Smart and Networking Underwater Robots in Cooperation Meshes

SWARMs

SWARMs Newsletter #3 | October 2017

SWARMs First Demonstrations

SWARMs team at Mangalia

The second stage of SWARMs demonstrations took place at the Black Sea coast in Mangalia, Romania, in first half of July 2017. This event lasted ten days, during which the consortium tested and validated the first integrated version of SWARMs system, mounted on different maritime robotic vehicles and support platforms. The tests carried out at the Black Sea were based on the results from SWARMs Early Trials in Gran Canaria island, and of course on the respective significant research and developments that followed. Using a similar approach as the one adopted back then, the following missions were planned and executed:

Mission 1: Environmental recognition with the vehicles

Mission 2: HF acoustic underwater data transfer

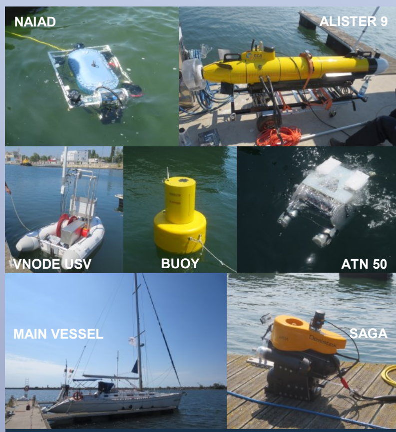
Mission 3: Integrated communication systems verification

Mission 4: Mission Management Tool (MMT), Middleware, Communication network, USV, AUVs and ROVs integration

Mission 5: Command and Control Station mission management

Mission 6: Intuitive input device remote control

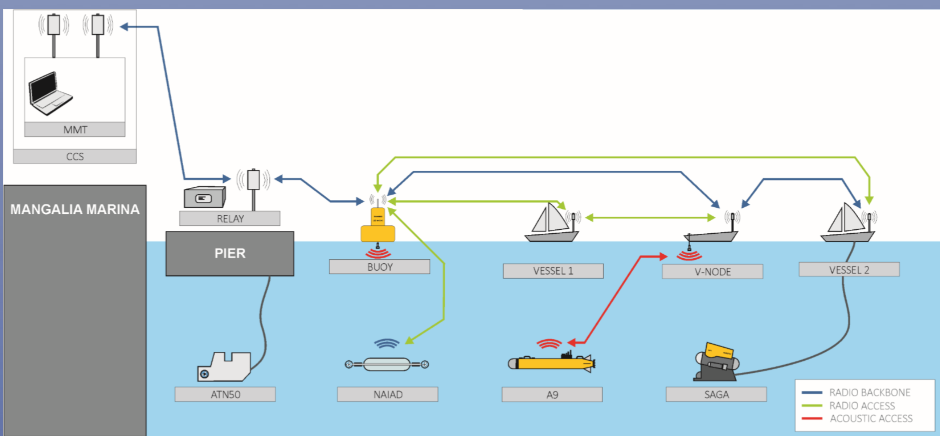
Mission 7: Mission planning and RSOA integration



Vehicles and support platforms

The objectives set for SWARMs first set of demonstrations were successfully achieved in Mangalia. The collaboration work performed by all partners allowed the validation of the technical developments carried out during the first two years of the project. The success obtained in exchanging data among the robotic sea vehicles through the use of the developed SWARMs communication network and middleware, supported by DDS, allowed to demonstrate the full integration of five vehicles in the SWARMs system. The lessons learned from this event will be used to plan the final demonstration activities in the second quarter of 2018 at Norway.

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.

