Before advocating for my self, I wish to to articulate what I am advocating for. I have been drawn to this profession since my first exposure[1], as a High School Junior, to the Campus and Faculty of the University of Washington. The core appeal to me has always been the vibrant intellectual community, and my years of experience have only served to confirm that no institution has greater influence on and responsibility to the world of ideas than a University. But personal appeal alone does not justify permanent appointment in a public institution. For most of my academic career, I only vaguely understood the philosophical and practical rationale for the tenure system. After reading and reflecting on the 1915 *Declaration* and 1940 *Statement* of the AAUP [4], I am convinced that tenure enables Academia to serve a critical societal need for the creation and dissemination of knowledge in isolation from political or economic pressures, and I am compelled to devote the remainder of my working days in service of these aims. Thus, I am writing this statement to humbly request your consideration of my permanent appointment to the Academy. What follows is my attempt to provide an accurate account of my effort, growth, and contributions to my University and Field throughout my tenure as an Assistant Professor.

1 Research

I am broadly interested in discovering, formalizing, and applying principles of sensorimotor control in humans and robots. My most significant contributions have been obtained in settings that have nonsmooth (hybrid) dynamics or systems that have humans in-the-loop with machines – my Ph.D. dissertation [5] focused on the former, my Postdoctoral training on the latter. Looking ahead, I am working to merge these disparate research threads under the broad umbrella of an emerging field, *neuroengineering*, that I expect will ultimately produce (i) intelligent assistive devices (co-robots, exoskeletons) that interface bidirectionally with our brains, bodies, and environments and (ii) personalized rehabilitative interventions based on continual (in-home/ecological) monitoring and automated diagnostics. Since many jobs are becoming increasingly automated, and since many people will experience impaired movement at some point in their lives, this field has the potential to profoundly impact daily life and redefine the human interface with technology. My research effort as an Assistant Professor has been devoted to helping lay the foundation for this exciting frontier.

1.1 Most significant publications

My College stipulates that I include and discuss three publications in this dossier that I consider to be my most significant or influential. I have chosen to highlight the following, each of which represents work undertaken entirely in my faculty role at UW with one of my Ph.D. students, and each of which underwent rigorous peer review in an archival publication venue:

[1] A. M. Pace and S. A. Burden. "Piecewise-Differentiable Trajectory Outcomes in Mechanical Systems Subject to Unilateral Constraints". In: *ACM Conference on Hybrid Systems: Computation and Control (HSCC)*. Apr. 2017, pp. 243–252. DOI: 10.1145/3049797.3049807

[2] B. S. Banjanin and S. A. Burden. "Nonsmooth Optimal Value and Policy Functions in Mechanical Systems Subject to Unilateral Constraints". In: *IEEE Control Systems Letters (L-CSS)* 4.2 (Apr. 2020), pp. 506–511. DOI: 10.1109/LCSYS.2019.2960442

[3] M. Yamagami, K. M. Steele, and S. A. Burden. "Decoding Intent With Control Theory: Comparing Muscle Versus Manual Interface Performance". In: *ACM Conference on Human Factors in Computing Systems (CHI)*. Apr. 2020, pp. 1–12. DOI: 10.1145/3313831.3376224

However, since none of these papers appeared in a traditional journal, and since they appeared too recently to have accumulated significant numbers of citations (although [1] is one of the papers that defines my h-index on Google Scholar), I will discuss them in the context of my earlier and

[1]As a first-generation college graduate, I was not privileged with prior access to/understanding of University life.

higher-cited journal publications as well as preprint manuscripts that are working their way through the multi-year review process that is typical for journals in my field. I will separately discuss how my contributions impact two fields: *nonsmooth (hybrid) dynamics* and *human-in-the-loop control*.

1.1.1 Nonsmooth (hybrid) dynamics

The smooth constitutive equations governing hydro- and aero-dynamics – the *Navier-Stokes* PDE – do not have an analogue on *terra firma*, where forces and velocities that define equations of motion change abruptly whenever a limb contacts the environment as in locomotion or manipulation tasks. This observation motivates the study of *terra*-dynamics, which others pursue empirically [6] and I pursue theoretically by studying nonsmooth (*hybrid*) dynamics that arise from the interaction of continuous-time *flow* and discrete-time *reset*. The central theme of my work in this area is characterizing when and how hybrid dynamics are intrinsically distinct from their smooth counterparts, and generalizing analytical and computational tools to apply in genuinely hybrid settings.

