# ABSTRACT

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| **TITLE:** | Networked Autonomous Surface Vehicles for Reservoir Monitoring. |
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**ABSTRACT:** On August 7, 2015 the Environmental Protection Agency accidentally released three million gallons of acidic mine drainage into Cement Creek near Silverton, Colorado. This catastrophe resulted in community, state, and world-wide alarms regarding the vulnerability of the City of Durango's water supply. A realization that this precious resource can easily be contaminated caused human-health concerns and environmental impacts to rise to the forefront of concern. This event, among other notable spills, provides motivation to examine the use of autonomous robotic systems, capable of performing real-time, remote monitoring for rapid detection and alarm.To this end, this project developed a robotic system capable of performing effective and efficient persistent aquatic monitoring.

The Robotic Guidance and Control for the Observation and Monitoring of the Environment (GNOME) Lab at Fort Lewis College, as part of a senior capstone research project, designed and built a networked system of Autonomous Surface Vehicles (ASVs) to continuously monitor the water quality and quantity in the City of Durango's water reservoir, Rogers Reservoir. The robotic system is designed for future applications and deployment in other aquatic resources in the surrounding Four Corners Region as well. This network consists of three ASVs; that enable accurate spatiotemporal monitoring of a dynamic environment. The network of ASVs provides information about the physical properties of the water that enable resource managers to assess and respond in near real time to water quality concerns. The Robotic GNOME Lab is also in collaboration with international educational institutions and local elementary schools. International collaboration is to facilitate data sharing and the development of autonomous sampling and data analysis algorithms. The local collaboration is to teach local elementary students about the physical properties of fluids, water quality, robotics, and the field of aquatic robotics.

The networked robotic system consists of three ASVs with custom hull designs optimized for local fresh-water reservoirs and the ability to withstand local weather and potentially low-pH (3-4) water. Each vessel optimizes power consumption for both sampling and operation to enable persistent, 24/7 autonomous operation. Typical weather in lakes and reservoirs in a mountainous environment include large temperature swings, wind gusts of 20 mph, various forms of precipitation such as hail and freezing conditions, which have all been considered in the design and construction. Autonomy is accomplished by on-board Arduino Mega 2560 microcontroller and navigation is performed by an Adafruit Breakout V3 GPS and IMU. Continuous power to the ASVs will be generated onboard with solar panels and battery storage to accomplish 24/7 continuous operation. Communication for data transfer and mission updates is handled over 3G cellular communicationthrough a Particle Electron board. The water quality sensor suite is designed to be modular with interchangeable sensors to target specific sampling requirements for each deployment location. All collected data are posted in near real time to a publicly-available website. The intended uses of the data are to inform local resource managers and policy makers, as well as to engage the public through educational outreach and citizen scientist programs.

All three ASVs are designed around a basic dual-hull catamaran design, and are roughly five feet in length, and 2.5 feet in width. ASV 1 has rectangular hulls, is heavy-duty, and impact resistant. It has a structural foam body with reinforced polyester, and hand-finished laminate. ASV 2 and 3 are cylindrical in shape, lighter, faster, and can carry more payload. These boats are made as a ribbed structure with reinforced epoxy and vacuum bag finished laminate. This second iteration of design was chosen to reduce the technicality and time of fabrication, the total weight of boat, carry more payload, and to increase stability.

For power, two 50-watt solar panels collect solar energy that is stored intwo 20 Ah LiFePO4 batteries. A commercial charger is used to charge both batteries and control the charging cycle. Mechanical relays are located at the grounding terminal of each battery and on the solar panels to disconnect all electrical sources if water enters the hulls or the electronics housing. The batteries are protected from a short circuit by a 15 amp fuse. The electronics for the boats are housed in a pelican case that is suspended between the hulls. An Arduino Mega was chosen to control the ASV and communicates via I2C with a Particle Electron that provides 3G cellular communication. Two Blue Robotics T200 thrusters are used to propel the boat. A thruster is mounted on the back of each pontoon to provide for differential thrust steering.

GPS waypoint navigation is being used with a geo-fence. An IMU is used to provide a magnetic tilt-compensated heading while the boat is traveling at low speeds, and the GPS provides a heading when the boat is traveling at speed greater than 0.5 meters per second.Waypoints are chosen based on a sampling algorithm within the geo-fence that provides adequate spatial coverage for optimal water quality monitoring and data collection. The user can change the sampling algorithm while the ASV is deployed through a web-interface on the website. This ability to communicate to the vehicles allows collaboration with international researchers to simultaneously test sampling algorithms with all three vehicles: one vehicle to perform ground truth and the other two vehicles for testing iterations to the sampling strategy.

The standard water quality monitoring sensor suite consist of temperature, pH, and salinity. These sensors have been included because they provide a fundamental picture of the aquatic environment. Each ASV is set up to accommodate up to three additional sensors, with the possibility of extending this capacity if needed. This network of ASVs will be deployed on Rogers Reservoir to monitor water quality at the Florida River and Animas River inlets, and at the outlet of the Reservoir. Real-time data will be posted on a publically accessible websiteand a database will be located on the Fort Lewis College server. Additional deployments will occur at regional lakes/reservoirs and in suitably-sized rivers to collect aquatic data of interest to researchers and scientists. The GNOME Lab will continue to develop and test planning and control of the network of ASVs for long-term deployment—requiring efficient data collection techniques, and cost-effective communications. This network of ASVs will eventually be coupled with autonomous underwater vehicles (AUVs) and unmanned aerial vehicles (UAVs) to form an aquatic robotic sensing system that can provide a means of understanding complex and dynamic aquatic environments.