Restoration of NASA's Mobile Analytical Lunar Platform (MALP) as a Prototype Science Exploration Device using a Public, Private, Academic (PPA) Model. M.J. Leonard[1], J.A. Morgan[2], M.E. Evans[3], L. D. Graham[3], M.R. Zanetti [4], [1]Texas Space Technology Applications and Research (T STAR), matt@tstar.us, [2]Texas A&M University (TAMU), [3]NASA Johnson Space Center (JSC), Astromaterials Research and Exploration Science (ARES), [4]NASA Marshall Space Flight Center

Introduction: The NASA JSC Astromaterials Research and Exploration Science (ARES) division recognized the need for a mobile platform that could evaluate and demonstrate lunar telerobotic scientific exploration capabilities, as well as an analog training platform for future exploration scientists.

Background: Since 2013, T STAR has been bringing together problem generators with problem solvers as it links NASA scientists and researchers with Capstone Teams at Texas A&M University (TAMU) to develop working prototypes, and in some cases, operational systems [1,2].

To date, over twenty projects have been completed using the PPA model providing a challenging and rewarding experiential education for over 100 young men and women at TAMU.

The first multi-team, multi-semester, multidisciplinary effort undertaken using the PPA model was the redevelopment of NASA's Mobile Analog Laboratory Platform (MALP): a telerobotically operated 6-wheeled rover originally built as an astronaut-carrying platform for lunar and planetary exploration (see Figure 1).

Figure 1: The NASA JSC MALP

The MALP had been stored for a decade in a warehouse at NASA JSC, and was not operational when delivered to T STAR. Most of the onboard electronics were out of date and had no documentation. The NASA scientists and T STAR agreed that MALP was an excellent candidate to test and validate the expansion of the PPA model. In the Fall of 2019, a draft of the proposed architecture for MALP was created and work began with two Capstone projects using students from both the Electronics program and the Mechatronics program within the College of Engineering at TAMU.

System Architecture: The overall program includes subsystem development by multidisciplinary undergraduate Capstone teams using a system engineering approach. To date, teams have developed a cellular-based communications system with time delay variation to emulate control on the Moon and Mars, full motion control of the platform, situational awareness and a four-axis robotic arm with selectable end effectors. The system architecture is demonstrated in Figure 2.

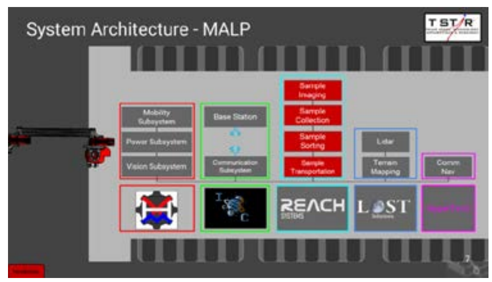

Figure 2: The MALP Overall System Architecture

Completed Subsystem Development: Initially, communications and motion were two of the most important developments necessary to transform the derelict MALP to a viable demonstration and training resource.

Communication, Data Delay and Graphical User Interface: "Interstellar Communications" was one of the first MALP capstone teams beginning in Fall 2020. Ensuring that MALP could be used in a variety of different locations, it was necessary to implement a wireless technology that had extended range, high bandwidth and off-the-shelf technology. Cellular communications, specifically Long-Term Evolution (LTE), was chosen to meet these requirements. In addition, a selectable, and variable, time delay in data transmission was necessary to properly emulate the conditions an operator on Earth would experience controlling a mobile platform on the Moon or Mars. Interstellar Communications started with these requirements, then developed a Graphical User Interface (GUI) and game controller capability for the operator to monitor and control MALP from a distance beyond line of sight.

Motion and Local Control. "HxMx", another Fall 2020 TAMU Capstone team, was assigned the responsibility of adding motion control and power subsystems to MALP. Their work began by completely removing all but the motors and power train from MALP and then rebuilding the motors and associated gear boxes. Once completed, HxMx reverse engineered the integrated motor controllers and designed an embedded microcomputer-based system that could communicate with the motor controllers and thus provide full motion control for MALP. In addition, HxMx provide wireless local control of MALP using a standard game controller as well as integrating their subsystem into the Interstellar Communication subsystem for remote control and monitoring as well as the transfer of real-time video and images to be displayed on the remote GUI. With a wireless and wired IP-based network configuration to support communications and motion control, the MALP architecture was now ready to be expanded in functionality.

