Detection of Low Permittivity Floating Plastic Sheets at Microwave Frequencies

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***Abstract*—Microwaves are surfacing in remote sensing as a viable or complementary technology to optical techniques for the detection and monitoring of floating plastic litter, given their advantages in, e.g., Earth observation missions. There is a limited number of studies that analyze the detection of low permittivity plastics in a systematic manner. To contribute to this topic, we evaluated the microwave response of a few typical floating targets in two scenarios, one with near-static water and the other with waves. We present an interesting example of target in this paper, which involves very low amount of material - stretched and crumpled plastic sheets. The results, obtained for different transmit and receive polarization combinations, indicate a strong, distinct response of the plastic sheets, in both cases. The study shows that, at least under the tested conditions, microwave radar may be sensitive to very low amount of plastic, through an indirect detection process.**

***Index Terms*—active radar, backscattering, macroplastics, marine plastics, polarimetry, microwave sensing, polarization, marine litter pollution, remote sensing, rough surface, scattering measurements.**

I. Introduction

Enormous quantities of plastic litter end up in the ocean yearly from different entry points [1]. Due to ocean currents, vast accumulations of floating and partially submerged macroplastics are formed in deep sea, far away from the shorelines. The lingering presence of these plastics endangers the marine ecosystem and has direct implications on the human food chain due to their degradation over time. Several missions and research strategies are underway to aid mitigating the problem.

The bulk of scientific research available on satellite remote detection of plastic litter accumulation focused, mainly, on the optical domain (λ = 400 to 2500 nm) combined with high spatial resolution (<3m), from both air- and spaceborne platforms [2]. In parallel, there is a growing interest is in Synthetic Aperture Radar (SAR) sensors (λ = 3.1 to 5.6 cm), as a viable alternative technology for marine litter (direct and indirect) detection [3], [4], [5], [6].

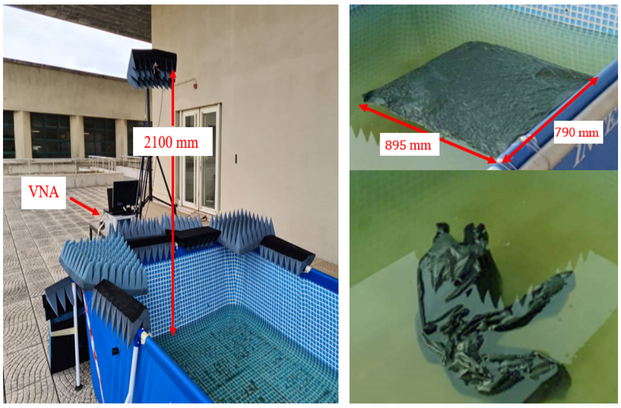
In general, remote sensing of marine litter, particularly floating macroplastic, based on Microwaves (MWs) has been emerging as an alternative or complementary technology due to their advantages in, e.g., Earth Observation missions [1], [7], [8]. This is of particular interest towards the community of Antennas and Propagation as there is lack of literature on this subject.

Here, we present a study of macroplastic detection using radar by assessing the radar response of a common plastic litter object, plastic sheets and bags [9], under two separate scenarios: static and dynamic water. Measurements in the static scenario were performed in our own facilities at Instituto Telecomunicações (IT), whereas for the dynamic scenario were conducted in a controlled indoor environment at DELTARES (NL) [10], that mimics deep sea wave conditions. In the static water scenario, the plastic litter backscatter response for different polarizations (VV, HV, VH and HH, respectively) has been evaluated, whilst in the dynamic water scenario, a demonstration on whether detection is possible under a more complex, realistic environment, is presented.

This paper is organized as follows: Section II describes the methodology used in processing the data from the measurement campaigns; Section III and IV describe the measurement campaigns and the respective results; lastly, main conclusions and future studies are drawn in Section V.

