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USE OF UNMANNED AERIAL VEHICLES FOR WATER SAMPLING IN HARD-TO-REACH WATER RESERVOIRS

Summary. Collecting water samples for laboratory analysis from hard-to-reach surface areas such as post-industrial reservoirs (for example, tailings depositories) or overgrown lakes and ponds poses several difficulties, and it is potentially dangerous for the persons carrying out such activity. This can be improved by the use of unmanned aerial vehicles (UAVs) while ensuring an adequate level of safety and full compliance with the requirements of PN-ISO standards. This article presents the possibility of using the BSP in the option of autonomous (automatic) operation, allowing for the collection of water samples intended for physico-chemical tests, from hard-to-reach surface reservoirs, following the provisions of the relevant PN-ISO standards.
Keywords: unmanned aerial vehicles, water sampling, surface reservoirs

1. INTRODUCTION

Polish Standards cover general principles and provide detailed guidelines concerning programmes, procedures and techniques of taking water samples for laboratory tests to determine its quality, from all types of reservoirs, in all aspects. However, they do not contain instructions relating to the specific situations in which this activity may occur [7]. Method for sampling water from natural lakes and artificial dam reservoirs in open water and ice-covered conditions, with or without aquatic vegetation present, is the subject of [9], while issues concerning quality assurance and quality control during sampling are presented in [8].

Sampling according to the requirements of PN-ISO standards is usually a time-consuming, labour-intensive and logistically complex activity. In the case of hard-to-reach surface water bodies, such as industrial reservoirs (for example, tailings depositories) or overgrown lakes and ponds, it poses many difficulties and can be potentially dangerous when carried out from steep banks or by boat. Therefore, there is a need to look for effective solutions to carry out this activity, eliminating the need for the researcher to personally reach selected points in the reservoir - usually where its depth is greatest.

This activity can be carried out with drones while ensuring an appropriate level of safety and full compliance with the requirements of PN-ISO standards.

2. OVERVIEW OF UNMANNED WATER SAMPLING SOLUTIONS

Various types of commercial water sampling support systems use remote-controlled flying or floating unmanned devices (drones). They are equipped with appropriate containers that are filled automatically when immersed in water or use special pumps, usually peristaltic, for this purpose.

The biggest advantage of floating drones (Figure 1) [4] is their high buoyancy enabling one-time sampling of a significant volume and mounting on board other devices, for example, a pump driven by an electric motor, an additional battery with increased capacity or a mobile probe submerged to an appropriate depth using another electric motor. The increased total weight of the additional equipment does not pose any problem for the operational stability of drones of this type. In addition, floating drones are characterised by ease of control and steering.

Fig. 1. Example of Instadrone floating drone for water sampling [4]

A major limitation in the use of these devices is the need for access to the coastline, which is not always possible and safe (cliffs, marshes, etc.).

The most versatile solution to efficiently reach any point on the surface of a water body, regardless of the state of the terrain around it, is the use of an unmanned aerial vehicle (BSP). Due to the widespread equipping of these drones with GPS modules, they are very suitable for autonomous flights. The main disadvantages of BSPs are their high price and low payload capacity. Therefore, it may be necessary to repeatedly sample smaller volumes of water until the standard required portion is collected. This is especially true for cheaper devices with low payloads. Another inconvenience is the high qualification of the drone operator and the need to have the required regulatory certification.

A solution called Nixie (Figure 2), for example, using a BSP to collect water samples, was used in New York City. A special device is attached to selected DJI drones, into which a bottle with a capacity ensuring the desired volume of sample is inserted for the time of water sampling. When the drone returns to the starting point, the bottle is removed from the device and sent back to the laboratory. Thus, there is no need to make several flights and pour water into other containers. Professional drones (DJI M600, M300 RTK) are used in this solution; however, their cost is very high. This is the main disadvantage of this solution.

Fig. 2. Nixie water sampling system using DJI drones [2]

A review of current solutions for the use of BSP for water sampling is included in the work [12]. The lifting capacity of the drones used for the considered purpose ranged from 0.6 to 12 kg. Depending on the solution, water containers manufactured in series were used, or special containers were made to fit a specific equipment platform. However, the paper does not present the construction details of the individual solutions.

On the other hand, the work [6] presents a device intended for the analysis of water parameters mounted to a drone made specifically for the research. The system has the possibility of taking samples for laboratory tests.

The problem of water sampling with BSP is so important globally that research in this area has been conducted at many universities, for example, the University of California-Merced, University of Tokyo, University of Nebraska and others [5, 12, 13, 14]. The value of the project carried out at the last university was almost 1 million dollars.

