AI4Space

Artificial Intelligence in Aerospace

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What is AI4Space?

- The application of Artificial Intelligence to the Aerospace domain
  - In practice, this takes existing machine learning applications and combines them with existing aerospace technology [1]

- Image Classification
  - Identifying Exoplanets
  - Scanning aircraft for needed repairs

- Computer Vision
  - Mapping free-floating objects

- Scheduling and Management
  - Air Traffic Control (ATC)
  - JPL ASPEN – Automating Space Mission Operations
  - Advanced Life Support Management

- Autonomous Driving
  - Rovers on lunar surfaces
  - Coordinating multiple rovers simultaneously
  - Asteroid deflection

Motivations and Significance

Space Exploration

Identify exoplanets and process data from satellites

Planet Exploration

Enable autonomous rovers for lunar missions

Earth Science

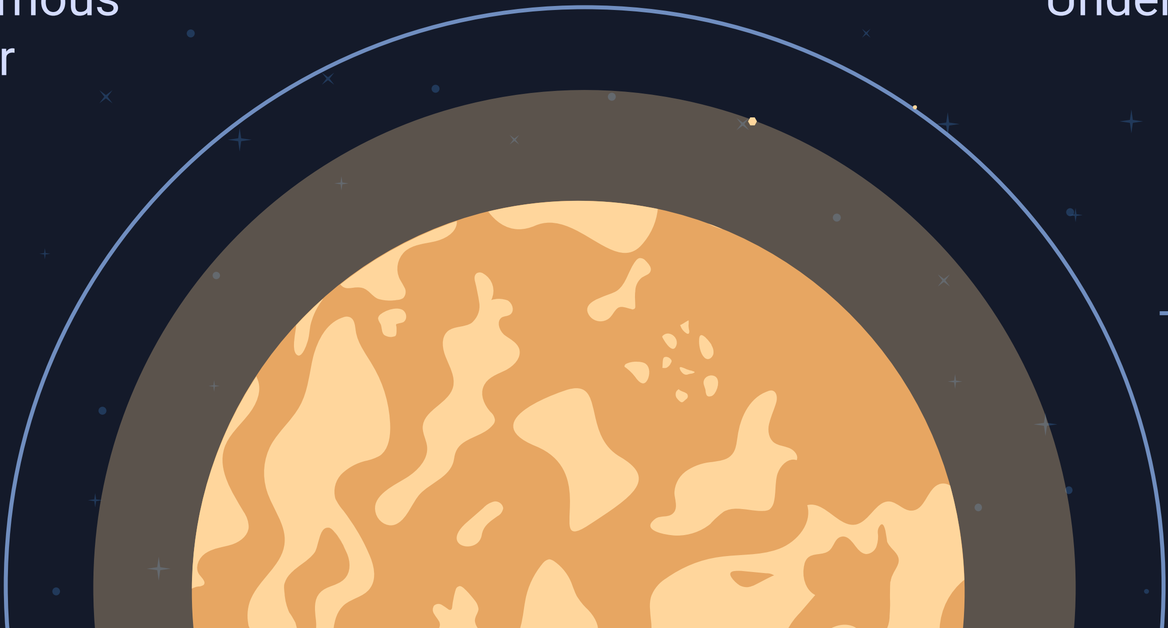
Understand our own planet

Flight Safety

Coordinate aircraft and identify repairs

Mission Assistance

Assistants that help astronauts with daily tasks

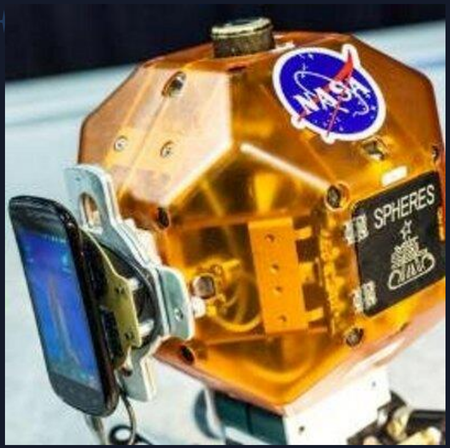


Completed Research

A few projects that have made significant advancements in AI4Space

Robotic Assistants

Robotic Assistants (RAs)

