**"MISSION CONTROL SOFTWARE": CLOUD-BASED ROBOTIC CONTROL AND COMMUNICATIONS SOFTWARE FOR DISTRIBUTED OPERATIONS OF COMMERCIAL LUNAR MISSIONS AND PAYLOADS.**

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**Introduction:** Upcoming commercial lunar missions promise exciting new opportunities for planetary scientists to conduct lunar research at multiple locations on/around the Moon, from orbital, landed, and rover platforms. However, unlike missions of the past, there will not be a centralized agency running these missions, nor will there necessarily be one primary mission objective. Rather, multiple unrelated payloads ("sub-missions") will run concurrently and independently on one landed mission. Therefore, distributed, separate mission operations will be required for each payload, or sub-mission. Lander providers and/or payload Principal Investigators will need to seek out software that will provide geographically distributed operations capability for use by mission and payload operators, and researchers. Mission Control Space Services Inc. (Mission Control) is developing an end-to-end software system that will meet this critical need, including "Mission Control Software" (MCS) for the ground segment, as well as the "Mission Control Moon Box" (Moon Box) for the space segment (Figure 1).

**Mission Control Software (MCS):** MCS is a cloud-based mission operations tool that will facilitate operation of commercial lunar spacecraft (including payloads and rovers), using Distributed Architecture for Robot Transmission (DART). DART is a distributed ground-based software framework that enables operation of platforms (e.g. payloads, rovers) with advanced algorithms independent of the flight system's processing capabilities, while securely distributing data access and command responsibilities to any number of users involved in a mission. MCS will provide scientific data to Principal Investigators (PI) and science teams, using custom designed graphical user interfaces (GUIs), or by integrating with existing GUIs already in use by teams. MCS will have the ability to store and organize all data. For lunar applications MCS will allow operators to offboard certain guidance, navigation and control algorithms that need not operate at high rates (e.g. path planning, trafficability prediction) to the ground segment, thereby enabling more autonomous behavior for computationally limited platforms [1] such as microrovers.

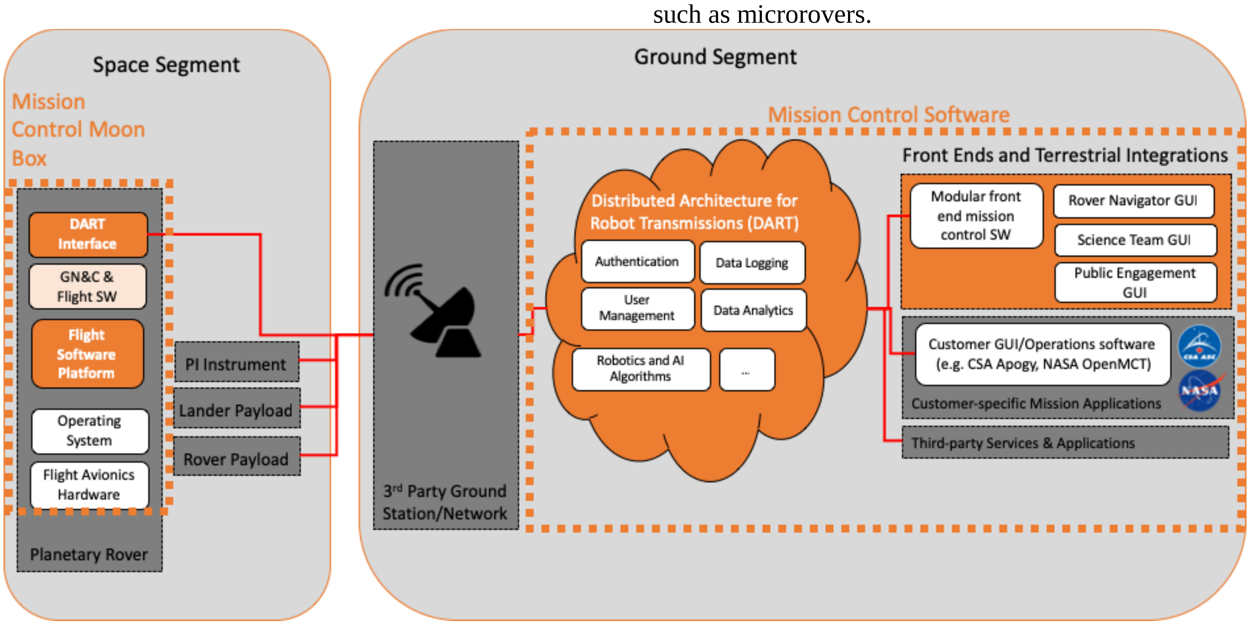


**Figure 1.** This diagram shows an end-to-end software system under development by Mission Control Space Services Inc. The Space Segment, "Mission Control Moon Box" (left, outlined by orange dashed-line) will be mounted on commercial lunar rovers, and will include software and hardware components. The Ground Segment "Mission Control Software" (right, outlined by orange dashed-line) includes software components that facilitate operations from the ground. Each element is designed to be a standalone service (shown in orange) or part of an end-to-end system.

