Ariel - Autonomous Coral Reef Monitor

Prudence Aquiatan, Constantinos Gerontis, Mrinal Ghosh, Sean Nemtzow, and Anirudh Watturkar

Abstract—Due to the effects of global warming and pollution, coral reefs are rapidly dying, which is destroying the habitats of many aquatic animals. Current methods to monitor the health of coral reefs are laborious and unscalable due to their reliance on divers. To assist marine biologists and conservationists in their efforts to monitor and restore the coral reefs, we propose an autonomous aquatic vehicle, Ariel, which can routinely measure the water quality around and image a specified area of the reef. Ariel will be able to provide color-corrected images of the coral reef as well as metrics such as pH, temperature, and turbidity each minute. In terms of design, it will be built to last many days at sea, and can be outfitted with different sensors as needed. Ariel is intended to increase the efficiency of conservation teams by reducing surveying time and cost.

Index Terms— Autonomous vehicles, Design, Real-time and embedded systems, Robotics

1 Need for this Project

CORAL reefs are dying at an alarming rate due to the acidification and warming of the ocean from global warming and large scale pollution. In the last 30 years, over 50% of all coral reefs have died, with half of the deaths occurring in the last 5 years. This is an alarming statistic for many reasons. First, coral reefs are home to over 25% of all known marine species. This means that coral reefs provide nutrients and food for 500 million people worldwide and play a key role in numerous ecosystems [1]. Additionally, reefs provide necessary protection against storm surges and coastal erosion, which is responsible for roughly $500 million per year in coastal property loss, including damage to structures and loss of land [2]. And finally, from an economic standpoint, coral reefs are a significant source of income for many countries for their role as a tourist attraction [3].

In order for marine biologists and conservationists to investigate how reefs are structured, how they change over time, and how they can better manage them in the face of global change, it is crucial to develop routine and expansive methods to survey and monitor the health of coral reefs. Current manual methods for reef surveying tend to be arduous, expensive, and unscalable. These methods usually involve deploying a team of divers to a site, where they spend many hours underwater either setting up a rigid camera system or manually imaging the site with handheld cameras [4]. Such methods limit the scope of surveying projects and hinders the efficiency of surveying teams.

Ariel will address this issue by providing surveying teams an easy to deploy, autonomous vehicle that can routinely collect water quality metrics and image a specified area of coral reef. Ariel will be designed for long term use and will be non-disruptive to the environment. Ariel's autonomy and routine behavior will allow surveying teams to monitor larger areas of coral reefs and provide richer analysis for the scientific and conservant communities.

- *Prudence Aquiatan CE' 21. E-mail: pdna@bu.edu*
- *Constantinos Gerontis CE' 21. E-mail: cgeron@bu.edu*
- *Mrinal Ghosh CE' 21. E-mail: ghoshm@bu.edu*
- *Sean Nemtzow CE' 21. E-mail: snemtzow@bu.edu*
- *Anirudh Watturkar CE' 21. E-mail: anirudhw@bu.edu*

2 Problem Statement & Deliverables

2.1 Problem Statement

Our proposed solution will significantly simplify data collection related to coral reef health by autonomously collecting data for long periods of time, congregating the data onto a server for marine biology labs to access, and processing it with machine learning to extract valuable metrics for marine biologists.

Our design will be a solar-powered aquatic autonomous vehicle that will be tasked with surveying coral reefs in a specified area. The vehicle will follow a path and periodically take images and measurements that can cover the entire area. An important feature of our design is maintaining a consistent monitoring schedule to provide valuable data points for further analysis. This means the vehicle will be designed to spend weeks to months at sea while keeping a consistent rhythm. Potentially, there can also be a local storage bay to house the vehicle during off-times and turbulent conditions. The vehicle can dock with the bay at the end of the monitoring phase and undock the next day. The bay can also double as a local server or relay to transmit the data from the vehicle. Deployment will consist of specifying the area to patrol, calibrating the vehicle, and then placing the bay and the vehicle in the water. Each part of our design is also subject to the constraint that it should be environmentally conscious and not disturb the local wildlife.

The vehicle will carry multiple sensors and a camera to collect measurements to assess the coral reef health. The non-imaging data we plan to gather are temperature, pH, and turbidity. The image data will be color-corrected images of the coral that could be stitched into a photomosaic. Other metadata will be color intensity trends of the images to determine if the reefs are bleaching.

The data captured during the robot's venture will be temporarily stored on the robot's memory. After that, it can either be lightly processed on board (compressed or filtered in some way), or directly sent to a server where it can be stored long-term. Once at the server, the data can be parsed and filtered to create a 3D representation of the scanned reef, as well as combine the other measured metrics to extract an overall reef health score and other valuable information for marine biologists.

