17th International Conference on Environmental Science and Technology

Athens, Greece, 1 to 4 September 2021

Benthic megalitter detection using unmanned surface vehicle (USV) and Automatic Target Detection: A case study in the Port of Thessaloniki, Thermaikos Gulf

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Abstract In the port of Thessaloniki, Greece, benthic megalitter detection was achieved using an Unmanned Surface Vehicle (USV) equipped with a compact high resolution sidescan sonar (SSS) and a single beam echsosounder (SBES). The benthic megalitter survey was organized in two separate phases. Firstly, a systematic hydroacoustic survey using the SBES and SSS managed to outline and map all the acoustic anomalies. The second phase followed using the ROV hovered over these acoustic anomalies and the sites were identified on the video camera. An Automated Target Detection procedure, based on acoustic texture analysis and Independent Component Analysis (ICA), was applied for the automated detection of acoustic anomalies. The ground truth survey attested that the anomalies represent megalitter (metallic items, car tires, wires, e.t.c.). The developed procedure had promising results towards fast detection of the benthic megalitter in coastal areas.

Keywords: Benthic megalitter, USV, Side scan sonar, ROV, Independent Component Analysis (ICA).

1. Introduction

Marine litter is considered as one of the fastest growing threats to the health of the world's oceans. Large amounts of marine litter including about 8 million tons of plastics enter the world ocean every year. Identifying the source of litter is a difficult task since most litter items may have originated from a variety of sources and activities. Most researchers tend to classify the marine litter sources to two main categories; land-based and marine-based sources (Papatheodorou 2012a). Due to UV radiation and mechanical forces, plastic litter in the world ocean gradually breaks down into smaller fragments (Galgani et al., 2015). Plastic litter is also categorized by size into different size classes: megaplastic (>100 mm), macroplastic (>20 mm), mesoplastic (5–20 mm), microplastics (<5 mm) and nanoplastics (<100 nm). Marine litter can be found throughout the marine environment; from the beaches to sea surface (floating litter), to water column and to seafloor (benthic litter). Taking into account that a significant part (~50%) of the plastics produced is heavier than seawater (Geyer et al., 2017), the ocean floor is expected to constitute a major sink (Ioakeimidis et al., 2017). Although the deep-sea environment can be considered as low-energy regime and is characterized by the absence of light, the degradation potential of plastic litter items remains significant introducing microplastics to marine environment (Ioakeimidis et al., 2016).

The detection and characterization of benthic litter relies on three different approaches and, in some cases, on a combination of them (Madricardo et al., 2020): (i) litter collection with bottom trawlers (Stefatos et al., 1999, Koutsodendris et al., 2008), (ii) optical means (scuba, towing cameras, R.O.V's) (Politikos et al., 2021) and (iii) remote sensing techniques (MBES, SSS and HRSS) (Fakiris et al., 2016).

Bottom trawling for benthic litter allowed litter collection over large seafloor areas and litter monitoring over long periods. On the other hand the bottom trawlers cause serious damages on the seafloor habitat and marine life and cannot operate on rocky seabed and seafloor of uneven morphology. The main limitation of the optical means is the limited coverage of the seafloor and the limited visibility while the effectiveness of the remote sensing techniques is highly affected by the resolution which is dependent on the sonar characteristics and the distance from the seafloor. The best solution in order to overcome the limitations of both methods seems to be the combination of two approaches that integrates their advantages.

The optical and remote sensing techniques operate on-board research vessels and lately on-board autonomous vehicles (USVs and AUVs). Autonomous platforms can perform close-to-bottom and in extremely shallow waters (<2m) for litter detection and photographic surveys. In this context, USV and AUV's equipped with optical and remote sensing means are likely to be the future of the benthic and floating litter surveys for shallow and deep waters, respectively (Madricardo et al., 2020).