Sample Imaging, Retrieval, and Sorting: The multidisciplinary team, "REACH", started work on MALP in the Spring 2020 semester (while Interstellar Communications and HxMx were ongoing). REACH worked on the development of a robotic arm for sample collection, sorting, and storage. Using HEBI intelligence modules, REACH was able to develop a fully controllable, four-axis robotic arm and two different end effector tools. These capabilities were then integrated into the MALP communications architecture for remote monitoring and control. The robotic arm is capable of sample identification via high-resolution images, sample collection using a shovel-like tool, and passive sorting of collected samples into three bin types. After transport on the MALP, the arm can then relocate the sorting bins to another vehicle using a second end effector tool. A tool caddie as well as the ability to store and change tools was also included in the REACH project. REACH provided video/images to be displayed from the HxMx camera and the REACH end effector camera mounted on the robotic arm (see Figure 3). Finally, using reverse kinematics, REACH was able to depict the location and orientation of the robotic arm to the remote site.

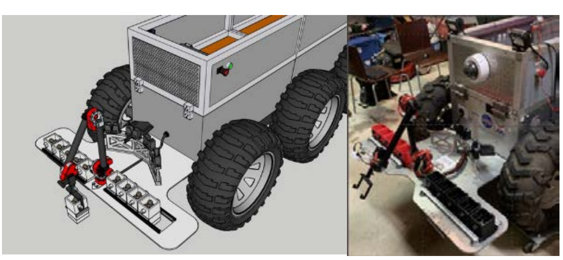

Figure 3: MALP Surface Sample Robotic Arm

Other Subsystem Development: The ARES/T STAR/TAMU team has developed a roadmap for additional subsystems to increase MALP capabilities.

LiDAR and Terrain Mapping: The TAMU "LOST" Solutions team (a Fall 2020 Capstone student team supporting the "Gandalf's Staff" project [3, 4]) is addressing NASA's need for collecting, conditioning, and storing LiDAR data collected from a mobile platform for post-collection 3D image processing and rendering. NASA has also identified the need for auxillary lighting and imaging as well as the ability to create and implement a robust end-to-end protocol of 3D models of environments. They are using data from an Ouster LiDAR (with on-board IMU) mounted on a dynamic walking-stick/backpack mobile platform. The aim is to use only LiDAR and integrated IMU data to build large-area 3D models of natural environments that will provide data for scientific interpretation (e.g. topography), operations planning and traverse support.

Communication and Navigation Subsystem: The "Hypertech" team (also supporting the "Gandalf's Staff" project [3, 4] beginning in Fall 2020) provides a 24v battery-driven power system for MALP capabilities, Specifically, they are creating the battery power budget and distribution system for planned instruments. Additionally, they are designing the router, antenna, and UHF radio repeater necessary to implement communications between the crew, MALP, Gandalf staff, and a nearby base station. A surface-based navigation function is planned to combine the MALP and Gandalf's Staff in a demonstration of relative navigation (similar to marine LORAN systems) that do not require a satellite-based network.

Conclusion: A mobile telerobotic platform to demonstrate capabilities and train operators has been successfully implemented using the PPA model. Teams of NASA scientists, T STAR personnel and TAMU faculty and Capstone students have modernized the MALP. The projects have also given students a unique experience in multidisciplinary design that are part of an integrated system. Future planned projects (including a lunar walking stick and cosmic dust collector) will allow 50 students from an expanding variety of engineering disciplines to participate in a unique learning environment that provides NASA with fully functional prototypes advancing planetary exploration capabilities.

References: [1] Morgan, J. A., et al (2016, June), *2016 ASEE Annual Conference*, 10.18260, [2] Colby R. et al (2018, April), *ASEE GSW Annual Conference*, peer.asee.org/31593 [3] Evans M.E. and Graham L.D. (2020) *NASA Lunar Surface Science Workshop – Instruments*, Abstract #5031, [4] Evans M.E. et al (2021) *LPSC* Abstract #1303