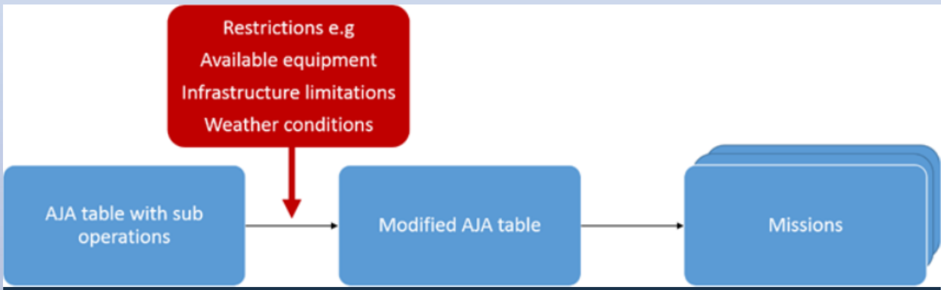


SWARMs first demonstrations communication network setup

Further in this issue

Methodology for V&V

The last step in the SWARMs methodology for designing autonomous systems relates to the verification and validation (V&V) step. As autonomous systems become more and more prevalent, it is important to find clever ways of performing V&V on these systems to ensure correct and safe behavior. This issue has been explored and a strategy for performing V&V in SWARMs has been put in place based on the experience from the previous demonstration activities. This strategy utilizes the structured autonomous job analysis (AJA) tables previously created in the project to make a detailed description of the operations, together with the requirements to produce a set of missions to verify and validate that the system is able to perform its role within such requirements and key performance indicators.



SWARMs methodology for verification and validation

Data Transfer Protocol

The interfaces for interconnecting the SWARMs middleware (MW) with the vehicles belonging to SWARMs Robot Systems have been fully specified. It has been decided to use Data Distribution Service Interoperability Wire Protocol (DDSI v2.1), together with a layer of Real-Time Publish-Subscribe (RTPS) protocol, as the MW communication underlying software.

DDS is a MW protocol standard for data-centric integration that features extensive fine control of real-time quality of service (QoS) parameters. This protocol relays on the Object Management Group (OMG) standard, referred to as DDSI-RTPS for implementation works, assuring interoperability with several DDS solution providers, such as Twin Oaks' CoreDX DDS and PrismTech's OpenSplice DDS (OSPL). The figure below on the left shows the RTPS Processing Data Unit (PDU) that is used in the CoreDX DDS solution. The header contains the following data:

RTPS; Protocol version: RTPS and protocol versions in the DDS iteration;

Vendor ID: Identifier of the vendor that has developed the DDS iteration;

GUID prefix: Globally Unique Identifier characterizing the sent message;

INFO_TS; Heartbeat: Sent message timestamp, and periodicity control info;

Submessage data: Contains the transferred data .

	Message PDU (Twin Oaks CoreDX)							
content	RTPS	Protocol version: 2.1	Vendor id: 01.06	GUID Prefix	Submessage Vendor-specific	Submessage INFO_TS	Submessage DATA	Submessage HEARTBEAT
no. bytes 106	4	2	2	12	8	12	34	32

Submessage DATA									
Submessage Id: DATA	Flags	Octets to next header	Extra flags	Octets to inline QoS	Reader Entity Id	Writer Entity Id	Writer Seq Number	Encapsulation	Serialized Data
1	1	2	2	2	4	4	8	4	6

Message PDU in Twin Oaks CoreDX DDS

PDUs development

Depending on the vendor, there are differences in the size of the message PDUs (submessage data field). A default PDU with serialized data of 63 bytes has a size of 138 bytes with OSPL, whereas with Twin Oaks it has 106 bytes. The main difference is that OSPL uses 40 bytes for QoS specification, whereas Twin Oaks includes an 8 bytes vendor submessage.

The picture below shows the defined content that is included in the Serialized Data parameter for SWARMs. The size of data to be exchanged has been carefully specified to cope with the limited bandwidth of underwater acoustic channel and suitable for acoustic modems relatively low throughput (typically below 2 kbps) to avoid excessive fragmentation of PDUs in transmissions. It has been defined a size of 63 bytes for this content, comprising a 24 bits header and 480 bits payload. The fields are described as follows:

- **Vehicle ID**: Identifier of the vehicle originating or receiving the message;
- **Type**: There are seven types of PDUs in SWARMs. Three represent the different message types the MW can send to a vehicle: requests, notifications and answers. The other four represent the message types that vehicles can send to the MW: periodic status information, reports, events and queries;
- **Subtype**: Further defines the type of PDU, from the seven;
- **Seq. Op.**: Random number for linking petitions and responses;
- **Data**: 60 bytes are available to transfer data (padding if needed).

