Supplementary Materials S1

Remote sensing and aerial surveys for monitoring floating litter with Unmanned Aerial Systems (UAS): general protocol guidelines for vessel and shore-based operations.

Fluxes of floating litter at sea vary depending on the proximity to shore, urban activities, coastal uses, wind and ocean currents. These factors can promote the accumulation of marine floating litter in convergence zones. Due to the spatial and temporal variability and dynamic nature of floating marine litter, it is crucial to develop a standard, cost-effective, repeatable and fast method that estimates its amount and distribution. Estimating litter trends over time is needed for efficient monitoring programs, management and reduction measures.

The use of remote sensing from "Unmanned Aircraft Systems"(UAS) from shore and vessels allows the detection of floating litter and the collection of spatially explicit information, enabling efficient comparable assessments of floating litter contamination in coastal and open waters. With adequate design and workflows, UAS-based remote sensing allows the identification of floating objects and assessing contamination levels with reduced sampling effort. The following guidelines for using drone-based aerial surveys from land-base and vessels intend to enhance the monitoring capabilities and standardization of floating litter detection methods and protocols.

1. Mandatory requirements

Fulfilment with the legislation and regulations in force for flight operations with drones and image collection. Namely:

- UAS, operator and pilot registration with the Civil Aviation Authority;
- Adequate legal certification for carrying out the operations;
- Civil liability insurance;
- Applicable authorizations for aerial image collection and flight;
- Compliance with privacy and data protection international, national and local legislation and regulations.

2. Equipment and Applications

Monitoring of marine litter by aerial remote sensing using unmanned aircraft requires an Unmanned Aerial System (also known as drone) equipped with camera, GPS and operational capacity for programmable flight. It also requires a controller or ground flight station and flight programming software for image collection. For floating litter monitoring activities, we recommend:

- Unmanned aircraft: multirotor drone with manual or pre-program flight planning equipped with RGB camera with manual settings (optional: additional multispectral or thermal camera). For vessel-based operations select a drone with a design and flight stability for a user to safely hold it in hands for deployment and retrieval (e.g. DJI Phantom series). Large drones are very hard to land on vessels and increase danger for crew and pilot. Smaller drones can be used, but special care must be given when grabbing aircraft.
- Flight planning controller and software with camera live view and telemetry and that enables pausing and continuing survey, even when turning off aircraft for battery replacement.

3. Flight planning (general):

A. Evaluate operational risks: prior assessment of airspace and characteristics of target areas to identify potential risks and hazards, including: proximity to airports or other fly zones with air traffic, obstacles and infrastructure, terrain topography and other eventual hazards and restrictions to operations. Establish maximum flight altitude and survey area give the site characteristics.

B. Updates and Calibration: Inspect batteries for signs of damage or swelling. Check and update firmware and software and test connectivity. Calibrate aircraft instruments and sensors. Check batteries, remote and tablet or phone are charged and available free space in memory card.

C. Assessment of atmospheric conditions: Assess weather forecasts and sea conditions to verify suitable conditions for operations with the aircraft, including:

- No precipitation;
- Low wind (winds below 10 knots, however, it will be depending on specifications of the drone in use);
- Calm sea;
- Ambient temperature between 10 to 40 °C.

D. Light conditions: for optimal results, plan flight operations for clear skies and sun at angles between 10º and 45º, as to obtain better contrast and minimize light backscatter.

E. Distance and target survey area: Unlike surveys over land, overlapping aerial imagery from open waters lack matching landmarks to produce quality mosaics. As such, floating litter monitoring from aerial imagery must rely on collection and processing of multiple images with no overlap. Altitude and image sensor size will determine image footprint area, which can be easily estimated.[1]

4. Aerial surveys:

[1] https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-calculator

A. **Survey Area:** The objective is to collect imagery at a pre-defined altitude, over transect(s) perpendicular or parallel to the shore line. Fly, for example, 1 km (or more) in a straight line. The transect length and total flight distance will depend on the drone's autonomy and the range signal between the drone and the controller. This means that transect length and scanning area must me adjusted to the drone in use:

    - Manually operated flights, with automated image capture are recommended to enable pilot control, but pre-programmed waypoints can also be used.
    - Flight direction may vary from strictly perpendicular or parallel to shore, which can be set to minimise backscatter by taking a heading away from the sun.

