University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Capabilities Training using Hybrid Reality Extraterrestrial Environments in Preparation for Interplanetary Operations (CTHREEPIO)

Approvals

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2.1 Project Customers

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3 Problem

The space industry is rapidly growing, and with a spike in development of commercially available flights and crewed interplanetary missions – especially returning humans to the moon – the only aspect behind the development curve is mission training. While there is little to no training needed for a commercial flight[1], the training required for human interplanetary missions is much more rigorous[2]. The current training simulations in place include parabolic in-flight training, Neutral Buoyancy Lab (NBL) time, and mock-up environment simulations, all of which are incapable of providing compact, realistic, in-flight-able training for future missions to the moon and beyond. In order to help progress the training field, Team CTHREEPIO shall design a hybrid-reality simulation to aid in the training of astronauts who will eventually work and live on the moon.

Training for tasks that will be carried out in space environments is extremely difficult to realistically and efficiently accomplish. A major problem with current training is its inefficiency, both financial and temporal. One current method being used to simulate reduced gravity, whether it be the moon's gravity or complete weightlessness, is a series of parabolic flights. While this method is useful to simulate these different gravitational needs, each period of reduced gravity lasts between 20-30 seconds, and each flight only includes fifteen maneuvers. Additionally, the leading commercial company offering this experience sells individual tickets at a price of $8200[3]. Another major training method used for human space operations is the NBL, where astronauts can train in simulated reduced-gravity environments and carry out hands-on training of basic surface operations. However, this training site does not incorporate some major challenges posed by the lunar surface, such as lighting and depth perception. Thus, a new method of training that enables lunar surface immersion is necessary.

Using hybrid-reality solutions, CTHREEPIO will provide a realistic lunar surface operation training simulation. The ability to interact with real-world elements while immersed in a virtual reality simulation will allow for more complex and technical missions to be fully simulated and practiced, thus granting trainees an invaluable sense of familiarity and confidence. CTHREEPIO's adaptability will also allow changes to the simulated environment to fit specific mission training needs. This gives way to impressive building capabilities, laying the foundation for a gamut of operational training for extraterrestrial human missions.

4 Previous Work

Lunar analog environments here on Earth predate the Artemis program. In 2006, NASA engineers and researchers led a series of field tests in the Arizona desert under the Desert Research and Technology Study (Desert RATS) with the goal of producing system requirements for extravehicular activities (EVAs)[4]. In preparation for the Artemis program, NASA is utilizing the NBL to prepare astronauts for a variety of tasks in a lunar environment. The NBL allows astronauts to train for tasks such as collecting lunar samples, conducting successful moonwalks, and climbing up and down a ladder in an environment that replicates lunar gravity[5].

NASA was an early adopter of using virtual reality for training astronauts. For a little over a decade, their Virtual Reality Laboratory in Houston has provided valuable training to astronauts for various scenarios, such as the Simplified Aid for EVA Rescue (SAFER), which allows astronauts to maneuver back to the ISS in case of an emergency where they become untethered[6]. Starting in 2020, Boeing also began training future astronauts in docking and emergency procedures for their Starliner program by utilizing Varjo headsets and developing high-fidelity 3D models of their vehicle in Unreal Engine[7].

CTHREEPIO plans to take the next step by creating a hybrid-reality, high-fidelity lunar surface environment in which astronauts will be able to train for various operations such as detection and collection of water ice samples near the lunar south pole, which is a major goal of the Artemis III mission.

5 Specific Objectives

	Level I	**Level II**
VR Environment		
	CTHREEPIO shall provide the user with a realistic virtual representation of the lunar surface.	CTHREEPIO may have a high-fidelity environment and include accurate lunar lighting and topography conditions.
	CTHREEPIO shall visually represent low-fidelity physical assets as high-fidelity virtual reality assets.	CTHREEPIO may create specific mission objectives that utilize hybrid reality assets.
Usability/Adaptability		
	CTHREEPIO shall have a user-friendly interface that can be tested by external users to gain feedback on usability and accessibility.	CTHREEPIO may be compact and effectively mobile for inflight training needs.
		CTHREEPIO may act as a simulation framework to allow for simplistic creation of various training exercises.
Hybrid Integration		
	CTHREEPIO shall utilize object tracking and projection during training simulation tasks.	CTHREEPIO may provide the capability of multi-user interactions.
	CTHREEPIO shall provide a user with the ability to interact with physical objects and represent these interactions in the virtual simulation.	CTHREEPIO may allow a user to interact with the individual object's physical attributes.
Human Constraints		
	CTHREEPIO shall safely incorporate environmental variables that would impact an astronaut during an EVA.	CTHREEPIO may provide informative displays of key user information in a form that is indicative of what a user will experience on an EVA.
		CTHREEPIO shall address human factors limitations, such as mobility constraints.