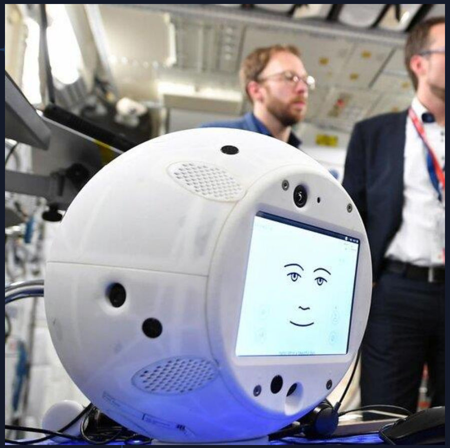


SPHERES

Synchronized Position Hold, Engage, Reorient, Experimental Satellites

Astrobee

NASA's next-gen of SPHERES with free-flying capability



CIMON

Crew Interactive Mobile Companion developed by the German Aerospace Center

Int-Ball

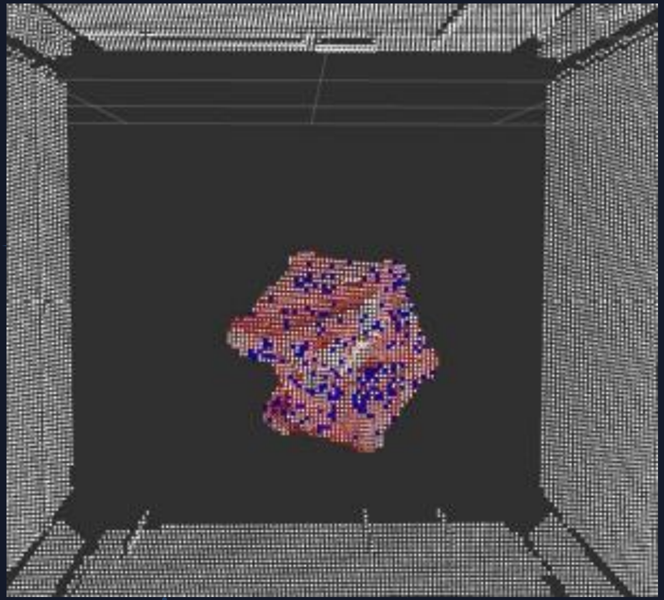
Japan Aerospace Exploration Agency's (JAXA) Internal Ball Camera

NASA SPHERES and Astrobee

Both of NASA’s Robotic Assistants leverage Computer Vision in their regular tasks. The most prevalent work began with the SPHERES VERTIGO Goggles

Vision Based Mapping and Localization onboard the International Space Station [1]

- Visual Estimation for Relative Tracking and Inspection of Generic Objects (VERTIGO)
- Uses Computer Vision (OpenCV) to build a three-dimensional map of a target object
- Enables remote observation of “an unknown, uncooperative and possibly moving and tumbling target object”



[3] Depiction of the target point cloud matching and registration process in the ISS Astrobee simulator

Exoplanet Identification

Exoplanet Identification

- The Kepler Space Observatory satellite built by NASA is dedicated to searching for exoplanets with the ultimate goal of finding other habitable planets
- NASA and Caltech keep the exoplanet candidate dataset open source [link]
- NASA's Exoplanet Exploration Page keeps an updated count of the number of confirmed exoplanets, number of NASA candidates, and planetary systems discovered: https://exoplanets.nasa.gov/

In 2021, a group of scientists developed a new deep neural network called ExoMiner which led to the addition of 301 planets to Kepler's Total Count [4]

> "For a fixed precision value of 99%, ExoMiner retrieves 93.6% of all exoplanets in the test set while this rate is 76.3% for the best existing classifier [5]"

