BIOGRAPHICAL SKETCH

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NAME: Li, Chen

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POSITION TITLE: Associate Professor

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE (if applicable)	END DATE MM/YYYY	FIELD OF STUDY
Peking University, Beijing, China	BS	06/2005	Physics
Georgia Institute of Technology, Atlanta, Georgia	PHD	12/2011	Physics
Georgia Institute of Technology, Atlanta, Georgia	Postdoctoral Fellow	05/2012	Physics
University of California, Berkeley, Berkeley, California	Postdoctoral Fellow	12/2015	Integrative Biology & Robotics

A. Personal Statement

My interdisciplinary scientific journey started 20 years ago, when I first learned to do materials physics research as a senior first-generation college student. After that, being always fascinated with animals, I chose to do a PhD on the physics of animal and robot locomotion on sand (Section C1). I learned how to use a physicist's approach—experimentally varying system parameters and seeking general principles and predictive models—to study problems that are not "mainstream physics". I learned that to tackle such challenging problems, I **must be brave to create my own tools and models** (and share them) because they are often not available (Section C5). By collaborating with biologists and roboticists to use animals and robots they provide, I learned not only how I can help them but also what I should learn from them. And I developed **a strong passion to help advance understanding of biological locomotion and advance robotic mobility in the real world**. This led me to do my postdoc with a biologist and a roboticist, where I chose to study legged locomotion in complex 3-D terrain, another new area that lacks tools and models. Besides working on my main project, I mentored 20+ undergraduates in biology and robotics to try out new ideas. This greatly helped me establish and mentor a large team of students when I started my lab at JHU. I expanded my lab's research into three major directions, legged and limbless locomotion in complex 3-D terrains (Sections C2, C3) and ground self-righting (Section C4). My lab's studies have **significantly expanded our understanding of terrestrial locomotion from largely 2-D to 3-D, and from largely on relatively flat surfaces to complex terrains**. Through the years, I have developed a **deep appreciation of how to integrate approaches across biology, robotics, and physics**. My lab is one of very few studying animal and robot locomotion that integrate all three disciplines (many labs do one, some integrate two, but very few all three). I continue to **expand my horizons to new problems in complex terrains**. I have an NSF grant to use robotic physical modeling to understand how web spiders use active leg behaviors to enhance vibration sensing to detect prey on their webs. I will lead an interdisciplinary team via a new HFSP grant to study how jumping spiders visually plan detours in cluttered forest terrains to stalk dangerous or elusive prey. I am also collaborating with experts to study vine robots growing into extremely dense rubble for search and rescue, as well as cell-like robots moving through dense elastic fibers like cells migrating through human tissue to help improve disease prevention and treatment.

<u>Commitment to Training and Mentoring:</u> I am committed to supporting the career of my lab members. Over near 9 years at JHU, I have mentored 120 trainees from diverse backgrounds in discipline and culture. These include 1 postdoc, 10 PhD, 37 master, 65 undergraduate, and 7 high school students, with 25% under-represented minorities (significantly higher than averages in Mechanical Engineering departments). Among my mentees, 10% have won competitive research awards and honors, 50% earned authorships on peer-reviewed papers and abstracts, 50% went on to top graduate and undergraduate programs, 20% went to leading companies in industry. 4 out of my 5 graduated PhD students started a postdoc in pursuit of an academic career, with the 5th to a top robotics company. My postdoc mentee became a permanent staff scientist at Army Research Laboratory.

Ongoing Research Support
NSF Physics of Living Systems (PHY-2310707), 8/23-7/26, PI, 1 mo., $391k
How orb-weaver spiders use leg posture to modulate vibration sensing of prey on webs
NSF Cyberinfrastructure for Sustained Sci. Innovation (CSSI-2209795), 7/22-6/25, co-PI, 0.5 mo., $100k
Frameworks: Simulating Autonomous Agents and the Human-Autonomous Agent Interaction
Burroughs Wellcome Fund, Career Award at the Scientific Interface, 7/15-12/24, PI, 1.5 mo., $500k
The terradynamics of biological movement in complex terrain. Note: This is a postdoc-faculty transition award

Completed Research Support
Arnold & Mabel Beckman Foundation, Beckman Young Investigator, 9/18-12/22, PI, 2 mo., $600k
Neuromechanics of legged locomotion on energy landscapes of complex terrains

