Environmental modeling with precision navigation using ROAZ autonomous surface vehicle

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Abstract*- The use of robotic vehicles for environmental modeling is discussed. This paper presents diverse results in autonomous marine missions with the ROAZ autonomous surface vehicle. The vehicle can perform autonomous missions while gathering marine data with high inertial and positioning precision. The underwater world is an, economical and environmental, asset that need new tools to study and preserve it. ROAZ is used in marine environment missions since it can sense and monitor the surface and underwater scenarios. Is equipped with a diverse set of sensors, cameras and underwater sonars that generate 3D environmental models. It is used for study the marine life and possible underwater wrecks that can pollute or be a danger to marine navigation. The 3D model and integration of multibeam and sidescan sonars represent a challenge in nowadays. Adding that it is important that robots can explore an area and make decisions based on their surroundings and goals. Regard that, autonomous robotic systems can relieve human beings of repetitive and dangerous tasks.

I. INTRODUCTION

Environmental concerns play an increasing role in the contemporary society. Human pressure and expanding nature resource exploration in the limited global ecosystem has raised awareness to our impact in the planet.

These concerns created a larger need for accurate and widespread monitoring of human activity environmental impact, and also for the deeper understanding of the environment dynamics and human interaction.

Robotic technologies play here a relevant role [1] due to their effectiveness in dealing both with spatial and temporal coverage along with precision information gathering at lower costs compared with other means.

In this paper we present recent results on the use of the autonomous surface marine vehicle ROAZ in environmental monitoring missions. These missions were performed in a diverse set of scenarios ranging from different river environments to ocean autonomous data gathering tasks. Moreover, the robotic vehicle has effectively been used in environment monitoring missions in a commercial setup on contract from different users. This experience is also reported here.

One particular situation where robots can be highly efficient is in marine environment monitoring and risk assessment [2]. These missions can be translated in physical bottom morphology characterization (bathymetry, obstacles, bottom sediment accumulation, geological properties), in water volume characterization (water parameters, biological and ecosystem information, plume identification, etc) and above water environment characterization, either in the air or air-water layer or in land border modeling (such as coastal or river margin mapping or risk assessment [2]).

Autonomous vehicles have been used in environment monitoring tasks, both surface vehicles [2], [3], [4] and underwater unmanned systems [5], [6], [7]. An extensive recent survey of the use of robots in environment monitoring is found in [1].

Traditionally autonomous surface vehicles (ASV) have been used either for monitoring in the above water zone [4], [1], [3], underwater vehicle support [8], [9] and less for underwater assessment. The latter has been addressed in the robotics community through the use of AUV systems [10], [11], [5].

The use of our autonomous surface vehicle permits a high load capability and continuous on-line communications. This allows real time data visualization and may serve as a communications relay with aerial and underwater vehicles. The vehicle is all electric and so it is pollutant free and has very low acoustic/sound noise. It is capable of carrying a diverse set of payload and, due to its autonomous guidance and control operationality, perform very precise trajectories.

II. ROAZ AUTONOMOUS SURFACE VEHICLE

The ROAZ unmanned surface vehicle is a custom built robot for marine operations (see figure 1). It was design for long endurance missions and to work in harsh environments, such as, medium sea state conditions and near-shore scenarios.

Figure 1. ROAZ_II autonomous surface vehicle

It has a catamaran shape with 4.2 x 2.2 x 1.7 m dimensions. In the middle platform has three watertight *Peli* cases, one for the computational and sensors system, and two for the power delivery system. The central tower has communication antennas, GPS antennas, an IR video camera, two GigE cameras, a standard pan&tilt camera, and sometimes a radar system for mapping and collision detection. The vehicle is propelled by a differential system with two Torqeedo electrical motors that allows velocities till 10 knots.

In the diverse field operations where ROAZ normally intervenes it is used has a testbed for several sensors and data gathering/monitoring missions.

For environmental purposes ROAZ can be equipped with Sonar systems: altimeters, multi-beam sonar, side-scan sonar, imaging sonar, sub bottom profiler; with video cameras: pan&tilt visual camera, Infra-Red camera, underwater cameras; CTD and sound velocity probe; and diverse water quality sensors and samplers.

III. VEHICLE NAVIGATION SYSTEM

A GPS/INS data fusion is the basics of our vehicle navigation systems that can be aided by other systems. Normally, visual and IR cameras, bottom/forward looking altimeters and the Radar collision detection system. The navigation sensor fusion is based in an Extended Kalman Filter.

