Load distribution to contact area analysis of Gecko’s limb and feet

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Abstract. Gecko possesses a distinct feature that enables it to move in lateral and vertical directions due to its adhesive foot structures. In the past few years, the research on Gecko is primarily focused on this adhesive feature. However, Gecko’s hind attachment relies heavily on the available contact area between its foot and its attaching medium. In this paper, physical observation and finite element analysis were performed to identify the load distribution pattern and contact area of Gecko’s hind. Further investigations were also performed to understand the force in each digit of Gecko’s feet. This research will provide readers with a more holistic understanding and complement previous research on Gecko’s attachment system.

1. Introduction

Gecko is a unique species that existed mostly in tropical regions. This type of reptile has adhesive foot structures that enable it to move and retain position even along vertical surfaces. It is believed that the adhesion ability of Gecko is possible through van der Waals interaction between millions of fibrillar stalk-like-setae on Gecko’s foot and the contact surface [1].

The system that enables Gecko to attach and detach is called hierarchy. Gecko’s attachment ability is followed by the fact that it gains full control of its attachment-detachment motion [2], recognized as smart adhesion. While walking, Gecko continually changed its orientation to adjust desired adhesion strength and detached its foot by a peeling motion (pull-off force at 90°).

Extensive research has been performed to study the unusual adhesive behavior on Gecko’s feet. [1] explored the hierarchy and structural design of Gecko’s setae, including its spatulae. [3] studied the reaction force of vertical climbing geckos and stated that their walking speed does not influence the attachment and detachment times. [4] analyzed the body’s lateral bending susceptible to slope degree changes. More recent research performed by Song et al. [5] provided a more specific concern towards distributed control on Gecko’s feet, enabling better performance on multiple terrains.

This study aims to measure the magnitude and load distribution pattern on Gecko’s feet by observing the movement’s movement and its attachment to the contact surface. The results are obtained through Gecko’s walking cycle and system hierarchy.

2. Experimental Materials and Methods

2.1. Animals
A Tokay Gecko was obtained from Boggy Sanjaya’s Gecko Conservation Facility for this research. The Gecko was 2-years old and weighed 76.9 grams. Its dimension was approximately 290 mm x 35 mm with 121 ml of volume.

2.2. Methodology

The research process began with observations of Gecko’s morphology and behavior. Images and videos obtained during the observation were then utilized as references in modeling the Gecko. The models were eventually analyzed using the Finite Element Method to get the magnitude and load distribution pattern on Gecko’s feet.

2.2.1. Gecko Observation

Gecko was placed inside a transparent aquarium, and a primary camera (facing upward) was positioned below the aquarium. This camera recorded both videos and images to obtain Gecko’s walking pattern and its attachment-detachment cycle. Secondary cameras were also used to capture top-view and side-view photos and videos.

Based on the observation, seven distinct Gecko’s steps were obtained in one walking cycle. The photos of each step were compiled in one picture (Fig. 2(a)) for modeling purposes, and the attachment types of each foot (Fig. 2(c)) were recorded.

The process of Gecko’s feet attachment (approximately 0.1 s) was far quicker compared to the detachment process (approximately 0.46 s). Therefore, four frames of Gecko’s detachment process were captured and compiled next to each other. A mark was given to each of Gecko’s feet to identify its attached surface area.

2.2.2. Gecko Modeling

Blender was used for Gecko’s initial 3D model design. To generate the 3D model, each view was traced according to the image obtained during the observation process. The most appropriate frames in a video for the tracing process were selected through Filmora, a video editing software. The finished model was exported as .objfile type and converted by SpaceClaim to .scdoc extension, so it was readable by ANSYS software. The final model (Fig.1) was validated by comparing the measured Gecko’s volume with the simulation results.

The model shown in Fig.1 was used as the reference to design Gecko’s models for one full cycle (Fig. 2(b)). The surface area of Gecko’s foot was simplified as a rectangle to aid the force reaction calculation. This surface area was varied to differentiate between fully attached Gecko’s limbs and half attached Gecko’s limbs (during attachment period).

As for Gecko’s feet’ modeling, four steps (1 cycle) of Gecko’s foot detachment process were modeled in detail. We assumed that the Gecko’s left-side feet’ geometry were the same as the right.
side, so we observed (Fig. 3 (a)) and modeled only one fore-foot (Fig. 3 (b)) and one hind-foot for each frame.

**Figure. 2** (a) Gecko’s actual full walking cycle, (b) Modelled version of Gecko’s walking cycle, and (c) Attachment types of each Gecko’s feet.

**Figure. 3** (a) Gecko’s actual detachment process and (b) Modelled version of Gecko’s detachment process.
3. Finite Element Analysis
ANSYS R19.1 software is chosen to conduct structural analysis. Gecko’s material properties were imported based on the data researched by Gao et al. [1]. Orthogonal and skewness value of 0.75 and 0.25 respectively was determined to produce optimal meshing quality, resulted in 0.002 m of the mesh size.

In analyzing the walking cycle of Gecko, the following parameters are applied to simulate the actual condition: (1) Gravity to replicate the internal load of Gecko’s body, (2) fixed support on each of Gecko’s foot and bottom part of Gecko’s body and tail. Planes were created on each of Gecko’s feet to analyze the amount of load applied to each of its feet.

The load distribution analysis on Gecko’s foot was performed by highlighting the foot’s attached parts at different time frames to obtain the contact area.

4. Findings and Discussion
The first simulation provided us with information regarding load and moment applied to each step of Gecko’s walking cycle. This information was plotted in Fig 4.

![Figure 4](image)

**Figure. 4** (a) Force and (b) moment applied on Gecko’s limb at each step.

Fig 4(a) showed the load distribution pattern on each Gecko’s step. Dissimilar contact areas resulted in different loads applied on each foot. It can be inferred that in one cycle, the increase of load (during the attachment process) is always followed by the decrease of the load while detaching. Furthermore, the force applied to the hind-limb is noticeably higher than on the fore-limb.
Figure. 5 The contact area of (a) Gecko’s fore-digit and (b) Gecko’s hind-digit over time.

The moment for each limb was later determined by measuring the reaction force and length of each limb. Based on Fig 4(b), the moment applied on the right hind-limb was increasing over steps due to the increment of its length. The parallel relation between moment and hind length applies to other limbs, but the trends are weaker for fore-hinds due to insignificant limb length differences.

Figure. 6 Force applied on (a) Gecko’s fore-digit and (b) Gecko’s hind-digit over time.

Gecko’s digits are labeled from 1 (far-right digit) to 5 in counter-clockwise order. The contact area measurement results of each digit during Gecko’s detachment process were then plotted in Fig. 5. To obtain the force applied on each digit (Fig 6), the area measurement data was converted as a percentage out of the total contact area of the foot, then multiplied by the load applied on each limb ($7.27 \times 10^{-3}$ N for fore-limb and $12.29 \times 10^{-3}$ N for hind limb).

According to Fig. 5, both fore-limbs and hind-limbs’ contact areas decrease over time as they detached. However, contradicting trends are shown in Fig. 6, mainly due to less-even load distribution at the detachment process. The most significant load was applied to digit 2, confirming that digit 2 has the biggest contact area.
Conclusions
In one cycle, the load distribution and the moment on each Gecko’s hind forma reciprocating pattern, with peak points achieved at the fully attached stage and stretched limb, respectively. Analysis performed on Gecko’s feet proved a linear correlation between the surface area and each digit’s force distribution.

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