

Multi-AUV localization and navigation exploiting acoustics

Benedetto Allotta^{b,d}, Andrea Caiti^{a,c,d}, Riccardo Costanzi^{a,c,d}, Davide Fenucci^{a,c,d},
Niccolò Monni^{b,d}, Alessandro Ridolfi^{b,d}

^a *Department of Information Engineering (DII), University of Pisa, Italy*

^b *Department of Industrial Engineering (DIEF), University of Florence, Italy*

^c *Research Center "E. Piaggio", University of Pisa, Italy*

^d *Interuniversity Center of Integrated Systems for the Marine Environment (ISME), Italy*

Localization and navigation represent a crucial point of the control system of marine robots because of the impossibility of exploiting sensors based on radio waves commonly used for air or land applications (e.g. Global Positioning System - GPS). Sensors based on acoustics are, instead, used to enhance the localization and navigation performance obtainable through Inertial Measurement Units (IMUs) and Doppler Velocity Logs (DVLs). A lot of research activity has been oriented within the scientific community on different integration strategies of the acoustic sensors information with IMU and/or DVL. Within the Interuniversity Center of Integrated Systems for the Marine Environment (ISME), the University of Pisa and the University of Florence nodes began to collaborate on this research topic since several years. In particular, the research is oriented to provide a team of cooperating Autonomous Underwater Vehicles (AUVs) with strong georeferencing capabilities; to this aim, the AUVs are equipped with acoustic modems with both communication and mutual localization capabilities. The specific research activity was undertaken following three different topics, summarized in this abstract with the main results achieved in last years. In particular, the effort has been divided on:

- Acoustic network architecture - different solutions were studied and tested to simultaneously optimize the positioning of the cooperating vehicles and the information exchanged.
- Single vehicle navigation filtering strategies - different sensor fusion techniques have been developed and validated by comparing Extended Kalman Filters (EKF) and Unscented Kalman Filters (UKF) based on non-linear dynamical evolution of the states and capable of dealing with the different functioning rate of the involved sensors.
- Acoustic sensors experimental characterization - a considerable effort has been dedicated to this activity with the aim of quantify the expected performance of the different acoustic sensors.

In particular, the considered acoustic sensors network was composed of both fixed and mobile nodes, following a mixed Long Base Line (LBL) / Ultra-Short Base Line (USBL) approach. Within this framework, the vehicles of the team represented the mobile nodes. Among the team, one member acting as the leader was equipped with an USBL to enhance the overall localization and navigation capabilities of the vehicles. The fixed sensors, represented by re-deployable acoustic modems, were employed to set up in the operational area an LBL-like ad-hoc installation through which the leader can localize itself during typical underwater operations. In such a scenario, the localization information exchanged between the vehicles is embedded in the communication scheme, which is carried out exploiting a Time Division Multiple Access (TDMA) protocol among the vehicles. During its time slot, the team leader pings in turn all the nodes of the network, localizing them and transmitting the information to the other vehicles. Current research activities are directed to study the impact of different network topologies, localization strategies and team configurations on the localization and navigation accuracy of the vehicles.

As it concerns the navigation strategy of the single vehicle, a Kalman Filter approach was the natural choice for the state estimation. The research effort was oriented on the definition of both the prediction and the correction steps. The dynamic evolution of the state used in the prediction step

was designed as a trade-off between the model accuracy and the uncertainty on the involved parameters; a kinematic model with explicit dynamics only on the longitudinal and the lateral degrees of freedom is the final adopted solution. Regarding the correction step, a suitable choice of the state components allows to obtain linear measurement equations represented by a matrix (H) whose dimension is resized at each iteration according to the sensor signals updated during the last period. This way, it is also possible to deal with sensors having considerably different update rates (e.g. common functioning rate for a depth sensor can be 10 Hz whereas the acoustic localization through an USBL system can be usually obtained slower than 1 Hz). Moreover the performance of different Kalman based approaches have been investigated concentrating on the Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF) because of the strong non-linearity of the state update equations. According to the carried out experiments, UKF demonstrated higher performance in particular in the cases when some sensors (e.g. DVL) are not available.

Finally, extensive sea-trials aimed to experimentally characterize the employed acoustic sensors were contextually performed. The research activities in this branch were addressed with a dual purpose: on one hand, experimentations allowed to assess the precision of the considered acoustic positioning systems. On the other hand, effort was focused on integrating the acoustic positioning measurements (ranges, bearing and elevation angles) with the information from the other navigation devices (e.g. GPS position) to quantify the expected localization precision in a realistic situation where all the sensors are mounted on-board a vehicle.