ROAZ uses a *Septentrio* dual frequency RTK-GPS system with three L1/L2 antennas for high positioning accuracy. It can be connected to a base station for continuous DGPS/RTK position corrections.

For high-precision positioning and attitude the vehicle is equipped with a high-cost *IMAR* inertial fiber optical navigation system (specs: 0.75º/h, 1.5 mg, 400 hz).

In missions where there's no need for high quality sensors it is equipped with a low-cost *Microstrain* INS and a *Novatel smart-antenna* GPS receiver.

Besides the high quality sensors that equip our ASV and the pose estimation filters we also use post-processing techniques to improve our data quality.

Our GPS positioning data is post-processed with correct satellite orbits. With this high-accuracy geodetic correction one can get GPS data with centimeter precision.

The sonar systems data like multibeam and sidescan sonar are visualized on-line while the vehicle is doing is mission. But for seafloor mapping or high-resolution sonar mission it is done a post-processing routine to improve the data quality and remove outliers.

Our navigation high-quality sensors are very important due to the amount of sensor mounted systems that need referential transformations matrix and high-accuracy pose.

Regard that having an autonomous robot with long endurance capability and mission control maneuvers, give us an important tool for marine environments patrol and monitoring. In this type of environments the AUVs are the most common used vehicles, but our solution, gives absolute positioning with high quality and for near-bottom operations it can have towed sensors or use a tether vehicle attached.

IV. UNDERWATER MODELLING PROCESSING

Studying our lakes, rivers and oceans is a key factor in an economical and environmental way on this global world. A well treated environment allows us a good income of goods; access to fisheries, sources of energy, rich natural resources, and major transportation of goods on waterways reducing the carbon footprint. An important science for this idea is hydrography, a science that involves the mapping and surveying of inland waters, rivers and oceans which reveals information about what the seafloor and movement of water above looks like.

Using this tool it is possible to study environmental issues. The seafloor mapping allow us to research the increase/decrease of a reef colony or fish population; or to search for potentially hazardous material or pollutant wrecks in a waterway.

ROAZ is used in several environmental scenarios, such as: underwater bathymetry to search for underwater hazardous material, long term monitoring of underwater sediments; sonar inspection of underwater pipeline conditions.

The vehicle is equipped with a set of underwater sensors to model the bottom morphology.

Starting from an *Imagenex Sportscan* dual-frequency sides-scan sonar that provides us acoustic images of the seabed. Besides, the near-visual representation of the bottom it also give general indication about the nature of the seafloor. Depending on the signal reflectiveness it indicates the bottom texture: low reflection is silt or mud, and high reflection presents a rocky or gravel floor [12]. The side-scan sonar is physically attached to the vehicle gaining an accurate GPS positioning and INS measurements corrections (roll, pitch and yaw angles). It can also be used as a tow fish that allows greater deep ranges. The side-scan sonar is used in shallow water (<100 meters) and its images faithfully reproduce small details on the bottom due to its resolution of a few centimeters.

It is also equipped with two echo-sounders; an *Imagenex 863* altimeter and a new *Tritech Micron DST*. The latest uses CHIRP technology that dramatically improves the range resolution compared with conversational sonars.

It uses an underwater sound velocity probe (*Reson SVP71*) to continuously correct the underwater sound velocity value, since the sonars use the sound velocity value to calculate the echos time-of-flight.

Finally, an *Imagenex Delta-t 837* multi-beam sonar that performs large mapping sweeps of the seafloor. Our multi-beam can operate from 120 till 480 beams and with an aperture of 120 degrees. Compared to single beam sonars or near bottom AUVs, this near surface multi-beam sonar can map wide areas rapidly and accurately.

The accuracy of a bathymetry survey is highly sensitive to perturbations of the angular measurements, and movements of the vehicle must be very accurately compensated. The data from our sonars systems, GPS and INS sensors are all recorded and synchronized for post-processing.

After the data is gathered, the acoustic measurements are corrected with the high-precision INS measurements. Also, if the sonar measurements wasn't supported by the sound velocity probe values, one can also post-process the data and refine the measurements. Finally the sounding data is georeferenced with the position from the RKT-GPS (with corrected orbits).

In the example of the *DeltaT* multi-beam we receive/recorded data for the beamforming process, then using an *Imagenex* software we get a set of points that are corrected by the INS and GPS measurements and form a point cloud that later creates an underwater mesh of the bottom.

