Underwater Robotics ready for Oil Spills

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Abstract

Underwater robotics ready for oil spills (URready4OS) is an EU DG-ECHO co-funded project aimed to join forces to make available to European Civil Protection a fleet of autonomous underwater vehicles (AUVs), unmanned aerial vehicles (UAVs) and unmanned surface vehicles (USVs) with operational capability to intervene against oil spills in European Seas using new cooperative multivehicle robotic technologies.

Tracking oil spills underwater before reaching the surface by using new emerging robotic technologies will bridge the gap between existing traditional technologies (modelling and satellites) as decision support system for Civil Protection decision makers. Underwater oil plumes can come from bottom leaks and from surface patches forming subsurface plumes as recently been brought into the public eye during the 2010 Deepwater Horizon incident. The distributed intelligence of these devices across the spill combined with hydrodynamic modelling will be able to build up a highly accurate and dynamic image of the spill. This cooperating multivehicle robotic technology will allow a cheap, flexible, expandable, precise and rapid decision support system, improving the capacity of responding to these events. Institutions from Spain, Portugal, Croatia and Cyprus are participating in this project.

Fluorometer sensor for crude and refined oil have been integrated into two types of AUVs (IVER2 and LAUV) being used in this project. Different approaches for integration have been adopted. The architecture and configuration of the whole system, together with results from the preliminary experiment held in Split (Croatia) from September 22nd to October 2nd, 2014 are shown. The objective of this experiment was to test communication between agents (vehicles) and improve protocols and software developed for multivehicle collaborative navigation. A demonstrative experiment will be held in Cartagena (Spain) in June 2015.

The team

Partners for this project are the Underwater Vehicles Laboratory (LVS) of the Technical University of Cartagena (UPCT) (Spain), the Underwater Systems and Technology Laboratory (LSTS) of the University of Porto (Portugal), the Laboratory for Underwater Systems and Technologies (LABUST) of the University of Zagreb (Croatia), the Oceanography Center of the University of Cyprus and the Spanish Maritime Safety Agency (SASEMAR).

Vehicles system Network

Four Autonomous Underwater Vehicles (AUVs), two Unmanned Aerial Vehicles (AUVs) and an Unmanned Surface Vehicle (USV) are the agents networked vehicles system to detect and track oil-in-water spills.

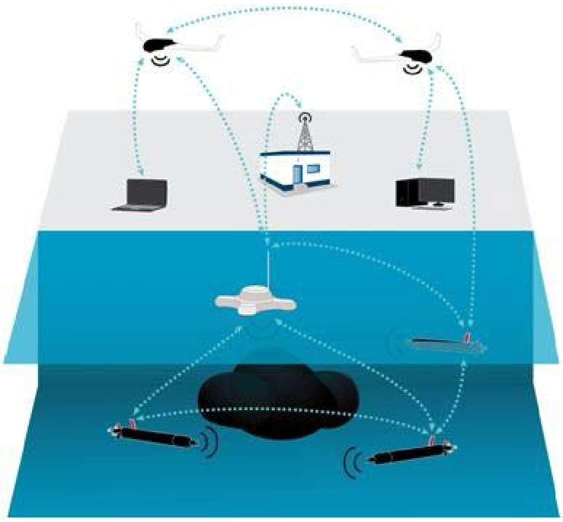

Figure 1. URready4OS vehicles involved in the project.

Three of the AUVs are Light Autonomous Underwater Vehicles (LAUV) that is a vehicle designed and manufactured by OceanScan and the LSTS, at the University of Porto, targeted at innovative standalone or networked operations for cost-effective oceanographic, hydrographic and security and surveillance surveys. With their latest innovation it can hold almost any king of sensors like the Turner Design® C7 fluorometer used here to sense oil-in-water.

The forth vehicle used is an IVER2 AUV, a small man-portable AUV manufactured by Ocean Server Technology, Inc. With a proven track record over thousands of missions, it is ideal for imaging and environmental surveys, including research, development, and OEM based applications. The IVER2 design allows to integrate new sensors and capabilities. It was modified with a new nose to integrate the oil-in-water probes used to detect crude or refines fuels.

The X8 is a low-cost COTS (Components Off-The-Shelf) Unmanned Aerial Vehicle, modified at the LSTS, which allows for quickly deployable surveilance missions. It’s a hand launchable vehicle perfected for low altitude reconnaissance scenarios with live video feed.