Table 1: Level I and Level II Objectives

6 High Level Functional Requirements

FR	Functional Requirement	Description/Rationale
F1	The VR environment shall simulate the South Polar region of the lunar surface.	The simulation shall closely resemble the location of Artemis III to enable visual immersion and exposure to the environment as a training element for future missions.
F2	The training simulation shall include the ability to interact with physical, real-world objects.	Optimal training can be achieved with both physical and virtual components.
F3	The VR environment shall reflect hybrid reality interactions and display them concurrently in the VR environment.	Feedback is necessary to reflect movement in the real world within virtual reality.
F4	To accurately simulate the lunar environment, the training simulation shall include various lunar environmental parameters (TBD).	The environmental constraints, which may include lighting, thermal, and FOV constraints, are necessary to provide an accurate simulation.
F5	The training simulation, including the VR environment and all physical aspects, shall keep the user, operator, and itself safe from harm.	The safety of the user and operator, as well as the safety of the simulation itself, are necessary for use and maintenance.
F6	The training simulation shall be appropriate for a laboratory environment.	The entire training simulation must be able to fit within the space provided by the sponsor.

Table 2: High Level Functional Requirements

Figure 1: Project Integration into Larger Scope of Lunar Mission Cycle

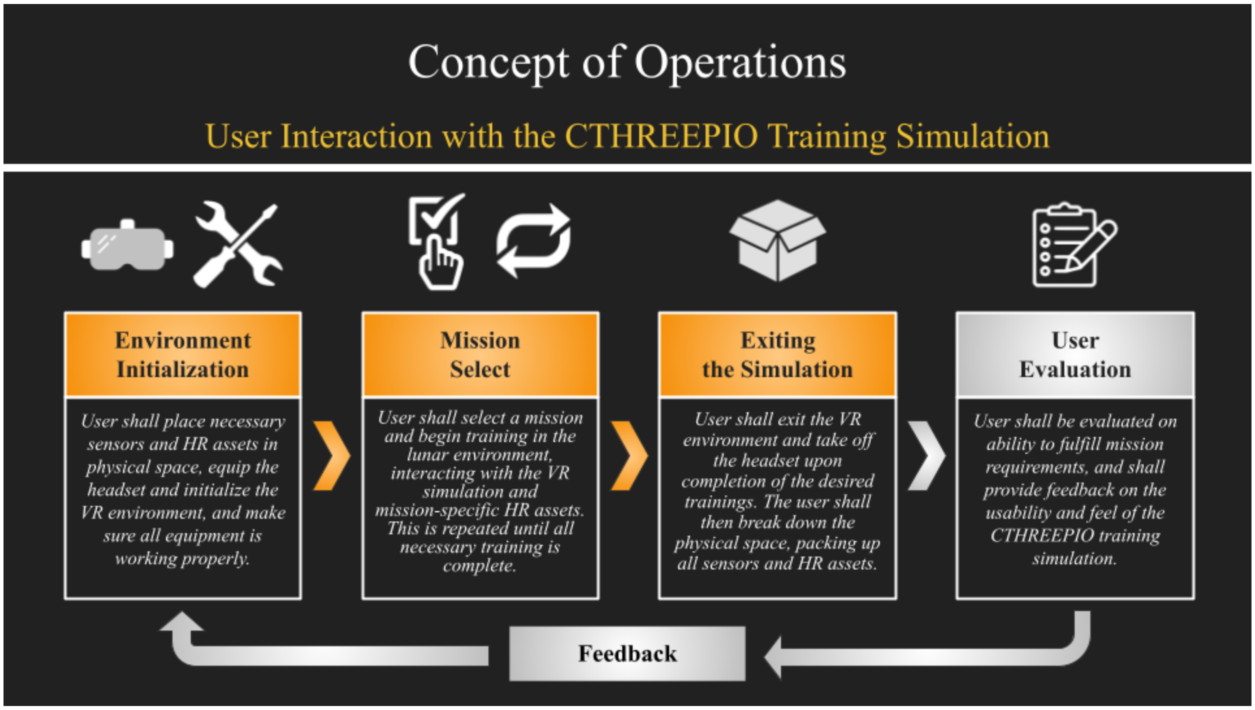

Figure 2: User Interaction with Training Simulation CONOPS

7 Critical Project Elements

CPE	Element	Description
E1	Hybrid Reality (HR) Support Equipment	The HR support equipment must be able to track user actions and interactions with utilized tools. The equipment shall integrate with the virtual reality instruments to provide visual cues that match user motion. Oversight would lead to integration challenges and obstacles that may impede on the overall immersiveness and quality of the training simulation.
E2	User-Associated Equipment	The user-associated equipment shall integrate such that all equipment does not impede on overall functionality. The user-associated equipment must follow the prescribed safety requirements. Oversight could impair HR effectiveness or result in person/equipment damage.
E3	Virtual Environment	The training simulation will utilize a virtual environment that is recognizable by the user as a lunar surface. This virtual environment must integrate with the real-world equipment such that the user's actions are paralleled in the virtual environment . Failure to successfully integrate the virtual environment will impede the ability of astronauts to have a high-fidelity and safe training experience.
E4	Testing	The simulation must be accessible, intuitive, and operable by a human user. The simulation must have the ability to test, validate, and verify requirements as set forth in the PDD and in future documents. Failure to have a user-friendly simulation would impede the training capability and may put the

