

PAPER

Improving Gecko Adhesive Performance in Robotic Systems through Trajectory Optimization

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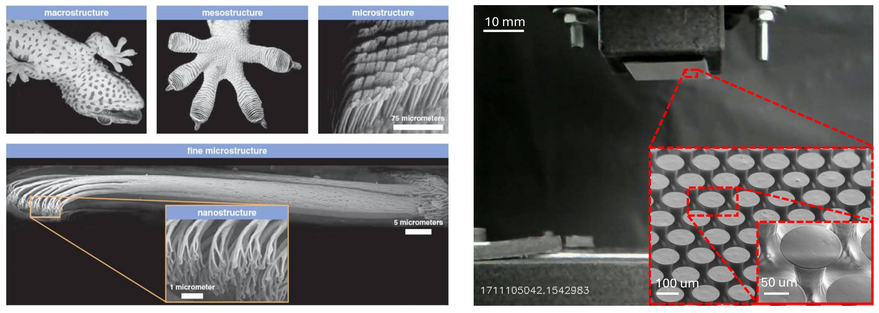
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Background

The gecko is the largest, heaviest animal relying on dry (physical) adhesion. Thus, it has been broadly studied and inspired the development of flexible dry adhesives. Such surfaces do not rely on the use of glues (chemical adhesion), thus, making them suitable for long-term use for reversible adhesion. Nevertheless, gecko-inspired adhesives have not become a central adhesion tool in climbing robots, robotic grippers, and even wall climbing, due to two reasons. First, since the adhesion force drops on rough surfaces, or surfaces with complex microscale morphologies. Second, these adhesives are highly sensitive to contaminants such as sand or large amounts of dust.

Introduction

Insects and reptiles use several adhesion mechanisms in order to attach and move on surfaces at various angles, perpendicular, or even invertedly. These mechanisms enable both effective attachment to surfaces, to prevent falling, and simple detachment to allow locomotion. Therefore, the adhesion mechanism needs to be strong enough to support the weight of the animal and weak enough to allow separation, sometimes rapidly (milliseconds), from the surface. Physical ("dry") adhesion relies on van der Waals forces[1], therefore, on the ability to approach closely (nanometer scale) to counter surfaces and to maximize the contact area. To achieve this, nature has developed hierarchical flexible "hairy" surfaces/materials that can conform to various types of surfaces, including rough surfaces and ones with complex geometry, together with energy efficient toe movement to attach and detach from a surface. In this project we seek to improve the adhesion performance of synthetic physical adhesives with artificial intelligence and optimization methods

