SWARMs

# Smart and Networking Underwater Robots in Cooperation Meshes

SWARMs Newsletter #1 April 2016

## Fostering offshore growth

Many offshore industrial operations frequently involve divers in challenging and risky activities. Since the number of such qualified professionals is rather limited, the dependency on their work represents an effective threat to offshore industry and its further development. The extended use of unmanned underwater vehicles, e.g. AUVs and ROVs, could solve this problem. However, such robotic vehicles are usually tailor-made for very specific tasks and can be difficult to operate, which makes their deployment too expensive and thus unattractive in most cases.

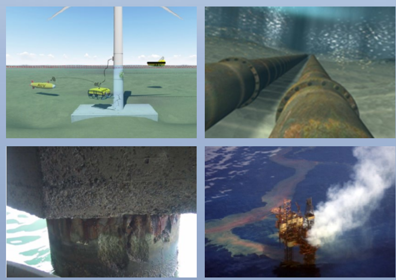
The SWARMs project targets to expand the use of AUVs and ROVs, eventually also supported by unmanned surface vehicles (USVs), to facilitate the creation, planning and efficient execution of maritime and offshore missions. Moreover, it focus on making autonomous operations a viable option in such industry, namely by reducing operational costs, increasing the safety of missions and professionals, and ultimately supporting the expansion of the offshore sector.

## How can it be achieved?

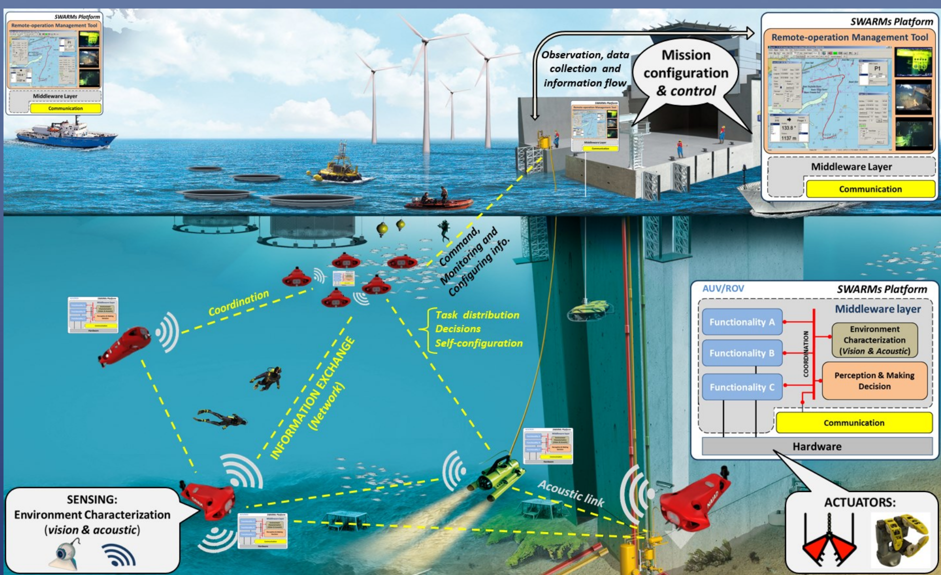
A framework has started to be developed within SWARMs, which main goals are to integrate, coordinate and improve the functionalities of the different vehicles in the context of carrying out complex unmanned offshore missions cooperatively. One key challenge that is inherent to the considered scenario is underwater data exchange, which is crucial for effective cooperation between robotic vehicles, as well as for reliable monitoring of operations and efficient mission management.

The following sections comprise a condensed introduction to the developments being made in the project, regarding data communication and other fundamental aspects to which SWARMs will provide solutions, in an integrated way.