3. METHODS

A DJI Phantom 4 Pro (Figure 3), class C2 four-rotor drone (Figure 3) was used in the field tests [10], with the following parameters [3]:

- MTOM - 1.388 kg,
- maximum ceiling - 6000 m a.s.l,
- maximum resistance to wind speed - 10 m/s,
- maximum flight time - approx. 30 min,
- operating temperature range - 0 to 40°C,
- vertical range of positioning accuracy - ±0.1 m with visual positioning and ±0.5 m with GPS positioning, and
- a horizontal positioning accuracy range of ±0.3 m with video positioning and ±1.5 m with GPS positioning.

The equipment of this drone model did not include the possibility of mounting on it any additional instrumentation in the form of slings and/or platforms, which had to be designed and manufactured. In this case, ready-made free models dedicated to the described BSP model were used, obtained from a website (www.thinkgiverse.com), which offers such solutions in the form of *.stl files. The selected models were printed (on CraftBot Plus printer using CraftWare software, version 1.17.1 and CraftPrint version 1.10), modified and adjusted according to the requirements and expectations concerning the fulfilment of the work assumptions (Figure 3).

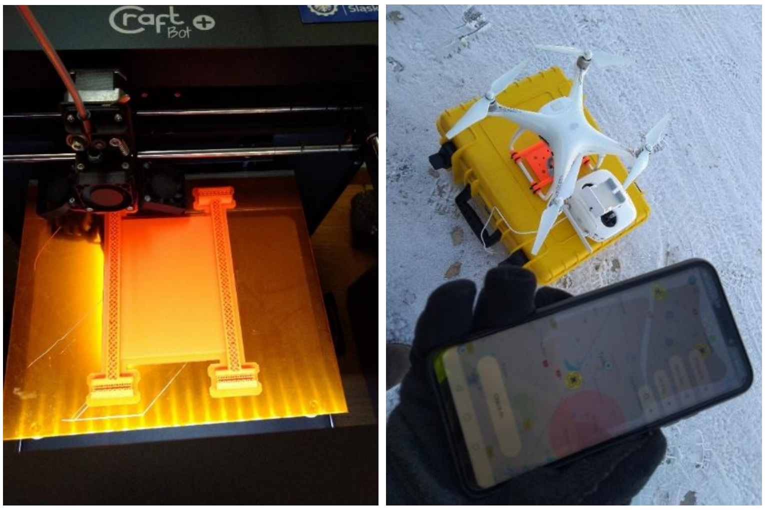

Fig. 3. The process of printing the sling on the 3D printer and the effect in the form of a modified and fitted platform on the BSP DJI Phantom 4 Pro

Only when equipped in this way did the drone allow the water samplers to be suspended. Due to its permissible lifting capacity, disposable water samplers PVC BIO, single-valve, 0.12 m diameter, 0.915 m length, 85 ml capacity and 30 g weight were used in this study (Figure 4). They represent the simplest solution for water sampling and can be lowered on Kevlar, polyester or steel cables.

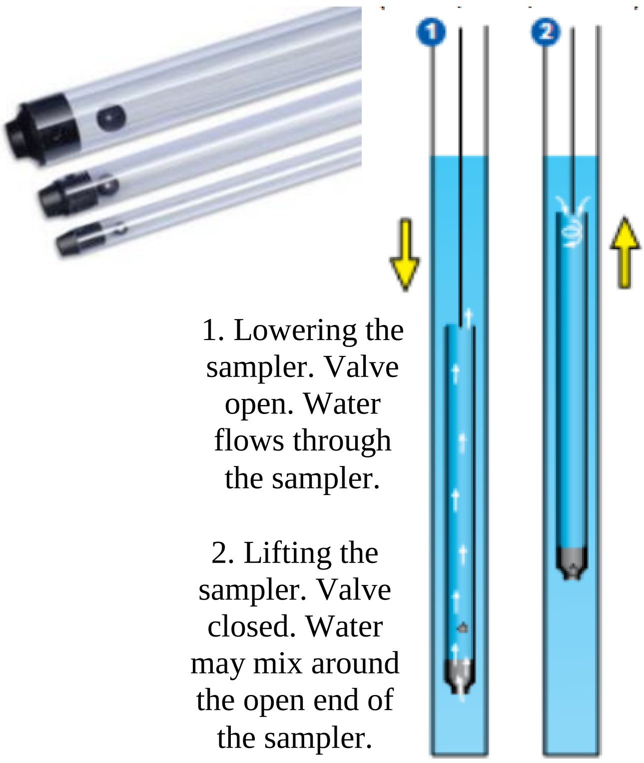

Fig. 4. Water samplers used in this study, including a description of their performance [1]

