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Comments on “Sidewinding with Minimal Slip: Snake and Robot Ascent of Sandy Slopes”

LIU Jinguo^{1,2}, GAO Yang², WANG Yuechao¹, MA Shugen^{1,3}, LUO Yifan¹

(1. State Key Laboratory of Robotics, Shenyang Institute of Automation, Chinese Academy of Sciences, Shenyang 110016, China;

2. STAR Lab, Surrey Space Centre, University of Surrey, Guildford GU2 7XH, UK;

3. Department of Robotics, College of Science and Engineering, Ritsumeikan University, Shiga-ken 525-8577, Japan)

Abstract: Marvi *et al* (*Science*, 2014, vol.346, p.224) concluded a sidewinder rattlesnake increases the body contact length with the sand when granular incline angle increases. They also claimed the same principle should work on robotic snake too. We have evidence to prove that this conclusion is only partial in describing the snake body-sand interaction. There should be three phases that fully represent the snake locomotion behaviors during ascent of sandy slopes, namely lifting, descending, and ceasing. The snake body-sand interaction during the descending and ceasing phases helps with the climbing while such interaction during the lifting phase in fact contributes resistance.

Keywords: snake robot; sandy slope; locomotion

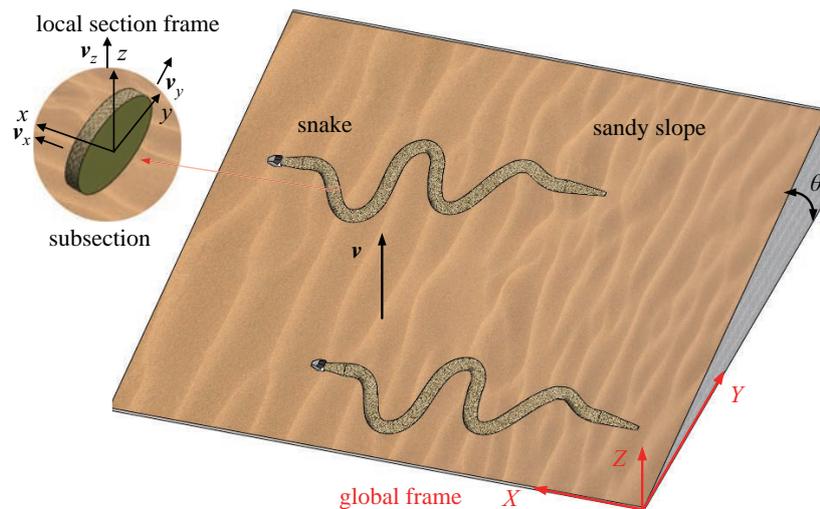
Main context

Snake is known for its versatile locomotion capabilities in a variety of environments such as grassland, desert, rivers, caves, trees and even cliffs. Marvi *et al*^[1] concluded a sidewinder rattlesnake increases the body contact length with the sand when granular incline angle increases. They also claimed the same principle should work on robotic snake too. This conclusion is only partial or incomplete in describing relevant snake locomotion behaviors. Our existing research on snakes and robotic snakes has revealed several locomotion behaviors including the serpentine locomotion^[2], sidewinding locomotion^[3], concertina locomotion^[4], traveling wave locomotion^[5], and rolling locomotion^[6]. It has been shown that the contact force rather than the contact length is the major influence on the snake's locomotion during ascent of sandy slopes. The contact force is determined by the total contact area of the snake with the sand (not just contact length), stress and friction distribution over this area.

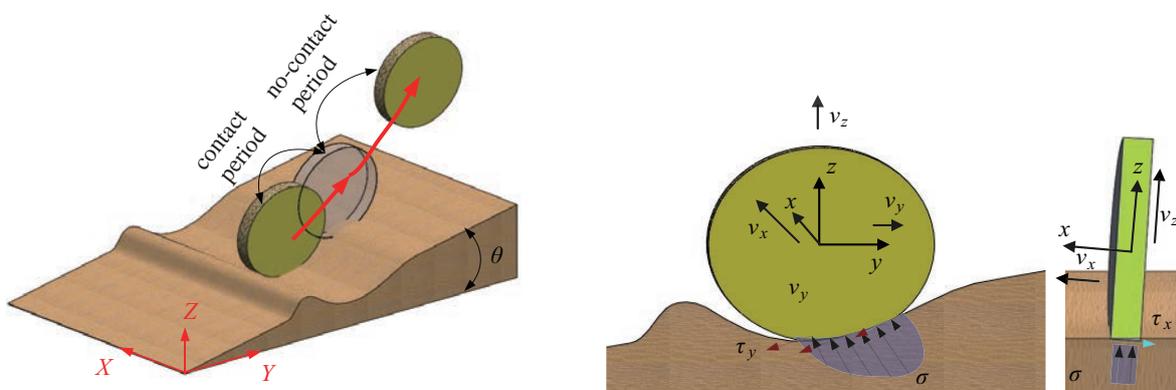
Three phases can be used to fully describe the snake locomotion behaviors during ascent of sandy slopes, namely lifting, descending, and ceasing. As shown in Fig.1, the snake body is seen as numerous sub-sections, each of which can be used to demonstrate a relevant terramechanics model similar to the robotic wheel-soil interaction^[7-8]. The contact force varies in