		users at greater risk. Failure to have a simulation that can test, validate, and verify requirements would impede the ability for this project to be considered a success by the customer.
E5	Safety	The training simulation must not cause any physical or mental harm to any user or operator. Precautions will be employed to ensure that while in the simulation, hazards are minimized to user, operator, and equipment.
E6	Financial	The total cost of the simulation equipment, integration system, and testing, along with any costs from research and development processes, must not exceed $4000. Extra funds may be secured from the University of Colorado Boulder College of Engineering if necessary. To stay within budget, the cost and time for the project will be carefully managed and balanced by a team Chief Financial Officer.

Table 3: Critical Project Elements

8 Sub-System Breakdown and Interdependencies

The following diagram outlines the interdependencies of the subsystems of Team CTHREEPIO. It is expected that a user will interact with physical objects, which will in turn report data to the simulation model. The simulation model may also pull in other data sets such as lunar topography data to ensure a high-fidelity visual is displayed to the end user. The simulation model feeds into the visual model, which directly interfaces with the user's display.

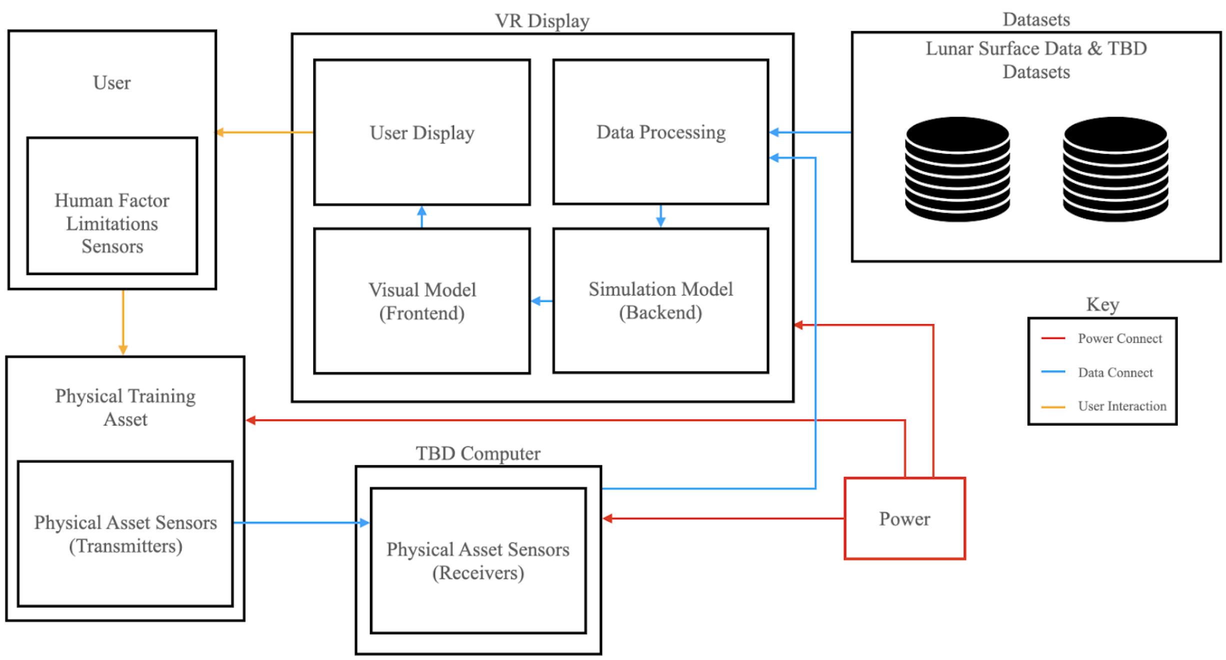

Figure 3: Subsystem Block Diagram

9 Team Skills and Interests

Member	Skills/interests	CPEs
Lily Allen	Skills: Software (MATLAB, Excel), Human Factors and Crew Systems, Systems Engineering, technical writing and public speaking Interests: Crew related mission design, bioastronautics, space habitat design	E1, E3, E4
Hannah Blanchard Obolsky	Skills: Software (MATLAB, LaTeX), Human Factors, Biomedical Engineering, Systems Engineering Interests: Physiology & Medicine in Extreme Environments, Human Factors	E2, E4, E5
Luca Bonarrigo	Skills: Software (MATLAB, Python, C++, Bash, IDL, UNIX), GitHub/Bitbucket, STK, Orbital Mechanics, Data Analytics Interests: Human Factors, ICE Environments, Space Medicine	E1, E3, E4
Nick Bottieri	Skills: Software(MATLAB,C++), Human Factors, Engineering Management, Space Policies and Practices Interests: Human Factors + Spaceflight Operations, Financing, Offworld Resources/Atmospheres/Environments	E1, E2, E3, E4, E5, E6
Andrew Czekay	Skills: Software (MATLAB, LaTeX, C++), Human Factors, Design, Engineering Management Interests: Leadership, Human Factors, Space Operations, Systems Engineering, Life Support Systems, R&D	E1, E2, E3, E4, E5
Skylar Edwards	Skills: Software (MATLAB, Python,CAD-Solidworks), Manufacturing (3D/Laser Printing, Machine/Wood Shop), Human Subject Research Interests: Human Factors, Space Medicine, EVA Operations, Astronaut Training (VR, Analogs, etc)	E1, E2, E3, E4, E5