Maritime Data Transfer Message Header			
Vehicle ID	Type	Subtype	Sequence Operation
4	4	8	8

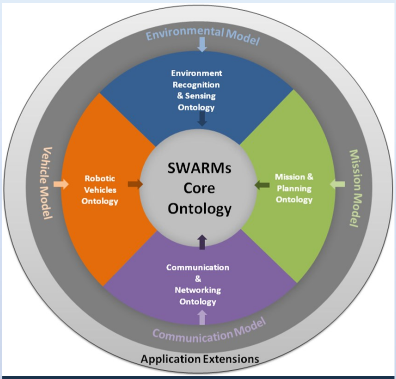
Maritime Data Transfer Message Payload
Data
480

SWARMs generic PDU serialized data

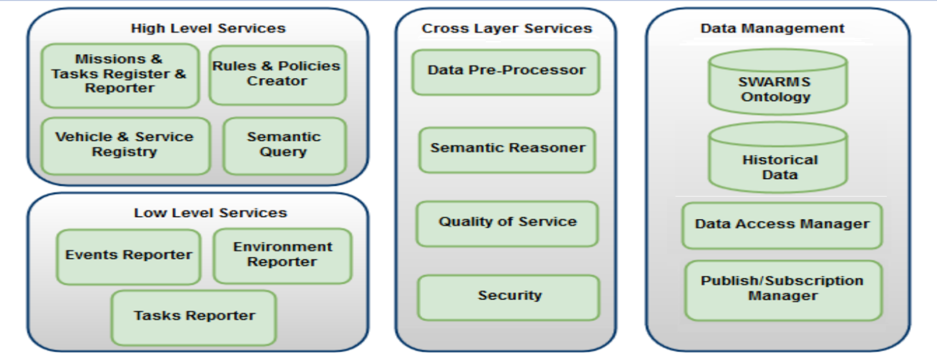
DDS-based Middleware

The main objective of the semantic, DDS-based middleware is to ensure reliable communication and coordination of a swarm of maritime robots, regardless of type, manufacturer and capabilities, when executing the tasks defined by the MMT. The SWARMs middleware (MW) includes the following features:

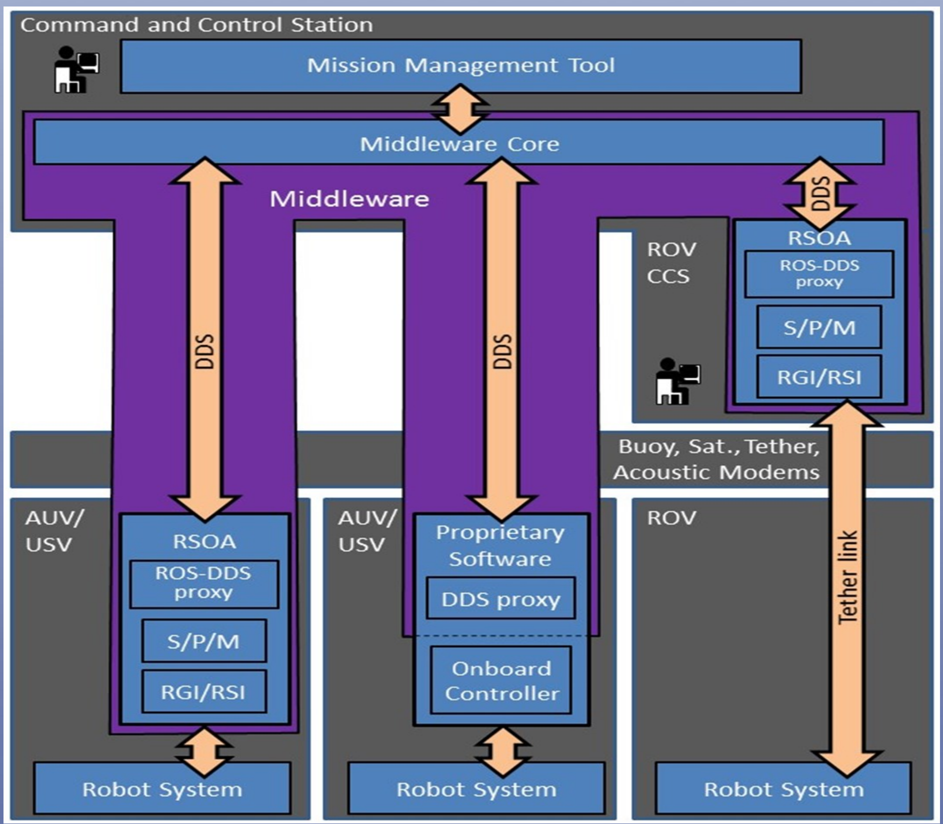
- **Common information model and semantic management**;
- **Communication**: exchange and process messages between MMT and vehicles;
- **Mission control**: sends tasks to the vehicles and forwards mission data to MMT;
- **Registration of available vehicles and services**;
- **Monitoring**: tracks and reports tasks statuses in a mission;
- **Reliability**: time decoupling using DDS and QoS policies;
- **Validation of data coming from the vehicles**;
- **Context awareness**: information from the environment;
- **Flexibility & Scalability**: hosts a RSOA for any type and number of vehicles.



