EXTENDED REALITY SIMULATION PLATFORM (ESP) FOR HUMANOID ROBOTS IN THE LOOP (HRITL) & HUMANS IN THE LOOP (HITL) FOR ISRU AND ISAM Miguel Arias, PhD[1], Bo Varga, MBA[2], [1, 2]Prefixa, Inc., Sunnyvale, CA 94089, ariasm@prefixa.com, varga@prefixa.com

Introduction: Extended Reality (XR) encompasses AR, VR, MR and AI/ML - which now generates 3D models & and simulations, including from text. Our ESP Simulation Center has planning, modeling, simulation, training, monitoring, support, and documentation levels, building on NVIDIA's Omniverse Enterprise full stack. Innovations include the use of scenarios for generation of synthetic data for AI/ML training and, via IIoT sensor input, predictive analysis matching real states with outcome scenarios. ESP implemented PNT and RPO in XR space can become an AR overlay to visually compare real states with planned or preferred outcomes for coupling, landing, and other applications.

Ubiquitous sensors and computing at the edge, combined with current AI/ML optimization of control systems, enables all space assets having robotic arms or other manipulators to assemble, construct, drill, excavate, pick & carry, load & unload, maintain, recharge, refuel, repair or replace for ISAM and ISRU applications. We propose HRITL will provide general purpose capabilities for many use cases based on economics, i.e. high volume fabrication of Humanoid Robots for assembly lines, care givers, construction, retail, security and defense applications has been launched **[1][2].** And HITL primarily via Tele-Robotics until robust, safe environments are enabled for humans.

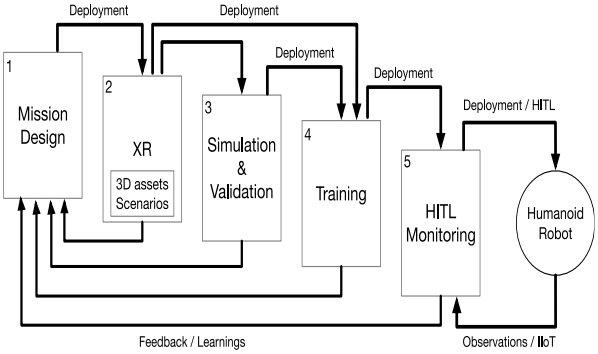
Intelligence for heavy equipment to extract raw materials and build structures in cis-Lunar space and beyond will be provided by control systems and AI/ML and, we propose, Tele-Robotics HITL operated or monitored HRITL based on costs and planned safe places for human operators, monitors, and support in LEO and Low Lunar Orbit platforms.

HRITL Usage. A key driver is economics – our civilization is built around human form factors. HRITL can and will be used as a precursor to HITL for colonization, exploration, industrialization, materials sourcing, and permanently for dangerous, extreme, or toxic environments, enabling major cost reduction versus local human presence, e.g. underwater. Recent developments indicate lower cost HRITL will replace humans in repetitive jobs on earth, as robots have already done for many petrochemical applications **[3],** based on Tele-robotics operation.

Tele-robotics. Tele-robotics combines the benefits of HITL operating HRITL in space from safe environments, for primary or secondary control of ISAM and ISRU applications, i.e. missions monitoring for intervention versus direct mission control and support.

Artemis Gateway and LLO satellites will enable tele-robotic operation on Lunar surface for assembly, construction, excavation, inspection, maintenance, mining, repair, etc. either directly or via earth relay.**[8]**

The ESP Platform architecture consists of Level (1) Creating & Validating mission & process planning to meet goals and operating parameters, resources, KPIs, etc.; (2) Creating 3D models, simulations, and scenarios; (3) Delivering Education, Training, Testing Use Cases; (4) Implementing Tele-Robotic and other mission & process operations; (5) Delivering AI/ML and HITL Monitoring, with alerts and alarms based on sensor input and deviation from planned state; (6) Delivering AI/ML and HITL Support via screen monitor or XR-Space avatar and team provides monitor with advice; (7) Enabling Generative AI (with human curation) for documentation, including text to video.

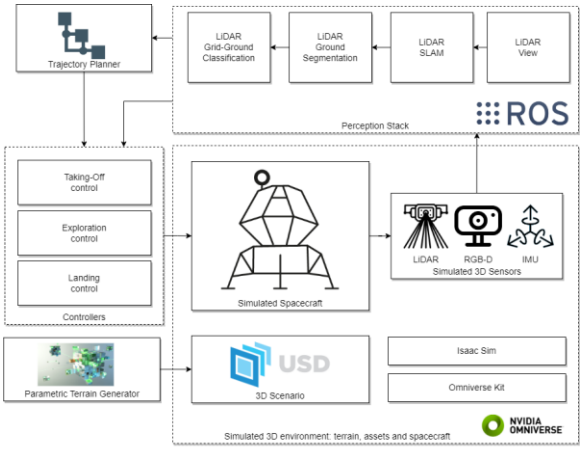


Current status includes implementation of Levels 2 and 3, based on mission requirements, multiple VR training products Level 4, and monitoring and viewer channels in Level 5, VR goggles or screen viewable.

