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Typhoon at CommsNet 2013: experimental experience on AUV navigation and localization

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Abstract: The CommsNet 2013 experiment took place in September 2013 in the La Spezia Gulf, North Tyrrhenian Sea. Organized and scientifically led by the NATO S&T Org. Ctr. for Maritime Research and Experimentation (CMRE, formerly NURC), with the participation of several research institutions, the experiment included among its objectives the evaluation of on-board acoustic Ultra-Short Base Line (USBL) systems for navigation and localization of Autonomous Underwater Vehicles (AUVs). The ISME groups of the Universities of Florence and Pisa jointly participated to the experiment with one Typhoon class vehicle. This is a 300 m depth rated AUV with acoustic communication capabilities originally developed by the two groups for archaeological search. The CommsNet 2013 Typhoon, equipped with an acoustic modem/USBL head, navigated within the fixed nodes acoustic network deployed by CMRE. This allows the comparison between inertial navigation, acoustic self-localization and ground truth represented by GPS signals (when the vehicle was at the surface). The preliminary results of the experiment show that the acoustic USBL self-localization is effective, and it has the potential to improve the overall vehicle navigation capabilities.

Keywords: Autonomous vehicles, marine systems, navigation, positioning systems, AUV (Autonomous Underwater Vehicle)

1. INTRODUCTION

In the framework of the THESAURUS project (Italian acronym for "TecnicHe per l'Esplorazione Sottomarina Archeologica mediante lUtilizzo di Robot aUtonomi in Sciami") a class of AUVs (called Typhoon) able to co-operate in swarms to perform navigation, exploration and surveillance of underwater archaeological sites has been developed. The project specifications are quite ambitious: the low cost vehicles have to operate with a maximum depth of more than 300 m, an autonomy ranging from 8 to 12 hours is required and a maximum speed of 5-6 knots has to be achieved. Briefly, the Typhoon class AUV is a low cost vehicle with remarkable performances and power on-board. In particular, it is worth to note that the depth specification is very significant for archaeological interests: the depth of 300 m is prohibitive for usual diver operations and it is also higher compared to the depth specification of many commercial low cost AUVs. The total carried payload is quantified in about 30-40 kg and the cost of the vehicle is limited (less than 50000 €). Low production and maintenance costs are a mandatory specification of the project, considering the necessity of producing several vehicles for a team composed of middle-sized vehicles. A first fleet of three different underwater vehicles, cooperating in a single team, has been developed, as visible in Fig. 1: see Allotta et al. (2012) and Allotta et al. (2013). The three vehicles can be characterized as follows.

Vision Explorer A vehicle equipped with cameras, laser and structured lights for an accurate visual inspection and surveillance of archaeological sites. The visual inspection involves a short range distance (few meters) between the vehicle and the target site, and the capability of performing precise manoeuvring and hovering;

Acoustic Explorer Preliminary exploration of wide areas to recognize potentially interesting sites involves the use of acoustic instruments, such as side-scan-sonar. Extended autonomy, a stable and a noiseless behaviour have to be preferred. This kind of vehicle can perform long range missions. Consequently, navigation sensors able to compensate the drift of the inertial sensors, such

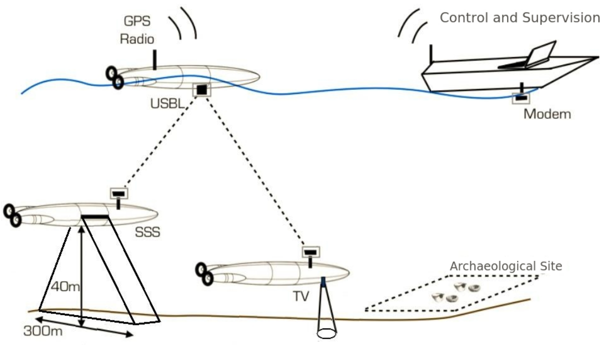


Fig. 1. Typhoon AUVs of the swarm

as a Doppler Velocity Log (DVL), have to be installed on board;

Team Coordinator A vehicle with extended localization and navigation capabilities is used to coordinate the team. This vehicle periodically returns to surface getting the GPS position fix and, more generally, detailed navigation information that can be shared with other vehicles of the team. Currently the authors have adopted the following approach: when the mission area is quite defined and a surface vehicle or a buoy are available, coordination and data transmission are performed by this dedicated device. On the other hand, when a different operating scenario is required, one or more vehicles of the team could periodically interrupt their mission performing the activity of team coordinator.

