Portable Catamaran Drone – an uncrewed sampling vehicle for micro-plastics and aquaculture research

Artur Zolich*, Andrea Faltynkova†, Geir Johnsen†, Tor Arne Johansen*
*Department of Engineering Cybernetics,
†Department of Biology,
Norwegian University of Science and Technology, Trondheim, Norway
artur.zolich@ntnu.no

***Abstract*—In this paper, we present a Portable Catamaran Drone (PCD) - an Uncrewed Surface Vehicle (USV) that may significantly improve the scalability of surface water particle sampling using a plankton net. We preset vehicle design and evaluate its potential during field-trials.**

I. Background and motivation

Water pollution is an emerging concern that is recognised as a global challenge [1]. Research of water quality involves numerous sampling and analysis methods [2]. Modern technologies, such as dedicated sensors and instruments, robots and Artificial Intelligence (AI), can increase efficiency of sample collection and reduce analysis time. Processing more samples can result in more accurate monitoring for policy development and actions planning.

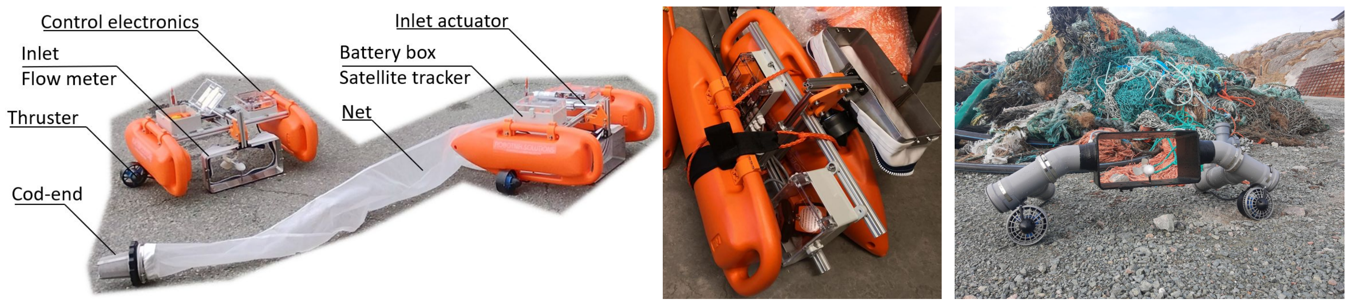
A need for a definition of monitoring requirements and practices for microplastics has started to emerge in some regulatory frameworks. For example, California's *California Safe Drinking Water Act* suggests that a standard methodology for testing for microplastics in drinking water should be adopted by 2021 [3], [4]. As another example, in the Arctic region, the topic of litter and microplastics is currently investigated by the Arctic Council. The Arctic Council is an intergovernmental forum promoting cooperation, coordination and interaction among the Arctic States: Canada, the Kingdom of Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States. The Arctic Monitoring and Assessment Programme (AMAP) – a working group of the Arctic Council – suggests that variability of the abundance of litter and microplastics may require high numbers of replicates and several years of observations to detect temporal trends with sufficient statistical power [5]. The programme recommends prioritisation of monitoring the primary indicators for beaches/shorelines, sediments (freshwater and marine), water (freshwater and marine), and seabirds.

There are various instruments and techniques available for environmental sample collection. One of the most common methods for surface water particle collection, e.g. in micro-plastics, plankton, or zooplankton research, is a *manta-trawl*. A *Manta-trawl* is a device traditionally comprised of a frame, flotation elements, a plankton net and a *cod-end*. The *cod-end* is a removable casing which collects the sample but also allows water to flow through the net. The full assembly, fixed to a boat using a wire cable, is trawled slowly. A flow meter registers the flow rate through the opening, which can be used to estimate water sample volumes in the surveyed area. When the *manta-trawl* is pulled in, the *cod-end* is removed and the sample it contains can be stored, and later processed in a laboratory.

Fig. 1: Portable Catamaran Drones

A certain drawback of today's methods of sampling using the *manta-trawl* is the requirement of boat support. The sampling process puts significant restrictions on boat speed and path. These restrictions may reduce available resources for other activities. Moreover, sample quality of samples collected close to the boat may be challenged by surface water layer distortion – caused by the wake from the hull or propellers. In addition, this traditional way of operating using a *manta-trawl* is challenging to scale. More samples require more boat time, and it is resource-demanding to collect several replicates.

