The Artemis "Gandalf's Staff" Science Suite for Crew EVA Lunar Field Geology.

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Introduction: During Apollo, NASA science advisory teams identified a requirement for a hand-held Extra-Vehicular Activity (EVA) tool to carry a camera, samples, and gnomon with camera calibration bars [1]. Described as a staff monopod to be carried by astronauts on foot [2], it was targeted for the last (cancelled) missions. The Artemis team will need a 21st century version of this tool. The proposed "Gandalf's Staff" provides many functions: 1) field site illumination, 2) a gnomon for photogrammetry, 3) a micro Infra-Red (IR) spectrometer for regolith measurements, 4) a 360° high resolution camera and video recorder, 5) a LiDAR and 6) a micro Inertial Measurement Unit (IMU) to create a robust three dimensional (3D) mapping of the traverse.

"Gandalf's Staff" Design Concepts: The instrument suite consists of a gnomon, calibration bars, and active devices. The 360° high resolution camera/video, LiDAR, IMU, and navigation antenna reside atop the 2m tall staff. The LED lights slide atop the spherical bearing connected to the retractable legs (which can independently hold the staff upright). An IR microspectrometer, located on the bottom of the staff, measures regolith components. All active data is recorded to terabit memory on the staff. Live streaming of active data is possible if sufficient lunar surface bandwidth is available. The 4 cm staff diameter easily fits the crew gloved hand, and a handle near the center of mass provides easy grappling. A dispenser for disposable surface tags is attached to one leg (for marking distinctive geologic features). A small retractable gnomon is attached to another leg. The staff interior is fitted with rechargeable batteries to power the instrument suite, and the staff is recharged on a crew mobility device or at the lander. The staff exterior includes color and gray bars for camera calibration. The 6 kg staff conceptual design is given in Figure 1.

Gnomon: A gnomon is the part of a sundial that casts a shadow. It was used in antiquity to tell time and orientation. The modern gnomon supports photogrammetry, which is the process of integrating multiple photographs of the same object from different angles to infer three dimensional structure. Distance and sample size are determined using perspective diagrams [3]. The Apollo gnomon included a gimbaled vertical rod (to determine sun angle and tilt) mounted to a 62 cm tall tripod. Color calibaration bars were added after Apollo 14 (see Figure 2). The retractable Artemis gnomon is attached to a leg of Gandalf's staff.

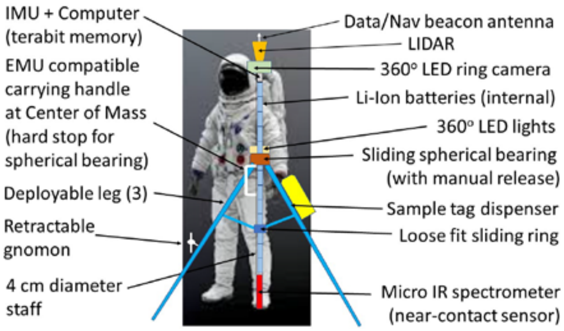

Figure 1: Gandalf's Staff Conceptual Design

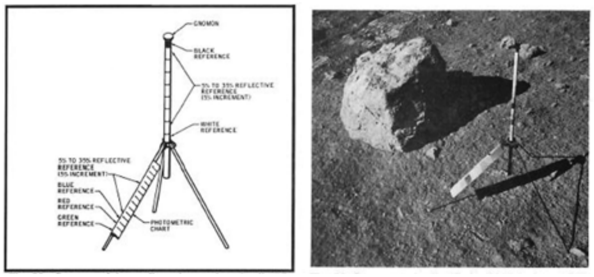

Figure 2: The Apollo Gnomon [4]

Camera and Video: The Apollo surface crews used Hasselblad cameras fitted with a reseau plate etched with small black crosshairs, called "fiducials" or "reticles", for photogrammetry. Each photograph imprinted with crosshairs established a geometrical basis for measuring objects or correcting distortion [5].

