OTIC: Virtual Reality for Reef Photogrammetry and Fieldwork

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As reefs worldwide undergo rapid ecological shifts due to climate change and other human impacts, research projects are underway to document them via photogrammetry and genetic sampling (`https://100islandchallenge.org/`, `https://www.reefscapegenomics.com/`). The fundamental science questions these efforts aim to address, such as the nature of the coral holobiont and the mechanisms underlying coral bleaching, are motivated [4] by interest in intervention measures [1] to protect reefs' tremendous biological, cultural and economic value.

This proposal seeks to formalize and support a multi-institutional working group formed in February 2024 to explore the use of virtual reality (VR) tools in reef photogrammetry. The group has identified three overlapping areas of interest, as shown in Figure 3: fieldwork planning, data analysis, and outreach. With experts in coral biology, computer visualization, and VR applications at academic, government, and non-profit institutions, the working group is well poised to explore the intersection of these topics. This proposal will focus on **dive planning**: Using historical dive footage as well as data from ongoing fieldwork, we will **test the hypothesis that incorporating VR into dive planning significantly increases divers' effectiveness and science yield.**

Work Plan/Deliverables:

We will outfit the Reefscape Genomics Lab (Cal Academy) and Sandin Lab (SIO) with VR systems for visualization of reef photogrammetry data. Each lab will receive a stationary system and two portable systems for fieldwork. PI Collins will set up the systems and provide in-person training sessions to each lab group on the use of these tools, which will be enhanced by informal outreach activities at Steinhart Aquarium and Birch Aquarium using data from Co-PIs Hoey and French. Dive leads will be supported in efforts to augment existing dive planning for fieldwork with VR tools for certain sites. Via logging and periodic surveys, each lab will record their use of VR over the duration of the grant, as well as data pertaining to the factors listed in Fig. 4. During fieldwork, orientation time will be measured and used as a metric for training efficacy (Fig. 2). Additional control data will be extracted from camera footage of previous dives. For a notional field trip of 50 dives with 5 divers, in which 2-3 divers participate in data collection for each dive, we can collect approximately 100 dive timelines, in addition to historical control data, for the multivariate analysis. VR interaction data will be supported by Co-PI Butkiewicz. The primary deliverables for this project will be a paper and dataset describing the human factors analysis and a conference presentation at OSM or AGU Fall Meeting describing the VR workflows used.

Intellectual Merit

Virtual reality has established application in training for operational environments under the DICE umbrella (**D**angerous, **I**mpossible, **C**ounterproductive, **E**xpensive [2]). As reef photogrammetry requires potentially dangerous fieldwork in remote settings, VR provides a way for divers to examine a site in detail before diving. Further, VR opens up possibilities for collaborators at different

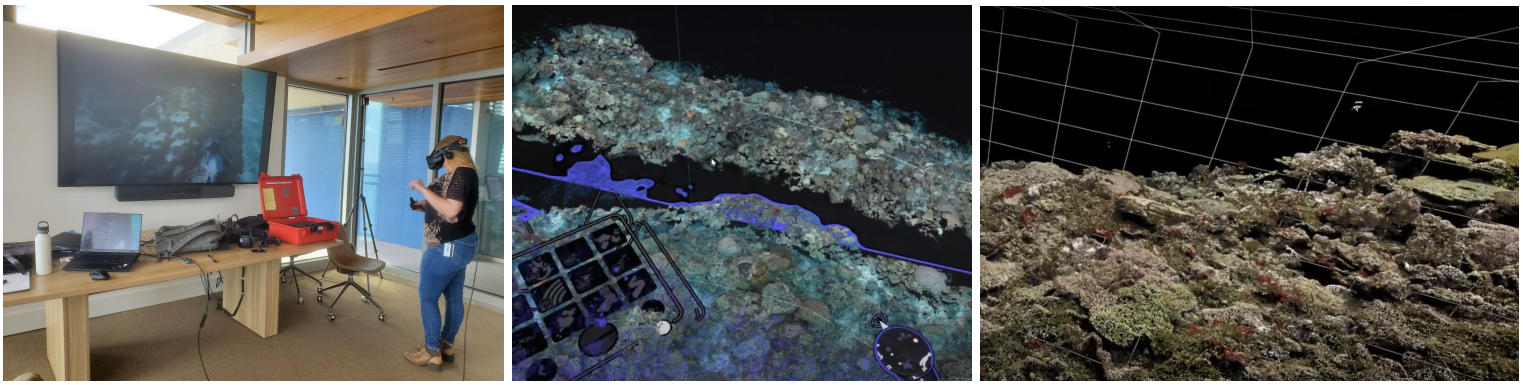

Figure 1: VR demonstrations prepared by the Reef VR working group. Left: Dr. French demonstrates a reef outreach experience developed by UNH/CCOM. Center: Pointclouds collected in 2020 and 2021 by Dr. Bongaerts and Dr. Hoey at Snake Bay, Curaçao are compared in OpenBrush. Right: Photogrammetry pointcloud collected at Palmyra Atoll in 2024 by Dr. French, displayed in VR Geoscience Studio. Demo videos are available at `https://youtube.com/playlist?list=PLTvFnCylkeSDslS_BuZKsUH0AV6A0aAPn`

