Preliminary Characterization of Microwave Backscattering of Floating Plastic

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***Abstract*—Microwaves (MW) may offer advantages over optical techniques for remote monitoring of marine litter. However, no systematic studies are found in the literature about microwave sensing of floating plastics. In order to assess the potential, we carried out two types of experiments and analysis. In one scenario we measured and characterized the MW backscatter of different densities of typical plastic bottles and jerry cans, floating in a small pool of static water. The results show a significant increase of litter response with litter density, thus demonstrating that floating plastic affects the MW backscattering of the water surface. In the second scenario, we assembled a setup to resemble a synthetic aperture radar system: a small container filled with water and floating plastic was linearly translated under a fixed antenna operating in monostatic mode; we have successfully reconstructed the energy backscattering map of the target. This preliminary work demonstrates that floating macro plastics do present a MW signature that may be relevant for remote monitoring of this type of marine pollution.**

Keywords—floating bottles, marine litter, microwave backscattering, microwave imaging, plastic bottles.

I. Introduction

Nowadays, one of the most important environmental problems in the planet is marine litter. Some scientists are warning that, by 2050, the quantity of plastic in the oceans will outweigh fish [1]. This will have not only harmful effects on marine life and biodiversity, but also negative impacts on human health.

In order to help removing plastics from the sea, it is necessary to monitor the presence of plastics throughout the ocean. This monitoring has been carried out from shore, ships, airplanes, unmanned aerial vehicles, sensing nodes, and satellites [2]. Unlike other monitoring approaches, satellites may coverage a large global area almost in real-time. However, currently, only a limited number of satellites are specifically equipped for detection of marine waste.

The topic of marine waste detection using remote and unsupervised methods is still very recent. Therefore, there is no technology rightly indicated to be used in the task at hand.

Techniques based on optical instruments, both in the visible and in the near infrared (NIR) and shortwave infrared (SIR) [3], are being investigated for marine litter detection. Although passive optical techniques enable detailed imaging of the plastic, they require a large amount of data to be stored and processed. Moreover, due to their vulnerability to bad weather and light conditions, they are not always available.

Microwave (MW)-based remote sensing techniques have been widely used in several land and sea Earth observation missions based on satellites [3]-[9]. Although MW sensing offers lower resolution compared to optical based methods, it is not significantly affected by weather or illumination conditions, which is a major point in favor of this technology.

Very limited work has been done on MW technology for marine litter detection [4]. In fact, to the authors' knowledge there is no study on the detection and characterization of floating marine litter using MW. As a result, the purpose of this work is to present a preliminary study, performed in a small-scale, on the characterization and imaging of floating plastic using MW technology.

To this end, this work presents two different experimental setups - one dedicated to the characterization of the response of different floating plastic densities to MW and other dedicated to MW imaging - and several metrics and methods to study the impact that MW has on floating plastic.

The remaining of the paper is structured as follows: Section 2 concentrates the theoretical formulation and methods used to process the data obtained from the experimental setups; Section 3 presents the experimental setup used to characterize the response of different floating plastic densities at MW frequency and respective results; Section 4 presents the experimental setup and respective results dedicated to MW imaging; and Section 5 draws conclusions.

II. Formulation and Methods

This section presents the metrics, graphs and algorithms used for MW characterization and imaging of floating plastic. This formulation will be useful to understand the results obtained in the following sections.

A. Characterization of floating plastic at MW frequency

Consider the geometry in Fig. 1. It represents an antenna positioned at height h at the side of a small body of water, with floating litter. The antenna is ultra-wide band, linearly polarized, and points at the center of the water area. A monostatic configuration is adopted for all cases, meaning that the data for analysis is the complex-value input reflection coefficient $s_{11}(f)$ at the antenna port at frequency f. The distance of the antenna to each point of the water surface is referred as d.

