Design of a Gecko Adhesive Climbing Robot

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Abstract

I present, ACROBOT, a gecko-adhesive enabled robot that can climb surfaces in any gravitational orientation or operate in full zero gravity. The robot is being developed as a prototype for inspection applications aboard the International Space Station (ISS) where current voids in inspection coverage both inside and outside the station pose risks to the vehicle. A specific area of interest for inspection is a narrow gap, approximately 1.5 inches wide, behind internal equipment racks. The prototype robot uses oppositional pairs of gecko adhesive pads that turn adhesion ON and OFF using an applied shear load. The robot is currently tele-operated and utilizes an inchworm style gait. The robot can turn in a tight circle, fits within a 1.5 inch gap, and can transition between orthogonal surfaces. Gecko adhesives leave no residue, are highly reusable, and create strong coverage both inside and outside the station. A bot is being developed as a prototype for inspection applications aboard the International Space Station (ISS) where current voids in inspection coverage both inside and outside the station pose risks to the vehicle. A specific area of interest for inspection is a narrow gap, approximately 1.5 inches wide, behind internal equipment racks. The prototype robot uses oppositional pairs of gecko adhesive pads that turn adhesion ON and OFF using an applied shear load. The robot is currently tele-operated and utilizes an inchworm style gait. The robot can turn in a tight circle, fits within a 1.5 inch gap, and can transition between orthogonal surfaces. Gecko adhesives leave no residue, are highly reusable, and create strong coverage both inside and outside the station. A bot is being developed as a prototype for inspection applications aboard the International Space Station (ISS) where current voids in inspection coverage both inside and outside the station pose risks to the vehicle. A specific area of interest for inspection is a narrow gap, approximately 1.5 inches wide, behind internal equipment racks. The prototype robot uses oppositional pairs of gecko adhesive pads that turn adhesion ON and OFF using an applied shear load. The robot is currently tele-operated and utilizes an inchworm style gait. The robot can turn in a tight circle, fits within a 1.5 inch gap, and can transition between orthogonal surfaces. Gecko adhesives leave no residue, are highly reusable, and create strong coverage both inside and outside the station.

Introduction

Biomimetic Inspiration

• Geckos’ toes are composed of a hierarchy of structures. On each toe, the gecko has tens of mm-sized flap called lamellae on which arrays of millions of micron sized ‘hairs’ called setae grow. Setae branch further into thousands of nano-sized hairs called spatulae that make intimate contact with a surface and stick using predominantly van der Waals forces.
• Directionally Controllable Adhesion
  • Adhesive is an array of millions of compliant directionally biased wedges
  • Adhesive turned ON by applying a shear force to pads in direction of bias
  • Adhesive turned OFF by removing shear force
  • Net van der Waals Intermolecular Force is directly proportional to real area of contact between adhesive and climbing surface

Metamorphic Compliant 4-bar Mechanism

• Synthesized 3-position, 4-bar linkage to lift gecko pads onto and off of climbing surface
• For ±10° crank angle the linkage maintains pads at parallel alignment with climbing surface for optimal adhesion generation
• Compliant, contact-aided, anisotropic coupler link passively adjusts to slight misalignments with climbing surface

Adhesive Characterization

• Preload vs adhesion strength testing under normal, shear, & moment loads
• Performance characterization yields design parameter limits
• Results: Preload ‘forces’ out slight misalignments between pads & surface

Adhesive Actuation Mechanism

• Two gecko pads oriented in directionally biased opposition
• Tension spring configured in parallel with a linear actuator to apply shear
• Linear guide rail & bearings constrain pads & ensure coplanar alignment

Robot & Mechanism Design

Synthesize collaborative mechanisms that allow the robot mobility along flat planes and the kinematic capability to execute orthogonal plane-to-plane transitions using an inchworm style gait.

- Optimize Center of mass
- Minimize weight

Mobility and Tail Mechanism

• Micro rack and pinion system for extension and contraction inch-worm locomotion
• Servo-actuated gear system for turning
• Passive tail counters gravity induced moment when only one gecko module is adhered to the climbing surface

Adhesive Characterization

Preload vs Adhesion Strength

Climbing Test Results

• Successful climbing on sloped & vertical surfaces in Earth gravity
• Can climb supporting own mass (0.323 kg) plus 0.2 kg payload
• Inverted hang using tail supporting additional 0.6 kg payload
• Inverted hang with only 1 module adhered supporting 0.375 kg

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