Study of the Froude Number for Human Locomotion in Space Environment

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1. Objective

This white paper proposes to collect data from the upcoming Artemis III mission for study and validation of the Froude number for human locomotion in space, using wearable lightweight cameras and IMU equipment and simple and short-duration EVA activities.

2. Background and Motivation

Video footages from the Apollo missions showed that the patterns of natural human locomotion on the lunar surface are significantly different these on earth. One theory explaining the difference is that human (and other vertebrate animals') locomotion tends to maintain a constant dimensionless number called *Froude number* defined as:

$$F_r = \frac{v^2}{gl}$$

where v is locomotion (gait) speed, g is the gravitational acceleration and l is the characteristic length of the leg [1]. As one's leg length maintains, the reduced gravity results in a lower gait speed and a decreased gait transition speed [2]. This relation has been well validated for legged animals in earth environment. However, when in an outside world such as the Moon, it was only visually verified from the video footages from Apollo missions [3], which is not a scientific verification without evidential data support. In addition, there were deviations from this relation. Some scholars predicted the value of Froude number to be around 0.5 for walking gait and about 0.25 for walk-to-run transition despite of the gravity [4,5], while others found that the walk-to-run transition could happen at a higher value of $F_r > 0.5$ when gravitational acceleration was under 0.2G in simulations [6–8], where G represents the earth gravity acceleration. The NASA Artemis mission provides an excellent opportunity to collect digital data, *for the first time in history*, to study the generic relationship between the Froude number and the natural human locomotion in space environment. We explain in the next section that the proposed data collection is very simple in terms of both the EVA time/effort and required instrumentation and thus worthy of doing.

The study of this life science problem not only expands the knowledge of space life science but also provides an extra scientific guidance for optimal design of future manned space infrastructure and also for optimal planning of future EVA operations. Such benefits will become increasingly significant with more and more manned space commercialization activities in future.

3. Brief Description of the Method

Data requirements: In order to conduct the proposed scientific study, the data shall capture the spatial and temporal body-limb postures of most natural walking and skipping/hopping for a sufficient long time and distance (e.g., 20sec and 200m) and data density. Images shall be taken in reasonably close distance and good lighting condition for data quality. Data of both astronauts should be taken to reflect the different parameter l values reflected in the Froude number definition. All the data analysis can be done on ground after the mission.

Equipment requirements: For human locomotion study in the Earth environment, a common data-collection method is to use a set of cameras installed around a large test area where the test subjects

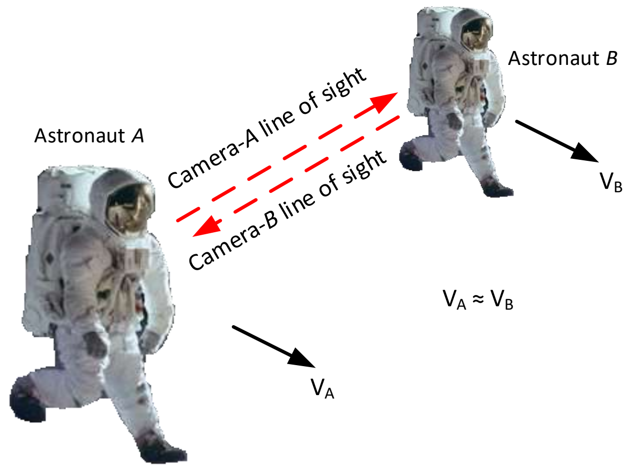

Figure 1 Example EVA scenario: Astronauts *A* and *B* both perform locomotion activities in parallel and automatically shoot video of each other using their body-fixed cameras

perform locomotion activities. Such a setting impractical for the Artemis III mission. A good alternative is to reconstruct human 3D poses from 2D video images recorded by *regular cameras*, using image process and deep learning technologies [9]. We can develop and verify data process software to control the reconstruction accuracy within acceptable threshold for human gait analysis. This technology does not need a fixed and known distance between the camera and test subject and thus, the camera can be worn by another person or vehicle to shot the video. Such wearable cameras must have been planned for the Artemis astronauts anyway. The astronauts may also wear a lightweight IMU sensor (mature technology) to collect extra motion data to improve the velocity calculation from the video data.

<u>EVA Activities</u>: Because continuous video data has to be collected in a reasonably long distance for capturing enough gait cycles, the cameras should not be fixed in location. A possible solution is that one astronaut performs test activity and the other astronaut follows the first one side by side while shooting the video. If body-worn cameras are used, then both astronauts can perform the activities while automatically shooting video of each other, as shown in Fig.1, for a more efficient EVA. The data process algorithms do not require the two people have synchronized activities and thus the effort is not difficult. The test activities include natural walk, natural skip/hop, and their transition. Data of walk and skip at specified speed may also be collected, which can be done by walking/skipping after a speed-controlled rover. Other potentially influential factors such as suite stiffness, carried mass, terrain properties, etc., may also be looked into if resources permit.

4. References

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