Different mission profiles should correspond to different vehicle layouts suitable and optimized for a specific task; however the authors, in accordance with the project requirements, have preferred a hybrid design able to satisfy different mission profiles, to reduce the engineering and production costs and to assure vehicle interchangeability. Each vehicle of the team can be customized for different mission profiles; so the team composition can be altered, e.g. two vehicles may be equipped for the visual inspection of a site. Since each vehicle differs only in terms of sensor layout and payload, the naval and the electromechanical design was focused on a common vehicle class. For instance, for an individual mission in which both acoustic and visual inspection of an archaeological site are performed by a single vehicle the instrumentation layout described in Fig. 2 can be easily assembled. Following

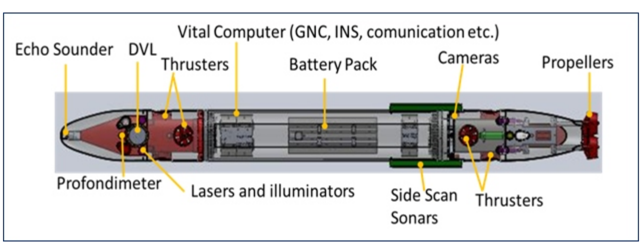


Fig. 2. Example of Typhoon vehicle, customized for both acoustic and visual inspection of a site

extensive engineering tests, that took part in summer 2013 within the THESAURUS project activities, one of the Typhoon vehicle, operated by the ISME groups of the Universities of Florence and Pisa, partecipated in the CommsNet 2013 experiment, organized by the CMRE in

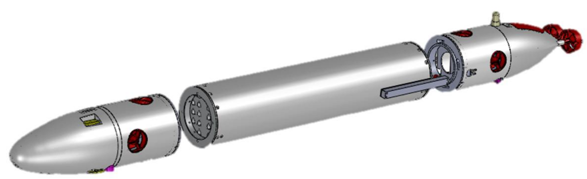


Fig. 3. Typhoon AUV: CAD design

Fig. 4. Typhoon AUV: final version

September 2013. The experiment included among its objectives the evaluation of on-board acoustic USBL systems for navigation and localization of autonomous underwater vehicles. In the following, the vehicle is described in more detail, the experiment is presented and the preliminary results are reported.

2. MAIN FEATURES OF THE TYPHOON VEHICLE

Typhoon vehicle is a middle-sized class AUV, whose features are comparable with other existing vehicles, such as Remus series from Kongsberg. Considering the vehicle sizes (length of 3600 mm, external diameter of 350 mm, weight of 130-180 kg according to the carried payload) and the expected performances (maximum reachable depth of about 300 m, at least 10-12 hours of autonomy and a maximum speed of 5-6 knots) the vehicle can be considered an intermediate one compared to the smaller Remus 100 and the bigger Remus 600. A cheap construction and maintenance is an important requisite for a vehicle which has been designed to operate in swarms of at least three vehicles. In Fig. 3 and Fig. 4 the Typhoon CAD design and its final built version can be seen. Compared to existing commercially available vehicles, Typhoon presents some innovative features which greatly contribute to reduce production and maintenance costs:

- The extended use of low cost corrosion resistant materials: thanks to the use of composite material such as fibreglass, the production cost of the hull is quite low. Also the maintenance is quite simple;
- Modular mechanical design with commercial components: the use of low cost commercial Lithium-Polymer batteries usually used for ground racing vehicles contributes to reduce the costs. The actuators and the propellers of the propulsion system are completely modular and interchangeable. Both propulsion, and manoeuvring thrusters are actuated

with the same motor and drive system: a standard actuation unit with a 200 W brushless motor and drive directly fed by the 48 V provided by the batteries and controlled through an industrial CAN bus, see Carlton (2012). The same actuation system can also be used to control movable navigation surfaces like rudders and fins, resulting in a highly customizable actuation system. The calibration of the pitch static attitude can also be performed moving the accumulators whose axial position is controlled by a screw system;

- Extended use of fast prototyping techniques: the vehicle is easy customizable since many components and accessories are built using ABS plastic material, shaped using 3D printers. This way, many components may be easily customized and rebuilt in few hours. Moreover, the prototyping techniques have greatly accelerated the production of the components.

