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Campaign on Remote Sensing of Plastic Marine Litter

TISPLALI

D9. Executive Summary Report

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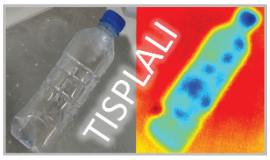

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Acronyms

CDS	Climate Data Store (https://cds.climate.copernicus.eu/)
DN	Digital Number
EPS	Expanded Polystyrene
FLIR	Forward Looking Infrared
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
LWIR	Long Wave Infrared
MWIR	Mid Wave Infrared
NIR	Near Infrared
PE	Polyethylene
PET	Polyethylene Terephthalate
RH	Relative Humidity
UAV	Unmanned Aerial Vehicle
UTC	Universal Time Coordinated
SWIR	Short-wave infrared
TIR	Thermal Infrared Radiance
VIS	Visible

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1 Project context and objectives

There is growing global concern over the chemical, biological and ecological impact of marine plastic pollution. Every year many millions of tons of plastic enter the global oceans but where it goes remains largely unknown. Remote sensing has the potential to provide long-term, global monitoring but for plastics in the ocean it is still in early stages. To date, most progress has been made in the field of remote sensing using visible (VIS), to near infrared (NIR) to short-wave infrared (SWIR) wavelengths, and it has become clear that remote sensing in VIS-SWIR spectrum would improve by using complementary measurements. Project TISPLALI (thermal infrared sensing of marine plastic litter) was proposed for ESA's 'Discovery and Preparation Campaign' on 'Remote Sensing of Plastic Marine Litter' to explore a novel sensing technology.

The physics explaining thermal infrared (TIR) reflectance is different from reflectance in the VIS- SWIR because TIR radiance leaving a surface is composed of reflected and emitted energy, while VIS-SWIR surface leaving radiance is just reflected light. This implies that not only does thermal emissivity affect surface leaving TIR but also temperature. TIR sensing requires no external light source like the sun and can therefore perform during both day and night. TIR sensing could detect plastic surfaces that are a challenge in VIS-SWIR sensing, such as clear and dark coloured plastics. Using TIR, we can detect plastic floating on the ocean surface, but it is not possible to sense plastic below the water surface as water absorbs TIR radiance within the top mm. We used common plastic litter items to evaluate the performance of TIR sensing under a range of different conditions, i.e., different water and air temperatures, light intensity, and cloudiness of the sky. There are two atmospheric windows in TIR, mid-wave infrared (MWIR, 3–5 µm) and long-wave infrared (LWIR, 8–14 µm). We used an UAV (unmanned aerial vehicle) and a TIR camera imaging in a single broadband in LWIR to assess the following questions. How can TIR sensing complement VIS-SWIR remote sensing? Can an UAV TIR camera operate as a TIR sensor? How does the TIR radiance transfer model perform? When and where can we expect the best results? Which plastic litter items give the best results? Can we separate plastic litter from other surface features on the water surface? Can we see plastic litter on different surfaces than water?

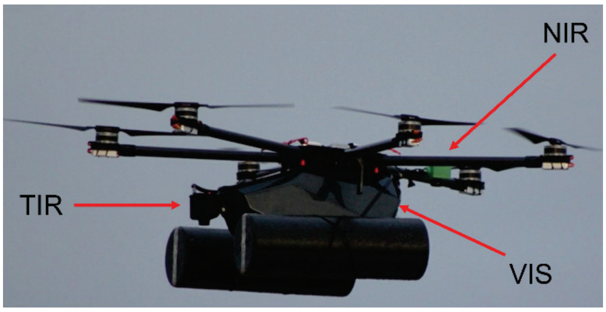

Figure 1. Flying Tetra TD7 UAV carrying three cameras imaging in, VIS using the ZENMUSE X5, a RGB camera in the UAV housing; NIR using a MAPIR camera (single narrow band at 850 nm); and TIR using the FLIR Vue Pro R 640 (single broad band at 7.5 - 13.5 µm).

2 Methods

A FLIR (Forward looking infrared) Vue Pro R 640 camera was used for TIR imaging, mounted on a UAV during surveys over the open ocean (Fig. 1) and in laboratory experiments. We used common plastic macrolitter items, and comparison and reference targets. Plastic litter items were composed of Expanded Polystyrene (EPS), Polyethylene (PE), Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), and Low-Density Polyethylene (LDPE). The targets were numbered as follows:

1. PET bottles, clear (0.5 l);
2. PET bottles, clear (2 l);
3. EPS foam board, white (thickness 5 cm);
4. EPS foam board, blue (thickness 3 cm);
5. HDPE milk bottles, semi-transparent white (2.3 l);
6. LDPE/HDPE binbag, black, two thin layers;
7. PE tarpaulin, white, single layer;
8. Aluminium foil (wrapped around 3);
9. Wooden, tree trunk disk (thickness 4 cm, radius 29 cm).

