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Omnidirectional Underwater Surveying and Telepresence

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***Abstract* – Exploratory dives are traditionally the first step for marine scientists to acquire information on a previously unknown area of scientific interest. Manned submersibles have been the platform of choice for such exploration, as they allow a high level of environmental perception by the scientist on-board, and the ability to take informed decisions on what to explore next. However, manned submersibles have extremely high operation costs and provide very limited bottom time. Remotely operated vehicles (ROVs) can partially address these two issues, but have operational and cost constraints that restrict their usage.**

This paper discusses new capabilities to assist scientists operating lightweight hybrid remotely operated vehicles (HROV) in exploratory missions of mapping and surveying. The new capabilities, under development within the Spanish National project OMNIUS, provide a new layer of autonomy for HROVs by exploring three key concepts: Omni-directional optical sensing for collaborative immersive exploration, Proximity safety awareness and Online mapping during mission time.

Keywords *- HROVs, telepresence, collaborative underwater exploration, advanced assisted 2D/3D mapping, autonomous safety awareness, mapping of challenging environments, mapping quality control.*

I. CONCEPT

The study of marine habitats is a key component for understanding and managing ocean resources. In addition to their scientific and economical interest, underwater studies can be used for assessing sites that are important from a conservation point of view, determining areas sensitive to disturbance and pollution, development of coastal and marine protected areas management plans.

Currently, such studies face serious challenges, mainly resulting from the harshness and the hazard of the underwater environment. The use of divers drastically limits the depth range and the duration of the studies, while the use of manned submersibles involves high operational costs.

Within the Spanish national project OMNIUS, a new paradigm is being pursued which provides the basis for more direct, interactive and efficient underwater studies, while reducing the associated costs.

From the hardware point of view, the proposal has three main elements (Fig. Figure 1): (i) an intelligent ROV that will be used to acquire and transmit data such as: panoramic visual data, acoustic imaging, and other mission-specific data; (ii) a data processing unit that will process the data acquired by the ROV, creating 2D/3D multimodal representations of the environment; and (iii) a telepresence environment, in which the scientists will have a 360 degrees panoramic real-time view of the area currently surveyed by the ROV, complemented with other navigation sensor information.

The starting hypothesis is that lightweight hybrid remotely operated vehicles (HROV), similarly to the Girona500[1], can be used by a much wider group of marine scientists without requiring specialized personnel, if such platforms are endowed with suitable mapping and navigation capabilities.

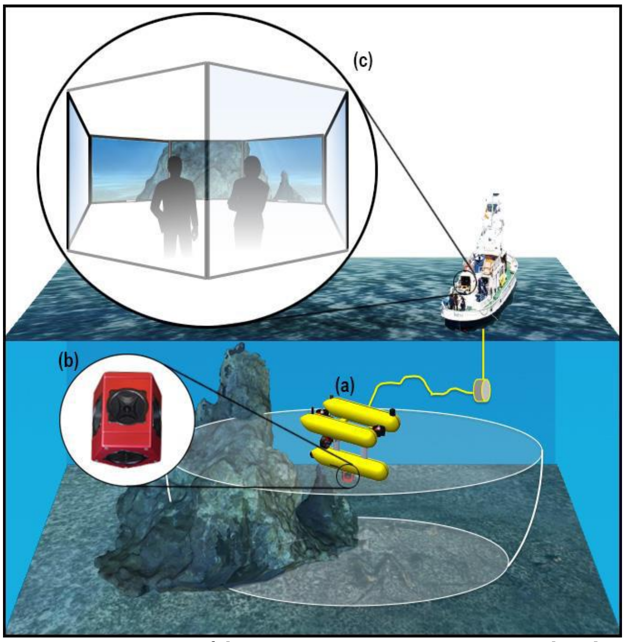

Figure 1 - Concept of the OMNIUS acquisition system. A tethered HROV (a) performs data acquisition using an omnidirectional camera (b) that provide the scientists with 360 degrees of visual feedback (c). This feedback is used to control and drive the acquisition

The goal of this effort is to develop new capabilities to assist scientists operating a lightweight hybrid remotely operated vehicle in exploratory missions of mapping and surveying, to ensure the creation of high quality map products at the end. The new capabilities provide a new layer of autonomy for HROVs that will assist scientists in using the platform as an exploratory tool.

