

An Underactuated Rigid-Soft Hybrid Gripper Prototype for Conforming Free-Flying Manipulation

Jordan Kam
Aerospace Engineering Program
University of California, Berkeley
Berkeley, United States
kamjk@berkeley.edu

Andres Mora Vargas
Intelligent Systems Division
KBR Wyle at NASA Ames
Moffett Field, United States
andres.moravargas@nasa.gov

Brian Coltin
Intelligent Systems Division
KBR Wyle at NASA Ames
Moffett Field, United States
brian.j.coltin@nasa.gov

Abstract—Astrobee is a free-flying robot that is used to perform zero-gravity manipulation tasks, such as perching onto the handrails of the International Space Station. The complexity of future space station subsystems will require free-flying manipulation to be more adaptive, dexterous, and conforming. This article presents a rigid-soft hybrid gripper prototype for conforming manipulation in zero-gravity environments. This proof-of-concept prototype is a three-finger underactuated tendon-driven gripper with rigid joints and hinges equipped with inflatable soft padding and soft distal joints. Integrated into Astrobee’s perching arm payload, this prototype is capable of grasping spherical geometries with reduced actuation and payload volume stowage. This gripper prototype is a step towards increased conforming manipulation capabilities for free-flying robots.

Index Terms—Astrobee, free-flying, rigid-soft hybrid, compliant manipulation, gripper prototype, zero-gravity

I. INTRODUCTION

Since 2019, Astrobee has been used for free-flying manipulation on the International Space Station (ISS) [1]. Such tasks include perching onto ISS handrails, gecko-adhesion manipulation, and ISS cargo transfer bag transport [2], [3]. While many of these tasks can be done using Astrobee’s perching arm payload, guest scientists can attach novel gripper payloads at the arm’s wrist joint to manipulate objects outside the grasp of the perching arm gripper. As manipulation tasks grow in complexity, new gripper payloads offer a novel solution to equipping free-fliers with the grasping needed to handle complex geometries.

Soft robotic manipulation has been identified as a promising alternative to traditional designs for on-orbit missions [4]. The increased degree of freedom (DOF) manipulation with conforming materials allows for adaptable and robust manipulation: two key attributes needed for future space missions.

II. METHODOLOGY

State-of-the-art soft grippers include one of the following types: pneumatic, vacuum, hydraulic, and electric grippers [5]. For an Astrobee soft gripper prototype, a rigid-soft hybrid is a promising approach given its robustness, payload volume, and power consumption [6]. The rigid element of the prototype is a three-finger underactuated gripper inspired by the design of the perching arm and the soft element is the fabric lining the distal and proximal joints. Attached onto Astrobee’s perching

arm, the prototype is used to demonstrate grasping capabilities with a 2mm screwdriver at NASA Ames’ Granite Lab.

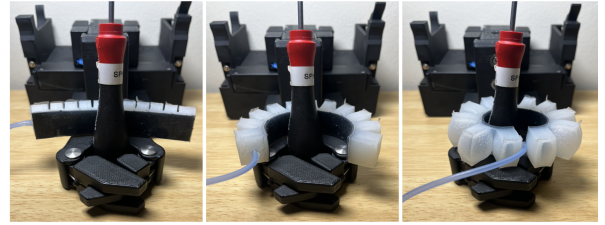


Fig. 1. Soft finger wrapped around the perching arm gripper payload.

A. Gripper design

A three-finger 1-DOF underactuated tendon-driven gripper design is used for the rigid frame of the payload. The inflatable conforming pads are then added to the palm, proximal, and distal joints of the gripper as seen in Fig 2 (a) and (b). This hybrid approach of rigid and soft components provides a compliant grasping region inside the three fingers for adaptable manipulation with reduced actuation and payload size.

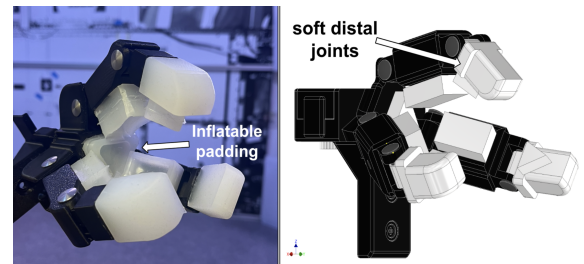


Fig. 2. Gripper prototype next to the Computer Aided Design (CAD).

B. Astrobee integration

The soft gripper will integrate into the perching arm at the arm’s distal joint as an end-effector. Occupying approximately 1U (10x10x10cm) on either of the payload bays (top/bottom), the soft gripper’s hardware can seamlessly integrate with Astrobee through the perching arm. Figure 3 (a) and (b) show the soft gripper payload in both a stowed and deployed configuration.

Once installed into the arm, the fingers can actuate in 1-DOF using a torsional spring to close and an actuated tendon to open similarly to the current Astrobee perching arm gripper. The additional space in the 1U payload could be used to store additional actuation equipment or sensors for the end-effector feedback.

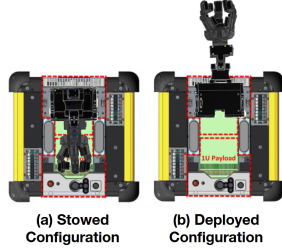


Fig. 3. Soft gripper payload in a stowed and deployed configuration.

