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Special issue on “Space computing and space AI”

Editorial

The path toward a space-based AI infrastructure is shaped as much by the ambition to push AI into orbit as by the physical constraints that make it hard. As constellations scale from dozens to thousands of spacecraft, and Earth observation shifts from downlinking raw imagery to answering questions in near real time, the line between where data are collected and where they are interpreted is disappearing. Computing is moving closer to the sensor, into low Earth orbit, to the network edge, and along the terrestrial-cloud continuum linking ground stations to spacecraft. The services space now promises, global connectivity, disaster response, environmental monitoring and ubiquitous sensing, impose hard targets on latency, energy, radiation tolerance and autonomy. The old model of downlinking everything to the ground for processing cannot keep pace. The field is converging on a new paradigm: networking and computing fused into a service, delivered anywhere, and increasingly powered by AI that can perceive, reason and act on board. This is no longer merely an efficiency gain; it is a prerequisite for the latency-critical, autonomy-dependent missions that space is expected to run.

This special issue brings together fourteen papers that capture this transition. They span the architecture and standardization of space computing itself, the networks that link spacecraft, on-board perception and change detection, the compression and robustness that make AI affordable under tight power budgets, the hardware, from resistive memories to in-memory computing, that will carry the workload, and the embodied AI of future space robotics. A common thread runs through them: alongside algorithmic progress, each paper engages the operational reality of space, scarce power, harsh radiation, intermittent links and sparse labels. Read together, they trace a discipline moving from isolated experiments to a coherent, standards-aligned field in which networking, computing and AI increasingly share one orbit.

Scanning the issue

The issue is organized around seven themes.

I. Setting the scene: The space-computing paradigm and its standardization

Two papers set out what space computing is and how it should be built.

Space computing in the era of intelligence: Key technologies and standardization research by Ma et al. reviews global practice and lays out a six-dimension standardization framework, general foundation, AI computing payload, computing system, space-based models, ground digital twin, and application and service management, to support interoperable, reliably engineered large-scale space computing.

Terrestrial-space interconnected collaborative computing: Architecture, scientific challenges, and application scenarios by Li et al. proposes a working definition and a five-layer architecture for TSICC, drawing clear boundaries against satellite edge computing, space-air-ground networks and cloud-edge-end collaboration, and mapping the open challenges in scheduling, network protocols, operating systems and AI models.

II. Networking and resource management for space

Two papers address the connectivity substrate.

A large-scale LEO satellite network topology generation method based on physical-logical semantic decoupling by Yv et al. separates physical feasibility from structural continuity and builds a stable, continuous topology for dynamic constellations, easing cross-temporal fluctuation and underpinning workloads such as task scheduling, federated learning and dynamic graph learning.

Beam-hopping optimization for regenerative satellites using a hybrid LSTM-transformer model by Worou Wouignanso et al. learns beam schedules from traffic demand, channel state and history, stacking bidirectional LSTM layers with a transformer encoder; the model improves spectral efficiency over deep-learning baselines while balancing fairness, QoS compliance and power utilization.

III. On-orbit perception and interpretation

Four papers advance on-board perception of Earth.

A review of weakly supervised semantic segmentation for airborne laser scanning point clouds by Luo et al. organizes the field around weak annotation, reliability modelling and supervision optimization, and points to standardized benchmarks, cross-scene generalization, promptable foundation models and multimodal remote-sensing fusion.

A query-aware CNN–transformer framework for multi-temporal crop classification and phenological stage estimation using Sentinel-2 time series by Öztop et al. conditions input sequences on day-of-year to align them with phenology, jointly classifying crops and predicting rice growth stages; its optimized inference pipeline cuts compute enough for on-orbit processing.

Detection-oriented diffusion super-resolution for autonomous remote sensing perception by Xie et al. couples a residual diffusion super-resolution branch to a frozen downstream detector, raising mAP50 on the DOTA benchmark for low-resolution imagery while staying lightweight enough for on-board use.

Dual-path adaptive frequency-aware network for SAR image segmentation by Xia et al. introduces DPAFNet, a global-local encoder that splits long-range structural reasoning from local detail recovery under speckle noise, with adaptive bridging and frequency-aware skip modulation to match overlap, agreement and boundary performance.

IV. Change detection and geospatial reasoning on board

Two papers move change reasoning on board.

A semantic prior-enhanced semi-supervised method for on-board change detection by Zhu et al. injects vision foundation-model priors (DINOv3) into a lightweight encoder, reaching state-of-the-art F1 with only five per cent labelled data under strict on-board compute limits.

On-orbit change detection for remote sensing applications: Opportunities and challenges by Ye et al. decomposes ground pipelines into observation, data, sensitivity and production lags, arguing that staged on-board workflows can deliver earlier alerts and cut unnecessary downlink without replacing ground analysis.

V. Efficient and resilient on-board AI

One paper takes on the affordability and reliability of on-board AI.

Diffusion-guided lightweight remote-sensing semantic models for on-board AI by Li et al. distils a large teacher into a compact student using a frozen diffusion U-Net, cutting parameters by over 96 per cent and reaching 22 FPS at 12.5 W on a Jetson AGX Orin under a 15 W profile, lifting energy efficiency from 0.61 to 1.76 FPS/W.

VI. Computing hardware and in-memory processing for space

Two papers focus on the physical substrate.