2.2 Deliverables

An aquatic autonomous vehicle capable of:

1. Patrolling a specified area on a consistent basis
2. Collecting measurements and color corrected images of the reef
3. Temporarily storing data locally that can be easily accessed remotely or physically
4. A modular sensor-bay capable of accommodating custom sensors

A data-pipeline capable of:

1. Handling a stream of metrics and images on a daily basis
2. Take time and location stamped images
3. Extracting useful metrics from the data such as overall coral health and water quality

3 Visualization

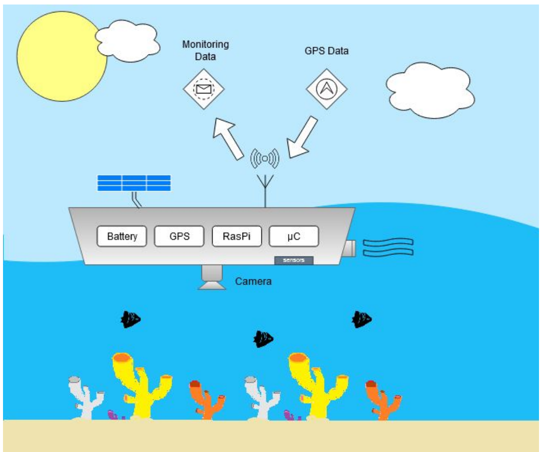

Fig. 1. This is a general depiction of the vehicle in operation. The unit consists of a camera and water quality sensors to collect data on the environment, a propulsion system on its rear to maneuver in the water, antennae to transmit the collected data and receive its location via GPS, and a solar panel to power the system while it operates. Internally, the unit will have a battery, GPS/location sensors, a Raspberry Pi and Microcontroller. The Pi will be the "brains" of the system, operating the controls of the system and transmitting the data. The microcontroller will collect and store the sensor data, and will send this to the Pi upon request

4 Competing Technologies

Scientists across several research groups are developing robotic vehicles for the purpose of efficient coral reef monitoring. The most significant among these are the MIT SoFi, the AIMS BlueROV2, and the QUT RangerBot.

4.1 MIT SoFi

Scientists at the Massachusetts Institute of Technology (MIT) Computer Science and Artificial Intelligence Laboratory (CSAIL) developed a soft robotic fish as a means of more effectively observing coral reef environments. The SoFi can swim untethered for a maximum of 40 minutes and can reach depths up to 18 meters but requires the use of a video game controller at a maximum of 21 meters away [5]. The SoFi uses a fisheye lens to take high-resolution photographs and videos of coral reefs and other marine life for ocean exploration and observation of risk reef environments. The SoFi was created with the goal of being non-disruptive to the environment in order for the robot to get as close as possible to coral reefs. This was achieved by mimicking the look and movement of a fish so the robot would be better accepted by other marine species. Additionally, minimal motor noise and low ultrasonic emission frequencies ensure the robot can closely observe and interact with marine life without causing disturbance [6].

4.2 BlueROV2

A research team from the Australian Institute of Marine Science (AIMS) developed the Blue Robotics BlueROV2 as a cost-effective technology to monitor the Great Barrier Reef. The BlueROV2 is a tethered underwater robot that can reach a maximum depth of 100 meters but requires a pilot at the water surface for navigation assistance [5]. The pilot controls the ROV using a gamepad controller and a laptop running open source ArduSub subsea vehicle control firmware. The BlueROV2 is equipped with dimmable lumen lights and a hyperspectral camera for vehicle navigation and data collection. The hyperspectral camera interfaces with machine learning augmented data process workflows, allowing it to provide more accurate and detailed information on reef health [7]. An important goal in developing the ROV was the ability to customize a monitoring system for specific research needs. Therefore, the BlueROV2 is offered with various configuration options and accessories to expand the and modify the ROV for particular applications, with costs ranging from $2,989 to $4,939 [8].

4.3 RangerBot

The Queensland University of Technology Robotics team developed the RangerBot as a successor to the COTSbot, originally developed to kill venomous crown-of-thorns starfish which eat coral reefs. This initial concept was expanded upon to develop the RangerBot, the first and only autonomous underwater robotic system designed specifically for detecting and addressing threats to coral reef environments [5]. While still fulfilling its original purpose of identifying and lethally injecting crown-of-thorns starfish, the RangerBot can also map the ocean floor and gather data to monitor coral bleaching, water quality, invasive species, and pollution. The RangerBot is operated using a smart tablet and uses computer vision for navigation and object avoidance. Researchers designed the RangerBot to be inexpensive and small, only 15kg and 75cm in size, with the goal to dramatically scale up and make the RangerBot readily accessible for coral reef monitoring [9]. Six RangerBots could cover double the area as six divers could for $720,000, which is half the cost of the equivalent human labor [10].

4.4 Ariel

Our product is similar to the competitors in that we will also be collecting water quality data and taking images for reef monitoring and observation. While our competitors' products are underwater robots which focus on deep sea coral reefs, our product will operate on the surface of the water. Like the BlueROV2, our product will be modular, with interchangeable sensors to adapt to the user's needs. Our product will also be untethered and fully autonomous, similar to the RangerBot. Additionally, our product shares the SoFi requirement of being non-disruptive to marine life.

5 ENGINEERING REQUIREMENTS

This section breaks down the engineering requirements per associated subsystem.