*The oceans are considered to host a substantial part of key resources, not only to sustain human life, but also to feed all kinds of industries, namely through oil or gas, and increasingly also via renewable energy sources, such as wind, tides and waves.*



*Furthermore, deep sea mining of metals such as copper, silver, gold, nickel and cobalt, as well as of rare earth minerals, which are used in numerous high tech devices and by cutting edge industry, will become common. To this end, new offshore infrastructures will need to be built, monitored and kept operational.*



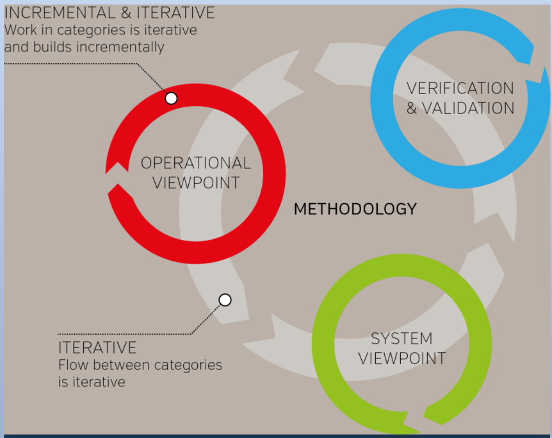

SWARMs Framework concepts

### In this issue

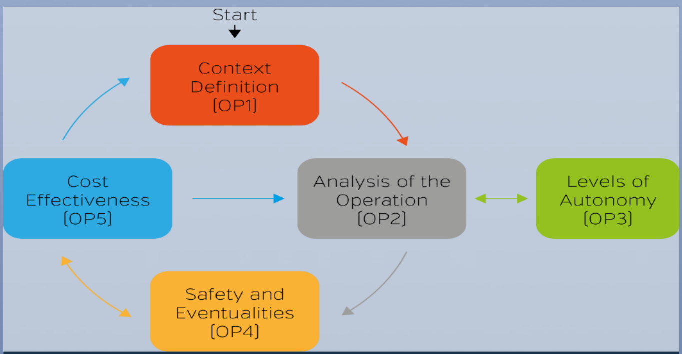
# Autonomous operations design

One goal of the SWARMs project is to provide a methodology that gives a structured way of analyzing autonomous maritime operations and systems. The goal of the methodology is to make the systems developers able to design, develop and validate autonomous functionality efficiently. This methodology emphasizes that autonomy is not all-or-nothing. It is therefore created as a family of approaches that leads to a system with some degree of autonomy. It analyses an autonomous operation from three viewpoints: The Operational Viewpoint, the System Viewpoint and the Verification and Validation Viewpoint. The way to use the methodology is an iterative and incremental approach.

The first versions of the Operational and System Viewpoint Methodologies, as well as User Interface Design Guidelines, have been delivered and are illustrated below.




**Iterative and incremental methodology**

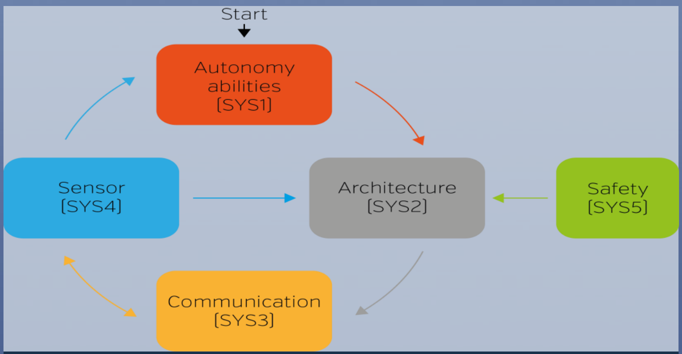



**Operation analysis**

## Operation analysis method

Design of a methodology for analyzing autonomous sub-sea operations:

- Context Definition;
- Analysis of the Operation;
- Levels of Autonomy;
- Safety and Eventualities;
- Cost Effectiveness.

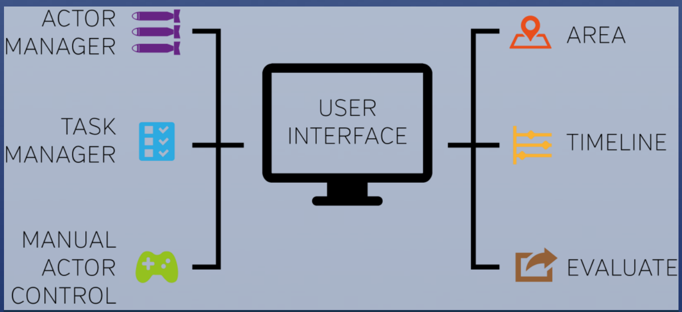



**System design**

## Design guidelines for autonomous underwater agents

Creation of methodology offering coherent, structured and sound methods and tools for designing autonomous technologies:

- Autonomy Abilities;
- Architecture, and Safety;
- Communication;
- Sensor.