2.1 Acoustic Communication

As mentioned in the Introduction, the acoustic communication system has been designed having in mind an operation with a team of Typhoon vehicles. To this aim, the vehicles have to estabilish a communication network based on a time-sharing bi-directional/broadcast communication scheme. The goal is to create a flexible structure capable of ensuring low-delay communication and the reliable transmission of specific messages necessary for the safety of the swarm and for exploration missions. The network is composed by a few layers, as shown in Fig. 5, and it does not include most of the complexity typically present in terrestrial networks. The implemented networking system has already been described in Caiti et al. (2013). Its main features are reported here for self-consistency. The bottom layer is represented by the EvoLogics acoustic modem/USBL, which manages the physical transmission of the signal into the water. The adopted communication mode provided by the modem, namely instant messaging, does not require connection establishment procedures, allows for broadcast messaging and permits a message maximum size of 64 bytes. The modem also implements collision avoidance techniques (Medium Access Control - MAC) and provides basic network functionalities, including an addressing system that can be exploited at the link layer. The medium access control is completed through a channel time division mechanism: time is divided into slots and each node is assigned a slot where it has to concentrate all its communication burden. The network link layer is composed by a combination of the modem networking features and of the Mission Oriented Operating Suite (MOOS) framework, Newman (2003). MOOS is a publisher/subscriber system for inter-process communication through message exchange. Messages are associated to an information descriptor, called topic, contained in the messages themselves. Publishers send their messages to a dispatcher, represented by a central database (MOOSDB), which is responsible for forwarding messages to the subscribers based on their topic. Subscribers have to preliminary declare their interest in specific topics by issuing subscription to the dispatcher itself. Within this setting, each acoustic node is equipped with a process that handles the communication with the acoustic device: when a new message is received from the modem, it publishes the information in the INBOX topic, whereas during a transmission, it reads a message from the OUTBOX topic and forwards it to the modem for the physical transmission. To increase the throughput of the network and the probability that an important message is transmitted as soon as possible, messages are organized in a priority queue. More specifically, four classes of messages have been identified, each of which associated with a decreasing priority; among them, the localization messages, periodically exchanged between the vehicles to have USBL updates or range measurements, are relevant to the aim of CommsNet 2013 experiment. To avoid an indefinitely growth of the queue when an application generates data at a higher rate than the acoustic channel can support, at each step the messages are filtered on the basis of the time slot duration and those that cannot fit into the available time are discarded. Moreover, the organization of the queue is performed both during the non-communication periods and the communication time slot available to the vehicle; this way, the network supports real-time data delivery, meaning that the data are produced, organized and then transmitted during the communication period of the node. Finally, the network link layer also includes an additional sub-layer, namely the performance/network layer, used to adapt the requests coming from the application level to the constraints of the layers below it and of the acoustic channel. The highest layer, namely the application layer, utilizes MOOS as software infrastructure. An application which wants to join the network has only to publish in the topic OUTBOX the data to be sent acoustically towards the desired nodes and to register to the topic INBOX to be notified when new acoustic messages are received. This way, the network becomes completely transparent from the application point of view.

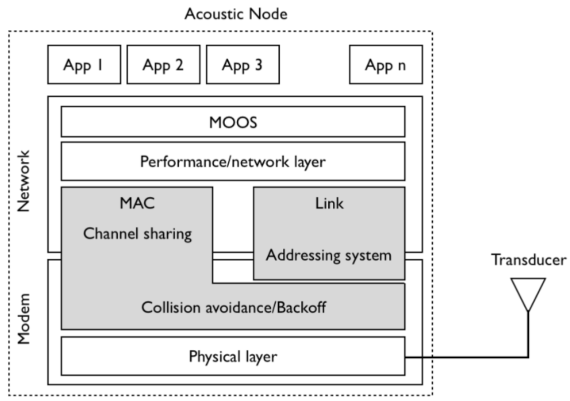


Fig. 5. Layered structure of the underwater acoustic network

3. EXPERIMENT DESCRIPTION

The CommsNet 2013 experiment has been organized by the NATO Centre for Maritime Research and Experimentation (CMRE, formerly NURC) with the main objective to test the performance of several acoustic communication and localization systems using underwater networks. Several teams from different institutions, each one interested in testing different systems, have been involved in the experimentations, held with the support of NRV Alliance.

