Design of a Buoyancy Control System for a Miniature Aquatic Robot

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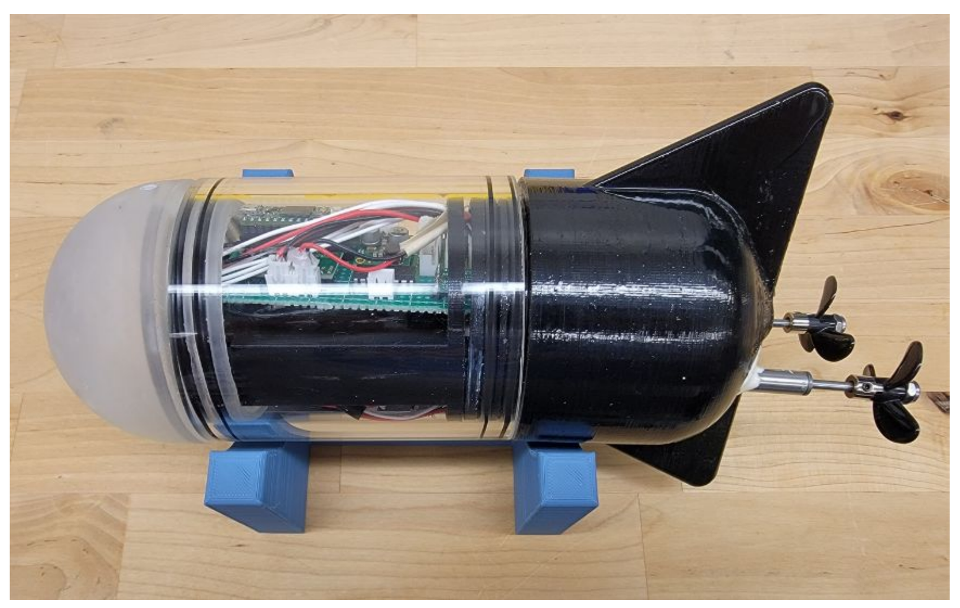
Introduction

- A buoyancy control system (BCS) allows precise buoyancy adjustments of an uncrewed underwater vehicle (UUV), enabling control over its vertical position underwater.
- BCS units tend to be large and heavy, limiting their integration into smaller submersible systems used for collecting data in shallow or constrained underwater environments. Compact BCS units are critical for accurate data collection in these environments.

Objectives

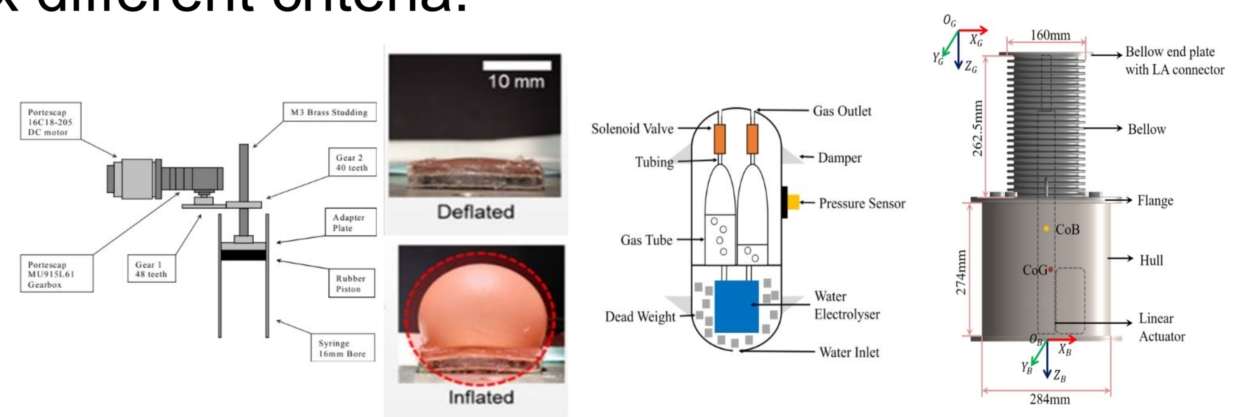
- This research aims to design a compact, modular BCS unit that can be incorporated into a larger system of miniature aquatic robots rated to operate at pressures of five meters depth and have a safety factor of two.
- The goal was to design a BCS that's smaller and more efficient than the one used in the MicroUUV, a previous ARSL student project designed by Jacob Herbert.



MicroUUV used for comparison in this research

Methods and Data Collected

- Several buoyancy control methods were evaluated before one was chosen for further research. Using a 5-point scale, each method was scored based on six different criteria.

