Overview and first year progress of the Widely scalable Mobile Underwater Sonar Technology H2020 project ⋆

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Abstract: The Widely scalable Mobile Underwater Sonar Technology (WiMUST) project is an H2020 Research and Innovation Action funded by the European Commission. The action's main goal is to develop robotic technologies exploiting Autonomous Underwater Vehicles (AUVs) for geotechnical surveying and geophysical exploration. The paper briefly describes the project and its state of the art after the first year of activities.

Keywords: marine systems, AUVs, geophysical exploration, geotechnical surveying.

1. INTRODUCTION

WiMUST (Widely scalable Mobile Underwater Sonar Technology) is an H2020 research project funded by the European Community (Work Programme 2014 - 2015, LEIT- ICT, 5. Leadership in enabling and industrial technologies - Information and Communication Technologies). The project is a 36 month Research and Innovation Action (RIA) having as main objective to design and test a system of cooperating Autonomous Underwater Vehicles (AUVs) for geotechnical surveying operations. In particular, the WiMUST system will be composed by a small fleet of AUVs carrying streamers equipped with hydrophones to acquire sub-bottom profiling acoustic data. Contrary to the classical technology based on ship towed streamers, the WiMUST solution will allow to change the geometry of the acoustic antenna by controlling the AUV formation. This paper aims at giving a brief overview of the project Al-Khatib et al. (2015a), Al-Khatib et al. (2015b) and Indiveri and Gomes (2014) after the first year of activities. For a longer version of this paper refer to Antonelli et al. (2016 (to appear)).

Section 2 provides an overview about the main concepts and approaches. Section 3 focuses on the distributed sensor array issues to be faced in the project. Section 4 describes the AUV cooperative control activities while Section 5 gives an overview of the mission planning issues and methodologies. Section 6 addresses the communication activities within the project while Section 7 briefly accounts for the necessary system integration and experimentation tasks. Concluding remarks are finally reported in Section 8.

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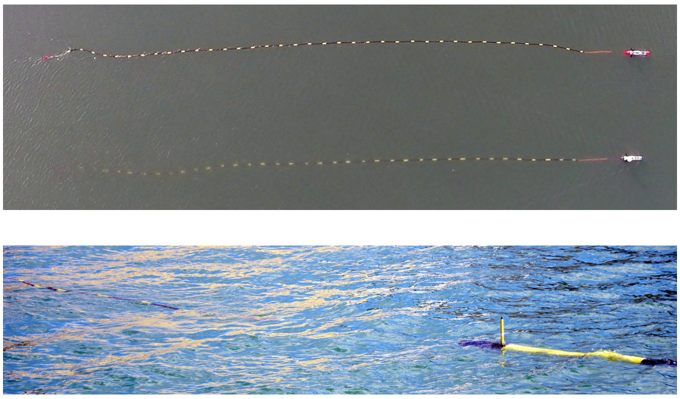

Fig. 1. Preliminary tests: MEDUSA (top) and Folaga (bottom) vehicles towing streamers.

2. OVERVIEW

The WiMUST project Al-Khatib et al. (2015a) aims at conceiving, designing, and engineering an intelligent, manageable, distributed and reconfigurable underwater acoustic array that could significantly improve the efficacy of the methodologies used to perform geophysical and geotechnical acoustic surveys at sea. It is expected that the use of the WiMUST system will be beneficial in a vast number of applications in the fields of civil engineering and oil & gas industry, where seabed mapping, seafloor characterization, and seismic exploration play a key role. The main novelty of the WiMUST system consists in the use of a team of cooperative autonomous marine robots, acting as distributed sensing and communicating nodes of a reconfigurable and mobile acoustic network. The vehicles are equipped with hydrophone streamers of small aperture, such that the overall system behaves as a distributed acoustic array capable of acquiring acoustic data obtained by illuminating the seabed and the ocean sub-bottom with strong acoustic waves sent by one (or more) acoustic source installed on-board a support ship / boat. By actively controlling the geometry of the robot formation, it becomes possible to change the shape of the acoustic array, according to the needs of the considered application. The resulting operational flexibility holds potential advantages, as it allows improving the seabed and sub-bottom resolution and obtaining sidelobe rejection at almost any frequency and for any plane. The proposed system, on top of improving the quality of the acquired data, will also facilitate the operations at sea, thanks to the lack of physical ties between a surface ship and the acquisition equipment. As an initial step for the research work of the project, the activities have started with an analysis of the reference scenario which needs to be characterized in terms of desired functionalities and expected behavior of the WiMUST system. In particular, the reference scenarios will cover both the 2D and 3D active geoacoustic exploration and geotechnical seafloor characterization cases. As a result, specifications for all the composing subsystems (mission planning, communication, distributed sensing, navigation, coordination) are being defined, together with a preliminary indication of the expected corresponding hardware resources (sensors, communication devices, infrastructures).

