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Education

Jun 2015 University of California, Irvine, Irvine, CA, Ph.D. in Mechanical Engineering,
Jun 2013 University of California, Irvine, Irvine, CA, Masters of Science in Mechanical Engineering
May 2010 University of Dayton, Dayton, OH, Bachelors of Science in Mechanical Engineering

Professional Experience

2015–Present Postdoctoral Researcher, *University of California, Berkeley*

- Conducting research on robotic legged locomotion in the Biomimetic Millisystems Lab directed by Prof. Ronald Fearing
- Published 4 journal publications and 4 refereed conference publications
- Research appeared in the inaugural issue of *Science Robotics*, as the jump mechanics of a new robot, Salto, which has led to multiple new research directions in the Biomimetic Millisystems Lab

2015–Present Consultant, *Plecnik Kinematics, LLC*

- Personal consulting business focused on spatial robot kinematics

2010–2015 Research Assistant, *University of California, Irvine*

- Conducted research in the computational kinematic design of mechanical systems
- Published 5 journal publications, 8 refereed conference publications, and 1 US patent
- Mentored 30 undergraduate and 4 masters students throughout 6 design projects that I initiated
- Served as an advisor for a 60+ racecar engineering senior project group for 5 years

2007–2008 Engineering Co-op, Ethicon Endo-Surgery, A Johnson & Johnson Co.

Awards

- 2016 National Science Foundation *Computational Design of Robot Locomotion Through Large-Scale Root-Finding*, P.I.: Ronald Fearing, Co-author: Mark Plecnik, Award No.: 1636302, $300,000
- 2015 National Science Foundation *EAGER Grant: Computational Kinematic Synthesis for Designing Millirobotic Systems*, P.I.: Ronald Fearing, Co-author: Mark Plecnik, Award No.:1549667, $144,788
- 2015 A. T. Yang Memorial Award for the Best Paper in Theoretical Kinematics received at the ASME International Design Engineering Technical Conferences.
- 2014 XSEDE Startup Allocation for the Gordon High Performance Cluster
- 2010 Research Fellowship at University of California, Irvine

Journal Publications

1. M. Plecnik and R. S. Fearing, 2017. “Finding Only Finite Roots to Large Kinematic Synthesis Systems,” *Journal of Mechanisms and Robotics*, 9(2): 021005. (link)
2. D. W. Haldane, M. Plecnik, J. K. Yim, and R. S. Fearing, 2016. “Robotic Vertical Jumping Agility via Series-Elastic Power Modulation,” *Science Robotics*, 1(1): eaag2048. (link)
3. M. Plecnik, D. W. Haldane, J. K. Yim, and R. S. Fearing, 2017. “Design Exploration and Kinematic Tuning of a Power Modulating Jumping Monopod,” *Journal of Mechanisms and Robotics*, 9(1): 011009. (link)
4. B. Tsuge, M. Plecnik, and J. M. McCarthy, 2016. “Homotopy Directed Optimization to Design a Six-Bar Linkage for a Lower Limb With a Natural Ankle Trajectory,” *Journal of Mechanisms and Robotics*, 8(6): 061009. (link)
5. M. Plecnik and J. Michael McCarthy, 2015. “Kinematic Synthesis of Stephenson III Six-bar Function Generators,” *Mechanism and Machine Theory*, 97:112-126. (link)
6. M. Plecnik and J. Michael McCarthy, 2015. “Controlling the Movement of a TRR Spatial Chain with Coupled Six-bar Function Generators for Biomimetic Motion," *Journal of Mechanisms and Robotics*, 8(5): 051005. (link)
7. M. Plecnik and J. Michael McCarthy, 2015. “Design of Stephenson Linkages that Guide a Point Along a Specified Trajectory,” *Mechanism and Machine Theory*, 96(1): 38-51. (link)

8. M. Plecnik and J. Michael McCarthy, 2015. "Computational Design of Stephenson II Six-bar Function Generators for 11 Accuracy Points," *Journal of Mechanisms and Robotics*, JMR-15-1055, 8(1): 011017. (link)
9. M. Plecnik and J. M. McCarthy, 2014. "Numerical Synthesis of Six-bar Linkages for Mechanical Computation," *Journal of Mechanisms and Robotics*, JMR-13-1145, 6(3): 031012. (link)