Manual to Machine Exoplanet Identification

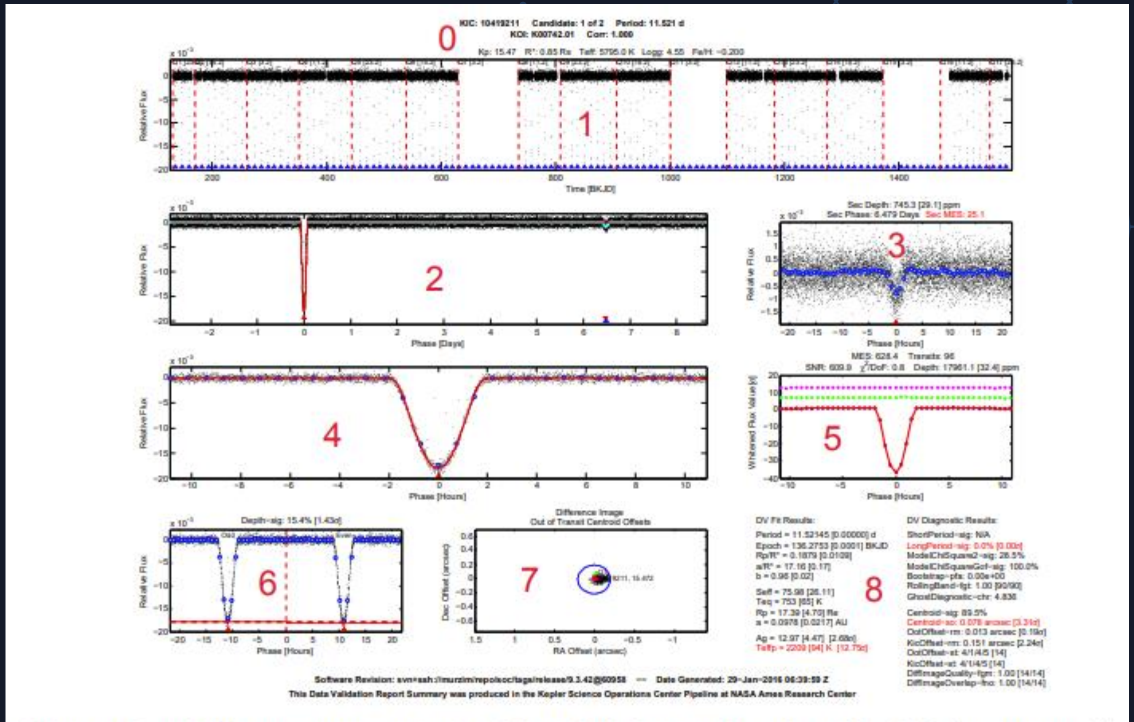


Figure 1. Example DV 1-page summary report. It includes multiple diagnostic plots and variables: (0) Stellar parameters, (1) Full time series flux, (2) Full-orbit phase-folded flux, (3) Transit-view phase-folded secondary eclipsing flux, (4) Transit-view phase-folded flux, (5) Transit-view phase-folded whitened flux, (6) Transit-view phase-folded odd & even flux, (7) Difference image (out-of-transit) centroid offsets, and (8) DV analysis table of variables.