B. **Altitude:** Altitude should be set between 10 - 30 meters depending on user preference. Low altitude provides higher resolution but lower area coverage).

C. **Camera settings:** camera should be set in Manual mode, with a minimum shutter speed of 200. Aperture should be set to minimise backscatter (EV -1.0 to -0.3 depending on conditions and preferred analysis method). Polarising filters are recommended in RGB cameras. Camera capture interval should be set depending on objectives and the minimum images required per transect. We recommend setting it every 5-10 seconds. When manually flying, maintain slow speeds and stop for the capture of imagery (i.e. use countdown and stop any movement 1-2 seconds before it reaches zero and captures an image). Lastly, camera angle should be set to 90° but can also be used with a slightly lower angle to minimise backscatter and sun glitter if image analysis will use manual annotation or machine learning for automated annotation and object detection (we recommend not <to go lower than 80°). It is recommended to do a manually operated hover flight at the desired altitude and visually inspect live feed to adjust aperture and shutter speed for optimal image contrast and results.

D. Keep track of each transect when doing more than one per flight (e.g. use a front facing image capture to separate imagery of each transect).

4.1. Land-based survey

No special considerations are required for flying from shore or land. Be aware of marine traffic and flight altitude and of people in the shore line during operations. Considering the need of flying in line of sight, we recommend flying 1 km in a straight line perpendicular to shore, 0,5 to 1 km parallel to shore and return straight line perpendicular to shore (**Figure S1**). Flight path does not have to be strictly perpendicular. The drone's flying distance will depend on the drone's autonomy and the range signal between the drone and the controller. This means that transect length and scanning area must be adjusted to the drone in use.

