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Floating remote-controlled water sampling device

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A floating water sampling device suitable for taking samples for remote sensing algorithm development or operational monitoring of multiple water bodies has been developed. The device is based on remote-controlled boat and the attached Van-Dorn sampler. Such a setup belongs to the category of unmanned surface vehicles being convenient for taking near-surface water samples off-shore from a distant site. Its efficiency compared to traditional sampling with an inflatable boat has been proved by reducing the average time between the consecutive samplings to about a half.

Keywords: Water quality; Sampling; Remote control; Unmanned surface vehicle

Introduction

Monitoring freshwater quality in lakes and ponds is increasingly important as water resources become gradually limited due to the population growth, environmental pollution, and climate changes. Water quality (WQ) monitoring programs have been developed and are being further expanded to obtain more WQ data. This is important for a better understanding of pollution sources, trends in WQ changes, and as a base for regulatory decisions ensuring the water resources protection and public safety.

As demand for the WQ data increases, the respective monitoring using traditional methods becomes inadequate in its spatiotemporal extent and capacity of sampling in many of the scenarios. To face this, various methods are utilized, from volunteer monitoring programs [1], via various unmanned water sampling and analysis devices [2,3], up to WQ models, based on satellite imagery [4].

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This paper deals with designing an unmanned device specifically for taking samples used in the development of satellite WQ modelling algorithms and their advantages over traditional sampling from a boat.

Research of the existing unmanned or autonomous water sampling and WQ measuring devices in the literature shows quite a broad range of types and the already proposed applications [3,5–13]. There are several categories of such devices, particularly unmanned aerial vehicle (UAV), unmanned surface vehicle (USV), and autonomous underwater vehicle (AUV). All these categories offer various levels of possible autonomous operation. Every type of such devices is suitable for different sampling scenario.

UAVs have been used, for example, to quickly take the water samples from predetermined sampling points to measure DO, EC, pH, and temperature [5], or to sample water for environmental DNA surveys [12]. The main advantages of UAV, in general, are fast operation, possibility to automate the sampling process [14], and availability of continually expanding range of commercially marketed UAV devices. While there are also relatively high load capacity UAVs, most applications in water sampling typically deal with a small sample size. For example, in one study, an UAV can take one sample of 130 mL [5]. In another study a different UAV is capable of taking three samples per flight, 20 mL each [14]. This is probably due to the fact that lifting heavier load to the air is less practical compared to other methods. UAVs can also be used for *in-situ* measurements of WQ parameters. For example, the UAVs being able to land on the water surface, perform the required measurements, and then lift again [3,8].

A typical example of AUV used in WQ monitoring is a device not designed for taking samples, but for direct measurement and mapping of WQ parameters and bathymetry simultaneously *in-situ* under the water [13].

Finally, there are surface devices. Principally, surface devices can be divided into two groups: (i) fixed buoys and (ii) moving devices resembling small boats – USVs. Buoys are practical mostly for continuous monitoring with *in-situ* WQ sensors [15] when being already widely used. USVs are utilized in discontinuous WQ monitoring and mapping, mainly using sensors carried on the floating platform [2,6,7], but they can also be used to take water samples for laboratory analysis [16]. As the sample container can be kept under the water during the whole process, the burden is reduced by buoyancy. This allows to take a proportionally large amount of sample for a relatively small device.

Materials and Methods

Purpose of the device and requirements

The sampling device described in the following chapters have been developed specifically for the task of taking samples for the purpose of remote sensing WQ algorithms development for chlorophyll-a and other WQ parameters estimation in relatively small water bodies [17,18]. While developing the WQ models, it has become evident that the traditional way of taking samples from an inflatable boat is limited with respect to the specific sampling scenario. Such limitations could be tackled by using an unmanned device for taking the samples instead.

The proposed sampling device would be suitable for sampling scenarios with similar requirements like those in the development of remote sensing algorithm for small water bodies [17,18]. These are:

- multiple water bodies have to be sampled in one day; typically, the day of satellite overpass;
- in the long term, the sampling should cover as many individual water bodies as possible and various water body types to train the resulting algorithm for diverse conditions;
- the samples are needed from open water, at a distance of tens of metres off the shore, as the satellite imagery algorithms have limitations in nearshore areas (based on imagery resolution vs. shore proximity effects);
- volume needed is often over one litre per sample (for chlorophyll-a laboratory spectrometer determination in relatively clean water to be precise enough [19]);
- only near-surface water samples are needed.

