Development of an Unmanned Surface Vehicle for Harmful Algae Removal

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Abstract

In this paper, we introduce a small and low-cost unmanned surface vehicle (USV), the *SMARTBoat 5*, capable of removing harmful algal blooms (HABs), which are a rising environmental issue worldwide. The proposed USV is a hovercraft type, operated by two propellers with duct fans; it is able to freely move even in shallow water and to approach shorelines. For eco-friendly, immediate, and safe control of algae without ecosystem disruption, the USV is equipped with a novel water suction mechanism that enables it to actively collect algae without physical contact. In addition, it is equipped with a mesh net-based filter system that is easily disassembled and replaced. The USV system is supported by the Robot Operating System (ROS) for expandability and use in diverse applications. Also, the performance of the proposed water suction mechanism and USV platform overall are validated through computational fluid simulation (CFD) and experiments in both lab and real environments.

Keywords

Harmful Algae Bloom, Unmanned Surface Vehicles, Computational Fluid Simulation, Robot Operating Systems, Successive Linear Programming

Introduction: Harmful Algal Blooms

In recent years, algal blooms happen frequently due to an increase in pollutant sources and a rise in temperature from climate change. They affect water quality and ecosystem, and lead to community complaints, the death of aquatic organisms, and water odor, and cause a lot of expenditures to resolve this environmental issues [1]. Although it has negative effects, algae play a necessary role in aquatic environments as prey of fish and plants in the food web [2].

Example of the HABs issues

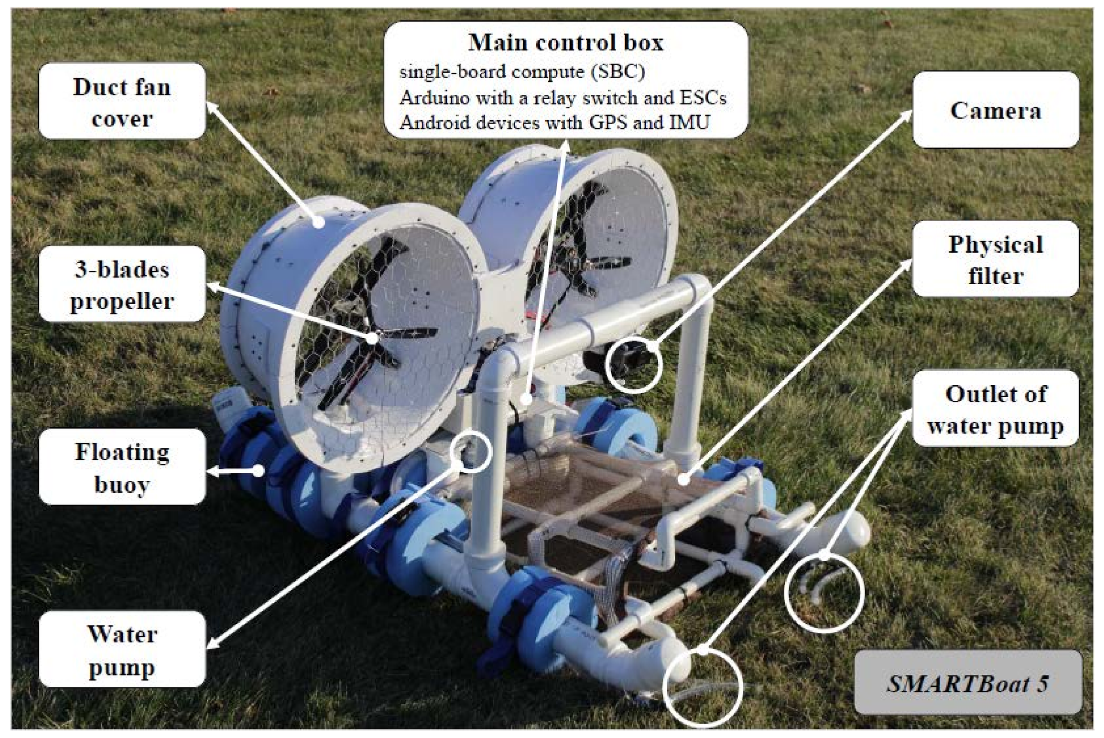
References

[1] Hoagland, P., & Scatasta, S. (2006). The economic effects of harmful algal blooms. In *Ecology of harmful algae* (pp. 391-402). Springer, Berlin, Heidelberg.