For the Artemis program, the collection of surface geologic samples can be documented in space and time with a full 3D model of the site. This requires high fidelity camera/video/LiDAR data and an IMU. The current xEMU helmet camera is insufficient for this function [6], so supplemental equipment is needed. The commercial market provides many options for small, high resolution 360° cameras [7]. The market also provides tools to create 3D models from image capture on mobile devices like iPads or phones [8], or with EVA camera/video data. The EVA data will be recorded to flash media on the staff, but high frame rate streaming of video data would require 15 Mbps real-time transfer on the lunar surface.

Lights for Surface Illumination: The lunar south pole has entirely different lighting constraints from the low latitude landing sites visited with the Apollo missions. The 1.34° inclination of the moon's rotational axis relative to the ecliptic pole ensures the south polar surface region never exceeds a sun angle of a few degress [9]. Although some areas near the south pole may receive up to 98% illumination [10], the low sun angle casts constantly shifting, long shadows around all objects. Crew geologic sampling will likely be in areas of near or total darkness. The xEMU suit is equipped with headlamps designed to support hand operations at arms length, but they are insufficient for illuminating the ground surface for geologic sampling [6]. The current Light-Emitting Diode (LED) commercial market provides extremely bright bulbs in flashlights that require little battery power (e.g. 710 lumens with a 856' beam distance and a lighttime of up to 13 hours powered by 4 AA batteries) [11]. These LED bulbs, mounted atop the staff, could provide needed lighting for EVA sampling activity in the dim shadows or complete darkness of the south pole.

Light Detection and Ranging (LiDAR): LiDAR uses pulsed laser beams to provide high precision, 3D images. NASA's Scientific Hybrid Reality Environments (SHyRE) team used a portable LiDAR to map the D1974 lava flow in the SW rift zone of Kilauea Volcano in Hawaii, then render the site in a Virtual Realtiy/Augmented Reality (VR/AR) environment [12]. A portable LiDAR, as used on autonomous vehicles for hazard avoidance [13], could provide the spacial record for sample location, orientation, and collection during EVA (estimated data size 500 kbits/frame). Enhanced with data from the 360° camera, a complete VR/AR model of visual and range data could be reproduced in near real-time (using data streaming) or post-EVA (using recorded data playback). The LiDAR would function in two modes: fast at 30 frames/sec (fps) for site sample collection, or slow at 4 fps for walking between sites. The fast frame rate streaming of LiDAR data would require 15 Mbps transfer on the lunar surface in real-time, and it would take over 18 hours to fill a 1 terabyte data storage card.

µIMU: The camera and LiDAR require a Micro-Electro-Mechanical System (MEMS) IMU with three axis rate sensors and linear accelerometers for attitude determination and image stabilization. Many commercial vendors provide these flight ready sensors [14].

IR µSpectrometer: Spacecraft orbiting the Moon have identified hydrated deposites using IR spectrometry [15-17] with emphasis on the hydration absorption wavelengths from 2.7 µm to 3.6 µm. The commercial market has numerous portable models for frequencies up to 2.5 µm, and Lead Sulfide - Lead Selenide (PbSe) detectors are available for development of ground truth sensing in the desired wavelengths [18].

Navigation Beacon: The staff transmitting system utilizes a simple omni antenna, a low power amplifier and a Software Defined Radio (SDR) [19] that communicates via line-of-sight to the lander base. While similar to a terrestrial satellite messenger system [20], it has significantly higher sustained transmission rates directed towards the base station. Once the staff is initialized at the lander base, it also provides relative navigation for the EVA traverse.

Beneficiaries: The Gandalf's Staff would greatly enhance the EVA science for Artemis surface missions by providing illumination and precise documentation of geologic sample location, orientation, and collection conditions. The science team could "stand beside" crew in near real-time VR/AR using a 3D visual and spatial model to analyze and assess crew activity and surface geology from infinite different positions.

The Gandalf's Staff live data stream (30 Mbps for camera/video and LiDAR) or recorded playback could provide access to the lunar surface for anyone in the world. Students and homemakers donning VR visors could stand next to the astronauts on the Moon. Engaging the public is an exciting and motivational incentive for development of this EVA tool. Commercial spin-off is another incentive. Hikers on Mount Everest or tourists in Antarctica could deploy Gandalf's Staff to allow family or colleagues to "stand beside" them as they explore remote reaches of the world.

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