The problem, right from the start, was how to mount the sampler under the drone in a way that would allow it to take off and land. This was due to both the size (overall dimensions) of the sampler and its mass, increased by the mass of the collected water sample. While working on a solution to this issue, it was also necessary to install an additional weight on the sampler to enable it to self-submerge (sink) - otherwise, it would float on the water surface. Experimental methods were used to select the minimum weights that would allow both the submersion of the sampler and its transport by drone (Figure 5). Both the original 0.915 m long sampler and one specially shortened to 0.25 m were tested. The samplers were suspended from the drone using 5 and 10m elastic cables.

Work is underway to develop the automatic lowering of the sampler from the drone at a stabilised altitude.

An indispensable part of this research, apart from the hardware aspects, was the software to ensure the autonomy (automaticity) of the raid. Collecting water samples from surface reservoirs with a BSP is not a major problem nowadays, as in most cases, it is done with a traditional (manual) drone raid over the collection site. This is because such activities are provided by any BSP with the appropriate lifting capacity. To automate this process (for autonomous/automated raid), it is necessary not only to provide the mentioned payload but also to provide a suitable BSP with which such a "mission" - autonomous (automated) raid - can be carried out. The choice of the BSP DJI Phantom 4 Pro resulted precisely from such a compromise and the consideration of both mentioned criteria. This model can transport objects weighing up to approximately 0.5 kg, and it also works with the DJI Pilot application providing autonomous raid.

Fig. 5. Tests of water sample transport using original and shortened samplers suspended on a BSP DJI Phantom 4 Pro

Using the DJI Pilot application (Figure 6), in the Mission Flight module, selecting the Waypoint option, a five-point flight path was designed in two variations - at 10 and 30 m AGL altitudes. The distance between the take-off point and the sampling point was 30 m. At the water sampling point, the ceiling was planned to be lowered, considering the length of the line on which the sampler was attached and meeting the PN requirements for its immersion 1 m below the water surface.

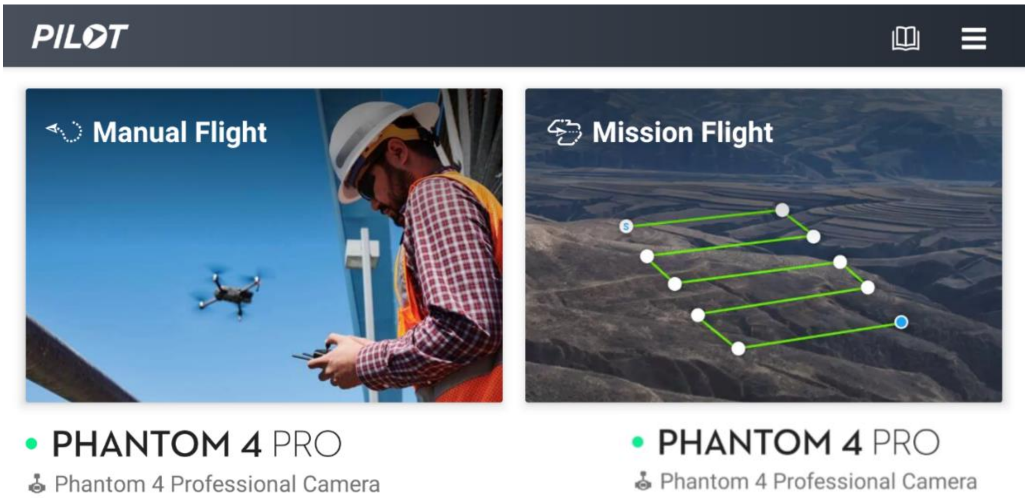

Fig. 6. Home screen of the DJI Pilot application with which the autonomous/autonomous flight of the BSP was planned in the Mission Flight module with the Waypoint option

In the first variant, where the take-off ceiling was 10 m and the line length was 5 m, the following parameters were set for the "mission" points:

- Point 1 - distance of 1 m from the launch site, ceiling 10 m AGL, hover 30 s, for stabilisation,
- Point 2 - distance 30 m, ceiling 10 m AGL, hover 30 s, for stabilisation,
- Point 3 - water sampling location, distance 1 m, ceiling 4 m AGL (sampler immersed 1 m below the water surface), hover 30 s,
- Point 4 - distance 1 m, ceiling 10 m AGL, hover 30 s, for stabilisation,
- Point 5 - a distance of 1 m from the launch site, ceiling 10 m AGL, hover 30 s, to stabilise and detach the sampler.