CommsNet 2013 took place from Sept. 9^{th} to Sept. 22^{th} in La Spezia and was originally planned in the west area of Palmaria island, Gulf of La Spezia, North Tyrrhenian Sea, where CMRE has a permanent testbed for underwater networking and communication purposes (LOON - Littoral Ocean Observatory Network - Alves et al. (2012)). In CommsNet 2013, the LOON installation consisted of four EvoLogics modems, placed on the seabed and cable-connected to the shore so that they could be continuously operated and monitored. The LOON modems are compatible with those installed on-board the Typhoon, so that the vehicle could use its USBL modem to estimate its relative position with respect to the fixed LOON installation. Hence, the role of the Typhoon in this experimentation was to perform both surface and underwater navigation in autonomous modality, while trying to localize itself or the other nodes of the network using the USBL measurement. In the first week, due to adverse sea and weather conditions, a preliminary test was carried out within the La Spezia harbour using re-deployable, battery operated, EvoLogics modems as fixed nodes. In the second week, the trial was carried out in the open sea close to the LOON area. The operating groups have worked in parallel as much as possible, but most of the trials were carried out in series to not interfere the one with the others. Due to the weather constraints and to the time-division nature of the experiment, it was possible to do a limited number of runs, all using the Typhoon mounting the USBL head. In the following, the preliminary results as obtained in some of the runs will be illustrated.

4. RESULTS

The results of the Typhoon trials that took place on Sept. 12^{th} and Sept. 22^{th} are now reported. In the first one, Typhoon has executed an autonomous mission within the La Spezia harbour, consisting in the repetition of a triangle-shaped path with vertices placed in the waypoints WP1, WP2 and WP3. In this area, some battery-operated modems were deployed to build an ad-hoc installation of fixed nodes: using them the vehicle can localize itself using the on-board USBL. In the second one, Typhoon was supposed to autonomously travel along a path on the LOON area, localizing itself with respect to the LOON submerged modems by means of the on board USBL modem. The reference path for the mission was defined by three waypoints respectively called Janus1, M2 (position of the second one of the four LOON modems) and Typhoon1. In both runs, the absolute position of the fixed nodes is known, so the relative localization with respect to them allows to deduce a measure of the absolute position of the Typhoon. In Table 1 the waypoints of the two missions are defined. In the Sept. 12^{th} run, Typhoon began the autonomous mission from waypont WP1, then it had to repeat the reference path twice, both on surface. Navigation was performed on the basis of GPS measurements, so that they can be used in post-processing as a ground-truth to evaluate the accuracy of USBL fixes. In the Sept. 22^{th} run, Typhoon reached J1 from the deployment point, then it travelled three times along the triangle J1-M2-T1-J1: the first and the third times on the surface whereas the second time at a depth of 5 meters surfacing on each waypoint and every two and a half minutes to reset the drift in the position estimation through a GPS fix. The paths were both covered with a reference speed of 0.7 m/s. The two triangles are between 550 m and 600 m long; the detailed subdivision of the paths is reported in Table 2. Tolerance on waypoints, to consider them achieved, was always set to 20 m. A direct comparison of raw navigation data (GPS, USBL and dead reckoning) is given in Fig. 6, where all the significant mission variables are shown. In the plots, the following elements are represented.

Table 1. Definition of the mission Waypoints

Date	Waypoint	Latitude (°)	Longitude (°)
Sept. 12^{th}	WP1	44.095000	9.862050
	WP2	44.094300	9.859420
	WP3	44.093750	9.861580
Sept. 22^{th}	Janus1 (J1)	44.031890	9.830962
	M2	44.032116	9.828285
	Typhoon1 (T1)	44.030610	9.829312

Table 2. Lengths of the path segments

Date	Segment	Length (m)
Sept. 12^{th}	WP1-WP2	225
	WP2-WP3	183
	WP3-WP1	144
	Total	552
Sept. 22^{th}	J1-M2	216
	M2-T1	186
	T1-J1	194
	Total	596

Magenta diamonds Waypoints, identified by their short name.

Continue blue line It represents the travelled path estimated through the GPS measurements in Fig. 6(a) and dead reckoning algorithm based on orientation measurements from IMU, a forward speed calculated as function of the longitudinal propeller thrust and GPS fixes in Fig. 6(b).

Red circles In Fig. 6(b), they represent GPS fixes; they are dense around the points of surfacing and absent when Typhoon antenna was underwater.