Regarding research and innovation, the general objectives are to devise and validate experimentally three new capabilities of high operational impact: (1) advanced assisted mapping, (2) spatial awareness and safety, and (3) user immersion/telepresence.

1 - Advanced assisted mapping - It addresses the need to provide the scientists with high-level information on the mapping data that is being acquired, during exploratory and mapping surveys. This high-level information addresses two common concerns – what areas in the surrounding regions contain interesting features to be mapped, and once the scientist has decided to start mapping, if that area is being properly mapped. This information will assist the scientist in taking informed decisions on what to map and inspect, while taking full control of the exploration process.

2 - Spatial awareness and safety - It aims at providing the vehicle with proximity awareness capabilities when navigating in complex 3D and unstructured environments. Examples of such environments are confined spaces or very steep slopes. The aim is to release human operators from the pressing need to monitor vehicle safety when operating in very close proximity to obstacles in the surroundings. The vehicle will know when it is unsafe to navigate, and override or correct human control input if needed. This will allow the inspection and mapping of difficult areas that, otherwise would not be reachable due to the risk of damaging or entangling the vehicle.

3 - Immersion and Telepresence - aims at validating and demonstrating the expected impact of using an omnidirectional optical sensor as part of a collaborative visualization and exploration tool. This effort addresses the following question: Can a low-cost, customized Hybrid ROV/AUV be used to replicate the experience of a group of scientists on a manned submersible for purely interactive (and reactive) surveying?

II. ONGOING WORK AND ACHIEVEMENTS

Several technical advances are being pursuit within the project.

Among others, underwater omnidirectional imaging is a key sensing technology. An Omnidirectional Multi-camera System (OMS), based on a commercially available 6-camera system, was adapted for underwater use (Fig. 2). A custom-made compact housing inspired the development of a new 3-stage calibration procedure due to its non-conventional geometry [6]. This camera system was used at sea with the Girona500 AUV (Fig. 3) for tracking a formation of AUVs navigating at both close distance to each other and to the benthos [4], and also to create virtual panoramic tours for public outreach, in a similar concept to Google StreetView [5,3] (Figs. 4 and 5).

Figure 2- Omnidirectional sensor based on a 6-camera system. A custom housing was designed and built, comprising a cylindrical viewport with a hemispherical cap, and a metal container for a small form factor pc.

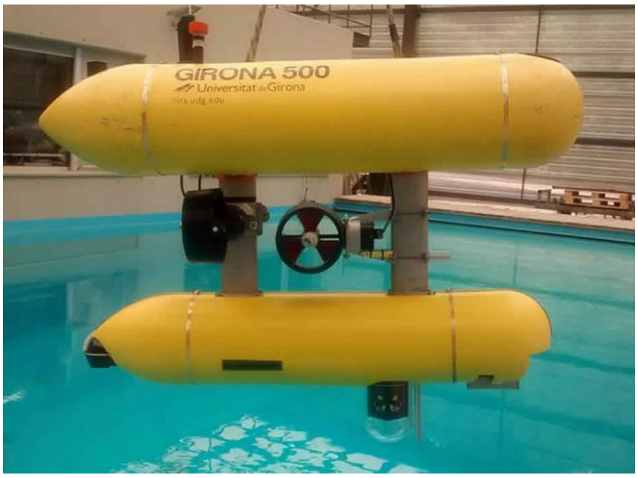

Figure 3 - Side view of the Girona 500 AUV/HROV with the omnidirectional camera installed.