For the characterization of the floating plastic response, three different density scenarios are considered: with low, medium, and high quantity of floating plastic items. The density parameter ρ is defined as:

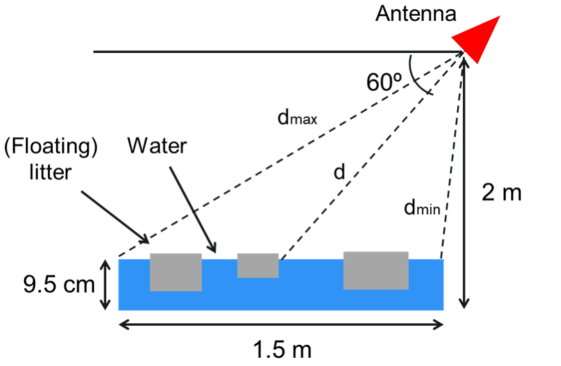

Fig. 1: Scheme of the experimental setup used in characterization of floating plastic at MW frequency.

$$\rho = \frac{N}{A} \tag{1}$$

where A is the area of the water surface and N is the number of floating items. For reference, measurements include a case without any floating item (just static water) and one with an absorber panel placed in the line of sight of the antenna. The two measurements can be subtracted to remove the frequency response of the antenna and of the RF circuit, which is common to both signals:

$$s_{11}(f)_{ref\ water} = s_{11}(f)_{still\ water} - s_{11}(f)_{absorber} \tag{2}$$

The response from the floating plastics is instead subtracted from the water response, therefore also removing the antenna and RF circuit frequency dependence:

$$s_{11}(f)_{plastic} = s_{11}(f)_{with\ plastic} - s_{11}(f)_{still\ water} \tag{3}$$

The frequency response itself does not provide much physical insight. It is more informative to transform it to the spatial domain using the following transform:

$$S_{11}(d) = \sum_{f=f_{min}}^{f_{max}} s_{11}(f)\ e^{2j\frac{2\pi f}{c}d} \tag{4}$$

where c is the speed of light in vacuum. Function $S_{11}(d)$ informs about the relative importance of scatterers contribution versus distance d. In order to compare the response among different scenarios, a metric is introduced that quantifies the disturbance that the different densities of floating plastic impose on the signals:

$$\int_{d_{min}}^{d_{max}} \left|S_{11}(d)_{with\ plastic} - S_{11}(d)_{still\ water}\right|^2 ds \tag{5}$$

where ds is the unit path length, d_{min} and d_{max} are the limits of the distance being considered, Fig. 1. This metric gives a measure of the scattered power picked-up by the antenna.

B. *Microwave imaging of floating plastic*

The objective is to evaluate if a compact amount of floating plastic can be identified using MW-based imaging. To this end, we adopt a wave migration algorithm that uses the translation geometry of the system to localize the position of a target. This technique consists in processing the input reflection coefficients, by "backpropagating" the wave and stacking it in each synthetical focal point. Due to its simplicity, it is currently used in diverse areas, as land mine detection [10] and medical image reconstruction [11].

This involves the same measured quantity from the previous Section, the input reflection at the antenna port, except that it is acquired at different translated positions of the antenna $s_{11}(f, ant)$. The calculation of the intensity I_{pix} at each pixel of the image involves the same transform (4) from the previous Section, but here extended to all antenna positions:

$$I_{pix} = \sum_{ant=1}^{n} \sum_{f=f_{min}}^{f_{max}} (s_{11}(f, ant)_{with\ plastic} - s_{11}(f, ant)_{still\ water}) * e^{2j\frac{2\pi f}{c}(d_{ant}+d_{pix-ant})} \tag{6}$$

where $d_{pix-ant}$ represents the distance between the pixel and the antenna in consideration, d_{ant} is the electric internal distance of the antenna [12].

Note that, in addition, the MW imaging was computed considering vertical polarization alone, horizontal polarization alone and both polarizations combined.

III. Backscatter Frequency Response

This section presents the experimental setup used to obtain the backscatter response of floating plastic at MW frequency and corresponding results.