In this paper, we report on a first exploratory survey using USV and ROV for benthic litter detection off the Port of Thessaloniki, in Thermaikos Gulf, an area completely uninvestigated in terms of marine litter. To the best of our knowledge, this is the first attempt to detect and map benthic litter using USV coupled with ROV. Moreover, an "Automated Target Detection" (ATD) procedure based on image texture and Independent Component Analysis (ICA) was succefully applied for the fast detection of megalitter.

2. Materials and methods

2.1. Field work

The benthic litter survey off the Port of Thessaloniki was organized into two phases. First a systematic survey of a selected area of 120 x 160 m was carried out using a combined single beam echosounder and side scan sonar on-board a USV (Fig. 1a). The second phase, which is a ground-truth survey, consisted of visual inspection based on the results of the first phase. During the first phase the survey area was systematically surveyed, achieving total coverage, and acoustic anomalies (targets) were located for further investigation. During the ground turthing survey, the ROV hovered over these locations and the targets were identified on the video camera. M.V. TYPHOON, a 72-meter long vessel, act as a surface support vessel for the USV and ROV, including the capacity to launch and recover both platforms and to provide subsea communications and positioning with ROV (Fig. 1b). M.V. TYPHOON vessel of the "A.C. Laskaridis Charitable Foundation" has the ability to conduct marine litter surveys using state of art methods (marine remote sensning equipment, USV and ROV) and clean up campaigns all around the Aegean Sea, year-round, by decontaminating the coasts and transporting the waste collected to recycling or proper disposal structures.

The mission utilized the i-USV170 model (https://imachines.gr/ West Sea Project), a 1.7 m long x 1.0 m width catamaran-shaped vehicle with a total weight capacity of 20 kg (Fig. 1a). The USV supported a side scan sonar system operating at 455/800 kHz kHz and a 83/200 kHz broadband single beam echosounder, both integrated in the Lowrance Elite-7 Ti sonar. A Blue Robotics ROV2 was used for the ground truthing survey supported by a Blueprint Seatrac USBL acoustic position system and the Dynamic Position system of the M.V. TYPHOON.

2.2. Data analysis and Automatic megalitter detection

The raw USV SSS sonographs underwent radiometric and geometric corrections; radiometric including beam-pattern compensation and ping energy level normalization while geometric slant range correction and ping by ping spatial registration. The USV SSS data were mosaicked with a 10 cm resolution using the ReefMaster software (Figure 2a).

For this survey, high reflectivity areas, covered by coarse grained sediments and/or concist of rock outcrops, exchibit light tones on sonographs while low reflectivity areas due to fine-grained sediments, show dark tones. Acoustic shadows have been recorded with black colour.

The SSS mosaic was processed with an image-based automatic classification procedure with the use of "SonarClass", a Matlab software package (Fakiris and Papatheodorou, 2007; Papatheodorou et al., 2012b; Fakiris et al., 2012; 2016; 2018). SonarClass performs image quantification and classification through a range of seafloor imaged features, i.e. first order grey-level statistics, grey level co-occurrence matrices (GLCMs) and 2D power spectrum specifications, forming a feature vector (FV) of 11 textural descriptors that describe the local image texture. This "Automated Target Detection" (ATD) procedure, was first used by Fakiris et al., 2016. According to that, Independent Component Analysis (ICA) is applied to the textural derivatives of the SSS mosaic to transform the FVs into a few meaningful components that maximize the separation among any potential targets. To identify which components are more likely to emphasize seabed irregularities/acoustic anomalies, the kurtosis criterion was used. Kurtosis, is considered an outlier indicator (related to the tailedness of the Gaussian distribution), it is much higher for components that emphasize small targets than for components reflecting larger scale seafloor characteristics.

In the present dataset, acoustic anomalies (targets) were automatically highlighted using the above described procedure. The Kurtosis criterion applied on the 11 extracted Independent Components (ICs) clearly identified IC5 (Fig. 2b) as the only one containing the total target information and thus a simple segmentation with thresholding value on the IC5 values (IC5>0.5) led to the final target map (Fig. 2c).