[2] Chapman, R. L. (2013). Algae: the world's most important "plants"—an introduction. Mitigation and Adaptation Strategies for Global Change, 18(1), 5-12.

USV for Harmful Algae Removal

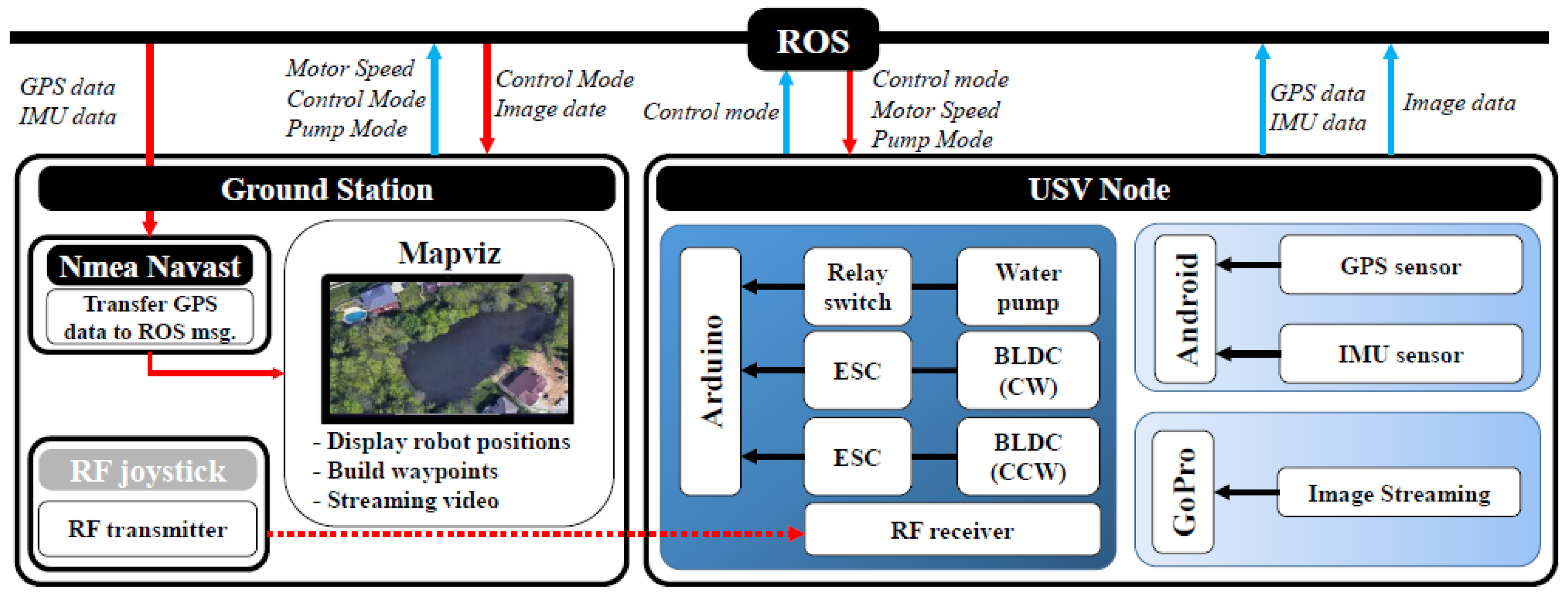
➢ USV for Harmful algae removal: *SmartBoat 5*