5.1 Mechanical

1. The vehicle must passively float in salt-water (density of ~1.025kg/L at surface level). Passive in this context is defined as without the help of any powered component in the system.
2. The vehicle must passively return to a neutral position if experiencing roll up to ±180°. This uses the same definition of passive as above. Neutral, in this context, is defined as a roll of 0±10°. Roll is one of the three rotational degrees of freedom a nautical vehicle has, which is a rotation along the bow-stern axis.
3. Must be waterproof. We are defining waterproof to be submersible up to 3ft in depth for up to 10 minutes without performance degradation or damage to components.

5.2 Autonomous Surveying

1. The vehicle must follow the desired preset path with an accuracy of at least 3m. The accuracy limitation comes from the maximum accuracy of consumer GPS systems, which is about 3m.
2. The vehicle must cover at least 75% of the specified area for areas at least $0.25km^2$.
3. The vehicle must operate with minimal human intervention. The user input is limited to (1) setting the surveying path and area, which should take no more than 2 hours, (2) deploying and receiving the vehicle, which should take no longer than the travel time to get to the vehicle's location, and (3) receiving the data collected by the vehicle, which should either be the same as the travel time to the vehicle, or none if in range to receive the data wirelessly (see next section).

5.3 Data Collection and Transmission

1. The vehicle must record the acidity/alkalinity (in pH), the temperature (in C), and the turbidity (in NTU) of the water, collected at least once a minute.
2. The vehicle must capture images of the reef, taken at least once per minute
3. Both the images and the sensor data described above must also be recorded with a timestamp and the GPS coordinates of where the measurement took place.
4. The vehicle must support at least one sensor to be removed and replaced with another sensor that uses the same communication protocol.
5. The internal computer must be able to store at least 64 GB of the annotated data on-board.
6. The vehicle must be able to wirelessly transmit data with a range of at least 1km and data rate of at least 250 kbps.

5.4 Power & Cost

1. The vehicle must be able to collect data in the predetermined route (as described in 5.2 and 5.3) for at least one week without needing to replace the battery.
2. The vehicle must be powered by solar panels and rechargeable batteries when in operation. Solar panels generate approximately 100 mW/in^2, and the vehicle is expected to be in sunlight for at least 8 hours a day [11].
3. The total component cost must not exceed $1000.

6 APPENDIX A REFERENCES

[1] IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

[2] "U.S. Climate Resilience Toolkit," Coastal Erosion | U.S. Climate Resilience Toolkit, 13-Sep-2019. [Online]. Available: https://toolkit.climate.gov/topics/coastal-flood-risk/coastal-erosion. [Accessed: 26-Oct-2020].

[3] M. Spalding, L. Burke, S. A. Wood, J. Ashpole, J. Hutchison, and P. Z. Ermgassen, "Mapping the global value and distribution of coral reef tourism," Marine Policy, vol. 82, pp. 104–113, 2017.

[4] S. Sandin, J. Smith, and B. Zgliczynski, "Large Area Imagery Collection & Processing Standard Operating Procedures Version 3.0 Single Rig," The Scripps Oceanography 100 Island Challenge, 2019.

[5] K. Brooks, "Meet the Inspirational Robots Protecting Coral Reefs," *Current by Distrelec*, December 21, 2018. [Online]. Available: https://www.distrelec.de/current/en/robotics/meet-the-inspirational-robots-protecting-coral-reefs/. [Accessed: October 4, 2020].

[6] A. Conner-Simons, "Soft Robotic Fish Swims Alongside Real Ones in Coral Reefs," *MIT News*, March 21, 2018. [Online]. Available: https://news.mit.edu/2018/soft-robotic-fish-swims-alongside-real-ones-coral-reefs-0321#:~:text=In%20a%20paper%20out%20today,real%20fish%20in%20the%20ocean. [Accessed: September 27, 2020].

[7] K. Lant, "Underwater Robots to Monitor the Great Barrier Reef," *Environmental Monitor*, October 12, 2018. [Online]. Available: https://www.fondriest.com/news/underwater-robo

ts-to-monitor-the-great-barrier-reef.htm. [Accessed: October 4, 2020].

[8] Blue Robotics, "BlueROV2," *Blue Robotics Inc*. [Online]. Available: https://bluerobotics.com/store/rov/bluerov2/. [Accessed: October 4, 2020].

[9] "Meet RangerBot, Robot Reef Protector," *Ocean News & Technology*, September 4, 2018. [Online]. Available: https://www.oceannews.com/news/science-technology/meet-rangerbot-robot-reef-protector. [Accessed: September 27, 2020].

[10] K. Houser, "This Autonomous Drone is Ready to Defend the Great Barrier Reef from Predators," *The Byte*, August 31, 2018. [Online]. Available: https://futurism.com/the-byte/rangerbot-autonomous-drone-reef. [Accessed: October 4, 2020].

[11] B. Zientara, "How much electricity does a solar panel produce?," Solar Power Rocks, 02-Apr-2020. [Online]. Available: https://www.solarpowerrocks.com/solar-basics/how-much-electricity-does-a-solar-panel-produce/. [Accessed: 26-Oct-2020].