The surface component of the system is a Unmanned Surface Vehicle (USV), an autonomous overactuated surface platform (PlaDyPos) with 4 thrusters forming the ”X” configuration. This configuration enables motion in the horizontal plane under any orientation. The platform has been developed at the University of Zagreb Faculty of Electrical Engineering and Computing, Laboratory for Underwater Systems and Technologies for tracking of underwater objects communication router between the surface and the underwater navigation aid.

A new nose has been design by the Technical University of Cartagena to integrate the Turner Designs Cyclops Integrator® in the IVER2 AUV. This design implied to add a second CPU to the AUV to be in charge of recording the Oil and Rhodamine data provided by the probe and merge them with the navigation data from the vehicle.

To integrate the Turner Designs® Cyclops 7 probes, OceanScan has designed a new nose section for the LAUV that can accommodate sensors from different manufacturers. Besides the probes for Refined Oil, Crude Oil and Rhodamine, it is also possible integrate most of the sensors in the market. The electronics board that interfaces with the sensors is based in AML's Metrec-X, that includes multiple analog input slots, to which the Cyclops C7 probes are connected. From the hardware point of view: wet connector is installed between flooded nose (wet side) and DVL compartment (dry area). The probes can be installed and connected directly on the connector or can be connected using extension cable, so the probe itself can be positioned anywhere on the vehicle. On the dry side, probe is powered by 12VDC from the AUV power distribution board and probe signal output (analog output) and range inputs are connected to the backseat PC. From the software point of view, backseat samples the probe measurement and automatically adjust the probe range. At the same time collects the position data from the front seat and internally log all this data together. In case of near real time data transfer, backseat communicate via Tritech ® Micron modem with the surface transducer and handles the transfer.

Hydrodynamic Model

To track and forecast the oil spills and design the vehicles' missions the MEDSLIK numerical model is used. MEDSLIK is an oil spill and trajectory 3D model that predicts the transport, fate and weathering of oil spills and the movement of floating objects. The MEDSLIK incorporates the evaporation, emulsification, viscosity changes, dispersion in water column and adhesion to coast. The transport of the surface slick is governed by currents, waves (Stoke's drift) and wind while its diffusion is modelled by a random walk (Monte Carlo) model. Oil may be dispersed into the water column by wave action but dispersed oil is moved by currents only. The oil is considered to consist of a light evaporative component and a heavy non evaporative component. Emulsification is also simulated, and the viscosity changes of the oil are computed according to the amounts of emulsification and evaporation of the oil. The pollutant is divided into a large number of Lagrangian parcels of equal size. At each time step, each parcel is given a convective and a diffusive displacement.

Oil viscosity changes and beaching on the coast and absorption depending on the coastal type. MEDSLIK covers by default the Mediterranean sea, the Levantine basin, the Black Sea and the Baltic Sea, but it can be used for any user-selected region in the world if the appropriate map, bathymetry and forecast files are provided.

MEDSLIK consists of four modules: 1) a setup module for model domain and parameters; 2) a visual interface for input of the spill data; 3) a run module that performs the simulation and 4) a visual interface for viewing the output.

Additional oil spill model capabilities are beaching, hindcast, automatic connection to EMSA CSN SAR detections, use of ESA images. Other features of MEDSLIK are: 1) It includes a built-in database (from REMPEC) of 230 oil types that are the most common in the Mediterranean Sea; 2) It allows to switch from coarse to high resolution ocean forecasting data, when the oil slick passes from a coarse to a higher resolution domain; 3) It allows assimilation of observations, in-situ or aerial to correct the oil spill predictions; 4) The effect of deployment of oil booms and/or oil skimmers-recovery can be examined. 5) Continuous or instantaneous oil spills from moving or drifting ships whose slicks merge can be modeled together; 6) Hindcast simulations for tracking the source of pollution; 7) Integration with the AIS in the Levantine Basin; 8) It includes a simple GIS to allow information on coastal and open sea resources and 9) Simulation of sub-surface oil spills.