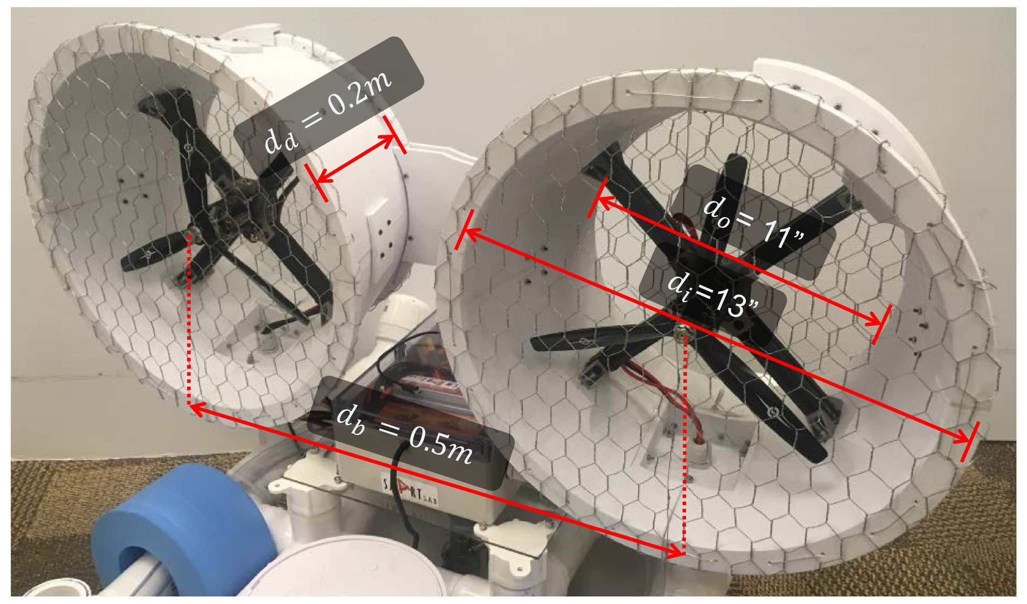
Type	Hovercraft
Size (LxWxH)	1.04x0.99x0.59m
Weigh	15 kg
Static Thrust	10 kgf
Max Speed	0.2 m/s
Operation hour	About 1 hour
Carrying capacity	0.033 m^3
Sensors	GPS, IMU, Camera

<Download the design files and source codes>

➢ System supported Robot Operating System (ROS)