The Portable Catamaran Drone (PCD) creates a new paradigm of sampling using the *manta-trawl*. The USV user-centred design makes the vehicle easy to operate and transport. Equipped with zero-emissions electric propulsion the PCD does not require boat assistance, which can reduce a total environmental impact of field campaigns. Controlled by an autopilot, the vehicle collects an environmental sample while automatically navigating a user-defined path. The vehicle can be deployed directly from shore, which allows



(a) PCD – key modules (b) PCD packed for transport (c) Autonomous Microplastics Sampler

Fig. 2: Portable Catamaran Drone

sampling in areas where boat use is restricted or impractical, e.g. small lakes. The vehicle does not require continuous supervision. During fieldwork in large areas, researchers can deploy multiple PCDs to survey a larger area at once and use time for other activities. Due to the small catamaran hull, samples collected by the PCD are less affected by the surface water disturbance traditionally caused by the boat wake.

In this paper, we present PCD and evaluate vehicle's potential of scaling-up sampling using a plankton net. In section II we briefly describe techniques of sampling with plankton nets. Section III presents the PCD design criteria and technical details. Section IV discusses vehicles performance during field work in Norway.

II. Sampling using plankton nets

Sampling with a special net – also referred to as *plankton net* – is one of the techniques used for collecting particles from water. The most common ways of sampling the water surface using a plankton net are using a *manta trawl* or a *neuston net*. The difference between the two is that a *manta trawl* floats unassisted, while a *neuston net* needs additional suspension. Wiebe et al. [6] distinguish 23 types of collection methods of net hauling and provides the standardised vocabulary for differentiation. The selection of a certain technique depends on the research question and which species/objects scientists plan to investigate. The PCD equipped with a water inlet opening-closing system can be considered as a *single net horizontal tow*.

Plankton nets used in research vary depending on the application too. Two key characteristics that differentiate nets are mesh size and opening area. There are numerous plankton net designs available, including commercial products (e.g. 15 to 500 μm [7]) and open-hardware initiatives [8]. The literature provides several examples where net size impact on sample quality and composition is discussed. Hidalgo-Ruz et al. [9] in their review present that in microplastics research mesh size range is from 53 μm to 3000 μm. However, the most commonly used mesh size for this application range from 300 to 390 μm. For a rectangular opening, (*neuston nets*) opening area size varies between 0.03 and 2 m^2. The length of net used in research varies as well, ranging from 1 to 8.5 m, with the majority between 3 to 4.5 meters.

Some practical concerns may impact sample quality. A typical towing time to collect a single sample is 15-30 minutes. Speed of towing is about 2 kn. Some manufacturers denote a maximum speed for their net, e.g 3 kn for 300 μm mesh size [7]. It is advised for samples to be collected during calm sea states with wave height less than 0.5 meters, or Beaufort Sea State 3 [2]. A key aspect of towing techniques is to keep the net opening away from the vessel wake, so sampled water is not disturbed by the ship. In addition, biological processes, such as diel vertical migration (DVM) of zooplankton, may determine aspects such as proffered time of day suitable for sampling.

III. PCD description

The PCD has been designed and developed with a strong emphasis on user feedback. Initially, a pre-prototype platform was developed (Figure 2c) to verify the hypothesis that USVs can help in optimizing the microplastics sampling process. A successful series of pre-prototype field trials resulted in user feedback that led to a definition of key requirements for the PCD:

Endurance - according to the literature on typical sampling duration, the robot should be able to run continuously for ca. 60 minutes.

Portability - a single person should be able to carry the robot while moving on foot.

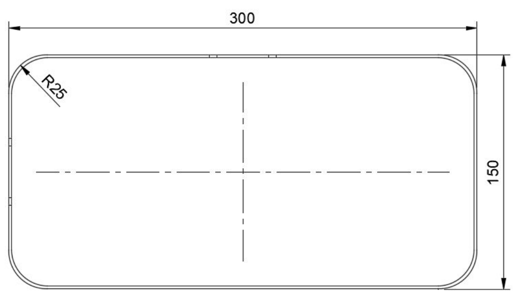
Transportability - multiple units should fit in a compact car, or on a boat. PCD should comply with airline regulations on the check-in and carry-on luggage (size, materials, batteries).

Safety - the risk of explosion or fire should be eliminated or at least significantly limited.