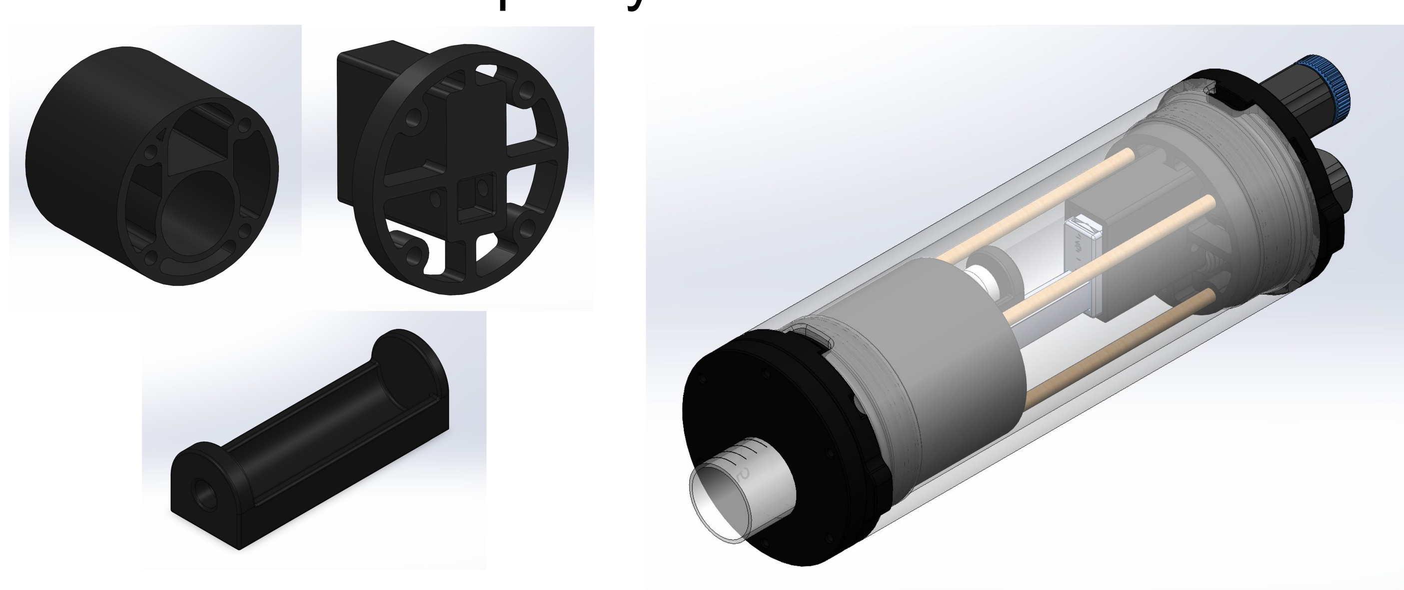


Examples of buoyancy control methods evaluated

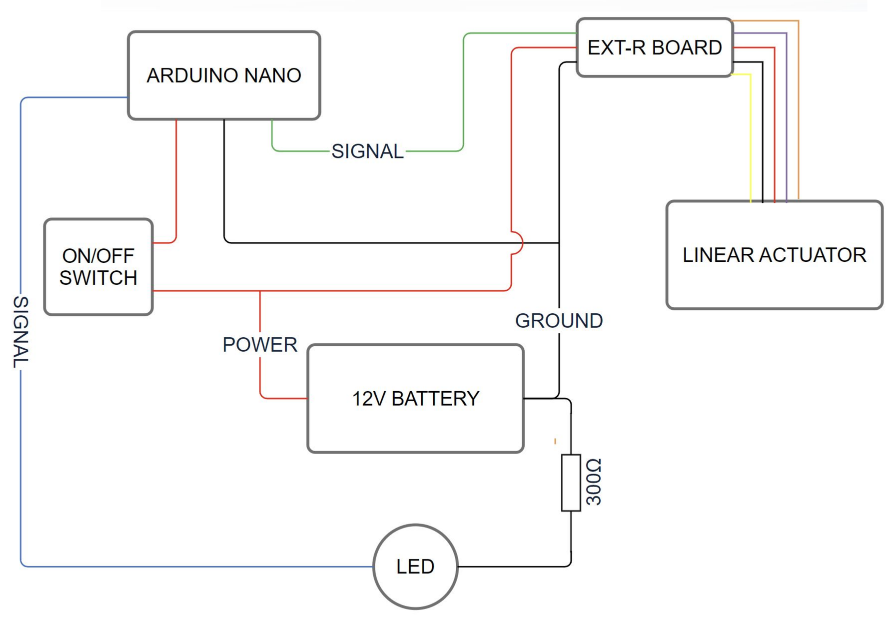
Decison Matrix	MicroUUV (Control)	LA & Syringe	Water Electrolysis	LA & Bellow	Thermal Phase Change
Volume	1	5	5	5	5
Mass	1	5	5	5	5
Speed	1	2	1	3	3
Complexity	4	5	2	4	3
Novelty	1	2	4	3	4
Controlability	1	4	2	2	2
Score	1.500	3.833	3.167	3.667	3.667