Refereed Conference Publications

1. J. Lee, M. Plecnik, J. Yang, and R. S. Fearing, 2018. "Self-Engaging Spined Gripper with Dynamic Penetration and Release for Steep Jumps," *IEEE 2018 International Conference on Robotics and Automation*, May 21-25, 2018, Brisbane, Australia. (submitted for publication)
2. M. Plecnik, S. Naik, R. Van Domelen, R. Ruopp, and R. J. Full, 2018. "Role of Geometric Constraints on Reachable Workspace of Insect Limbs," *Society for Integrative & Comparative Biology Annual Meeting 2018*, No. 246-414868, January 3-7, 2018, San Francisco, California, USA. (submitted for publication)
3. M. Plecnik and R. S. Fearing, 2017. "A Study on Finding Finite Roots for Kinematic Synthesis," *Proceedings of the ASME 2017 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Paper No. IDETC2017-68341, August 6-9, 2017, Cleveland, Ohio, USA. (link)
4. D. W. Haldane, M. Plecnik, J. K. Yim, and R. S. Fearing, 2016. "A Power Modulating Leg Mechanism for Monopedal Hopping," *Proceedings of the IEEE/RSJ 2016 International Conference on Intelligent Robots and Systems*, October 9-14, 2016, Daejeon, South Korea. (link)
5. M. Plecnik and R. S. Fearing, 2016. "Finding Only Finite Roots to Large Kinematic Synthesis Systems," *Proceedings of the ASME 2016 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Paper No. IDETC2016-60428, August 21-24, 2016, Charlotte, North Carolina, USA. (link)
6. L. Wang, M. Plecnik, and R. S. Fearing, 2016. "Robotic Folding of 2D and 3D Structures from a Ribbon," *Proceedings of the IEEE 2016 International Conference on Robotics and Automation*, May 16-21, 2016, Stockholm, Sweden. (link)
7. M. Plecnik and J. Michael McCarthy, 2015. "Synthesis of an Inverted Stephenson Linkage to Guide a Point Path," *14th World Congress in Mechanism and Machine Science*, Taipei, Taiwan, October 25-30, 2015. (link)
8. M. Plecnik and J. M. McCarthy, 2015. "Controlling the Movement of a TRR Spatial Chain with Coupled Six-bar Function Generators for Biomimetic Motion," *Proceedings of the ASME 2015 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Paper No. DETC2014-47876, August 2-5, 2015, Boston, Massachusetts, USA. (**Recipient of Best Paper in Theoretical Kinematics**) (link)
9. M. Plecnik and J. M. McCarthy, 2014. "Vehicle Suspension Design Based on a Six-bar Linkage," *Proceedings of the ASME 2014 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Paper No. DETC2014-35374, August 17-20, 2014, Buffalo, New York, USA. (link)
10. M. Plecnik, J. M. McCarthy, and C. W. Wampler, 2014. "Kinematic Synthesis of a Watt I Six-bar Linkage for Body Guidance," *Advances in Robot Kinematics*, Springer International Publishing, pp. 317-325. (link)
11. M. Plecnik and J. M. McCarthy, 2013. "Synthesis of a Stephenson II Function Generator for Eight Precision Positions," *Proceedings of the ASME 2013 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Paper No. DETC2013-12763, August 4-7, 2013, Portland, Oregon, USA. (link)
12. M. Plecnik and J. M. McCarthy, 2013. "Dimensional Synthesis of Six-bar Linkage as a Constrained RPR Chain," *New Trends in Mechanism and Machine Science*, Springer Netherlands, pp. 273-280. (link)
13. M. Plecnik and J. M. McCarthy, 2012. "Design of a 5-SS Spatial Steering Linkage," *Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Paper No. DETC2012-71405, August 12-15, 2012, Chicago, Illinois, USA. (link)
14. M. Plecnik and J. M. McCarthy, 2011. "Five Position Synthesis of a Slider-crank Function Generator," *Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Paper No. DETC2011-47581, August 28-31, 2011, Washington, D.C., USA. (link)

Media Spotlights

1. "World Science Journalists Explore Berkeley's Best" Berkeley News (link)

2. "Leapin' Robots" ASME.org (link)
3. "Galago-Inspired Robot Sets Leaping Record" AAAS.org (link)
4. "Jumping Robots Mimic Adorable Big-Eyed Primates" LiveScience.com (link)

Patents

1. M. Plecnik, D. Bissell, D. J. Reinkensmeyer, and J. M. McCarthy. Torque-Compensating Assistive Wrist Braces. US 20170079825 A1. 2017.
2. M. Plecnik, D. W. Haldane, J. K. Yim, and R. S. Fearing. Series-Elastic Power Modulation for Robotic Locomotion. 2017. (pending examination)

Invited Lectures and Presentations

1. "A Study on Finding Finite Roots for Kinematic Synthesis." *Session MR-2-1 Robotic Systems, 41st Mechanisms and Robotics Conference, ASME IDETC*, August 8, 2017, Cleveland, Ohio, USA.
2. "Finding Only Finite Roots." *Session MR-5-3 Synthesis, 40th Mechanisms and Robotics Conference, ASME IDETC*, August 24, 2016, Charlotte, North Carolina, USA.
3. "Kinematic Synthesis of Linkages." Two invited lectures for CS 194-028 Computational Design and Fabrication, University of California, Berkeley, October 6 and 8, 2015, Berkeley, California, USA.
4. "Coupled Six-bar Function Generators for Biomimetic Motion." *Session MR-2-3 Dimensional Synthesis and Novel Applications, 39th Mechanisms and Robotics Conference, ASME IDETC*, August 3, 2015, Boston, Massachusetts, USA.
5. "Vehicle Suspension Design Based on a Six-bar Linkage." *Session MR-1-6 Mechanism Design and Applications, 38th Mechanisms and Robotics Conference, ASME IDETC*, August 20, 2014, Buffalo, New York, USA.
6. "Kinematic Synthesis of a Watt I Six-bar Linkage for Body Guidance." *Technical Session 9, Advances in Robot Kinematics, 14th International Symposium*, July 2, 2014, Ljubljana, Slovenia.
7. "Synthesis of a Stephenson II Function Generator for Eight Precision Positions." *Session MR-1-5 Singularity Analysis and Application, 37th Mechanisms and Robotics Conference, ASME IDETC*, August 7, 2013, Portland, Oregon, USA.
8. "Design of a 5-SS Spatial Steering Linkage." *Session MR-1-8 Mechanism Synthesis - Methods, 36th Mechanisms and Robotics Conference, ASME IDETC*, August 15, 2012, Chicago, Illinois, USA.
9. "Dimensional Synthesis of Six-Bar Linkage as a Constrained RPR Chain." *Session Mechanism Design IV, 4th European Conference on Mechanism Science*, September 21, 2012, Santander, Spain.
10. "Five Position Synthesis of a Slider-Crank Function Generator." *Session MECH-9-2 Planar Synthesis I, 35th Mechanisms and Robotics Conference, ASME IDETC*, August 30, 2011, Washington, D.C., USA.