In practice, it is needed to travel among several water bodies and, at every stop, to prepare all the equipment, bring the sample to the shore from a distance, and then, after storing the sample, pack and clean everything again. This is a time-consuming procedure with an inflatable boat. Smaller unmanned device would be more time-and-labour effective. Based on the demands listed above, a remote-controlled USV type of sampling device was selected.

Components of the device

Already at the start, it has been decided that the USV should be constructed predominantly from parts and materials which are commercially available. It should carry a sampler capable of taking more than 1 L of the sample, better 2 L. The carrier should be able to navigate to a point in the distance of at least 30–50 m off the shore and return with the water sample. Principally, the device should be a combination of a water sampler and a carrier based on commercially available remote-controlled (RC) boat.

The sampler

The sampler is the primary part of the device and its properties were considered first. As the samples should be taken from a fixed near-surface depth and the carrier would move across the water surface, the sampler should be of the horizontal type. Considering the manner of movement of the device and the required way to remotely close the sample within the collector, type Van-Dorn horizontal sampler was selected. This type of sampler works on the principle of an open tube moving horizontally within the sampled water, while the water freely flows through the tube. At the sampling location, the sample is then closed within the tube by two closures at both ends of the tube [20]. Considering the required sample capacity, weight, price, and available options on the market, WaterMark Horizontal Polycarbonate Water Bottle (see Figure 1) was chosen, with capacity 2.2 L and dimensions approx. 40 × ∅ 11 cm without handle.

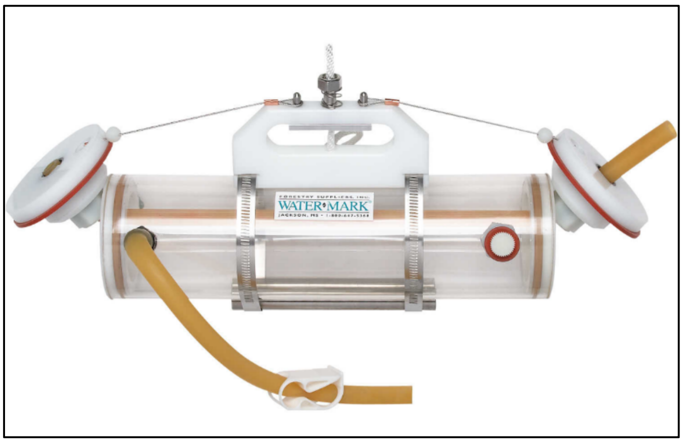

Fig. 1 WaterMark Horizontal Polycarbonate Water Bottle 2.2 L

The carrier

The carrier should have the size needed to handle the sampler. The carrier should be a RC boat able to navigate common inland water bodies, possibly with some minor vegetation in the way. In literature, it is frequently recommended, that a carrier of a moving USV should be of catamaran design because of better stability [2,6,7]. Catamaran pattern is also well suited for placing the sampler just under the water surface as needed, with the space to place it in-between the two floats of the catamaran. This design was thus selected. It had also been originally intended to radio control the mechanism closing the sampler. For that reason, from the selection of readily available options, the boat should be of a fishing bait boat type. Such boats have often about the right size, are designed to function in water bodies, potentially in the presence of some vegetation (propellers protected in a cage), and bearing an extra RC channel for releasing the bait into the water.

This mechanism had been planned to be used for releasing the closing mechanism of the sampler. Considering all the requirements above and available options, Joysway Sweet Bait Baiting 500 (Figure 2) model was selected. Main dimensions are 54 × 24 × 14 cm.

Fig. 2 Joysway Sweet Bait Baiting 500 RC boat

Spring mechanism and overall construction

The sampler had been originally designed to be closed by a messenger weight, descending on the releasing mechanism in the sampler handle. In the USV construction, the sampler was turned upside down for the operation under the carrier boat and fastened using plastic zip-ties. Laboratory rubber hoses were then used as a cushion between the boat and the sampler (Fig. 3 a).

As the sampler is turned upside down, its releasing mechanism is operated by pulling the release plate up by a string. The string is connected through the door in the boat middle to spring mechanism at the top of the boat. The spring mechanism had been made from a steel wire and embedded in a braced loophole at the stern (Fig. 3 b; the spring mechanism is depicted in tense state). The spring mechanism is released by a cotter made from a plastic zip-tie. The cotter is moving inside a plastic tube (fastened to the boat handle; see Fig. 3 c) and operated by a line from the shore. A light plastic line floating on the water was selected.

