Navigation, Guidance and Control of Underwater Vehicles within the Widely scalable Mobile Underwater Sonar Technology Project: an overview ⋆

Habib Al-Khatib[1], **Gianluca Antonelli**[2], **Andrea Caffaz**[3], **Andrea Caiti**[4], **Giuseppe Casalino**[5], **Ivan Bielic de Jong**[6], **Henrique Duarte**[7], **Giovanni Indiveri**[8], **Sergio Jesus**[9], **Konstantin Kebkal**[a], **Antonio Pascoal**[b] and **Daniel Polani**[c]

[1] *CGG, Massy, France (e-mail: habib.alkhatib@cgg.com).*
[2] *University of Cassino e del Lazio Meridionale - ISME Node, Cassino (Fr), Italy (e-mail: antonelli@unicas.it).*
[3] *Graal Tech S.r.l., Genova, Italia (e-mail: andrea.caffaz@graaltech.it).*
[4] *University of Pisa - ISME Node, Pisa, Italy (e-mail: andrea.caiti@dsea.unipi.it).*
[5] *University of Genova - ISME Node, Genova, Italy (e-mail: pino@dist.unige.it).*
[6] *Geo Marine Survey Systems, Rotterdam, The Netherlands (e-mail: info@geomarinesurveysystems.com).*
[7] *GeoSurveys - Consultores em Geofsica, Lda., Aveiro, Portugal (e-mail: henrique.duarte@geosurveys.pt).*
[8] *University of Salento - ISME Node, Lecce, Italy (e-mail: giovanni.indiveri@unisalento.it).*
[9] *SiPLAB, FCT - Univ. of Algarve, Faro, Portugal (e-mail: sjesus@ualg.pt).*
[a] *EvoLogics, Berlin, Germany (e-mail: kebkal@evologics.de).*
[b] *Laboratory of Robotics and Systems in Engineering and Science (LARSyS), ISR/IST, University of Lisbon, Lisbon, Portugal (e-mail: antonio@isr.ist.utl.pt).*
[a] *University of Hertfordshire, Hatfield, United Kingdom, (e-mail: d.polani@herts.ac.uk).*

Abstract: 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 geophysical surveying with a view to exploration and geotechnical applications. 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.

Keywords: Marine systems, Robot Navigation, Autonomous vehicles.

1. INTRODUCTION

The WiMUST (Widely scalable Mobile Underwater Sonar Technology) project has been favorably evaluated 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 Research and Innovation Action (RIA) project financed with Grant agreement no: 645141 under the Strategic objective: ICT-23-2014 - Robotics. The project has a planned duration of 36 months having started on February 1st, 2015. The project 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. The consortium is composed of nine partners: four academic and five industrial ones. In particular 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).

The activities will cover the issues of Scenario Analysis, Distributed Sensor Array, 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. By allowing the group of vehicles to change their geometrical configuration, an end-user can seamlessly change the geometry of the "virtual streamer" trailing the emitter, something that has not been achieved in practice and holds potential to drastically improve ocean surveying.

The objective of this paper is to give an overview regarding the objectives, methods and approach for the navigation, guidance and control (NGC) of the WiMUST system. For further reading about the project please refer to Indiveri and Gomes [2014] and Al-Khatib et al. [2015].

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Section 2 describes the project main concepts and approaches while Section 3 briefly introduces the navigation, guidance and control issues that are relevant to the action. Finally, concluding remarks are addressed in Section 4.

2. CONCEPT AND APPROACH

The WiMUST project aims at conceiving, designing, and engineering an intelligent, manageable, distributed and reconfigurable 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 employment 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 changing 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.

Fig. 1. A representation of the traditional ship towed methodology for geotechnical surveying (from CGG web page).