In my first significant contribution to this area [7], I proved that, near a periodic orbit that resets at isolated instants in time, hybrid dynamics generically reduce dimensionality and can be "glued" using techniques from differential topology [8] to produce a smooth dynamical system (smooth flow on a smooth manifold – a smoothing of the *hybrid flow* and *hybrifold* from [9]). This result provides a systematic route to generalize theoretical and computational techniques from smooth dynamical systems theory to the hybrid setting. For instance, I applied this result to obtain my own generalization of *averaging* to hybrid systems [10], and the result has been cited by others similarly seeking generalizations in the hybrid systems [11], control [12, 13], estimation [14, 15], robotics [16], and biomechanics [17] areas.

Subsequently, and in sharp contrast to the previous result, I proved several classes of hybrid dynamics are *not* smooth-able when resets are not isolated, starting with a class of discontinuous vector fields in [18] and generalizing this finding with my student Andrew Pace in [1] to the class of hybrid systems I defined in [19] that model robot locomotion and manipulation. In particular, our results show when the hybrid system flow is *piecewise-differentiable* in a specific technical sense that (i) agrees with the intuitive notion[2], (ii) is intrinsically nonsmooth (i.e. generally not smooth-able), and (iii) provides a suite of analytical and computational tools from nonsmooth analysis [21]. Leveraging these results, I generalized *infinitesimal contraction* analysis to hybrid systems [22] using the intrinsic distance metric I derived for hybrid state spaces [23].

Recently, in [2] my student Bora Banjanin and I proved that optimal value and policy functions in hybrid models of robot locomotion and manipulation are nonsmooth, which implies state-of-the-art algorithms for trajectory optimization and reinforcement learning are not applicable, since such algorithms require existence of a linear first-order approximation (namely, the gradient of the cost) that simply *does not exist*. My recent preprint [24] provides efficient schemes to represent and compute the actual non-linear derivative, indicating a route to rigorous and practical algorithms.

1.1.2 Human-in-the-loop control

Human behavior is richly variable and nonlinear in general. Nevertheless, it has been known for decades [25, 26] that humans behave remarkably linearly in-the-loop with machines. This empirical fact is theoretically unsurprising since (i) the Hartman-Grobman Theorem [27, Thm. 7.3] ensures all smooth regulatory processes are approximately linear, and (ii) such processes are ubiquitous in human/machine interaction (e.g.: piloting vehicles; robot-assisted surgery; active exoskeletons). However, it is profoundly valuable to know that humans behave linearly in control loops since this fact enables use of a comprehensive toolkit for robust and optimal control [28]. The central theme of my work in this area is extending and applying data-driven techniques for analysis and synthesis of human-in-the-loop control systems by leveraging established techniques for optimal and robust

[2] A function ought to be piecewise-differentiable precisely when its "domain can be partitioned locally into a finite number of regions relative to which smoothness holds" [20, Sec. 1].

control of linear systems together with recent advances in learning and game theory.

After initially attempting to model nonlinearity in human sensorimotor transformations [29, 30], I fully embraced experiment design and analysis in a linear systems framework originally developed to study sensorimotor integration in aerial, terrestrial, and aquatic animals [31–33]. This pivotal change has led to an exciting and fruitful line of work I believe will be highly impactful. After establishing our trajectory-tracking experimental paradigm in [34], my student Momona Yamagami conceived of and led an innovative study comparing the performance of conventional *manual* (joystick) interfaces with novel *muscle* (surface electromyography, EMG) interfaces [3]. Although EMG has already been explored as a computer interface, prior work focused on *discrete* tasks like keystrokes or mouse clicks, whereas we studied *continuous* tasks like piloting a vehicle. We found that subjects better implemented *feedforward* control of a second-order system using the EMG interface, suggesting muscle interfaces may outperform manual for control of highly-maneuverable vehicles. In a subsequent study that is under review [35], we found that controllers learned with one hand transfer to the other, and that learning improves performance by suppressing sensorimotor noise, suggesting training times could be halved for bimanual tasks like robot-assisted surgery.