3. Results

The interpretation of the side scan sonar mosaic revealed four Acoustic Backscatter Patterns (Fig. 2a). ABP 1 includes wide areas of high backscatter intensity (light tones) with locally a patchy tonal character (Fig. 2a). ABP2 characterizes areas of low and homogenous backscatter (dark tones) (Fig. 2a). ABP 3 shows areas of moderate backscatter intensity (Fig. 2a). The boundary of the patterns is distinct while between ABP1 and ABP3 often laced. ABP 4 includes small areas of high reflectivity with more or less certain shape (geometry) accompanied with narrow zones of acoustic shadow (Fig. 2a). This acoustic pattern seems to superimpose to the high (ABP1) and low (ABP2) acoustic backscatter patterns. ABP4 is considered to represent scattered acoustic anomalies (targets). The base of the breakwater of the Port has been recorded as high backscatter linear feature associated to a wide area of acoustic shadow (Fig. 2a).

Fifty six (56) acoustic anomalies (targets) were automatically detected within the survey area based on the fifth Independent Component (IC5) (Fig. 2b) and a target map was created using IC5 values greater than 0.5 (Fig. 2c). The spatial distribution of the targets is characterized by homogeneity. Slightly higher spatial density is observed at the eastern part of the survey area, close to the breakwater (Fig. 2c). The target size distribution is bimodal presenting two local maximums; a primary at 0.6m and a secondary at 1.5m (Fig. 2d). Thirty three targets, a significant percentage (59%) of the population, have similar dimensions, between 0.5 and 0.7m (Fig. 2d). Only seven targets (12.5%) greater than 1 m was detected in the survey area (Fig. 2d). The ground truthing survey showed that the water column of the area is characterised by high turbidity and poor visibility conditions and therefore the detection and the identification of the targets is a challenging task. Nonetheless, the visual inspection of many targets showed that represent man-made items like metallic pieces, car tires, wires, e.t.c. (Fig. 3). Moreover, the inspection revealed the colonization and encrustation of marine litter by marine biota.

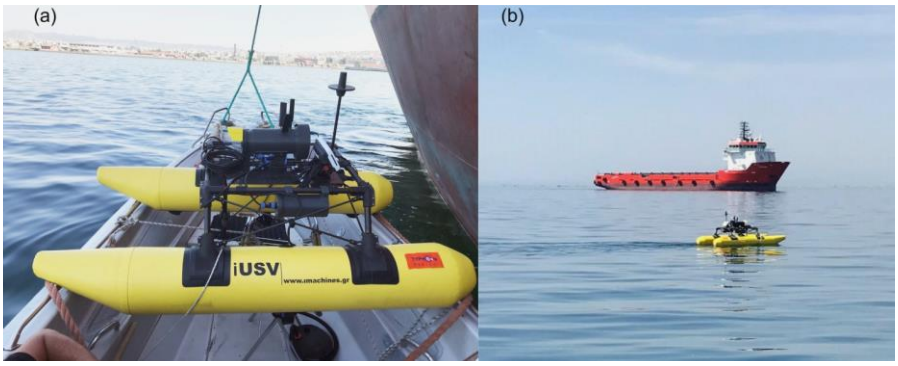

Figure 1. (a) iUSV170 used for the benthic megalitter survey, (b) USV operates off the Thessaloniki Port close to the surface support vessel MV TYPHOON.