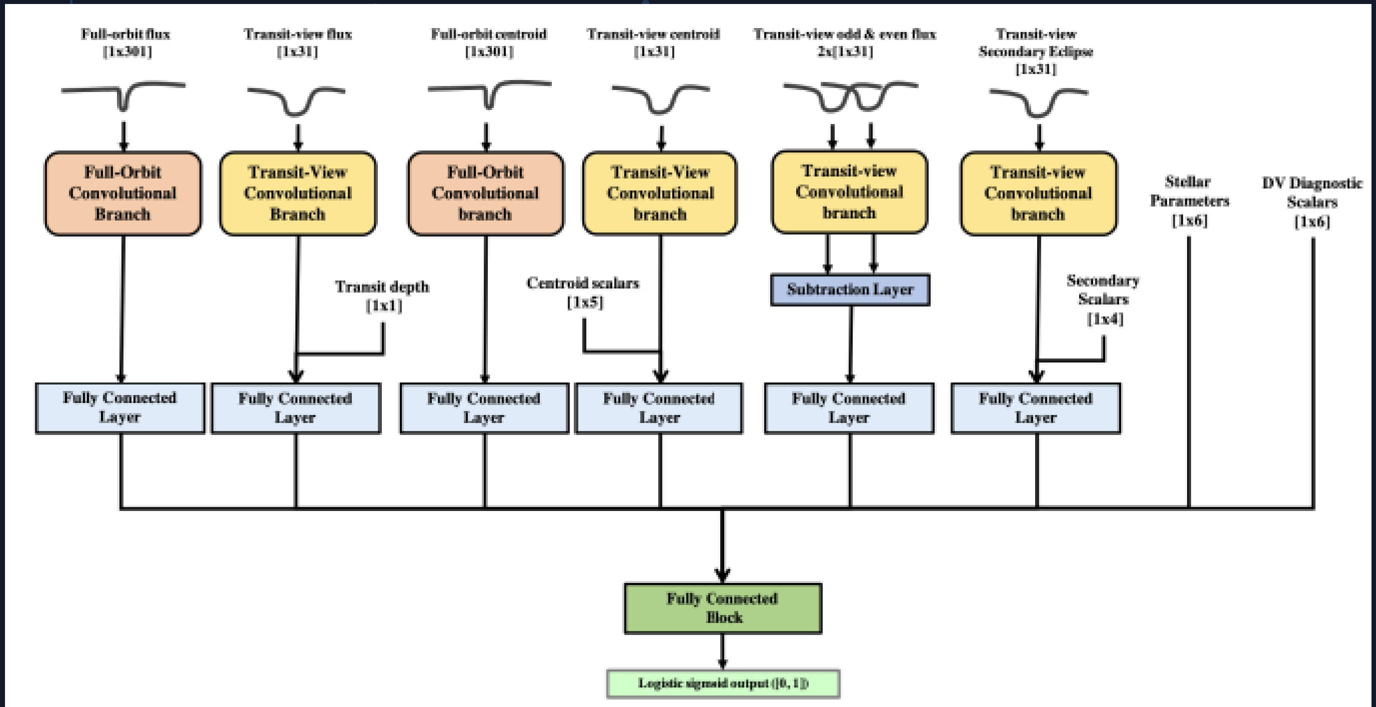


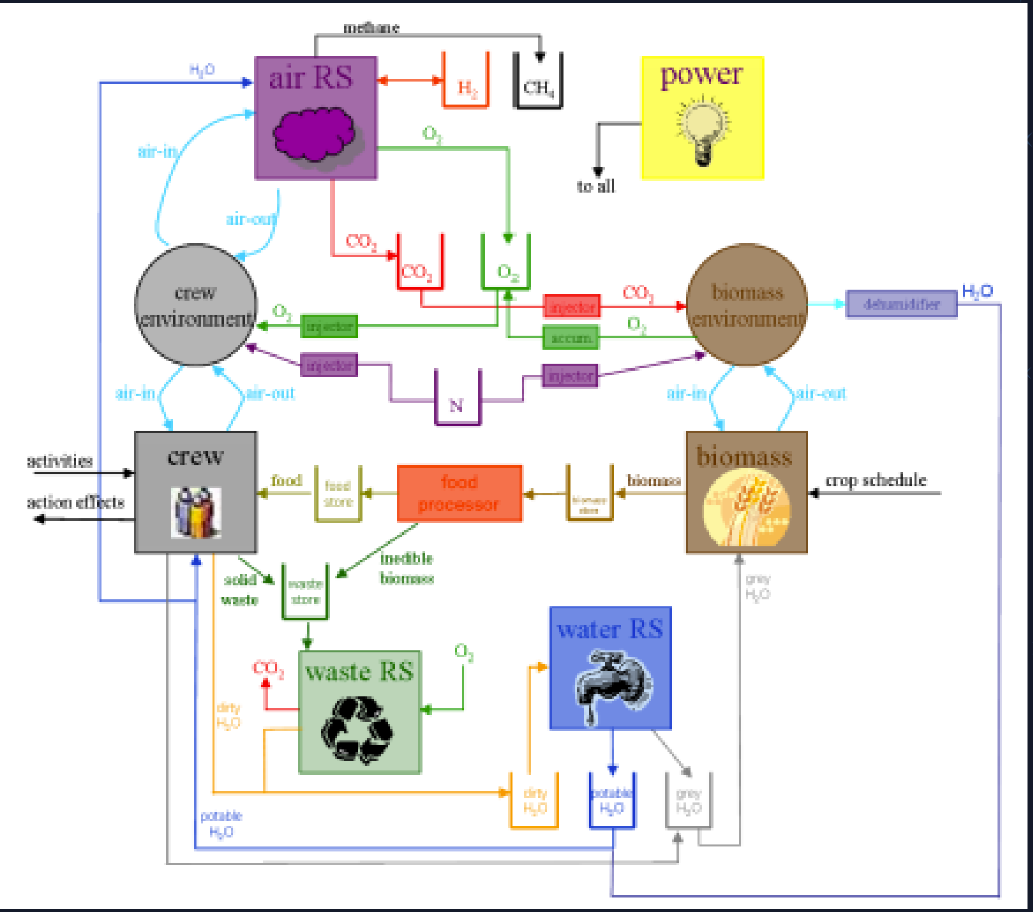
Figure 4. ExoMiner architecture.