Humans continually adapt to changes in their world – when the world includes an an intelligent machine that adapts to the human, the two agents play a *game* [36]. Strategic interactions between decision-making agents have been studied extensively from the game theory perspective in economics [37] and control theory [38], but there has been comparatively little work from the game theory perspective in sensorimotor control [39], although co-adaptation is recognized as a central issue in human/robot interaction [40], brain/machine interfaces [41], and assistive devices [42]. In a long-running collaboration with my colleague Professor Lillian Ratliff, we characterized Nash equilibria [43] and, together with our co-advised student Ben Chasnov, analyzed convergence of gradient-based learning [44] in continuous games. These results are already of great interest in the machine learning community, but I think they will have even more significant impact in neuroengineering. For instance, in recent work with my colleague Professor Amy Orsborn and our co-advised student Maneeshika Madduri [45], we study the "two-learners" problem in brain/machine interfaces and provide a theoretical explanation for others' empirical observations [41].

1.2 Contributions to collaborations and mentoring relationships

All of my work is the result of a rich constellation of collaborations with my mentors, my colleagues, and my students. Every co-author contributes substantively to the idea, findings, and presentation. When I am listed as either first or last author on a manuscript, that generally indicates I was responsible for most of the text, scholarship, and technical proofs; the exceptions are [19, 22, 23], where those responsibilities were shared equally with my contemporary co-authors, and [44], where my colleague Professor Lillian Ratliff and our co-advised student Ben Chasnov were responsible.

In the three "most significant publications" referenced above, [1–3], my Ph.D. students led the simulation or experimental elements, and we worked side-by-side on all other aspects of the papers. In the case of [3], co-author Professor Kat Steele co-advises Momona Yamagami, and helped conceive of the project and establish our findings in the human/computer interaction community, with which I was previously unaffiliated. This latter case exemplifies the kind of collaborative relationship I seek to cultivate with my mentees, wherein they discover open problems through their own independent explorations of application domains (possibly facilitated by co-advisors or collaborators), and we work together to create novel technical solutions.

1.3 Funding and awards

My research has been funded by the National Science Foundation (Cyber-Physical Systems; National Robotics Initiative; Mind, Machine, Motor Nexus) and Army Research Office (Mechanical Sciences). I received the ARO Young Investigator Program (2016) and NSF CAREER (2021, M3X) awards, as well as my College of Engineering's Junior Faculty Award (2021).

2 Teaching

I think I have been a good lecturer since I started as an Assistant Professor – it was a skill I deliberately practiced during the extensive teaching assistant and public outreach experiences I pursued throughout my undergraduate and graduate education. I also think I have always had good rapport with students – due in no small part, I'm sure, to the innumerable advantages I enjoy in the classroom as a member of the majority race and gender. But despite my (earned) skill at lecturing and my (unearned) privilege in the classroom, I have found teaching incredibly challenging.

Although it is likely that I am not as good at lecturing nor get along as well with students as I think, I have learned that there is much, much, *much* more to teaching than simply talking amicably at the front of a classroom. My teaching has benefitted tremendously from adoption of evidence-based methods for *curriculum design* and *active learning*. Some of my success has been hard-won, based on my own inefficient process of trial-and-error, but I owe significant debts to incisive feedback from colleagues in my Department and my College's *Educational Teaching & Learning Center* as well as my participation in the NETI-1 Workshop offered by the *National Effective Teaching Institute*.

2.1 Curriculum design

With every new class I teach, I make the classic mistake of starting "from scratch". Although I collect multiple examples of related courses taught by colleagues at my own and other Departments and Universities, I inevitably identify what I think are flaws in each of them and conclude that I will be better off creating my own version of the course. Regardless of whether I am correct in my assessment about what others get *wrong* in existing courses, I certainly fail to understand what they get *right*, that is, what features of the curriculum design support students and improve learning outcomes by providing scaffolding in lecture material, by employing effective formative and summative assessments, and by carefully aligning student work with lecture material. I have labored to get these things "right" (or, at least, less "wrong") by iteratively improving each offering.

As evidence that I have had some degree of success in this regard, I refer to the significant improvements in summary statistics from my course evaluations, particularly in the senior-level undergraduate course I teach on feedback control systems (EE 447) – specifically: (i) *Summative Items* median improved from 3.3 to 4.3 out of 5 between the first (2018) and second (2019) offering, and then to 4.5 in the third (2020) offering; (ii) *Student Engagement* (quantified by fraction of time spent on the course that was "valuable in advancing your education") improved from $\approx 50\%$ to nearly $\approx 100\%$ between the second (2019) and third (2020) offering. Similar trends appear in my graduate courses, though the gains are less significant since the starting points were higher.