Low-cost 3D-Printed Duct Fan Design



Details of the 3D-printed duct fan

Successive Linear Programming (SLP) optimization

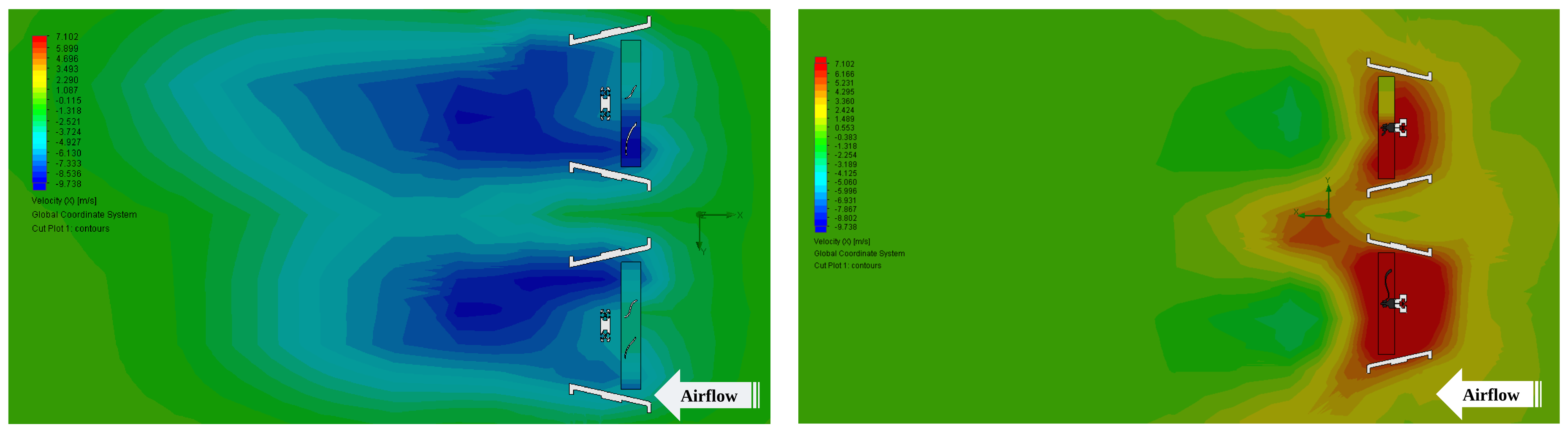
$$\begin{aligned} &Minimize\text{:} f(d_i, d_o) = 1 - \eta_p \\ &Subject\ to\text{: } g_1(d_i, d_o) = d_{i_{min}} \leq d_i \leq d_{i_{max}} \\ &\qquad g_2(d_i, d_o) = d_{o_{min}} \leq d_o \leq d_{o_{max}} \\ &\qquad g_3(d_i, d_o) = r_{min} \leq \frac{d_i}{d_o} \leq r_{max} \end{aligned}$$

To minimize losing the efficiency of the duct fan by determining its outl and inlet dimensior

$$\eta_p = \frac{P_{flight}}{P_{fan}} = \frac{T \times \omega}{P_{loss} - P_{gain}} \quad (1)$$

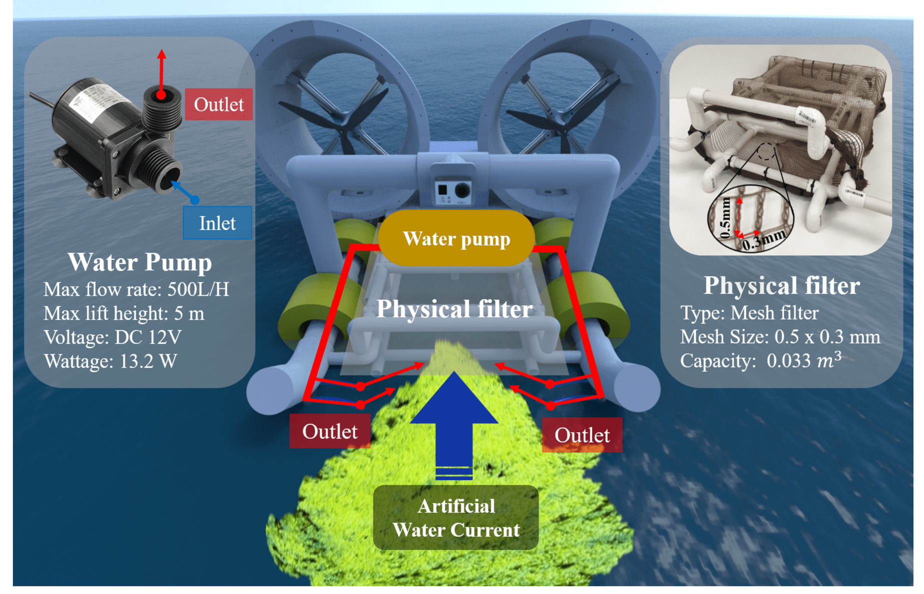
$$P_{loss} = \frac{\nu_e^2 d_c^2 \frac{\pi}{4} \omega \rho}{2} \quad (2)$$