The top of the boat incorporates a waterproof case for GPS device Trimble Juno SB. Before sampling, the GPS device would be put into the case and fastened using the band on the stern top, under the wire spring. The overall view of the USV, including the line, is apparent from image (Fig. 3 d).

The final construction is a result of several iterations of testing and design changes. The most prominent changes were:

1. The steel wire spring mechanism. First proof-of-concept version of the spring mechanism had been based on spring made from a fresh willow stick. It worked surprisingly well, but the stick needed replacing in intervals of about two weeks.

2. The release mechanism of the spring had been originally operated by the wireless RC opening the feeding door in the middle of the boat. It worked but was not unfailing. For that reason, it was replaced by the cotter and string mechanical release by a line. This line also serves as a safety element in case of boat power failure and as a way of return to the shore without consuming on-board battery energy.
3. Change of the material of cushions between the boat and the sampler. Originally soft plastic foam bars had been used, but these bars did not keep shape, causing that the sampler was gradualy releasing and, moreover, being soaked with water.

Fig. 3 Details and overall construction

Results and discussion

Device *in situ* operation

When taking one sample from the given water body including sample temperature measurement, the whole operation consists of several steps:

1. Collecting equipment to the shore – the sampling device, GPS unit, notebook, thermometer.

2. Preparation – GPS device has to be set to record track, put into the waterproof case and strapped to the boat. The boat and the remote controller has to be powered up, the sampler opened, and the spring mechanism loaded. The sampler should be washed with water of the sampled water body, while the sampler outlet and air valve have to be closed. The device is then put on the water surface.
3. Reaching the sampling location – The boat is tethered by safeguard string 40 m long on a reel. It is needed to alternately unwind the line and navigate the boat with the remote control to the desired location, when operated by one person.
4. Sampling – After stopping the boat at the desired location, the spring mechanism is released by recoiling the string.
5. Return – As the boat is tethered, the return to the shore is carried by rewinding the string back on the reel. This is faster and preserves batteries compared to a return via remote controlled motoring.
6. Sample collection and temperature measurement – the device is removed from the water, put on the ground bow down and the rear cap of the sampler is lifted to allow access of thermometer tip into the sample. After temperature measurement and recording, sampler is closed again. The device is put into an elevated position and the sample collected into sampling bottle via the opened outlet hose. The flow of sample is regulated by the air valve.
7. Finishing the operation – The sampler and boat should be washed, GPS device removed from case, and the track recording stopped. Everything is returned to the car.

The whole operation (with the above-specified seven sequences) takes typically 25–40 min if going smoothly. The boat with the connected sampler under it has quite some added friction when moving in water. Accordingly, its speed is not as that without the load. The asymmetry of the sampler due to its side outlet tubing causes that the boat has tendency to turn constantly to the same side. It has to be compensated by using the remote control, but it is manageable.

Comparison with sampling from a manned boat

Compared to sampling from the inflatable boat, which was used prior to utilization of the USV device, the whole operation needs considerably less time. This is the main advantage of the sampling device. Typical operation time with the inflatable boat was 60–120 min.; the reason for the difference being mostly a time period for assembling and inflating the boat and then to deflate it, clean and dry it sufficiently to accomplish the transport to the next location. Also, a launching on the water and lifting the boat back to the shore including loading and unloading of the equipment can add considerable time, especially, at a location with difficult terrain; nevertheless, the time periods of operation were not systematically recorded. What can rigorously be compared is the time between the consecutive samplings (TBCS). The column "time" in Table 1 specifies all times of sample collection for samplings performed in the years 2017–2020 for cases, when the respective samples were collected consecutively without interruptions (like stops for a meal); one sample per water body being taken and done exclusively from the USV (2019–2020) or the inflatable boat (2017–2018). TBCS is the difference between two such consecutive sampling times. Average TBCS were computed for both sampling methods. These time periods have depended also on the distance between the water bodies sampled, distance of the parked car from the water body, traffic conditions etc. in the individual cases, but their averages should be representative. The average TBCS for the USV was 53 minutes shorter than that for the inflatable boat. This means it is reduced almost exactly down to 50 % of the average TBCS for the inflatable boat, where a symbol "n_t" used in the table is number of time transitions between the consecutive samplings, for which individual TBCS values have been computed.

