The Widely scalable Mobile Underwater Sonar Technology (WiMUST) project: an overview

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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 project aims at developing a system of cooperative Autonomous Underwater Vehicles (AUVs) for geotechnical surveying and geophysical exploration. The project will address underwater communication, acoustic distributed sensor array, mission planning and robot navigation, guidance and control issues. The paper gives an overview of the project objectives and methods.**

I. Introduction

The WiMUST (Widely scalable Mobile Underwater Sonar Technology) project proposal has been recently approved by the European Community within the H2020 framework (Work Programme 2014 - 2015, LEIT- ICT, 5. Leadership in enabling and industrial technologies - Information and Communication Technologies). WiMUST is a RIA (Research and Innovation Action) project financed through Grant agreement no: 645141 under the Strategic objective: ICT-23-2014 - Robotics. The action has a planned duration of 36 months and has started on February 1st, 2015. The partnership brings together a group of research institutions, geophysical surveying companies and SMEs with a proven track record in autonomous adaptive and robust systems, communications, networked cooperative control and navigation, and marine robot design and fabrication. In particular, the consortium is composed of nine partners: four academic and five industrial ones coming from five different countries. The academic partners are the Interuniversity Centre on Integrated Systems for the Marine Environment - ISME (Italy), Instituto Superior Técnico - IST-ID (Portugal), Centro de Investigação Tecnológica do Algarve - CINTAL (Portugal) and University of Hertfordshire - UH (United Kingdom). The industrial partners are EvoLogics GmbH - EL (Germany), Graal Tech S.r.l. - GT (Italy), CGG (France), Geo Marine Survey Systems B.V. - GEO (the Netherlands) and GeoSurveys - Consultores em Geofísica, Lda. - GS (Portugal). The Coordinating partner is ISME that is composed by a network of Italian Universities: its headquarters are at the University of Genova (formal beneficiary for the action) whereas the other ISME nodes involved in the project are the Universities of Salento (Lecce), Pisa and Cassino that take part to the project as linked third parties. The beneficiary CINTAL has also a linked third party contributing to the project, namely the the University of Algarve (Portugal).

Building on a preliminary scenario analysis, the project activities will include work on Distributed Sensor Arrays, Cooperative Control, Mission Planning, Communications and finally Integration and Experimentations. The ultimate goal of the project is to design and test a system of cooperating Autonomous Underwater Vehicles (AUVs) able to perform innovative geotechnical surveying operations. In particular, the WiMUST system will be composed by a small fleet of AUVs carrying hydrophones to acquire sub-bottom profiling acoustic data. Contrary to the classical technology based on ship towed streamers (figure 1), the WiMUST solution will allow to change the geometry of the acoustic antenna: something that has not been achieved in practice and holds potential to drastically improve ocean surveying.

This paper aims at giving a brief overview of the project [1] [2]. Section II addresses the main concepts and approaches. Section III focuses on the distributed sensor array issues to be faced in the project. Section IV describes the AUV cooperative control activities while Section V gives an overview of the mission planning issues to be faced in the project. Section VI addresses the communication activities within the project and Section VII briefly accounts for the necessary system integration and experimentation activities. Finally Section VIII reports concluding remarks.

Fig. 1. Ship towed methodology for geotechnical surveying (picture courtesy of CGG).

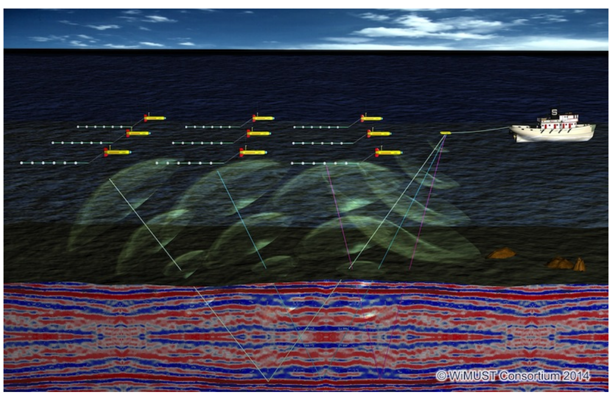

Fig. 2. Artist rendition of the WiMUST system or sub-bottom profiling with source - receiver decoupling.

II. Concept and Approach

The WiMUST project aims at conceiving, designing, and engineering an intelligent, manageable, distributed and re-configurable underwater acoustic array that could drastically improve the efficacy of the methodologies used to perform geophysical and geotechnical acoustic surveys at sea (refer to figure 1). 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 are fundamental operations. The novel key feature of the WiMUST system consists in the use of a team of cooperative autonomous marine robots, acting as intelligent sensing and communicating nodes of a reconfigurable moving acoustic network. The vehicles are equipped with hydrophone streamers of small aperture, such that the overall system behaves as a large distributed acoustic array capable of acquiring acoustic data obtained by illuminating the seabed and the ocean sub-bottom with strong acoustic waves sent by an acoustic source installed on-board a support ship / boat (figure 2). 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 tremendous 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 availability of the proposed system, other than improving the quality of the acquired data, will also greatly facilitate the operations at sea, thanks to the lack of physical ties between a surface ship and the acquisition equipment.