Related Publications (1-3 are review papers synthesizing several of my works on a topic)

1. **Li C ***. Recent Progress in the Physical Principles of Dynamic Ground Self-Righting. ***Integrative and Comparative Biology***. 2024 July 26; icae124. Available from: https://academic.oup.com/icb/advance-article/doi/10.1093/icb/icae124/7721605 DOI: 10.1093/icb/icae124
2. Othayoth R, Xuan Q, Wang Y, **Li C ***. Locomotor transitions in the potential energy landscape-dominated regime. ***Proceedings of the Royal Society B: Biological Sciences***. 2021 April 21; 288(1949):20202734. Available from: https://royalsocietypublishing.org/doi/10.1098/rspb.2020.2734 DOI: 10.1098/rspb.2020.2734
3. Fu Q, Gart S, Mitchel T, Kim J, Chirikjian G, **Li C ***. Lateral Oscillation and Body Compliance Help Snakes and Snake Robots Stably Traverse Large, Smooth Obstacles. ***Integrative and Comparative Biology***. 2020 July; 60(1):171-179. Available from: https://academic.oup.com/icb/article/60/1/171/5811762 DOI: 10.1093/icb/icaa013
4. **Li C**, Zhang T, Goldman D. A Terradynamics of Legged Locomotion on Granular Media. ***Science***. 2013 March 22; 339(6126):1408-1412. Available from: https://www.science.org/doi/10.1126/science.1229163 DOI: 10.1126/science.1229163

B. Positions, Scientific Appointments and Honors

Positions and Scientific Appointments

2024 -	Associate Professor, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD
2024 -	Secondary Appointment, Center for Functional Anatomy & Evolution, Johns Hopkins University, Baltimore, MD
2016 -	Core Faculty Member, Laboratory for Computational Sensing & Robotics, Johns Hopkins University, Baltimore, MD
2016 - 2023	Assistant Professor, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD

Honors

2024 - 2018	Best Student Paper Finalists (6 student selected across 2024, 2023, 2019, 2018), Society for Integrative & Comparative Biology Annual Meeting, Division of Comparative Biomechanics
2022	Outstanding Locomotion Paper Finalist, IEEE International Conference on Robotics and Automation
2022	Editor’s Choice Paper, Advanced Intelligent Systems
2021	Space@Hopkins Award, Johns Hopkins University
2021	Trusted Reviewer, for exceptionally high peer review competency and ability to constructively critique scientific literature to an exceptional standard, Institute of Physics
2019	Catalyst Award, Johns Hopkins University
2019	Kavli Frontiers of Science Fellow, National Academy of Sciences
2018	Beckman Young Investigator Award, Arnold and Mabel Beckman Foundation
2018	Best Paper, Advanced Robotics
2017	Young Investigator Award, Army Research Office
2016	Highlight Paper, IEEE/RSJ International Conference on Intelligent Robots and Systems

2016	Highlight Paper, selected for outstanding new research, receipt of the highest praise from referees, and the largest number of downloads last year, Bioinspiration & Biomimetics
2015	Career Award at the Scientific Interface, Burroughs Wellcome Fund
2012	Miller Research Fellowship, Miller Institute for Basic Research in Science, University of California, Berkeley
2012	Best Student Paper, Robotics: Science and Systems Conference
2012	Sigma Xi Best PhD Thesis Award, Georgia Institute of Technology
2009	Best Student Paper, Society for Integrative & Comparative Biology Annual Meeting, Division of Comparative Biomechanics
2009	Gil Amelio Fellowship for Excellence in Research, Georgia Institute of Technology, School of Physics
2009	First Place Oral Presentation, Georgia Institute of Technology, Graduate Research Symposium
2004	Award for Academic Excellence, Peking University

