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Towards Posidonia Meadows Detection, Mapping and Automatic recognition using Unmanned Marine Vehicles

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Abstract: This paper reports the development of a new methodology for automatic detection and mapping of underwater vegetation by means of highly autonomous marine robotic platforms. In particular, the work describes the exploitation of a Remotely Operated Vehicle (ROV), equipped with a multi-parametric sensors package, for the exploration and characterization of sea-bottoms interested by the presence of the *Posidonia oceanica* seagrass, which represents a valuable indicator of the environmental health. The proposed methodology relies on the systematic exploration of the sea-bottom by means of the ROV acquiring acoustic data and video imagery of the seabed, in order to reconstruct a 2.5D model of the environment (i.e. an elevation map of the sea-bottom). The data collection is achieved by the employment of a single beam echosounder for seabed range measurements and a down-looking underwater camera. Furthermore, an acoustic data procedural analysis is developed to automatically detect the Posidonia presence, so that in future works it will be possible to operate also in low-visibility conditions. Data acquisition was carried out over different seafloor types in coastal area near Biograd Na Moru (Croatia) and the results are reported in the paper.

1. MOTIVATION AND STATE OF THE ART

The importance of environmental monitoring of marine and oceanic areas has become universally acknowledged over the last years in order to guarantee sustainability and maintenance of ecosystems and habitats. The Mediterranean sea is colonised by the endemic seagrass *Posidonia oceanica*: in some specific areas, sandy and hard bottoms from the surface up to more than 40 meters deep are covered by Posidonia seagrass which builds specific systems, called meadows. Posidonia meadows are considered among the most representative and important Mediterranean coastal ecosystems for complexity, persistence and extension (Buia et al. [2004]). *Posidonia oceanica* meadows play a number of key functions for littoral ecosystems: they produce and export large amount of organic matter and oxygen, form complex ecosystems and support high level of biodiversity and tropic interactions, represent areas of refuge and nursery for fish and invertebrates also of commercial importance, reduce sedimentation, stabilizes the seabed and reduce coastal erosion (Boudouresque et al. [2006]). Moreover, *Posidonia oceanica* is considered a good biological indicator to determine the quality of coastal waters and, in general, the ecological status of Mediterranean marine environment due to the ability of the plant or meadow to respond strongly to environmental alterations with changes in its structural and functional characteristics (Romero et al. [2007]; Gobert et al. [2009]; y Royo et al. [2010]). For these reasons, *Posidonia oceanica* meadows are protected by the Habitat Directive 92/43/EU (Annex I, Posidonion oceanicae, code 1120) and are included in the reference list of priority habitats of the SPA/BIO Protocol of Barcelona Convention (Association with *Posidonia oceanica*, code III.5.1) (Protocol [1995]; Relini and Giaccone [2009]).

Within this framework, the continuous monitoring of Posidonia plays a key role in its preservation. The Posidonia monitoring methods operate at three levels: (i) system scale (aerial photographs, measurement of bottom cover, permanent transects), (ii) meadow scale (e.g. photographs of Posidonia around cement markers positioned along meadow limits, shoot-density, permanent quadrats) and (iii) shoot scale (e.g. plagiotopic to orthotropic rhizome ratio, laying bare of the rhizomes, lepidochronology, leaf epiphytes, leaf biometry) (Boudouresque et al. [2007]). Some of these methods, in particular those at meadow and shoot scale, require the presence of divers that perform the photographs in order to calculate the extension and coverage of the of Posidonia meadow. In addition, the measurements must be repeated periodically in order to study the changes in seagrass meadows overtime. All these monitoring technologies can be quite expensive if performed on-board conventional oceanographic vessels and need strong expertise of the divers. The introduction of highly autonomous robotic technology can overcome the problem of assigning repetitive, tedious and expensive tasks to human operators. Furthermore the small robotic platforms, characterised by a very small draught, could access interesting shallow water areas reducing the risk of grounding (Fumagalli et al. [2014]). For these reasons, a large field of interest is the use of Unmanned Marine Vehicles (AUV/ROV) in a wide variety of marine geo-