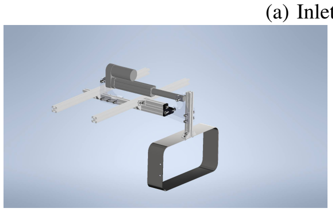
User training - the user should be able to perform basic operations with the vehicle after a brief introduction.

Abnormal situations handling - the robot should enable remote handling of abnormal situations by an expert user. In case of loss of control, a backup GPS tracking system is required.

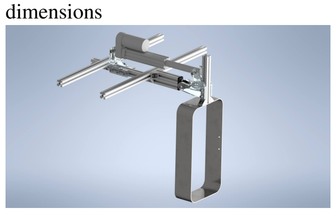
Sampling control - the PCD should allow to start and stop sampling at user-defined locations.



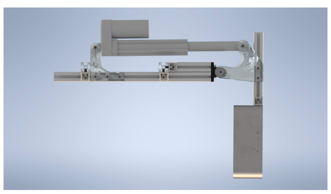
(a) Inlet dimensions



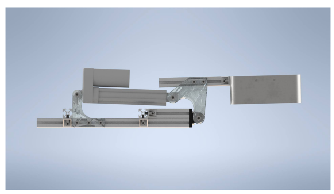
(b) Horizontal configuration



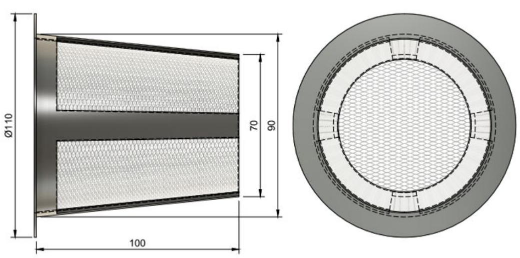
(c) Vertical configuration



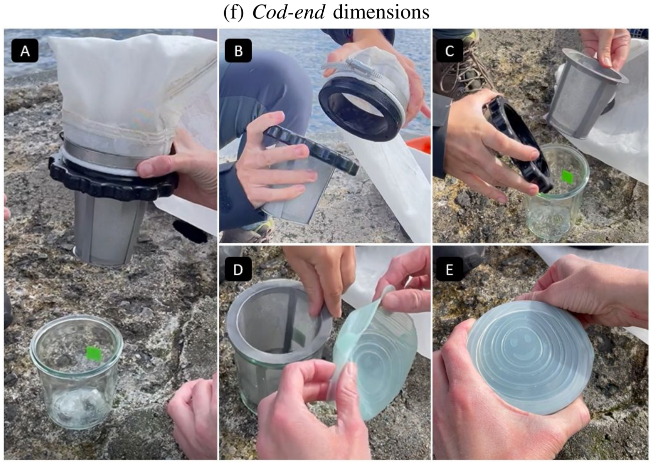
(d) Sampling position



(e) Lifted position



(f) *Cod-end* dimensions



(g) Sample retrieval. A) *Cod-end* attached to robot's net. B) *Cod-end* detached from the net. C) Mounting bracket removed. D) Stainless filter placed in a glass container. E) Container sealed with a silicon cover

Fig. 3: Water inlet and *cod-end* details

Deployment/Recovery - the PCD should not require special tools to deploy and recover from shore, piers, or boats.

Multi-robot operations - it should be possible to run and control many vehicles at the same time.

Configuration - the PCD should allow water inlet adjustments - depth of sampling, the horizontal-vertical position of the inlet, and net replacement.

Samples retrieval - the system should allow retrieving samples and replacing batteries wearing gloves without additional tools.

Samples management - the system should propose a system for temporary samples storage so multiple samples can be collected before transferring to the lab.

The PCD key modules are highlighted on Figure 2a. Mechanical elements of the PCD utilise commercial-of-the-shelf (COTS) such as lifeguard buoys and universal construction aluminium profiles. Joints were manufactured using Fused Deposition Modeling (FDM) 3D printing. External dimensions and features make it possible to deploy from a shore, pier or boat (Figure 4). In addition PCD is modular, and can be disassembled for transport (Figure 2b).