SWARMs information model



SWARMs middleware core

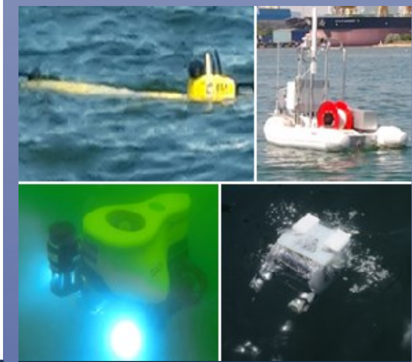


SWARMs architecture

MW testing during Black Sea demos

The middleware was used in Mangalia coast to receive status vectors from the involved robotic vehicles (AUV, ROV and USV) in real-time, as well as to send tasks for them to execute, using SWARMs communication network (acoustic when underwater and IP over RF when overwater or through tether). Four vehicles were involved in the MW testing demo missions:

- **Alister 9**: integration of an AUV with SWARMs underwater network, using a proprietary DDS proxy and EvoLogics acoustic modems;
- **Static USV**: integration of a USV (VNODE) with RSOA and SWARMs overwater network;
- **SAGA** and **ATN 50**: integration of two ROVs with the open source RSOA and SWARMs overwater network.



Alister 9, VNODE, SAGA and ATN 50

Large scale 3D mapping

An advanced autonomy interface developed in SWARMs was showcased during the Black Sea demonstrations, using the ECA Alister 9 AUV. As an example of the new operation mode, real-time quality analysis and control of a bathymetric survey conducted using the AUV sonar payload (Klein 3500 interferometric side-looking sonar) was demonstrated. A quality factor was extracted in real-time from the raw sonar data, measuring the so-called interferometric baseline decorrelation, which originates in reduced signal to noise, or multipath interference in shallow water, and degrades accuracy of the depth soundings. The quality factor measurement was used to adapt on the fly the altitude of the AUV survey between 4 and 6 meters to increase the accuracy of the soundings, where water depth varied between 5 and 8 meters in the test area.

The full process for 3D scene reconstruction was also shown during the demos. The initial steps of the developed color correction and visibility enhancement enabled high-quality stereo matching and 3D scene reconstruction for close range sensing, as illustrated here further below, where darker grey represents bigger distance (black is lack of information). Sonar sensing was employed for object and scene reconstruction over larger distances where visibility was too poor for vision.

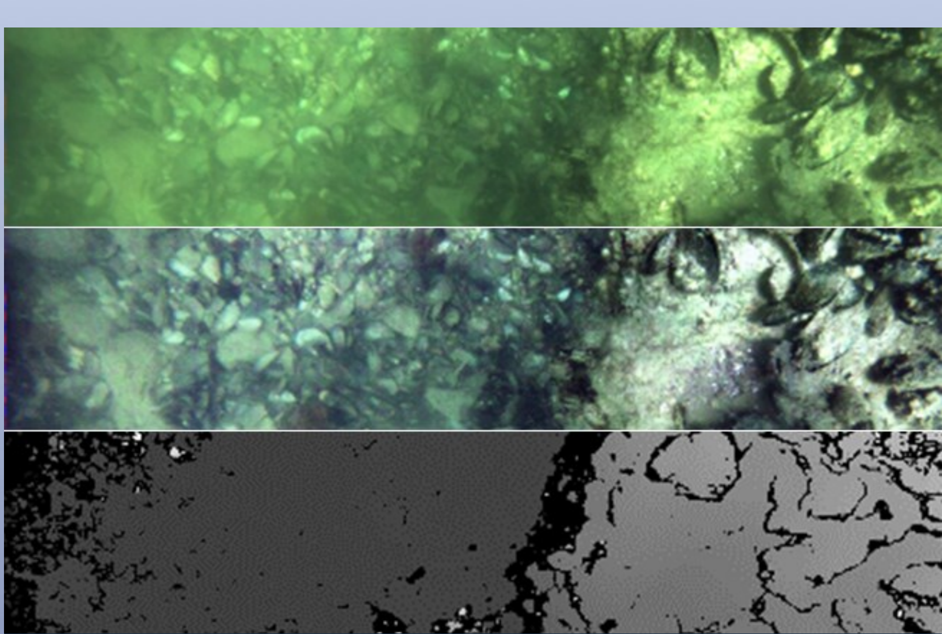


Image enhancement, from top: original, processed, and together with resulting depth map

