FIELD TESTING OF A WEARABLE VISION NAVIGATION SYSTEM FOR ASTRONAUT NAVIGATION ON THE LUNAR SURFACE

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Abstract. *For future crewed Artemis missions to the Lunar surface, astronaut navigation is critical both for crew safety and science objectives. The Draper Wearable Kinematic System (WKS) leverages vision-aided navigation (VAN) algorithms to provide this navigation information and has demonstrated success in a simulated Lunar South Pole environment in Arizona as part of NASA's JETT testing. This presentation will provide an overview of the WKS and present results from JETT tests in October 2022 and May 2024.*

Introduction. When astronauts perform extravehicular activities (EVAs) on the lunar surface during Artemis missions, knowing their location is important for both science objectives as well as astronaut safety. During Apollo missions, astronauts navigated using paper maps. For Artemis, a higher fidelity navigation approach is required, and preferably one that is lightweight and can be integrated easily into the astronaut suit. This capability must be robust to the challenging lighting conditions at the Lunar South Pole and meet performance requirements over the maximum 8-hour EVA durations [1]. Draper's Wearable Kinematic System (WKS) is a vision-aided navigation (VAN) solution designed to meet this need and has demonstrated success with this system as part of NASA's Joint EVA Test Team (JETT) field test in Arizona. This presentation describes Draper's WKS design and presents results from JETT test events in October 2022 and May 2024.

WKS Hardware. Figure 1 shows Draper's WKS, which originally developed to quantify astronaut position and orientation within the International Space Station (ISS) [2]. Included in the design are a FLIR Blackfly S camera, ADIS16448 inertial measurement unit (IMU), Intel NUC for processing, and a lithium ion battery pack, which are packaged in a 3D-printed enclosure. In its current form, the WKS is 7.8" x 6.8" x 5.1" and weighs approximately 4 pounds. Since the development focus to-date has been on algorithm testing and demonstrating the feasibility of this system to provide a navigation capability for the lunar surface, this packaging design could be further optimized or fully integrated into astronaut suit design.

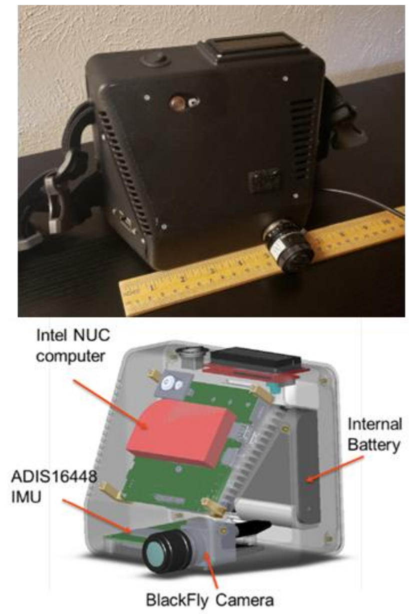

Figure 1. WKS Hardware and Internal Design.

WKS Software. The software running on the WKS includes a suite of VAN software to provide navigation estimates. VAN refers to the use of camera measurements to aid an IMU-based navigation solution, where integrating IMU data causes unbounded drift. This is especially true for lower-cost, lighter-weight IMUs, which are critical for this design to avoid adding unnecessary weight for astronauts to carry. By tracking features in sequential camera images and fusing these measurements with the IMU data, this error can be reduced to a rate of ~0.5-1% of distance traveled. Draper's sensor fusion algorithm that performs the overall estimation is called SAMWISE [3][4]. SAMWISE stands for Smoothing and Mapping with Inertial State Estimation and utilizes a sliding window incremental nonlinear smoother to fuse data from an IMU with data from any available combination of aiding sensors to produce a robust, high-rate, high-accuracy position, velocity, and orientation estimate

Test Overview and Results. Draper initially tested this system for use on the lunar surface as part of NASA's JETT3 test event just north of Flagstaff, Arizona in October 2022. JETT3 was NASA's third in a series of tests to simulate moonwalks on the Lunar South Pole to prepare for future Artemis missions. The test was located in a remote area near S P Crater which provides unique terrain and geology and involved two astronauts performing EVA missions while wearing mockup spacesuit systems. A total of four analog moonwalks were performed as part of JETT3, all taking place at night with the use of a simulated sun to provide low-angle sunlight conditions to match the challenging lighting conditions at the South Pole. Figure 2 shows an example of the test environment for JETT3.

Figure 2. Astronauts performing analog moonwalks during JETT3, where a sun simulator is used to provide the low lighting angles at the South Pole.

To test Draper's WKS, a test engineer wore the mockup spacesuit along with the WKS hardware and performed traverses to test the navigation performance of the WKS. During these traverses, the engineer would stop occasionally to simulate motion representative of astronaut activity during EVAs. The engineer would also move out of the path of the simulated sun light to perform activities in the shadows, where the only light source was from the four lights on the spacesuit mockup. Figure 3 provides an example where the test engineer was outside of the path of the sun simulator and is using the lighting provided by the suit.

Figure 3. Testing of Draper's WKS during JETT3. Test engineer is wearing the WKS with a mockup spacesuit.

Despite the challenging conditions provided by the low lighting angles and simulated astronaut EVA activities, Draper's WKS navigated well during this test. Unfortunately, an issue with logging on the astronaut suit mockup prevented the collection of GPS data for comparison but a qualitative assessment of the results showed that the trajectory reflected the path traveled, the final location was representative of the expected end location, and the system was robust to the periodic stops and arm motion in front of the WKS camera. Figure 4 shows the resulting navigation solution for the traverse performed by the test engineer during JETT3.

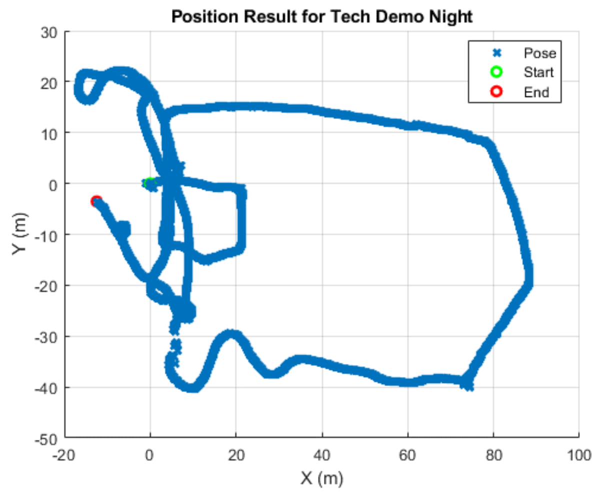

Figure 4. WKS navigation result during JETT3 test.

Draper will be continuing this testing as part of JETT5 in May 2024 and has since integrated a GPS directly into the WKS for a better comparison with truth. These results will be included as part of the presentation.

References.

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[3] T. J. Steiner, R. D. Truax, and K. Frey, "A vision-aided inertial navigation system for agile high-speed flight in unmapped environments," *in Proce. IEEE Aerospace Conference.* 2017

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