Democratizing Access to the Deep Sea through SHared Autonomy for Remote Collaboration (SHARC)

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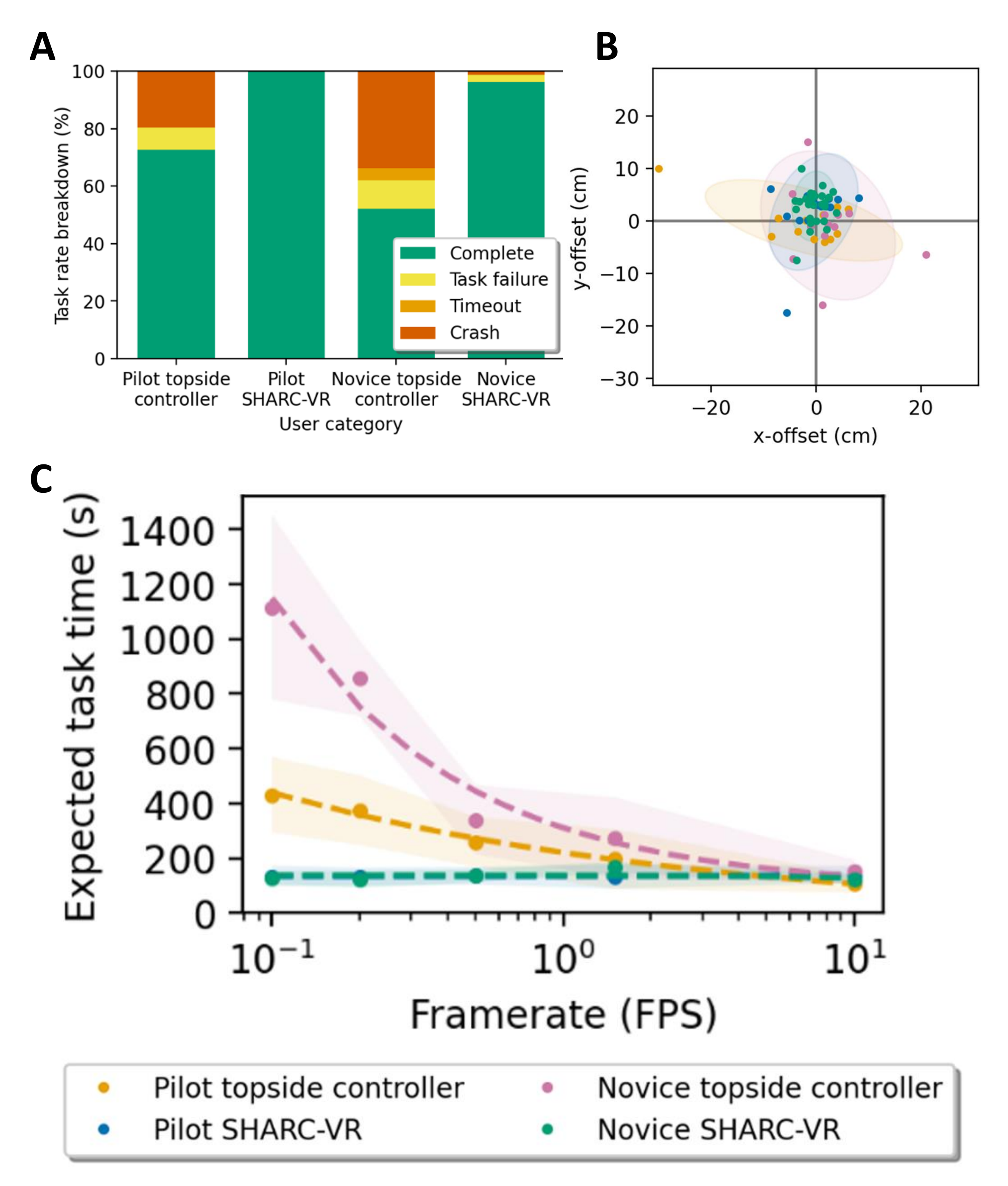
Challenge