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science studies, originally focused on seafloor mapping but more recently expanding into water column geochemical and oceanographic measurements. Their ability to operate autonomously of a host vessel makes them well suited to exploration of extreme environments, from the world's deepest hydrothermal vents to beneath polar ice sheets (Wynn et al. [2014]).
A further advantage of these robotic platforms is the fact that they can be equipped with different types of sensors in order to acquire data to characterize the seabed under different points of view. Many studies and works have been published in literature focusing on seabed characterisation and underwater vegetation monitoring, using different technique (Kenny et al. [2003]). Multi-beam and side-scan sonar systems are described as the standard for bottom classification by authors of Rodríguez-Pérez et al. [2014]. In Penrose et al. [2005] a review of the acoustic techniques for the identification, classification and mapping of benthic habitats is given. Finally, work in Bonin-Font et al. [2016], describes the application of computer vision technologies to detect and map Posidonia Oceanica, employing a lightweight Autonomous Underwater Vehicle (AUV).

The aim of the paper is to propose a method for detecting and characterizing vegetation on the seabed (*Posidonia oceanica*) using the acoustic response from a conventional single beam echosounder mounted on the hybrid AUV/ROV robotic platform e-URoPe. This kind of analysis of the seabed was ground-truthed by direct measures, for example video observation. In this work, together with echosounding data, pictures of seabed were collected using an underwater camera, which allowed to qualitatively discriminate between echoes from different seafloor types.

2. METHODOLOGY

2.1 Overall Framework

The data acquisition campaign involved the employment of an hybrid AUV/ROV marine robotic platform characterised by highly reliable mission definition and control architecture and equipped with different types of sensors, in particular acoustic and video. These multi-sensor data were merged to obtain very precise seabed vegetation detection and mapping. A computer running GNU/Linux based real-time applications collected the data gathered by the video and acoustic devices and integrated them with GPS data and attitude (roll, pitch and yaw) data coming from the vehicle navigation system.

2.2 Acoustic and Video Imagery Sensors

As far as acoustic data collection is concerned, the measurements were performed with a lightweight, small and portable single beam echosounder ECS400 (Echologger) working at 200 kHz and providing in output not only the depth of the seabed but the entire spectrum of the signal (back-scatter data). This frequency is suitable to analyze seafloor characteristics because it cannot penetrate in the sea-substrate and it is mainly scattered.
The video acquisition system is based on the Bullet Network Camera VIVOTEK IB8168, mounted on a support alongside that of the echosounder. The IB8168 is an ultra-mini bullet network camera characterised by low weight (83 g) and small dimensions (32 mm x 117 mm) and it is equipped with a 2-megapixel sensor able to output 15 frames per second at the maximum resolution (1920x1080). This camera is designed to work in dry conditions but a stainless steel (aisi 316) canister to adapt it for marine and underwater use was built. The whole module was mounted on e-UroPe by means of a 3D printed support permitting to adjust the pan of the camera.

2.3 e-URoPe ROV-AUV

The hybrid AUV/ROV robotic platform e-URoPe (e-Underwater Robotic Pet) is the new unmanned marine robot developed by CNR-ISSIA and it is characterised by reduced dimensions, 1.0 (length) x 0.7 (width) x 0.5 (height) m x 150 kg (weight), and a maximum operating depth of 200 m. New design methodologies and material choice have led to the construction of a robust and highly reliable vehicle, as well as reduced weight and size allowing lighter logistics constraints. The modular payload interconnection design allows to reconfigure the vehicle for a specific mission in a very short time, in both hardware and software fashion.
From an operational point of view, the vehicle guarantees the complete navigation capabilities thanks to a fully actuated propulsion configuration (4 horizontal and 4 vertical thrusters) and the presence of inertial sensors for attitude and acceleration measurements, combined with a DVL system for velocity reading. The integration of an USBL device provides the relative position localisation for a more accurate navigation capability during coordinated manoeuvres. The overall control architecture, inherited from other CNR-ISSIA robotic platforms, allows the execution of highly autonomous navigation and guidance procedures (e.g. general path-following as described in Bibuli et al. [2015]) and complete complex missions (as described in Ferreira et al. [2012]).
The e-URoPe vehicle is depicted in Figure 1.

