Assessment of Suited Reach Envelope in an Underwater Environment

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Background

Predicting the performance of a crewmember in an extravehicular activity (EVA) space suit presents unique challenges. The kinematic patterns of suited motions are difficult to reproduce in gravity. Additionally, 3-D suited kinematics have been practically and technically difficult to quantify in an underwater environment, in which crewmembers are commonly trained and assessed for performance.

The goal of this study is to develop a hardware and software system to predictively evaluate the kinematic mobility of suited crewmembers, by measuring the 3-D reach envelope of the suit in an underwater environment. This work is ultimately aimed at developing quantitative metrics to compare the mobility of the existing Extravehicular Mobility Unit (EMU) to newly developed space suit, such as the Z-2. The EMU has been extensively used at NASA since 1981 for EVA outside the Space Shuttle and International Space Station. The Z-2 suit is NASA's newest prototype space suit. The suit is comprised of new upper torso and lower torso architectures, which were designed to improve test subject mobility.

Methods

The testing is currently in progress in the Neutral Buoyancy Laboratory (NBL) at the NASA Johnson Space Center. The EMU and Z-2 space suits are being tested to compare their performance. This opportunity was used to develop and evaluate a new hardware and software-based motion capture system. Thus far, four subjects have participated in the test series. The subjects were tested in the Z-2 and EMU suits on separate days. Both suit types were pressurized to 4 psid.

Each subject was positioned with both feet secured in an Articulating Portable Foot Restraint (APFR), set at height of 0.84 m level from the floor. The subject performed sweeping motions using their hands, one at a time, then both together as directed by the test conductor. Motions were designed to capture the maximum (a) full-body reach and (b) arm-only reach of the subject in the forward, backward and side-to-side directions. Vertical and horizontal sweeps were used to paint a "reach grid." Vertical sweeps were performed at 0° (forward), ±45°, ±90° and individual maximum azimuths. Horizontal sweeps were performed at the lowest level near the knees, shoulder level, overhead level and with maximum backward bending, crossing between the leftmost and rightmost positions.

The measurement space was defined by a 6.4 m x 6.7 m surface located at 12.2 m depth in the pool. Multiple commercial off-the-shelf cameras (GoPro Hero4), each of which was secured in a waterproof housing and calibrated for optical distortion corrections, captured the video recordings of active LED markers on the suited subject's gloves and feet. Video was recorded at 60 frames per second and 1920 x 1080 pixel resolution. Flashing strobe lights were used to synchronize the video recordings. Software tools were developed based on open-source kits, including OpenCV, Python and Blender, which triangulated the 3-D coordinates of the markers.

The measured marker traces were used to estimate a reach envelope. Specifically, the reach envelope was approximated by a parametrically deformed icosphere, of which surface points corresponded to the least square distances to the marker traces. The deformation parameters were composed of a finite set of control point coordinates for a radial basis interpolation, which can concisely represent the reach envelope geometry.

Preliminary Results

The preliminary results indicate that the motion capture system provided an acceptable level of accuracy and reliability, with the estimated error of $\pm$1.2 cm on average. Further, the parametrically estimated envelopes showed an average surface-to-reach point error of 5.5 cm. The volume and area of the reach envelopes can be used as metrics to quantitatively characterize the mobility performances of the suits. The preliminary analysis showed envelope volumes of 2.2-2.6 m^3 for one-handed reaches and 4.5-5.2 m^3 for two-handed reaches combined, on average. More detailed results will be discussed in the full report.

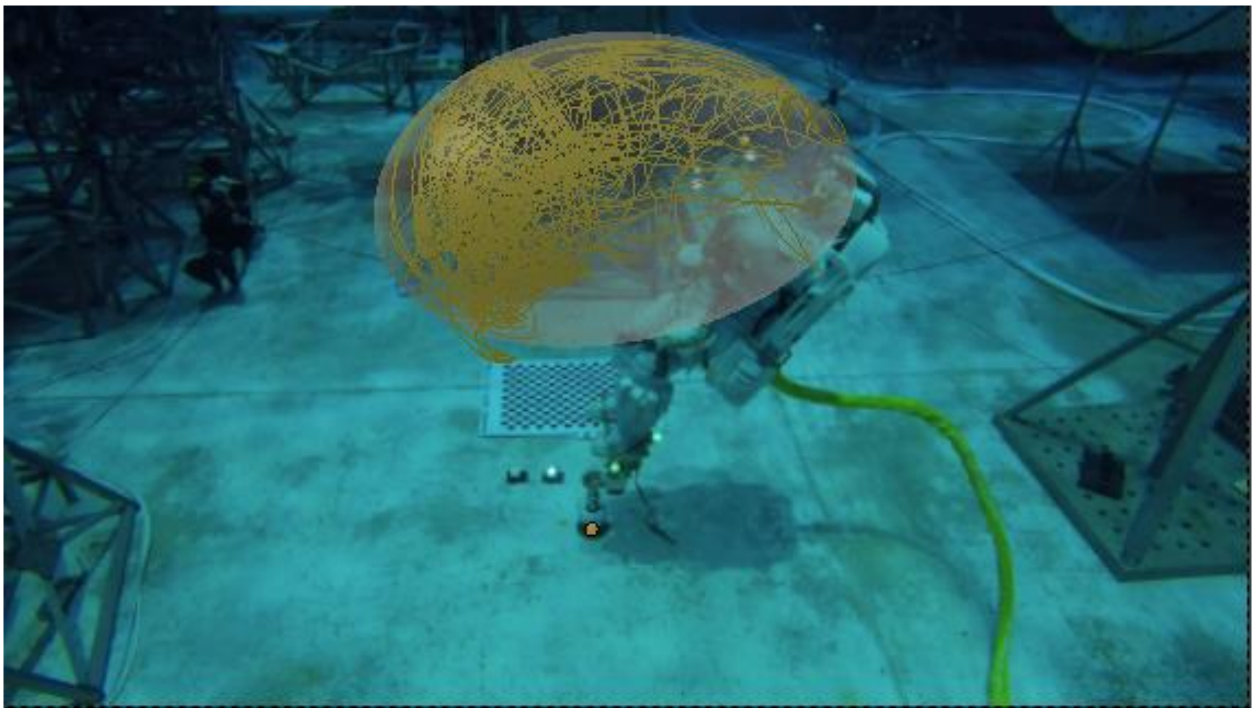

Figure 1. Reach trajectories of the subject in an EMU suit (lines). The highlighted surrounding region indicates a parametrically approximated reach envelope.

Discussion and Future Work

In this study, a framework was developed to measure the suited 3-D reach capabilities in an underwater condition. This system is composed of the off-the-shelf commercial devices and open-source software, thus providing more opportunities for further improvements and enhancements at a reduced cost. The parametric approximation of the reach envelopes can be also validated with an increased number of subjects. Overall, this framework is expected to provide a quantitative tool to predictively assess the mobility performances for EVA across different suits.