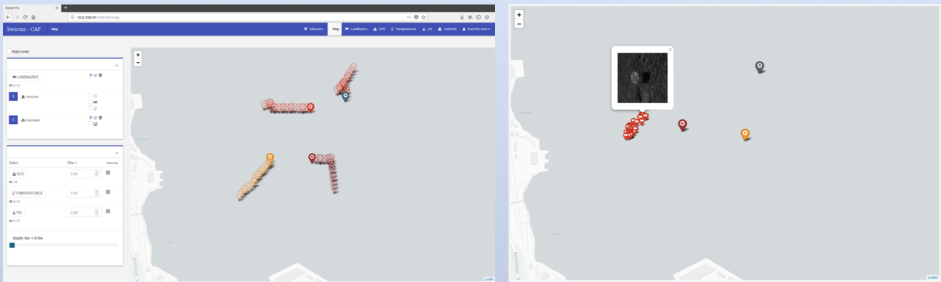
Mission abort

Two types of abort commands:

- Soft abort: The current action is aborted. The vehicle waits for further instructions from RSOA;
- Hard abort: All the actions are aborted. The vehicle will then float to the surface.

Environment data in CAF

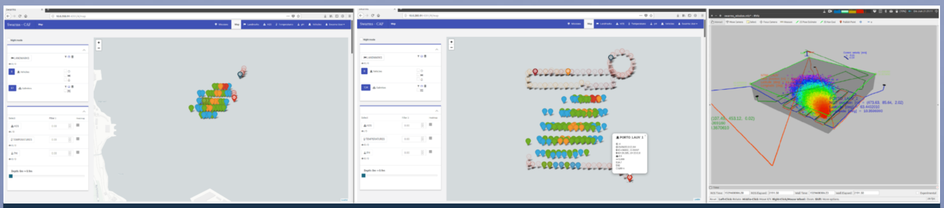
SWARMs Context Awareness Framework (CAF) makes available in its GUI both vehicles situational and environment data, which allows the CCS operator(s) to monitor and eventually take informed decisions on a mission progress. The figures below illustrate the representation of such distinct data, in this case, the position history of vehicles (tracks) involved in a mission, and also one of the extracted landmarks acquired after post-mission offline processing.



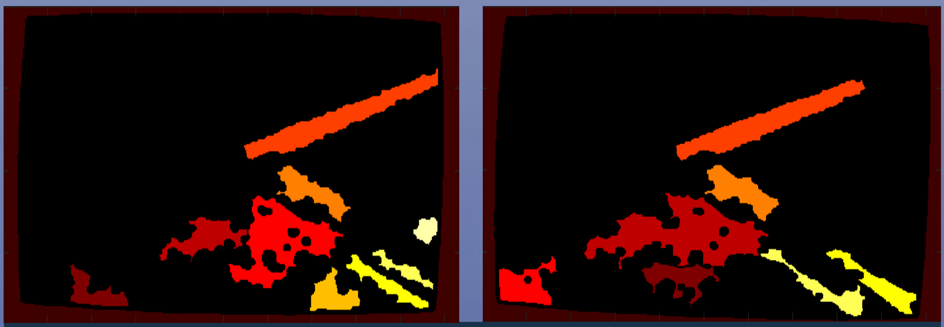
Situational and Environment data representation in CAF GUI

In SWARMs Main Mission, executed late June 2018 at Trondheim, the up-to-date position data provided by the vehicles involved in the mission were used by SWARMs middleware to query in real-time a wastewater Plume Simulator in order to associate the respective simulated salinity measurements to each vehicles' positions. The acquired simulated measurements are stored in SWARMs knowledgebase together with the received effective vehicles situational data.

The CAF GUI displays, upon selection, together with other data and information, the collected salinity measurements, which are used to represent the wastewater plume, as they are stored and the plume is discovered in real-time by the involved vehicles, as illustrated in the pictures below. The salinity measurements are represented in different colour gradients according to their salinity level, being the red colour used to represent salinity measurements below 5 g/kg (closer to sweet water), and blue to represent salinities closer to typical sea water (above 30 g/kg). Effective validation of the appropriate detection of the simulated wastewater plume can be observed in the figures below by comparing the pictures in the center (CAF) and on the right (Plume Simulator).