All the above research topics were extensively experimented during several sea-campaigns conducted in the last few years with our self-developed AUVs, Typhoon and MARTA:

- **THESAURUS** experimentations conducted in the Tuscan archipelago. THESAURUS is a project funded by the Tuscany region aiming at developing a swarm of AUVs cooperating for underwater archeology.
- **CommsNet13** experiment on underwater acoustics, organized in the Gulf of La Spezia by the NATO STO Center for Maritime Research and Experimentation (CMRE) with the support of the NRV Alliance.
- **AUVALC** experimental campaigns on Israeli archaeological sites of Akko and Caesarea with the support of the Israeli Antiquities Authority. AUVALC has received funding by ONR-G under a NICOP.
- **ARROWS** experimentations, including the trials at the Breaking The Surface '14 workshop, organized by the LABUST, University of Zagreb and the final demo in Sicily and the Baltic Sea. ARROWS project, proposing a team of heterogeneous AUVs for underwater archeology, has received funding from the European Unions Seventh Framework Programme for research.

Experimental results obtained both in post-processing and in real-time will be included.

ACKNOWLEDGEMENTS:

This work has been partially supported by ARROWS project (it has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 308724), WiMUST project (it has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement no. 645141), SUONO project (it has received funding by the Italian Ministry of Education and Research in the framework of the challenge on "Sea Technologies" of the call "Smart Cities and Communities"), THESAURUS project (PAR FAS REGIONE TOSCANA Linea di Azione 1.1.a.3) and MARIS project (Italian National Project PRIN).

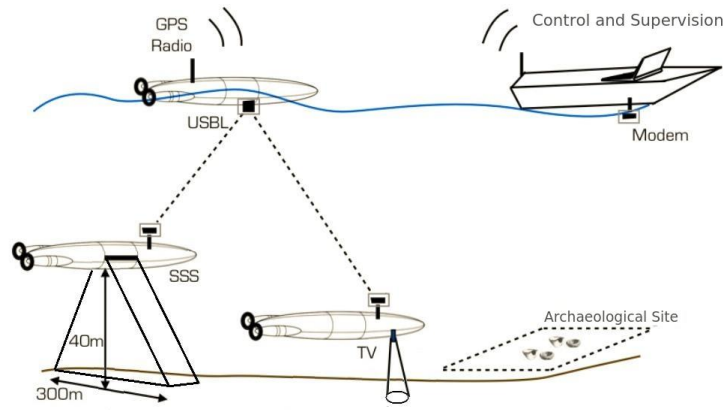


Figure 1 - The swarm of cooperative AUVs.



Figure 2 -The Typhoon AUVs: final versions of TifOne and TifTu on the NATO Research Vessel Alliance.

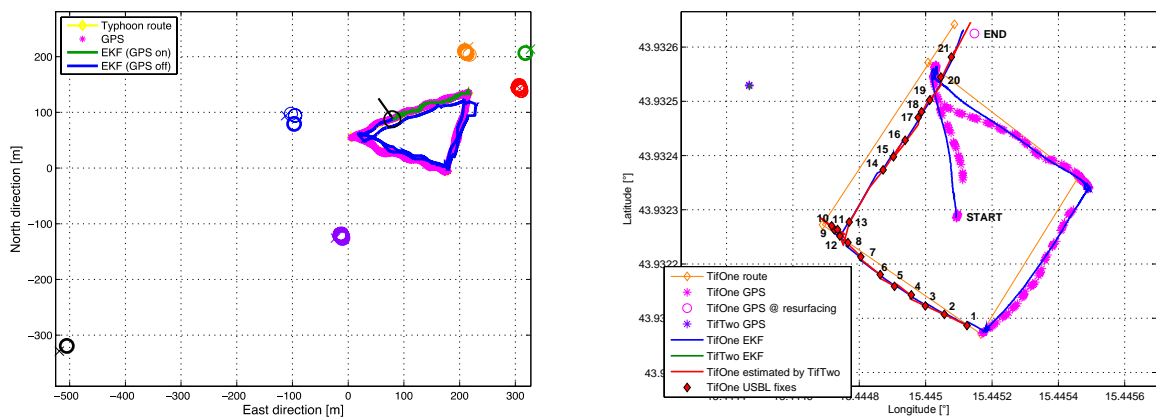


Figure 3 - Some representative post-process results of the acoustic-aided navigation algorithms developed within University of Pisa and University of Florence.