Advanced Life Support

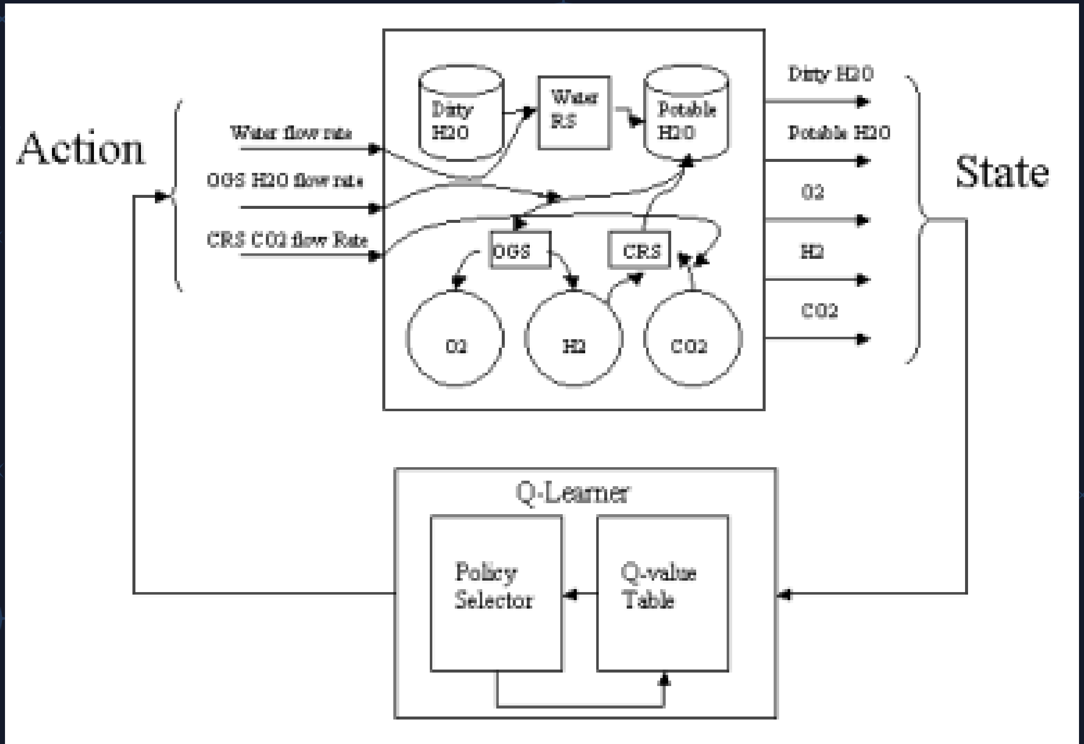
Advanced Life Support (ALS)