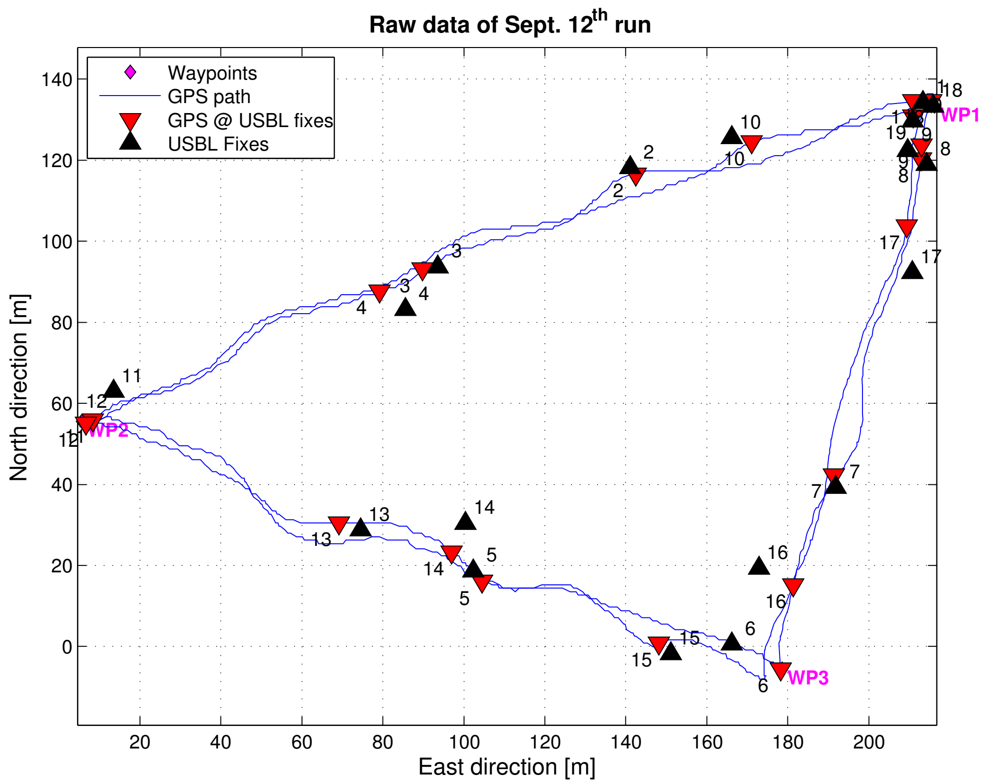
Red downward-pointing triangle Points of the estimated path corresponding to the moment when Typhoon was able to localize one of the LOON modems.

Black upward-pointing triangle The Typhoon estimated position on the basis of the acoustic fixes from the USBL modem.

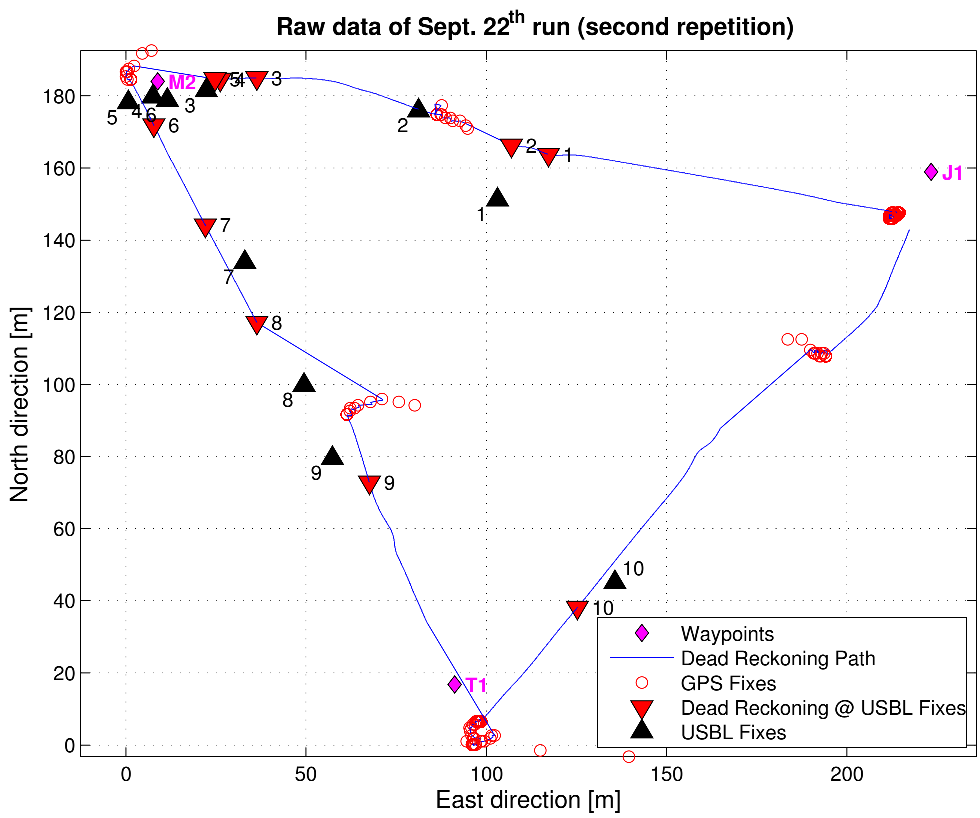
Downward-pointing triangles and Upward-pointing triangles are associated through a progressive numeration. The