CAF Backend and Frontend GUI

The CAF general web-based GUI allows to interact with environment data and information available at SWARMs CAF backend, in many cases obtained after processing collected sensing data. Such environment data is split in two major types:

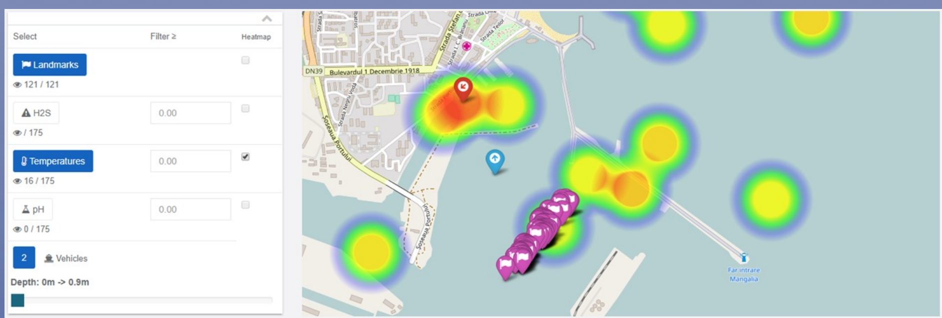
- **Offline environmental** data only available post-mission, in some cases after multiple processing stages using specific developed algorithms, such as seabed type classification and landmarks extraction through sonar image processing;
- **Online situational** data from maritime robotic vehicles, such as depth, position, speed and battery level, which are almost available continuously, although depending on the communication channel limitations.

The environment georeferenced data and higher-level information available in SWARMs CAF can be used for assisting and optimizing missions management.

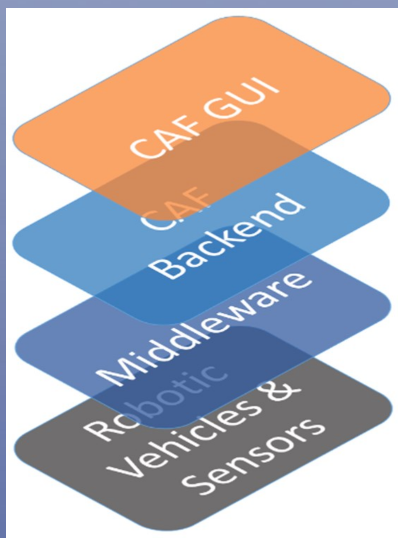
The CAF can be decomposed in the two referenced major elements or layers, as depicted here below, interfacing with SWARMs robotic vehicles and their sensors, through the SWARMs middleware.

Context Awareness Framework

A first version of the SWARMs Context Awareness Framework (CAF) has been developed, with multiple features, including a graphical user interface (GUI).



CAF representing multiple data, with vehicles, their heading, landmarks and temperature



CAF layers on top of SWARMs MW

Enhanced communication system architecture

The latest development of the SWARMs communication system architecture has been driven by the results achieved at SWARMs Early Trials in September 2016 and by the requirements of the missions demonstrated at the Black Sea. Taking into account the availability of various maritime robotic vehicles, the general complexity of the integrated network was expanded, adding new functionalities, in order to integrate heterogeneous platforms/nodes provided by different suppliers:

- **AUV**: ECA Alister 9 mounted an Evologics (EVOL) MF modem together with its main SERCEL modem. Both acoustic systems worked during the missions and no interferences occurred. The AUV was integrated in SWARMs network by using a specific DDS-Proxy adaptation module, and it shared status vector data. Moreover the USBL functionality was verified in very shallow water when the AUV was tracked by the VNODE's surface modem.
- **ROVs**: Adapting the SPM-EM module developed by Sabancy University and Desistek, two ROVs were able to transfer status data from the respective local control stations to the SWARMs CCS, through the established RF / Wi-Fi link.
- **USV**: The VNODE platform was integrated and tested in the Black Sea to verify the capabilities of the communication system to be installed on board of an USV. The preliminary box tested during the Early Trials was upgraded and improved, by adding other functionalities, like custom RF and Wi-Fi integration, management of a winch to deploy and recover the surface node MF acoustic modem, and control the vehicle dynamics with electric engines (not integrated).