A. *Experimental setup*

The purpose of this setup was to obtain MW responses from floating plastic in order to characterize them posteriorly.

To this end, as depicted in Fig. 1, measurements in the frequency range of 4-26.5 GHz and vertical polarization were performed using a static ridged horn antenna (model QRH40 [13]), pointed to a pool with 1.5 m of diameter filled with water and with a number of plastic bottles and jerry cans in random positions. Fig. 2 depicts the experimental assembly for different densities of floating plastic distribution: low, medium, and high density. The detail of the plastic content is listed in TABLE I. As a reference, we also measured the antenna input reflection signal for plain water without floating plastics, and for an absorber positioned at the center of dry pool.

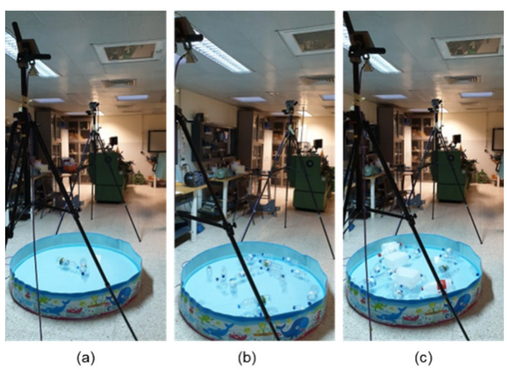

Fig. 2: Experimental setup used in electromagnetic characterization of different densities of floating plastic: (a) 2 bottles; (b) 21 bottles; (c) 21 bottles plus 6 jerry cans.

TABLE I. THREE DIFFERENT PLASTIC DENSITIES

Density	Floating items	ρ [nr. items/m^2]
low	2 bottles	1.1
medium	21 bottles	11.9
high	21 bottles + 6 jerry cans	15.3

B. Results

We present in Fig. 3 the frequency response of the three different densities of floating plastic, as given by Eq. 3. For reference, the frequency response of flat water without any litter is also presented in Fig. 4. The curves show some differences between them, but there is no significant feature, like a dominant sub-band, to distinguish the three cases among them, and even when compared to flat water.

In Fig. 5, the response of the floating plastic is quantified in terms of distance d between scatterers and the antenna, using Eq. 4. Now the figure shows a clear response from the floating plastic, at distances compatible with its distance to the antenna. Moreover, it is also clear that intensity of the scattered signal increases with plastic density. The metric defined by Eq. 5 is used to quantify the differences. The values are shown in TABLE II.

These set of results jointly demonstrate that floating plastic originates a MW response, and that its intensity can be related to the quantity of plastic present.

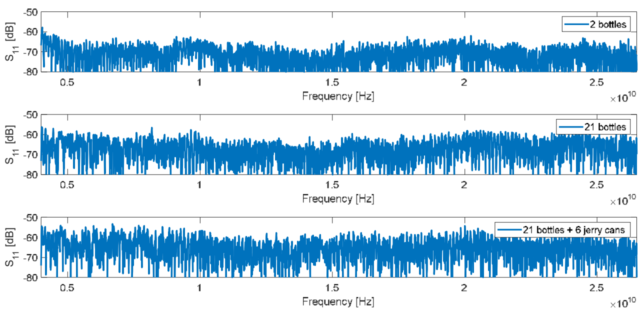

Fig. 3: Frequency response of different densities of floating plastic: 2 bottles, 21 bottles and 21 bottles and 6 jerry cans (computed by $s_{11}(f)_{with\ plastic}$ minus $s_{11}(f)_{still\ water}$).

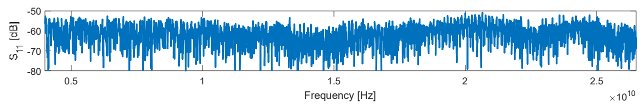

Fig. 4: Frequency response of water (computed by $s_{11}(f)_{still\ water}$ minus $s_{11}(f)_{absorber}$).