$$P_{gain} = \frac{M}{2} \times \omega^2 \quad (3)$$

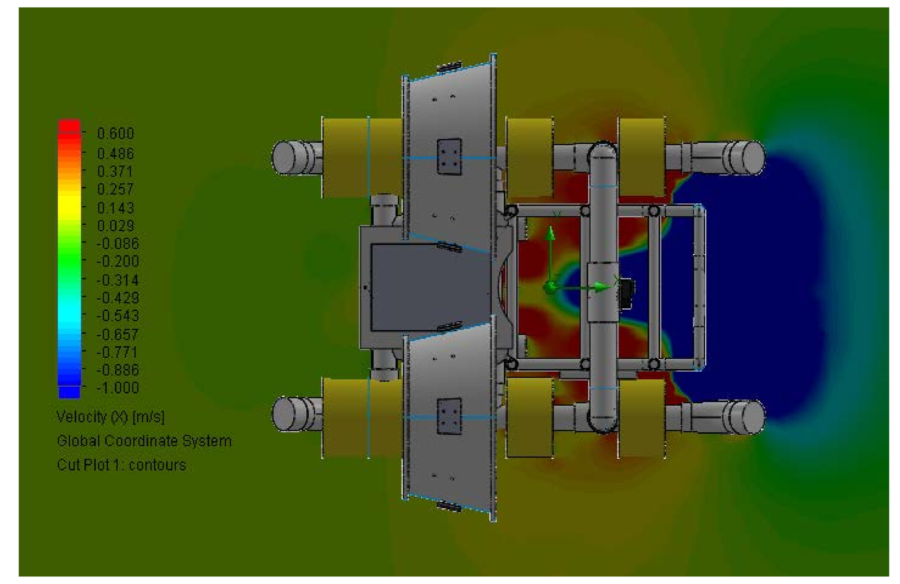


CFD analysis of the 3D-printed duct fans (left: moving forward, right: moving backward)

