OFF-THE-GROUND MOBILITY ON THE MOON TO PROSPECT FOR LUNAR POLAR ICES. L. Richter[1] (lrich@softserveinc.com), L. Czyz[1] (lcyz@softserveinc.com), L. Demkiv[1] (ldemkiv@softserveinc.com), Y. Feffer[2] (Yifat.Feffer@wespacetech.com), Y. Harel[2] (Yigal.Harel@wespacetech.com), and S. Kaczmarek[2] (Sylvester.Kaczmarek@wespacetech.com) [1]SoftServe (201 W 5th St Ste 1550, Austin, TX 78701, United States of America) [2]WeSpaceTech Ltd (Ra'ana, Israel).

Introduction: In this talk, an approach for accessing and characterizing volatiles in the polar regions of the Moon from free flying, thruster propelled platforms is described. Due to proximity to the ground and the capability to hover above points of interest, remote sensing data with high spatial resolution and exquisite signal to noise can be acquired that can elucidate the nature of ices and other volatile species in lunar PSRs and elsewhere on the Moon. Moreover, contact measurements are possible if the drone sets down at selected locations. A design option with refueling is being studied.

Lunar polar volatiles and their importance: Several of the orbital missions to the Moon conducted since 1994 provided clear evidence of water equivalent hydrogen in the permanently shadowed regions (PSRs) present near the poles of the Moon. Bistatic radar measurements over the polar regions as well as neutron scattering mapping from lunar orbit show signatures consistent with deposits of ices in some PSRs, and generally enriched concentrations of hydrogen in high latitudes, even outside PSRs [1]. Polarization characteristics of returned radar signals from lunar orbiting radars show Circular Polarization Ratios (CPRs) of the interior of PSR that are consistent with ice-regolith mixtures, and there is even evidence of directly exposed water ice in PSRs [2]. The targeted impactor experiment LCROSS of October 2009 conducted a high velocity impact into a carefully selected, shaded crater near the lunar South pole that based on neutron spectrometer data acquired by the LRO satellite and thermal data was suggested to be enriched in volatiles. A concentration of ~5 % of various volatiles was implicated in the material ejected by the cratering event. [3]. LCROSS only assessed volatile concentration at a single location, and therefore the data obtained cannot be considered representative of the majority of PSRs.

Missions are currently being developed to perform the first soft landings at high lunar latitudes for performing controlled sampling (surface and subsurface) of the regolith from fixed and mobile platforms to obtain ground truth on the nature of volatile species at the scale of spacecraft, such as NASA's VIPER mission, Intuitive Machine's PRIME-1, ispace's M2, and China's Chang'e 7. In addition, lunar orbiting instruments will in the near future provide higher spatial resolution data on hydrogen signatures around the lunar poles, augmenting in situ data from sample analysis at the surface.

Both directions are of great importance not only from the point of view of planetary science – shedding light on the evolution of the Earth-Moon system and the role that volatile elements played during the evolution of the Solar System – but also from the perspective of the potential exploitation of lunar polar volatile deposits, in support of crewed outposts and overall cislunar space exploration that would be benefiting from using propellants and other consumables made from lunar resources (e.g. [4]).

An efficient mobility method for polar volatiles prospecting: Searching and characterizing deposits of lunar volatiles at ground level as currently planned in upcoming surface missions will require repeated attempts to investigate many possible candidate sites in situ. This is compounded by the challenging, rugged topography of the lunar polar regions that will make mobility of surface rovers a tedious undertaking. China's Yutu-2 – operated mostly through command loads and on board autonomy rather than by real-time tele operation – to this day has traversed just ~ 1.3 km over a period of 45 lunar days (corresponding to ~3.5 years), thus typically covering 10…40 m per lunar daytime period. Real-time tele operation was implemented for the Lunokhod 1 and 2 rovers by humans on the ground using slow-scan video allowing higher traverse rates.

Uncrewed surface rovers will always suffer from several shortfalls: i) all ground vehicles are subjected to limits in mobility that vary depending on the exact vehicle configuration: performance characteristics such as gradability and obstacle negotiation capability are limited by definition, preventing access of ground vehicles to particularly steep or rough terrain; moreover, soft terrain constitutes an immobilization hazard; ii) effective speed of uncrewed rovers, i.e. ground covered vs. time, is typically very low; this is particularly true if no real-time tele operation is feasible due to line-of-sight issues with Earth as applicable in lunar polar regions with frequent occultations of the Earth by terrain features.