Scientific exploration of the deep ocean is vital for understanding natural Earth processes, but remains inaccessible to many (1, 2). Dexterous sampling operations at depth are typically conducted by robotic manipulator arms onboard remotely operated vehicles (ROVs), which are directly teleoperated by pilots aboard surface support vessels. This presents barriers to access due to the infrastructure, training, and physical ability requirements for at-sea oceanographic research. Enabling shore-based participants to observe and control robotic sampling processes can reduce these barriers; however, the conventional direct-teleoperation approach is infeasible for remote operators due to the considerable bandwidth limitations and latency inherent in satellite communications. Thus some degree of ROV autonomy is required to support remote operations (3).

Solution

To address this need, our team developed the SHared Autonomy for Remote Collaboration (SHARC) framework, which enables remote participants to conduct shipboard operations and control robotic manipulators with using only a basic internet connection and consumer-grade hardware, regardless of their prior piloting experience. SHARC extends current supervisory control methods by enabling real-time collaboration between multiple remote operators, who can issue goal-directed commands through free-form speech and hand gestures to execute a robotic motion plan. SHARC couples these natural input modalities with an intuitive 3D workspace representation, which that segments the workspace and actions into a compact representation of known features, states, and policies.



Laboratory-based performance testing (**A**) Task Completion Rate breakdown among test groups, both pilots and novices had a higher *Task Completion Rate* with SHARC-VR than with the conventional topside controller. (**B**) Map of push core placement locations by test group relative to the target center. Confidence ellipses (2σ) are shown for each group. For both pilots and novices, push core locations achieved using the SHARC-VR formed a tighter confidence ellipse than those with the topside controller. (**C**) At decreased framerates, pilots and novices complete sampling tasks quicker using SHARC-VR than with the topside controller. *Expected task times* are relatively insensitive to framerate across 2 orders of magnitude using SHARC.

