

# Autonomous Modular Water Sampling System

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**Abstract**— In-situ water sampling systems are often large, cumbersome, and costly. The objective of this project was to create a low-cost, standalone system to autonomously gather a sample of water at prescribed depth. Based on review of existing systems, a specific need was identified for an affordable system for academic usage onboard a variety of payload delivery vehicles. Ease of use, low cost, and attritability were valued in the design process. The developed system consists of a syringe, linear servo, depth sensor, and an enclosure obtained from Blue Robotics. The system can gather a 45ml sample once at depth and can be attached to remotely operated vehicles, or other delivery systems. This paper summarizes design, construction, and testing of the prototype system.

**Keywords**—Autonomous, Modular, Water Collection, Robotics, Environmental Testing, Underwater Equipment, Underwater Technology

## I. INTRODUCTION

This paper offers details on the design and construction of a modular, affordable, autonomous water collection device utilizing a syringe system. The result of this effort is a device that can be attached to a wide range of crewed and uncrewed delivery platforms for retrieval of a sample of water at a prescribed depth without the use of a human operator. The system is power and control independent from its host platform to enable versatility in deployment options. The paper provides further detail on the design and fabrication process, software, test results, and opportunities for improvement and further development in future work.

This project was completed as part of a 10-week Research Experiences for Undergraduates (REU) supplement to an NSF-funded project on maritime robotics. The research experience began with a comprehensive literature review. Numerous existing solutions were reviewed and helped inform the design of the prototype system. Many of the systems reviewed were implemented on surface or subsurface vessels and utilized either a syringe system on a motor to gather their sample, a

gulper system which is also a syringe system however it is a spring-loaded system rather than a system on a motor, or pump systems. A smaller subset of systems gather samples via Unmanned Aerial Vehicles (UAVs). A brief overview of these systems and their applications is as follows.

### A. Overview of syringe systems

For example, in [1], Sepulveda placed a 25mm puck filled with filter material into the water, valves are opened on the puck, and the internal syringe pulls water samples through. Once a full sample is gathered, the filtering process is stopped and all the excess is purged from the system and an additive is added before the puck is placed in storage. In [2] and [3], the research team prioritized creation of a small, person-portable autonomous surface vessel capable of collecting samples up to 50 m depths alongside in situ water quality measurements. The system described in [4] utilized a catamaran capable of collecting and storing up to 60kg of water samples. The team in [5] developed an Optical Phytoplankton Discriminator (OPD) and equipped a REMUS Autonomous Underwater Vehicle (AUV) with it, to monitor harmful algae blooms. The system described in [6] also utilizes a syringe system for collecting up to 49 200-mL samples at ocean depths. Stoker *et al.* in [7] describe an AUV that collects 8 water samples using syringes as well as gathering a soil sample using an arm and a sample box. In [8], a sampling system is implemented on an AUV comprised of a syringe system on a magazine; that study prioritizes affordability seeking to develop an affordable solution for researchers who do not require commercial level capabilities. Pargett *et al.* in [9] describe a UAV with an in-situ ecogenomic sensor system deploying the Monterey Bay Aquarium Research Institute (MBARI) developed Environmental Sample Processor (ESP), which serves as a lead-in to MBARI-developed gulper systems as described in the next subsection.

### B. Overview of gulper systems

MBARI developed what they term a gulper-style system which can draw 10 1.8L samples and is transported aboard a REMUS 600 AUV [10]. These gulpers can be individually triggered via an onboard computer to collect samples. This system has been used for in situ and ex situ studies of various topics in marine ecology [11-14]. Wulff and colleagues at the Alfred Wegener Institute for Polar and Marine Research (AWI) developed a similar gulping-type system for use aboard a Bluefin Robotics AUV [15]. Their system collects 22, 220 ml samples and has been demonstrated in arctic environments [15-16].

### C. Pump Systems

A sample pump system is presented in Brier *et al.* [17] with a characteristic use case in Govindarajan *et al.* [18]. Much like the MBARI gulper systems, the pump system was attached to a REMUS 600 vehicle. The system, dubbed Suspended Particulate Rosette (SUPR) is capable of filtering 30-100L samples rapidly.

