Accepted abstract. 17th International Planetary Probe Workshop 2020.
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END-EFFECTORS FOR FRANGIBLE SUBSTRATE IN EXTREME UNDERWATER ENVIRONMENTS

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Brief Author Biography: Monica Li received her B.S. from Caltech in 2016 and her M.S. from UC Berkeley in 2018, both in mechanical engineering. She is now a Ph.D. student in the Embodied Dexterity Group at UC Berkeley, where her research focuses on end-effector design for frangible (fragile and brittle) substrates under water.

Abstract: Robots hold the potential to explore challenging underwater environments beyond human reach. Spacecraft may one day dive into ocean worlds; for example, scientists are motivated by the indication of hydrothermal activity and potential habitability on Enceladus. Earth's hydrothermal vents may be analogous to environments on ocean worlds such as Enceladus, Europa, and Titan [1], [2]. Hydrothermal vents are formed as minerals precipitate. These deposits form rugose, chimney-like structures. Some vent substrate, such as at the Strytan Hydrothermal Field, is frangible and crumbles easily with external forces. Similarly, due in part to lack of light, mesophotic (30m-150m) corals have thin, frangible skeletons. Physical collection and analysis of coral samples from these depths is difficult for human divers, but can increase our understanding of ocean ecology. Our goal is to create end-effectors that can effectively grip onto and sample these types of frangible substrates.

Spines are effective for attaching onto rocky surfaces in the ocean [3]. A microspined anchoring platform is realized for attaching to hydrothermal vent substrate with one degree of actuation and over one-hundred degrees of freedom. This highly underactuated mechanism adapts to the shape of the surface it is grasping. Actuation is performed through a ratcheting clamp so the mechanism can be deployed by a diver using one hand. Initial tests show that strength of the substrate is a contributing factor to how effectively microspine mechanisms can anchor. This is consistent with other works, e.g., [4]. When surfaces are frangible, spine engagement can result in crumbling of the substrate underneath, resulting in grasp failure.

Methods are investigated for attaching to the frangible substrates (Fig. 2). (i) Distal spikes are added to the end of each phalange. This spike is intended to penetrate the substrate, allowing for a stronger grasp. (ii) Blunted spines, or *teeth*, interlock with the surface geometry without penetrating the substrate [5]. (iii) Soft material adapts to the surface, increasing contact area and distributing stress more evenly, potentially preventing crumbling of the substrate. Ongoing work evaluates these attachment classes to characterize how they can be coupled together into a robust mechanism for frangible substrate attachment in a variety of extreme environments.

A field expedition in March 2020 utilizes a human-portable remotely operated underwater vehicle (BlueROV2) as a lightweight and accessible method to interact with marine environments. The goal is to effectively grip onto and detach samples of mesophotic coral. A spring-loaded cam mechanism delivers impacts to break coral, while a toothed gripper holds onto the sample to bring back to the surface. We aim to develop enabling technologies and design methods that can then be applied to a number of underwater exploration applications, both on Earth and celestial bodies. At IPPW, we will present findings from the recent field expedition.

Figure 1. **Underwater hydrothermal vent anchoring platform.** Inset shows microspines from a phalange digit that the platform uses to attach to the substrate. In the lab, simulated frangible substrate crumbles under the localized stresses of microspines.

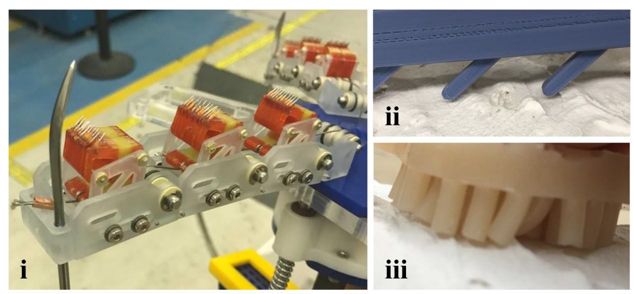

Figure 2. **Attachment classes to grip onto frangible substrate.** (i) A large spike is added to the microspine anchor to penetrate the substrate for a stronger grasp. (ii) blunted spines for geometric interlocking with rugose surfaces and (iii) soft urethane pad distributes loads to prevent substrate crumbling.

Figure 3. **Field Expedition** - The human-portable ROV can be deployed from a small boat (left). Closeup of the gripper as the ROV approaches coral (right).

Acknowledgements: The field expedition at CRIOBE on Moorea, French Polynesia was supported by the LabEx NUMEV (2011-LABX-076) incorporated into the I-Site MUSE. Monica Li is supported by the NASA Space Technology Research Fellowship (NSTRF).

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