Dissertation

The Kinematic Design of Six-bar Linkages Using Polynomial Homotopy Continuation, Advisor: Prof. J. Michael McCarthy

This dissertation presents the kinematic design of six-bar linkages for function, motion, and path generation by means of polynomial homotopy continuation algorithms. When no link dimensions are specified beforehand, the synthesis formulations for each design objective yield polynomial systems of degrees in the millions and billions, suggesting a large number of solutions. Complete solution sets to these systems have not yet been obtained and is the topic of this dissertation. Function generation for eleven positions is explored in most detail, in particular the Stephenson II and III function generators, for which we calculate multihomogeneous degrees of 264,241,152 and 55,050,240. A numerical reduction using homotopy estimates these systems to have 1,521,037 and 834,441 roots, respectively. For motion generation, the Watt I linkage can be specified for eight positions, producing a system of a multihomogeneous degree over 19 billion. However, for this work we focus on the smaller case of six positions, numerically reducing this system to an estimated 5,735 roots. For path generation we take a different approach. The design of path generators is formulated as RR chains constrained to have a single degree-of-freedom by attaching six-bar function generators to them. This enables us to use our results obtained on Stephenson II and III function generators to create four types of eleven position path generators: the Stephenson I linkage, two types of Stephenson II linkages, and the Stephenson III linkage.

Teaching Experience

2015	MAE 294 M.S. Project: Served as an additional advisor to master's students projects including the design of a heapedal robot and a geometrically constrained exoskeleton.
2014	MAE 279 Clifford Algebras: Prepared lecture notes on topics of Rodrigues' equation, pole triangles, Clifford algebras, rotational/planar/dual quaternions, and the exponential of vectors and screws.
2013–2014	Summer Racecar Class: Instructed on the use of SolidWorks to model/analyze a racecar chassis.
2011–2014	MAE 145 Theory of Machines: Served as TA creating homeworks, quizzes, tests, video tutorials; running discussion sections and lectures if needed. Topics included planetary gears, four-bar linkage analysis, suspension design, vehicle driving simulator and dynamic analysis of a slider crank.
2010–2015	MAE 189 Racecar Engineering: Served as TA for a 60+ senior project racecar team that competed in FSAE Lincoln, the UCI Energy Invitational, and the California Challenge. Provided project management/technical advice and managed documentation/online resources.
2012–2014	MAE 245 Spatial Mechanism Design: Served as TA for graduate level course in mechanism design.
2013	MAE 183 Computer Aided Mechanism Design: Served as TA assisting with homework and creating an online repository of special geometry linkages for use with the class final project.
2012	MAE 52 Computer-Aided Design: Served as TA running discussions, and grading homeworks, midterms, and tests. Topics include engineering drawings, GD&T, modeling parts, and mating assemblies in SolidWorks.

Research Statement

The Design of Mechanical Intelligence

The concept of mechanical intelligence [1] refers to the ability of a mechanism to respond/react to the environment or automatically perform some function(s) without guidance from a controller. This approach is beneficial for a variety of quasi-static and dynamic applications including human movement enhancement (exoskeletons, orthoses, prosthetics), manufacturing equipment (high-speed machinery, grippers), and robot locomotion (legs, wings, suspensions). For example, legged robots propel themselves through short ground contact periods where the forces that may be exerted are subject to the limits of the motor/controller setup. Instead, if passive mechanics were to automatically drive the desired forces/motion, the online effort to control low level mechanics is transplanted to the offline effort to design mechanical intelligence. But due to the complexity of underlying problems, no design tools exist. Nonetheless, this approach is capable of removing the power and bandwidth limitations associated with traditional serially actuated mechanisms. Therefore, I see mechanical intelligence playing a vital role in realizing the next level of dynamic machines.

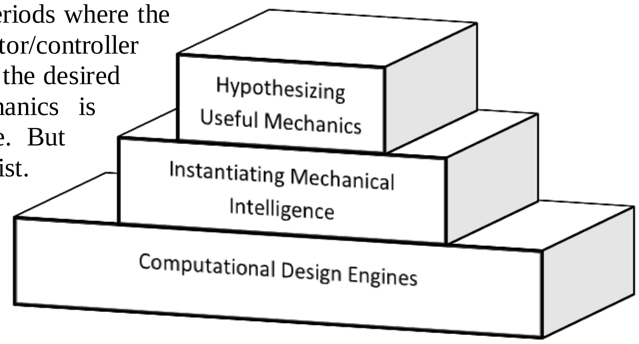

Figure 1. Three major research topics: Computational design engines provide the means for mechanical instantiation. Mechanical instantiation is driven by requirements spawning from hypothesized useful mechanics.

My research may be decomposed into three topics: (1) hypothesizing useful mechanics, (2) instantiating mechanical intelligence, and (3) creating computational design engines, see Fig. 1. The **first** of these is the highest level, posing scientific questions about which locomotive strategies might be most useful. If taking inspiration from a jumping animal, the hope is that not every muscle connected to the exact skeleton of the animal is necessary to replicate its locomotive capabilities. But rather, principles of design might be uncovered that can be reproduced with engineering components. For example, biologists have observed that the lesser bushbaby *Galago senegalensis* produces jump motions beyond the power output of its muscles [2]. It accomplishes this through a variable lever ratio built into its leg geometry that allows transient energy storage in muscle-tendon complexes which is used to multiply jump power 15 times than what the muscles can produce alone. My colleagues and I took note of this phenomenon and built a robot, Salto, with a specialized leg that reproduces these mechanics with a geared brushless motor, a latex spring, and carbon fiber links [3], see Fig. 2. We have termed these useful jump mechanics *series-elastic power modulation* and shown that it enables high vertical jumping agility.