### D. Overview of UAV systems

Koparan *et al.* [19-20], deploy a UAV that uses what they refer to as a “thief style” water sampler system. The UAV hovers over specified coordinates, drops a water sampler, followed by water capture and return to home coordinates for the UAV, with the water sample in tow. Furthermore, Doi *et al.* conduct eDNA sampling via a UAV using a similar dropped sampler approach in [21]. Alternatively, Ore *et al.* [22] deploy a UAV that rather than dropping a sampler, pumps 3 20ml water samples into mounted vials.

It is worth noting there is also considerable literature on in-situ sampling, some with samples collected in parallel as described previously. A comprehensive overview on the state of the art of in situ sampling is provided in [23] and a literature search on remote sampling by AUV is in [24]. Lastly, we note a novel application of a minimal power consumption balloon AUV sampler by Sung and Yu in [25]. Their emphasis on sampling the water column vertically, simply and efficiently in an almost glider-like manner provides significant inspiration for this effort.

With this background, and recognizing the wide array of implementations ranging from shallow to ocean depths, deployment aboard surface and subsurface vessels, spectrum of cost ranges from high performance commercially integrated solutions to more academic budget-oriented tools, an opportunity was identified for a low-cost, simple, modular water sampling system, that a user could then adapt for their specific academic application, and it was perceived that a syringe system would be ideal to meet these goals.

## II. DESIGN AND FABRICATOIN

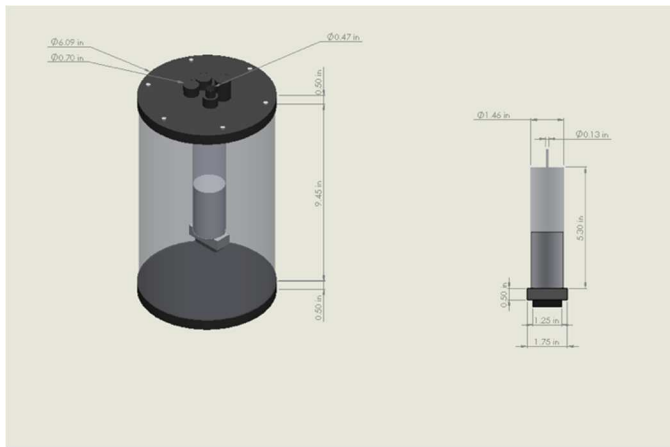
The Autonomous Water Sampling System (AWSS) documented here is designed to be a low-cost, academic-use water sampling system. Modularity, ease of deployment, and

affordability were high priority versus many of the commercial solutions documented in Section I. A Blue Robotics watertight 75x240 mm acrylic enclosure rated for a maximum depth of 300 m [26] was selected as the system housing. To collect a water sample, a syringe, plunger, and motor system controlled via Arduino Pro Mini were repurposed from a SeaGlide [27] underwater glider kit. A Blue Robotics depth sensor [28] and I<sup>2</sup>C level convertor [29] were integrated into the system and the original SeaGlide code was modified to incorporate the depth sensor, allowing a sample to be autonomously drawn at a prescribed depth and released via remote-control once at the surface, as described further in Section III.

To protect the electronics compartment from water ingress, a vacuum plug [30] was epoxied to a M10 vent and plug [31], all acquired from Blue Robotics, and installed with the plug side to the interior of the pressure vessel to seal the system from the outside, while still allowing the syringe mechanism to draw a sample of water. In-water testing was conducted in a captive water tank as described in Section IV of this paper. Fig. 1 show CAD renderings of the system and a photo of the completed system with a remote controller. A wiring diagram for the system is provided in Fig. 2 The total system cost came out to be \$600, shown below in Table I. This met the desire for it to be sufficiently low-cost so as to be viewed as attritable.