To allow the management of a higher number of nodes, the RF subnetwork was also improved by adding the following capabilities:

- Implementation and test of a RF subnetwork status monitor console, to check the status of the connected nodes and the links during the mission;
- Integration of different Wi-Fi nodes (various HW) in AP repeater mode. This was tested up to the maximum range already verified at the Early Trials (2 km).

Vehicles integrated in SWARMs communication network, and associated functionalities

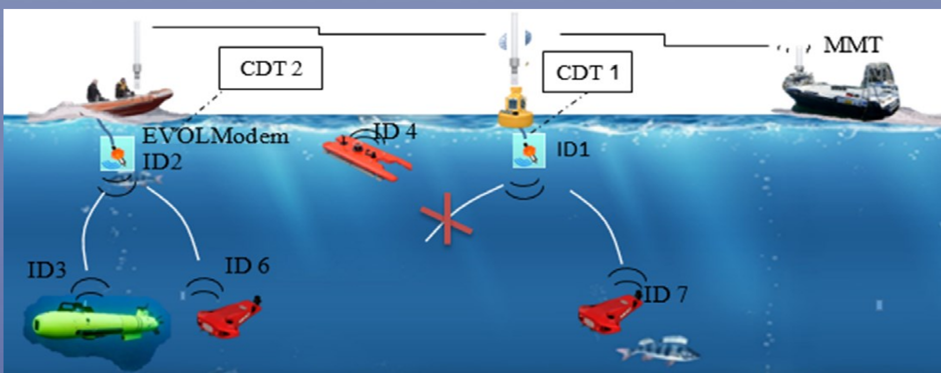
Underwater subnetwork

Integration of MF subnetwork with SWARMs DDS-MW is based on the implementation of the CDT/ VDT functionalities. CDT connects the overwater MW located at the CCS to the acoustic modem at a surface node, while the VDT connects the Robot System to an acoustic modem. Their tasks are:

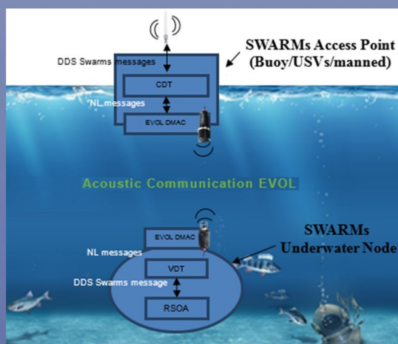
- Read messages (in EVOL NL-format) from modem, which translates to SWARMs message structures and publish on a DDS -topic that the MW subscribes to;
- Subscribe to DDS-topics, read messages (in SWARMs format) published by the MW, translate them into NL-format and sends through a socket to the modem.

Specific functions are implemented improving the underwater network:

- Access Point (AP) polling allows fair communication (AP asks sequentially each host to send data in a maximum time window) and early host lost detection (AP detects missing vehicles, notifies MW and reconfigures its host list).
- Neighborhood discovery in multi-hop ad hoc network, to dynamically join an underwater AP. The integration with SWARMs MW creates a full vehicle discovery procedure to manage clustering and multi-AP configuration.
- Random Linear Network Coding, and Clustering, both already tested in Evologics modems, but still need to be fully integrated.



