Integration and Autonomy for Intra-Vehicular Robots: Results of the ISAAC Project

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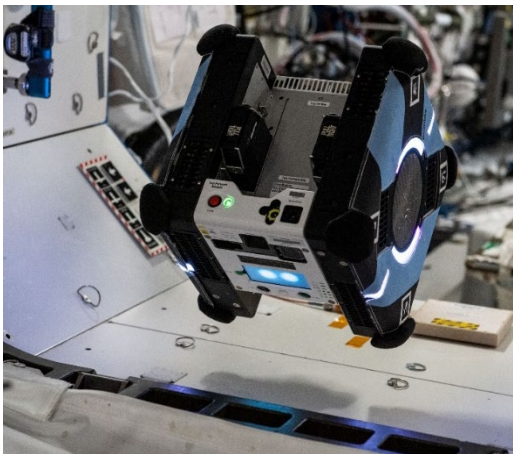


Bumble performing a close-up inspection of a hatch seal



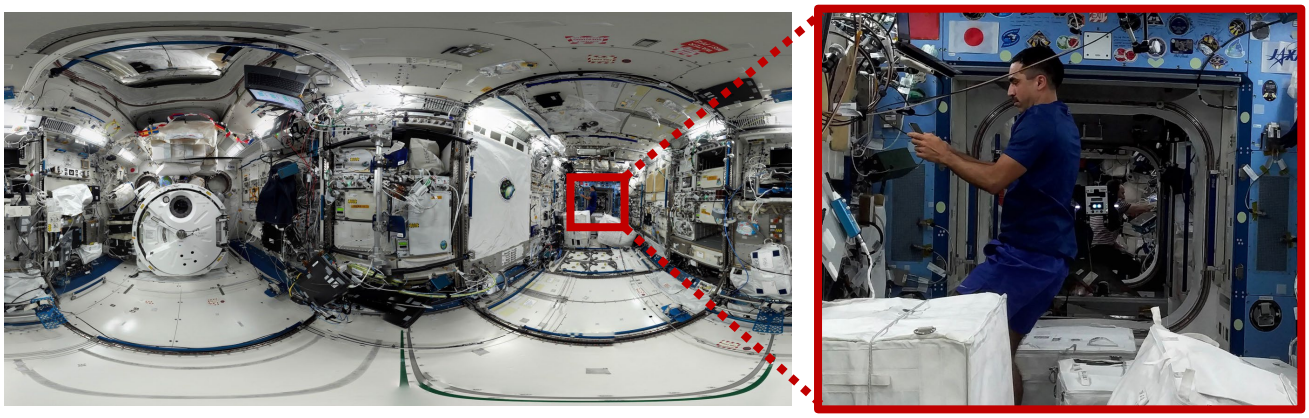
NASA astronaut Kayla Barron supporting SoundSee/ISAAC activity

Introduction. Since 2019, NASA's Integrated System for Autonomous and Adaptive Caretaking (ISAAC) project, based at NASA's Ames Research Center and Johnson Space Center, developed technology for autonomous caretaking of spacecraft, primarily during uncrewed mission phases. ISAAC aimed to integrate autonomous intra-vehicular robots with vehicle infrastructure. ISAAC technology has been demonstrated in software simulation, ground testing, and during 16 activities with the free-flying Astrobee robots in the International Space Station (ISS). This abstract reviews ISAAC final results.

Technology. ISAAC has three main technology themes: (1) Integrated Data: ISAAC has linked spacecraft data and models with autonomous robots, as well as linking 3D geometry with multimodal sensor data map layers and detecting changes and anomalies. (2) Integrated Control Interface: ISAAC developed prototype control interfaces that visualize spacecraft data and multi-robot data together, improving system-level situation awareness and operator productivity. (3) Coordinated execution: ISAAC developed prototype execution managers that use automated planning and coordinate multi-robot activities.

Highlighted demonstrations. *Autonomous state assessment:* ISAAC used two Astrobee free-flyers to demonstrate an autonomous multi-robot, multi-sensor interior survey of two ISS modules, coordinating the robots using onboard automated planning and execution. The resulting data was used to build a panoramic tour valuable for ISS operators.

Autonomous logistics management: In software simulation, ISAAC demonstrated an uncrewed cargo transfer scenario involving an Astrobee robot flying multiple cargo bags from modules of the Gateway lunar space station to a docked cargo vehicle where they could be stowed by a Robonaut manipulator



First full 360° interior panorama captured with a robot in space (stitched from 56 SciCam images)

robot. An automated execution manager translated the high-level goal to coordinated actions and executed them on both robots.

Integrated fault management: Using an Astrobee on ISS, a high-CO_2 anomaly was injected into synthetic vehicle telemetry. The Astrobee responded by performing an automated inspection of a mockup obstructed intake vent and used computer vision to detect and report the obstruction. (In a fuller scenario, a manipulator robot would then have cleared the obstruction, but no manipulator was available on ISS.)

Results. ISAAC's accomplishments included several space robotics firsts: (1) The first time a robot autonomously navigated between multiple modules inside a spacecraft. (2) The first time a robot located a sound source inside a spacecraft (in collaboration with the SoundSee Astrobee payload team from Bosch USA). (3) The first time a mobile robot surveyed a spacecraft interior to build a map for human viewing. Most ISAAC software and data from ISAAC ISS activities has been released open-source to the public, including significant improvements to the baseline flight software on the Astrobee robots that will benefit future users of the ISS Astrobee Facility. ISAAC staff have also mentored dozens of student researchers over the years to help train the next generation of space robotics talent. Overall, ISAAC has taken important initial steps toward demonstrating the feasibility of using intra-vehicular robotics for vehicle caretaking.

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