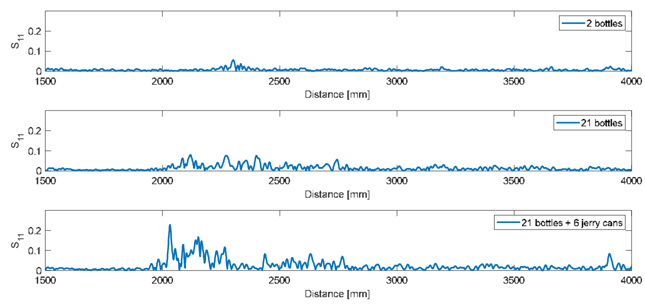

Fig. 5: Scattering amplitude versus distance from antenna to scatterers: 2 bottles, 21 bottles, and 21 bottles and 6 jerry cans (computed by $s_{11}(f)_{with\ plastic}$ minus $s_{11}(f)_{still\ water}$).

TABLE II. POWER OBTAINED FOR THREE DIFFERENT DENSITIES OF FLOATING PLASTIC (LOW, MEDIUM AND HIGH)

ρ [nr. items/m^2]	Floating items	Backscattering power (Eq. 5)
1.1	2 bottles	0.103e-3
11.9	21 bottles	0.601e-3
15.3	21 bottles + 6 jerry cans	2.527e-3

IV. MICROWAVE IMAGING

This section presents the experimental setup used to obtain the responses of floating plastic to posteriorly reconstruct the MW images and discuss the results.

A. Experimental setup

The purpose of this setup was to mimic the MW image that a satellite would obtain from a macroscopic compact amount of floating plastic. To that end, the same ridge horn antenna from the previous chapter was used in the range of frequencies 4-14 GHz, in horizontal and vertical polarization. The antenna was kept static at coordinates (0, -0.96, 1.65) m, pointing to the mid position of a linear scanner (0, 0, 0), Fig. 6. The scanner pushed a shallow container filled with water, along the x-axis from -0.9 m to 0.9 m, with a step of 0.010 m, corresponding to a total of 181 measurements points.

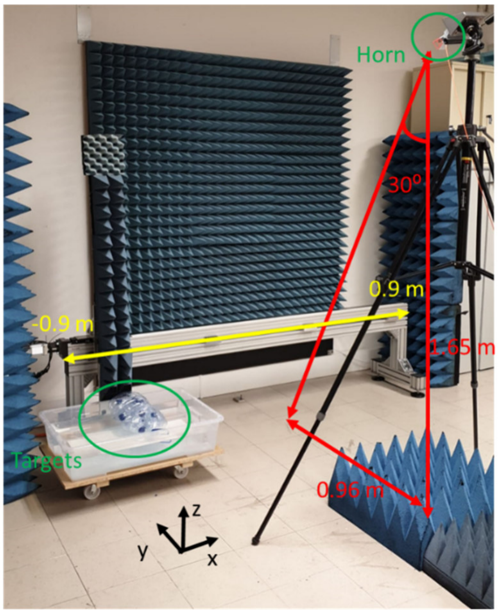

Fig. 6: Scheme of the experimental setup used to obtain a microwave imaging of floating plastic.

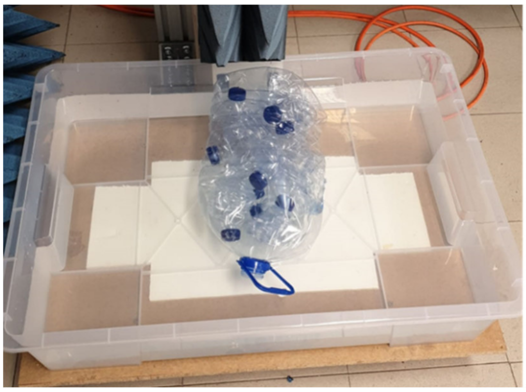

Fig. 7: Container filled with water and a plastic jerry can filled with plastic bottles.

