Developing a 3-DOF Compliant Perching Arm for a Free-Flying Robot on the International Space Station

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I. MOTIVATION

The Intelligent Robotics Group at NASA Ames Research Center is building a free-flying robot, Astrobee, which will be operated inside the International Space Station (ISS) to perform a variety of intravehicular activities. Astrobee is expected to support autonomous operations, remote operation by ground controllers, and human-robot interaction with crew members. As a part of the Astrobee robotic system, a compliant, detachable perching arm is being developed to support long duration tasks. This arm will grasp ISS handrails to hold its position without using propulsion or navigation to minimize power consumption. It will also support Astrobee robots grasping each other to enable future research related to satellite servicing.

There was considerable research related to the various techniques of perching for free-flying robots including claws, magnets, suction, gecko-adhesion, electro-adhesion, micro-spines, etc. In order to meet the allocated mass, power, and size requirements, a compliant claw gripper with a two degree-of-freedom (DOF) arm is being developed as the first prototype of an Astrobee perching arm as shown in Fig. 1. Since the crew's safety is of the utmost importance on the ISS, the perching arm is designed such that the gripper can be released automatically when a certain amount of external force is applied in both normal and shear directions and can be released manually by the crew. The 2-DOF arm is used to stow the gripper inside of the outer structure during flight so that it is not exposed to collision hazard while stowed. When the arm is successfully perched, it can also operate as a pan-tilt module for a camera attached on the opposite side of the robot to support remote monitoring operations.

II. 3-DOF COMPLIANT PERCHING ARM

The main objectives for developing the prototype of the Astrobee perching arm, shown in Fig. 1, are to verify the grasping functionality and the range of pan-tilt motion. The 2-DOF arm consists of 2 Dynamixel AX-12A motors and the tendons in the gripper are connected to a Pololu metal gearmotor. Dynamixel motors are directly controlled from a BeagleBone board and the Pololu motor is controlled using a Baby Orangutan B-328 board, where the desired commands are sent from the BeagleBone board via serial. The length and mass of the Astrobee perching arm are 24.0 cm and 315.0 g, respectively.

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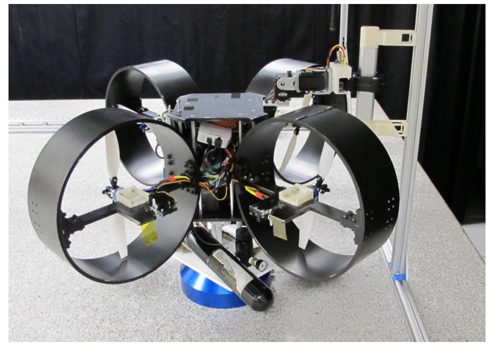
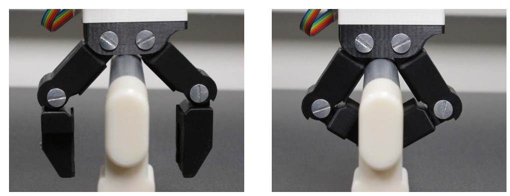


Fig. 1. A prototype of Astrobee grasping an ISS handrail on the top of a micro-gravity simulating surface.



(a) Opened configuration (b) Closed configuration

Fig. 2. Snapshot of the Astrobee perching arm grasping an ISS handrail

Fig. 2 shows the open and closed configurations of the perching arm while grasping an ISS handrail. The gripper uses torsional springs for joint flexion and an actuated tendon for extension. This allows gripping force to be maintained even with the motor turned off. It also allows external forces to open the gripper by overcoming spring torques, rather than having to back-drive the motor. Furthermore, independent flexion torques at the proximal and distal joints provides passive compliance to the shape of the grasped object; the perching procedure is thus robust to positioning errors with respect to the handrail. We plan to perform a formal quantification of the allowable positioning error is in a follow-up study.

The 2-DOF arm provides a pan range of -90.0° to 90.0° and a tilt range of -30.0° to 90.0° from the center of Astrobee while perched. However, when the prototype of the perching arm was tested on the micro-gravity-simulating 2D surface, the gripper force was insufficient to both enclose the handrail and generate a pan motion simultaneously. Design optimizations to increase the contact area between the gripper and the handrail and to minimize the overall size of the arm's structure for the flight unit are left as future work.