SWARMs underwater network supported by surface nodes providing access to MMT



SWARMs CDT/VDT interfacing

Robotic vehicles integration

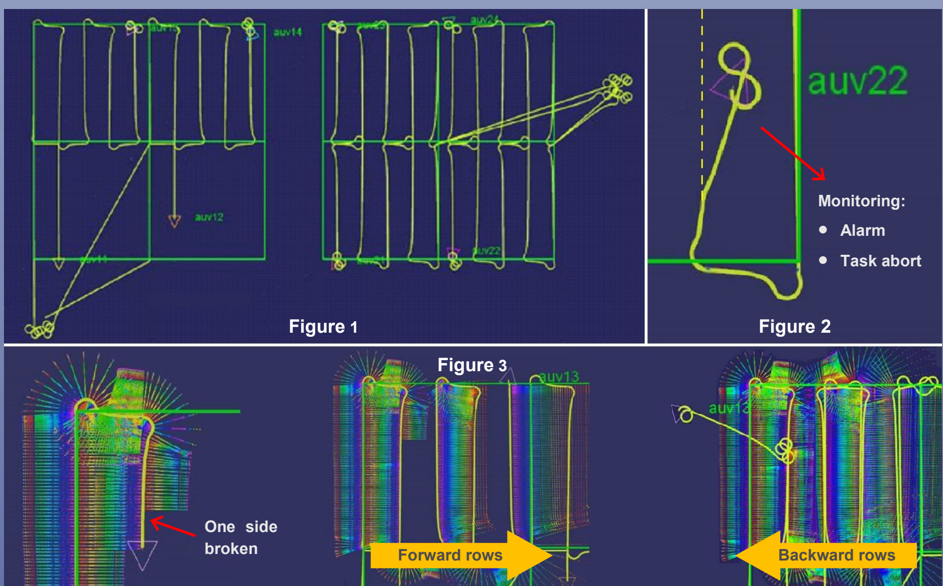
Autonomous Underwater Vehicles (AUVs), Remotely Operated Vehicles (ROVs) and Unmanned Surface Vehicles (USVs) are the end actors of a SWARMs mission. A generic and modular software architecture, called RSOA (Robot System Onboard Architecture), has been developed in SWARMs. The RSOA is instantiated on SWARMs robotic vehicles to provide each robot with semi-autonomous or autonomous capabilities:

- Communication with the Mission Management Tool (MMT), receiving high-level mission tasks from it and sending vehicle data to it, but also with other vehicles;
- Computation of individual plans of actions and their adaptation when required;
- Supervision of the execution of actions and of the replanning process;
- Monitoring of internal and external states to diagnose and adapt to faults and environmental data;
- Adaption to the multiple heterogeneous SWARMs vehicles.

At the Black Sea demonstrations, a survey mission performed by a swarm of 8 vehicles on a 200 meter by 200 meter area was simulated, where each vehicle implemented one RSOA. Several runs highlighted the nominal and reconfiguration capabilities of the architecture:

- **Nominal execution of the mission** (Figure 1): basic planning, execution and supervision of actions (including activation and deactivation of payload), storing of robot position, robot status, environment data and robot alarm;
- **Recovery operation**: aborting of mission, selection in real-time of one recovery area, and recovery achievement;
- **Online and autonomous adaptation to disruptive events**: also known as plan repair, e.g. after a deviation caused by propulsion decrease associated to currents (Figure 2), or breakdown of one side scan sonar of the robot (Figure 3).

Some further experimentations were also carried out during the Black Sea demos. Desistek Robotics' SAGA and Autonomous Systems' ATN50 ROVs were subject to a partial RSOA integration in their local command and control stations. Also Leonardo's static USV integrated part of the RSOA in its system. For the final demonstrations in Norway mid-2018, the RSOAs on robotic vehicles will include further developments, such as functions enhancement, advanced individual planners and improved monitoring, namely towards specific demonstration goals.



Nominal simulation and autonomous adaptation

Robot Operating System (ROS)

To ensure good level of genericity, the Supervisor, Planner and Monitor functions of the RSOA have been implemented using ROS framework. The Supervisor is central in SWARMs RSOA.

Supervisor

Modeling of expected behavior of SWARMs robotic vehicles in nominal situation, as well as when disruptive events occur. Interface and preliminary experimentation with ROVs and USV, with overall performance evaluation through simulation during Black Sea demo.

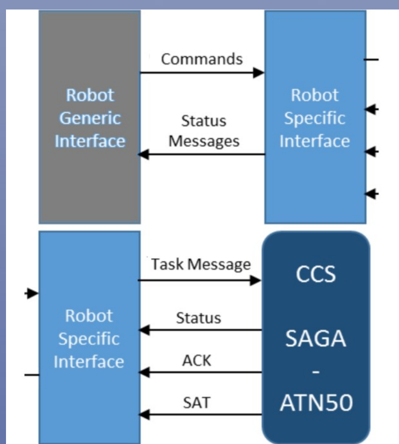
Planner

Development of several planners:

- Computation of plans for each type of high-level task, e.g. TRANSIT, SURVEY, INSPECT;
- Area coverage;
- Optimization of robots trajectory taking into account sea currents;
- Feedback motion planning.