To visualize the multibeam and side-scan information we use the manufacture software, or we work the data and plot the point cloud (or triangulation mesh) on *Matlab*. We are also starting to integrate the multi-beam and side-scan data for high resolution image mosaic in the MB-System. MB-System is an open-source software package for the processing and display of bathymetry imagery data [13].

All data can be seen on-line while the vehicle is performing autonomously its mission. ROAZ as real-time communications with the base station and on-line transmission from all data, including all sonars. This allows the base station supervisor to assess preliminary on-line data from side-scan and multi-beam and if needed change the mission. The human supervisor on the loop can decide to survey another area or to refine the mapping in some hotspot, and can do it on-the-fly without waiting for the mission conclusion like the majority of the AUV systems.

V. VEHICLE OPERATION IN REAL SCENARIOS

On field operational scenarios our setup involves the ASV and a base station with communications to the vehicle. Normally the ASV is transported in a trailer, and depending on the water access, it can be deployed from the trailer or it might need a crane to hoist it. A few sensors are mounted on site and the computational and power cases need to be connected and all systems boot up and tested. On the other hand we have to setup the base station, a rough computer with a sun-light readable monitor running a Linux distribution (see figure 2).

Figure 2. Sun readable operation and supervision console on board of a support boat.

The command and control console uses a GTK2 software that allows the creation of all mission maneuvers and on-line control over the mission cycle. The console allows control over the vehicle by teleoperation or to create a mission with several maneuvers and goals to be achieved and command the vehicle to execute it autonomously. In the console we visualize the mission performance and data from all sensors that where deployed. Figure 3 shows a deployment mission and how one can activate/deactivate systems or rearrange the mission maneuvers on-line and re-send it to the vehicle. The base station computer is a central network system that allow other computers/vehicles to connect and operate. The base station has WiFi communications to the vehicle that allows a high-bandwidth with 1-2 miles range.

The initial setup and the final pick up takes normally 30 minutes each and depending on the missions objectives the ROAZ ASV is on the water operating till 8 hours.

In a real scenario operation ROAZ can be on-board guided by a human operator; can be teleoperated from the base station or other computer connected to the network centric communications; or performing autonomous missions with perception and control. The unmanned autonomous missions are of high value, given that, it performs repeated task with high-precision trajectories in risk assessment scenarios.

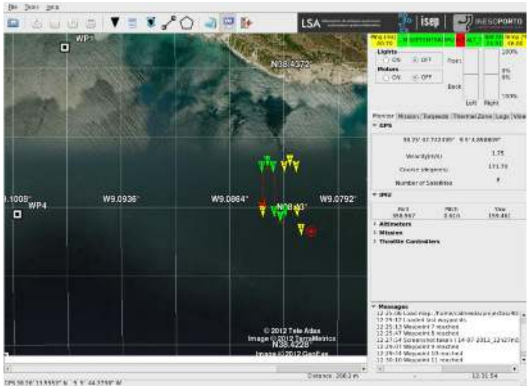

Figure 3. Screenshot of one of the supervision console views in a sidescan and multibeam sonar mission off the coast of Sesimbra

ROAZ is involved in several operational missions but on this work we'll only address the ones regarding environmental issues.

The first ROAZ missions involved the inspection of water surface oil spills or pipeline leakage and single beam mapping inside the harbor. The latest missions are more complex and we'll a few different scenarios.

One mission that our autonomous surface vehicle was involved occurred in the Tua river, Portugal. The Tua is a narrow canyon river, with rapid shallow waters, sharp rocks near surface, and with several inaccessible places from land; was a perfect scenario to use an unmanned surface vehicle and don't risk human lives or high value hydrographic vessels. A major Portuguese company wants to construct an hydropower dam in Tua river and we use the ASV to map the riverbed. The riverbed multibeam mapping was merged with surface laser scanning from *Artescan* [14] and a final 3D map of surface and underwater was created (see figure 4 for the digital terrain modeling). Regarding the construction and the river changes the company wanted to survey the environmental surroundings to assess future changes. Also to monitor continuous changes on the riverbed and margins by the water dam outfalls.

Figure 4. Shows the ROAZ ASV risk assessment bathymetry survey for laser scanning and bathymetric data integration in the Portuguese Tua river.

We performed an interesting contract service with ROAZ where it had to monitor the near-shore bottom morphology and sand movements. ROAZ performed several perpendicular trajectories along the coastline till the surf zone while gathering bathymetric data. For this work it was very important the GPS precision, the depth measures quality and the vehicle need to perform accurate straight line trajectories. This mission was repeated for each year season and allowed to study the effects of sand transport dynamic movements and the sea bottom morphology changes after a major breakwater construction.