The control electronics design of the PCD tries to minimise the number of elements and is based on COTS modules. PCD's autopilot runs on a Single Board PC (BeagleBone Blue, BeagleBoard.org Foundation, USA). The unit – with Linux Debian 10.3 operating system – runs an autopilot Ardupilot Rover 4.2. Navigation sensors available on the SBPC are completed with an additional GPS module integrated with a compass (BN-880, Beitnan, China). The robot is motorised by two thrusters (T-200, BlueRobotics Inc, USA), driven with a standalone ESC (P50A, T-Motor, China). The energy source is a single 18V 5Ah battery (BL1850B, Makita Corporation, Japan). Short-range communication is available by SBPC's WiFi module, while remote-access link use a 4G gateway (TRB142, TELTONIKA IoT GROUP, Lithuania). In addition robot carries an independently powered, satellite tracking device (SPOT Gen3, SPOT LCC, USA) configured to report its GPS position every 5 or 10 minutes.

The stainless steel water inlet is driven by an electric actuator (RE801, Remore, China) controlled with a brushed motor controller (MD10C, Cytron Technologies Sdn. Bhd, Malaysia). The inlet surface area is 4.45 dm^2 (0.044 m^2). Exact dimensions are presented on Figure 3a. Its design allows mounting in vertical or horizontal configuration (Figure 3b, 3c). Sampled depth can be adjusted by extending or shortening the inlet arm.

As mentioned in previous sections, the sampling net features vary depending on the application. During fieldwork, several custom-made nets (120 μm and 300 μm) were accompanied by commercial design (300 μm, Hydro-Bios Apparatebau GmbH, Germany). For micro-plastics sampling, a custom *cod-end* has been developed (Figure 3f). Stainless steel (316), 300 μm mesh is protected from outside with an additional rigid, stainless steel structure. The *cod-end* is attached to the net using a dedicated, threaded ring. Ring design allows it to be operated in gloves without additional tools. For transport and storage, the *cod-end* is

Run	Sampling duration [seconds]	Distance traveled [meters]	Average speed [m/s]	Average speed [kn]	Power used [Wh]	Volume sampled [liters]
1	502	315	0.63	1.23	14	13990
2	521	294	0.56	1.11	13	13090
3	405	233	0.58	1.13	11	10380
4	507	296	0.58	1.14	14	13141
5	520	297	0.57	1.12	12	13193
6	743	437	0.59	1.15	20	19422
7	748	438	0.59	1.15	21	19492
8	746	447	0.60	1.18	21	19893
9	14	6	0.43	0.85	0	270
10	980	599	0.61	1.20	27	26652
11	975	588	0.60	1.18	28	26149
12	966	602	0.62	1.22	28	26771
13	2062	1202	0.58	1.14	68	53442
14	815	374	0.46	0.90	19	16610
15	1041	623	0.60	1.17	33	27679
16	1242	699	0.56	1.10	42	31076
17	863	480	0.56	1.09	26	21341
18	881	503	0.57	1.12	27	22383
19	844	488	0.58	1.13	26	21702
20	850	482	0.57	1.11	26	21448
21	850	500	0.59	1.15	25	22237
22	460	289	0.63	1.23	12	12868
23	759	474	0.62	1.22	20	21068
24	1033	620	0.60	1.18	27	27574
25	750	477	0.64	1.25	21	21226
26	753	309	0.41	0.80	16	13740
27	977	580	0.59	1.16	32	25767
28	956	572	0.60	1.17	36	25438
29	1014	610	0.60	1.18	42	27110
30	787	493	0.63	1.23	32	21926
Total	**24563**	**14328**			**740**	**637080**

TABLE I: Statistics of sampling runs

(a) From a cliff

(b) From a pier

(c) From a boat

Fig. 4: Deployment and recovery techniques

designed to fit into a COTS glass jar (742, J. WECK GmbH u. Co. KG, Germany). Six *cod-ends*, secured in glass jars, with a silicone cover on top fit a stackable Makita Type II toolbox. The process of sample retrieval is presented in Figure 3g.

IV. Robot performance assessment

Vehicles' performance has been assessed for micro-plastics sampling during a field-work campaign at Runde island in Norway. Samples were collected on exposed South-Western (SW) and protected Eastern (E) part of the island over 3 paths (Figure 5a). On SW site PCDs were deployed from a cliff (Figure 4a) while on the E site from a pier (Figure 4b). Recovery and deployment on SW site were performed from rocks and a pier on E site. Sea state was ranging from 0 (0 meter waves) to 4 (1.4-1.6 meter waves). The temperature was around 12 degrees Celsius.