II. Methodology

In terms of radar detection, background and artifact removal are extremely important. Strong responses from the environment surrounding the target, in this case, water surface, can mask the target's response. For this case in particular, the targets consist of very-thin and lightweight plastic sheets (see Fig. 1b and 3b) that have a low electric permittivity ($\epsilon_r \approx 2.1$ @ $4GHz$ [6], [11]), and, thus, expected to yield a weak MW response in contrast to the water background. Evidently, in the static water case, where the water surface is approximately flat, we have an ideal detection scenario as the water acts like a mirror and has no backscatter contribution



(a) (b)

Fig. 1. Static Water Setup: (a) Monostatic setup geometry; (b) Plastic sheet targets.

(assuming that we are not in a normal incidence angle). Therefore, only the light wrinkles in the plastic surface are responsible for the backscattered response. In the case of a dynamic water scenario, e.g., rough surface background, the detection problem exacerbates, since we have the backscatter contribution of the water in addition to the one from the target. Thus, for each scenario with different water states, two different types of measurements were logged: water-plus-plastic backscatter, as well as just the water backscatter, all swept across a wide frequency interval. The processing involves subtracting the mean detection level of the measurements of the water background to each measurement of the target-plus-water. Subsequently, the Inverse Fast Fourier Transform (IFFT) is performed to obtain each signal in the distance domain [12]. Finally, for each presented scenario we normalize the backscatter intensity in the distance domain to the maximum value of the analyzed curves.

III. Ideal Detection Conditions

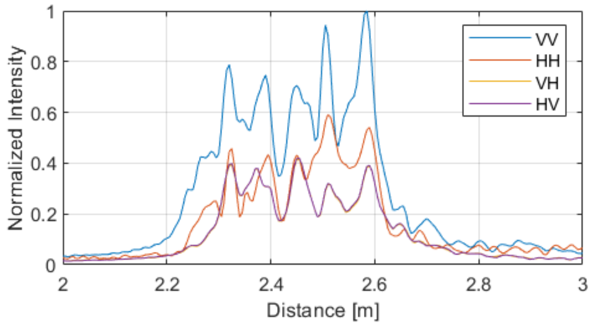
A. Experimental Setup

The monostatic setup for static water conditions is represented in Fig. 1a. The MW illumination is obtained with a dual-polarized ridged horn (both vertical and horizontal linear polarizations) that is impedance-matched over the 2-20 GHz frequency band (QRH20E, [13]). The antenna was mounted at one of the ends of the pool, roughly, 2.1 m above the water surface and with a look angle of 37°. Both ports of the antenna were connected to ports 1 and 2 of an Agilent e5071c Vector Network Analyzer (VNA) that acquired the S-parameter matrix for VV, VH, HV and HH data.

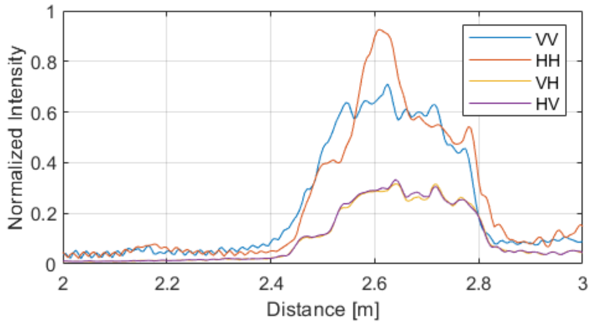
In this scenario we considered the plastic sheet target shown in Fig. 1b in two different forms: (1) Plastic sheet stretched on top of the water (see top image of Fig.1b); (2) Crumpled and wet, as if splashed by waves. (see bottom image of Fig.1b).

B. Measurement Results and Discussion

The results for the two plastic sheet cases are presented in Fig. 2a and 2b, respectively. Albeit in the latter case the target is further away from the antenna due to the light wind breeze,



(a)



(b)

Fig. 2. Time-averaged co- and cross-pol radar backscatter signals for the static water cases: (a) Plastic sheet stretched on top of the near-static water; (b) Crumpled and wet plastic sheet on top of the near-static water.