**SWARMs user interface**

## User Interface Design Guidelines

A work process consisting of four main sections has been described:

- Manage;
- Plan;
- Operate;
- Evaluate.

Such process leads to a list of content that needs to be included in the user interface and guidelines for how they should work together.

# The coordination architecture

The SWARMs system will consist of three main functional components: 1. Mission Management Tool (MMT); 2. Middleware System; 3. Robot Systems.

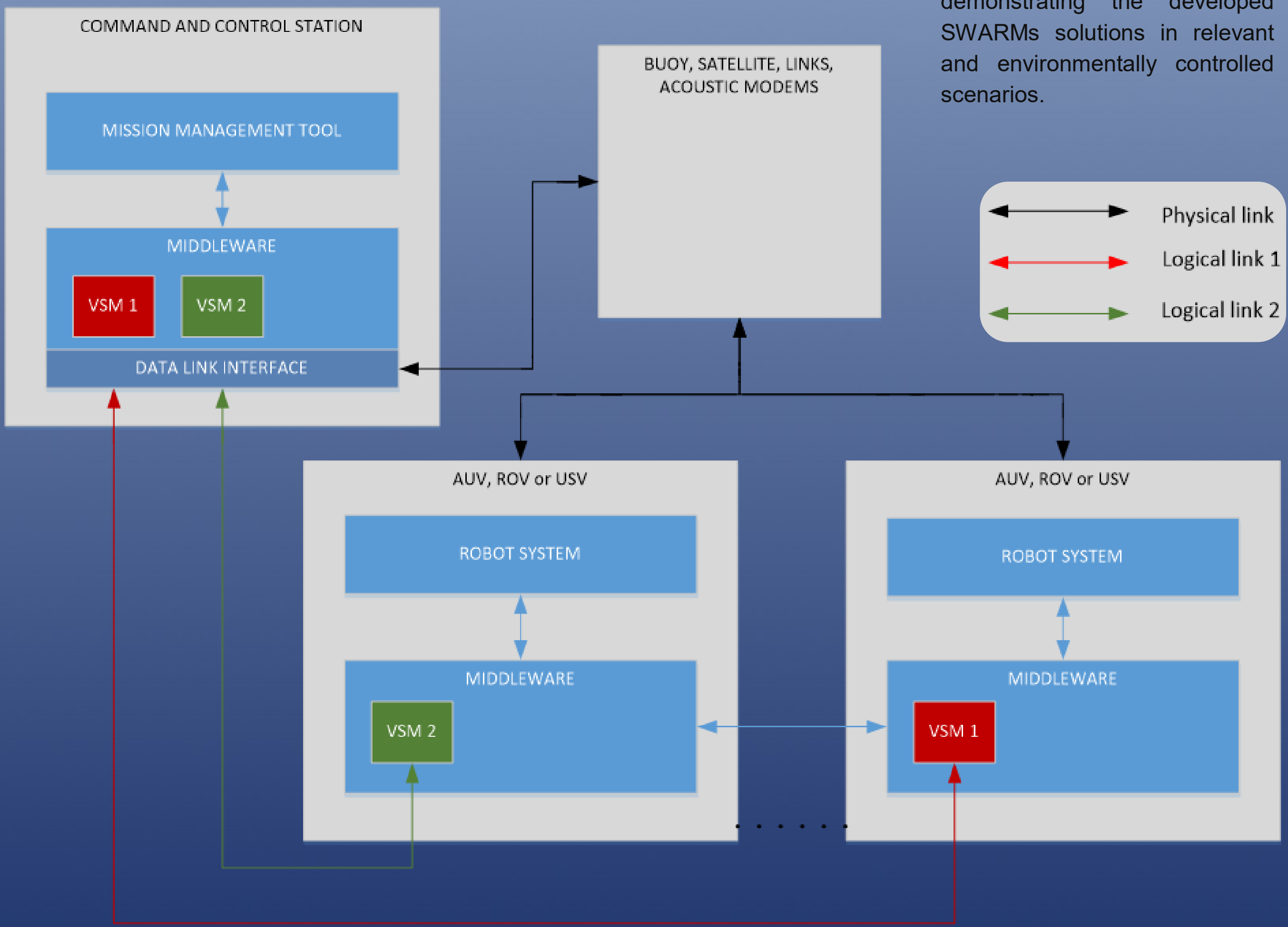
1. MMT is located inside the Command and Control Station (CCS), and it is responsible for the generation of missions, the assignment of tasks to robots, and the supervision of such missions. The MMT contains the Human Computer Interface, which allows a human operator to interact with the system, defining and supervising missions, and also controlling non autonomous vehicles, e.g. ROVs.
2. Middleware ensures the information exchange between MMT and all involved vehicles, underwater or at surface, regardless of manufacturer or capabilities, using buoys or USVs as communication nodes. Therefore, it is not a stand-alone physical component and is distributed by nature in several places. Nevertheless, due to its specific role, it is a stand-alone logical component, which ensures that all robots are able to follow CCS commands, and coordinate amongst themselves.
3. Robot Systems are AUVs, ROVs, USVs, and any other type of vehicle or equipment with actuators and sensors, which are modelled in MMT as resources, and can be assigned specific tasks within a mission through the Middleware.