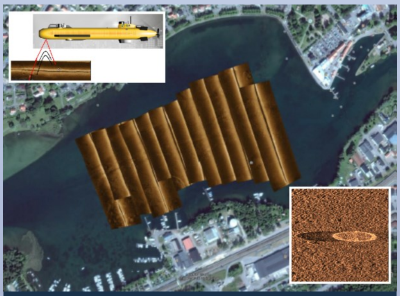
Detected wastewater plume discovered in real-time, and simulated plume (on the right)



Saliency-based stereo matching

UNDROIP toolbox

The UNDROIP toolbox is an open-source software that can be used to process underwater side-scan sonar images. UNDROIP provides many functionalities for side-scan sonar imaging, e.g. image normalization, sea-bottom detection or bottom first returns, landmark detection, registration, speed correction, removal of water column and bathymetric matching. UNDROIP has been developed in SWARMs project within the scope of Environment Recognition and Sensing.



UNDROIP Image Processing Toolbox

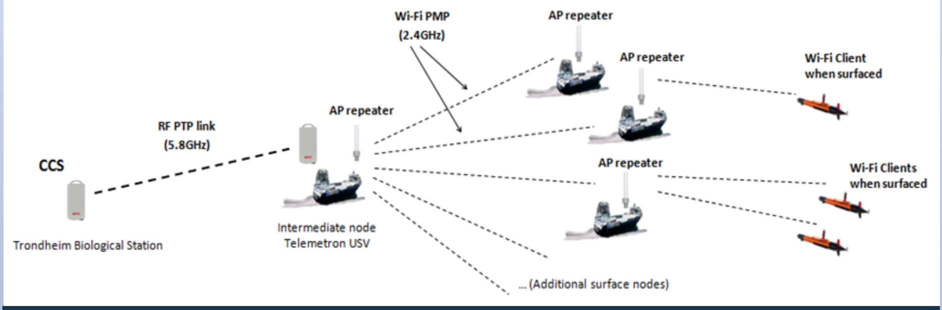
Sonar imaging is currently considered the exemplary choice used in underwater imaging. Nonetheless, as acoustic signals are absorbed by water and due to sound interference, and other related problems, underwater maps obtained from sonar images will be difficult to process.

UNDROIP's objective is to share functions of different methods that can be used, for example, to normalize the images against echo decay, and to perform speed correction, registration, landmark detection, etc. The hope is that these functions are pruned further to better performance, and additional functions to be added in the future by the people interested in such software. An example of outcomes of such newer possible functions can be seen in the pictures here on the left produced by saliency-based stereo matching.

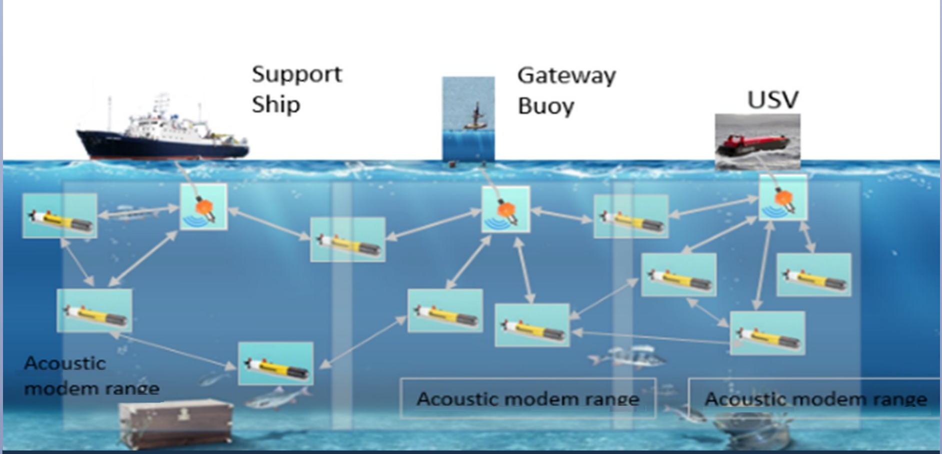
UNDROIP was made in SWARMs and is available at GitHub: https://github.com/UNDROIP/UNDROIP

Communication system V&V

The aim of SWARMs communication system was to provide a reliable, robust, scalable and easily deployable communication network to connect underwater nodes to the ashore control station (CCS). The work done in the three years of the project was addressed to define, implement, test and validate a "general purpose" communication network, able to match the requirements of SWARMs selected scenarios and use cases. This infrastructure was based on commercial hardware and on the development of new components and applications to extended the existing functionalities. The integration of single high performance capabilities allowed to optimize the network performance and to compensate weaknesses of each node and component, as it was successfully demonstrated in all the sea trials performed in operative conditions, including at Norway's last demo missions.