The specialized leg of Salto is an instantiation of mechanical intelligence, the **second** topic area listed above. That is, passive mechanics automatically drive several functions: (a) the leg aims the ground force through the center of mass while (b) inducing transient energy storage in the elastic element via a near singular crouched configuration that transitions into (c) a mechanical advantage profile that defines a constant ground force during leg extension while (d) balancing angular momentum between moving links throughout a jump motion that lasts less than 200 ms [4]. This instantiation of mechanical intelligence was the product of a computational design method made possible by kinematic synthesis engines developed during my dissertation work [5-7]. Mechanical instantiation is exciting. This type of research is capable of inventing patentable technology [8, 9], generating new research directions [10], or inspiring university fostered start-ups [11].

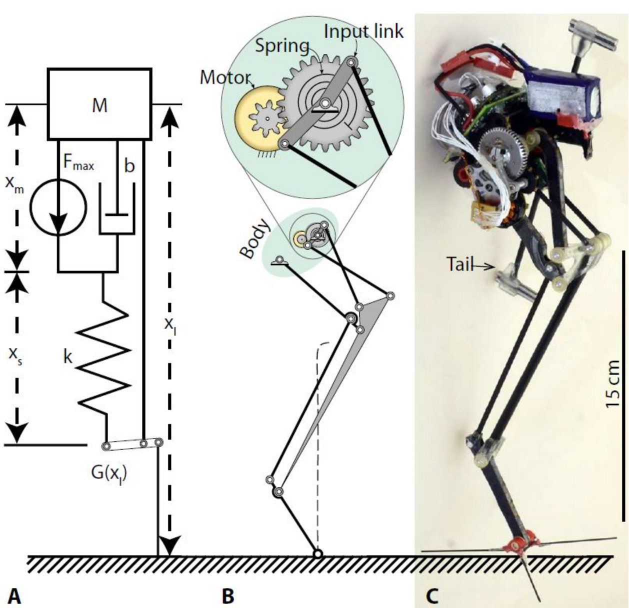

Figure 2. (A) An abstracted model that exhibits the design principle of series-elastic power modulation. (B) Mechanical intelligence was instantiated into a leg mechanism according to this principle. (C) The resulting jumping robot, Salto.

The **third** and foundational research topic I mention is computational design engines used to instantiate mechanical intelligence. The key phase in my computational approach is called *design exploration*. The design parameters of a multi-loop leg mechanism are embedded in a high dimensional nonlinear space such that brute force grid searches are impractical. This curse of dimensionality is corralled with a solution technique called numerical homotopy continuation. Mechanical intelligence is decomposed into motion primitives that are encoded into a polynomial system of which the roots indicate portions of the design space worth exploring. These systems are of very high degree (> 1,000,000), and the only methods capable of finding all or most roots are homotopy techniques. For mechanism synthesis problems, homotopy methods are particularly burdened by infinite roots, which consume around 97% of computations. I have devised a new way to construct homotopy startpoints and start systems which avoids tracking all infinite roots [12], and has been shown to decrease computational workload by 95% [13]. This approach brings into reach mechanism topologies which were previously considered too difficult for synthesis computations, increasing our ability to design mechanical intelligence.

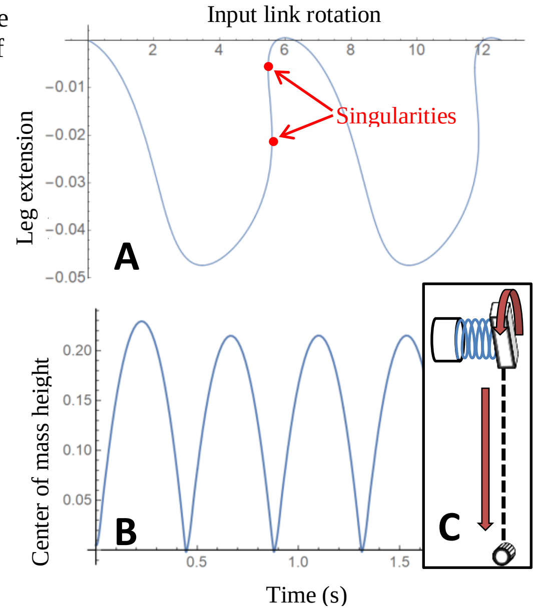

Figure 3. (A) A proposed configuration space (CS) capable of period-1 passive dynamics. (B) Time evolution of height from proposed CS. (C) Schematic of a series elastic powered hopper.

Future Directions

Stable, High-Powered Gaits With Low-Powered Actuators

Series-elastic power modulation demonstrates mechanics that overcome actuator power limitations. I believe these mechanics are a single instance of many new energetic locomotion strategies enabled by mechanical instantiation. For example, it is feasible to specify a limb configuration space that multiplies mechanical power and results in period-1 stable motions with no motor control. In contrast, the literature suggests periodic orbits of a 1D spring-loaded hopper are period-2, require at least open-loop control, and trade off power for more stability [14]. An example of a stable configuration space which avoids this trade-off appears in Fig. 3. This configuration space possesses multiple singularities which are used as energy wells, periodically settled into and shot out of as the foot contacts the ground.

The locomotion strategy proposed above can be viewed as a mechanical proprioceptive reflex that triggers push-off upon ground contact. It is functionally similar to the proprioceptive sensitivity available to direct drive legs [15, 16], which make toe contact visible to the motor by removing reflected inertia and the low-pass filtering caused by a gear train. In contrast, I propose making passive dynamics reactive rather than the motor, providing the desired reflex without sacrificing the benefits of gearing and series-elasticity.