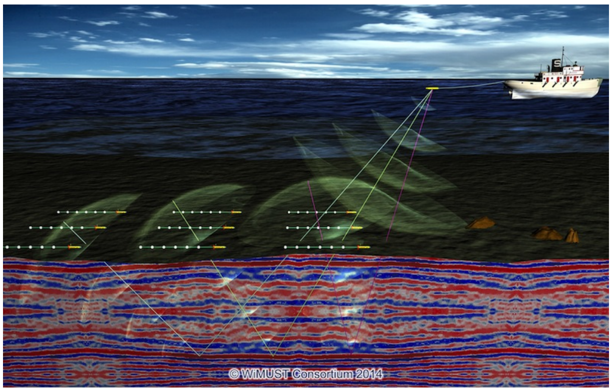

Fig. 2. Artist rendition of the WiMUST system or sub-bottom profiling with source - receiver decoupling.

3. NAVIGATION, GUIDANCE AND CONTROL ISSUES

The WiMUST system will be composed of a set of underwater vehicles performing cooperative motion tasks in order to acquire the acoustic signals emitted by a sufficiently powerful source and reflected from the sea bottom. In order for the acquired data to be useful for sub-bottom profiling, the collected signals need to be accurately synchronized. The necessary intra-vehicle clock synchronization accuracy will depend on the acoustic signal frequency spectrum and on the vehicle formation geometry: hence it cannot be specified "a priori" in general terms, but it can be estimated that it will be arguably higher than what can be currently achieved with off the shelf commercial technologies. Likewise, the necessary accuracy with which the AUVs will need to maintain formation is stringent and eventually larger than todays typical standards. As a consequence, the navigation, guidance and control specifications of the WiMUST system result to be stringent and require specific research work. Cooperative navigation issues will be addressed within the project exploiting a combination of global and relative positioning systems. In particular, the global information will be acquired through GPS at the surface and anchors with "high grade" motion sensors. The relative information will be acquired resorting to USBL and range-measuring devices. Indeed single range navigation and localization techniques will play an important role within overall system. The observability properties for single range localization and navigation have been addressed in the aerospace, mobile robotics and marine robotics literature since several years by now. Some of the relevant studies regarding single range navigation observability issues and filter design are listed in the Bibliography. A complete survey of the additional papers on the subject and of the specific results in the literature goes far beyond the scope of this paper and will hence not be included. The specific NGC tasks within the WiMUST project will include Cooperative Navigation, Cooperative Motion Control and Single Vehicle Motion Control.

3.1 Cooperative Navigation

Because WiMUST aims at developing methods applicable to large teams of autonomous marine robots, the cost of each unit must necessarily be kept as low as possible. Meeting this goal mandates the use of new methods that can dispense with the need for expensive inertial-like navigation units. Especially challenging is the objective of achieving the team navigation goals by resorting to acoustic inter-vehicles ranging devices and internal sensors only, a topic that is the subject of current theoretical research (refer to the bibliography for relevant references). Research will focus mainly on solving the problem of relative navigation among vehicles; algorithms will be developed so as to fully exploit the potential of range based navigation methods aided by internal sensors, as well as the use of vehicle dynamic models with output uncertainty estimates for performance assessment.

3.2 Cooperative Motion Control

Cooperative motion control is one of the issues at the hart of the WiMUST project. The WiMUST vehicles will need the capabilities to: i) maneuver cooperatively at close range and "stay close" to a desired geometric formation and ii) adapt their geometrical formation and 3D spatial paths in response to episodic commands received from higher decision level layers of the system. Notice that given the overall framework, these objectives must be met in the presence of stringent inter-node communication links and limited navigation/positioning data, in particular. New cooperative decentralized motion control algorithms that explicitly account for the dynamics of the vehicles for formation keeping will be addressed. Specially relevant will be the development of range-only based formation control systems, coupled with logic-based communication strategies to decide when motion data should be communicated among the vehicles. The emphasis will be placed on sensor-based control techniques that rely on the minimization of performance indices embodying suitably defined control errors, as well as on the study of coordinated path-following control systems yielding quantifiable measures of performance. Moreover, since formation changing commands issued from higher- level layers require the nodes to change from an initial to a final configuration of interest, new strategies will be devised or sensor-based formation changing, so as to enable the nodes to smoothly transfer between formations while avoiding collisions and keeping acoustic contact. Sensor-based control techniques that rely on the minimization of performance indices will also be exploited. Especially challenging will be the computation suitable cooperative maneuvers to meet time or energy consumption requirements under stringent sensor and inter-vehicle communication constraints. Communication models and protocols, together with appropriately defined device interfaces, will be integrated.