The architecture functional (logical) and physical components are represented below, highlighting the distribution of the Middleware across the different physical components in order to ensure the collaboration between robots. To achieve this, it is necessary to have dedicated HW/SW modules for each robot, named Vehicle Specific Module (VSM), which may also be distributed on different physical components as well, either on-board the robot, in the CCS or in both.

## Architecture goals

The main goals associated with the SWARMs architecture analysis and specification are the following:

- Developing an environment characterization and coordination system for a swarm of underwater vehicles, e.g. AUV and ROV, together with other supporting vehicles/robots (USV), and also vessels, to achieve mutual goals collaboratively in a mission;
- Enabling monitoring and control of offshore underwater industrial operations;
- Accommodating existing and new innovative technologies, in an interoperable way;
- Being flexible and generic enough to allow the management of a large variety of missions and types of operations;
- Allowing testing, validating and demonstrating the developed SWARMs solutions in relevant and environmentally controlled scenarios.




**Functional and physical components of the simplified SWARMs architecture**

# Heterogeneous networking

The management of multiple kinds of underwater vehicles demands for a robust communication network, which should be able to connect the remote Command and Control Station, typically ashore or on board a support ship, with the robotic vehicles operating offshore in underwater missions. The communication network is composed by the underwater nodes, i.e. vehicles and fixed modems, by surface access points, such as floating/moored buoys, USV or vessels, and by the CCS. The communication solution being designed in SWARMs is split in three parts:

- A RF overwater sub-network will implement a short/medium range wireless P2P (Point-to-Point) link. The architecture is designed to extend the range by using UHF/VHF OTH (Over-the-Horizon) and/or satellite based solutions. In parallel, the development of Next Generation Offshore Telemetry will allow short-range, robust, high-speed ad hoc communication solution to increase the flexibility;
- A medium frequency (MF) underwater acoustic sub-network will be used to transfer small data packets at medium/long distance, with low bit rate. This part is used to send commands to vehicles and acquire health status information and sensors data. Using EvoLogics modems it is possible to build a star topology network allowing good flexibility in management of up to five vehicles. By adding an optional bottom node, e.g. TNO's bottom node, it is possible to improve the network performance, namely through range increase and parallel backup link;
- A short-range high frequency (HF) underwater acoustic sub-network is used for transferring large packets at higher bit rate, e.g. HQ images, video streaming, and sonar data. Due to the specific task, this consists of a P2P link between a vehicle and a surface access point, or in some cases between two vehicles. This part is based on Water Linked (WLink) modems, which can eventually be integrated with Sabancı University innovative transducers. Also, data rate limitations when using a HF TNO bottom node and ship/shore node will be investigated and demonstrated.