Decision Matrix

- Design analysis determined a linear actuator and syringe system would work best. The components chosen for this system were a linear actuator with a 75mm stroke length and maximum force rating of 35lbs, a 20ml syringe, and an Arduino Nano.
- SOLIDWORKS was utilized to design a 3D printable frame which compactly mounted all BCS internals.



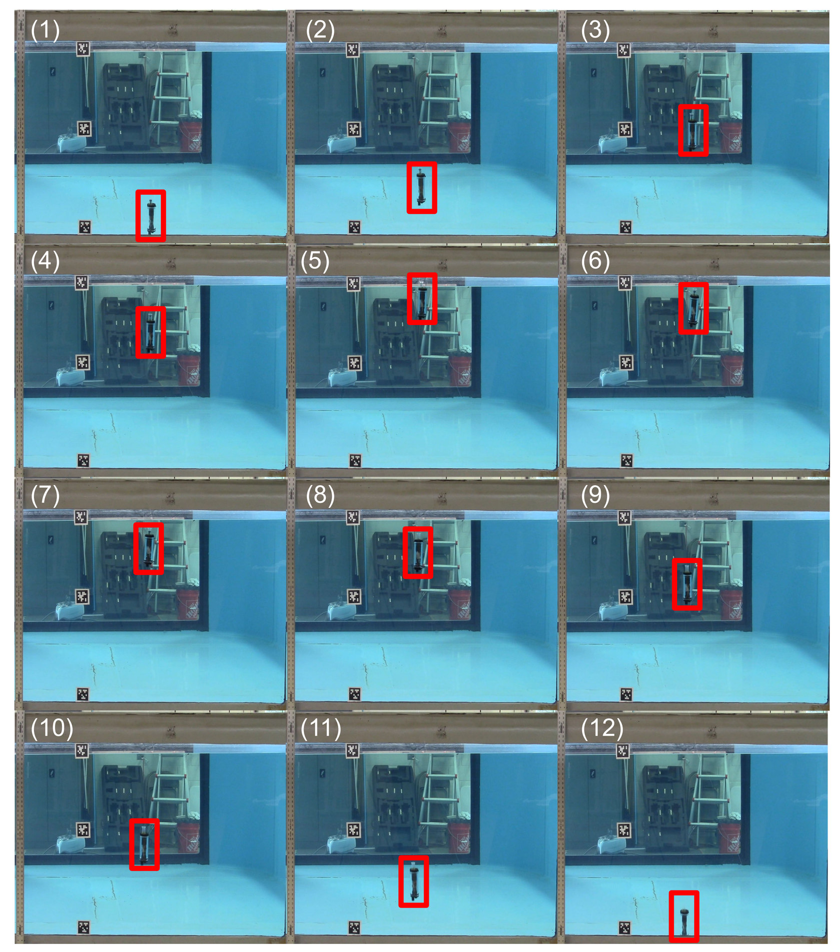
Examples of CAD

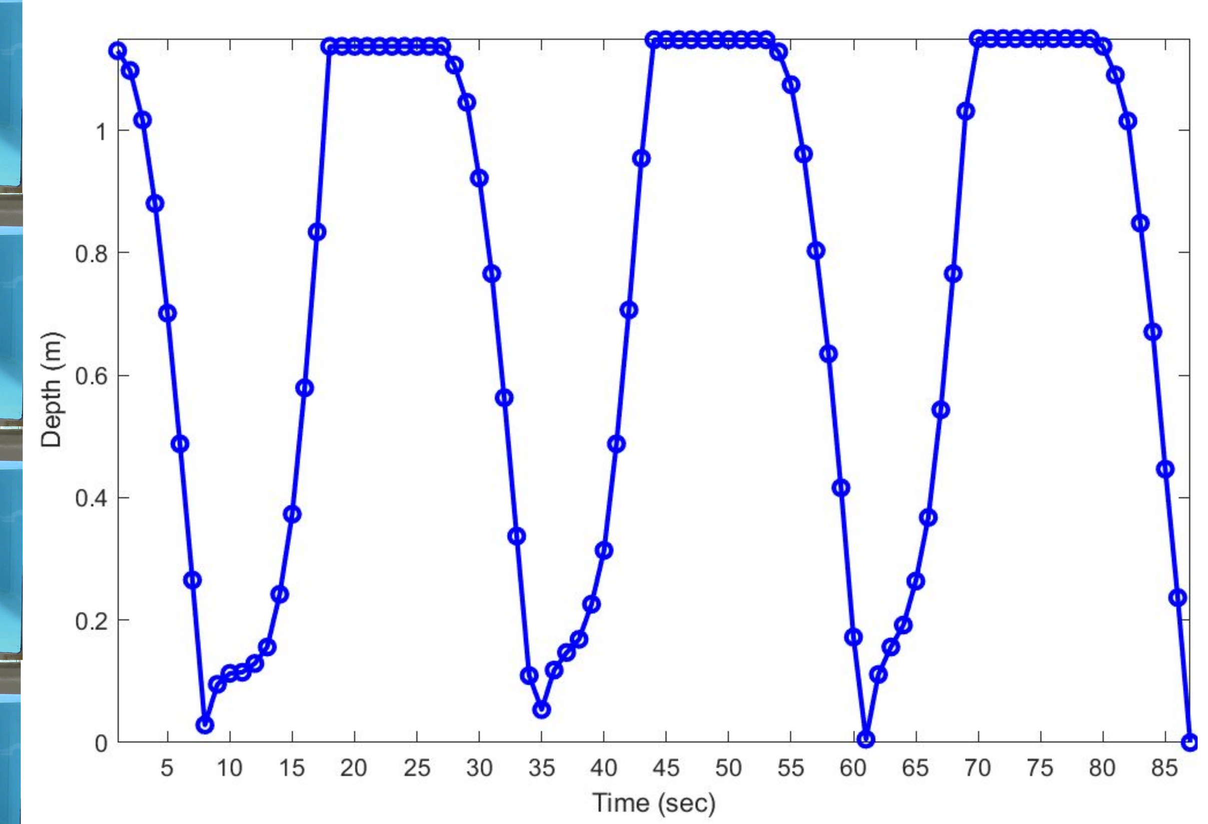


Wiring schematic for electrical design work

Results

- For testing, the UUV was fully assembled, placed in the BATT CAVE's 5,000-gallon water tank, and commanded to run a simple test of sinking and rising. The depth data collected was analyzed to produce a plot describing the rate at which the BCS changes depth of the UUV over time.





Left: 12 frames of the UUV changing its buoyancy (first 6 rising, second 6 sinking)
Right: Experimental UUV depth versus time data plot showing three cycles of sinking/rising

Conclusions

- A BCS was designed and tested. Testing characterized the efficiency of the BCS and proved that it could achieve one cycle of rising and sinking in 18-20 seconds and operate continuously for about 580 cycles before running out of power.
