Research Statement – Federico Vasile

"The goal for many amputees is no longer to reach a 'natural' level of ability but to exceed it, using whatever cutting-edge technology is available. As this new generation sees it, our tools are evolving faster than the human body, so why obey the limits of mere nature?"– ***Daniel H. Wilson***

Modern prosthetic technology has achieved remarkable advances, yet the goal of matching—and possibly exceeding—natural human capabilities remains out of reach for millions of amputees. Although prosthetic hardware has advanced significantly—including dexterous multi-fingered hands with several degrees of freedom—the critical bottleneck lies not in mechanical design, but in **intelligent control**. Most commercial hand prostheses rely on electromyography (EMG) or mechanomyography (MMG) signals, which require placing electrodes on the amputee's skin surface and performing muscle contractions to translate these input signals into motor velocity commands. However, this control strategy becomes increasingly complex as the number of degrees of freedom to control grows, ultimately hindering dexterous manipulation and intuitive control.

Building on this observation, complementary input modalities can be introduced to improve dexterity without sacrificing system usability. To this end, *my research explores the use of Computer Vision to enable dexterous and intuitive prosthetic hand control*. More specifically, during my PhD, I focused on vision-based prosthetic grasping: using a camera (with eye-in-hand placement) to predict a hand configuration while the amputee approaches the object for grasping. Two different directions have been explored: first, I devised computer vision datasets and models for predicting a hand pre-shape [1] and wrist orientation [2] based on the object in the image; second, motivated by the partial overlap between robotics and prosthetics, I investigated how vision-based grasping strategies can be adapted to the prosthetic context [3, 4], addressing the unique challenges that arise when replacing a robot with a human user.

Below, I first elaborate on my key contributions along these two themes, and then conclude with my future plan on this emerging research area.

Research Progress

1. Pre-shape and Wrist Control for Prosthetic Grasping

Pre-shape prediction [1]. A key limitation of current vision-based prosthetic systems is the lack of standardized datasets and benchmarks, which hinders reproducibility and requires custom data collection for each new scenario. To address this gap, I developed a framework for synthetic generation of videos for prosthetic grasping. Moreover, most existing models predict a single grasp configuration per object, neglecting the variability in how an object can be approached and grasped—ultimately limiting dexterity. In contrast, the proposed data generation pipeline produces diverse, human-like approach-to-grasp trajectories for different object parts. These synthetic videos are used to train models that predict a hand pre-shape configuration right before grasping the object. Experimental results show promising generalization performance, with models achieving zero-shot sim-to-real transfer across scenarios of increasing complexity. In conclusion, this work demonstrates the potential of synthetic data for building adaptable and robust vision-based prosthetic grasping models. The dataset and code were made available to the scientific community.

Continuous wrist control [2]. While the previous work focused on improving dexterity through hand pre-shape prediction, it overlooked the wrist orientation. This forces the user to perform compensatory movements with the elbow, shoulder and torso to adapt the wrist for grasping. As a further step toward human-level dexterity, I proposed a vision-based system for continuous control of the wrist degrees of freedom in a prosthetic arm from an eye-in-hand camera, promoting a more natural approach-to-grasp motion. This pipeline allows to seamlessly control the prosthetic wrist to follow the target object during the approach, and finally orient it for grasping according to the user intent. The system includes a real-time control scheme and an instance segmentation model, both evaluated through quantitative experiments. The system was deployed on a hand prosthesis, enabling natural wrist motion during the approach and intuitive grasp executions. This work emphasizes the importance of dedicated wrist control for achieving human-like dexterity in upper-limb prostheses.

2. From Robotic to Prosthetic Grasping

Leveraging robotic grasp generators for prosthetic applications [3]. Vision-based grasp synthesis in robotics has made remarkable progress, but its potential remains underexplored in prosthetics, where unique challenges—such as the need to conform to user intent—make its adaptation non-trivial. To investigate this opportunity, I proposed a vision-based grasping system for upper-limb prostheses that integrates a robotic grasp generator with modules for dense depth prediction and user hand trajectory estimation during the approach. From the user's perspective, the system infers intent during the approach and use this information to automatically select the most suitable grasping pose. The approach was deployed on a hand prosthesis and tested on both healthy and amputee participants. Results demonstrate robust generalization across unseen objects and faster grasp executions compared to a baseline relying solely on EMG signals. This work shows the promise of leveraging robotic strategies in prosthetic control, opening new avenues beyond traditional frameworks.

Learning from demonstrations [4]. Previous works focused on structured environments (e.g., table-top settings), where grasp labels and user intent can be readily defined. However, extending these systems to unstructured scenarios—such as cluttered scenes or handover tasks—introduces significant challenges. In such cases, manual annotation (e.g., segmentation maps of handheld objects) and specifying grasp targets (e.g., determining the correct contact area on a mug during a handover) become impractical. In contrast, demonstrations inherently encode the necessary information to perform these tasks. This makes Imitation Learning a compelling alternative. To explore this direction, a dataset of demonstrations across diverse objects and environments was collected and used to train an Imitation Learning policy from visual input. Quantitative results show that the learned policy outperforms previous methods in unstructured settings. In conclusion, learning from demonstrations represents a viable solution to scale prosthetic autonomy in real-world scenarios.

Future Research Agenda

What comes after grasping? While previous works have focused on grasping objects using an eye-in-hand camera, this view becomes occluded once the object is held. Many real-world tasks—such as pouring water into a glass—require coordinated, bimanual actions that go beyond grasping. In these cases, an egocentric view from a head-mounted camera provides a richer perspective of the environment and task to be executed. Therefore, I plan to explore vision-based control strategies for bimanual prosthetic manipulation, enabling the prosthesis to collaborate with the intact hand. This shift introduces new challenges in perception, intent inference, and control, but it is a crucial step toward restoring more natural and functional interaction in daily activities.

References

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