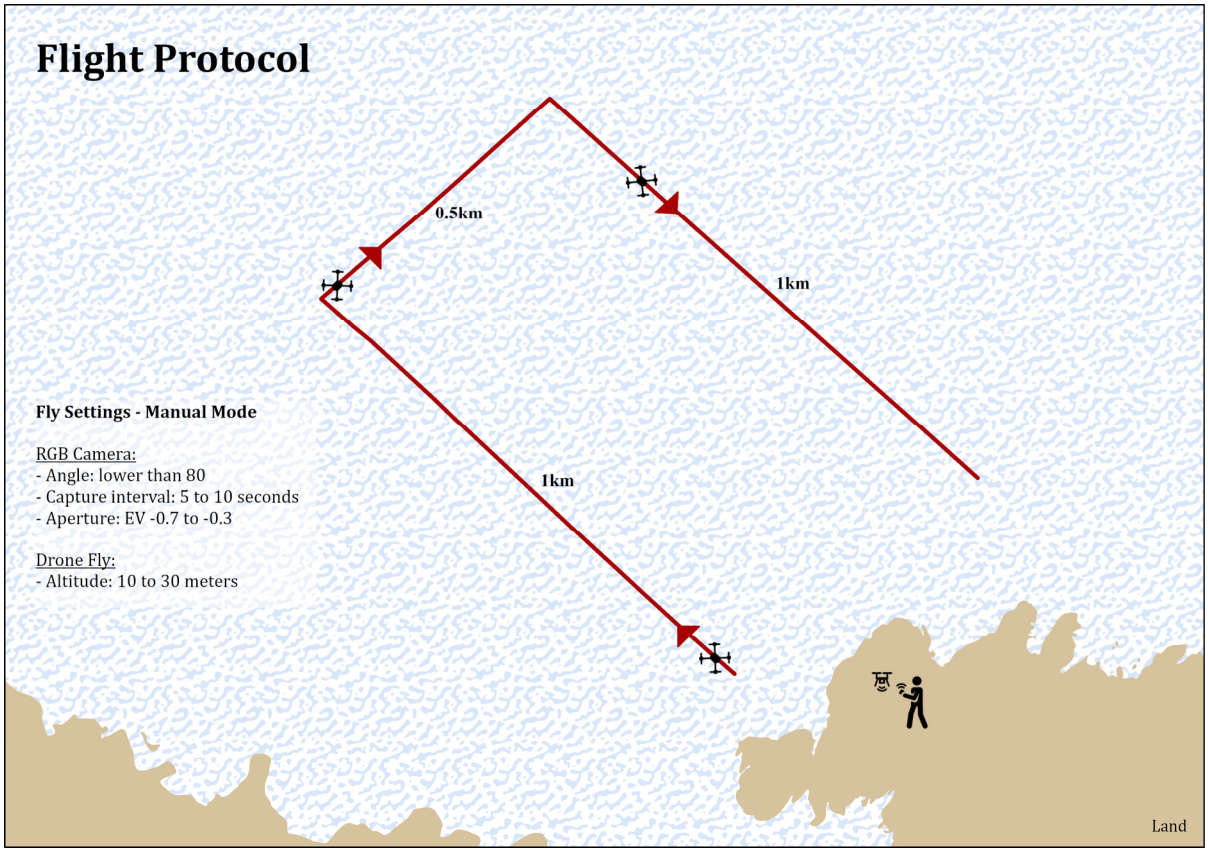

Figure S1: Summary of basic flight operations for land-based transect survey for monitoring floating litter contamination (transect distance and values used on Mavic 2 Pro quadcopter; adapt depending on drone model, sensor size, camera and range).

4.2. Vessel-based survey

It is important to have in consideration that drone operations from vessels have multiple particularities, including safety in launch and retrieval and possible sources of interference:

- For launch and retrieval, it is recommended that users are able to hold the drone in hand for launch and retrieval or to have a large deck for safe take-off and landing. Some drones can land in water, making this an additional option for retrieval;
- In vessels equipped with electronics like AIS and radar, interference may be an issue, for which it is suggested for them to be switched off when possible;
- Compass and drone positioning systems have issues due to magnetic interference and/or boat movement during drone boot. To minimise it, switch the drone on while holding it in hand and try to maintain it steady and away from sources of magnetic interference.

Take in consideration the specificities of vessel-based operations when selecting **drone model**:

- Multirotor drone with manual and pre-program flight planning equipped with RGB camera with manual settings (optional: additional multispectral or thermal camera);

- A drone with a design and flight stability for a user to safely hold it in hands for deployment and retrieval (e.g. DJI Phantom series).

Vessel-based operations can be done from stationary position, drifting or with the vessel following the UAS. Depending on vessel and scenario, some considerations are recommended:

- From large ships and vessels with automatic positioning capabilities, plan flight paths and transects as from land-based operations;
- From large ships and vessels that are not actively maintaining stationery positioning (ie.; drifting), make sure to adjust flight course considering the drifting of your ground station. For safety, general precaution dictate that flight course is down current and in the same direction than vessel drift, however, other options are possible under slow drifts: for example, fly 1 km perpendicular to current and drifting direction, 1km down current and 1 km back to the vessel;
- From small vessels (e.g., rib boats), we recommend that transects and flight course is upwind, with manual flight operations and for the vessel to follow the UAS. Transects can generally be longer than 1 km, as you do not have to return to the launch site (e.g., the UAS can be recovered from pursuing vessels).

5. Safety recommendations:

- During flight operations, it is necessary to ensure real-time monitoring of the status of the UAS (e.g., flight time and battery; loss of signal between drone and controller; changes to the predefined flight paths; approach of obstacles (birds, other UAS equipment);
- In the event of an unforeseen risk being identified or an incident or anomaly, it is necessary to interrupt the flight;
- If the battery reaches 25% charge, it is recommended to pause the mission, return to home, land and replace the battery before summarizing the mission;
- Flight operations should be done in good weather conditions, with low wind and waves and when the sun is not very high (also to minimise backscatter);
- make sure to comply with regulations and legislation for drone operations.