Products: Our product focus is a multi-level and multi-scale ESP Simulation Center that enables planning, training, testing of many scenarios, and operations. VR products include training for construction & excavation equipment operation, equipment maintenance, nuclear reactor operation and general purpose VR environments – walk through and fly through. We are both developing in house and working with commercial VR product vendors to integrate within the ESP environment.

NVIDIA Omniverse. This sandbox has extensive

tools and use cases to build AI/ML, digital twin, and robotics applications with acceleration provided by NVIDIA hardware. It provides robust physics models, including microgravity, Lunar gravity, etc. as well as easy conversion of CAD drawings and models into 3D models and simulations. GenAI is a new and major thrust with potential high value for documentation and text to VR applications.



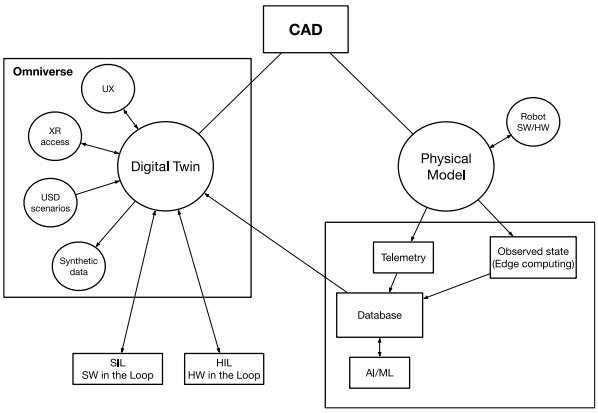
Team Experience. Our prior work includes semiconductor die on wafer probing - with micron accuracy & precision - and automobile manufacturing metrology - with mm accuracy & precision – useful for precise assembly and maintenance and for future labs & fabs in cis-Lunar space and beyond. While HITL space suits provide cm level accuracy & precision, HRITL can deliver mm to micron accuracy & precision, with replacement hand, leg, and arm fixtures depending on missions & tasks, including field swap flexibility.

Business Model. Our experience includes working with business partners and research institutes to develop whole products as well as in house product development and release to markets.

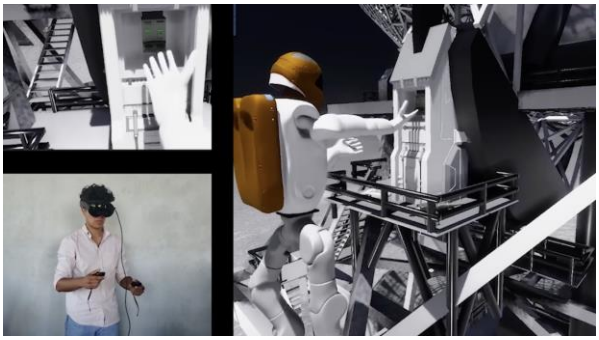
WIP. Work in process includes integration of MBE, MBSE with ESP as well as control systems for semi-autonomous mobile platforms, in the context of HILT monitoring and command and control intervention when needed, in particular via tele-robotics interfaces.

Scenarios. Spawning multiple scenarios to optimize infrastructure designs and engineering, procurement and construction is in use for large projects **[4]**. Spawning multiple scenarios to train AI/ML is leading edge and coming into increasing use **[5].** Real time predictive analytics without backhaul.

Digital twins. Digital twins, curated to account for "as built, as maintained, as repaired, as upgraded" is a must have for aerospace **[6],** although we have found many early stage space companies developing products without implementing digital twins.



Open USD. The Open Universal Scene Description Alliance was launched by Adobe, Apple, Autodesk, NVIDIA, and Pixar/Disney August, 2023 to create a standard for 3D Models and Simulations developed in one environment so they run in each other's environments. **[7]** Membership has expanded to include Intel, Meta, Siemens and Epic Games, the alternative 3D Modeling and Simulation platform to NVIDIA Omniverse. 3D assets, environments, scenarios will become re-useable, reconfigurable components



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[7] https://aousd.org/#membership

[8] Humanoid robot demo https://vimeo.com/prefixa/robonaut?share=copy