Robotics testbed for autonomous operations development

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***Abstract*—Surface operations for setting up and maintaining infrastructure will be needed to enable the capabilities proposed in the Artemis Program for long-term presence on the Moon and Mars. Most of these operations will have to be performed by autonomous robots due to the limited availability of astronaut time especially in the early stages of the program, and the limited communication bandwidth with ground operators. The development of specialized autonomous robotics capabilities can be facilitated with testbeds that replicate the tasks that need to be performed, and the conditions on the Moon or Mars. The reliability and safety of these autonomous robotics operations will have to be validated and verified in order to be deployed alongside astronauts. Autonomous robotics capabilities will likely be developed by multiple teams but will have to be demonstrated for specific tasks for the Moon and Mars. The Ocean World Lander Autonomy Testbed (OWLAT) system developed at NASA JPL for demonstrating autonomous robotic operations is an ideal model for the development of these capabilities.**

***Index Terms*— technology assessment; trust in autonomous Systems; robotic systems**

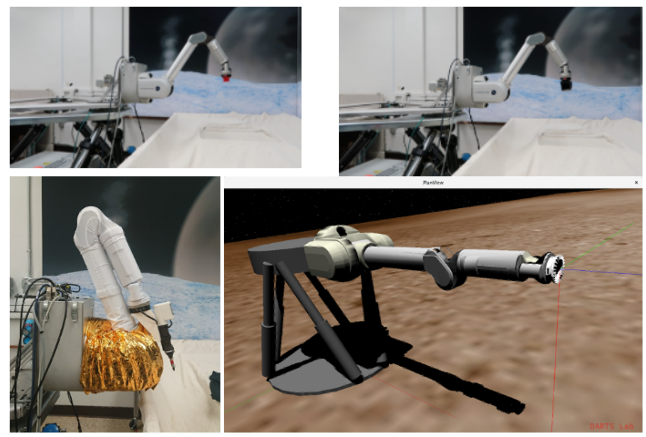

Figure 1 Views of the OWLAT testbed and a virtual dynamics simulator of the testbed (bottom right).

I. Introduction

Surface operations for setting up and maintaining infrastructure will be needed to enable the capabilities proposed in the Artemis Program [Smith, 2019; Boggs, 2020; Smith, 2020] for long-term presence on the Moon and Mars. Most of these operations will have to be performed by autonomous robots due to the limited availability of astronaut time especially in the early stages of the program, and the limited communication bandwidth with ground operators. The development of specialized autonomous robotics capabilities can be facilitated with testbeds that replicate the tasks that need to be performed, and the conditions on the Moon or Mars. The reliability and safety of these autonomous robotics operations will have to be validated and verified in order to be deployed alongside astronauts. Autonomous robotics capabilities will likely be developed by multiple teams but will have to be demonstrated for specific tasks for the Moon and Mars. The Ocean World Lander Autonomy Testbed (OWLAT) system [Nayar, 2021] developed at NASA JPL for demonstrating autonomous robotic operations is an ideal model for the development of these capabilities.

OWLAT was setup under the NASA SMD ARROW and COLDTech:Autonomy programs [Mercer, 2022] to facilitate infusion of autonomous robotics technologies into future NASA missions. The program supports the development of functional- and system-level autonomous capabilities that aim to increase the productivity of surface operations, reduce the need for frequent uplink/downlink cycles and hence ground control, and handle spacecraft faults, degradations, failures, or other unexpected conditions. It was structured to award teams with mature capabilities to adapt their technologies to mission applications in less than two years. Under this program, the OWLAT team has worked with three academic institutions [Hossen, 2023; Touma, 2023; Zhu, 2023] to develop demonstrations of autonomous operations pursuing varied objectives.

The physical components of the OWLAT system consist of a platform, a manipulator arm, a sensor suite, a set of instruments and an environment simulator. The platform represents a mobile base on the planetary surface. The platform can move in response to dynamic loads from the relative motion of components as well as from the interaction with external objects and the environment during operations. The platform component in OWLAT is a 6 DOF Stewart platform that can be controlled to emulate dynamic behavior on low-gravity environments. The 7 DOF robot arm on the lander deploys instruments, performs manipulation and sampling procedures. The sensor system consists of a COTS 3D-camera mounted on a pan and tilt unit that is attached to the platform and several force-torque sensors (FTSs) used to implement advanced capabilities for emulating dynamic behavior of the platform on any planetary body. The manipulator has an integrated six-axis FTS on its tool/instrument interface that is used to detect and measure interaction with the environment. In addition, three six-axis FTSs are sandwiched between the top plate of the Stewart platform and a mounting interface plate on the platform. They are configured to be used in combination to measure forces and torques on the platform.

Several tools for performing geotechnical measurements and for sampling operations have been developed for use with the testbed. The suite of tools includes probes, a scoop, and a drill. A COTS quick-release interface plate was adapted to mount on the manipulator end-effector to allow rapid manual change of tools on the robot. The probes developed include a pressure-sinkage plate, a shear bevameter and a cone penetrometer. A scooping device was designed for use as a sample manipulation tool to scrape, capture and transfer material for loose granular material on the ground. For sampling harder materials, a drill was designed with the capability of capturing swarf in a chamber and transferring it to a sample processing system.

Autonomy software interacts with the testbed through a ROS command and telemetry interface to conduct operations mimicking some of the behaviors and ideocracies of the core flight software command sequencing architecture used on JPL missions [Murszynski 2023]. The testbed provides three modes of use through this interface: 1) a virtual hardware-in-the-loop (HITL) version of the testbed is available as a stand-alone software package that the autonomy developer can use at their local facility to emulate the operational conditions and perform simulated tests, 2) remote access over the internet to the physical testbed is available through a secure VPN-based communication channel to command and receive telemetry from the testbed, 3) directly commanding and getting data from the testbed while in the testbed laboratory through ROS commands and telemetry communication. The HITL dynamics simulator, built using the DARTS software [Jain, 2019], models all the articulated components of OWLAT. In addition, the simulator is also configured to provide sensor measurements as would be obtained from the physical system. This includes FTS readings and camera images that may be then processed through the control algorithms or the 3D-image processing pipeline. Remote access was implemented to meet the strict cyber-security protocols. The connection process requires the testbed team to first connect to the autonomy system and establish the communication to allow remote commanding and receipt of telemetry with the testbed. All three modes of access use the identical ROS command and telemetry interface.

The OWLAT system has been built with capabilities for use as a platform for evaluating autonomous robotics technologies. The advanced control system implemented to emulate spacecraft dynamic behavior on any planetary body, the built-in safeguards, monitoring software and software simulator will provide a realistic Earth-based testbed to provide a rigorous selection of autonomy technologies for future NASA missions and could serve as a model for development of critically needed autonomous robotics capabilities for the Artemis Program.

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