C. Contribution to Science

1. **Established the first terradynamics of legged locomotion on flowable ground.** The fields of aero- and hydrodynamics of fluid-structure interactions have advanced our understanding of biological locomotion in air and water, and advanced aerial and aquatic vehicles and robots. The field of terramechanics of wheel/track interaction with flowable substrates (sand, soil, snow) has advanced off-road vehicle mobility. But our understanding of terrestrial legged locomotion is relatively limited to that on solid ground. As a PhD student, I led the first systematic studies of legged locomotion on sand, a flowable substrate, by **integrating biological experiments, robotic physical modeling, and physics experiments/modeling**. I discovered how an animal (lizard)/robot's leg morphology, muscle function, kinematics, and substrate's yield strength together affect solid–fluid transition and locomotor performance. I created a granular resistive force theory to accurately predict lift and drag forces and thus locomotion dynamics and performance. Overall, my work **established the first "terradynamics" of leg-ground interaction on flowable ground**.
   a. **Li C**, Zhang T, Goldman D. A Terradynamics of Legged Locomotion on Granular Media. ***Science***. 2013 March 22; 339(6126):1408-1412. Available from: https://www.science.org/doi/10.1126/science.1229163 DOI: 10.1126/science.1229163
   b. **Li C**, Hsieh S, Goldman D. Multi-functional foot use during running in the zebra-tailed lizard (*Callisaurus draconoides*). ***Journal of Experimental Biolog****y*. 2012 January 01; 215(18):3293-3308. Available from: https://journals.biologists.com/jeb/article/doi/10.1242/jeb.061937/257284/Multi-functional-foot-use-during-running-in-the DOI: 10.1242/jeb.061937
   c. **Li C**, Umbanhowar P, Komsuoglu H, Goldman D. The Effect of Limb Kinematics on the Speed of a Legged Robot on Granular Media. ***Experimental Mechanics***. 2010; 50(9):1383-1393. Available from: http://link.springer.com/10.1007/s11340-010-9347-1 DOI: 10.1007/s11340-010-9347-1
   d. **Li C**, Umbanhowar P, Komsuoglu H, Koditschek D, Goldman D. Sensitive dependence of the motion of a legged robot on granular media. ***Proceedings of the National Academy of Sciences***. 2009 March 03; 106(9):3029-3034. Available from: https://pnas.org/doi/full/10.1073/pnas.0809095106 DOI: 10.1073/pnas.0809095106

2. **Pioneered studies of legged locomotion in complex 3-D terrains.** Research on leg-ground interaction dynamics has advanced our understanding of how legged animals walk and run on relatively flat, near 2-D surfaces by stabilizing the body upright. This enabled legged robots to walk and run upright stably on such simplified ground. But we know little about legged animal locomotion in complex 3-D terrains with cluttered large obstacles (e.g., forest floor vegetation, mountains rocks), and legged robots still struggle to in such terrains (e.g., earthquake rubble, lunar/Martian rocks) for search and rescue or planetary exploration. I pioneered studies of legged animals (cockroaches) and robots in complex 3-D terrains with a diversity of large obstacles, by **integrating biological experiments, robotic physical modeling, and a new potential energy landscape modeling approach** that I created. I discovered that cockroaches can traverse with high locomotor performance, by transitioning across diverse locomotor modes, with large 3-D body motions and body/appendage adjustments well beyond upright walking. I discovered how an animal/robot can use diverse strategies to modulate its physical interaction with obstacles to **de-stabilize** itself, either to facilitate transitions to desirable modes that lead to traversal, or to suppress transitions to undesirable modes that lead to failure. I created a legged robot that integrates these strategies to make

locomotor transitions to traverse diverse obstacles with high performance. Overall, my work **expanded legged locomotion, from largely single-mode upright walking/running on near 2-D flat surfaces, to multi-modal locomotor transitions with 3-D motions in realistic 3-D terrains**.

a. Xuan Q, **Li C ***. Environmental force sensing helps robots traverse cluttered large obstacles. ***Bioinspiration & Biomimetics***. 2023 November 17; 19(1):016002-. Available from: https://iopscience.iop.org/article/10.1088/1748-3190/ad0aa7 DOI: 10.1088/1748-3190/ad0aa7
b. Wang Y, Othayoth R, **Li C ***. Cockroaches adjust body and appendages to traverse cluttered large obstacles. ***Journal of Experimental Biology***. 2022 May 15; 225(10):jeb243605. Available from: https://journals.biologists.com/jeb/article/225/10/jeb243605/275496/Cockroaches-adjust-body-and-appendages-to-traverse DOI: 10.1242/jeb.243605
c. Han Y, Othayoth R, Wang Y, Hsu C, de la Tijera Obert R, Francois E, **Li C ***. Shape-induced obstacle attraction and repulsion during dynamic locomotion. ***The International Journal of Robotics Research***. 2021 March 15; 40(6-7):939-955. Available from: http://journals.sagepub.com/doi/10.1177/0278364921989372 DOI: 10.1177/0278364921989372
d. Othayoth R, Thoms G, **Li C ***. An energy landscape approach to locomotor transitions in complex 3D terrain. ***Proceedings of the National Academy of Sciences***. 2020 June 15; 117(26):14987-14995. Available from: https://pnas.org/doi/full/10.1073/pnas.1918297117 DOI: 10.1073/pnas.1918297117