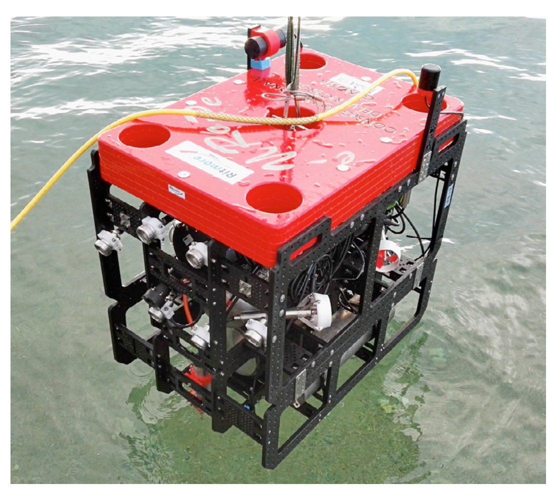

Fig. 1. The e-URoPe ROV/AUV.

3. EXPERIMENT EXECUTION AND DATA GATHERING

The combined sampling of acoustic and video data described in this work was carried out in a shallow water coastal area (depth < 10m) near Biograd Na Moru (Croatia). In this area the sea bottom is characterised by high variety: rocky areas alternate with sandy areas and others covered with Posidonia, making it particularly interesting for the purposes of our tests on seabed characterisation and Posidonia detection.

The employment of the e-URoPe ROV/AUV, and its related control architecture, allows the fully autonomous execution of a lawn-mower motion over a predefined horizontal grid above the area of interest. To minimize the disturbing effects of wind, waves and sea current, the experiments were carried out maintaining the vehicle submerged at a constant depth. Despite the unavailability of the GPS signal while operating underwater, high precision navigation is obtained by means of an USBL (Ultra-Short Base Line) underwater position system provided by EVologics GmbH (the USBL head is mounted on the shore, while the acoustic beacon is installed on the vehicle) combined with a model-based extended Kalman filter (eKf) that fuses the USBL data with IMU readings providing the position estimation with an error of the order of the centimeter (Caccia et al. [2008]). The acoustic positioning system is composed by the so called NaviPack which comprises the USBL head rigidly mounted with a GPS receiver and a compass. The NaviPack allows to obtain the correct position of the vehicle during underwater operation without any further calibration operations prior to the mission. A comparison of GPS and USBL positioning data during vehicle navigation is show in Fig. 2, where the vehicle performed the motion at 0.5 m of depth with the USBL pinger immersed in the water and a GPS antenna raised above water line in order to collect synchronized data.

Given the knowledge of the vehicle dynamics' model, an

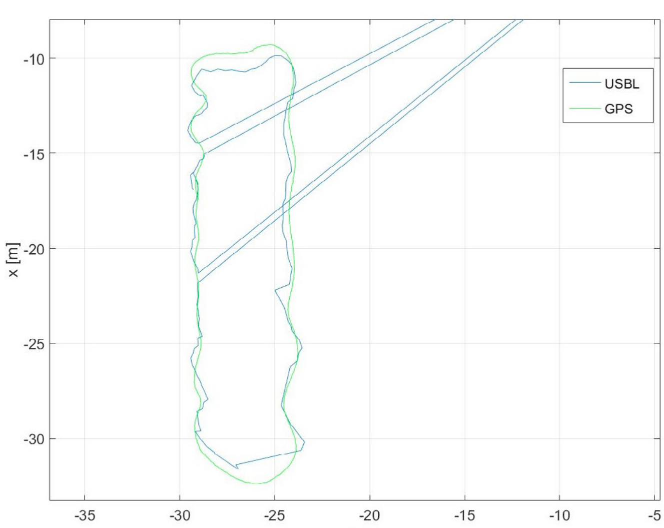

Fig. 2. Comparison of USBL and GPS measurements. The USBL presents two glitches due to acoustic misreadings.

efficient extended Kalman filter can be designed and tuned to smooth the USBL measurement and remove outliers. An adaptive scheme to cope with variable measurement delay is currently under study. A comparison of the raw USBL measurement with the filtered signal is depicted in Fig. 3. From an operative point of view, the user has only to select

