CRYOGENIC ROBOTIC SWARMS FOR LUNAR PERMANENTLY SHADED REGIONS (PSRS).
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Summary: We discuss NASA-MINDS Cryogenic Robotic Swarms task to meet Artemis Mission Tech. Area TA4: Robotics, Telerobotics and Autonomous Systems, requirements.

Introduction: This is the 2nd year of the Cal State LA Cryo-Swarm Team's NASA-MINDS task, which seeks to develop a new robotic swarm technology platform for Science and In-Situ Resource Utilization (ISRU), that supports the NASA Artemis Mission objective of returning astronauts to the moon and the establishment of a sustainable presence, i.e., a Lunar Base Station [1]. The Cryo-Swarm Team will design a lunar science mission that conceptually enables the delivery of cryogenically rugged UAVs and a Hexapod Lander, i.e., a Cryo-SpyderBot, to Lunar permanently-shaded-regions (PSRs). The Cryo-SpyderBots could directly detect the presence of water-ice, measure regolith composition, and map the PSR terrain, in coordination with other robotic platforms at the lunar surface.

The Cal State LA Cryo-SpyderBot Swarms Project will ask mission critical questions related to the deployment of robotic swarms in cryogenic conditions.

Background: The presence of water-ice on the Earth's Moon would be an enabling geomorphological feature, as the water-ice could be source of water, hydrogen, or oxygen, and would be treated as a prospective resource for In-situ Resource Utilization (ISRU) activities. A full discussion of the Lunar PSRs, (e.g., the Shackleton Crater) and (e.g., the Nobile Crater) is well beyond the scope of this article.

The Artemis Mission plan is supported by substantive experimental evidence indicating the presence of water-ice in the permanently-shaded-regions (PSRs) located near the south pole of the Earth's Moon, and has been obtained by the following NASA Missions: the LCROSS Crater Experiment [2-3], the Lunar Reconnaissance Orbiter (LRO) Instrument Package, which contains: the Lunar Orbiter Laser Altimeter (LOLA) [4-5], the Diviner Lunar Radiometer Experiment (DLRE) [6-7], the Lyman Alpha Mapping Project (LAMP) [8]; and the Jet Propulsion Laboratory's (JPL) Moon Mineralogy Mapper (M^3) which flew as part of the Indian Space Agency's Chandrayaan-I mission to the Moon [9]. In addition, the analysis of data returned by the LRO mission, gives an estimate for the temperature within the PSRs in the range 25 K to 70 K [10].

To date, the LRO measurements do not reveal the presence of surface water-ice deposits in the south pole region PSRs, e.g., the Shackleton Crater. The LRO Camera (LROC) Narrow Angle Cameras (NACs) were designed to image illuminated portions of the Moon, and not shadowed areas [11]. As discussed by Bickle *et al*, the LROC NACs can only image PSRs through long-exposure imaging, taking advantage of light reflected from nearby Sun-facing slopes. The reflected light LROC-NAC imaging results in down-track elongated, 1 m by 20-40 m per pixel images, which does not allow accurate imaging of hazards within a PSR. The use of machine learning or downscaling methods applied to the LROC NAC images results in a best resolution of 3-5 m^2 areal density per pixel, enabling the resolution of boulders within PSRs at a scale of ~ 3m size, which is not at the 1 m scale resolution desired to enable safe operations of roving assets or astronaut AVAs. Based on the downscaled LROC-NAC images, Bickle *et al* found no evidence of surface frost or near-surface water-ice in the south polar PSRs.

The latest version of the NASA LROC-NAC technology, with 200 times better sensitivity, is called the ShadowCam Instrument, and it will be flown on the Korea Pathfinder Lunar Orbiter (KPLO), the first lunar mission of the Korean Aerospace Research Institute (KARI). The KPLO launch date is August 1, 2022.

NASA has just selected the Nobile Crater, as the landing site for the Volatiles Investigating Polar Exploration Rover (VIPER) Mission, which has a 2023 launch date. VIPER will perform critical measurements that will search for the presence of water-ice and characterize its properties. Hopefully, the high-resolution images from the ShadowCam instrument will be available to support the VIPER traversals of the Nobile Crater. The detection of water-ice by VIPER would be profound. However, following VIPER, a significant task still lies ahead for accurately mapping the terrain in PSRs like Nobile, as well as characterizing the properties and morphology of sub-surface water-ice. These tasks are ideal for robotic swarms, and the Cryo-Swarm Project will seek to establish new science and engineering requirements for these tasks. The Cryo-Swarm Project will also follow JPL Flight Project Practices and Principles, to support project pedagogy.

Approach: In the first year of the NASA-MINDS Cryo-Swarm Project, the team selected the Tello EDU drone (See Fig.-1) as a testbed to develop Python-based codes for control of single Tello EDU Drones and to implement Python-based machine-learning codes to enable real-time swarming with a single lead Tello EDU drone, via Python Packet Sender codes and a WiFi-Router used to control the Tello EDU Drone swarms.

In the second year of this project (Spring-2022), the Cryo-Swarm Team will execute the following tasks:

1) Implement Python-based codes to control Tello EDU drone swarms. We plan to fly 2 squadrons, each with 3 Tello EDU Drones, each led by a single Tello Robomaster TT (Tello-TT) drone with an Arduino Interface. Swarming will be facilitated with machine-learning coding between single lead Tello-TT and Tello-EDU swarms.

2) Investigate implementing GPS communications capability for the Tello-TT drones, via the Arduino interface.

3) Purchase two Freenove Corp. Big Hexapod Robot Kits (See Fig.-2) with Raspberry Pi 4B electronics, and develop Python-based coding to enable communications between Tello-TT led swarm and a single Hexapod Lander; and

4) Retrofit second Hexapod Lander with custom-built TF-Luna LiDAR and GPS Sensing instruments, as well as a suite of instruments scavenged from an Apple iPhone-SE (Fluxgate Magnetometer, Accelerometer, and an 8 MP Camera (to serve as Nav-Cam), etc.).

Fig.-1: Tello RoboMaster TT testbed.

Discussion and Conclusion: The primary Cryo-SpyderBot Swarms Team deliverable is to demonstrate that small homogeneous swarms of Cryo-SpyderBots could be operated on the lunar surface via algorithms and software simulations, which could be an enabling breakthrough technology to aid in NASA's quest for technologies needed to live on the moon. The Human Landing System (HLS) that will house astronauts on the lunar surface, will require access to water and other critical ISRU. NASA's selection of the western region of the Nobile Crater for the 2023 VIPER mission, is quite strategic as it is a more forgiving landing site geographically, than the Shackleton Crater; the crater for which we have been designing our mission hardware.

Fig.-2: Hexapod Robot Testbed.

Our mission concept would support a follow-on manned lander to the Nobile region, by deploying an array of LiDAR sensors on the crater rim, to provide 1 m or better resolution for geological features in the crater, to support astronaut AVAs. A robotic Hexapod Lander deployed to the crater region would enable measurements on steep slope sections of the Nobile region, that are not accessible to a VIPER-styled rover. As the Cryo-Swarm mission concept grows, lessons learned from VIPER, will no doubt influence our path forward. Our project goal is to create a conceptual hardware development path for robotic systems that will satisfy all NASA mission requirements for operation at cryogenic temperatures within the lunar PSRs.

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