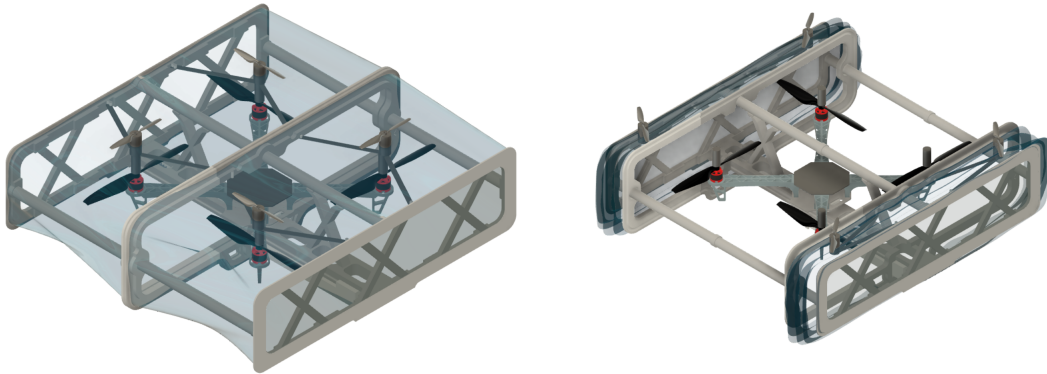


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A UAV-UUV Transformative Housing for Minimal Logistics Underwater Exploration

Tsai Chung Hsuan, Armagan Elibol, and Nak Young Chong



Transformative waterproof housing case in UUV mode (left) and UAV mode (right).

Abstract—Robotic vehicles that can operate in an underwater environment (*e.g.*, Unmanned Underwater Vehicles (UUVs), Remotely Operated Vehicles (ROVs), and Autonomous Underwater Vehicles (AUVs)) have been drastically improved over the last two decades. Several different areas have been benefiting from their usage. However, their usage and deployment are still both labor and expertise-intensive. They needed to be transported by vessels to the deployment area. Similar to underwater robotics, Unmanned Aerial Vehicles (UAVs) have been able to accomplish several tasks in our life, and the scope of their usage is extensively diversified. In this paper, a preliminary design of a robotic case for UAVs that allow them to operate in the underwater environment as well is presented. This robotic case is composed of a moving waterproof outer cover controlled by a servo motor. This allows the case to be open while operating in the air and closed while it needs to operate in the underwater environment. There is also an additional propeller designed to provide the diving ability to different depth levels. This robotic case is intended to be generic and suitable to be used with most of the existing UAVs without modifying aiming to add a capability to operate in the underwater medium.

I. INTRODUCTION

Thanks to increased research efforts on UAVs, UAVs are now capable of realizing different tasks beyond aerial video and image capturing. However, there is a still high demand for multi-task/purpose transformative platforms to be employed under different conditions especially capable of operating both in air and underwater (*e.g.*, inspection task for off-shore floating wind turbines). Although there are robotic vehicles operating in an underwater medium [1], [2], [3], [4] and air separately, there are very few studies

on developing an aerial and submersible vehicle that can operate in both [5], [6], [7], [8]. Such combined vehicles will greatly reduce the deployment and logistics problems (such as transportation to the deployment location, expertise, time, and manpower requirements, and similar others) of underwater robotic vehicles.

The main objective of this research is to design a transformative robotic case that can enable UAVs to dive and navigate in the underwater environment autonomously. This waterproof case will provide a submersible exploration capability to UAVs so that it can also realize some data collecting tasks (water sampling, optical data gathering, and many others) in an underwater environment. This robotic case is designed to be able to open and close autonomously by a servo motor according to circumstances. When it needs to operate underwater, the robotic case will reduce the buoyancy by the use of the pumping motor, and the additional propeller will provide the power to the robotic case to be able to dive in different depth levels.

II. RELATED WORKS

Most existing studies using UAVs for underwater investigations are focused on carrying exploration and sampling instruments [9], [10], [11]. UAVs used in their research are mostly off-the-shelf and not waterproof. Some of them can float only on the water and deploy the instruments into the water to investigate and collect data or samples. This kind of design has no demanding requirement for UAVs as they are solely used as a carrier of transportation. This makes the investigation range very limited and cannot be employed for different depths of water at the same time.

In some studies [5], [6], [8], it was focused on retrofitting UAV so that it has the capability for water-resistance and let the UAV do transition smoothly between air and water.

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But it is difficult and time-consuming. The research proposed in [7] is the most closely related research to our proposal in this paper. It was aimed to make the UAV waterproof by 3D printing waterproof case. However, the main drawback is that the waterproof case is not generic and targeted to the specific UAV. Also the propeller and motor that are designed to be outside of the waterproof case also need waterproof housing.

To overcome these problems, we propose to design a generic robotic waterproof case to allow UAVs to operate inside the water. Our novel design avoids the necessity of retrofitting the UAV and it can be used with most of the off-the-shelf UAVs endowing them with the capability of collecting data from different depth levels.

III. UAV-UUV TRANSFORMATIVE DESIGN

Our cooperative mechanism design is composed of 3 different parts; Main Body, Structural Design, and Operational Design.

A. Main Body Design

The main body (as shown in Fig. 1) is composed of two groups of sliding parts, two groups of non-sliding parts, two sets of the waterproof sleeve that can be stored and folded, four additional propellers, two sets of racks, one gear, one servo motor, one sampling motor, and one Pressure Altitude Sensor (PAS).