Table 3. Error between estimated position and USBL fixes

Sept. 12^{th}				Sept. 22^{th}	
Fix	Error (m)	Fix	Error (m)	Fix	Error (m)
1	2.35	11	8.48	1	18.89
2	2.27	12	2.15	2	27.41
3	3.38	13	5.94	3	14.42
4	8.18	14	8.44	4	19.26
5	3.04	15	4.26	5	24.85
6	13.23	16	9.83	6	7.89
7	2.91	17	11.55	7	14.91
8	1.89	18	1.32	8	21.76
9	3.11	19	1.16	9	12.20
10	5.09			10	12.49



(a)



(b)

Fig. 6. Plots of the two experiments. In Fig. 6(a) the Typhoon run of Sept. 12^{th}, executed in La Spezia harbour, is represented. In Fig. 6(b) part of the Sept. 22^{th} Typhoon experiment, conducted on the LOON, is illustrated.

amount of acoustic fixes obtained during the two missions is respectively 19 and 10, recieved with an average period of 69 s in the first trial and 119 s in the second one. In Table 3 the navigation errors between the position estimated through the measurements of the navigation sensors and the corresponding one based on the USBL fixes are reported for both trials. Since the navigation of the Sept. 12^{th} trial was entirely based on GPS measurements, the errors obtained from this run are particulary relevant to quantify the reliability of the USBL-based position estimate with respect to the effective navigation position. The position estimation error accumulated during the underwater navigation of the Sept. 22^{th} mission can be evaluated as the distance between the first GPS fix after surfacing and the last estimated position before it. Typhoon surfaced five times during the analyzed part of the mission; for each of these, the value of the accumulated drift is reported in Table 4. While the errors reported in

Table 4. Error of the dead reckoning position estimation with respect to GPS fixes

Surfacing	Accumulated drift (m)
1	13.99
2	22.39
3	35.05
4	19.59
5	24.36

Table 3 and Table 4 are to be expected considering the navigation sensors employed, it is clear that the combination of acoustic and on-board sensor navigation offers the opportunity to improve navigation capabilities. This processing is currently on-going and it will be reported in the near future.

5. CONCLUSIONS

The paper presents the contribution of the Typhoon AUV, developed in the framework of the THESAURUS project, to the CommsNet 2013 experiment, organized by NATO S&T Org. Ctr. for Maritime Research and Experimentation (CMRE, formerly NURC), held with the support of NRV Alliance. Typhoon AUV, at its first experimental experience after the end of the THESAURUS project, proved to be able to perform the required tasks completely autonomously, playing a fundamental role for the CommsNet 2013 experiment. The paper reports the raw navigation and acoustic localization data logged from the on board sensors during a part of one of the missions performed by Typhoon during the two weeks of experimentation. The logged data will be used for a systematic post-process activity in order to investigate and test navigation data fusion procedures to improve localization accuracy with respect to the raw data here reported. Fig. 7 shows Typhoon AUV during a surface phase of one of the missions performed in the Ligurian Sea in front of Porto Venere during CommsNet 2013 experiment.

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Fig. 7. Typhoon AUV during CommsNet 2013 experiment

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