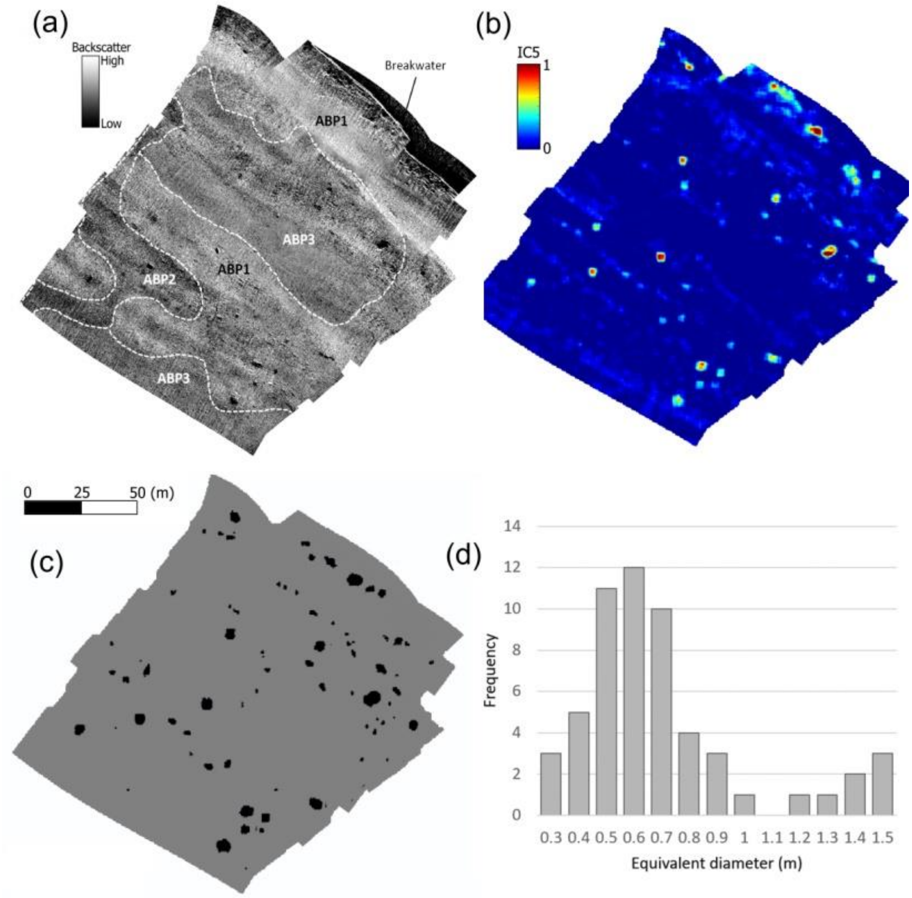

Figure 2. (a) SSS mosaic showing the Acoustic Backscatter Patterns (ABP), (b) the Independent Component 5 (IC5) highlighting targets, (c) final target map based on IC5>0.5 and (d) target size distribution based on the equivalent diameter of the target boundaries.

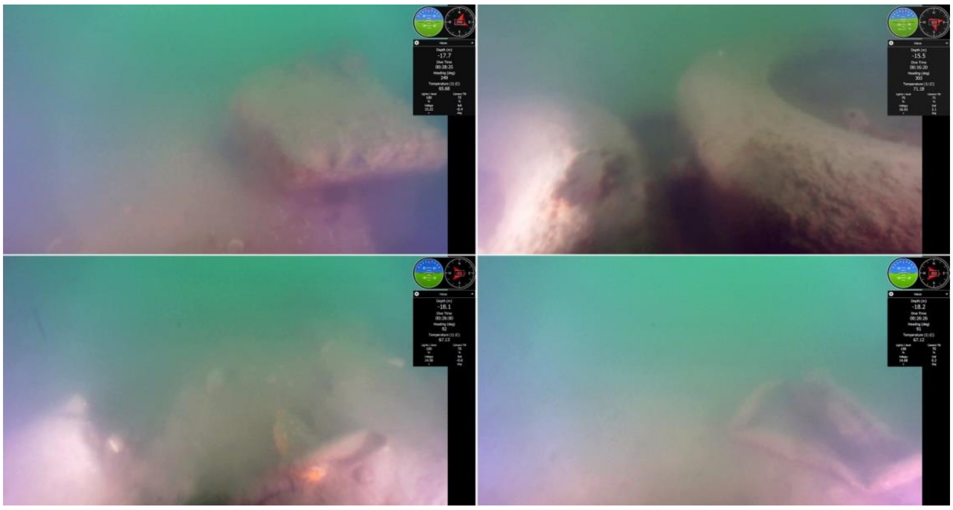

Figure 3. Underwater photos of megalitter recovered by the ROV.

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