Modulation of orthogonal body waves enables versatile maneuverability in limbless locomotion

DANIEL GOLDMAN, Georgia Tech, A COLLABORATION

— Limbless organisms can create different motions by modulating axial undulations that pass through their bodies. Sidewinding snakes generate horizontal and vertical waves, with a phase offset of $\pi/2$, resulting in posteriorly-propagating alternating regions of static contact with the substrate and elevated motion, resulting in a “stepping” motion of body segments. We have discovered that sidewinder rattlesnakes (Crotalus cerastes) are quite maneuverable and possess at least two turning methods: “differential turning” and “reversal turning.” In differential turning, the amplitude of the horizontal wave changes along the body length, resulting in turns of average $25.6 \pm 12.9^\circ$, maximum $86.1^\circ$ per cycle. In reversal turning, the vertical wave’s phase rapidly changes by $\pi$, resulting in a sudden, large change in movement direction (average $77.8 \pm 27.4^\circ$, maximum $160.5^\circ$ per cycle) without body rotation. We applied these control mechanisms to a 16-link snake robot capable of sidewinding on sand. By modulation of horizontal wave amplitude gradient along the body, we replicated differential turning, and by producing a $\pi$ phase shift in the vertical wave, we replicated a reversal turn. More complex wave modulations lead to enhanced robot maneuverability.

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Daniel Goldman
Georgia Tech