(Target funding: Army Research Office BAA Apr 2017-May 2022 Mechanical Sciences)

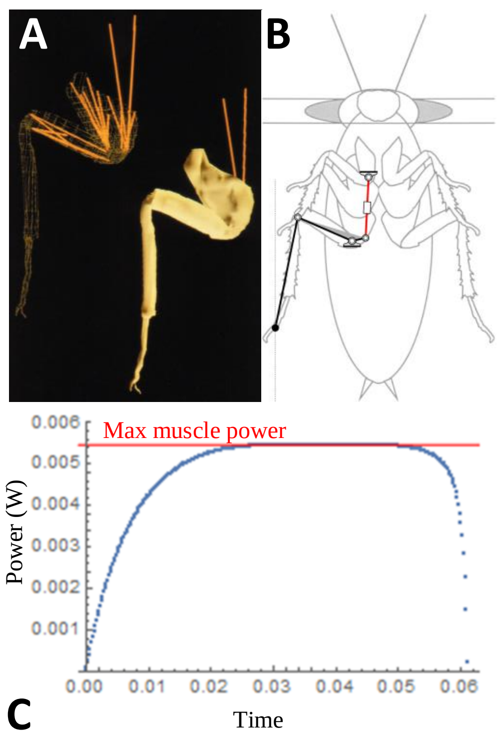

Figure 4. (A) Measurements of muscle locations in the hind limb of *Blaberus discoidalis* taken from [17]. (B) A simplified model of the hind limb. (C) Simulation results of the time evolution of power during an acceleratory gait cycle. The muscle spends the majority of its time in its maximum power state.

Geometric Constraints That Operate Motors At Peak Power

Regardless of force generation, energy gained during an acceleratory gait cycle is the product of the duration of ground contact and average actuator power over this duration. This suggests two extremes for increasing energetic output: (1) increase the duration of contact (e.g. longer stride length), or (2) increase power output of the actuators. Effectiveness of the first strategy is dependent on duty factor. The duration of contact for an individual leg is less important if another foot makes contact as soon as one lifts off, suggesting the first strategy is more suitable for jumping locomotion. For accelerative running, power is key, but simply adding larger motors is counterproductive towards the mass budget. Alternatively, average power increases if the motor operates near its peak power state, i.e. half of no-load speed. I propose a means of designing leg mechanics that promote first order motor dynamics toward this peak power state. It turns out, the solution to these dynamics yield a single algebraic constraint, which I term the *constraint of constant power*. The more closely leg mechanics obey this constraint, the greater the average power output of the motor. To my knowledge, this constraint does not appear in the existing literature.

The biological analog to motors are muscles. Muscle in a state of tetanized concentric contraction (such as during acceleration) forms a force-velocity curve which is similar to the torque-speed curve of a DC motor, with a few nonlinearities introduced. Preliminary analyses of the leg mechanics of the cockroach *Blaberus discoidalis* indicate that its hind limb closely obeys the constraint of constant power, allowing the animal's main propulsive muscles (femoral extensors located in the coxa) to output an

average power near their maximum, see Fig. 4. Searching the hind limb dimensional space and running dynamic simulations indicates the hind limb promotes near optimal muscle power output.
(Target funding: National Robotics Initiative 2.0)

Automatic Identification of Useful Mechanics

Hypotheses regarding useful mechanics are often inspired from literature on the principles of animal locomotion [18,19]. Alternatively, stochastic optimization may be employed to determine viable locomotive strategies. I propose, as a collaborative effort with future colleagues engaged in state of the art optimization/learning, employing these techniques to discover useful input/output relationships of "invisible" mechanisms. That is, information which is usually contained within the Jacobian matrix of a mechanism, however, discovered irrespective of any physical system. In this way, optimal techniques are used to identify useful mechanics decoupled from mechanical instantiation, which could be accomplished by computational design engines. This approach provides for the natural inclusion of stochastic environment variables such as inconsistent friction and rough terrain.
(Target funding: NSF CDS&E Computational and Data-Enabled Science & Engineering)

Solving Unsolved Problems in Mechanism Design via the Finite Root Generation Technique

As describe earlier in this statement, homotopy continuation plays a key role in design exploration. A few blackbox homotopy solvers exist (Bertini [20], PHCpack [21], among others), which have benefited several engineering disciplines, including my own work in kinematic design [5-7]. Recently, I have realized a new homotopy solution technique termed Finite Root Generation (FRG) which substantially reduces the computational effort needed to solve complex synthesis systems. This is accomplished by avoiding computations of the infinite roots which dominate the problems of interest. An FRG codebase for computation on a graphical processing unit has recently been written. The software is ripe for solving synthesis problems in mechanism design that were previously out of scope. There is much research to be done here: discovering the practical bounds of FRG, categorizing new classes of synthesis equations, and reporting those which are most useful. I envision FRG as a foundation off which many new research directions can be built over several years. I have identified the application of FRG to robot locomotion as a fruitful path forward, but it may just as easily be applied to collaborative efforts with other disciplines (biorobotics, product design) or fit to align with the specific interests of a motivated graduate student. See Fig. 6 for some applications. As well, providing access to cutting edge research software in elective courses in mechanical design provides an exciting learning experience for students that can evolve into research.
(Target funding: NSF EDSE Engineering Design and System Engineering)

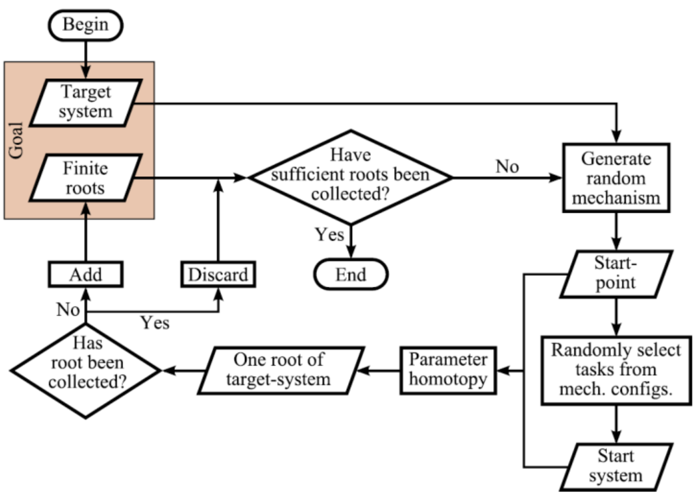

Figure 5. Flowchart of the Finite Root Generation algorithm.