SWARMs communication system entities and nodes in Norway's final demo missions



MANET overwater and underwater communication subnetworks

SWARMs communication nodes and components as used for testing and validation

Nodes integration

Throughout the project, several different communication nodes were integrated in the SWARMs network:

- P2P Radwin RF link
- Up to 7 AP – AP/R Wi-Fi nodes (Ubiquiti Rocket + Ubiquiti Bullet modems and 4 different types of antennas)
- 4 different configurations of surface relay nodes (PLOCAN1, Arctica, Capella, MAROB USV)
- 5 different configurations of surface gateway nodes (PLOCAN2 floating buoy, Leonardo floating buoy, Leonardo SUSV, Manta gateway, MAROB USV)
- 7 different underwater vehicles (ECA A9 AUV, DES SAGA ROV, ATN ATN50 ROV, MDH NAIAD AUV, NTNU Fjordtif LAUV, ISR Noptilus LAUV, ISR Nemo LAUV)

Moreover, 4 different modems were tested and used in the trials and demos to enable underwater communication:

- EvoLogics S2CR 18/34 is the standard for vehicles integration
- EvoLogics S2CM High Frequency
- Water Linked High Frequency modem, also used to remotely control of a BlueROV
- TNO High Speed modem

SWARMs acoustic modems

Robotic vehicles integration

A generic and modular Robot System Onboard Architecture (RSOA) based on ROS (Robot Operating System) middleware was developed in the project. This architecture allows robotic vehicles to autonomously achieve the considered high level tasks and to adapt their mission when disruptive events occur. The RSOA has been instantiated for two use cases: sonar survey, and plume detection and tracking. It has been integrated and tested on several heterogeneous vehicles: 4 AUVs, 2 USVs, and in the local control station of 2 ROVs. The RSOA has been validated through several simulation and maritime experimental demonstrations.