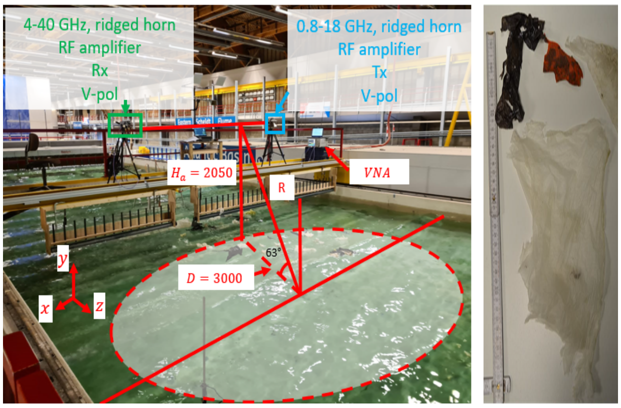
we still note higher intensity responses in the co-pol cases (either VV or HH) rather than the cross-pol ones (VH or HV). In the stretched plastic sheet case, the VV response is the most suited towards target detection whereas, in the crumpled and wet plastic sheet case, the HH response is the most intense one (closely followed by the VV response). This differentiation is most likely dependent on the sheet target shape that differs from one test case to another. The shape of the plastic sheet also affects the form of the scattering signal, i.e., the shape of the signal in Fig 2a originated by the plastic sheet stretched on top of the water shows clear peaks, whereas the shape of the signal in Fig 2b produced by the crumple and wet sheet has a more uniform shape. The distance interval corresponding to the target response in Fig 2 is consistent with the projected horizontal distance of plastic sheet in each test case.

These results indicate that, in small-scale measurements of this ideal scenario, plastic litter sheets can indeed be detected by MWs, and co-pol signals seem to increase the detection level more than cross-pol ones.

IV. Realistic Detection Conditions

A. Experimental Setup

A measurement campaign was conducted at a 75 m × 8.5 m water basin, inside a closed pavilion, at DELTARES facilities [10]. The waves were generated by computer-controlled wave paddles, creating a JONSWAP spectrum [14] with three significant wave heights H_s= 5, 9 and 17 cm, and period T_s = 1.2 s. This facility creates close to real sea wave conditions.



(a) (b)

Fig. 3. Dynamic Water Setup: (a) Bistatic setup geometry; (b) Types of plastic litter target collected in nature measured

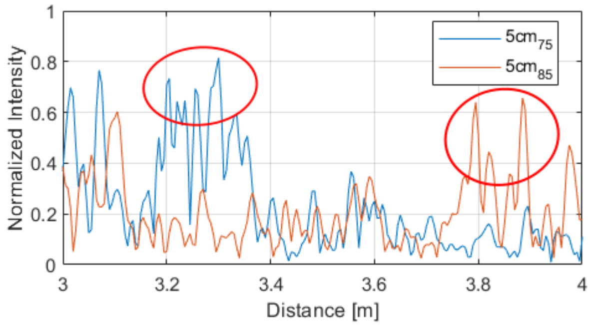
The setup is represented in Fig. 3. The antennas were mounted at mid-length of the bridge, 2.05 m above the mean water level, with mutual separation of 1 m, pointing at a common point on the water surface with 37º incidence angle. Although we adopted a bistatic configuration in this case, the antenna separation is small compared to the distance to the water, therefore it does not harm the comparison with the static water case. This allowed using amplifiers at the transmitter (Tx) and receiver (Rx) ports. In both Rx and Tx ends only the vertical polarization ports of the antennas are connected to the same Agilent e5071c VNA that acquired the VV measurements. The antennas produced an elliptical footprint on the water surface centered at the middle of the water basin.