As a preliminary step for the research work of the project, the activities will start with an analysis of the reference scenario which will be first of all 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 scenarios. As a result, specifications for all the composing subsystems (mission planning, communication, distributed sensing, navigation, coordination) will be drawn out, together with a preliminary indication of the expected corresponding hardware resources (sensors, communication devices, infrastructures).

III. Distributed Sensor Array

Given the nature of the described WiMUST system, specific work will be necessary to integrate and eventually develop hardware and software for the implementation of an acoustic distributed sensor array for generic applications involving dynamic coherent processing of a multi-sensor arrays formed by a swarm of underwater vehicles. The application at hand will encompass the geophysical characterization of bottom and sub-bottom seafloor properties. Hardware requirements will be drawn from actual array processing algorithms and existing payloads on vehicles. Existing algorithms will be adapted and new will be developed for determining optimal array structure compatible both with vehicle navigation restrictions and environmental conditions at hand for the specific task to be performed. A key issue is to properly account for the intra-vehicle communication system both in terms of network topology and performance (bandwidth, latency, packet loss, etc.).

As for the array geometry, the determination of the optimal feasible distributed array geometry for each objective will be sought. In particular, the analysis of the array geometry will have to account for various system constraints such as number and type of vehicles, navigation and positioning accuracy, data communication performance as well as the environmental scenario. Environmental details that may impact on the choice of array geometry include the bathymetry, the geographical conditions and the acoustic propagation characteristics (sound speed profile). Array geometry will include acoustic source positioning. Figures of merit and performance predictions will serve as guidelines / optimization criteria for each possible array geometry. The accuracy of the estimates will bound the system performance and it will impact on the interpretation of results. Moreover, as the array geometry may impact on the connectivity of the AUV team, the array geometry will impact on the navigation and motion control algorithms of the cooperative AUV team. Indeed, it is expected that sensor - vehicle positioning information as drawn from the acoustic communication coupled with the WiMUST navigation system will be merged with the acoustic system for processing. In practice, the acoustic receivers relative position precision should be known at a fraction of wavelength of the acoustic signal. Array navigation data, sensor position, and acoustic data will be processed together with the environmental information for bottom stratification and layering estimation.

IV. Cooperative 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. Ultimately, this can be seen as the system's infrastructure to achieve Optimal Sensor Placement of a sonar array of hydrophones. Indeed specific work will be necessary for the development of new cooperative, range-based decentralized motion control algorithms that address explicitly the dynamics of the vehicles in the presence of uncertainty, noise, currents, and other disturbances, the constraints imposed by the topology of the inter-vehicle communications network, and the problems that arise due to temporary communication losses and delays. Communication constraints - as well as the optimization of the communications topology itself -must be taken explicitly into account at the level of cooperative motion control by continuously monitoring the performance of the ensemble and enabling on line adaptation of the relative distances among vehicles accordingly. Navigation algorithms that merge internal sensor data (DVL, IMU, Depth-meter, AHRS, compass, gyroscopes), the outputs of dynamic vehicle models, and information on inter-vehicle distances obtained using acoustic ranging devices will be developed by resorting to filtering techniques that, among other objectives, will need to exhibit robustness to outliers that are typical of acoustic signals. For additional details about the cooperative navigation, guidance, and control research directions to be addressed in the WiMUST project refer to [2].

V. Mission planning

The execution of WiMUST missions will require the availability flexible mission planning algorithms for the deployed robotic units. An innovative approach towards mission planning is developed which extends existing hand-designed algorithms for mission planning by novel intelligent methodologies. The proposed methodology is based on adaptive evaluation of the sensing-acting interaction of the robot group with its environment. The approach will make explicit use of marine systems dynamic modeling taking into account single vehicle hydrodynamic effects (added masses, viscous frictions, restoring torques and forces, currents, etc.) as well as intra - vehicle acoustic communication constraints. The key innovation of the approach is to move away from inflexible hand-designed algorithms to a flexible approach that promises the ability to incorporate situation-specific response capability.

VI. 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, as well as development of algorithms and procedures to synchronize their clocks with sufficient accuracy. 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 will be organized along two major lines: long range and short range communication issues.

As for the short range communication requirements, high bit rate communication of AUVs at short range is a pre-requisite 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 (one of the WiMUST partners) provided a significant increase of practically achievable bit rates, however, still not high enough for "raw" payload data transports between vehicles in large teams. The objective is hence to focus on the evaluation of practically achievable bit rates within the necessary team geometries of the practical interest, which will enable successful implementation of the navigation and motion control tasks within the project. Accounting for specific AUV formations and typical environmental conditions, the achievable bit rates will be firstly obtained by modeling and simulation. After this phase, the expected bit rates will be compared with the results of practical experiments. In this manner, the basic estimates of currently achievable bit rates will be provided in short time to be accounted for the needs of the project. The task will include adjustments of the modems' "wet-ends" (matching the wide-band transducers and power electronics), based on the use of the transducers, which are possibly commercially available. Expected frequency range of the transducers is between 200 and 800 kHz, so that an expected short-range bit rate (in a burst data transmission) can exceed 100 kbps. To enable a reliable communication necessary to adequately control the AUVs formation, a robust data transmission with the use of advanced networking protocols will be implemented and tested.