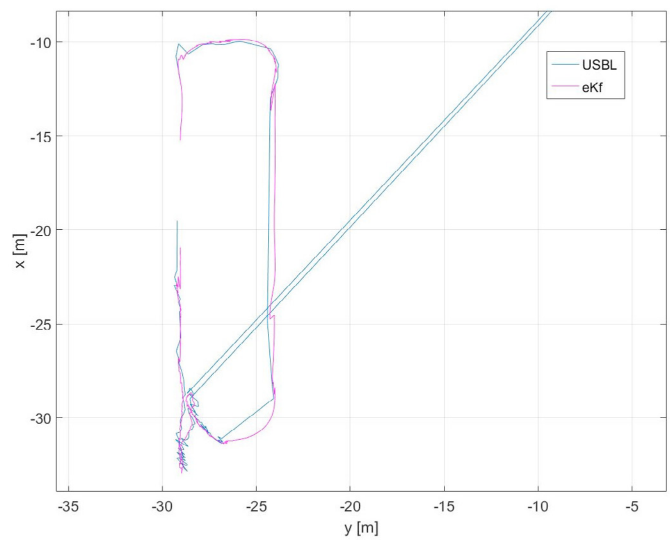

Fig. 3. Comparison of raw USBL measurement and eKf generated signal. The plot highlights raw signal smoothing and outliers removal.

the parameters for the mission execution, i.e. the position and dimension of the area of interest to be inspected, as well as the orientation and the number of transects to be executed for the data gathering operation; setting the desired operating depth, the system will also regulate the vertical motion of the vehicle. Once the mission execution starts, the user can focus only on the quality of the gathered data, leaving the system to autonomously manage the navigation and guidance issues to comply with the required mission specifics (details on the mission control system can be found in Bibuli et al. [2009]).

During the mission execution all the navigation data and sensor readings are logged so that all the collected information can be replayed, analyzed and processed at the end of the mission. Figure 4 shows the horizontal motion of the vehicle executed during a mission where a 10-transects lawn-mower motion was required over an area of 20 x 10 meters. This area is characterised by the presence of both rocky zones and Posidonia meadows and thus worth the sampling and investigation with the advanced methodology and tools proposed in this work.

4. DATA ANALYSIS

The sonar ECS400 can record the raw data and get the power spectrum corresponding to each ping. In each spectrum there are the signal sent, a peak representing the interaction with the bottom (first echo) and sometimes a secondary peak due to multiple reflections. The start of the first echo, corresponding to the bottom depth, must first be accurately found. To do this we use the algorithm for peak detection described in Ferretti et al. [2015]. The raw data were used not only to calculate the depth of the seabed but also to infer the acoustic properties of the bottom. The acoustic reflectance of the seabed depends on

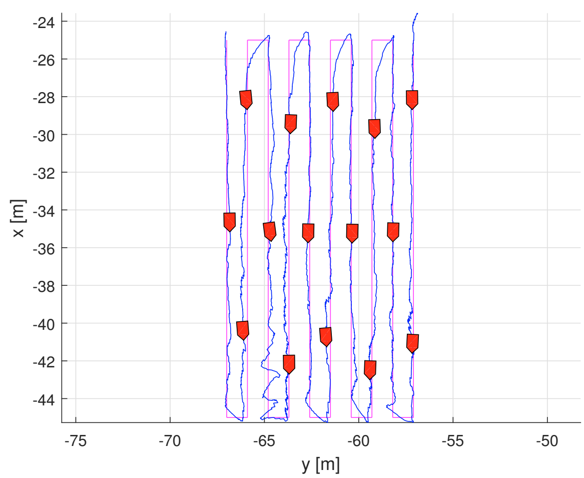

Fig. 4. The reference and actual lawn-mower motion executed by the e-URoPe ROV/AUV.

its composition: a smooth and flat bottom reflects most of the incident signal back to the transducer with its shape substantially unchanged. Conversely a rough and irregular bottom returns energy by back scattering of the beam and so the return signal will have a lower peak amplitude and a longer tail than the case of the smooth bottom (Hamilton [2011]). Comparing the power spectra obtained in correspondence of different types of seabed, it can be noticed that the shape of the first echo varies depending on the type of the seabed: for sandy and rocky bottoms it is narrow with a steep rising edge. In case of Posidonia, on the contrary, it has a more enlarged shape with a rising edge less steep. These differences in shape and intensity of the returning echoes are visible in Figure 5, where the acoustic spectra corresponding to two different seabed types and the relative pictures are shown.