**Mission Control Moon Box:** On the space segment, the Moon Box will allow for merging of data from multiple missions and payloads in cases where this is desired. This will allow for increased machine learning capabilities, for example by applying terrain classification data from one lunar location to another, and thereby facilitating safer rover navigation.

*Increased Rover Autonomy*. The Moon Box will allow for more autonomous rover operations, including terrain perception, path planning, control, and data analytics. This will reduce operator workload, enable more distributed ground operations, enable multi-rover collaborative missions, and increase the safety, yield and efficiency of mission(s) [2,3,4,5]. Examples of autonomy algorithms that have been previously developed by Mission Control and will be deployed include the Autonomous Soil Assessment System (ASAS) that uses data in real-time to learn terramechanics models for non-geometric hazard prediction; the Skid Steer Optimizer (SSO) that can plan energy-optimizing maneuvers for skid steer vehicles; and the Intelligent Planner that uses predictive capabilities by ASAS and SSO to plan multi-objective path profiles that minimize hazards and energy consumption.

Rover autonomy will be particularly important for commercial missions, as private companies will have economic incentives to make missions more efficient and productive, and also to reuse software across multiple payloads and missions.

**MCS for Analogue Missions:** In addition to commercial lunar missions, MCS is available to support terrestrial human and robotic analogue missions. MCS will allow for remote operation of a rover (with simulated latency as needed), options for rover navigational autonomy in scenarios where this is desired, as well as interfacing with all sensors and science instruments.

For example, Mission Control will test components of MCS as well as science applications of ASAS for increased science autonomy during analogue missions conducted in Iceland over the next two summers. Mission Control is part of a team led by Texas A&M University on a NASA-funded project called SAND-E (Semi-Autonomous Navigation for Detrital Environments), which will study Mars-like volcanic sand environments in Iceland. We will compare a number of science operations approaches with varying degrees of autonomy, using rover and drone platforms, in order to inform NASA's Mars2020 rover operations [6,7].

**MCS for Education and Outreach:** MCS has its roots in Education and Outreach. The earliest version of MCS was developed to facilitate the "Mission Control Academy" program that was developed for the International Space University, in which students learn about, plan for, and ultimately remotely operate a rover, located on the other side of the world in a Mars analogue environment, to conduct a simulated life-detection mission. As such, future versions of MCS will also be able to support similar education and outreach initiatives, and can even allow students or the general public to log-in and passively observe certain aspects of mission operations and/or data from specific instruments (e.g., camera images).

**About Mission Control Space Services Inc.:** Mission Control is a space exploration and robotics company with a focus on mission operations, onboard autonomy and artificial intelligence. We develop mission operations and robotic control software. Our technology allows customers to operate and automate robots deployed in harsh and remote environments – including the Moon, Mars and analogue sites on Earth – improving the autonomy, productivity, safety, and scientific return of missions. We are committed to inspiring the next generation of explorers through our immersive technology-based education program, Mission Control Academy, which allows students to operate a real rover, as if it were on Mars. We have expertise in conducting rover and human planetary analogue missions around the world, ranging from logistics planning and management, to conducting operations and trafficability research internally, to integrating and enabling research by external teams of researchers.

**Conclusions:** In conclusion, Mission Control's end-to-end software system for including Mission Control Software (MCS) and the Mission Control Moon Box is a new full-stack command and control software suite that is currently under development by Mission Control Space Services Inc. MCS will facilitate a new concept for planetary mission operations, in the emerging age of commercial planetary exploration. MCS will allow for control of robotic assets and payloads, as well as data communication and management, on commercial lunar missions, terrestrial analogue missions, simulated missions for education and outreach purposes, and other future planetary missions.

Platforms for democratizing the use of space assets for Earth observation and telecommunications exist/are under development, however no such product exists yet for space exploration. We are currently investigating the needs of scientific payload PIs to ensure our software is aligned with the requirements of the scientific community.

**References:** [1] Lentaris et al. (2018) *J Aero. Info. Sys 15, 178-192*. [2] Burns et al. (2017) *IAA-17*. [3] Dupuis et al. (2010) *iSAIRAS 2010*. [4] Gingras et al (2014) *iSAIRAS 2014*. [5] Reid et al. (2017) *IAC 2017*. [6] Ewing et al. (2018) *AGU 2018*. [7] Battler et al. (2019) *WISC 2019*.