Research Technologies for Robotic Construction of Lunar Surface Assets. A. Quartaro[1], J. Martin[2], and E. Komendera[2], [1]NSTGRO Award Recipient, Virginia Tech Blacksburg, VA 24061, USA, [2]Virginia Tech Blacksburg, VA 24061, USA (Contact: aquartaro@vt.edu)

Introduction: To establish a long-term crewed facility on the lunar surface, aligning with NASA's goal to create a robust human lunar enterprise [1], it is imperative for the implementation of robotic technologies to assist in construction and maintenance activities. For persistent lunar presence, routine maintenance operations are inevitable. However, the cost and risk of a full EVA for crew is inefficient. Robotic assembly and maintenance technologies will greatly reduce the risk associated with EVA activities and enable the expansion of possible structures beyond pre-built modules like the ISS, allowing for piece by piece strut assembly to form. Autonomous robotics would expand the possibilities of a constructed, habitable facility before astronauts even descend to the surface.

Long Reach Manipulator Applications: The Lightweight Surface Manipulation System (LSMS) was originally developed at NASA Langley Research Center [2] to perform construction and offloading activities in a low gravity environment [3]. The tendon-actuated serial arm has a load capacity of 1000kg (Moon gravity) with a 7.5m reach [2].

A new LSMS has recently been built at the Field and Space Experimental Robotics (FASER) Laboratory, shown in Fig. 1b, with the goal to continue its use as a long-reach manipulator to assist in autonomous assembly processes. The replication of LSMS in a new labspace has allowed the design to be updated to reflect innovations in motor control and used new commercial off-the-shelf (COTS) parts that matched or improved the outdated components. In addition, the LSMS architecture was changed to implement a network based system - all motors, sensors and other potential add-ons are controlled over ethernet, with general kinematics methods remaining the same. Furthermore, a gantry system was underslung on the forearm of LSMS, improving range of motion and adding additional capabilities such as additive manufacturing [4] and dexterous manipulation.

Dexterous Manipulation: While the LSMS provides the ability for large translations for high mass loads, it does not possess the ability to perform jigging tasks. There has been extensive research into robotic dexterous manipulation [3], but such work almost always make rigid body assumptions of assets or requires crewed intervention. An operational lunar enterprise will require

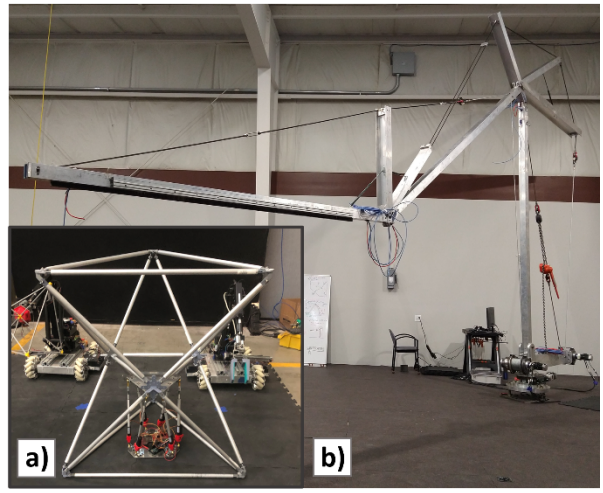

Figure 1: (a) SP for rigid/flexible operations, (b) LSMS

incoroportation of all non-structural components such as electrical routing, payload installation, solar array alignment, and maintenance tasks that require precise movements in tight quarters.

Work currently being performed under a NSTGRO Award is pursuing the use of a small scale (0.5-1 meter) dexterous manipulator, such as a Stewart-Gogh Platform (SP), shown in Fig. 1a., to be placed internal to a structure and assist in closeout assembly tasks. A model is being developed to allow for near real-time manipulation of non-rigid objects, such as cable routing and non-uniform payloads, within a confined environment. The model, Structure-Aware Simulataneous Localization and Mapping (SA-SLAM), is expected to bridge the gap between autonomous robotic technologies and the need for assembly and maintenance operations in tight quarters, where the rigid body assumption is not reliable enough to ensure success.

References: [1] NASA (2020), *Online: https://www.nasa.gov/sites/default/files/atoms/files/artemis_plan-20200921.pdf*, Accessed 3/4/2022. [2] Doggett W. et al. (2008), *AIAA SPACE.* [3] Komendera E. et al (2017), *IEEE/RSJ IROS*, 4672-4679. [4] Chapin W. and Komendera E. (2020), *IEEE/RSJ IROSI,* Abstract.