Academic Journey and Research Achievements

I am a Ph.D. candidate at the Brain-Body Dynamics Lab (Valerolab) at the University of Southern California. I have a strong background in both neuroscience and machine learning and my current focus is on context dependent data-efficient learning algorithms that can be implemented in real-world applications. I would like to take this chance to walk you through details of my academic background, contributions, current focus and, and future research plans. I have also provided my volunteering, leadership, and mentoring contributions to the field as well as my plans on promoting outreach and diversity.

For me, it all started with a simple question, and what follows is my journey to find the answer.

We can land space shuttles on the moon, perform surgeries using robotic manipulators, yet our cutting-edge robots cannot perform some of the tasks that are considered to be very simple to the humans, or animals in general. We have seen robots that can walk, run, and even jump. But have you seen a robot being able to dance like a ballet dancer? Or one that can climb rough edges of the mountains, after only a few tries, like a mountain goat? What are our so-called "cutting-edge" systems missing? That is the very same question that steered my entire journey.

When I was in high school, I was fascinated by animals (I still am) and how they can do things that are far from what man-made autonomous systems can. After some research, I was confident that the answer is in the brain: the most fascinating system known to humankind! That is why I decided to study Biomedical Engineering, to try to understand how the brain works how we can mimic its behavior. My goal was to focus on both theory and on real-world applications. As my undergrad capstone project, I built a complete system (both hardware and software) which could decode navigation commands issued by the user to steer an electric wheelchair. This system harvested electrical activities produced by eye movements (EOG), filtered them (using both analog and digital filters) and decoded these signals as navigation commands. I published this work in a peer-reviewed IEEE conference and the work is cited more than 10 times so far.

I realized that to be able to mimic the learning and decision-making process in the brain, I needed an even deeper understanding of neuroscience, algorithms, signals and systems, and coding. I did two master's in Biomedical Engineering, and Electrical Engineering at Amirkabir University of Technology (the center of excellence in the BME field at my home country, Iran) and University of Southern California (USC), respectively. I also did an internship as a Data Scientist at NovaSignal (previously, Neural Analytics; California, Los Angeles), which is a company working on a new generation of robotic brain imaging systems. During this time, I mastered several skills and techniques in all the areas I had aimed for and published a number of state-of-the-art papers. I was now able to develop and train machine learning algorithms that would outperform humans in many tasks such as decoding brain signals, or tune control parameters on a blood glucose regulator. But when I wanted to implement this knowledge in real-life everyday tasks, to have my systems work in real (as opposed to simulation), physical environments and in the presence of uncertainty in state space, everything was breaking apart; there was still something missing.

I started my Ph.D. research focusing on different modalities of neural recordings (spiking activity, ECoG, EEG, etc.) and trying to understand the underlying processes of the brain during learning, decision making, and execution of motor commands. This led to a number of publications including an IEEE EMBC 2017 publication on decoding finger movements based on ECoG recordings. At the same time, I was investigating neuromechanics in biological structures to understand the complexity of the problem our brain faces while controlling them. It was only after repeated, long, but enthusiastic meetings with my Ph.D. advisor and mentor, Professor Francisco Valero-Cuevas, that I reached an understanding which felt like a revelation to me: Our brain doesn't look at any aspect of life in a divorced fashion or out of context. It processes everything with regards to their priors and the subspaces that are confined by the physical limitations of the tasks. Moreover, by doing so, it can use hierarchy to limit learning at each level and distinguish task specific features with more higher-level general concepts that are common across a wider set of tasks. Finally, it seemed like that I had found the last missing piece of the puzzle. That is when I decided on pursuing this approach and extending it to the field of machine learning. We call this hierarchical and intertwined learning in which signals are collected, processed, and interpreted within their context "Autonomous Learning in the context of Brain-Body Coevolution" which is also the title of my Ph.D. dissertation. I would like to open up this topic and its applications a bit further by going over some of my most recent work:

In a paper (first authored) published in Nature machine intelligence, we provided an efficient, hierarchical Reinforcement Learning (RL) based algorithm that enables bio-inspired tendon-driven robots (which are known to be challenging in their controls due to their under- and over-determined activations) learn functional locomotion in as short as 5 minutes. It was done using the idea of "motor babbling", which is letting the system explore its physics using random activations and observing its resulting kinematics (similar to playing in juvenile vertebrates). We further limited the search space to cyclical patterns (inspired from Central Pattern Generator circuits in peripheral nervous system) which drastically reduced the duration of the trial-and-error phase. Enabling learning using interactions with real, physical world and letting the RL agent absorb all of its characteristic through exploration made our algorithm agnostic to modeling errors and even eliminated the need to have any kinematic model to start with! The work was considered revolutionary in many aspects and made it to the cover of the March 2019 issue of Nature machine intelligence, and got covered by a wide range of domestic and international news outlets including PCmag and VOA.

In another paper (first authored), in a collaboration with Dr. Jie Tan (from Google Brain/Robotics) we have tested the ability of this model agnostic, context-based learning approach in an assisted locomotion task in the presence of elastic elements on the limb. Elastic elements are known to be extremely hard to model and account for in analytical control frameworks. Our results showed that not only our approach was successful in finding relevant control strategies, but also able to utilize low-pass filtering and energy storage capacities of these elastic elements which would lead to smoother and more energy efficient locomotion behavior. This is a great example of how physics of elements, which might often get disregard due to simplifications in modeling or analytical processing challenges, can be treated as subsystems with "embodied intelligence". Embodied intelligence is described as the way in which physics of a system play a part in processing the way it interacts with its environment or processes signals/actions (such as low-pass filtering movements in the elastic element case; as another example, a car differential is a great example of embodied intelligence) which is best embraced when the learning algorithm is designed to be aware and interact with physics of the system and the task it is working on. This will lead to faster, more robust, and more efficient learning and control solutions. This work was accepted and published in IEEE EMBC 2020 proceedings, which is IEEE's flagship conference in Biomedical Engineering and Bio-inspired systems.