An important aspect in exploratory missions is the ability by the scientists to adequately perceive the visual information from the surroundings, since they have to decide on-the-fly where to navigate next. As such it become important to improve the live imagery in real-time, to counteract part of the image degradation that the underwater medium creates. Towards this goal a new method for color correction of underwater images was proposed [7], using the Lab color space and having a low computational cost suitable for on-line operation.

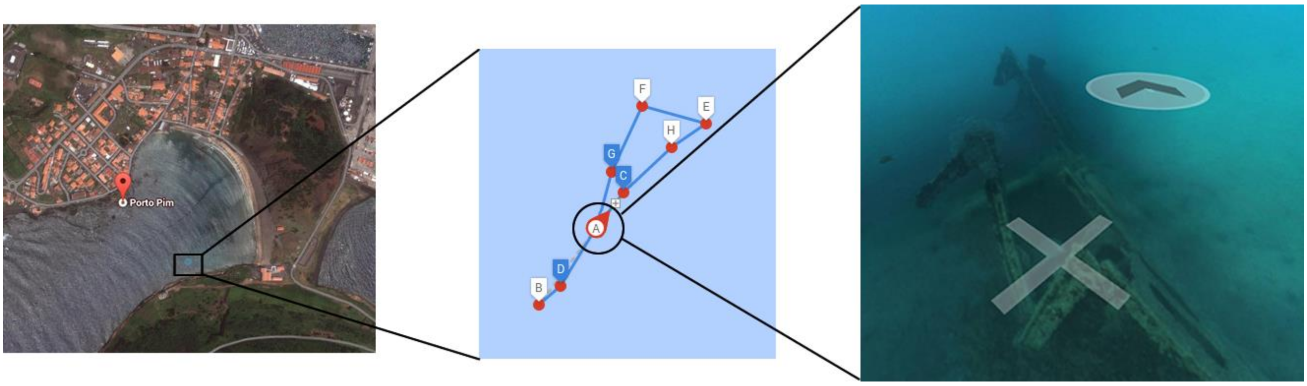

Figure 4 - Location and sample image of a shipwreck virtual tour in Google Maps

Another key aspect is the ability to build optical maps during mission. Several steps have been taken to perform optical mapping using computationally efficient approaches, towards the goal of on-line operation[8]. The case of multi-camera mapping has been addressed in the context of habitat mapping in the Azores [9], along with the problem of creating high quality 3D surfaces from noisy point data [2].

An important operational concern relates with the quality of the navigation data that is used in the mapping process. While altitude, depth and heading can be assumed to be highly reliable in most conditions, the same is not necessary true for latitude and longitude, which depend on the quality of inertial systems and/or on the presence of an acoustic positioning infrastructure. In this sense effort was devoted for the creation of optical maps when only the image measurements are assumed to be reliable (i.e. in absence of navigation data). These methods make use of graph theory to devise efficient approaches for image overlap prediction and joint optimization of the image registration, on large images sets [10,11,12]

III. FUTURE DIRECTIONS

The technologies developed within the OMNIUS paradigm aim at the study of the benthos immersively and in real time, and at the remote interaction with the vehicle in a safe and intuitive manner. Within this paradigm, several future directions can be identified as being of high potential impact for marine science. Two new integrated capabilities are pointed out due to their high operational relevance.

The first one is the ability to identify benthic structures of interest **automatically and during mission time**. An example of such is the detection of a particular invasive species, such as the *Caulerpa webbinana* in the Azores, or small man-made objects such as marine munitions or accident debris. Such detection is particularly well suited for the large field of view of the omnidirectional camera, and will serve to complement (and improve upon) the visual detection conducted by the scientist piloting the vehicle.

The second is the **automated detection and characterization of temporal changes**, for areas that are visited repeatedly over time. This ability is central to a number of ecology studies, and traditionally involves extensive manual work. The automated change detection and interpretation underwater requires techniques, such as pre-processing, registration and classification, that have not yet reached the required maturity and performance level.

Figure 5 – Panoramic image using the equirectangular projection of a shipwreck survey in Horta, Azores Islands in September 2014.

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