2.2 Active learning

Philosophically, I endorse *scientific teaching* [46], i.e. applying the scientific method to instruction. Practically, my adoption of evidence-based methods has been gradual. I was first introduced the merits of *active learning* [47] methods in particular in an interactive session taught by my colleague Professor Mary Pat Wenderoth[3] in a training workshop for new UW teachers. But despite experiencing the effectiveness of such methods first hand (MPW's engaging workshop employs a variety of active learning techniques to teach the effectiveness of said techniques) early in my tenure at UW, I did not begin implementing these techniques in my courses until I participated in the NETI-1 workshop after my first year of teaching. The specific techniques I have implemented are categorically different in the pre- and post-COVID eras, so I will discuss them separately.

Pre-COVID, I employed the think/pair/share strategy extensively, punctuating my otherwise-conventional lectures every 10 to 15 minutes by prompting the students to work on a problem individually ("think") and collectively ("pair") over the course of a few minutes before I call on groups to report solutions to the entire class ("share"). I chose this strategy based on advice and evidence

[3] Those familiar with education literature will no doubt recognize MPW as a preeminent researcher on the topic [47].

I received at the NETI-1 workshop. Specifically, the data shows this method is effective because (i) attention drops off exponentially during traditional lecture, but is restored by engaging students in problem-solving and (ii) students benefit from individual and collective problem-solving. Of course, the data also shows that students actively oppose active learning methods – to overcome this reluctance, I am transparent about this fact, telling the students before the first think/pair/share: "you won't like this, but it's good for you; you're welcome!"

Post-COVID, or more specifically starting in my first online-only quarter (Spring 2020), I adopted a completely "flipped" model wherein I provide pre-recorded lectures asynchronously and lead interactive discussion synchronously with students during scheduled class time. I adopted this model out of necessity: for students, I anticipated that significant new constraints would be imposed on their availability and bandwidth, so they needed the flexibility of a flipped classroom; for myself, this model provided flexibility in the event that I, or someone in my care, suddenly became severely ill. However, since (i) the flexibility afforded by the flipped model also benefits on-campus instruction (the need to accommodate a variety of schedule constraints and learning styles will remain after the pandemic ends), and since (ii) I have had great success with the flipped model (my course evaluation summary statistics significantly *increased* after the transition to online-only instruction, and multiple groups of students have spontaneously expressed their preference for the flipped model), I plan to continue flipping the classroom on-campus, even though the data is not yet conclusive about the superiority of the flipped model for in-person instruction [48].

3 Service

As a first-generation college graduate, I am committed to broadening participation of underrepresented groups in STEM careers. There are two reasons I view this work as critical: morally, we owe it to others – those in positions of power should dismantle systems that privilege them; selfishly, we owe it to ourselves – perpetuating gross inequities in access impoverishes scientific progress. To this end, I have found the service I engage in as a faculty member to be deeply fulfilling.

Specifically, I have: mentored more than a dozen students from underrepresented groups in research (3 of my current 5 Ph.D. students are women); presented and exhibited to thousands of students, teachers, and families at outreach events; and employed evidence-based methods for creating inclusive environments in my classrooms and research lab. Starting next year, my NSF CAREER award will support an Alternative Spring Break outreach program in an underserved Latinx or Tribal community high school. Finally, I serve as the (first) *Associate Chair for Diversity, Equity, and Inclusion* in UW ECE, a position I lobbied to create wherein I work with students, staff, and faculty to define and implement an impactful and sustainable strategy.

My most significant contribution to broadening participation started in the first year of my faculty position when I became co-PI on an NSF *Scholarships in STEM* (S-STEM) grant that helps fund the Washington STate Academic RedShirt (STARS) program, which provides 32 students from underrepresented backgrounds per year specialized curriculum designed to help them succeed in engineering [49]. To date (cohort 7), 86% of the STARS students had Pell Grants, 73% were first-generation college students, 49% were URM, and 41% were women. My role in STARS is to create and manage a *faculty mentorship program* that pairs students with faculty in their field of interest to provide guidance about education, research, internship, and career opportunities. I have recruited 72 engineering faculty from 10 Departments to serve as mentors for 102 STARS students.

My most significant service activities outside the realm of broadening participation: (i) founding co-director of the *Laboratory for Amplifying Movement and Performance*, a 3400 square foot facility for analysis of human and machine movement shared between Departments in the College of Engineering and School of Medicine; (ii) organizer in 2017 for *Dynamic Walking*, the premier international meeting for legged locomotion research spanning control, learning, mechanics, robotics, rehabilitation, and neuroengineering, together with Professor Andy Ruina (Cornell University).

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