3. DISTRIBUTED ACOUSTIC SENSOR ARRAY

One of the most important aspects of the WiMUST system is that the AUV-based acoustic sensing array is physically disconnected from the source. This allows for a new and fundamental freedom relative to the sensing array geometry. If we abstract from the physical constraints associated to vehicle guidance and navigation, the WiMUST sensing system may be viewed as a Distributed Sensor Array (DSA) free to adopt any geometry. Moreover, that geometry may change along time, upon request. So, in terms of data processing, the fundamental question to be tackled is *whether the seismic data acquisition and processing protocol established for ship towed streamers is also suited for the mobile AUV-based acoustic sensing system?* And, if not, in which situation and how should it be modified. Determining the geophysical properties of the ocean bottom is an old and non trivial problem with scientific as well as engineering implications. Although electromagnetic approaches do exist Ziolkowski and Wright (2012), the vast majority of survey methods are based on the analysis of bottom acoustic returns complemented with in situ observations and historical information. The problem is complicated by the fact that sound velocity strongly varies in consolidated sediments, which makes it difficult to determine at the same time bottom layering (i.e., layer thickness), based on the time-of-flight of acoustic arrivals, and compressional velocities on each layer where those arrivals propagate. This makes the problem non-linear. There are two main classes of methods to address this problem: one is based on the matching of the observed data with the acoustic full-field calculated for a physical model of the bottom, including layering and layer physical properties. This is the so-called Matched-Field Inversion (MFI) class of methods. The other is based on transforming the non-linear problem into two linear steps: in the first step the time-of-flight of identified bottom returns are matched assuming a given velocity model (based on a priori knowledge); in the second step, arrival times are successively matched with those obtained from the data and, as later arrivals are considered, the grazing angle changes and the focal point moves deeper into the bottom, which requires successive adjustment of the velocity model until a good match is obtained. This is the approach used in classic Time-Of-Arrival (ToA) seismic surveying Yilmaz (1987). For various reasons MFI is more often used with vertical arrays and for high-resolution of superficial sediments in shallow water, while ToA is used with horizontal (towed) arrays, both in shallow and deep water, for low resolution bottom imaging of large high intensity reflectors deeply buried into the bottom. The latter is the typical problem faced in oil and gas exploration where the objective is to detect a salt crust sometimes one or more km below the ocean bottom.

4. COOPERATIVE NAVIGATION, GUIDANCE AND CONTROL

Cooperative navigation, guidance, and control of the AUV robotic vehicle team is one of the pillars of WiMUST system. The WiMUST vehicles will need accurate relative navigation and control capabilities, ensuring inter-vehicle collision avoidance and yielding a virtual structure to accurately position each hydrophone streamer, thereby shaping the formation of the resulting sonar receiving array. Acquiring seismic data with well defined characteristics requires the acoustic source and each of the acoustic receivers to maintain a specific geometric formation. In the scope of WiMUST, this translates into a clear control task: steer each vehicle so that all vehicles, the streamers being towed, and the acoustic source (usually a sparker) maintain a specified formation geometry. We make the simplifying, yet realistic assumption that the trajectory followed by the source (usually towed from a support vessel) is known with an adequate degree of accuracy, usually obtained from a Differential Global Positioning System (DGPS) or Real Time Kinematic (RTK) Global Positioning System (GPS) installed on the source. At this point in the project, two types of candidate solutions arise for this control problem, each with its advantages and disadvantages. Within the cooperative navigation, guidance and control framework of the WiMUST project work is being addressed in the areas of

- Cooperative Path Following
- Target and Trajectory Tracking
- Single range navigation and guidance

The cooperative path following solution is being designed building on solutions Ghabcheloo et al. (2009) explicitly accounting for communication losses and time delays. The target and trajectory tracking issue is addressed extending approaches and results as outlined in Abreu et al. (2015). The cooperative control algorithm assumes that each vehicle has full knowledge of the path to be followed in a close future, with no associated timing law, and that the paths of all vehicles are parametrized with an along-path coordinate. The absence of an associated timing law implies that the algorithm does not impose where each individual vehicle should be at each instant in time, but just that all vehicles should be at corresponding points on their paths.

The target/trajectory tracking family of algorithms, described and analyzed formally in Abreu et al. (2015) resorts to a fundamentally different approach. The goal is for a single vehicle to follow a trajectory with an associated timing law, i.e. enforcing where the vehicle should be at specific times.

During the initial phase of each mission, when the vehicles move towards a given waypoint in order to reach the desired formation, a single range aided navigation could be used to improve the localization performance. To this effect, a novel strategy has been proposed by De Palma et al. (2015b) that addresses the problem of driving an underwater vehicle to a desired position while optimizing the performance of a single-range based localization system. Indeed single range navigation approaches as derived in De Palma et al. (2015a) can also be used to address multi-vehicle relative localization issues that are relevant in WiMUST cooperative motion tasks.

