Electronic Supplementary Material

Contribution of friction and adhesion to the reliable attachment of a gecko to smooth inclines

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(1) Detailed derivation process of Equation 4 in manuscript

When gecko moves on inclines, the toes gradually increase their role in making contact with the substrate, and provide a driving force. Correspondingly, the contact between the foot and the substrate enters a concomitant contact state involving both the heel and the toes (Fig. S1(a), in which the forces acting on all the toes are simplified to equivalent forces acting on a single toe in the planar mechanical model).

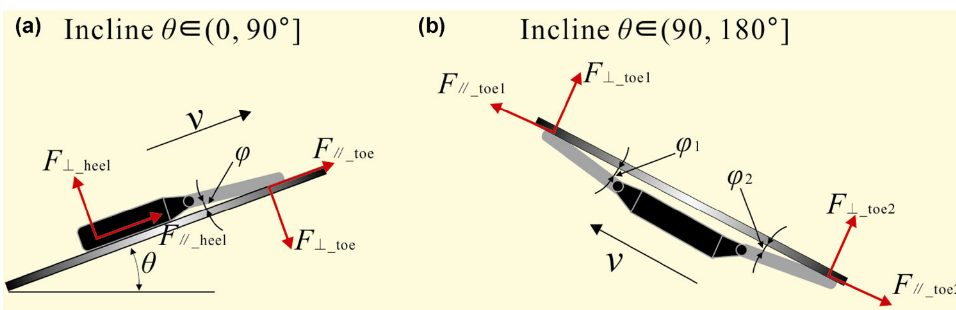

Fig. S1 The planar mechanical model of contact between foot and the inclined substrate. θ: incline of the substrate; v: locomotive direction. (a) A mechanical model of contact when incline does not exceed 90°. The state of contact is a concomitant contact of friction and adhesion. The toe pulls toward the substrate to generate adhesive friction force ($F_{//\_\mathrm{toe}}$) and adhesion force ($F_{\perp\_\mathrm{toe}}$), while the heel pushes away the substrate. φ: angle between the toe and the substrate. (b) A mechanical model of contact when the incline exceeds 90°. More toes adhere to the substrate to generate adhesion and friction forces, whereas the heel does not make contact with the substrate. $F_{\perp\_\mathrm{toe1}}$ and $F_{\perp\_\mathrm{toe2}}$: the adhesion forces acting on toe1 and toe2; $F_{\perp\_\mathrm{heel1}}$ and $F_{\perp\_\mathrm{heel2}}$: the adhesive friction forces acting on toe1 and toe2; φ_1 and φ_2: the angles between the toe1/2 and the substrate.

The α^* value for the foot is determined based on the friction of the heel and the adhesion of the toe (Eq. S1).

$$\alpha^* = \tan^{-1}\left(\frac{\left|\vec{F}_{\|\_\mathrm{heel}} + \vec{F}_{\|\_\mathrm{toe}}\right|}{\left|\vec{F}_{\perp\_\mathrm{heel}} + \vec{F}_{\perp\_\mathrm{toe}}\right|}\right) = \tan^{-1}\left(\frac{\left|\vec{F}_{\|\_\mathrm{heel}}\right| + \left|\vec{F}_{\|\_\mathrm{toe}}\right|}{\left|\vec{F}_{\perp\_\mathrm{heel}}\right| - \left|\vec{F}_{\perp\_\mathrm{toe}}\right|}\right) \tag{S1}$$

Here, assuming that the heel is in the critical state of dry friction, the frictional force ($\vec{F}_{\|\_\mathrm{heel}}$) and the normal

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force ($\vec{F}_{\perp\_\mathrm{heel}}$) can be described by Eq. S2 in accordance to

$$\left|\vec{F}_{\parallel\_\mathrm{heel}}\right| = \mu \bullet \left|\vec{F}_{\perp\_\mathrm{heel}}\right| \tag{S2}$$