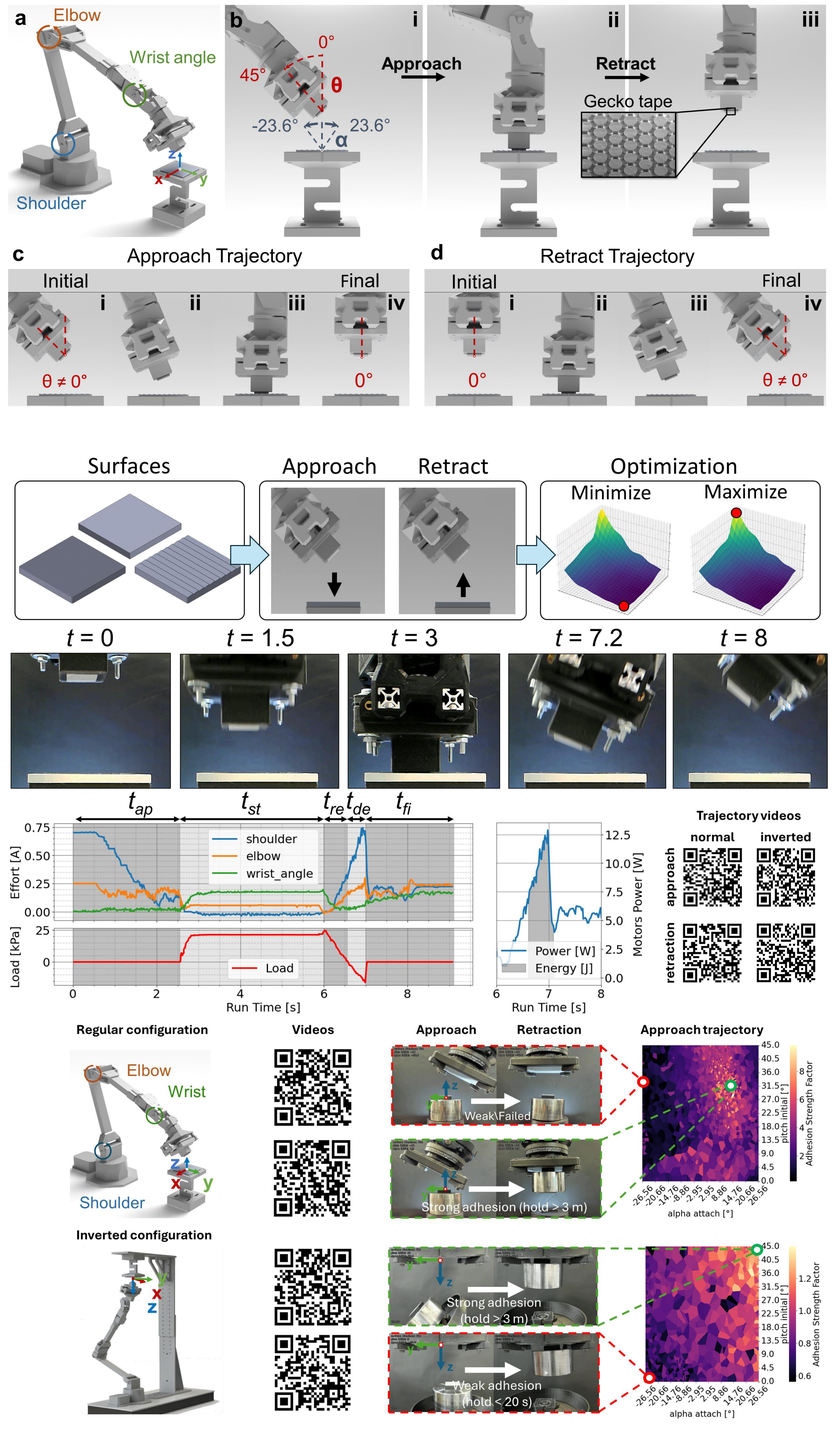


1. The hierarchical structure of the gecko toe[3] 2. SEM imaging of the gecko adhesion tape mounted on the end effector, the micro-size pillar structure facilitate the physical adhesion between the tape and the counter surface using van-del-walls forces

Methods

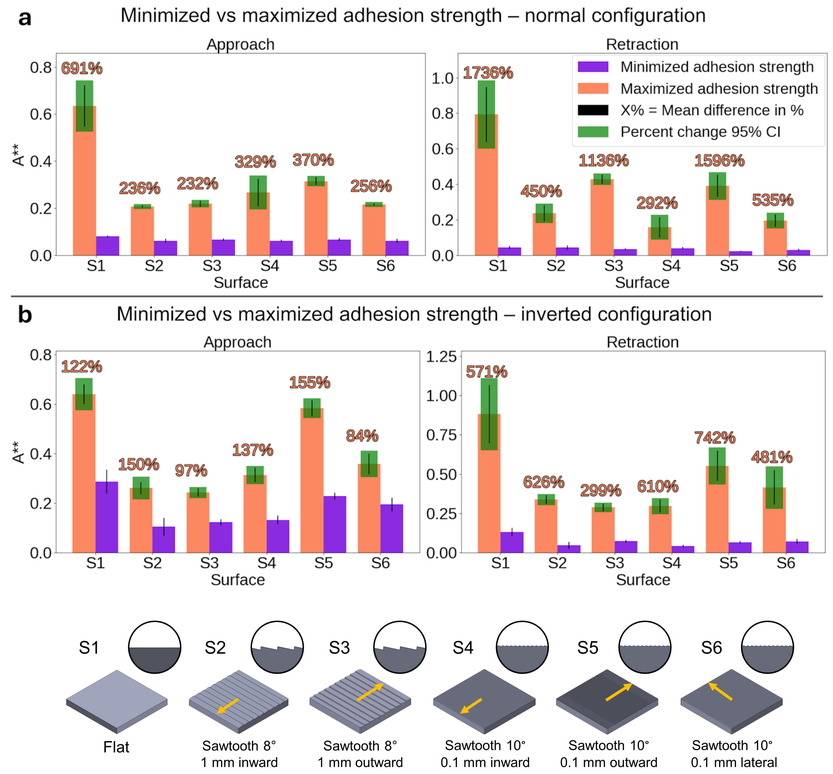
The experimental setup features a manipulator arm with gecko adhesion tape attached to its end-effector, and a base plate outfitted with swappable surface plate patterns serving as the counter surface for the gecko adhesion tape attachment. In each optimization process, the end-effector moves from an initial posture towards the base plate (attachment trajectory) and from the base plate towards a final posture (detachment trajectory), the end-effector trajectory is defined by the pitch and alpha angles. Depending on the objective of the experiment i.e. attachment or detachment, the relevant parameters is used (initial vs final angles). For each combination of trajectory parameters, the “adhesion energy factor” is calculated from the energy consumption of the manipulator arm motors at the time of detachment.

Experimental Setup



Results

Optimization results revealed distinct low and high adhesion strength regions associated with the corresponding attachment and detachment trajectory parameters alpha and theta. A difference between the adhesion strength minimization (purple) and the maximization (orange) results of surfaces S1-S6 are shown for the normal (a) and inverted (b) configurations. We were able to receive 84% to 1736% improvement in adhesion strength between the minimization and maximization optimization results, 43/48 scenarios improved (89.5% success rate), 274% adhesion strength improvement compared to the unoptimized trajectory, and longer adhesion duration time when attaching objects with the optimized trajectory.



Discussion and Importance

In our work we succeed to enhance the performance of the same physical adhesive, both for applications that demand stronger attachments, and in applications that require easier detachments by controlling the approach and retract trajectories of the adhesive relative to the substrate. Advances in physical adhesion technology can benefit robotic applications such as legged climbers, industrial grippers and object manipulation in space, to name a few.

References

[1] Autumn, K et al. Proc. Natl. Acad. Sci. 2002

[2] Sikdar, S et al. Robotics 2022

[3] Autumn, K. 2006