- Nonlinear coupled dynamical systems that require an effective control strategy for optimal efficiency [5]
- TracLabs, in collaboration with NASA, modelled the open source BioSim simulation to represent ALS
  - Individual modules have consumer/producer relationship
  - Controls allow for adjusting the flow of resources between modules

BioSim | An Integrated Simulation of an Advanced Life Support System for Intelligent Control Research



Q-Learning for ALS



- Q-Learning is a type of Reinforcement Learning, a semi-supervised machine learning method that learns through rewards
- In a given state, predict the reward value of taking an action to move to another state
- Klein, et al., focused on controlling the air and water recycling systems by adjusting the flow rates of dirty water, potable water, and carbon dioxide:
  - Oxygen Generating System (OGS)
  - Carbon Dioxide Reduction System (CRS)
  - Water Recycling System (WRS)
- End Goal: Maximize the mission length

Example Q-Learning Cycle

Step 02

Receive a reward

Step 04

Choose the next state based on current value estimates

Step 01

Adjust the flow rates of dirty water, potable water, and carbon dioxide

Step 03

Recalculate the expected value of all states

Step 05

Repeat

The Future of AI4Space

Where is it going and are there any concerns

Future Research

Data Processing

Space missions, satellites, and telescopes generate massive amounts of data for analysis

EarthData

Understand our own planet before venturing to explore others [7]

Spacecraft Telemetry

Understanding the metrics generated by space craft and identifying areas of concern

Autonomous Missions

Using AI for navigating rovers and automating exploration with limited human interference

Ethical Concerns

Ethical concerns with AI4Space align with ethical concerns for AI in general as well as ethical concerns with non-AI enabled aerospace technology. AI4Space should adhere the standard codes of ethics for both Aerospace and Software Engineers.

Manned Missions

Stakes are higher for manned missions as human lives are put at risk

Autonomous Driving

Reliability of AI for traffic control and autonomous driving

Space Sustainability

Space exploration must not do harm and must leave the visited planets no worse than before we visited

Questions?

References

[1] “Artificial intelligence in space.” *ESA,* https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space. Accessed 8 April 2023.

[2] Tweddle, B.E., Saenz-Otero, A., and Miller, D.W. (September 2012). **The SPHERES VERTIGO Goggles: Vision Based Mapping and Localization onboard the International Space Station,** International Symposium on Artificial Intelligence, Robotics and Automation in Space, Turin, Italy, 4-6 September, 2012.

[3] C. Oestreich, A. Teran, J. Todd, K. Albee, and R. Linares. **On-Orbit Inspection of an Unknown, Tumbling Target using NASA’s Astrobee Robotic Free-Flyers.** *Conference on Computer Vision and Pattern Recognition, (Virtual)*, 2021.

[4] “New Deep Learning Method Adds 301 Planets to Kepler’s Total Count.” *NASA,* https://www.nasa.gov/feature/ames/new-deep-learning-method-adds-301-planets-to-keplers-total-count. Accessed 9 April 2023.

[5] H. Valizadegan, M. J. S. Martinho, L. S. Wilkens et al. **ExoMiner: A Highly Accurate and Explainable Deep Learning Classifier that Validates 301 New Exoplanets.** *Astrophysical Journal.* 21 November 2021.

[6] Klein, T., Subramanian, D., Kortenkamp, D., and Bell, S., "Using Reinforcement Learning to Control Life Support Systems," SAE Technical Paper 2004-01-2439, 2004.

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