In the second variant (30 m launch ceiling, 10 m line length), the following "mission" point parameters were set:

- Point 1 - distance 1 m from the take-off point, ceiling 30 m AGL, hover 30 s, for stabilisation,
- Point 2 - distance 30 m, ceiling 30 m AGL, hover 30 s, for stabilisation,
- Point 3 - water sampling location, distance 1 m, ceiling 9 m AGL (1 m below the water surface), hover 30 s,
- Point 4 - distance 1 m, ceiling 30 m AGL, hover 30 s, for stabilisation,
- Point 5 - distance 1 m from the starting point, ceiling 30 m AGL, hover 30 s, for stabilisation and detachment of the sampler.

  For reasons of flight safety and the need to observe the behaviour of the cable and sampler during flight, all operations were conducted within visual line of sight (VLOS).

4. RESULTS

The tests were conducted during the winter period, when the conditions, both for BSP operations and sampling of surface reservoirs, can be considered somewhat extreme, but even under such circumstances, a BSP raid is conducted, and water samples are taken.

Field tests were conducted in January 2022 in Tychy, where the testing ground was the area in the vicinity of Paprocany Lake.

The weather conditions according to the UAV Forecast application data were good for conducting the raids (Figure 7). The temperature oscillated within 0°C (the lower temperature limit recommended by the manufacturer in the specification of the BSP used), and the wind speed was about 8 km/h (2.2 m/s, with a permissible wind resistance of 10 m/s) from the SW, with no precipitation and its probability, with full 100% cloud cover and visibility of 16 000 m. The KP index, indicating the radiation index of solar particles affecting the Earth's magnetic field, was 2 (its value within 1-3, or <4, indicates safe flight conditions). The number of visible satellites was 15 when it is assumed that 6 visible satellites is an acceptable number for GPS support.

The raid was conducted at two altitudes - 10 m AGL (initially with a 50 m long belay cable - a "tethered drone") and 30 m AGL. It was concluded that flying at a higher ceiling was too risky at this current stage of the research. The 10 m AGL ceiling represents conditions of not too difficult access to the reservoir with good visibility (grassy waterfront, low shrubs). A ceiling of 30 m AGL represents shoreline conditions with tall shrubs and/or trees.

The first autonomous (automatic) raid and water sampling took place using a shortened sampler (0.25 m) at a low ceiling of 10 m AGL under the belay of a 50 m cable ("tethered drone"). The sampler was attached to the BSP with a 5 m cable. The test went smoothly as expected. This stage of the research was successfully completed.

A second raid was also planned at 10 m AGL with a belay using the original 0.915 m long sampler. On take-off, the BSP was noticed to be unstable due to the size and weight of the sampler, which was the reason for stopping and terminating the research at this stage (no further raid was continued).

The third flight was carried out at 30 m AGL, without backup, with the shortened probe suspended on a 10 m line. The take-off of the BSP went smoothly. During the flight, rocking of the suspended sampler was observed. Problems with its immersion were also observed. The sampler loaded with the collected sample showed the most stability (less rocking).