In this scenario, several plastic sheets and bags collected in nature (only a few are presented in Fig 3b) were measured. These were placed behind the measurement setup, and they drifted towards the end of the flume, following the current.

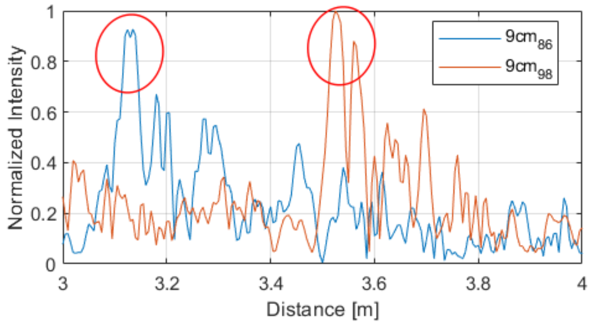
B. Measurement Results and Discussion

Typically, the higher the waves, the higher the velocity of the objects that drift on the surface [15]. However, as tested for plastic sheets, each individual sheet drift velocity is also affected by its shape, density and volume. Thus, one simple test to ensure that the plastic targets are being detected is to compare the estimated drift velocity from consecutive radar backscatter measurements and the rough drift estimation from the optical images.

In Fig. 4, we can observe two radar backscatter VV signals measured at separate instants. In each case, we can observe the target, or spikes, highlighted in red and green. Even though we increase the significant wave height of the water waves, it is still possible to detect some of the plastic sheets at this range. This is a very encouraging result as it corroborates the high intensity response observed in the ideal setup, and shows that it can be detected in a more realistic scenario. For the red ellipses highlighted in the 5, 9 and 17 cm cases, the estimated drift velocities were, 2.83, 2.28, and 2.5 cm/s. In Figure 5, we marked the plastic sheets responsible for the radar



(a)



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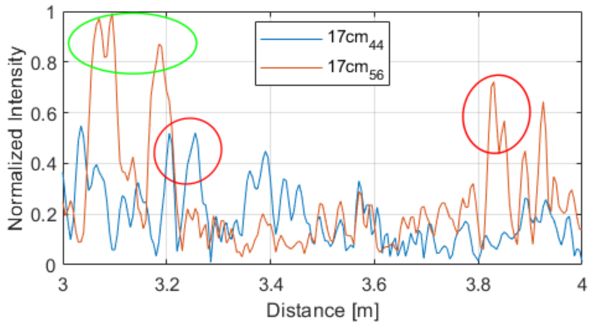
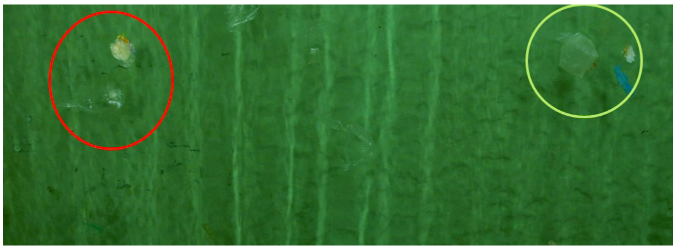


(c)

Fig. 4. Radar backscatter VV signals (4-14 GHz) measured at two separate instants for the three different JONSWAP spectrums with period T_s = 1.2 s and significant wave height H_s of: (a) 5cm (instants 75 and 85); (b) 9cm (instants 86 and 98); (c) 17cm (instants 44 and 56). Red and green circles represent targets highlighted in Fig.5

backscatter responses in each case from the optical images recorded by a camera positioned directly above the antenna footprint. Since we know the length of the camera FOV, we can obtain an approximate drift velocity of the targets for each case. For the 5, 9 and 17 cm case we obtained a drift velocity of 2.85, 2.3, and 2.2 cm/s. Comparing these values with the estimations from the backscatter MW responses, we obtained good agreement, therefore confirming the detection of the sheets.

