Large Scale Unmanned Vehicles Oceanic Exercise REP(MUS)19 Field Report

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I. Extended Abstract

The REP(MUS)19 is an exercise that takes place annually since 2010 in the south of continental Portugal. LSTS (Underwater Systems and Technology Laboratory) has co-organized these events, since the beginning, together with the Portuguese Navy and, in more recent years, with NATO-CMRE. NATO's MUS (Maritime Unmanned Systems Initiative) initiative joined the event in 2019. The target of these exercises is to have technological experimentation activities that engage armed forces, universities, and industry, in the unmanned system's operation. The event operational environment enables interactions between all parties to share experiences and needs to drive research in the direction of real-life needs. LSTS' participation in the 2019 event consisted of eight exercises.

A. Endurance Offshore Survey

It was part of a three-day continuous survey of Setúbal Canyon with AUVs. This exercise was a scientific event with the participation of the University of Lisbon Science Department. In this exercise, one AUV was launched near shore and traveled 30 km offshore to the canyon, surveying and collecting CDT data continuously for over 48 hours. We used a LAUV AUV [1] equipped with a CTD and able to operate for more than 60-hours.

The challenge for this operation is the area that is part of a ship lane and thus with collision probability with ships. The vehicle was launched from shore at Sesimbra and traveled about 30 km offshore to Setúbal Canyon with no boat support to survey it for 48 hours. The AUV was controlled from shore via satellite communications and using AIS data to mitigate collisions. The communication with the AUV was done on scheduled times, where compressed collected data was received on shore, and new survey commands could be sent (either to navigate around traffic, or explore an area of interest seen by the received data). The AIS monitoring was used to monitor and take evasive actions. This end up to be a successful operation with validation of this kind of long range, remote monitoring operations.

As part of this operation, a VTOL UAV was going to be launched for long-range communications test and to collect thermal imagery co-temporal with the AUV. This flight was over water with a FlightWave Edge VTOL. On the launch the UAV got out of control, which resulted on minor damages. Post-incident analysis pointed to a GPS signal interference in the area (other teams also suffered from this). The source was not identified. This issue made us to abort this exercise with the VTOL.

B. Sado River Estuarine Outflow Study

Sado River estuarine outflow study (third consecutive year exercise) event has the participation of the University of Aveiro and aims to study the Sado River outflow. CTD and chlorophyll data were collected by the AUVs for 13 hours on a couple of days.

As the previous operation (section I-A), we operated, for the most part in this case, the AUV from a distance. The added challenge for this mission was the proximity of shore and the narrow ship lane to enter and exit the river, which made it more difficult to operate. For the most part the operation was completely autonomous, but in this case we were close to monitor the ship traffic, that for the most part don't have AIS and so not able to fully automate a warning system. The operation on both days occur with no issues and with three years worth of data we are contributing for the study of this estuarine outflow.

C. SubAUV

SubAUV was an exercise to study a manned submarine detection capability of unmanned underwater vehicles. This exercise was executed with one of the manned submarines from the Portuguese Navy trying to detect with its sensors our LAUV AUV doing different mission profiles.

The LAUV executed a series of runs, exposing different aspects, with sensors on and off. The aim was to do usual AUV operation to allow the Portuguese Navy manned submarine to investigate the better ways to detect the LAUV operations. At the end this was successful.

D. CDC3

CDC3 aim the use of an acoustic modem to bridge the air-water communication of commands and data between remote

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command and control center and remote unmanned underwater assets. This exercise had the collaboration of the NUWC (Naval Undersea Warfare Center, Newport Division, USA) and the University of Hawai'i. Our LAUV was launched allong side with NUWC's Iver3 AUV, UHawai'i's WAM-V ASV and seabed node. Our water landing octocopter equipped with a Blueprint Seatrac acoustic modem worked as a bridge between command and control center over Wi-Fi and underwater assets over an acoustic modem. All those assets from different vendors were integrated to talk with the same language. We successfully managed to communicate between all the assets. Detailed results will appear at [3].

E. DISSUB

DISSUB employed digital acoustic communications to aid a distressed manned submarine to communicate with a search party in a more efficient and less error-prone way.

This exercise was executed in cooperation with the Portuguese Navy's Submarine Division and NATO's CMRE allowing the test of JANUS (STANAG 4748) for acoustic digital communications among different vendors. This digital communications is more reliable in situations of distress and allowed the use of AUVs to listen to these messages and automatically execute search surveys. The operation was successful on the communication part and (LAUV) search. For the next year we will investigate more search patterns and data to communicate.

F. Mine-Counter Measure Exercise

This MCM exercise was executed by several navies in the survey for mine detection. We operated jointly with our spin-off company Oceanscan-MST.

Each team was given a set of coordinates for five different areas (Alpha through Foxtrot), with approximately 0.25 Km^2, where various decoy mines had been deploy at unknown locations. After identifying possible contacts the LAUV swept the marked areas using the optical cameras aboard the LAUV.

Experiences shared between all participants using AUV vehicles such as LAUVs, REMUS, and Gavias was a good outcome of this exercise.

G. Cooperation Area Coverage

In the scope of the EU project EUMarineRobots Transnational access activities (TNA), REP19 robotic infrastructures were open to candidates to test their research. In this edition, a TNA was granted to researchers from Indraprastha Institute of Information Technology (IIIT) of Delhi, in India. Their proposed work was about "Multi-AUV Area Coverage under Currents"[1]

The aim of this experiment was to develop and validate in the field novel multi-AUV coverage algorithms that can handle currents and faults during a mission. A robust path following controller using adaptive integral LQR (Linear Quadratic Regulator) was implemented. Although the developed path following algorithm based on SDRE proved to still need optimization to be able to run onboard of an AUV a solution was achieved to generate offline plans for the vehicles taking the current information into account and the area coverage algorithm was successfully validated in the field using multiple AUVs.

[1] A paper will be published in *2020 IEEE OES Autonomous Underwater Vehicle Symposium* entitled "Multi-AUV Coverage with Functional Constraints and Currents"

H. Sado Inflow

Autonomous underwater vehicles typically have low endurance and speeds. In many operation areas the speed of the water currents can reach or exceed the AUV's maximum speed. Hence there is a clear benefit in using trajectory planning methods which can integrate water velocity predictions to route vehicles through areas where the currents will provide a net increase in the vehicle's average velocity.

LSTS implemented a system which is able to plan minimum-time trajectories to a given target area, using water velocity predictions from a hydrodynamic model [2]. The system can also integrate bathymetry data, so that the generated trajectories will avoid areas where the water column height is less than a given value.

A successful test run was conducted on September 25th, with the vehicle following an optimal trajectory to enter the Sado river from the outside of the estuary. The difference between the expected and observed mission duration was approximately 2 minutes, with the total predicted duration was a bit more than 3 hours. The observed increase in the average velocity (relative to the nominal velocity of 1 m.s^{-1}) was 28%, which is equal to the predicted increase. This suggests that the hydrodynamic model predictions are sufficiently accurate for our purposes, and that the vehicle was able to track the planned trajectory.

II. Conclusion

In this paper, we briefly presented the exercises we conducted in a two weeks period, and share some of the results and challenges. In all of the exercises, we used our LSTS Toolchain [4] an open-source software suite for mixed-initiative control (humans within the planning and control loops) of networked heterogeneous unmanned systems, and also vehicles created on the lab (some already commercially available such as the LAUV.

All the scenarios were successfully carried out and our systems and technologies proved to be robust to operate in real application scenarios.

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