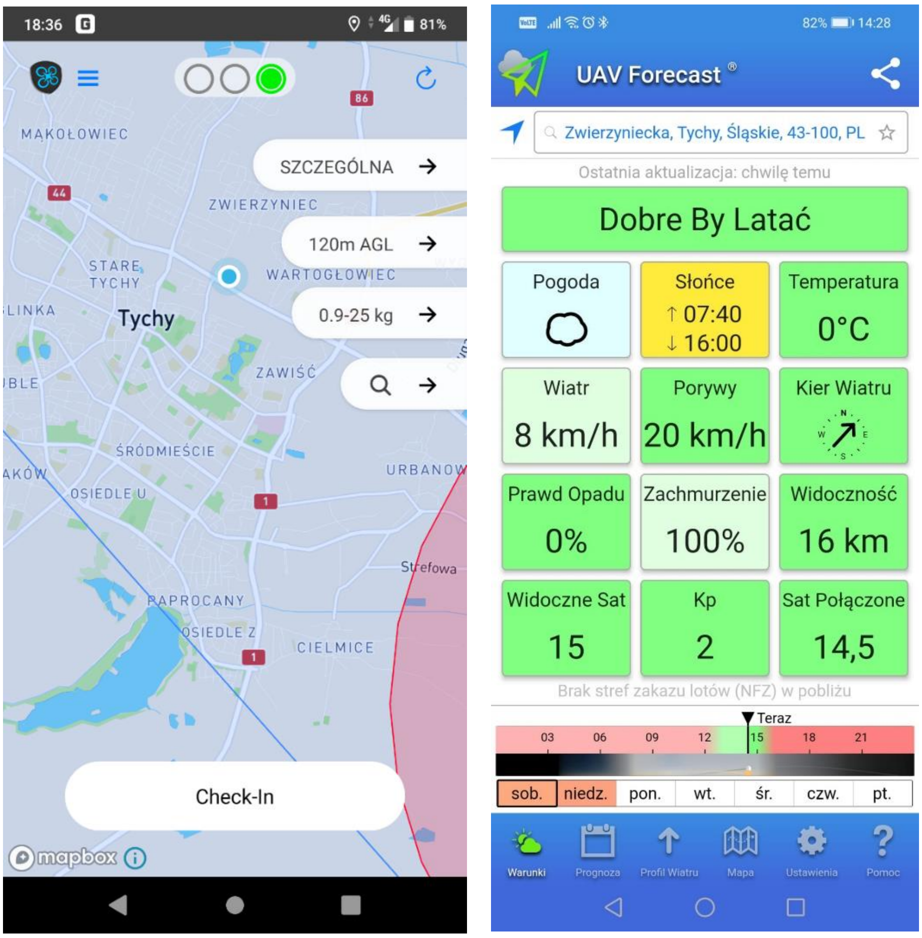

Fig. 7. Location in the DroneRadar application and weather conditions in the UAV Forecast application

Emergency situations (RTH - Return To Home procedure) were tested at a ceiling of 60 m. Observations of the drone and the suspended sampler behaviour (both original and shortened) do not recommend flights at such a high ceiling due to the observed flight instability caused by too much rocking of the suspended sampler (both types). Perhaps in stable (calm, windless) weather conditions, a "mission" at such a ceiling could be carried out, but based on the research, it is discouraged because of the issues of risk and safety of the pilot, the drone and the transported sample.

5. CONCLUSIONS AND RECOMMENDATIONS

Serially produced BSPs cannot and do not provide equipment dedicated to specialised requirements. These deficiencies are, however, satisfied by a well-equipped and rich market of drone accessories which can be purchased as finished products or manufactured by ourselves, for example, in the form of elements printed using 3D printing technology. Each of these elements can be adjusted to individual needs and expectations, as well as to a given model of a drone - this refers to the size (dimensions) of such an element, size (diameter), and number or placement of additional holes.

Sampler models available in the market are not fully developed for applications involving the topic of testing. They are suitable for them after certain modifications related to the change of their dimensions (length) and weight. Too long makes it difficult (if not impossible) to fly the BSP - especially during the take-off and landing phases, too heavy makes transport impossible.

The weather plays a major role in the transport aspect. If temperature issues (0 to 40°C) can be ignored by following the BSP specification, the resistance to wind speed (10 m/s), which relates to the flight of the drone, causes significant difficulties during transport, as the specification does not cover such actions. Observations made during this study indicate the need for further research focused on the effect of wind speed on the transport of objects by drone, including the effect of the length of the cable on which the sampler is suspended.

The autonomy of BSP flight depends on two factors: the drone model and the relevant application. Not every drone (even with the right payload) works with applications that provide the ability to perform "missions". The analysis of the software market allows us to state the presence of several basic programs that count in the design of autonomous (automatic) flights. The combination of DJI Pilot and DJI Phantom 4 Pro used in this study seems to meet the expectations of accuracy, as well as intuitiveness, ease and simplicity of conducting this study.

Based on the flights carried out, flights at higher altitudes are associated with a risk of instability (which was considered in the initial assumptions) and are therefore not recommended unless necessary. The positive results obtained for a ceiling of 10 m AGL suggest that, if possible, this altitude is sufficient for the operations in question. Limitations on the flight ceiling are, of course, related to the reservoir boundary conditions. Hence, the need for field vision (or at least map analysis) arises to select the most suitable place to perform the "mission". It is absolutely recommended to perform flights within visual range (VLOS), especially as they are performed over the water surface.

In addition to the aspects related to meeting the environmental standards mentioned in this article, one should not forget about the issue of the current legal regulations on the performance of BSP flights - respecting the separated geographical zones, having the appropriate BSP pilot privileges, having the required approvals and permits to perform the flight, etc. [10, 11].

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