Polymer composition of items 6 and 7 was not specifically known and we therefore refer to these as binbag and tarpaulin respectively. Number 8 was a reference target used to estimate background TIR. We deployed the wood disk (9) during the summer surveys as a comparison to plastic. These items were used in both field surveys and laboratory experiments.

Temperatures of air, water and target surfaces were measured using temperature dataloggers and handheld sensors and light intensity and relative humidity were logged using dataloggers to obtain environmental conditions at the same time as the FLIR recording. Additional UAV-mounted cameras imaging in VIS and NIR took concurrent measurements of targets floating on the water surface (Fig. 1). We quantified response of the FLIR camera to TIR intensity by digital numbers (DNs) of its images, and averaged DN of target- and water surface pixels and their differences (delta). On the UAV we took continuous TIR images at a frame rate of 1 Hz and we calculated 1-minute averages to account for changing environmental conditions.

Four field surveys were performed in Thurso Bay in the Pentland Firth on the north coast of Scotland during different seasons and times of the day (Table 1). During the surveys, we hovered the UAV at 30 m altitude over 0.5 × 0.5 m targets floating near the shore in about 1 m deep water carrying the (Fig. 2). Parameters of the higher atmosphere were retrieved from the Climate Data Store (CDS).

Table 1. Details of the four field surveys, LT = UTC+1; location Thurso Bay (58.5987 °N, -3.5166 °E)

Survey	*Day (2021)*		*LT*	*Sky condition*	*Sea state*
1	1 April	day	07:40	Cloudy	smooth
2	23 April	night	04:14	Overcast (no stars)	slight
3	3 August	day	12:01	Overcast (100% cloud cover)	calm (rippled)
4	4 August	night	01:41	Clear sky (stars and red moon)	calm (smooth)

In the laboratory we used the FLIR mounted on a tripod, with all lights and heating radiators turned off and window blind closed to reduce incoming daylight. In these controlled conditions a single TIR image sufficed. In the laboratory we measured the effect on TIR imaging to, floating plastic litter on the water surface, plastic surface wetness, water temperature, background TIR and biofouling of the plastic.

To investigate biofouling on plastic surfaces we deployed two racks with a selection of plastic litter items on 13th April 2021 (expecting to catch the spring algal bloom) in a sheltered location under a floating pontoon in Scrabster Harbour (58.6122 °N, -3.5490 °E). One rack was retrieved after two weeks to see the first signs of biofouling and the other after three months for a denser biofouling cover. After two weeks significant biofouling was already visible with mass increase ranging between 101.4% (PET) and 106.5% (binbag). After three months, biofouling had visibly increased with 108% (PET) to 500% (binbag) mass increase compared to virgin items.

3 Results

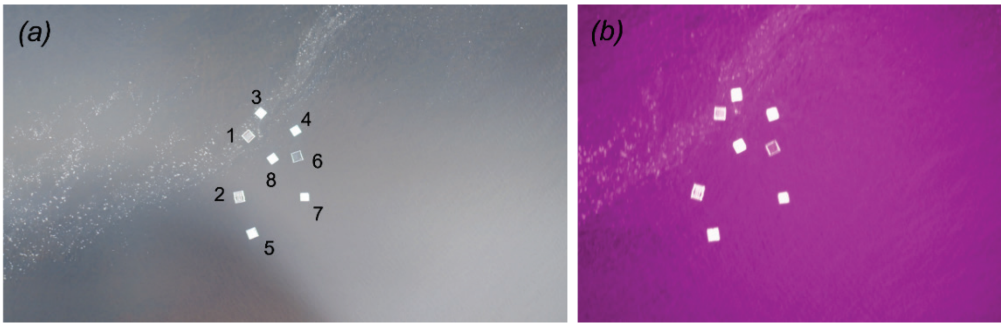

Figure 2. Snapshots taken 1 April in (a) VIS, and (b) NIR. Target numbers indicate 1-PET S, 2-PET L, 3 -EPS white, 4-EPS blue, 5-HDPE, 6-binbag, 7-tarpaulin, and 8-aluminium.