3. **Pioneered studies of limbless locomotion in complex 3-D terrains.** Limbless animals like snakes can adaptively use its long body to traverse almost any terrain. Similarly, snake robots hold the promise as a versatile platform for various applications. Biological studies largely focused on how snakes move on near 2-D surfaces, where they mainly use lateral body bending for propulsion and can easily maintain stability. But we know little about limbless locomotion in complex 3-D terrains that are highly uneven, which requires large vertical body bending and makes it hard to move stably. Thus, snake robots still struggle to traverse complex 3-D terrains with animal-like performance. I pioneered systematic studies of snake and snake locomotion in complex 3-D terrains, by **integrating biological experiments, robotic physical modeling, and physics experiments and simulations**. I discovered that snakes continuously control the long body to transition between lateral and vertical bending, and their passive body compliance helps maintain stability when they lift part of the body off ground. I created a snake robot that combine these strategies to traverse similar terrain faster than previous snake robots. I also discovered that snakes can bend their body vertically to push against terrain unevenness to generate propulsion. I created snake robots that can use this strategy to move in uneven terrain, by sensing terrain contact forces to guide its vertical pushing. Overall, my work **expanded terrestrial limbless locomotion, from largely using near 2-D body bending on near 2-D flat surfaces, to using 3-D body bending in realistic 3-D terrains**.
   a. Fu Q, **Li C ***. Contact feedback helps snake robots propel against uneven terrain using vertical bending. ***Bioinspiration & Biomimetics***. 2023 August 01; 18(5):056002-. Available from: https://iopscience.iop.org/article/10.1088/1748-3190/ace672 DOI: 10.1088/1748-3190/ace672
   b. Fu Q, Astley H, **Li C ***. Snakes combine vertical and lateral bending to traverse uneven terrain. ***Bioinspiration & Biomimetics***. 2022 April 20; 17(3):036009-. Available from: https://iopscience.iop.org/article/10.1088/1748-3190/ac59c5 DOI: 10.1088/1748-3190/ac59c5
   c. Fu Q, **Li C ***. Robotic modelling of snake traversing large, smooth obstacles reveals stability benefits of body compliance. ***Royal Society Open Science***. 2020 February 19; 7(2):191192-. Available from: https://royalsocietypublishing.org/doi/10.1098/rsos.191192 DOI: 10.1098/rsos.191192
   d. Gart S, Mitchel T, **Li C ***. Snakes partition their body to traverse large steps stably. ***Journal of Experimental Biology.*** 2019 January 01; 222(8):jeb185991. Available from: https://journals.biologists.com/jeb/article/doi/10.1242/jeb.185991/259452/Snakes-partition-their-body-to-traverse-large DOI: 10.1242/jeb.185991

4. **Pioneered physical principles of ground self-righting in 3D.** When interacting with large obstacles, a legged animal/robot can flip over and must right itself. Previous biological studies described behavior and quantifying neural and motor control and robotic studies developed mechanisms for self-righting. Despite simple models of ground self-righting in 2D, we still lack physical principles to understand how self-righting occurs in 3D via self-propelled interaction with the ground. I pioneered systematic studies of ground self-righting in 3D, by **integrating biological experiments, robotic physical modeling, and physics models and simulations**. I quantified 3-D motions and behavioral transitions of animals (cockroaches) and robots and developed a new potential energy landscape approach, dynamic simulations, and analytical models to understand how self-propelled motions interacting with the ground allows an animal/robot to accumulate

energy to overcome potential energy barriers to self-right. I discovered that an animal/robot often uses some appendages to push against the ground and others to perturb itself, and the coordination in these motions are crucial for self-righting. I discovered that inherent randomness in these motions can increase the chance of self-righting, by finding good appendage coordination to accumulate more energy to overcome barriers. Overall, my work **expanded ground self-righting from 2D to 3D and established its physical principles**.