In another extension of this experience-driven learning approach, we have trained a neural network using the data from a short motor babbling phase and predicted the joint angles in a tendon-driven robotic system by only reading motor forces and tendon tensions. Therefore, we could eliminate the need for joint angle sensors. This is revolutionary for the humanoid robotic design since by eliminating the need for placing either actuators or sensors on the joints, they can get rid of bulky joints and have flexibility in changing the center of the mass toward the main body (more proximal). This would significantly reduce energy consumption, increase flexibility and enable smoother and more humanlike movement. This work was accepted and published in IEEE IROS 2020 proceedings, which is one of the IEEE's flagship conferences in Robotics and Autonomous systems.

Lastly, I was a part of the Health, Technology, and Engineering program (HTE) at USC, where we went through a four years training on different subjects such as idea development, prototyping, costumer discovery, market analysis, patenting, etc. to be well prepared to come up with and pursue ideas (hardware, software, or both) that will have real-world applications and can survive in a competitive market with an especial focus on the healthcare field. This training significantly helped me to have a better vision on how to close the gap between research and applications which lead to winning or becoming finalist in a number of hackathons or tech-based entrepreneurship competitions.

Research Agenda

Currently, I am diving deeper into the realm of brain-body coevolution and exploring in more detail how system and task physics can be considered to enhance learning: how the learning algorithm can utilize physics of the system and constraint of tasks to enhance learning and facilitate control process. I am planning on pushing this field of research further and toward a wider range of applications such as brain machine interface devices (BMI/BCI), autonomous robotics, and medical prediction and decision making applications with a goal of developing system that can learn from limited data (as opposed to vast offline/simulation datasets which is the current trend in AI), generalize to new and unforeseen situations without catastrophic forgetting of prior tasks, and act accurately under uncertainties of real-world challenges.

Moreover, I am pushing my research on modular and hierarchical learning algorithms even further which would inherently confine the lower-level subtasks which yields extremely data-efficient learning on individual tasks within a task repertoire. This approach will also enable generalizability in the higher-level subsystem that oversees the task learning and orchestrate their timely execution by distinguishing lower-level task-specific features from higher-level communalities across tasks. This higher-level network would process tasks within their conceptual level and generate intention signals that will translate to action further down the hierarchical pipeline (similar to how higher-level cortical regions such as posterior parietal cortex interacts with more peripheral nervous circuits).

Funding and Collaboration Statement

I have been very actively involved with a number of grants proposal preparation and submission process based on this line of work and in the context of domestic and international collaborations which has yielded significant funding awards from some of the most competitive agencies (such as US Defense Advanced Research Projects Agency Lifelong Learning Machines – DARPA L2M – program). During my prospective research program, I am planning on continuing this approach and being actively in touch with both my domestic and international collaborators (who are from a wide range of expertise including neuroscientists, brain machine interface experts, roboticists, biomechanics, AI experts, etc.) as well as reaching out to institutes and agencies for collaborations, contracts, and/or grant applications.

Diversity and outreach statement

I am a big advocate of diversity since I deeply believe that a diverse set of cultures is an essential part of any society, including work environments, to function in a healthy way. Not only do different cultures provide different perspectives to challenging problems but also being in a vibrant and diverse society enables individuals to absorb essential values such as respect, acceptance, and tolerance, without which we would be doomed in an unhealthy and low-spirited society in which it would be impossible to thrive and flourish. It is important to note that what makes us special as humans are our ideas, passions, and the ability to empathize, none of which are reserved to a specific race, culture, or ethnicity.

I also believe that actions speak louder than words. That is why I did my best to engage in programs promoting diversity and outreach. During my Ph.D. at USC, I volunteered to teach programming to high school students through the SHINE program (targeted outreach to underrepresented minority groups and girls). Also, every year, I was an active member of the USC robotics open house which is an entire day open house exhibition at the robotics division of USC for students, families, or robotic and autonomous system enthusiasts in general, to visit labs and interact and have discussions with roboticists at USC and exchange ideas about their passions and prospective future plans on how to join and contribute to the field.

Services and contributions summaries

- **Services and leadership summary**
  - Assistant editor of Paladyn, Journal of Behavioral Robotics – De Gruyter
  - Chairing the "Brain-machine Interface and Sensory Perception" session at ICONIP2020
  - Co-chairing the "Biorobotics and Biomechanics & Computational Systems & Synthetic Biology; Multiscale modeling" session at IEEE EMBC 2018
  - Reviewing more than 40 papers for highly credible journals and conferences such as IEEE Transactions on Pattern Analysis and Machine Intelligence (IEEE TPAMI), IEEE IROS, IEEE EMBC, and ICONIP
  - Mentoring more than 15 undergraduate and master students which has led to successful engineering applications and peer-reviewed publications
  - President of the student branch of the Society for Brain Mapping & Therapeutics (SBMT) at USC
  - Vice president of the Iranian Graduate Student Association (IGSA) at USC
  - Membership and participations: IEEE Student member; Society for Neuroscience (SfN) student member; American Society of Biomechanics (ASB) student member

- **Professional contributions summary**
  - Authoring and co-authoring 14 peer-reviewed papers
    - Citations: 73; h-index: 6; i-10 index: 4
    - Published with credible publishers (Nature Publishing Group, SpringerNature, etc.) and conferences (IEEE IROS, IEEE EMBC, etc.)
  - Giving invited talks at cutting-edge research institutes (Google Brain, Disney Imagineering, MathWorks)
  - Being featured on more than 80 news outputs (news stories, technical articles, interviews, etc.)