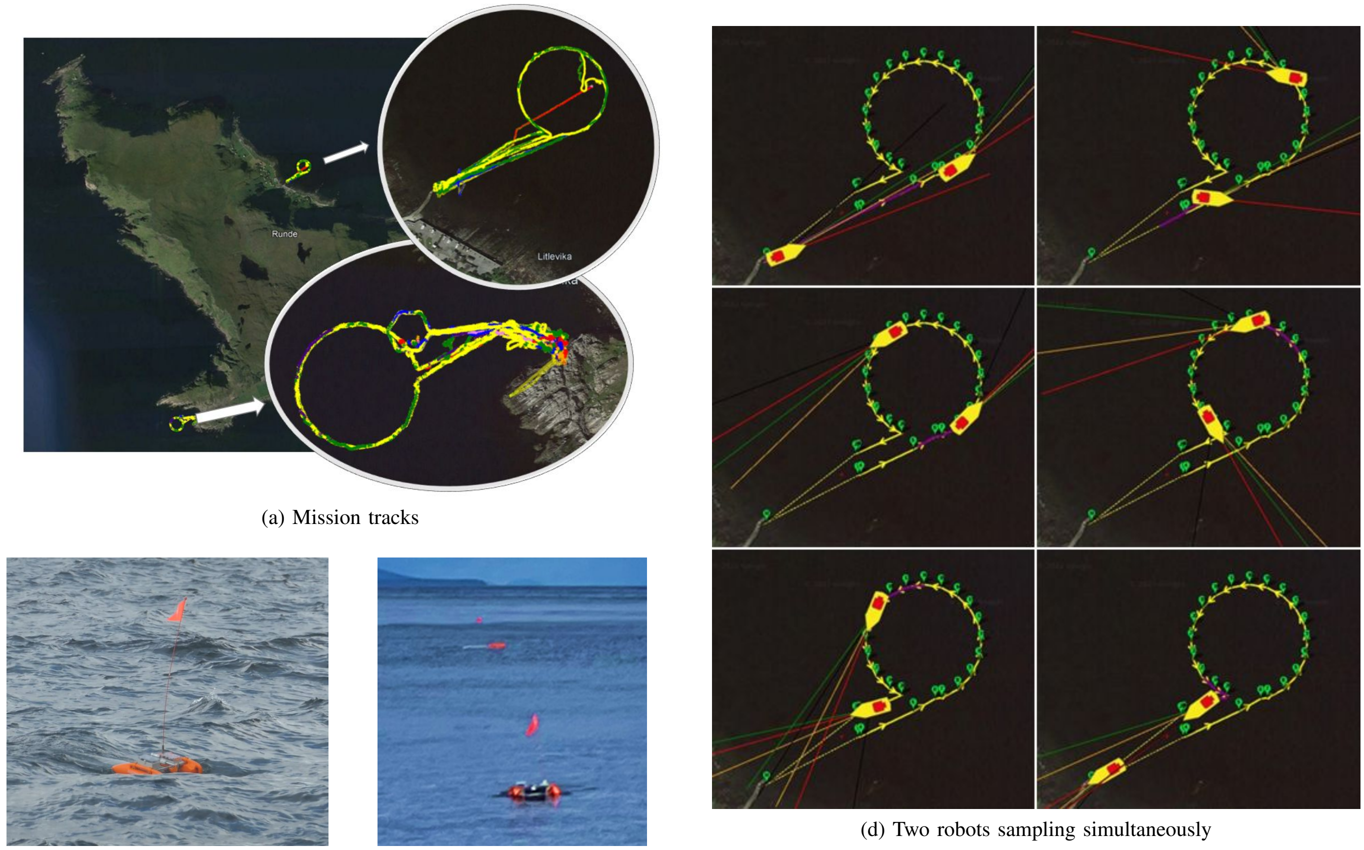
During 4 days of trials, robots travelled 24 km in total, out of which 14 km was sampling (inlet in water). The total sampling time was 6 hours 49 minutes. All PCDs combined used 740 Wh which is the equivalent of energy stored in 0.077 litres of gasoline. At that time total volume of water that passed through the net was estimated to be ca. 637 thousand litres. 35 samples were collected for further analysis.

In addition operation with two vehicles sampling simultaneously, following each other on the same path has been presented (Figure 5c & 5d). Such a scenario reduces the time of acquiring multiple sample replicates and can be used to scale-up field-work efficiency.