- The focus for the future of this research is on creating a BCS that's able to be incorporated into a larger system of miniature aquatic robots. These compact, lightweight BCS units are essential for precise movements, maximizing payload capacity, energy efficiency, and scalability, enabling optimal performance and cost-effective production of the robot system.

References

- A. Keow, Z. Chen and H. Bart-Smith, "PIDA Control of Buoyancy Device Enabled by Water Electrolysis," in IEEE/ASME Transactions on Mechatronics, vol. 25, no. 3, pp. 1202-1210, June 2020, doi: 10.1109/TMECH.2020.2968322.
- Stinchcombe, Fred & Horsfield, Ian & Melhuish, Chris & Irgens, Chris. (2001). Toniwha-bot: Towards Energetically Autonomous Marine Sensing.
- Lee, J., Yoon, Y., Park, H., Choi, J., Jung, Y., Ko, S.H. and Yeo, W. (2022), Bioinspired Soft Robotic Fish for Wireless Underwater Control of Gliding Locomotion. Adv. Intell. Syst., 4: 2100271. https://doi.org/10.1002/aisy.202100271
- T. Ranganathan, V. Singh and A. Thondiyath, "Theoretical and Experimental Investigations on the Design of a Hybrid Depth Controller for a Standalone Variable Buoyancy System—vBuoy," in IEEE Jo urnal of Oceanic Engineering, vol. 45, no. 2, pp. 414-429, April 2020, doi: 10.1109/JOE.2018.2875576.