IAF SPACE SYSTEMS SYMPOSIUM (D1)
Innovative and Visionary Space Systems (1)

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AI-IN-ORBIT-FACTORY - AI APPROACHES FOR ADAPTIVE ROBOTIC IN-ORBIT MANUFACTURING OF MODULAR SATELLITES

Abstract

Ongoing advances in modular satellite architectures, coupled with improvements in adaptive manufacturing processes are paving the way for innovations in manufacturing in space and, beyond that, even on-orbit servicing. However, timeframes of just a few days for manufacturing, deployment and start of operations for highly specific satellite missions remain a distant vision. Current challenges for in-orbit manufacturing of satellites include, in particular, highly reliable, precise and adaptive manufacturing and inspection processes, teleoperation methods to resolve unexpected problems from Earth, and means for a digital representation of all relevant activities and conditions to maintain full control.

For these challenges, the project AI-In-Orbit-Factory applies a variety of AI methods. AI has significant potential, as it enables the effective use of operational data to enhance process stability. Likewise, knowledge-based approaches provide options to infer explainable information from manufacturing processes.

For the necessary digital representation of the in-orbit factory and all ongoing processes, an ontology serves as foundation. This knowledge-based approach enables adaptive, flexible and understandable manufacturing processes. Especially the complex information flow between different manufacturing machines, digital process twins that orchestrate the production process and digital twins of satellites in production can be described. Furthermore, conflicts and possible error sources can be identified through inference.

Utilizing the aforementioned knowledge base and standardized modular components the composition of a mission specific satellite is automatically planned based on the desired mission requirements. A robotic manipulator grasps each individual satellite module, feeds it through optical inspection, where the boards are checked for production errors using a high-resolution camera and reference images, before they are integrated into the satellite structure. Once integrated, the submodules undergo optimized testing and anomaly detection routines with learned nominal subsystem behavior models as input. Additionally, each manipulation step is supervised using force-feedback and vision-based anomaly detectors.

For cases where automated assembly fails, a bilateral teleoperation system with force feedback is developed. In order to increase precision during teleoperated assembly and reduce mental and physical load, the human operator is assisted by adaptive virtual fixtures (haptic constraints). Adaptive fixtures are learned from both demonstration and simulation and parametrized depending on the manipulation phase, providing coarse to fine-grained support throughout approaching, positioning and haptic manipulation phases. A neural network detects the current manipulation phase to select the appropriate supporting fixture and ensure smooth transitions.

This paper outlines the AI methods and our approach to reliable and adaptive in-orbit manufacturing and presents first results.