To get information on the composition of the seabed, the following echo characteristics are studied (Torres Medina [2010]):

- *Surface Scattering Coefficient derived from the backscatter Energy* (SSCE), that is the energy of the first peak (integral);
- *Surface Scattering Coefficient derived from the backscatter Intensity* (SSCI), that is the intensity of the echo at the point corresponding to the bottom;
- *Rise time*, that is the time it takes the signal to reach the maximum value once it has interacted with the bottom.

Using the video images as ground-truth, two groups of spectra are created: one corresponding to seabed covered with Posidonia and the other corresponding to rocky seabed. For each spectrum of each group, the previous indexes are calculated and a k-mean method is used to generate two clusters of data. To validate the algorithm and test its ability to reveal the presence of Posidonia on the seabed, a sub set of data whose category is known is used. For each spectrum the indexes are calculated and the spectrum is assigned to one of the two clusters based on the minimum distance criterion. It is assessed that the percentage of correct classification exceeds 95%. The results are displayed in a graph that colors differently the points based on the type of bottom (orange for seabed without Posidonia and green for seabed with Posidonia) and are superimposed to the map corresponding to the location where the data were collected (the coastal area in front of Biograd na Moru, Croatia). There is a good correspondence between the results obtained by the algorithm and the effective presence of Posidonia on the seabed, as shown in Figure 6.

The high-resolution images, acquired along with the acoustic spectra, were used in addition to the ground truth also to realize mosaic images of the bottom. The overall sea-bottom photo-mosaic has been obtained employing an open-source ROS package named BIMOS (Binary descriptor-based Image MOSaicing), initially developed by the University of Balearic Islands for vessel visual inspection through the employment of a Micro-Aerial Vehicle Garcia-Fidalgo et al. [2015] and then adapted also for the usage with underwater imagery sets Garcia-Fidalgo et al. [2016]. In Figure 7 (left) the mosaic of the area inspected with the vehicle is shown. It has to be remarked that, thanks to the robot's navigation filter, it is possible to cross-link the GPS position of each image and thus georeference the mosaic with respect to the absolute earth-fixed reference frame.

Subsequently the bathymetric map obtained from acoustic data has been merged with the mosaic obtained from the images: in this way the reconstruction of seabed with superimposed texture has been created (Fig. 7 right). This kind of data could be exploited to develop an algorithm for Posidonia meadows boundary tracking which could be integrated in the control system of the autonomous vehicle.

5. CONCLUSIONS AND FUTURE STEPS

This work has reported the description of the adopted methodology based on robotic platforms usage for the tasks of sea-bottom exploration, characterisation and reconstruction, particularly focused on the detection of Posidonia meadows. The proposed methodology highlights the easiness of the operations from a user perspective, as well as the precision of data gathering and subsequent environment characterisation and modeling. In fact, the exploitation of robotic agents allows the execution of autonomous operations, leaving the user to focus only to the quality of the acquired data. The paper has also focused on a preliminary verification of automatic procedures for the detection of Posidonia seagrass presence by the execution of data processing algorithms on the echograms registered from the acoustic sensor measurements. The data processing and result validation can be ground-truthed comparing the Posidonia acoustic based detection with the imagery data set in order to evaluate the discrepancy.

Future works will be focused on deep verification and validation of the acoustic based detection methods, in such a way to provide a robust system to be employed also in low-visibility conditions (i.e. where imagery data are useless). On the basis of a robust detection, the aim is to integrate a contour tracking procedure with the automatic guidance module so that the robotic system will be able to track the Posidonia meadow boundary in different time instants, thus allowing a fast assessment of the Posidonia grow/decrease rate over the time.