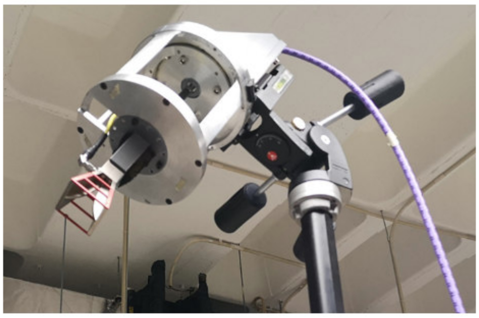

Fig. 8: Antenna and rotary joint.

A plastic jerry can, itself filled with small plastic bottles, was floating in the water, Fig. 7. This measurement configuration with fixed antenna and moving target, is equivalent to a fixed target with moving antenna, as happens in the actual satellite scenario. However, in the lab, the used configuration avoids phase errors due to bending of the vector network analyzer cable. In addition, as depicted in Fig. 8, a rotary joint was attached to the antenna in order to turn the horn 90º degrees, allowing easy measurement of both orthogonal polarizations.

B. Results

As previously mentioned, MW images of a compact amount of floating plastic were obtained using the wave algorithm described above. While Fig. 9 presents the MW images for horizontal and vertical polarization, Fig. 10 presents the attained MW image when both polarizations are merged.

The image clearly shows the floating jerry can. These results show that the adopted algorithm, although commonly used for satellite scenarios, allows imaging floating plastic in very small-scale lab scenarios, making it possible to carry out systematic controlled tests.

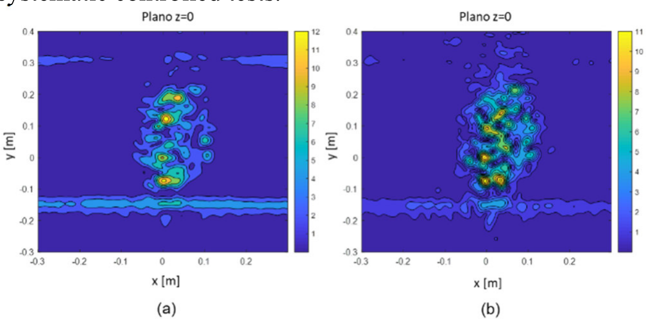

Fig. 9: Two-dimensional microwave imaging of floating plastic using: (a) horizontal polarization; (b) vertical polarization.

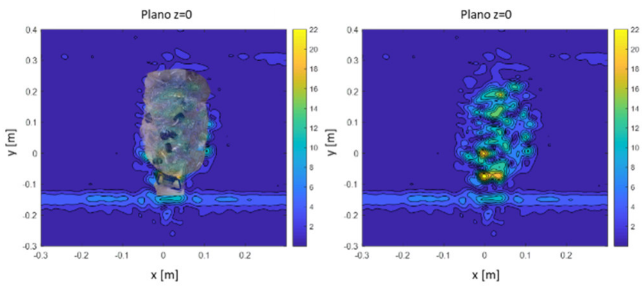

Fig. 10: Two-dimensional microwave imaging of floating plastic fusing information from both polarizations (horizontal and vertical): (a) with the translucid image of the real position of the target (b) without the translucid image of the real position of the target.

V. Conclusion

The purpose of this work was to characterize the MW response of different densities of floating plastic (low, medium and high) as well as demonstrate the MW imaging obtained from a macroscopic amount of compact floating plastic. To this end two distinctive setups were built, and corresponding results were obtained. One may conclude that the presence of floating plastic promotes a perturbation of the MW response depending on its quantity, and that MW imaging allows the detection of a compact amount of floating plastic.

The work presented in this paper is still very preliminary. Future work will include the characterization of floating plastic at larger scale. We will also study the effect of floating litter on sea wave pattern, in order to enable the detection of litter.

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