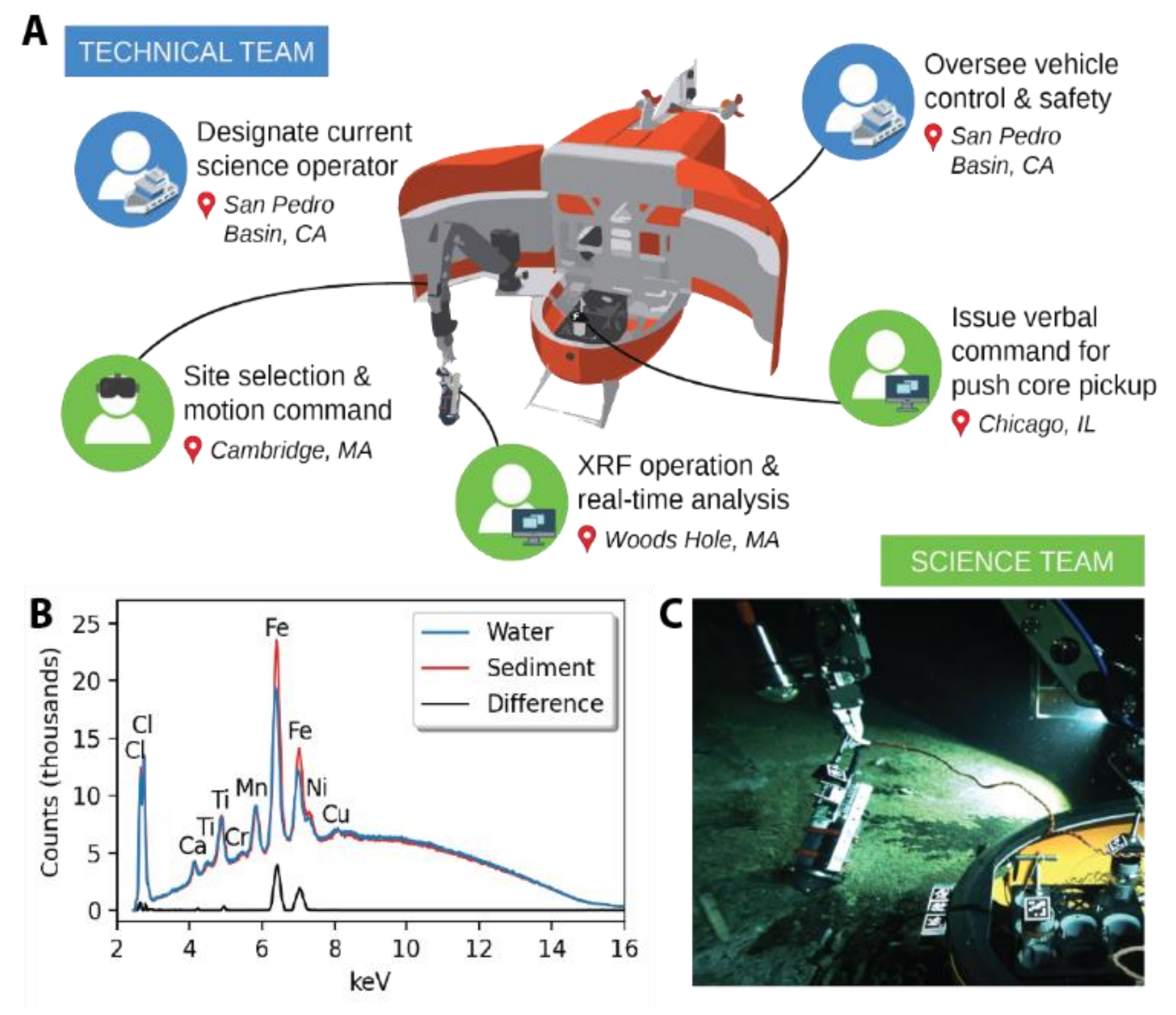
Scientific Impact

SHARC couples the advantages of automated low-level motion planning and control with an immersive real-time 3D reconstruction of the work space, while enabling human supervisory (goal directed) control. This minimizes human cognitive burden while also providing scalability for human-human cooperation within the workspace and parallelization of tasks.

In September 2021, a team of remote operators distributed across the continental United States conducted a robotic dive operation at more than 1000 m deep in the Eastern Pacific Ocean. The remote team, located more than 4000 km away used SHARC to sample visually distinct areas of the seafloor within and around a microbial mat. Real-time feedback from SHARC enabled active tuning of the XRF parameters to maximize the signal-to-noise ratio while the sample was being collected. The XRF spectra revealed elemental compositions within the microbial mats, which suggested the presence of chemolithoautotrophs. In order to independently determine the presence of these microbes, the remote science team then collected a physical push core sample from the same microbial mat with SHARC.

Broader impacts

SHARC enables efficient human-collaborative manipulation and can out-perform conventional teleoperation in in complex, unstructured environments. SHARC's ability to relax infrastructure requirements and engage remote scientists, including novice shore-side users without requiring additional bandwidth from the ship or specialized hardware has potential to further democratize access to deep sea operations. This provides a promising avenue for democratizing access to deep-ocean science and expanding scientific engagement to a broader audience, including classrooms and the general public.



Ocean science operations: real-time, *in-situ* XRF analysis. (**A**) Illustration of the sampling process with SHARC. Remote scientists (green) using SHARC-VR (headset icon) and SHARC-desktop (monitor icon) collaborated with the onboard crew (blue) to take an XRF measurement and push core sample of a microbial mat within the San Pedro Basin. (**B**) XRF spectra indicate elevated iron concentrations in the microbial sample (red) above ambient (blue). (**C**) Snapshot of a representative video frame broadcasted with SHARC during measurement.