Monitor

Use of robot internal status check to make diagnosis (*present*) and prognosis (*future*) for each generic vehicle action. Regular monitoring of position, depth, heading, and other measurements. Furthermore, generation of monitoring alarms.

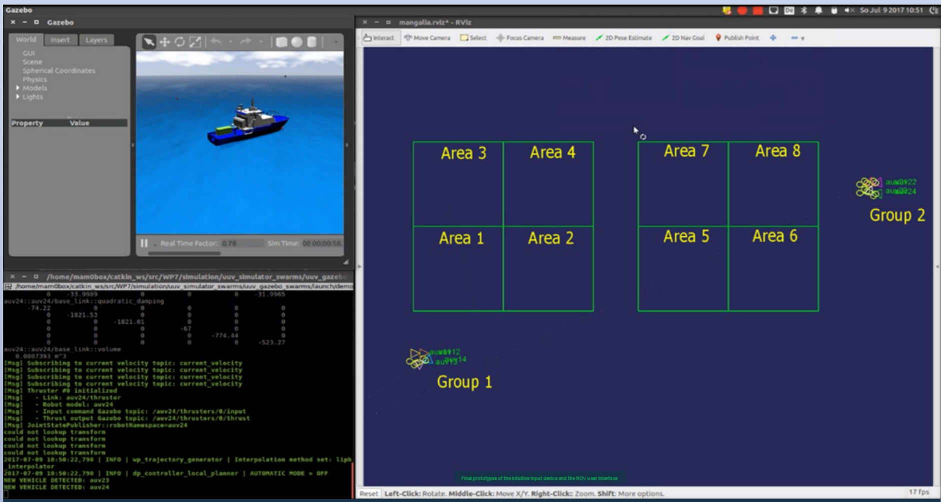


Partial RSOA in ROVs local CCS

SWARMs missions simulation

The UUV-simulator open source simulation environment, which is developed within SWARMs, is an important tool to test the functionalities of the developed approaches, and considered scenarios, before testing them under real conditions. During the second year of the project, controllers and manipulators for different robotic vehicles have been developed, as well as advanced functionalities, which enable easy set-up of operation. Also, the developed simulation environment is connected to the SWARMs MW by the RSOA.

At the Black Sea demonstrations, a mission simulation was showcased involving multiple vehicles, connected to RSOA, scanning delimited seabed areas. In order to fully show the RSOA functionalities, some specific events were considered.



Mission simulation considering 2 groups of 4 vehicles to do survey inside delimited areas

User interaction

The information available in the SWARMs user interface is arranged in clear groups, e.g. map and control panel are shown in separate windows, and there is no overlapping of information. Intuitive navigation is provided by clear infographics where only essential information is displayed. This is ensured by distinct information layers that can be switched on/off depending on individual user needs.

Final prototypes of SWARMs intuitive input device and ROV user interface

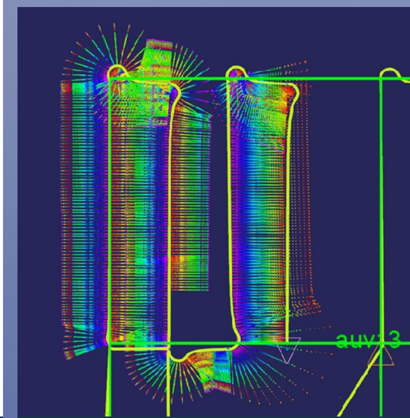
Simulation and UI demos

The first considered event, a failure on the left side of a side-scan sonar was emulated and lead to a replanning of the mission. This is represented in the figure here below, where after such local disturbing event, the vehicle finishes the survey of the area and further task replanning is needed to cover the blind spot caused by the defective side sonar.

A second event demonstrated the robot onboard monitoring detecting a thruster failure. This lead to a monitoring alarm and subsequent abortion of the mission.

Final prototypes of SWARMs intuitive input device (IID) and the user interface (UI) were also demonstrated. The IID consists of two space mouse devices, which allow the independent operation of vehicle and manipulator. Led lights and force feedback gives input also to facilitate operations. A function button can be configured, for example to limit the degrees of freedom of the manipulator, which facilitates pick and place tasks in certain situations. The prototype of the IID was demonstrated by remotely controlling a robotic arm located in Trondheim, Norway. Moreover, operating the simulator with the IID was also shown.

The SWARMs YouTube channel shows a demo of the ROV-control room, including pick & place task.



Mission simulation emulating failure

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