these three phases. In the beginning of the lifting phase, there is a contact period between the snake and the sand. Fig.1(b) shows frictional resistances τ_x and τ_y on each of the snake subsections during this contact period. The integral body of the snake overcomes the gravity and friction. The friction disappears in the no-contact period when the snake sub-section is off the slope. The descending phase moves from no-contact to contact periods as shown in Fig.1(c). In this contact period, the snake sub-section disturbs the original state of sand and slip is envisaged to occur. The stress σ , lateral friction τ_x and τ_y induced by the sand all work against the descending motion. And in return the sub-section gets a compressive force for lifting other sections. During the ceasing phase shown in Fig.1(d), the snake has little movement in the sand though the sand's contact forces still exist for lifting other sections. In summary, the above qualitative analysis shows that snake-sand contact during the descending and ceasing phases helps the snake to climb, while on the other hand the contact during the lifting phase induces resistance.

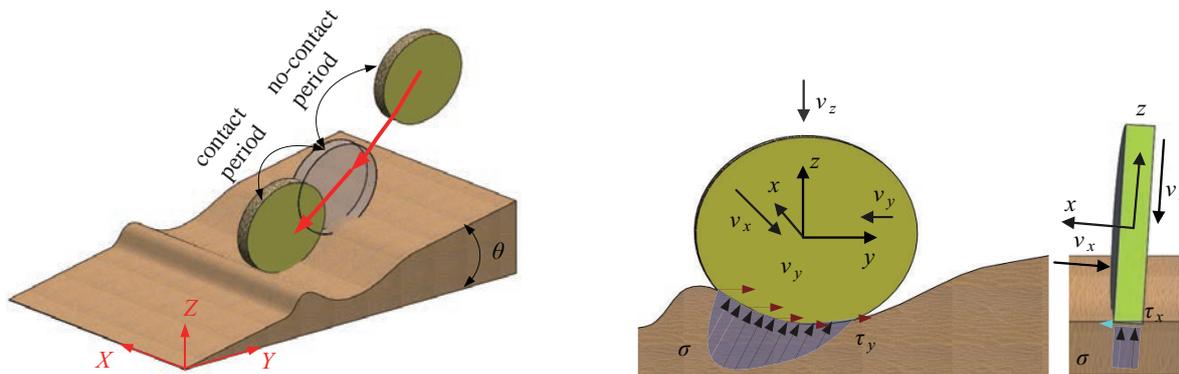
The existing studies have made use of the synergies between the simplified model for snake body-sand interaction and the typical terramechanics model developed for the rover wheel-soil or leg-soil interaction to perform detailed analysis on the contact forces^[7-9]. Work in literature [10] suggested soft artificial skin to perform direct quantitative measurement of contact forces.



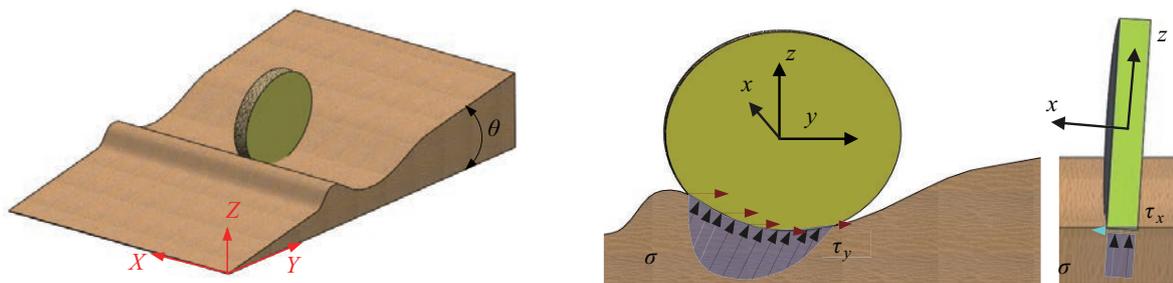
(a) Snake moving on a sandy slope; a sub-section of the snake body is used to demonstrate a relevant terramechanics model



(b) Lifting phase: snake body sub-section interacting with the sandy slope



(c) Descending phase: snake body sub-section interacting with the sandy slope



(d) Ceasing phase (ready for the next lifting phase): snake body sub-section interacting with the sandy slope

Fig.1 Contact interaction analysis on the snake climbing sandy slope

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About Authors:

LIU Jinguo (1978 –), male, Ph.D., Professor. His research interests include modular robot, rescue robot, space robot, and bio-inspired robot.