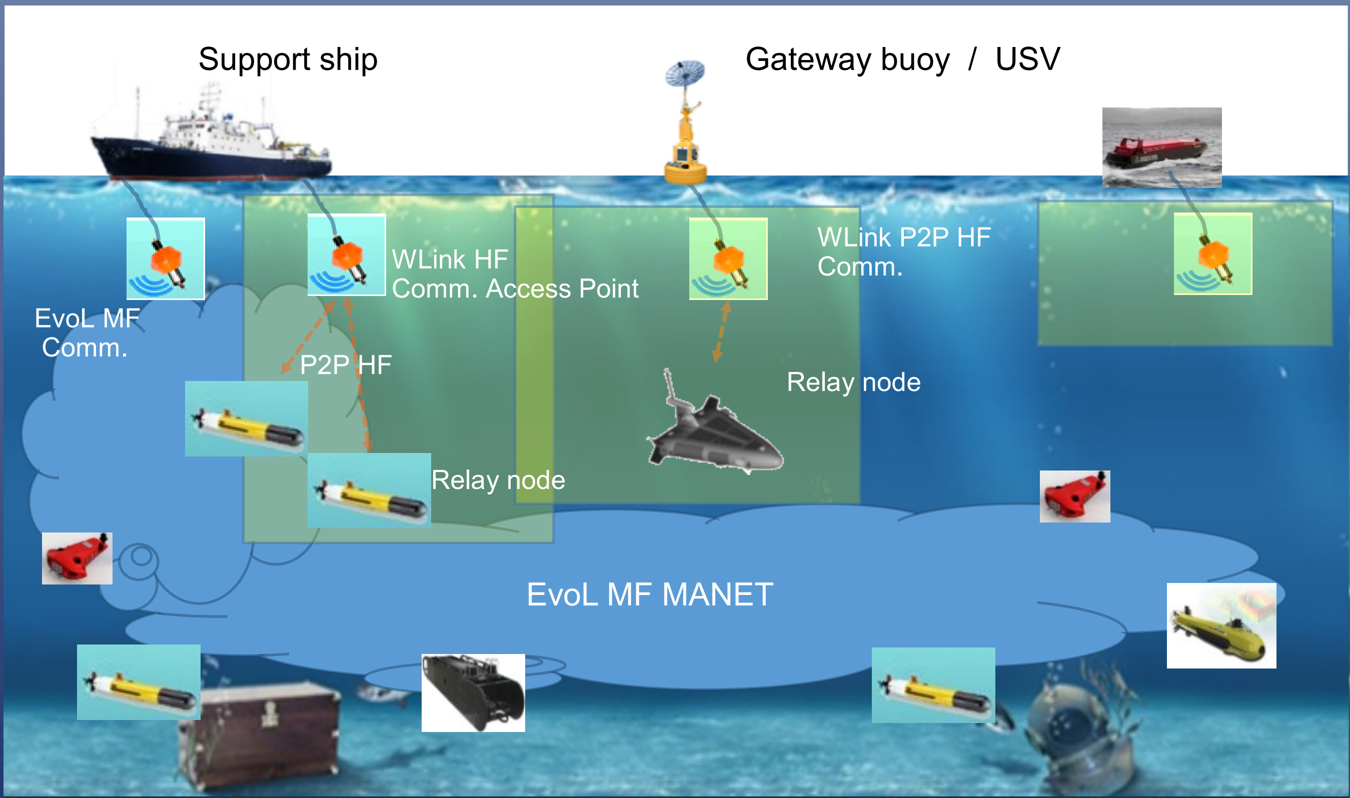
HF WLink modem

## Underwater communication

Compared to RF communication systems used overwater or on land, the underwater environment imposes several constraints that limit enormously data transfer speeds. An underwater network should be ad hoc designed according to the specific requirements of the swarm control.