Previous studies have demonstrated that a gecko's toe adhesion is direction-dependent, and that the adhesive force is limited by the shear force and the value of α^* of the toe, equal to 25.5° [S1]. If the angle between the toe and the substrate is smaller than the α^* value of the toe, then the adhesion ($\vec{F}_{\perp\_\mathrm{toe}}$) and shear forces ($\vec{F}_{\parallel\_\mathrm{toe}}$) acting on the stretched toe are given by Eq. S3 [S2, S3]. To evaluate the contribution of the friction generated by the heel and the adhesion generated by the toes to achieve a reliable attachment, we define the contribution ratio $r_{\mathrm{p\_t}}$ (Eq. S4).

$$\left|\vec{F}_{\perp\_\mathrm{toe}}\right| = \left|\vec{F}_{\parallel\_\mathrm{toe}}\right| \bullet \tan\varphi \tag{S3}$$

$$r_{\mathrm{h\_t}} = \left|\vec{F}_{\perp\_\mathrm{heel}}\right| \Big/ \left|\vec{F}_{\perp\_\mathrm{toe}}\right| \tag{S4}$$

Thus, Eq. S1 can be simplified as Eq. S5, in accordance to

$$\alpha^* = \tan^{-1}\left(\frac{\mu r_{\mathrm{h\_t}} + 1/\tan\varphi}{r_{\mathrm{h\_t}} - 1}\right) = \tan^{-1}\left(\mu + \frac{\mu + 1/\tan\varphi}{r_{\mathrm{h\_t}} - 1}\right), \quad r_{\mathrm{h\_t}} > 0, r_{\mathrm{h\_t}} \neq 1 \tag{S5}$$

(2) Detailed derivation process of equation 5 in manuscript

The adaptability to an incline of the above concomitant contact state is severely limited by the adhesive capability of the toe and the friction coefficient of the heel. When the incline is larger than 90°, the non-adhesive heel will be pulled away from the substrate by gravity, leaving only the toes attached to the substrate. Geckos can safely remain attached to an inverted surface by stretching their first and fifth toes into a *Y*-configuration, thus avoiding the failure of the adhesion of a single toe [S4, S5]. The forces acting on each toe of the foot are equally deployed to toes 1 and 2 in a planar mechanical model (Fig. S1(b)). The α^* of the foot is determined by the combined adhesion between the toes (Eq. S6). The contribution ratio ($r_{\mathrm{t\_t}}$) is defined to evaluate the contribution of the adhesions generated by different toes to the attachment (Eq. S8).

$$\alpha^* = \tan^{-1}\left(\frac{\left|\vec{F}_{\parallel\_\mathrm{toe1}} + \vec{F}_{\parallel\_\mathrm{toe2}}\right|}{\left|\vec{F}_{\perp\_\mathrm{toe1}} + \vec{F}_{\perp\_\mathrm{toe2}}\right|}\right) = \tan^{-1}\left(\frac{\left|\vec{F}_{\parallel\_\mathrm{toe1}}\right| - \left|\vec{F}_{\parallel\_\mathrm{toe2}}\right|}{\left|\vec{F}_{\perp\_\mathrm{toe1}}\right| + \left|\vec{F}_{\perp\_\mathrm{toe2}}\right|}\right) \tag{S6}$$

$$\left|\vec{F}_{\perp\_\mathrm{toe1}}\right| = \left|\vec{F}_{\parallel\_\mathrm{toe1}}\right| \bullet \tan\varphi_1 , \ \left|\vec{F}_{\perp\_\mathrm{toe2}}\right| = \left|\vec{F}_{\parallel\_\mathrm{toe2}}\right| \bullet \tan\varphi_2 \tag{S7}$$

$$r_{\mathrm{t\_t}} = \left|\vec{F}_{\perp\_\mathrm{toe1}}\right| \Big/ \left|\vec{F}_{\perp\_\mathrm{toe2}}\right| \tag{S8}$$

Thus, Eq.S6 can be simplified as Eq. 9, in accordance to

$$\alpha^* = \tan^{-1}\left(\frac{r_{\mathrm{t\_t}}/\tan\varphi_1 - 1/\tan\varphi_2}{r_{\mathrm{t\_t}} + 1}\right) \tag{S9}$$

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