C. Material selection

Soft robotics uses a variety of elastomers that could be suitable for space applications given its robustness and actuation capabilities [4], [7]. A survey of this material and other commonly used components in soft robotics highlights the potential of siloxane gels, silicone elastomers (Ecoflex 00-30), fluoroelastomers (Viton FKM), thermoplastic polyurethanes (TPU), and reinforced polyetheretherketones (PEEK) in particular. A summary of the main characteristics of these five materials that make them viable for pad fabrication can be seen in Table I.

TABLE I
MATERIALS FOR CONFORMING INFLATABLE PADS

Material	E (MPa)	SR	Details
Siloxane Gel	0.01	Low	Ultra-soft with a decrease in durability in a vacuum
Ecoflex 00-30	0.125	Med	High flexibility, but needing a low-outgassing grade
Viton FKM	7.0	High	Chemically resistant due to space seals
TPU-Fabric	5–20	High	State-of-the-art for inflatable aerospace structures
Reinf. PEEK	60–100	High	Strong and space radiation-tolerant

^aE: Elastic modulus. ^bSR: Space readiness (*Low/Med/High*).

Although other materials could serve as viable selections, based on the air tightness, flexibility, durability, and wide use in traditional soft robotics, Ecoflex 00-30 is the conforming material used for this prototype.

III. DEFORMATION ANALYSIS

We simulate the gripper's capability to grasp objects with finite element methods in AutoDesk Inventor's simulation environment. Using Inventor, the soft distal joints made with the Ecoflex 00-30 material is simulated in zero-gravity to test deformation under a 10 lbs per inch force in the x-axis direction. Figure 4 shows the results of this finite element simulation compared to the CAD model used and fabricated prototype.

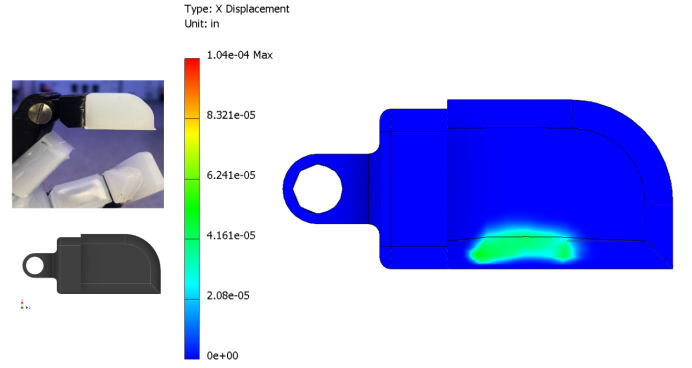


Fig. 4. Finite element analysis of the deformation of the silicone distal joint.

Using finite element simulation software in zero-gravity environment with assigned material properties allows for validation of the gripper's deformation and interaction with rigid objects in a realistic ISS environment. The imported load is meant to simulate the same force as grasping a screw driver as seen in Figure 5.

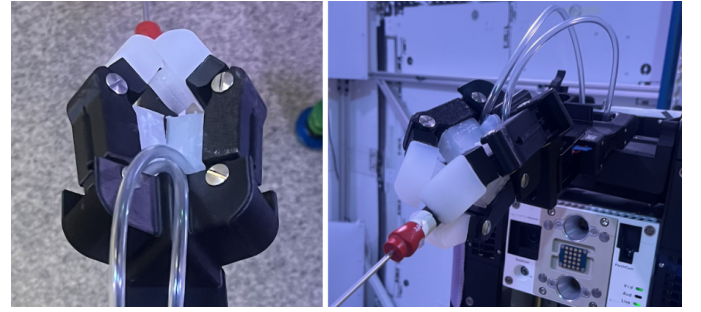


Fig. 5. Rigid-soft hybrid gripper prototyped grasping a screwdriver.

REFERENCES

- [1] Smith, Trey, et al. "Astrobee: A new platform for free-flying robotics on the international space station." International Symposium on Artificial Intelligence, Robotics, and Automation in Space (i-SAIRAS). No. ARC-E-DAA-TN31584. 2016.
- [2] Park, In-Won, et al. "Developing a 3-DOF compliant perching arm for a free-flying robot on the International Space Station." 2017 IEEE International Conference on Advanced Intelligent Mechatronics (AIM). IEEE, 2017.
- [3] Chen, Tony G., et al. "Testing gecko-inspired adhesives with astrobee aboard the international space station: Readyng the technology for space." IEEE Robotics & Automation Magazine 29.3 (2022): 24-33.
- [4] Zhang, Yongchang, et al. "Progress, challenges, and prospects of soft robotics for space applications." Advanced Intelligent Systems 5.3 (2023): 2200071.
- [5] Hughes, Josie, et al. "Soft manipulators and grippers: A review." Frontiers in Robotics and AI 3 (2016): 69.
- [6] Gerez, Lucas, Che-Ming Chang, and Minas Liarokapis. "A hybrid, encompassing, three-fingered robotic gripper combining pneumatic telescopic mechanisms and rigid claws." 2020 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR). IEEE, 2020.
- [7] Agarwal, Gunjan, et al. "Stretchable materials for robust soft actuators towards assistive wearable devices." Scientific reports 6.1 (2016): 34224.