The model has been used successfully at the Costa Concordia incident and the one in July 2013 in the Famagusta Bay, Cyprus, following an incident from a tanker. Moreover, MEDSLIK has been used from 2007 to April 2012 for operational 24 hours forward and backward predictions coupled with EMSA- CSN and ESA ASAR images detecting possible oil spill in the Mediterranean Levantine Basin. MEDSLIK is used by several agencies throughout the Mediterranean (Cyprus, Italy, Israel, Malta, Spain), and is in the core of the Mediterranean Decision Support System for Marine Safety (www.medess4ms.eu), a service for operational oil spill predictions in the Mediterranean.

Decision Support System

Neptus has been developed and thouroughly tested by LSTS for commanding and controlling fleets of unmanned vehicles. Neptus supports AUVs, UAVs, ROVs, ASVs and different types of non-actuated sensors. Operators not only can use Neptus to observe real-time data of networked vehicles but also to revise data from previous missions, plan and simulate future missions to be executed by one or several vehicles. Neptus provides a comprehensive distributed environment where operators and vehicles can join in and leave the network as time floes. Operators are able to interact with a dynamic set of available assets as well as each other in real-time by commanding plans and receiving data from the network.

Neptus is the C2 (Command and Control) software used to command and monitor our unmanned systems. It is written in Java and it currently runs in Linux and Microsoft Windows operating systems. The main Neptus communication interface is IMC, making it interoperable with any other IMC-based peer. Despite the heterogeneity of the controlled systems, Neptus provides a coherent visual interface to command all these assets. The main purpose is for an operator to take advantage of what these assets have to offer in terms of sensor and actuator capabilities without having to dwell into specific C2 software and details.

Neptus is a framework that was created from scratch having in mind its adaptability and flexibility to encom-pass needs from diverse vehicles, scenarios and operator experiences. As a result, it provides the rapid creation of derived tools and can be customized according to operator and mission needs.

A plug-in can be developed independently of the main Neptus source and added as a compiled jar file. This way Neptus can be extended by a third party with new components with the added possibility of not sharing source code among developers (which can sometimes be a requirement for ITAR-constrained code, for instance).

Neptus supports planning for different vehicle types. This is done by having a profile of each vehicle's sensors and maneuvering specifications. Different types of geographical data can be used in the planning phase, including S57 charts, tiled raster images from various sources and user-defined features. Plans can be simulated and validated before execution according to vehicle capabilities (battery endurance, maneuver support, sensors, etc).

During the execution phase, Neptus can be used to visualize incoming real-time data from multiple vehicles, to teleoperate individual vehicles and to give maneuver commands to multiple vehicles. In order to support limited communications, the expected behavior of vehicles disconnected is simulated so that the user gets a comprehensive, quick glimpse of the state of the entire network.

The review and analysis phase takes place on site or after the mission (or plan) is concluded. In this phase, the collected data is processed and analyzed to compile the mission results or evaluate individual plan execution in order to adjust and re-plan to achieve another desired outcome.

Documentation

A text where protocol performances of the vehicles, design and missions, requirements, communication, and detailed description of deployment and recovery of the vehicles will be produced. This document will gather each step of the interventions to be performed in a systematic and detailed way together with the requirements for third parties vehicles and assets to be added to the fleet in case of emergency.

The Experiments

The Preliminary Experiment

A preliminary experiment working at sea with a total of 6 vehicles took place from September 22nd to October 1st in Split, Croatia. The teams involved in the URready4OS project had to coordinate and check the correct functioning of the networking vehicles. A simulation of an oil spill was performed with Rhodamine WT dye. The place where the experiment took place was in the North of the peninsula of Marjan peninsula in Split, a place of easy access to the sea which allowed us to develop our work under the best conditions. The site was provided by the Croatian Navy.

The vehicles that participated in the experiment were: two Light AUVs (named *Xplore* and *Xtrem*); and two X8 UAVs from the University of Porto, the Light AUV *Lupis* and the USV *PlaDyPos* from the University of Zagreb; and an IVER2 AUV from the Technical University of Cartagena. In addition, the team from University of Cyprus was responsible for making predictions used to establish the routes to be followed by the vehicles above mentioned with MEDSLIK.

In total, 20 people that for 10 days took the first step for the project's main goal which was the achievement of a fleet of vehicles operating in case of a possible oil spill, and the existence of a document that works as a guide to use underwater vehicles in these cases.

The milestones of the experiment were:

Probes Integration Test in each Autonomous Underwater Vehicle (AUV).

