Paper ID: 116046
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33rd IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (B4)
Small Satellite Missions Global Technical Session (9-GTS.5)

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FROM SYNTHETIC DATA GENERATION TO ON BOARD DEPLOYMENT: A PERCEPTION PIPELINE FOR AI DRIVEN SPACE IMAGING

Abstract

Small satellite missions increasingly rely on onboard autonomy to overcome fundamental constraints in downlink capacity, power, and operational latency. Onboard AI driven perception, particularly for Earth and space imaging payloads, has emerged as a key enabler—but practical deployment remains challenging due to fragmented workflows spanning data generation, model training, validation, and flight ready implementation.

This paper presents an end to end perception pipeline designed specifically for small satellite imaging missions, integrating synthetic data generation, data centric machine learning, and deployment on resource constrained onboard hardware. Building on prior work in CNN based onboard data selection and image reduction, the proposed approach addresses the scarcity of labeled flight data through game engine generated mission specific synthetic datasets that model realistic illumination conditions, target morphology, and sensor characteristics. This enables robust training and evaluation of neural networks before launch, reducing mission risk and development cost. The trained models are subsequently optimized for execution on resource constrained FPGA based System On Chip suitable for direct integration into platform processing systems or payload such as camera, with emphasis on power awareness, reproducibility, and functional validation against mission objectives. The workflow is informed by hands on experience from in house camera development and operational constraints derived from small satellite mission scenarios at Tartu Observatory.

Beyond a single mission implementation, this work promotes a "perception as infrastructure" paradigm, treating AI perception not as a standalone payload feature but as a reusable, system level capability for future small satellite missions. The presented pipeline demonstrates how small satellites can achieve higher autonomy and scientific return while maintaining low cost and rapid development cycles. The results and lessons learned are directly transferable to emerging international missions and are particularly relevant for young professionals interested in game development and AI integration into operational space systems.