Preliminary Development of a High and Long Jumping Lunar Robot. C. Xiao[1*], S. Gallegos[1], S. C. Garcia[1], D. R. Lopez[1], E. Pors[1], C. Tang[1], and E. W. Hawkes[1#], [1] Department of Mechanical Engineering, University of California, Santa Barbara ([*]charles_xiao@ucsb.edu, [#]ewhawkes@ucsb.edu)

Summary: We propose and report on the preliminary development of a robot capable of high and long jumps for lunar exploration.

Motivation: Jumping[1] potentially allows for rapid and efficient locomotion across lunar surfaces.

While this modality of transport has been proposed before for lunar exploration, to our knowledge, no other jumpers proposed for this application have demonstrated high altitude (>5 m on Earth), long range jumps [2-4].

Recently, Hawkes et al. demonstrated a jumper, from here on referred to as the Hawkes Jumper, (Figure 1) capable of jumping over 30 m on Earth [1]. It achieves such heights due to a lightweight construction and novel spring design. Obviously, it is limited in capability and far from ready for lunar missions, but nonetheless, its performance suggests the utility of jumpers with high jump velocities.

Consider a jumper on the Moon with the same takeoff velocity as the Hawkes Jumper of about 28 m/s. Launched vertically, such a jumper can reach an altitude of over 240 m, and if launched at a 45° angle, it can travel almost half a kilometer in a single bound with an apex of about 120 m and flight time of about 24 s.

Additionally, such a jumper is energy efficient. Currently, a 2.8 g lithium polymer battery (~1400 J) provides enough energy for about 10 jumps for the Hawkes Jumper; thus, a lunar jumper with similar energy consumption and battery can travel almost 5 km on a single charge. Replacing this small battery with one that is 10× larger would decrease the jump to ~60% of the original, meaning a single jump could cover 0.3 km, but could be repeated 100 times to cover 30 km. Furthermore, the absence of drag on the Moon might make it possible to recover significant fractions of the jump energy upon landing, allowing it to travel even further.

Motivated by these calculations, we propose using lightweight jumping robots for rapid and energy-efficient exploration and have begun the engineering required to translate the Hawkes Jumper into a viable lunar scientific exploration platform.

Potential Applications: Crater exploration is a clear application for jumping robots. With their ability to traverse long distances and reach high heights, they can be used to jump in and out of shallow craters. This might provide a viable way to explore permanently shadowed regions.

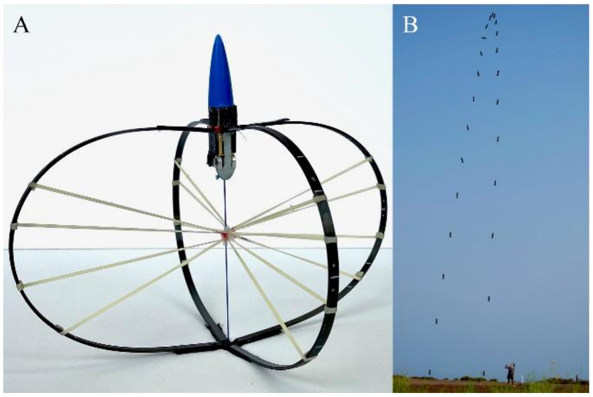

Figure 1 A. Close up of the Hawkes Jumper. B. Timelapse of a jump exceeding 30m on Earth. Black lines are super imposed over the jumper position for enhanced contrast. Images reproduced with the author's permission.

Alternatively, like *Ingenuity*, they can be used as robotic scouts for rovers[2] [5]. With their ability to jump long distances, they can quickly map an area with higher resolution than what orbiters can provide.

Additionally, the robot might be used to gather small regolith samples for a rover or a lunar base.

Beyond imaging, the robot can potentially provide other sources of data. For example, the foot of the jumper might act as a type of penetrometer. When the robot takes off or lands, the foot presses into the ground. Regolith properties can potentially be inferred from the force-displacement relations (see Future Work section). The jumper robot can also obtain scientific data of the atmosphere by carrying spectrometers as part of its scientific payload [6].

Other applications include jumping high to relay signals from other robots.

Current Work: Currently, a senior undergraduate team is developing and testing technologies that will enable a high and long jumping lunar robot. Given the time constraints of a senior project, we focus our attention on engineering the jumper in five core areas: attitude control, steering, landing, spring design, and imaging.

Attitude Control. In order to take detailed surveys of the lunar surface and to land safely, the robot must be able to stabilize itself to take aerial photographs and reorient itself for landing. The current design utilizes reaction wheels to impose angular acceleration in all three axes. An on-board microcontroller then uses IMU data and a PID controller to stabilize and reorient itself

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[1] Jumping as defined by Hawkes et al. requires constant mass through the process. Thus, devices that use propellants are not jumpers [1].

[2] Helicopter-like drones such as *Ingenuity* are not possible on the Moon due to the near absence of an atmosphere; thus, alternative locomotion methods are needed.

midair. Currently work is being done in developing a testbed and a PID controller for stability and reorientation.

Steering. Successful navigation requires controlling the direction of travel. We tested a tripod design that enables the robot to reorient itself upright and point to any direction within 60° of vertical. We will proceed with tests to determine the accuracy of landing position control through this steering concept. To do so, we will compare predicted landing position with the landing position calculated from the commanded take-off angle.

Landing. The ability to absorb impact energy at landing is essential to maximizing the robot's lifespan. Additionally, reusing this energy for future jumps could substantially improve its range. We tested various landing mechanisms and analyzed them with high-speed imaging.

Spring Design. More efficient spring designs allow the jumper to carry greater payloads with less spring mass. We present analysis on potential new spring designs.

Imaging. An imaging system is needed to survey and provide navigational data. We report on the development of a miniature visible camera system for the jumper.

Future Work: We anticipate that work in the core areas will continue in the following months and years, and as those technologies mature, we plan on furthering the scientific aspects of prospective missions.

Soon, we plan on beginning more comprehensive studies of robot-regolith interactions. These interactions will likely affect jump performance. Understanding these terradynamic interactions will help us develop designs that are robust and efficient across terrains. For instance, large-area foot designs may be required to jump off of low-compaction-ratio regolith. Alternatively, it could be possible to perform a compacting routine (vibration) before the jump is attempted. At the same time, our studies of robot-regolith interactions will help us determine the usefulness of using the foot as a penetrometer.

Additionally, if needed, we plan on working to accommodate other scientific payloads such as soil sampling mechanisms and spectrometers.

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