Table I. Components and corresponding costs for AWSS

| Item (Quantity)                                       | Cost         |
|-------------------------------------------------------|--------------|
| Blue Robotics 75mmx240mm Acrylic Tube (1)             | \$179        |
| Blue Robotics 75mm Aluminum End Cap – 4 M10 Holes (1) | \$14         |
| Blue Robotics 75mm Aluminum End Cap –Blank (1)        | \$14         |
| Blue Robotics 75mm O Ring Flanges (2)                 | \$70         |
| Blue Robotics Pressure Relief Valve (1)               | \$28         |
| Bar30 High-Resolution 300m Depth/Pressure Sensor (1)  | \$85         |
| I <sup>2</sup> C Level Converter (1)                  | \$25         |
| Blue Robotics M10 Enclosure Vent and Plug (1)         | \$9          |
| Vacuum Plug (2)                                       | \$16         |
| SeaGlide Buoyancy Engine (1)                          | \$65         |
| SeaGlide Electrical and Power Supply (1)              | \$95         |
| <b>Total</b>                                          | <b>\$600</b> |



(a)



(b)

Fig. 1. (a) CAD renderings of system, (b) photo of as-built AWSS

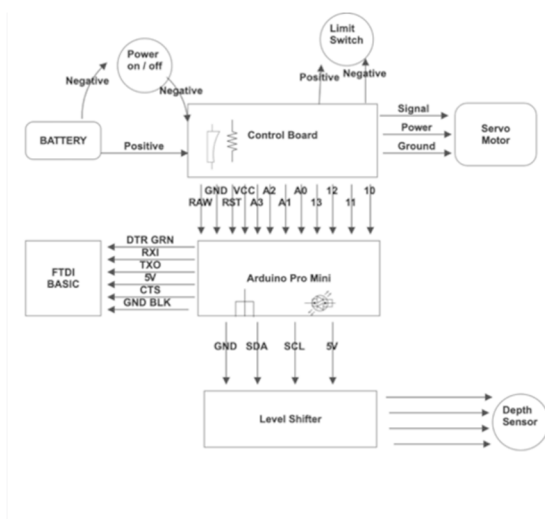


Fig. 2. Wiring Diagram

The wiring diagram, Fig. 2, illustrates the key electronic components for the AWSS. The control board distributes power from a 9V battery to all components including the

servomotor, power switch, and limit switch, which was used to let the system know that the plunger has reached the syringe limits. The Arduino Pro mini was used to store the augmented SeaGlide code, described further in Section III, as well as gather digital data from the IR sensor and the I<sup>2</sup>C level shifter and distribute the functions to the control board to execute. The IR sensor was a component that came with the SeaGlide electrical and power supply kit. This sensor was incorporated into the AWSS so that handlers would be able to extract the collected sample without the need to take the system apart. The I<sup>2</sup>C level shifter was necessary to run the Bar30 depth sensor because it utilizes 3.3V whereas the Arduino pro mini utilizes 5V. The Bar30 depth sensor was chosen for this system because it was compatible with the Blue Robotics enclosure keeping the system watertight, and can not only read depth but also: pressure, temperature, and altitude, which enables future capability expansion. Blue Robotics offers two other variants, a 2-bar and a 100-bar, however for the purposes of this system the 30-bar variant was deemed more than sufficient for the anticipated maximum depth of 5m. An RGB LED was added to the system to indicate what functions were being executed. Red indicates a sample being drawn in, green indicates a sample is being dispensed, and purple indicates that the system has entered a standby mode. Standby mode is the setting the system enters once the play/pause function has been selected and the system's autonomous functions are executed until a sample has been retrieved. Once the sample has been retrieved the servomotor is disengaged and the system waits for user input to dispense the acquired sample.

### III. SOFTWARE

Fig. 3 and Fig. 4 show the logical flow of the system. Once the system is powered on, a setup process is launched. This process leverages the setup processes provided by SeaGlide [27] coupled with code from Blue Robotics to initialize the Bar30 sensor [28]. Once the sensor is initiated, the Blue Robotics code was edited so that the plunger is pulled back all the way until the limit switch is activated, disengaging the servomotor. The servomotor is then reengaged and the plunger is then pushed back until the plunger bottoms out at the front of the syringe. This concludes the device setup. At this point, the operator utilizes the play/pause function on the remote control, included with the SeaGlide electrical and power supply components, to engage a custom script for autonomous functionality. The autonomous functionality commands the system to enter the standby mode until the depth sensor reads the prescribed depth, at which point the software sends a command to draw a 45 ml water sample.