The following analysis presents runs when the vehicle was controlled by an autopilot. Table I presents statistics for PCDs during sampling while Figure 6 displays the difference in energy consumption between a vehicle travelling to the sampling area (lifted inlet), and sampling (inlet in water). Record number 9 has been discarded from analysis due to the short duration - run has been aborted due to the operator error discussed further in the paper.

During sampling, vehicles were moving with an average speed over the ground of 1.14 kn (0.58 m/s). The average power consumption during sampling was 5.05 Wh per 100 meters travelled (σ 0.69 Wh/100m). For comparison, with the water inlet lifted the average power consumption drops to 3.18 Wh per 100 meters travelled (σ 0.71 Wh/100 m). In the presented scenarios travel with an inlet in water consumed ca. 59% more power per 100 meters when compared to travel with the inlet lifted. Assuming a 90 Wh battery pack, the power budget allows for 45-59 minutes of sampling and 66-105 minutes of travel with a lifted inlet, depending on conditions.

Similar results can be achieved with different mesh sizes, for example in Salmon lice monitoring. During tests in Hardangerfjord (Norway), the PCD was deployed and retrieved from a boat Figure 4c to tow 120 μm net while researchers handled moorings with stationary research in-



(a) Mission tracks

(b) PCD during sampling

(c) Two PCDs sampling at once

(d) Two robots sampling simultaneously

Fig. 5: PCDs' tracks during fieldwork at Runde

struments. The PCD's water inlet was in a horizontal configuration, suspended dozen of centimetres under the surface of the water. The run – in good weather conditions – lasted for 29 min 47 sec during which the PCD travelled 1167 meters resulting in an average speed of 0.65 m/s (1.28 kn). 44 Wh were consumed, 3.73 Wh per 100 meters.

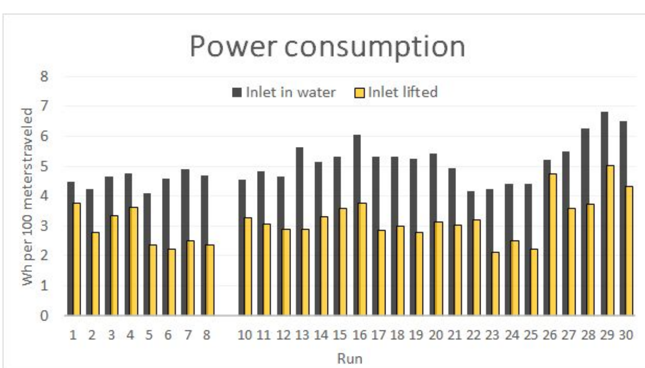


Fig. 6: Power consumption during runs at Runde

A certain challenge is PCD's speed control against water current. Vehicles measure their velocity using GPS. Measurements present speed over the ground, and water current velocity or direction is not known. That causes a potential threat to non-uniform plankton's net speed in water when running in different directions, e.g. while sampling in circular patterns. The issue was addressed by limiting allowed thrusters' output power to 60%, and setting desired PCD velocity to a value that the vehicle should not be able to achieve, even if supported by the water current. Such a setting causes the vehicle to run continuously on constant thrusters output, so force against water is balanced independently of water current speed or direction. In abnormal situations, the PCD operator can change the settings and manoeuvre with full available power. PCD autopilot is equipped with several failsafe mechanisms. If these are not sufficient, a remote operator can access and resolve problems using an LTE communication channel to the vehicle. During the presented fieldwork remote operator assistance was used on 3 event types. The first occurrence was the accidental pausing of the mission by the operator on-site (run 9 in Table I). Another situation was the blocking of thrusters by seaweed, to prevent that from happening again additional seaweed guards were added. Finally, one run was aborted to investigate a compass glitch. Operators recovered from all events using available communication channels and vehicle control methods, without boat assistance.

V. Conclusions

In this paper, we present a Portable Catamaran Drone – an Uncrewed Surface Vehicle developed to scale-up surface water particles sampling using a plankton net. We present vehicle design and evaluate its capabilities during fieldwork. We showcase multi-robot operations that can increase sampling throughput. During micro-plastic research, campaign vehicles covered 24 kilometres in sea states ranging from 0 to 4 on Beaufort's scale. Samples were collected with a 300 μm net and into a custom *cod-end* over a distance of 14 kilometres, with an average speed of 1.14 kn. An estimated 637080 litres of water were filtered into 35 samples. Additional test with 120 μm net for Salmon lice monitoring shows similar capabilities in other research.

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