In Fig. 6, we present some examples of the backscatter frequency response of the considered JONSWAP wave spectrum, i.e., the parameter S_{12} for each frequency between 4 and 14 GHz. In each case, we present an example of a measurement with just the water surface, e.g., reference measurement, and a measurement with plastic sheets (first measurement of each

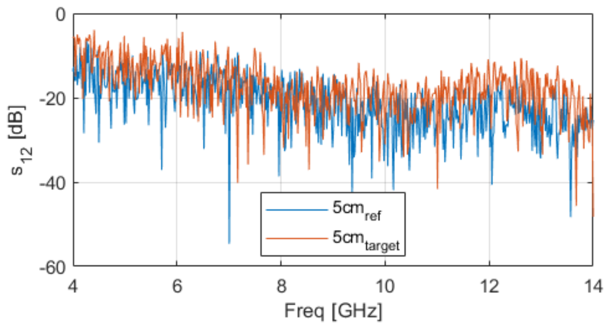


(a)

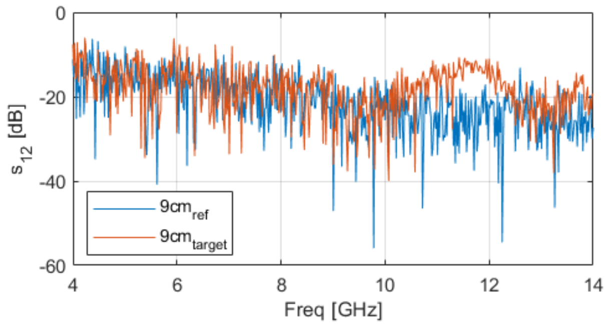
(b)

(c)

Fig. 5. Plastic targets (sheets and bags) identification and marking based on the radar backscatter responses outlined in Fig. 4 for each JONSWAP wave pattern with significant wave height H_s of: (a) 5cm; (b) 9cm; (c) 17cm



(a)



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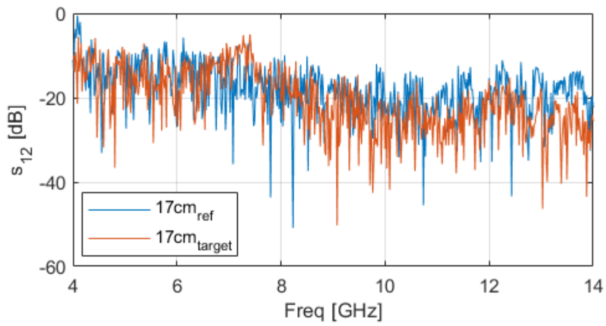

(c)

Fig. 6. Example of a reference and target measure of the frequency backscatter VV signals (S_{12}) measured for the three different JONSWAP spectrums with period T_s = 1.2 s and significant wave height H_s of: (a) 5cm (target measure 75); (b) 9cm (target measure 86); (c) 17cm (target measure 44).

case presented in Fig. 4). By comparing reference and target responses, we can conclude that the presence of the plastic sheet affects the frequency response across the MW frequency spectrum measured for all three cases considered.

V. Conclusions and Future Work

In this work, we demonstrated, through two small-scale setups, that it is possible to possible to detect very thin floating plastic sheets using MW radar, despite the minimum plastic material content. This points to an indirect detection of the effect of plastic on the water.

Under ideal conditions, we demonstrated that both co- and cross-polarized signals are capable of detecting low permittivity plastic sheets and, for small scale setups, co-polarized signals seem to increase detection level more. In presence of water waves, it is harder to detect the plastic sheets with increasing wave heights due to the overwhelming water rough surface scattering. Still, we demonstrated that it is possible to have target detection.

Similar behavior was found with other types of low permittivity plastic litter, not shown here. This encourages to proceed with the study in detail of the dominating scattering mechanisms, and investigate the effect of the backscatter response in different MW bands. Lastly, we plan to escalate the measurement campaigns and evaluate macroplastic MW responses from airborne or satellite sensors.

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