MF EvoLogics S2CM acoustic modem

HF TNO bottom and ship/shore nodes

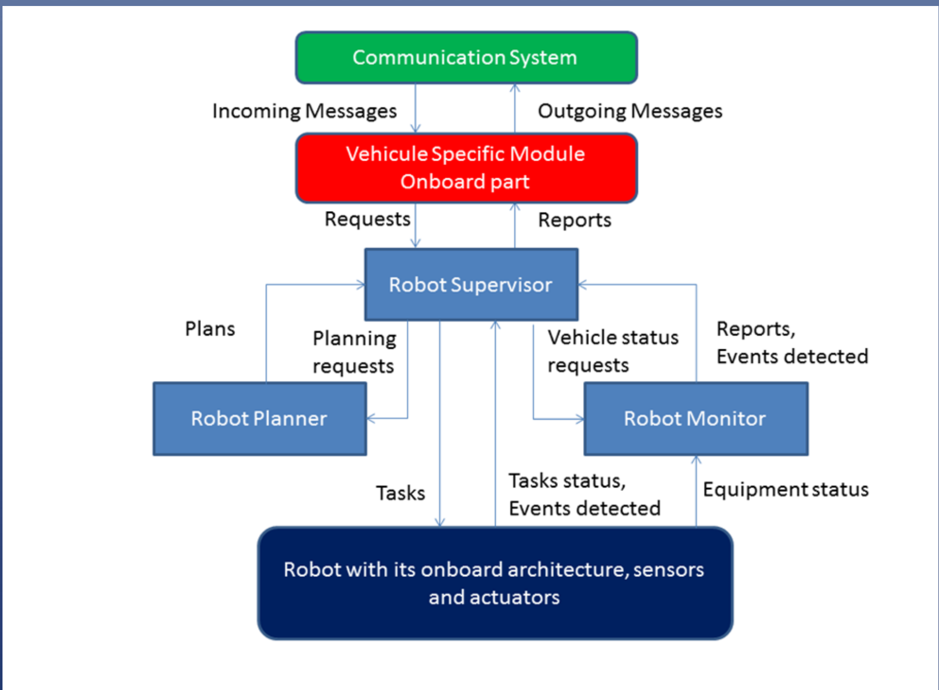



SWARMs underwater network communication architecture

# Robotic vehicles integration

All robots used in the project are equipped with their usual proprietary on-board control software, which allows them to be operated individually with their own control and command station. One of SWARMs goals is to make heterogeneous robots operate in a coordinated way. For that, a high level interface has to be defined and implemented for each robot according to the generic integration architecture presented below, which consists of four main software components:

- The Vehicle Specific Module is in charge of interfacing the robot with the Middleware via the communication system. It acts as a communication bridge allowing to deliver messages to and from the robot generic architecture, taking in charge the implementation of the messaging protocol used by Middleware;
- The Robot Supervisor manages the execution of the different processes needed to achieve a consistent behavior of the robot within the SWARMs system. It receives Requests and Notifications from the VSM and emit Reports or Queries. For instance when receiving a new tasking message from the MMT, the Robot Supervisor first verifies that the task can be performed by the robot and if so will trigger the Robot Planner in order to build an individual detailed plan for the robot, which will be used then to generate specific and safe commands to the robot on-board control system. The supervisor will monitor the execution of these tasks and assess the impact of the current plan execution on the mission and eventually react to events such as task delay or task failure;
- The Robot Planner allows to build or repair the plan of tasks according to the robot capabilities, e.g. sonar, video or path planning. As an example, a vehicle with sonar could be ordered by the MMT to perform bathymetric measurements, and the planner must determine the configuration setup of such sonar, while the path planning calculates the grid of trajectories to be followed;
- The Robot Monitor monitors the robot activities in order to detect faulty behaviors, such as equipment failure or bad quality of produced data. The detections made will be forwarded to the Robot Supervisor, which will decide if a re-planning is needed or if this information has merely to be forwarded to the MMT through the Middleware, or even if a diagnosis has to be triggered. The type of malfunctioning which can be detected will greatly depend of the available data coming from the existing software architecture of the vehicle.




**Robot system integration architecture**

## Integration with Robot Operating System (ROS)

To ensure good level of genericity, a possible implementation solution is to use ROS as the underlying framework, where in such case each robot will have to run one ROS master node as well as nodes corresponding to the Vehicle Specific Module, the Robot Supervisor, the Robot Planner and the Robot Monitor. The embedding will require the development of a specific interface with the existing on board robot control software mainly for the Robot Supervisor and Robot Monitor nodes.