Noise-aware fine-tuning as a hardware noise margin: Cross-layer co-design for robust low-bit RRAM in-memory computing toward space-borne edge inference by Tian et al. treats bounded activation as a physical noise clamp and uses noise-aware fine-tuning to reshape weight distributions into unused conductance headroom, cutting 4-bit inference error across activations on a fabricated RRAM test chip.

Memristive technologies in spatial artificial intelligence architectures: A comprehensive review of advantages, bottlenecks, and mitigation strategies by Deng et al. compares emerging non-volatile memories under space conditions, singles out RRAM for its radiation tolerance and efficiency above 10 TOPS/W, and lays out hardware-software co-design, 1S1R topologies, vertical thermal conduits, bit-slicing and ensemble averaging, toward flight-ready hardware.

VII. Toward embodied AI for on-orbit servicing and space robotics

Beyond sensing and computing, future missions need machines that physically act in orbit, from on-orbit servicing and assembly to debris removal. One paper lays the embodied-AI foundation.

Vision language action models for robotic manipulation: A comparative evaluation of policy and value architectures by Wang et al. runs a controlled real-robot study on a LeRobot platform covering block grasping, placing and sorting, showing that value-guided retraining of VLA policies improves closed-loop reliability, task completion and takeover rate; such embodied-AI results are a building block for future on-orbit robotic operations, while also flagging limits from task diversity, evaluation scale and value-target reliability.

Looking ahead

Read together, these fourteen papers trace a single arc: space computing is moving from ground-centric processing toward a distributed, AI-native, standards-aligned ecosystem in which networking, computing and AI converge in orbit. Much remains open, notably operational validation under real radiation and link dynamics, standardized benchmarks for on-board AI, and the governance of terrestrial-space collaboration. As constellations grow and spacecraft become truly autonomous, the boundary between ground and orbit will keep fading, and the AI resident in space will shape how the planet is observed, understood and acted upon. We hope this issue serves as a reference point as the community builds a genuinely AI-powered space infrastructure.

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TABLE OF CONTENTS

	Page
Regular paper	
Geospatial data sharing: Understanding intergovernmental emergency response data-sharing activities <i>Chul Min Lee</i>	288
Papers of the special issue on “Space computing and space AI”	
Space computing in the era of intelligence: Key technologies and standardization research <i>Xiaowen Ma, Zhenting Li, Zheng Ji, Zhongxin Wang</i>	301
Terrestrial-space interconnected collaborative computing: Architecture, scientific challenges, and application scenarios <i>Yongwei Li, Ruming Liu, Yu Cai, Wei Li</i>	314
A large-scale LEO satellite network topology generation method based on physical-logical semantic decoupling <i>Minghui Yv, Caihong Cao, Hui Xv, Zhimi Cheng</i>	325
Beam-hopping optimization for regenerative satellites using a hybrid LSTM-transformer model <i>Issiakou Worou Wouignanso, Olfa Ben Yahia, Stéphane Martel, Guillaume Mantelet, Gunes Karabulut Kurt, Brunilde Sansò</i>	340
A review of weakly supervised semantic segmentation for airborne laser scanning point clouds <i>Ziwei Luo, Jun Jiang, Yuan Wu, Xiaoyun Yan, Yangjun Ou, Zhaojing Wang</i>	357
A query-aware CNN–transformer framework for multi-temporal crop classification and phenological stage estimation using Sentinel-2 time series <i>Yusuf Öztop, Berrin Bilgin, Sudenaz Şenbay, Ozan Çelik, Cavit Karakuş</i>	372
Detection-oriented diffusion super-resolution for autonomous remote sensing perception <i>Mingming Xie, Hongwei Li, Mengni Xu, Chaojie Zhang, Chunhui Wang</i>	387
Dual-path adaptive frequency-aware network for SAR image segmentation <i>Zihan Xia, Jin Liu, Zhiwen Zheng, Xingru Huang, Svetlana Illarionova, Jinfeng Liu, Wangmeng Zuo, Changqing Zou, Evgeny Burnaev</i>	398
A semantic prior-enhanced semi-supervised method for on-board change detection <i>Kexin Zhu, Zizhen Zhang, Jun Pan</i>	409
On-orbit change detection for remote sensing applications: Opportunities and challenges <i>Su Ye, Yuchen Tao, Xiucheng Yang</i>	430
Diffusion-guided lightweight remote-sensing semantic models for on-board AI <i>Xinyue Li, Hongwei Li, Jingwen Wang, Chunhui Wang, Chaojie Zhang</i>	440
Noise-aware fine-tuning as a hardware noise margin: Cross-layer co-design for robust low bit RRAM in-memory computing toward space-borne edge inference <i>Yang Tian, Dunan Hu, Lingzi Zhang, Lili Gao, Kequan Xia, Tuo Shi, Jianguo Lu</i>	452

Memristive technologies in spatial artificial intelligence architectures: A comprehensive review of advantages, bottlenecks, and mitigation strategies <i>Haoyue Deng, Huiqin Ma, Tuo Shi, Xiaoxin Xu</i>	464
Vision language action models for robotic manipulation: A comparative evaluation of policy and value architectures <i>Hongliang Wang, Jin Liu, Xiaolin Zhu, Qiang Fu, Yuhua Zheng, Wangmeng Zuo, Changqing Zou, Evgeny Burnaev</i>	477