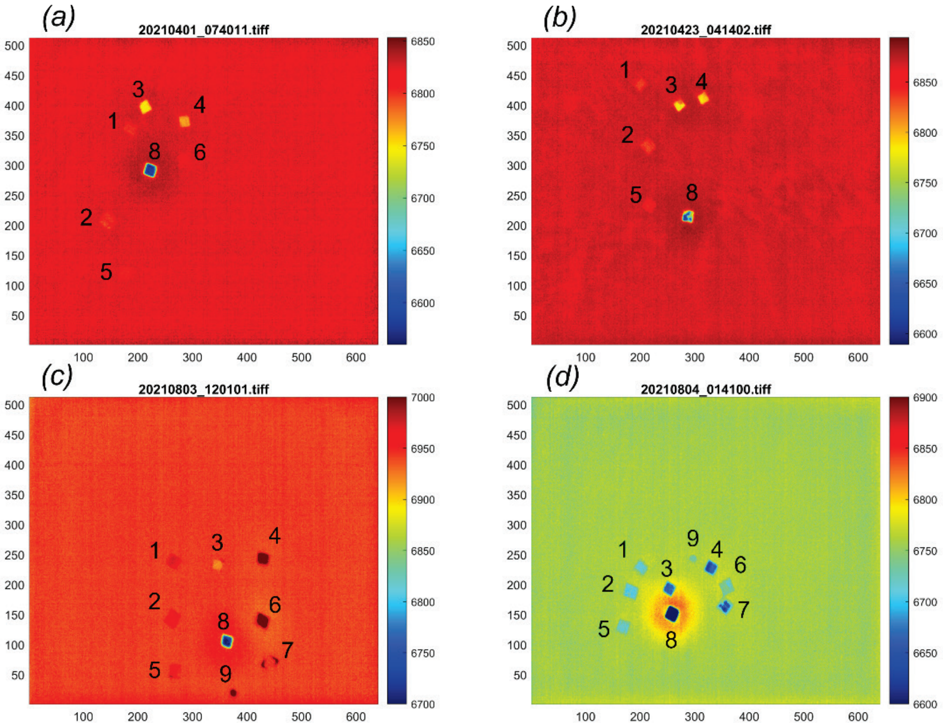

Figure 3. Snapshots of TIR camera during survey (a) 1 April, day, (b) 23 April, night, (c), 3 August, day, and (d) 4 August, night. Images are corrected for vignetting and pseudo colour indicates DN. Target numbers indicate 1-PET S, 2-PET L, 3-EPS white, 4-EPS blue, 5-HDPE, 6-binbag, 7-tarpaulin, 8-aluminium foil, and 9-wood.

Figure 2 shows the floating plastic targets in VIS and NIR images taken in the first survey. During this early morning in April, we could detect all targets in the TIR image except tarpaulin (Fig. 3a). Seafoam visible in the VIS and NIR images (Fig. 2) did not show up in the TIR image (Fig. 3a). During a night survey later that month we could see all targets in TIR except tarpaulin and binbag (Fig. 3b). In the night survey in August, when the sea state was glassy, all targets were clearly visible in TIR (Fig. 3d). The TIR images taken in the August survey around noon were the only ones that showed target leaving TIR higher than water leaving TIR (Fig. 3c). During this survey, TIR leaving radiance was dominated by warming of the plastic targets while the other three surveys were dominated by reflectance of cold background TIR. We called the latter scenario A and the former scenario B. The two scenarios are illuminated by bar diagrams of delta = DN(target) – DN(water) (Fig. 4). The most negative delta in scenario A was during clear sky conditions in survey 4.

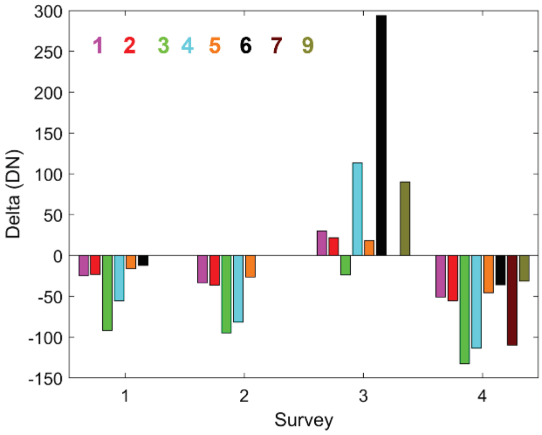

Figure 4. Bar diagram of delta = DN(target) – DN(water) during survey (1) 1 April, day, (2) 23 April, night, (3), 3 August, day, and (4) 4 August, night. Surveys 1, 2 and 4 (3) related to scenario A (B). Target numbers indicate 1-PET S, 2-PET L, 3-EPS white, 4-EPS blue, 5-HDPE, 6-binbag, 7-tarpaulin, and 9-wood. Delta of 8-alu was -262, -219, -245, and -1214 DN for surveys 1, 2, 3 and 4 respectively.

