Edge Computing Architecture for Optimized Deep Sea AUV Communication

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***Abstract*—Approximately seventy-one percent of the Earth is covered in water. Of that area, ninety-five percent of the ocean has never been explored or mapped. There are several engineering challenges that have prevented the exploration of the deep ocean through human or autonomous means. These challenges include but are not limited to high pressure, cold temperatures, little natural light, corrosion of materials, and communication. Ongoing research has been focused on trying to find optimal and low-cost solutions to effective communication between autonomous underwater vehicles (AUVs), and the surface or air. This paper introduces an architecture that utilizes an edge computing approach to establish a network of devices that could enable further exploration of the deep ocean. For this network, we use existing technologies that have been tested in the field or are nearing the end of their development and compare different approaches.**

***Index Terms*—AUV, ROV, tethered, edge device, mother ship.**

I. Introduction

Exploration of the deep ocean is crucial to study climate change, energy, ocean conservation, and human health. Further knowledge of what lies in the dark depths of the ocean seabed could help discover renewable energy sources, advance natural medicine research, and protect the ocean ecosystem [4].

Before introducing the architecture, there are several constraints that have shaped previous and current implementations of solutions to deep ocean exploration. Many of the underlying ones stem from physical and chemical phenomena, but there are also many other controllable factors such as cost and choice of communication technology. Although this paper does not focus on the physical design aspects of the devices used for exploration, these challenges can help minimize the wear on devices or the cost after each mission; hence why we account for them in our network.

A. Temperature and Pressure

In ocean depths past six thousand meters, the pressure of water reaches approximately 596 atm. This is problematic for most of the electronics that need to be mounted on the AUV such as cameras, lights, and computers. Since most are built to operate above the water, they operate in 1 atm of air. To combat this, the most practical solution is to enclose the technological devices in air-filled housing that will not collapse under such intense pressure.

The temperature at such depths in the ocean can reach to around four degrees Celsius. This poses a problem for dissimilar materials - materials that are difficult to join as a result of their chemical or physical compositions - because they may shrink or expand at various rates when the temperature falls [2].

B. Corrosion and Darkness

On the theme of what materials to use, saltwater is an electric conductor and so will accelerate the corrosion of metals that are immersed in it. In the development of AUVs and remotely operated vehicles (ROVs) are engineered with materials that are low on the Galvanic scale. A material like gold would be perfect but the cost of gold makes titanium a more suited material for construction.

Moving away from the materials aspect and onto the technology, we focus on the sensors and lights on the device that will help it navigate and collect data. There is very little natural light below 200 meters in the ocean and no sunlight whatsoever below 1000 meters. With underwater creatures, terrain, and other organisms to consider, AUVs need to produce ample light. These lights also need to be positioned in such a way that they don't reflect off of marine snow - reflective organic material in the deep ocean - and blind the cameras. Usually, AUVs and ROVs are armed with sonar as well as cameras to determine their position, listen for the seabed below, and detect sea creatures around them [2].

C. Communication

Lastly, we move onto communication methods as that is what the focus of this paper will be. Traditionally, some form of radar or EM waves would be used for autonomous vehicles but radio waves do not travel very far through water and are very susceptible to noise. This leaves solutions that are separated into categories that involve a tethered connection and untethered connections [2].

Tethered connections to vehicles involve cable(s) that are either coaxial, in twisted pairs, or are fiber-optic. Since this is a direct connection to a mothership on the surface, tethered solutions have a high data transfer rate but may have lower ranges. Outside of these considerations, a long cable extending into the ocean faces entaglement, breaking, fraying, and encounters with creatures.

Untethered connections involve communication from the vehicle to another device via radio waves, acoustic waves, or optical methods such as lasers or LEDs. Having already discussed the drawbacks of radio wave communication, acoustics are widely used because of their long range abilities. However, most acoustic solutions succumb to high noise and low bandwidth in data transfer. The relatively newer idea of optical communications, with some research in space exploration being pioneered by NASA, solves this issue by providing higher bandwidth although within closer distances [1]. Additional factors such as power consumption and latency are also higher for acoustic communication methods than they are for optical methods. Table I and Table II show the comparisons between the communication types [1].

Type	Technology	Data Rate	Range
Tether	Twisted Cables	10 Gb/s	100m
Tether	Optical Fiber	10 Tb/s	10,000m
Wireless	Acoustic	10 Kb/s	1000m
Wireless	Optical	100 Mb/s	100m
Wireless	Radio	10 Mb/s	1m

TABLE I
COMMUNICATION TECHNOLOGIES, THEIR TYPES, THEIR MAXIMUM DATA RATES, AND THEIR MAXIMUM RANGES

Tech	Use	Availability
Twisted Cables	control/nav/video	commercial
Optical Fiber	control/nav/video	commercial
Acoustic	control/nav	commercial
Optical	control/nav/video	research
Radio	control/nav	commercial

TABLE II
COMMUNICATION TECHNOLOGIES, THEIR USES, AND THEIR AVAILABILITY

D. New Edge-Based Network

Keeping all these constraints in mind for the development of our new network, we propose a new system that uses tethered devices and untethered devices and involves several devices communicating with each other. The goal is to process data efficiently nearer to the device in the deep ocean and minimize transfer up to the surface or shore. This system will use fiber optic cables, lasers, acoustic modems to communicate all the way from the deep ocean to a mother ship on the surface.

Our system attempts to model this by having 3 levels of devices in the ocean. On the surface, a mother ship stands to receive the gathered data and send any necessary, minimal instructions to an AUV. On the second level, approximately 6000 meters below sea level, we have an intermediary ROV that performs data processing and acts as a translator between the mother ship and the AUV nearer to the seabed. This intermediary ROV will be tethered to the mother ship. Finally, on the third and deepest level, the untethered AUV collects data from the deep ocean and sends it to the intermediary ROV through wireless methods. The full architecture will be discussed in later sections.

II. Related Work

Before introducing the architecture and findings of our system, it is worth looking at similar studies and models that have had a similar idea to ours.

A. GFOE Deep Discover

In 2022 the Global Foundation for Ocean Exploration had built one of the most capable ROVs to date called the Deep Discover (D2). The D2 boasted some great specifications with an ability to drop down to 6000 meters below sea level, used 27 LED lights, high definition cameras, a suction sampler, a manipulator arm, coral cutters, and a temperature probe. Its purpose was to collect videos, physical samples, and additional oceanic data for use by scientists.

In terms of the architecture, the D2 was tethered to a camera sled, Seirios. Seirios lit up the area under D2 and allowed D2 to safely crawl the seabed. Seirios was then tethered to a NOAA ship, Okeanos Explorer, with a six-mile-long cable made of steel. This model allowed pilots of the D2 to safely guide the ROV while it explored even the darkest parts of the deep ocean. The data transfer pipeline was through the tethered connections and allowed only the most crucial data to be transferred through the tethers without the D2 needing to surface. [2]

B. Opensea IQ Edge

A private company called Greensea Systems made waves in the computing aspect of deep ocean exploration by using untethered, commercially available, ROVs loaded with batteries, an acoustic modem, and revolutionary onboard software. They managed to put a parallelized NVIDIA edge platform on the ROV which allowed the ROV to process sonar and video data while also maintaining its navigation and communication capabilities.

Similar to the D2 from GFOE, Greensea's ROV only sent the most crucial information to human operators and did most of the data processing onboard. This method allowed the use of acoustic modems as the amount and frequency of data was drastically reduced. The company ran a successful test of their system in March 2023. [3]

References

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