3.3 Single Vehicle Motion Control

Central to the development of advanced cooperative navigation and motion control systems for a group of vehicles is the availability of properly designed guidance and control systems for each of the vehicles involved (e.g., inner loops for depth, heading, and speed control). These systems must yield enhanced maneuvering capabilities in the presence of plant parameter uncertainty and unpredictable external disturbances. To meet these objectives, WiMUST research will pursue three key steps: i) vehicle dynamic modeling, ii) development of real time parametric identification techniques, and iii) design and implementation of algorithms for robust motion control. Vehicle models will also be exploited to aid in cooperative navigation, for example, to help predict the relative positions of two vehicles in the presence of temporary losses in communications or ranging measurements.

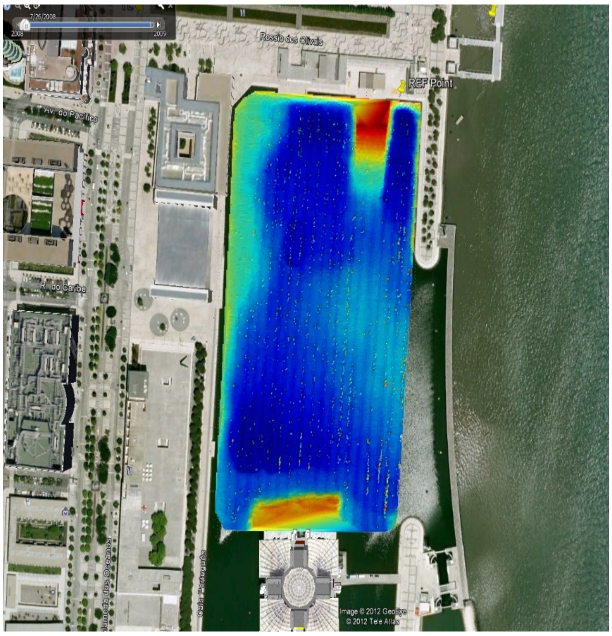

Fig. 3. Lisbon site for preliminary tests and integration.

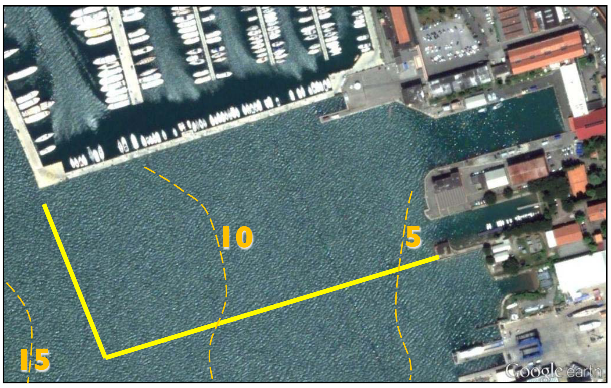

Fig. 4. La Spezia site for preliminary tests and integration.

4. CONCLUSION

A brief description of the H2020 WiMUST (Widely scalable Mobile Underwater Sonar Technology) project has been outlined. In particular the paper describes the major NGC issues that will be faced to achieve the final goals. The resulting WiMUST system will be validated through final tests in a site that will be either close to the Elba island in Italy or to the Setubal area in Portugal. Preliminary tests as well as integration activities will be performed at the partners premises and, in particular, at the IST-ID site in Lisbon (Portugal) (figure 3) and at the ISME site in La Spezia (Italy) (figure 4).

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