5. MISSION PLANNING

The execution of WiMUST missions will require the availability of flexible mission planning algorithms for the deployed robotic units. An innovative approach towards mission planning is developed which extends classical algorithms for mission planning by novel intelligent methodologies. The proposed approach is based on the information-theoretic quantity empowerment Klyubin et al. (2005) Klyubin et al. (2008), which is associated to the state of a robot and can be exploited to generate preferred behaviors without having to resort to specialized cost functions, which usually vary from task to task and have to be hand-designed. Technically speaking, empowerment is defined as the Shannon channel capacity between the robot controls and its states in subsequent time-steps, therefore it is measured in bits. Its computation is based on adaptive evaluation of the acting-sensing interaction of the robot group with its environment. Within the WiMUST project empowerment is used for the first time in the context of marine robotics.

In WiMUST we investigate how empowerment can be used as a vehicle-intrinsic metric to evaluate autonomous underwater vehicles' desirable trajectories in terms of mobility and survivability. Hence, while performing team formation control, the overall WiMUST mission planner may benefit by the possibility of monitoring online the empowerment of the state of each vehicle. Since empowerment is zero in situations where the vehicles have no mobility at all, one rationale for its use is to detect the robots being in or approaching undesirable conditions as being stuck or crashed.

6. COMMUNICATIONS

The main objectives of the communication related research within WiMUST are the development of algorithms and procedures for accurate distance measurements (up to the centimeter scale) between AUVs moving in formation, reconstruction of their relative positions in 3D space, and precise synchronization of their local clocks. These are required to assign temporal and spatial tags to acquired data that are consistent across the formation of vehicles, and to support some modalities of navigation that require explicit relative positions to control the shape of the formation of vehicles. Moreover, it will be necessary to achieve an estimation of practical data throughput boundaries for different AUV formations. Based on such estimates, specific work will address the development of communication algorithms and procedures to support the different operative and environmental conditions. The work in this area is organized along two major lines: long range and short range communication issues for which different technical and algorithmic solutions are being pursued.

As for the short range communication requirements, high bit rate communication of AUVs at short range is a prerequisite for the design of cooperative teams of underwater vehicles for the operations envisioned in the WiMUST applications. Typical bit rates by conventional acoustic modems are rather low usually reaching, in practice, effective bit rates on the order of several hundred bits per second having nominal bit rates of several kilobits per second. Recent modem developments made by EvoLogics provided a significant increase of practically achievable bit rates. The objective is to focus on the evaluation of practically achievable bit rates within the necessary team geometries of practical interest, which will enable successful implementation of the navigation and motion control tasks within the project.

As for the long range communication requirements of the overall system, the exploitation of advantages given by sweep-spread communication technology of EvoLogics opens the way to practically achievable bit rates of about a several to tens kilobit/s in long range. While the range of data transmission and the capacity of the underwater acoustic channel may change vigorously in consequence of changes in environmental conditions, an efficient implementation of an acoustic communication network will strongly depend on the capability of the modem to automatically adjust its bit rate to the actual channel conditions.

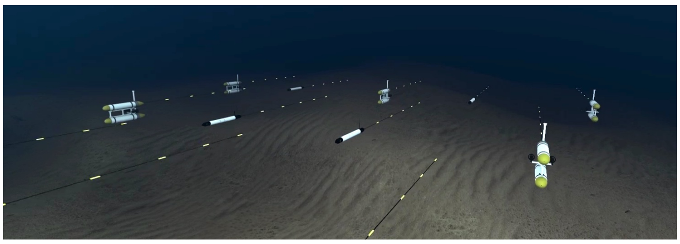

Fig. 2. Computer animation of a WiMUST mission towing streamers.

7. INTEGRATION AND EXPERIMENTATION

Specific activities for system integration are planned within the project: indeed, all the subsystems and functionalities developed within the project will need to be integrated to form the final WiMUST system. Moreover, the overall system will be validated through experimental tests at sea. The vehicles constituting the WiMUST system will need to perform cooperative guidance, navigation - localization and control by implementing the solutions and methods derived in the action. In the final experiment, the WiMUST vehicles will need to exhibit a sufficient degree of autonomy and intelligence in controlling the required formation while concurrently performing operational tasks related to the level of individual power supply, intra-vehicle distance, and quality of service of vehicle-to-vehicle communication. The final experimental tests will thus serve as a validation for all project goals. Such tests are planned to be executed either in the Setubal area (Portugal) or close to the Elba island (in Italy).

With reference to the system integration activities, these will initially deal with mechatronic integration of the sensing payloads and the communication devices on board the AUVs. Successively, the software modules concerning group navigation and coordination will be finalized and inserted in the final AUVs' software architecture together with the distributed sonar algorithms and the communication protocols and strategies.

Once the basic functionalities will be validated in lab and through the "wet" engineering experiments, sea trials on the overall WiMUST system will be executed. Data gathered during experiments will be finally analyzed for obtaining indications on the real performance of the WiMUST system.

8. CONCLUSIONS

The vision underlying the WiMUST project is that of developing advanced cooperative and networked control / navigation systems to enable a large number (in the order of tens) of marine robots (both on the surface and submerged) to interact by sharing information as a coordinated team (not only in pairs). The WiMUST system may be envisioned as an adaptive variable geometry acoustic array. A brief overview of the objectives and methods used in the project have been provided. For further details refer to Antonelli et al. (2016 (to appear)).

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