Advancing Computational Design Engines

I have surmised an additional way to preclude the infinite roots involved in homotopy tracking. Whether it is superior to FRG is to be determined. Homotopy continuation algorithms track startpoints to endpoints. Endpoints are the roots to the target system we seek, and startpoints/start systems are generated some other way. One common approach is to construct a system of equations composed completely of products of linear expressions that has nearly the same monomial structure as the target system (at least more general). The task of constructing startpoints then involves setting various combinations of linear expressions equal to zero and solving the resulting linear systems. Depending on the degeneration of monomial structure from start target system, some (high) percentage of startpoints will track to infinite roots. In order to weed out these startpoints from the onset, one might exploit symmetries in the target system, e.g. groups of equations composed of linear combinations of the same monomials. These symmetries indicate that patterns most likely exist in the combinations of linear expressions used to construct startpoints that will track to infinite endpoints. Finding these patterns by hand is an overwhelming task. Instead, these patterns might be discovered through supervised learning. Sample sets of startpoints could be constructed and tracked to either finite or infinite roots, providing a training set. After running the learning algorithm, the learned function could be evaluated on a new sample of startpoints. If accuracy is high enough, the learned function indicates all the startpoints which will track to infinite roots so that they may be avoided.
(Target funding: NSF AF Algorithmic Foundations)

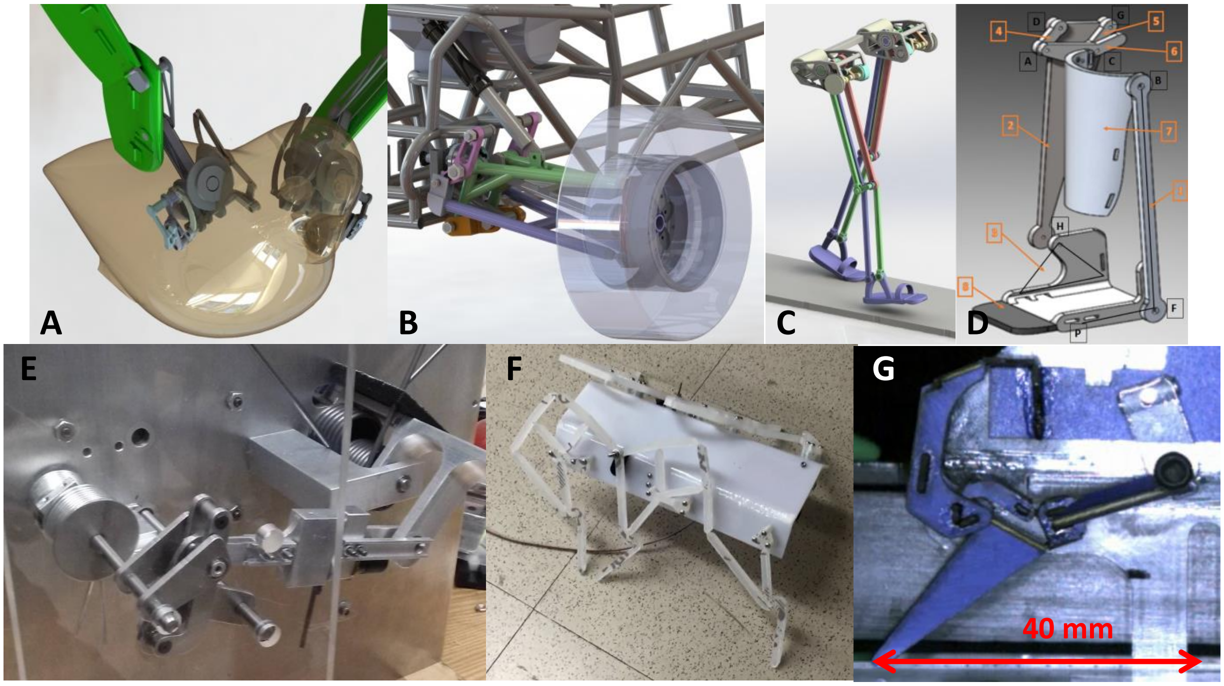

Figure 6. Designs resulting from my past work in computational kinematic synthesis: (A) a biomimetic flapping device [22], (B) a novel off-road suspension [23], (C) an exoskeleton [5], (D) a lower limb orthosis (courtesy Shramana Ghosh [24]), (E) a spastic wrist torque cancelling device for stroke patients [25], (F) monolithic leg mechanisms of a walking robot, and (G) a six-bar walking mechanism fabricated with Smart Composite Microstructures.

Summary

I have divided my past and future research into three topic areas, sorted from highest to lowest level: (1) hypothesizing useful mechanics, (2) instantiating mechanical intelligence, and (3) computational design engines. I have listed several future directions under these topics, each capable of branching out into more future work. Finally, the topics I list represent diverse types of research. (1) Hypothesizing useful mechanics involves pulling knowledge from disparate domains (e.g. biology, stochastic optimization), preparing and drawing conclusions from physical simulations, and setting up collaborations to inform and test design principles. (2) Mechanical instantiation is application-based, requiring 3D modelling tools, iterative prototyping, and good engineering practice to be successful. Consequently, this research can lead to marketable products for more entrepreneurial under/graduate researchers. (3) Advancing computational design engines poses mathematical and algorithmic challenges to graduate researchers. Providing diversity in the research workload allows students to align and realign their interests, while I chart out the depth of individual projects accordingly.