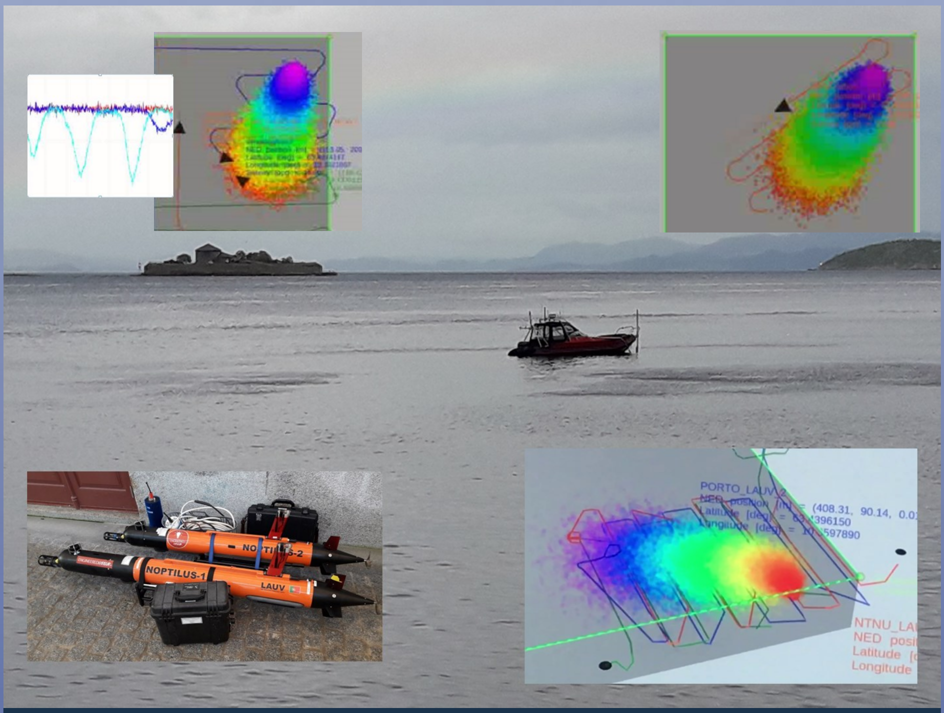
Demonstration at sea - June 2018

The sea demonstration in the fjord of Trondheim showed that all components of the SWARMs system were in the loop. The RSOAs were onboard all robotic vehicles involved in the final demonstration missions, and such integration was validated in multiple vehicles, e.g. three AUVs (NTNU Fridtjof LAUV and LSTS (lab in University of Porto) two Noptilus LAUVs) and one USV (Maritime Robotics Telemetron). The added capabilities of the RSOA respected the enhancement of all modules and the adaptation of functions to the new scenario, as the use case was based on detecting and tracking a plume of wastewater, which was simulated in real-time. The nominal mission was successfully performed at sea, with representation in the CAF of the salinity measurements, which decreased when taken from within the plume.

Simulation demonstration - June 2018

The simulation of the same use case highlighted the onboard strategies computed onboard and online to obtain a maximum of information on the plume so as to find its origin. A three-step behavior was achieved for AUVs:

- Computation of a boustrophedon in the survey area (in picture, bottom-right)
- When exiting plume, stop in ongoing row and anticipation of U-turn (top-left)
- Computation of new survey given the monitored data of the salinity (top-right)



Plume detection carried out during simulated mission in final demonstrations

RSOA concepts

SWARMs RSOA is based on the following main concepts:

- Architecture centered around the Supervision function
- Planning and Monitoring functions associated to Supervisor
- Modularity ensured by the use of the ROS framework
- Genericity both between and inside functions

Supervisor

Management of the execution of actions and of the replanning processes. Online and onboard plume mapping:

- Recording of salinity values
- Building of plume map
- Survey adaptation to detection from Monitoring
- Redefinition of survey areas

Planner

Development of several planners for high level tasks:

- TRANSIT: motion planning considering obstacles and currents
- SURVEY: coverage solvers reducing distanced covered and with different patterns
- INSPECT: start point, follow-up of area contour, loop on several inspects
- Recovering and surfacing with and without GPS acquisition
- Development of a planner for the mission level (tasks sequence) and plan repair

Monitor

Use of robot internal check to make diagnosis (at present) and prognosis (future) for each generic vehicle action. Regular monitoring of position, depth, heading, and measurements. Generation of monitor alarms regarding the salinity increase and decrease in the final demonstration.

SWARMs)))

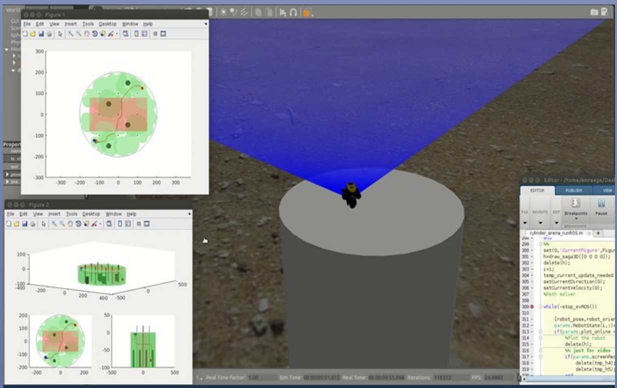
Semi-autonomous manipulation

The objective of the semi-autonomous manipulation is to relief the operator from the burden of individually commanding all degrees-of-freedom of the manipulators end-effector, leaving instead just the most critical decisions open to human judgement and action. In the specific mission scenario a ROV is sent to approach a blowout preventer (BOP), activate the blowout preventer and thereby sealing the well. The valves on the BOP panel are identified with individual visual markers. These markers allow a detection and estimation algorithm to fuse the vehicle's inertial and visual information, in order to provide an estimation of the vehicle odometry with respect to the marker. The pose of the gripper with respect to the marker is determined, so that an automatic positioning and orientation of the gripper in front of the valve is possible. Only the tasks of approaching the valve, gripper closing and valve turning are left to the operator.