Moreover, specific work will aim at developing a decentralized clock synchronization algorithm based on the data exchange using short range link. The algorithm will allow to keep mutual clock drifts much smaller than for traditional computer clocks. The overall short range communication system will allow to extend the existing point-to-point algorithms of distance measurement in the WiMUST team of AUVs. The challenge here is to provide sufficiently accurate distance measurement in the distributed network of moving vehicles.

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. Since parallel / asynchronous transmission of many differently prioritized data streams from one or many data sources (connected to one single modem) represents one of standard features of EvoLogics modems, the communication bit rate can be adapted to the WiMUST operating conditions.

Fig. 3. Setubal (Portugal) area: one of the candidate sites for the final WiMUST tests.

VII. 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 co-operative guidance, navigation - localization and control by implementing the solutions and methods derived in the action.

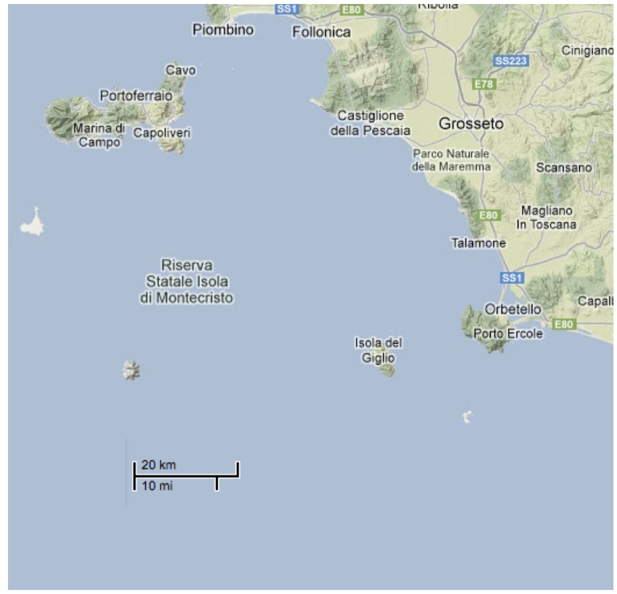

Fig. 4. Elba island (Italy) area: one of the candidate sites for the final WiMUST tests.

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 obstacle avoidance and other 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) (figures 3 - 4).

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. First, the basic sensing and communication functionalities will be tested through engineering tests and preliminary experiments performed only on subsets of a few AUVs. Then the whole system will be considered and the final experiments will be setup and executed. The location of the final experiment will be either in Italy or Portugal (figures 3 - 4) where the national partners have considerable experience with the logistics required. The choice of the location will be made according to scientific and organizational criteria. In particular, an a priori geoacoustic characterization of the site should be known for validation purposes. Data gathered during experiments will be finally analyzed for obtaining indications on the real performance of the WiMUST system.

VIII. Conclusions

The WiMUST (Widely scalable Mobile Underwater Sonar Technology) project aims at expanding and improving the functionalities of current cooperative marine robotic systems, effectively enabling distributed acoustic array technologies for geotechnical surveying and geophysical exploration. Recent developments have shown that there is vast potential for groups of marine robots acting in cooperation to drastically improve the methods available for ocean exploration and exploitation. Traditionally, seismic reflection surveying is performed by vessel towed streamers of hydrophones acquiring reflected acoustic signals generated by acoustic sources (either towed or onboard a vessel). In this context, geotechnical surveying for civil and commercial applications (e.g., underwater construction, infrastructure monitoring, mapping for natural hazard assessment, environmental mapping, etc.) aims at seafloor and sub-bottom characterization using towed streamers of fixed length that are extremely cumbersome to operate. The vision underlying the WiMUST project is that of developing advanced cooperative and networked control / navigation systems to enable a large number (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. This paper has provided an overview of the WiMUST objectives and methods.

Acknowledgments

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References

[1] G. Indiveri and J. Gomes, "Geophysical surveying with marine networked mobile robotic systems: The WiMUST project," in *WUWNET '14 Proceedings of the International Conference on Underwater Networks & Systems*, Rome, Italy, November 12-14 2014. [Online]. Available: http://dx.doi.org/10.1145/2671490.2677084

[2] H. Al-Khatib, G. Antonelli, A. Caffaz, A. Caiti, G. Casalino, I. B. de Jong, H. Duarte, G. Indiveri, S. Jesus, K. Kebkal, A. Pascoal, and D. Polani, "Navigation, guidance and control of underwater vehicles within the widely scalable mobile underwater sonar technology project: an overview," in *Proceedings of IFAC Workshop NGCUV 2015 (Accepted)*, Girona, Spain, April 28-30 2015.