References

[1] N. T. Ulrich, 1989. *Grasping With Mechanical Intelligence*. Ph.D. Dissertation. University of Pennsylvania.
[2] P. Aerts, 1997. “Vertical Jumping in *Galago senegalensis*: The Quest for an Obligate Mechanical Power…,” *Phil. Trans. of the R. Soc. of London*. B.
[3] D. W. Haldane, M. Plecnik, J. K. Yim, and R. S. Fearing, 2016. “Robotic Vertical Jumping Agility via Series-Elastic Power…” *Science Robotics*.
[4] M. Plecnik, D. W. Haldane, J. K. Yim, and R. S. Fearing, 2017. “Design Exploration and Kinematic Tuning of a Power…” *J. Mech. and Rob*.
[5] M. Plecnik and J. Michael McCarthy, 2015. “Computational Design of Stephenson II Six-bar Function Generators for…” *J. Mech. and Rob*.
[6] M. Plecnik and J. Michael McCarthy, 2016. “Kinematic Synthesis of Stephenson III Six-bar Function Generators,” *Mech. and Mach. Theory*.
[7] M. Plecnik and J. Michael McCarthy, 2016. “Design of Stephenson Linkages that Guide a Point Along a Specified…” *Mech. and Mach. Theory*.
[8] M. Plecnik, D. W. Haldane, J. K. Yim, and R. S. Fearing, 2017. Series-Elastic Power… US Provisional application (currently in conversion).
[9] M. Plecnik, D. Bissell, D. J. Reinkensmeyer, and J. M. McCarthy, 2017. Torque-Compensating Assistive Wrist Braces. US 20170079825 A1.
[10] D. W. Haldane, J. K. Yim, and R. S. Fearing, 2017. “Repetitive Extreme-Acceleration (14-G) Spatial…” *IEEE/RSJ Int. Conf. on Int. Rob. and Sys.*.
[11] “Red Lion Robotics Wins Orange County Aging 2.0 Regional Business Competition and Continues On…” UCI Applied Innovation News, 2017.
[12] M. Plecnik and R. S. Fearing, 2017. “Finding Only Finite Roots to Large Kinematic Synthesis Systems,” *J. Mech. and Rob.*, 9: 021005.
[13] M. Plecnik and R. S. Fearing, 2017. “A Study on Finding Finite Roots for Kinematic Synthesis,” *Proc. of the ASME 2017 Int. Design Eng. Tech. Conf.*
[14] J. G. Cham and M. R. Cutkosky, 2007. “Dynamic Stability of Open-Loop Hopping,” *J. Dyn. Sys., Meas., and Control*, 129: 275-284.
[15] G. Kenneally, A. De, and D. E. Koditschek, 2016. “Design Principles for a Family of Direct-Drive Legged Robots,” *IEEE Rob. and Auto. Letters*.
[16] D. J. Hyun, S. Seok, J. Lee, and S. Kim, 2014. “High Speed Trot-Running: Implementation of a Hierarchical Controller Using…” *Int. J. Rob. Res*.
[17] R. J. Full and A. N. Ahn, 1995. “Static Forces and Moments Generated in the Insect Leg: Comparison of a 3-Dimensional Musculo…” *J. Exp. Bio*.
[18] R. M. Alexander, 2003. *Principles of Animal Locomotion*, Princeton University Press.
[19] M. S. Gordon, R. Blickhan, J. O. Dabiri, and J. J. Videler, 2017. *Animal Locomotion: Physical Principles and Adaptations*, CRC Press.
[20] D. J. Bates, J. D. Hauenstein, A. J. Sommese, and C. W. Wampler. Bertini: Software for Numerical Algebraic Geometry. Available at bertini.nd.edu
[21] J. Verschelde, 1999. “Algorithm 795: PHCpack: A General-Purpose Solver For Polynomial Systems By Homotopy…” *ACM Trans. on Math. Soft*.
[22] M. Plecnik and J. M. McCarthy, 2015. “Controlling the Movement of a TRR Spatial Chain with…” *Proc. of the ASME 2015 Int. Des. Eng. Tech. Conf.*
[23] M. Plecnik and J. M. McCarthy, 2014. “Vehicle Suspension Design Based on a Six-bar Linkage,” *Proc. of the ASME 2014 Int. Des. Eng. Tech. Conf.*
[24] S. Ghosh, N. Robson, and J. M. McCarthy, “Design of Wearable Lower Leg Orthotic Based on…” *Proc. of the ASME 2017 Int. Des. Eng. Tech. Conf.*
[25] D. M. Bissell, 2015. *WRIS T (Wrist Resonator for Independent Stroke Training)*, M.S. Thesis, University of California, Irvine.

Teaching Statement

Background

My teaching experience includes teaching assistantships in core undergraduate courses in CAD and Theory of Machines, as well as senior capstone and elective courses, and finally graduate courses on mechanism design. My involvement covered all aspects of teaching a course including creating syllabi, homeworks, quizzes, tests, notes, and video tutorials; lecturing; running discussion sections; grading; and managing online resources such as message boards, assignment dropboxes, online gradebooks, and shared student workspaces. These experiences include both small and large classes, as well as theory-based and project-based classes.