Table 1 Time between consecutive samplings for USV and inflatable boat

USV				Inflatable boat			
date	sample	time	TBCS	date	sample	time	TBCS
20.08.2020	1	13:35	–	18.09.2018	1	13:05	–
	2	14:55	01:20		2	14:31	01:26
14.07.2020	1	15:17	–	02.08.2018	3	12:18	–
	2	16:13	00:56		4	14:11	01:53
23.04.2020	1	11:03	–	31.07.2018	1	13:26	–
	2	12:01	00:58		2	15:52	02:26
	3	12:37	00:36	31.05.2018	1	15:24	–
	4	13:25	00:48		2	17:44	02:20
25.07.2019	1	10:17	–	29.05.2017	1	10:24	–
	2	11:08	00:51		2	12:27	02:03
18.07.2019	2	14:35	–	19.05.2017	4	10:43	–
	3	15:38	01:03		5	11:47	01:40
20.06.2019	1	14:24	–	11.05.2017	2	11:18	–
	2	15:24	01:01		3	12:37	01:19
16.04.2019	1	11:20	–				
	2	12:00	00:40				
$n_t = 9$		average: 00:54		$n_t = 7$		average: 01:47	

All times in mm:ss (minutes:seconds) format

With the smaller USV, it is also easier to access water and take the samples in places, where the terrain is difficult for manipulation with an inflatable boat, or when it is impossible to get close to the water with a car.

Another advantage of the smaller USV is that it causes less disturbance of the sampled water than that with an inflatable boat. Not only because of its size but also due to the way the water is coming into the sampler at the bow of the USV before being disturbed by the movement of the boat, unlike when it is taken from the inflatable boat. Additionally, small unmanned device operated from shore represents a lesser disturbance for wildlife in the sampled water bodies.

There are also some comparative disadvantages or possible difficulties. It can happen that the spring mechanism does not close the sampler fully or fails and the operation of loading it and navigating the USV to the target position has to be repeated. It comes true only occasionally, and it occurs mostly due to operator's mistake during the preparation phase. Even in the case of such a failure, the total time of the sampling would still be less than that with a manned boat.

Yet another potential disadvantage is that if a measurement of Secchi disk depth (SDD) is needed it is not performable *in-situ* from the unmanned vehicle. It can be solved by measuring the SDD after sampling with a transparency tube [21], or measuring other parameter that characterizes similar water property. For example, nephelometric turbidity can be used alternatively, measured in the lab or *in-situ* with a probe.

Similarly, the sample temperature had to be measured after the sample is brought to the shore and not at the time of sampling. This could be avoided by employing a temperature sensor integrated with the USV device. However, the sample volume is enclosed in the tempered sampler for a short time of few minutes and submerged in the water of virtually the same temperature as that for the sample. It can be safely supposed that the possible sample temperature change between the time of sampling and time of measurement should be negligible compared to thermometer precision of ±0,4 °C.

The operational use shows that the selected boat has a relatively short battery life with the original battery pack (4,8 V, 5000 mAh NiMH). Moreover, the accumulator seems to suffer from quite unexpected rate of self-discharge. Being fully charged the previous day, it exhibits evidently shorter life during the next day. Combined with the late low battery warning, this was initially the cause of some failed samplings. For that reason, second battery pack was purchased. Both batteries have always to be fully charged the previous day and recharged again shortly before departure to sampling. This situation should be prevented in the future by having an alternative power source for the boat. The two fully charged batteries are sufficient for taking four samples from different water bodies safely, which is usual maximum needed in our sampling scenario.

Speed of the boat, its on-water maneuverability and battery life could be further improved via a larger RC boat with higher power capacity as the platform. This would probably allow to achieve even shorter operation time, but at the expense of the increased weight and decreased ease of on-shore manipulation and transport. The resultant benefit of such modification on TBCS is hard to estimate.

Conclusion

The USV sampling device proved itself to be a feasible alternative to sampling from an inflatable boat. Its main advantage is a shorter time needed to get the sample from the water body when several water sites are sampled consecutively. The average TBCS shortened to a half the average time needed when an inflatable boat was used. The device also allows easier access and sampling of water bodies with difficult near-shore terrain or if collection of samples takes place at a greater distance from the road. When pointing out some workflow modifications that have to be made, it is necessary to change the way of measuring some other WQ parameters, which are normally done *in-situ* by the operator on an inflatable boat.

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