**Robotic vehicles used in SWARMs**

## Local Situation Database

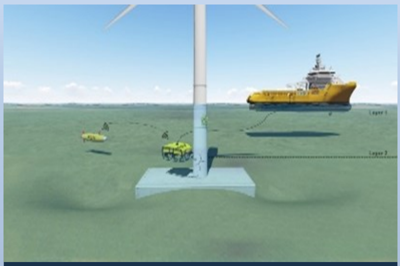
A local database must also be associated with this architecture in order to allow the storage of the current situation of the robot/vehicle, e.g. environment of robot, current plan under execution, health status of the robot, known robots in its neighborhood, etc. Such data can be produced by the robot itself or come from the external world through reception of messages. Those messages can be shared by the different modules of the architecture. For instance, the Robot Planner producing the plan that will be used by the Robot Supervisor for execution, or the Robot Monitor, which produces synthetized state of the vehicle that can be transmitted to the global mission management tool.

# Semi-autonomous manipulation

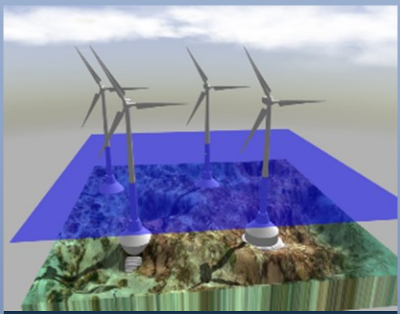
Tele-operating several vehicles underwater, each of them performing a complex task, requires highly trained pilots. The goal here is to provide a set of functions to drastically simplify the tele-operation tasks by providing more autonomy to the vehicles and to facilitate the operation through driver assistance functions, where a completely autonomous operation is not feasible. These functions will be the necessary link between high-level goals given by the operator or the task planning process and the actual safe, efficient and autonomous motion of each vehicle operating in a mission.

During the first months of SWARMs project, the following aspects have been addressed:

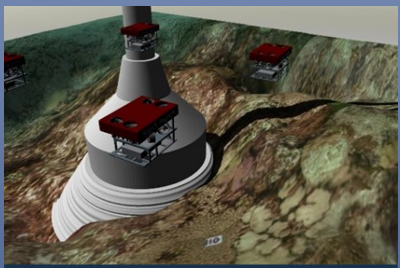
- Based on a requirements analysis of real world scenarios, the concepts associated with the vehicles and manipulators have been defined, as well as the operation strategies for the five defined use cases;
- For the model based development and virtual mission preparation GAZEBO simulation environment has been chosen, as it is the most popular 3D simulator within the ROS ecosystem, and with a rapidly growing community. The SWARMs Middleware will be based on ROS, therefore GAZEBO should fit perfectly to the central development goal of the project. Nonetheless, this simulation environment is currently not yet widespread within the underwater robotics community, and for that, some considerable effort will be necessary in order to adapt it appropriately. In that respect, different plugins have been already developed for GAZEBO, within SWARMs;
- Hydrostatic (buoyancy) and hydrodynamic effects, such as added mass or linear and non-linear damping, on underwater vehicles consisting of one or several rigid bodies, can now be simulated;
- Special plugins simulate thrust forces produced by thrusters. They use one of several implemented dynamics models, i.e. *no dynamics*, *first-order*, *second-order*, *Yoerger*, or *Bessa*, and a conversion function mapping commanded values to the thrust force (*quadratic*, *quadratic w/ dead-zone*, *linear interpolation of measured values*). Basic controllers are implemented so a user can control accelerations or velocities of a ROV using a gamepad-like device;
- Sensors have started to be modelled by implementing inertia sensors, reusing noisy gyroscope and accelerometer from the EuRoC project. In addition noisy magnetometer and underwater barometric sensors have been implemented;
- As an underworld world a small wind park was modelled within GAZEBO in which swarms of vehicles can now be simulated and operated virtually;
- Additionally, 3D models of ROV and AUV are ready to be used in the simulator.



Corrosion prevention Use Case



Offshore wind farm in GAZEBO



Virtual ROVs swarm near foundation

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