In this paper, we are stipulating another method of post-landing mobility in lunar exploration being *off-the-ground* mobility: benefiting from the modest gravitational acceleration of the Moon, thruster propelled vehicles – hereafter referred to as lunar "drones" – can carry out powered or ballistic flight arcs, constituting an efficient way of achieving regional exploration and vehicle relocation with kilometer-scale distances that are covered in a matter of minutes, irrespective of surface conditions. Already in the 1960's, early studies were investigating free flying vehicles on the Moon for larger scale mobility [5].

Lunar drone notional concept: WeSpace Technologies have developed a scalable lunar drone concept with multi-landing capability and an attractive cumulative flight time that is achieved by minimizing vehicle dry mass through conscious use of novel technologies. On-board guidance for controlling powered flight, landings and take-off is vision-based with a monocular camera system and an IMU and a SLAM algorithm (Simultaneous Localization and Mapping) that performs autonomous navigation to reach pre-assigned targets. Typical flight speeds during traversing to a target are ~15 m/s and flight altitudes are some 10's of meters. For a 70 kg wet mass design, ~5 kg of science instruments can be carried, and the cumulative flight time can be as high as ~20 minutes. We are showing results of flight simulations that have been developed using the *Gazebo* simulation environment that were developed in context of defining the autonomous navigation system.

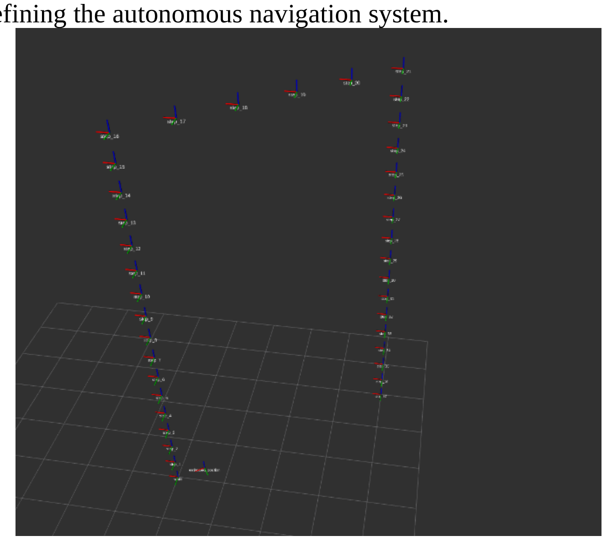

Fig. 1: Lunar drone simulated flight path showing take-off, lateral flight, and descent at a new location.

Mission scenario: The lunar drones would be delivered to the lunar surface as fueled spacecraft by some of the upcoming, uncrewed lunar landers that are currently in flight development. The free flyer vehicles would take off some time after landing of the main spacecraft and carry out their own assignments with mission profiles determined on Earth and uplinked to the drones. Some lander missions – uncrewed but also crewed – could even accommodate more than one such free flying vehicles that after landing would be launched either independently or in a choreographed sequence to carry out reconnaissance and exploration missions to pre-selected science targets.

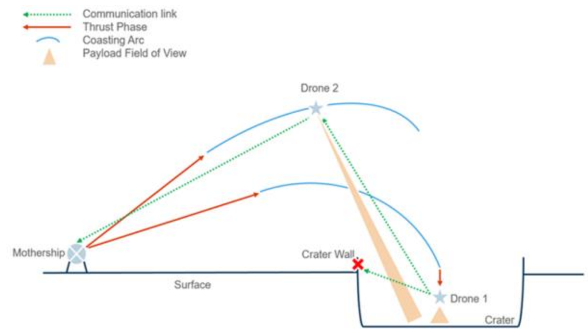

Fig. 2: Schematic of two lunar drones operating in concert to explore the interior of a lunar PSR.

Downward looking or side-viewing remote sensing observations performed during flight or during pre-programmed hover phases will deliver unique data relevant to lunar science and exploration. This is because of the much closer range to the ground compared to lunar orbital missions as well as owing to low relative velocities to the terrain affording exquisite signal-to-noise ratios of the observing instruments especially over unlit terrain. A lunar drone can also be designed to have multi-land capability, affording measurements from the surface. If deployed to the polar regions of the Moon, thruster-propelled drones or "hoppers" promise to not only provide critical data for understanding the distribution and physical nature of lunar polar volatiles at 10 to 100 m scales, but they also allow for an efficient search strategy within a single mission as down looking observations can be performed along the flight path, or multiple drones can be deployed to perform a coordinated mapping. A notional Design Reference Mission to explore a PSR would have the drone delivered to a landing site near a PSR and the vehicle crossing the threshold to the shaded terrain, flying over the interior of the PSR. While descending in powered flight, remote sensing data using radar, thermal IR imaging and laser reflectometry would be acquired ever closer to the ground. The vehicle may be either directed to an impact inside the PSR – avoiding thruster exhaust impingement on volatiles – or may perform a soft landing for short duration contact measurements.

References:

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