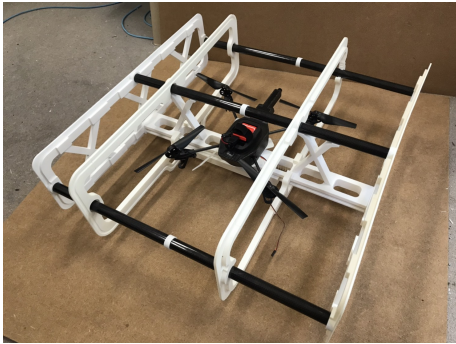


Fig. 1. Main body design of the transformative waterproof housing case with UAV.

There is a linkage between additional propellers and groups of sliding parts. In the UAV mode (the case is open), the additional propellers will move together with the case synchronously in order not to affect the UAV flight. In the UUV mode (the case is closed), additional propellers will work with the UAV's propeller together as they are connected to each other with a magnet. When the robotic case is closed, the pumping motor will pump water to the bags, which are designed to store water inside the case. As the water is being pumped, the bags will expand its dimensions. This will allow the case neither to be deformed due to the water pressure outside the case. The additional propeller will not be affected by buoyancy so that it can move in the water without requiring much force. Two groups of sliding parts are respectively equipped with rack that can be used with gears to open and close the case. When the robotic case is to be transformed to the UAV mode, the gear connected to

the servo motor starts to rotate and moves the rack to let the case open (as shown in Fig. 2). To be transformed to the UUV mode, the gear connected to the servo motor will rotate in the opposite direction to let the robotic case close (as shown in Fig. 3).

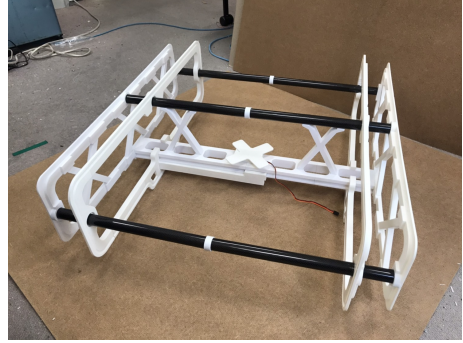


Fig. 2. UUV mode: the sliding parts on both sides are moving towards the center to be closed.

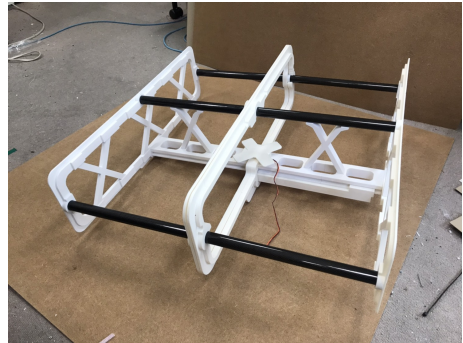


Fig. 3. UUV mode: the sliding parts on both sides are closed.

B. Structural Design

In this research, we used Inventor and SolidWorks software to design the robotic waterproof case for UAVs. We used a 3D printer with 15% infill density and full honeycomb patterns to print all parts using Polylactic Acid (PLA) material. The weight of the robotic case is currently 1Kg while the existing available UAV is also 1Kg. We estimate most UAVs with a payload of 3kg can carry this robotic case. The challenging point in this research is how to dive the specified depth, and maintain the specified depth until the data collection task is completed, then transport the sampled data back to the mission control center. On the way to dive in the water, there might be disturbances by water flow or other forces. In order to overcome such problems, the additional propeller and PAS are planned to be incorporated into the system. Additional propellers will be connected to the UAV's propeller, and this connection is designed using the ratchet mechanism controlled by propellers of UAV. This way of connection allows propellers to work in a single direction. In UUV mode, the servo motor will rotate on the opposite side, only driving additional propellers to move in the water while keeping UAV's propellers not moving. To avoid the wind in a closed area generated by the propellers of UAV (that

might also affect the attitude of UUV), this design allows keeping the air inside the case and this allows stabilizing and maintaining an attitude of UUV. Thanks to this design, there is no need for an additional controlling unit dealing with the wind problem. In order to deal with underwater disturbances and smooth operation of UUV in a horizontal direction, one side of the propellers is designed to generate more force.

C. Operational Design

For the case opening and closing functions, we use a servo motor to control. When diving into the specified depth, we use the propeller and PAS providing the current depth and maintain a specified depth. The pumping motor is used to draw water samples and other sensors attached to collect data. For the control, Arduino Single Board PC is used and necessary software will be developed in Python programming language environment. Since the commands cannot be transmitted in the water, before diving into the water, the targeted depth will be set and, then the robotic waterproof case will use this information to automatically complete the task.

IV. CONCLUSIONS

Over the last several decades, the research on UAVs has been prevailing and extensively diversified in terms of both its scope and depth. In this paper, we presented a preliminary mechanical housing design that allows off-the-shelf UAVs to go from air to water and vice versa with minimal logistics costs. The presented design is composed of two groups of sliding blocks and two groups of non-sliding blocks, covering the housing with waterproof material. The proposed design would make UAV accomplish a variety of underwater explorations in an efficient way such as rescue and salvage missions, underwater topographic surveys, and many other similar purposes. The validation of the proposed design will be confirmed through real-world experiments.

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