A workclass ROV approaching the BOP, front and lateral views (video)

Simulation of 3D path planning

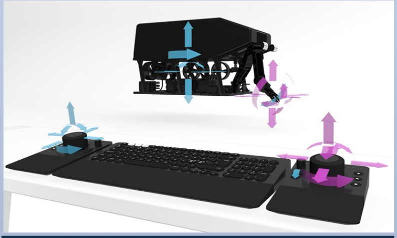
In order to simplify the tasks of the operator of a vehicle or to perform tasks in full autonomy, path planner modules were developed in the SWARMs project. Three partners have addressed the generic planning problem with the vehicles they have developed. Two methods rely on well known rapidly expanding random tree RRT methods. These are improved by drastically reducing the state space. The non-holonomic case for survey AUV was solved by first calculating the holonomic case and using this as a basis to calculate possible trajectories based on clothoids that account for speed and curvature constraints. By this, the survey AUV can move constant transit speed along the entire path. The approach for a ROV covers the state space with funnels which size is limited only by obstacles, thereby reducing the density in obstacle sparse regions in comparison against RRT. Within these funnel regions a controller policy suitable for the ROV is employed. The algorithm is therefore capable of solving the coverage, path planning and navigation/control problem simultaneously. Finally an anisotropic motion planning module based on ordered upwind methods was developed. It accounts for the orientation of the vehicle relative to sea current. The risk of entering areas with strong currents is minimized as well as the collision with obstacles.



Simulation 3D path planning for a ROV using UUV simulator

Intuitive input device

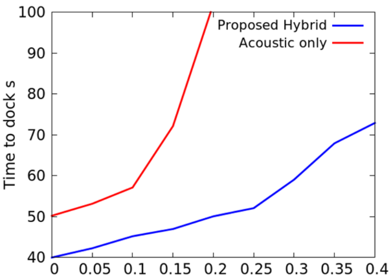
An intuitive input device developed in SWARMs was demonstrated in July 2017 controlling remotely a robot manipulator arm located at the time in Trondheim, Norway, from Mangalia, Romania (video). In the second set of demonstrations, which took place in June 2018, the device was made ready to control a real ROV during the demonstrations at Trondheim. This was achieved by software modules connecting to a BlueROV and a Windows user interface.



Intuitive input device controlling ROV

Docking maneuver simulation

A docking concept was proposed within SWARMs which invokes an hybrid acoustic-based and RF communication scheme to guide an UUV to a docking station. At a certain distance during approach the communication is switched from acoustics to RF, and thus allowing higher localization accuracy and higher controlling gain of UUV. Simulations show a much faster approach of UUV to target than with acoustics guidance only (video). The latter may even fail when underwater currents exist.



Time to dock vs. water current

Give us your feedback: http://www.swarms.eu/contacts.html

SWARMs

UNIVERSIDAD POLITÉCNICA DE MADRID
POLITÉCNICA

acciona Infraestructuras

tecnalia

PLOCAN PLATAFORMA OCEÁNICA DE CANARIAS
Gobierno de Canarias

TTI

HI iberia

BOSCH Invented for life

EvoLogics®

ECA GROUP

ONERA THE FRENCH AEROSPACE LAB

THALES

GS-LDA

instituto de telecomunicações

universidade de aveiro

SINTEF

NTNU Norwegian University of Science and Technology

MARITIME ROBOTICS

INVENTAS

WATER LINKED®

DeepVision

MÄLARDALEN UNIVERSITY SWEDEN

TNO innovation for life

s[&]t

teamnet

Autonomous

Desistek

Sabancı Universitesi

LEONARDO DEFENCE SYSTEMS

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

End-user subcontracted by S&T:

Boskalis Dredging & Marine Experts

SWARMs Consortium

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

GOBIERNO DE ESPAÑA MINISTERIO DE INDUSTRIA, ENERGÍA Y TURISMO

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
MINISTÈRE DE L'ÉCONOMIE DE L'INDUSTRIE ET DU NUMÉRIQUE

DGE DIRECTION GÉNÉRALE DES ENTREPRISES

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

The Research Council of Norway

VINNOVA

Rijksdienst voor Ondernemend Nederland

Ministero dell'Istruzione, dell'Università e della Ricerca

National funding entities

ECSEL Joint Undertaking
Electronic Components and Systems for European Leadership