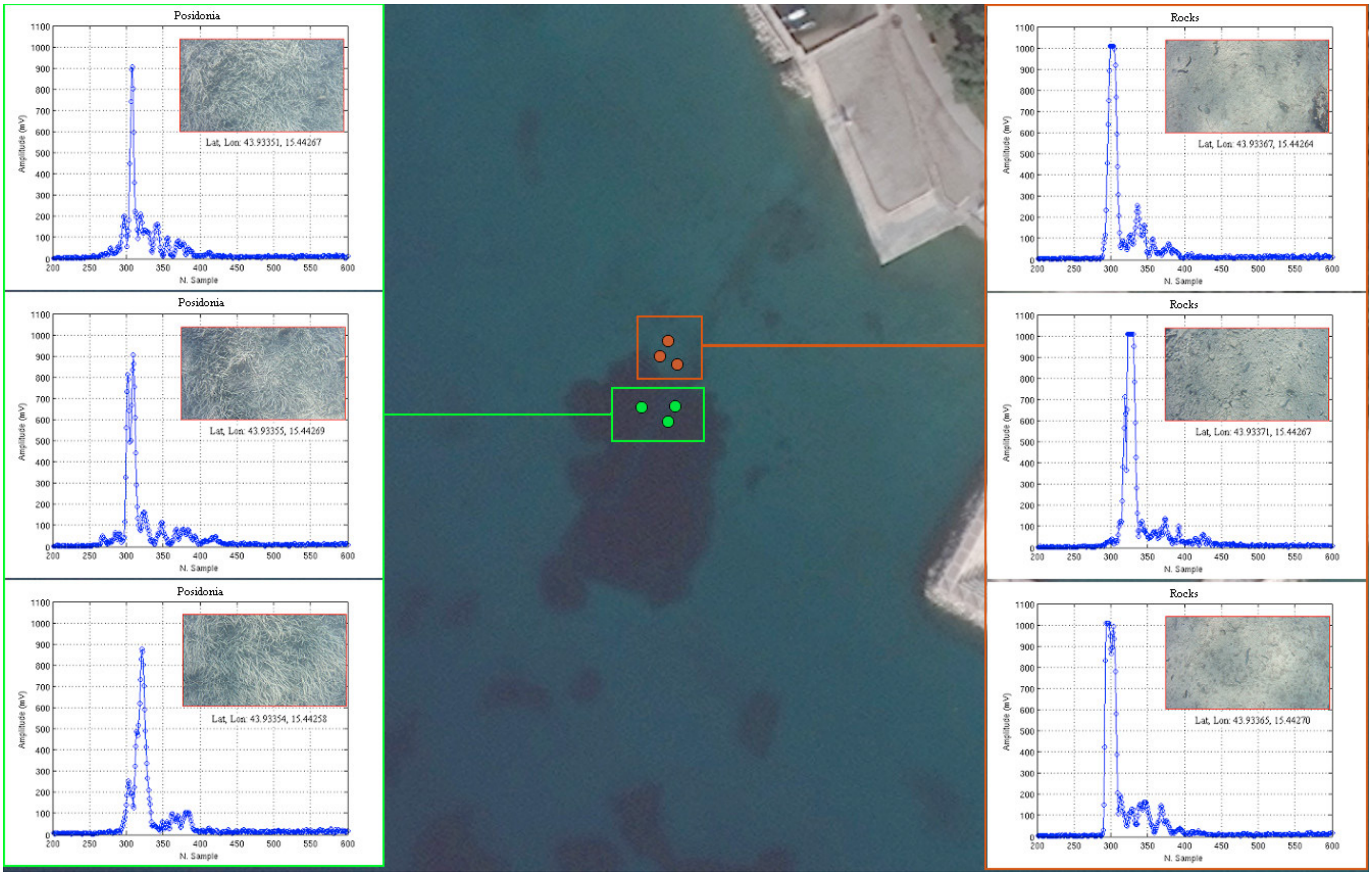

Fig. 5. Acoustic spectra of different seabed composition are presented together with their relative pictures. On the left irregular bottoms (Posidonia) are shown while on the right hard bottoms (rocks) are shown.