The software configuration is designed in this manner such that samples can be collected from a delivery vehicle with minimal operator involvement. Once the delivery vehicle reaches the prescribed depth, the system will exit standby mode and retrieve a sample. Once the sample has been obtained the system reenters its standby mode until manually

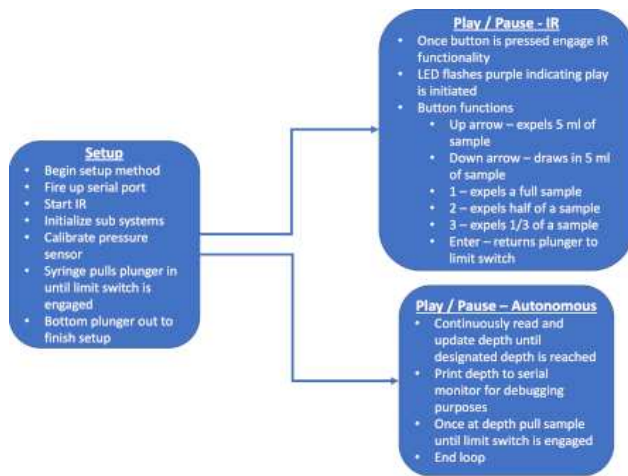


Fig. 3. Pseudocode

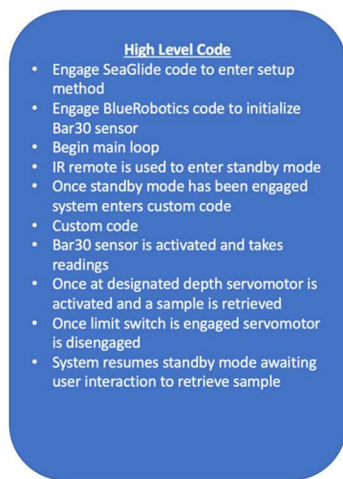


Fig. 4. High Level Code Architecture

retrieved from the delivery vehicle. Once retrieved, the user can expel a sample from the system using the IR remote.

Specifically, on the IR remote, button 1 expels a full sample, 2 expels a half sample, and 3 expels 1/3 of a sample. The IR remote also enables manual sample collection via the up and down arrows, which command the system to either dispense or gather 5 mL worth of a sample, respectively. The IR remote's 'enter' command instructs the system to pull the plunger back to the limit switch. After any manual command is executed, the servomotor disengages and the system reenters standby mode.

#### IV. TESTING AND EVALUATION

The system was tested in 2 stages. Stage one consisted of bench testing to ensure that the sensor and the syringe system were working well together. This was deemed complete once the system's serial monitor was used to see if the sensor was accurately monitoring pressure and the syringe engaged when the depth requirements were simulated and met by blowing air on the sensor. Bench troubleshooting and debugging largely

focused on ensuring the system would safely retain a sample until the user was ready to expel it, and ensuring that the pressure sensor sampled pressure at a frequency of 1 Hz to accurately monitor depth.

Once bench testing proved the system to be reliable for drawing and storing a sample, in water laboratory tests were conducted in a tank approximately 2 m in depth. Initial testing confirmed watertight seals on the system. The system then successfully demonstrated the ability to capture and return a sample at prescribed depths within this confined environment and given the depth constraints of the laboratory environment. Stage two was deemed a success when water samples were acquired autonomously and the system reentered standby mode until the user commanded the system to dispense the acquired sample per the process described in Section III.

#### V. FUTURE WORK AND CONCLUSIONS

In laboratory testing, the system performed as expected and collected a sample at the prescribed depth. As such, the next step in testing is to conduct a comprehensive open-water test set aboard both a surface and subsurface vehicle to verify functionality at target depths up to 5 m and full autonomous operation. Because of its modular design, this system is capable of being expanded to incorporate onboard water quality sensors, such as conductivity, temperature, pressure, dissolved oxygen, etc. Additionally, for surface applications, one could incorporate a GPS into this system for precise geotagging of samples. For multi-sample operations, it would be a relatively straightforward modification to equip a single housing assembly with multiple syringe samplers.

Ultimately, the goal of this project was to demonstrate feasibility of development of a low-cost water sampling solution for academic purposes. This system is designed such that it is simple, modular, and would be a viable option for classroom or outreach activities where a large number of samplers may be desired, that can be customized to specific applications, but depth and breadth of functionality are secondary considerations to cost and modularity.

#### VI. ACKNOWLEDGMENT

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