Depending on the conditions, some kinds of plastic litter items were easier to detect in water than others. In scenario A, plastic-water TIR difference increased from black binbag (6), to bottles (1, 2, 5), to EPS foam board (3, 4). In scenario B, dark plastic (6) gave the largest plastic-water TIR difference. White EPS foam board (3) stood out as a plastic with the lowest emissivity (highest reflectivity). Aluminium reference foil (8), being almost a perfect reflector in TIR, was a good indicator of background TIR. This was supported by atmospheric data from CDS (Climate Data Store, https://cds.climate.copernicus.eu/) which showed that aluminium leaving TIR increased with increasing cloud base cover, and it decreased with cloud base height. We could not prove a relationship between plastic surface temperature and TIR intensity. During field surveys, more targets were seen in TIR with smaller waves. It was too difficult to investigate wetness of the plastic on the TIR signal in the field, and we did this in the laboratory.

Our laboratory experiments confirmed our field findings during scenario A when plastic-water TIR difference increased from binbag (6), to bottles (1, 2, 5), to EPS foam board (3, 4). According to our laboratory experiments, plastic-water TIR differences were less sensitive to the presence of plastic litter on water when it was wet, unless when air and sea temperatures were similar and wetness cooled the plastic.

Biofouling on wet plastic reduced TIR reflectivity or surface temperature, this happened after only two weeks in the water. Dense biofouling on dry plastic was found to enhance TIR reflectivity in case of brown-green algal materials on clear and white plastic, and to decrease TIR reflectivity in case of white barnacles that connected to the black binbag. The latter case corresponded to brightening plastic in NIR and VIS, while the former to darkening plastic in those bands.

4 Conclusion

We have shown the previously unconfirmed potential of using TIR sensing for floating plastic litter. A UAV TIR camera could monitor floating plastic litter at sea by imaging surface-leaving TIR. Different scenarios (identified by water, air, and plastic surface temperatures, light intensity, and the presence of clouds) produced different relationships between the radiometric response of the camera and plastic litter surface in view. This complicated the relationships but could also bring unique opportunities, such as the ability to use the contrast between day and night measurements. More surveys under a range of different environmental conditions are needed to fully explore this. TIR sensing could complement VIS-SWIR remote sensing in valuable ways. For example, TIR sensing could be used during the night, to detect plastics invisible in VIS-SWIR remote sensing, and to exclude whitecaps and features of the sea floor. The TIR radiance transfer model performed well if we estimated background TIR from the higher atmosphere. Where and when plastic was most detectable depended on the kind of plastic litter (colour, shape, and composition). The calmer the sea state, the more litter was seen. Biofouling reduced or enhanced detectability in TIR, depending on the wetness of the plastic, and for dry plastic emissivity increased (decreased) with biofouling darkening (brightening) its colour. We could separate plastic surfaces from aluminium foil and seafoam, but we need more research for other materials such as driftwood and vegetation, as well as TIR sensing over backgrounds other than water. For applications at higher altitude, i.e., planes or satellites, there is the need to test the minimal detectability in terms of plastic concentrations (surface area covered by plastic in a pixel). We would likely require TIR multi-spectrality to unmix signals from mixed-materials pixels.

5 Public outreach

The launch of project TISPLALI made local and national newspapers and sites.

- **BBC news** – 19 November 2020: https://www.bbc.co.uk/news/uk-scotland-highlands-islands-55001488
- **John O'Groat Journal** – 19 November 2020: https://www.johnogroat-journal.co.uk/news/thurso-based-researchers-in-bid-to-detect-plastic-pollution-from-space-218795/
- **Packaging Scotland** – 19 November 2020: https://packagingscotland.com/2020/11/new-method-of-detecting-plastic-pollution-from-space-to-be-trialled/
- **The Press & Journal** – 20 November 2020: https://www.pressandjournal.co.uk/fp/news/highlands/2663320/can-highland-researchers-detect-marine-plastic-pollution-from-space/
- **The National (Scotland)** – 20 November 2020: https://www.thenational.scot/news/18882929.uhi-scientists-explore-ways-detecting-plastic-pollution-space/

A **Scottish Parliamentary Motion** was lodged commending TISPLALI – 23 November 2020: https://bb.parliament.scot/Motions/DetailsPartial/S5M-23444/20201124

STV, news (Iain Ramage) – filmed visit to Thurso for 6 pm news item

- Start of the project - 24 November 2020: https://www.youtube.com/watch?v=-0MTwt3Dlik
- Update on the project – 7 October 2021: https://www.youtube.com/watch?v=Tt7U81Au-rw&t=5s

MASTS Cast, interview by Hannah Ladd-Jones – 25 November 2020: https://youtu.be/7ZMrrVbgHY