In another set of missions, on the Douro river (near Vila Cova), the ROAZ system performed underwater visual and mapping surveys to find underwater wrecks. Besides, scientific data gathering, the vehicle also mapped several small shipwrecks and several hazardous material from a construction site nearby.

One of the latest operational missions was developed at sea (near a city called Sesimbra, Portugal). This mission was carried out to develop new scientific contributions and test new autonomous capabilities: From above water visual inspection; through new lawnmower autonomous maneuvers; and by underwater modeling and dataset gathering.

Figure 5. ROAZ_II deployed at Sesimbra sea

ROAZ performed a two day mission in this Sesimbra improvement exercise. In the first day it was deployed in the Sesimbra harbor and was use to do surveillance of surface pollution spills with Infra-Red and visible cameras. It was also used to map the harbor seabed and some underwater structures. The harbor is a place where a few environmental crimes can occur form pollutant liquids disposal till waste material thrown overboard. The seafloor map showed several tires and other man made structures in the bottom of the harbor that can concern a problem for the marine life.

On the second day ROAZ performed its missions at 1-2 miles from the coast at high sea as it is depicted in figure 5.

The ASV carried out several different missions; from early mission with visual and IR cameras; a mission using the side-scan and multi-beam to detect and identify objects in the water column (school of fish or buoy chains); till seafloor mapping integrating multi-beam and side-scan information with long endurance autonomous lawnmower sampling trajectories.

VI. RESULTS

The ROAZ ASV proven to be an important tool for environmental monitoring missions. This section presents some results of the data obtained in field operations.

Figure 4 shows the integration of multibeam data and surface laser scan in the Tua river. A continuous site mapping allows a time evolution monitoring of the surrounding environment.

The next figure shows an example of an acoustic image from our synthetic aperture sonar with a few shipwrecks and some marine life.

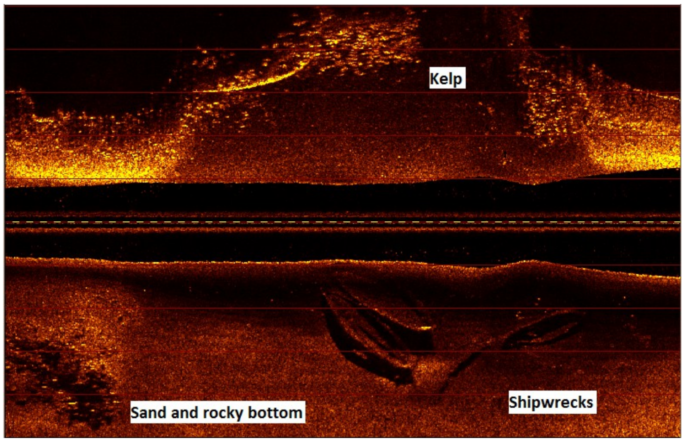

Figure 6. A sidescan sonar acoustic image showing three shipwrecks in Douro river.

Figure 7. Autonomous trajectories made by ROAZ for environmental 3D modeling of the seafloor.

During the high sea mission the vehicle performed several lawnmower trajectories for underwater environmental modeling with multibeam and sidescan sonars. Figure 7 shows a few trajectories made along Sesimbra coastline and figure 8 presents an extract of the multibeam environmental modeling of the seafloor.

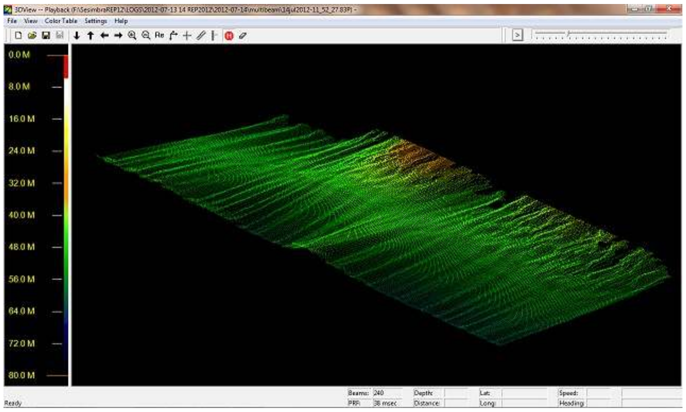

Figure 8. A point cloud from the multibeam sonar

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