I am comfortable teaching the subject areas of mechanical design, computer-aided design, computational methods, kinematics, statics, dynamics, and senior capstone courses. I would be very interested in creating elective courses on Computational Machine Design and Advanced Robot Kinematics. Computational Machine Design would survey techniques for designing planar and spatial mechanisms with a focus on polynomial homotopy, and culminate with a design project. Advanced Robot Kinematics would cover the various mathematical constructs used to model robots including complex numbers, isotropic coordinates, Lie groups, Lie algebra, screw theory, matrix exponentials, Clifford algebra exponentials, quaternions, and dual quaternions.

Philosophy

My teaching experiences include both small and large classes, as well as theory-based and project-based classes. One principle I learned during this time was the value of student interaction in the classroom and its barriers to implementation. It is the instructor's interaction with the students that allows him/her to calibrate his/her own teaching efforts for a diverse student population. This form of feedback control not only encourages in-class participation but informs the instructor how to more thoughtfully give out assignments that increases out-of-classroom learning as well. For example, by learning of the students' mechanical design issues in their concurrent capstone projects, I was able to create new homework problems for Theory of Machines that directly addressed their questions.

Working in small or project-based classes, I found my interaction with students to come quite naturally. Smaller classes and discussion sections of about 40 students allowed me to structure classroom time in blocks of whole-class teaching divided by periods of individualized attention. This strategy is particularly effective for labs that can be broken into checkpoints. Project-based courses cast me in the role of a manager of project managers, which necessitated numerous formal and informal meetings with students such that these classes most personally connected me with students.

The most challenging scenario is establishing student interaction in large 250-student, theory-based lectures where limited instructor time causes students to become "numbers" rather than "faces". For example, Theory of Machines had this format, and this class is of particular importance to me because it is the portion of the undergraduate curriculum that most closely touches my research. Furthermore, I have noticed this subject matter originally motivated many students to enter the field of mechanical engineering.

The departmental solution to the "numbers" problem was instituting smaller TA-led discussion sections to take in tandem with large lectures. But the onus is still on the instructor to create a quality lecture which, I believe, is largely dependent on student interaction. I was given the opportunity to lecture periodically as a TA for Theory of Machines. I spoke from well-structured slides allowing in between Q&A periods with the class, however, no students asked any questions indicating the class was not being engaged.

During conversations with professors, a strategy was suggested that is not very different from my treatment of small discussion sections. In the future, I look to create in-class "checkpoint" problems to be completed in small groups, where answers would be shared immediately. These exercises would encourage on-the-spot critical thinking necessary to inspire thoughtful questions in the classroom. This two-way communication informs the instructor how to pace and frame course material.

Undergraduate Courses Interested in Teaching

Theory of Machines The kinematics and dynamics of machinery including the topics of mobility, vector loop modelling, position, velocity, and acceleration analyses, forward and inverse kinematics, dynamic modelling, power transmission, and design principles of gears, cams, and differentials.

Senior Capstone Course Semester or year long projects that take students through the engineering design process which includes defining requirements and criteria, ideation and synthesis, analysis, construction, testing, and evaluation.

New Graduate Courses to be Developed

Computational Machine Design An introduction to the techniques used in designing planar and spatial mechanisms with a focus on polynomial homotopy continuation. Topics include types of homotopies, formulating design equations in terms of polynomials, obtaining solution bounds, using continuation to solve mechanism design problems, and the use of optimization theory in machine design.

Advanced Robot Kinematics An overview of the mathematics in robot theoretical kinematics. Topics include rigid body transformations, planar, spherical and spatial displacements, homogeneous transforms, derivatives of motion and lie algebra elements, Plucker coordinates, screws, twists, wrenches, and screw displacements, quaternions, dual quaternions, Grassman algebra and Clifford algebra.

Experience

MAE 294 M.S. Project 2014 – 2015: Served as an additional advisor for students completing Master's projects under Dr. J. Michael McCarthy. Projects included the design of hexapedal walking robot and a geometrically constrained exoskeleton.

MAE 279 Clifford Algebras 2014: Prepared lectures and notes for a seminar course on the theory of spatial displacements, Rodrigues' equation, pole triangles, Clifford algebras, rotational/planar/dual quaternions, and the exponential of vectors and screws as applied to the analysis and synthesis of robot manipulators.

Summer Racecar Class 2013 – 2014: Served as an instructor for a two-week summer course at UCI that introduced high school students, college students, and high school teachers to the fundamentals of racecar engineering. I was responsible for training the students in solid modeling and finite element analysis of a simplified vehicle chassis using SolidWorks.

MAE 145 Theory of Machines 2011 – 2014: Served as TA for this large junior-level lecture course, creating syllabi, homeworks, quizzes, tests, and video tutorials, as well as running discussions and occasionally lecturing. I created several custom homework assignments to correspond to students' concurrent work in senior capstone courses. Each homework included derivations and a computer simulation. Topics included linkages, geartrains, cams, suspension design, a vehicle driving simulator, and machine dynamics.

MAE 189 Racecar Engineering 2010 – 2015: Served as TA for a senior capstone course consisting of 60+ students focused on designing and building racecars to compete in the Formula SAE Lincoln competition as well as the UCI Energy Invitational and California Challenge. Duties included providing project management and technical advice, weekly meetings with the student leadership, implementing documentation procedures to grade the students, and managing online student workspace.

MAE 245 Spatial Mechanism Design 2012 – 2014: Served as TA for this graduate elective course on mechanism design. I provided support for homeworks and advised final projects, developing new computer code for student use.

MAE 183 Computer Aided Mechanism Design 2013: Served as TA for this undergraduate elective course on mechanism design. Duties include assisting with homework and creating an online repository of special geometry linkages for students to use in their final projects.

MAE 52 Computer-Aided Design 2012: Served as TA for this introductory course to engineering drawings and the SolidWorks CAD package. I ran discussion sections and graded homeworks, midterms, and tests. I also instituted an online message board to help in answering student questions.