28th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM (A5)
Interactive Presentations - 28th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM (IP)

Author: Mr. Nijanthan Vasudevan
West Virginia University, United States

Mr. Oudayl Massat
Space Generation Advisory Council (SGAC), United States
Ms. Padmapriya Sampathkumar
India
Mr. Arjuna Karthikeyan Senthilvel Kavitha
Drexel University, United States
Mr. pavithiran vasudevan
India

ADAPTIVE AI-DRIVEN, EDGE-COMPUTING ROBOTIC PLATFORMS FOR ADVANCED HUMAN-ROBOT COLLABORATION IN EXTRATERRESTRIAL HABITAT CONSTRUCTION

Abstract

Establishing sustainable habitats on the Moon, Mars, and beyond requires strong human-robotic collaboration to overcome the formidable challenges of construction and maintenance in hostile environments. This research introduces Adaptive AI-Driven Robotic Assistants (AIDRAs), a platform designed to operate alongside astronauts during habitat construction missions. By integrating machine learning algorithms, modular robotic systems, and refined human-robot interaction (HRI) interfaces, AIDRAs aim to enhance efficiency, safety, and adaptability. During the design and simulation phase, we employed CAD and physics-based modeling tools in togther with software frameworks such as ROS/Gazebo—customized with planetary environment plugins—to emulate low gravity, extreme temperatures, and communication constraints. These simulations validated the structural integrity and performance of a versatile robotic platform equipped with modular end effectors, including precision drilling units, autonomous welding systems, and adaptive material manipulators. Laboratory experiments incorporating multispectral LiDAR and thermal imaging sensors confirmed accurate real-time environmental sensing. AIDRAs leverage deep reinforcement learning (DRL) to optimize construction tasks through iterative interactions, ensuring robust performance across varied scenarios. A federated learning framework supports decentralized AI model training, boosting adaptability without centralized data dependencies. The integration of multispectral LiDAR and thermal imaging enables precise topographical mapping, material characterization, and hazard detection, while edge computing ensures low-latency decision-making in communication-constrained environments. The platform's modular architecture allows seamless transitions among tasks such as structural assembly, habitat sealing, and infrastructure maintenance. Scalable multi-robot coordination protocols enable multiple AIDRAs to collaborate on large-scale projects, increasing throughput and efficiency. Meanwhile, intuitive HRI interfaces—including augmented reality (AR) overlays and natural language processing with gesture recognition—streamline communication between astronauts and robots, minimizing cognitive load. To validate structural and functional aspects, iterative design and simulation processes were undertaken. Laboratory experiments focused on sensor integration and data processing reliability, while HRI development followed user-centered design principles to refine usability. Future work explores advanced in-situ resource utilization (ISRU) techniques, enabling on-site fabrication and repair of structural components from local materials, thereby reducing logistical demands and enhancing mission

resilience. These efforts culminate in an AI-driven robotic solution that adapts to shifting mission requirements, reduces operational costs, and accelerates the establishment of permanent human outposts beyond Earth. By outlining a clear roadmap for upcoming missions, this research underscores the indispensable role of intelligent robotic assistants in realizing complex space infrastructure initiatives.

Keywords: Adaptive AI, Robotic Assistants, Extraterrestrial Habitat Construction, Human-Robot Interaction, Modular Robotics, Deep Reinforcement Learning, Augmented Reality, Federated Learning, Edge Computing