Geoff Lord	Skills: Software Development (Python, C++, MATLAB, JS), Git, Cybersecurity (Secure Coding, Vuln Remediation) Interests: Cybersecurity, Simulation Software, NLP	E1, E3, E5
Autumn Martinez	Skills: Software(MATLAB, C++, Overleaf), Hardware(Soldering, circuit design, arduino), Teamwork, Leadership. Interests: Mechanical, Electrical	E1,E2, E4,E5
Sarah Martinez	Skills: Software (Python, MATLAB, C++, Bash), Avionics, Electronics Design Software (EAGLE, Altium), Github, Electronics Fabrication Interests: Electronics Design and Fabrication, VR simulations	E1, E2, E4, E5
Thomas O'Connor	Skills: Software (MATLAB, C++, LaTeX), CAD, Engineering Management, Hardware (Arduino, Soldering, Rudimentary Circuits), 3D Printing Interests: Mechanical, Electrical, Human Factors, VR Simulations, Virtual Asset Modeling, Leadership	E1,E2, E3,E4, E5
Nathaniel Shiba	Skills: Software (MATLAB, LaTeX), CAD, Hardware (Arduino, Raspberry Pi, Soldering), Budgeting Interests: Financing, Virtual Asset Modeling, Virtual Environment Modeling	E1, E3, E6

Elijah Stubbs	Skills: Software (MATLAB, C++, LaTeX), Rudimentary Circuit Design, Photography Interests: Software, Orbital Mechanics, VR Simulations, Astrophysics	E1, E3, E4

Table 4: Team Skills and Interests

10 Resources

Critical Project Elements	**Resource/Source**	
E1	Resource: Motion Tracker	Source: Vive
E3	Resource: VR Headset	Source: Vive/Oculus
E3	Resource: VR developing environment	Source: Unity

Table 5: Necessary Resources

11 References

[1] Perrett, C. (n.d.). *Jeff Bezos and his fellow Blue Origin astronauts have started training for Tuesday's space flight. 'new shepard is ready to fly,' the company said.* Business Insider. Retrieved September 7, 2022, from https://www.businessinsider.com/bezos-and-blue-origin-astronauts-are-training-for-tuesdays-space-flight-2021-7#:~:text=The%20process%20for%20Bezos%2C%20who,orbital%20sales%20at%20Blue%20Origin

[2] Mars, K. (2015, February 11). *Johnson Space Center Home*. NASA. Retrieved September 7, 2022, from https://www.nasa.gov/centers/johnson/home/index.html

[3] "The Zero-G Experience® - Zero-G." *Zero*, 16 June 2022, https://www.gozerog.com/the-zero-g-experience/.

[4] Romig, Barbara, et al. "Desert Research and Technology Studies 2006 Report." *SAE Transactions*, vol. 116, 2007, pp. 170–93. *JSTOR*, http://www.jstor.org/stable/44719455. Accessed 7 Sep. 2022.

[5] Roberts, Jason. "Preparations for Next Moonwalk Simulations Underway (and Underwater)." *NASA*, NASA, 23 Sept. 2020, https://www.nasa.gov/feature/preparations-for-next-moonwalk-simulations-underway-and-underwater.

[6] "How NASA Uses Virtual Reality to Train Astronauts." *Space Center Houston*, 21 Jan. 2019, https://spacecenter.org/how-nasa-uses-virtual-reality-to-train-astronauts/.

[7] "Varjo & Boeing: A New Era in Astronaut Training Using Virtual Reality." *Varjo.com*, 27 Apr. 2021, https://varjo.com/boeing-starliner/.