Integrating the probes in the vehicles was developed differently by each team, choosing each of them different sensor models. Therefore, one of the first goals was to verify that the integration was performed correctly. An intercalibration was performed thereof, ensuring that the measurements between the probes were homogeneous. A dilution of Rhodamine WT dye with a concentration of 100 ppb was prepared. As all values obtained by each of the vehicles were close to 100 ppb it was only necessary to make some adjustments to the calibration coefficients.

Communications Test between Vehicles and to the Ground/Ship Station.

Synchronization and verifying that the communication between the UAVs and the AUVs (LAUV-xplore1, LAUV-Lupis and IVER2-EM190) was produced correctly was another goal of the experiment. Making that the data from marine vehicles in the process of their appearance in surface reached the land base was possible thanks to the coordination between them and the aerial equipment. The mission of the latter was not only to transfer that information but also from its privileged position, to make panoramic photos of the Rhodamine WT plume.

Underwater Communications Test between USV, AUVs.

From 5 to 10 seconds was the time interval that the vehicles took to send the information to the base station while being submerged. Those in charge were two vehicles performing these functions differently: the Lupis did it through a signal sent to the vehicle in the surface, using an acoustic modem that was in charge of sending that signal to an aerial equipment or directly to the base camp via Wi-Fi. The Xplore performed this task differently. Its signal, also acoustic, was sent directly to a receiver located at the ground station.

Positioning Test of all Vehicles in Command and Control Console (NEPTUS).

Knowing the position of each vehicle at any time is a basic point for the actions to develop in a coordinated and accurate manner. To achieve this goal NEPTUS was the tool used. This software allowed verifying and checking the location of all the equipment simultaneously in real time.

Integration of Data Test in the Command and Control Console (NEPTUS).

The capabilities of NEPTUS are not just limited to showing the simultaneous location of all vehicles, regardless of their position, but to also to enable data collection and display them collectively. Thus, in a next mission, vehicles can approach the source of the stain to obtain more accurate data. The optimization was evident, accelerating and improving performance times.

Test of Protocols for Communication.

The communication in any experiment is a key factor. Before this test, each vehicle was developing and using its own protocol, but for the success of the mission it was vital to set up a common one for all of them. During those days we worked on it. The best example of achieving this goal was the integration of a vehicle (IVER2), developed by an unrelated commercial enterprise to the NEPTUS system.

Operational Test with Several Vehicles Deployed at a Time

Once the above test were performed one more operational test with all the vehicles in the water and in the air were carried out. The AUVs were responsible for measuring the Rhodamine WT (an iniquitous stain) under the water, a UAV responsible for transmitting data to the ground, and a USV responsible for collecting the data under the water. To perform this mission, and through a boat donated by the Croatian Navy, the whole team started working. The next stage was to gather information about which of the different sampling strategies of the vehicles was most appropriate in these emergencies. At the end of the day it was possible 1) to detect the plume under the water, 2) receive data in real time while the vehicles were submerged, 3) to synchronize all the vehicles with the onboard computer and 4) to draw the data in NEPTUS to know the position of each of the teams at any moment.

The Demonstrative Experiment

Once carried out successfully the preliminary experiment it is planned to perform a demonstrative experiment off the coast of Cartagena (Spain) from the 22nd to the 26th of June. The experiment will consist in five days trials at sea, the last two days open to anyone interested in participating as observer.

The experiment will take place on board of the *Clara Campoamor* vessel operated by SASEMAR (Spanish Maritime Safety Agency) and based in Cartagena. It belongs to the type of multipurpose ocean going tugs and has 80 meters long, 20,600 horsepower, 228 tons of towing and 1,750 m^3 of storage capacity. With a crew of 18 people, sleeps up to 38 people in their cabins. The two cranes installed in the middle of the ship allow them to ship containers of 10 or 20 feet and can lift 20 tons each with a range from 4 meters minimum 15 meters maximum. Equipped with two auxiliaries vessels: one of 9 meters long, with a pulling capacity of two tons; and other 7 half meters long, capable of reaching 33 knots powered by waterjets. All these characteristics with an open space at the stern make this ships a perfect platform to work with underwater and aerial robotics systems.

During the experiment a plume of Rhodamine WT will be produced simulating an oil spill. AUVs equipped with oil-in-water probes will detect and follow the plume transmitting the information to the ship through the ASV and the UAV. New strategies for designing and execute missions will be tried.

Acknowledges
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