Eco-friendly Water Suction Mechanism



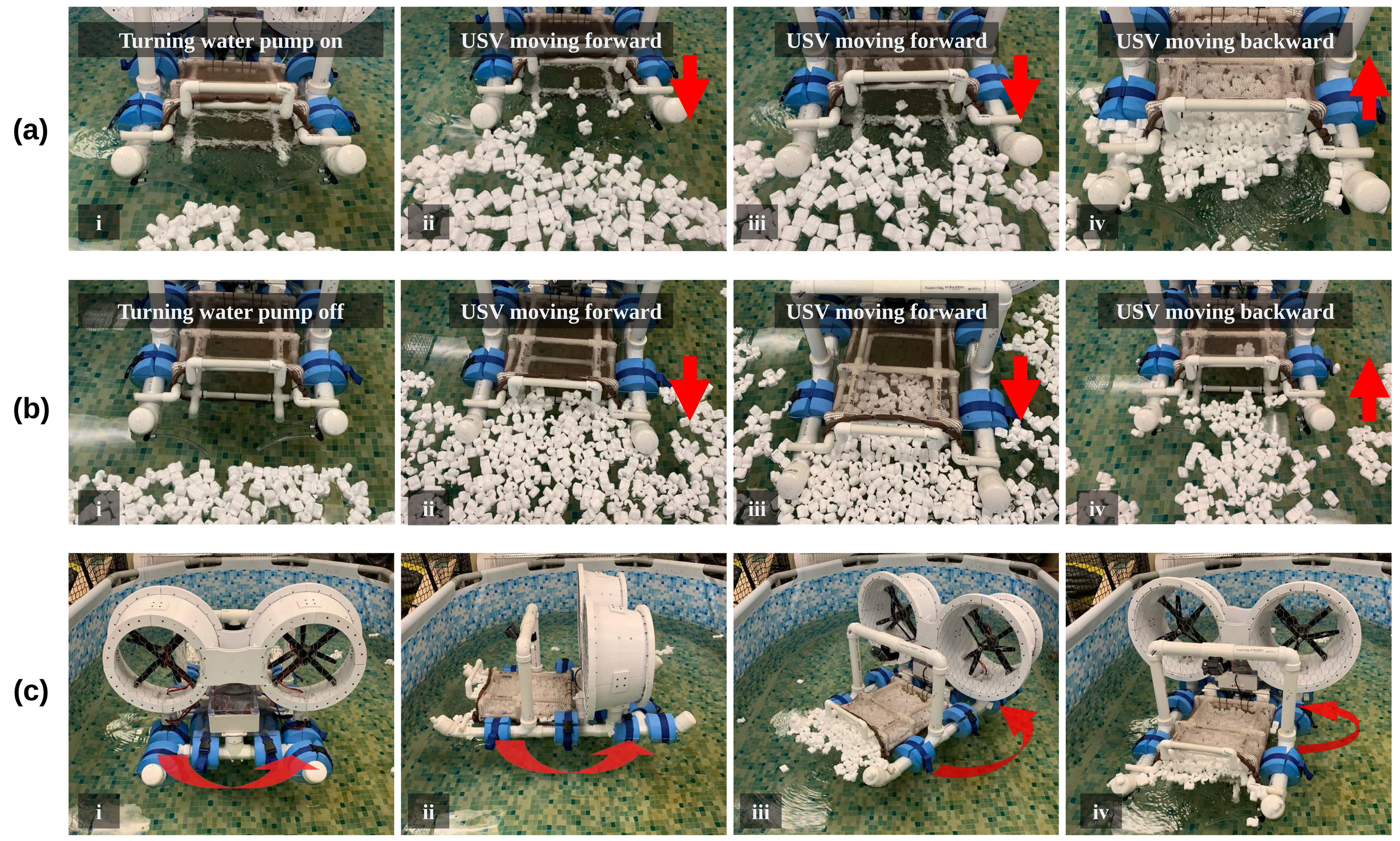
Water suction mechanism diagram



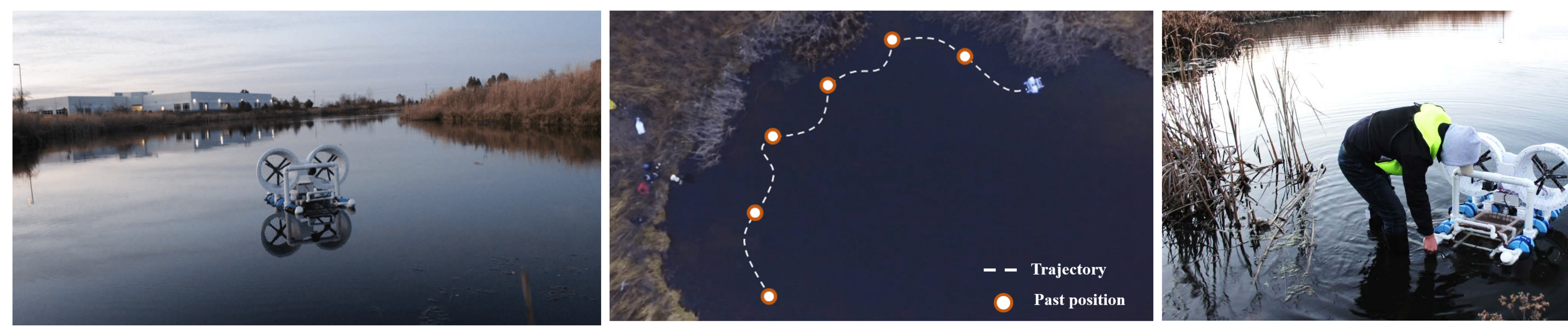
CFD analysis of the wat suction

Experiment and Results

➢ Water suction mechanism tests



➢ Usability Tests in real pond



Usability tests at Purdue Research Park, West Lafayette, IN USA

Future Works

- Enhance the control system to deal with increasing mass of the platform due to the collection
- Develop a multi-robot team to overcome the storage limitation and to cover lager areas

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