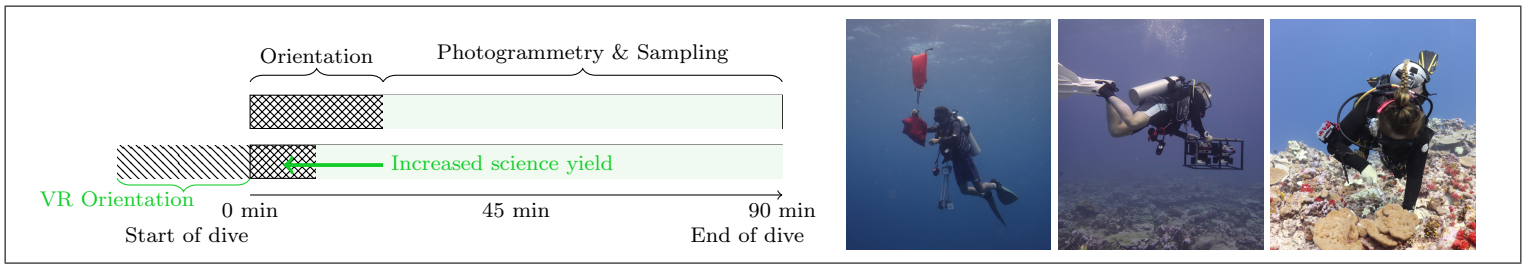

Figure 2: Notional dive timelines: the top represents current practice. Preparing for a dive in VR is expected to reduce underwater orientation time for divers at a given site, thus increasing science yield during the photogrammetry and sampling steps, shown at right.

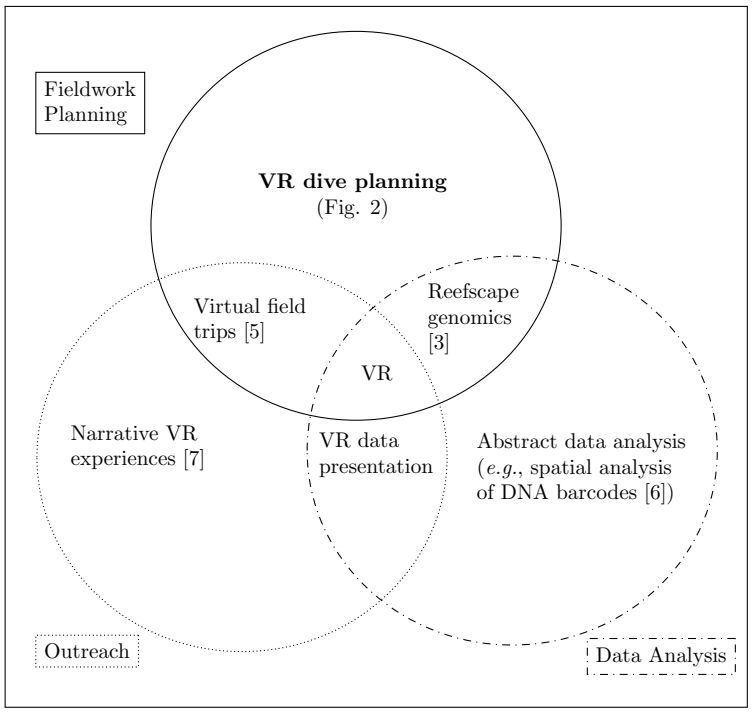

Figure 3: Applications for virtual reality in reefscape research.

Diver Experience	• Lifetime dive experience • Prior familiarity with site • Familiarity with dive tasks and team
VR Format	• Multiuser vs single-user • Human-scale versus dynamic scale • Time spent in VR • Time between VR experience and dive • Self-reported comfort in VR • Use of annotations in VR • Use of multi-user VR experiences
Reef Environment	• Change since last data collection (due to bleaching, wave action, other environmental disturbances) • Difficulty of dive (current, surge, swell, visibility, time of day)

Figure 4: Factors to consider in multivariate analysis.

locations to meet virtually before and after a dive to discuss and annotate data in 3D. Comparable research in VR training for firefighters [12] demonstrates that supplementing operational training with VR simulations results in better outcomes for orientation; Tate et al. [11] uses a similar methodology to the one proposed here.

Broader Impacts

Interdisciplinary Research: The methods developed in this work are applicable to fieldwork and to Earth and space science data generally. Virtual reality also suggests considerable potential for future work in analysis of abstract data, including DNA barcodes [8, 10]. Advanced visualization of these multidimensional data [6] may illuminate new aspects of the coral holobiont.
Personnel: This exploration will stimulate collaborations between institutions (SIO, Cal Academy), supporting the development and sharing of best practices [9]. This project will support early-career researchers, per scope discussion below.
Public engagement & outreach: The Birch (SIO) and Steinhart (Cal Academy) Aquariums are public aquariums that collectively serve ∼2 million visitors annually. This visitorship offers ample opportunities to engage with diverse audiences about coral biology, coral reef conservation, and the use of VR technologies in research.

Suitability and Scope

Per PD 98-1680, this project enhances the observational and analytical capabilities of the ocean science research community, through dive planning and analysis respectively. **This project's scope is flexible, and should be determined pending discussions with the Program Officer.** At the EAGER level (budget $300k, duration 2 years), it would provide partial salary support to two early career researchers (Collins, French), outfit labs and incorporate data collection and outreach activities as described above. All proposed work will be conducted with commercially available software and hardware. At a larger scale, the proposal may be structured to additionally support fieldwork, a PhD student (Pierce), a postdoctoral researcher (Elmquist), and development of a standardized open-source software pipeline for photogrammetry data. This may include coordination with existing open-source software projects, including CoralNet-Toolbox (Pierce), HabiCAT3D (Beregovyi), and OpenSpace (Elmquist, Collins), as well as Viscore (Petrovic).

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