a. Othayoth R, **Li C ***. Propelling and perturbing appendages together facilitate strenuous ground self-righting. ***eLife***. 2021 July 07; 10:e60233. Available from: https://elifesciences.org/articles/60233 DOI: 10.7554/eLife.60233
b. Xuan Q, **Li C ***. Randomness in appendage coordination facilitates strenuous ground self-righting. ***Bioinspiration & Biomimetics***. 2020 October 09; 15(6):065004-. Available from: https://iopscience.iop.org/article/10.1088/1748-3190/abac47 DOI: 10.1088/1748-3190/abac47
c. Xuan Q, **Li C ***. Coordinated Appendages Accumulate More Energy to Self-Right on the Ground. ***IEEE Robotics and Automation Letters***. 2020 October; 5(4):6137-6144. Available from: https://ieeexplore.ieee.org/document/9146711/ DOI: 10.1109/LRA.2020.3011389
d. **Li C ***, Wöhrl T, Lam H, Full R. Cockroaches use diverse strategies to self-right on the ground. ***Journal of Experimental Biology.*** 2019 August 01; 222(15):jeb186080. Available from: https://journals.biologists.com/jeb/article/222/15/jeb186080/223383/Cockroaches-use-diverse-strategies-to-self-right DOI: 10.1242/jeb.186080

5. **Created and shared tools and models for biological and robotic locomotion in complex terrains.** A major challenge that hindered research efforts across communities of biological and robotic locomotion is the relative lack of experimental tools and models for studying and understanding motion in 3D and in complex terrains, compared to the well-established tools and models for studying locomotion in 2D, on solid surfaces, or in fluids. Driven by my passion to help advance understanding of biological locomotion and advance robotic mobility in the real world, **I created and shared many tools and models**: From Contribution 1: An apparatus to control and vary sand compaction/strength. A granular resistive force theory for predicting lift and drag forces. From Contribution 2: Automatic tracking and 3-D motion reconstruction techniques to solve the problems from large 3-D ranges of motion and occlusions by cluttered obstacles. Two robots' designs, mechanical designs, control algorithms, and sensor integration and data acquisition. Methods to apply potential energy landscape approach to model locomotor transitions for diverse large obstacles. A "terrain treadmill" to enable long spatiotemporal measurements (~1000 cycles and body lengths) of small animals traversing cluttered large obstacles at high spatial resolution. From Contribution 3: Two snake robots' mechanical designs, control algorithms, and sensor integration and data acquisition for studying limbless locomotion in complex 3-D terrains. Anew mathematical method for quantifying 3-D shape of snakes more accurately than previous 2D-based methods. From Contribution 4: Robot design and simulation and analytical models for studying ground self-righting. Overall, they are **catalyzing the fields to shift towards locomotion in 3D and in more realistic terrains**.

a. Othayoth R, Strebel B, Han Y, Francois E, **Li C ***. A terrain treadmill to study animal locomotion through large obstacles. ***Journal of Experimental Biology***. 2022 July 01; 225(13):jeb243558. Available from: https://journals.biologists.com/jeb/article/225/13/jeb243558/275973/A-terrain-treadmill-to-study-animal-locomotion DOI: 10.1242/jeb.243558
b. Ramesh D, Fu Q, **Li C ***. SenSnake: A snake robot with contact force sensing for studying locomotion in complex 3-D terrain. ***IEEE International Conference on Robotics and Automation***; 2022 July 12; 2068-2075. Available from: https://ieeexplore.ieee.org/document/9812159 DOI: 10.1109/ICRA46639.2022.9812159
c. Othayoth R, Xuan Q, Wang Y, **Li C ***. Locomotor transitions in the potential energy landscape-dominated regime. ***Proceedings of the Royal Society B: Biological Sciences***. 2021 April 21; 288(1949):20202734. Available from: https://royalsocietypublishing.org/doi/10.1098/rspb.2020.2734 DOI: 10.1098/rspb.2020.2734
d. Fu Q, Mitchel TW, Kim JS, Chirikjian GS, **Li C ***. Continuous body 3-D reconstruction of limbless animals. ***Journal of Experimental Biology***. 2021 Mar 12; 224(6): jeb220731. Available from: https://journals.biologists.com/jeb/article/224/6/jeb220731/237931 DOI: 10.1242/jeb.220731

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