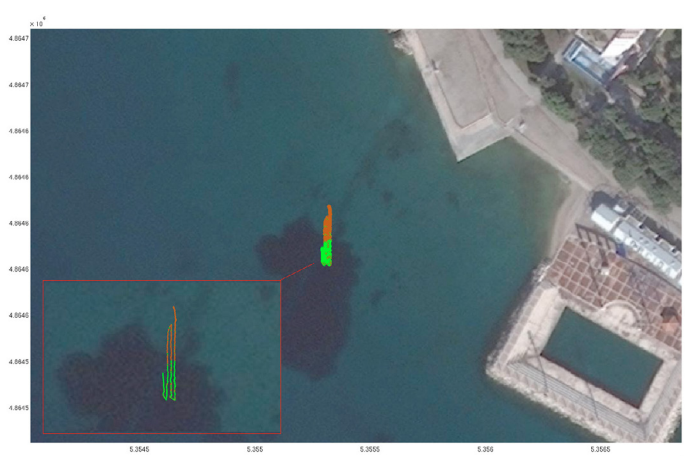

Fig. 6. Map of the coastal area in front of Biograd na Moru, Croatia. The results of acoustic spectra classification show with orange dots spectra from rocky seabedred and with green dots spectra from seabed covered with Posidonia.

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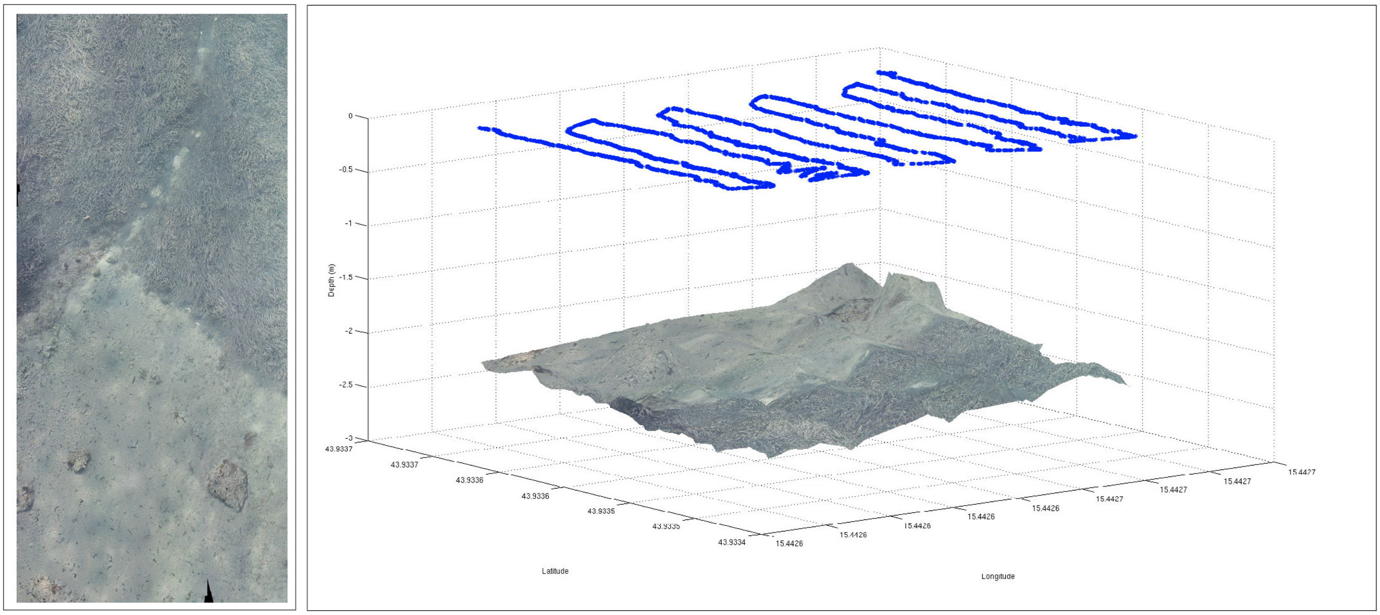

Fig. 7. Left: mosaic image of the area inspected with the e-URoPe vehicle, obtained from the high-resolution VIVOTEK IB8168 camera. Right: reconstruction of the seabed with superimposed texture. The blue line represents the horizontal motion of the vehicle during the data taking: 10 transects over an area of 20 x 10 meters.

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