A VIRTUAL REALITY TRAINING ENVIRONMENT FOR MYOELECTRIC PROSTHESIS GRASP CONTROL WITH SENSORY FEEDBACK

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ABSTRACT

Upper limb myoelectric prosthesis control is difficult to learn. Virtual reality has seen increased deployment in recent years for prosthesis training because it is repeatable, engaging, and can be implemented in the home. While most virtual reality prosthesis simulators do not challenge grasp function, this paper presents the Virtual Prosthesis Emulator (ViPEr), a virtual reality environment for prosthesis grasp control with sensory feedback. For sensory feedback in ViPEr, we have derived data-driven transfer functions that best approximate the applied force from a physical prosthesis and integrated them into a sensory feedback system. This system allows us to relay the interaction force using mechanotactile tactors and recreate realistic interactions, including objects' specific lift, crush, and deformation characteristics. We will use ViPEr in an upcoming study to evaluate the skill transfer to physical prosthesis performance and the effect of providing sensory feedback in virtual reality training.

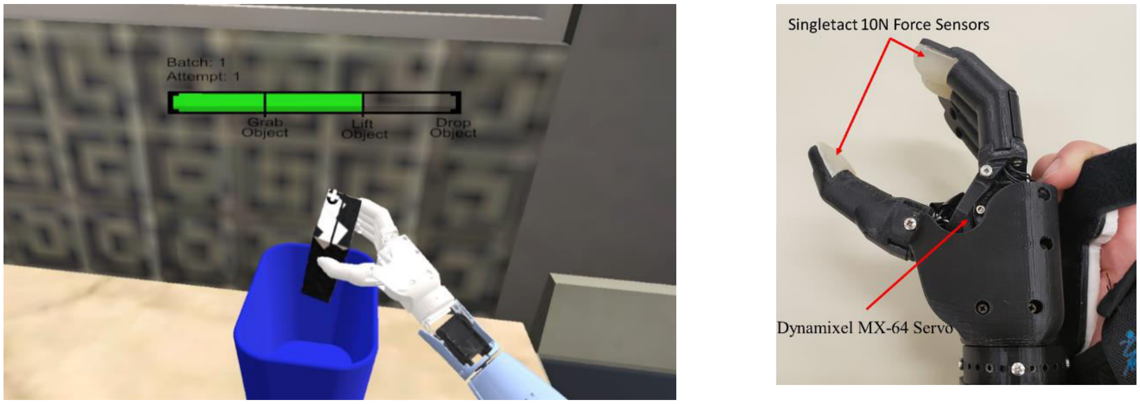
INTRODUCTION

Myoelectric control for prostheses is complex and often proves challenging due to its learning curve [1]. The difficulty is compounded because prosthesis fitting can take several months following an amputation. This prolonged period of disuse of the residual limb can lead to muscle atrophy and intact arm compensation [2], further complicating the learning process of operating the prosthesis once fit. As a result, individuals can experience dissatisfaction with their prostheses and abandon them [3]. Current training methods typically involve pre-fitting muscle contraction visualizations, training with physical hardware at the clinic [4], and intensive post-fitting daily training sessions [2], which can be logistically demanding.

In response to these challenges, researchers have begun to explore the potential of Virtual Reality (VR) environments as a tool for prosthesis training [5-7]. Their purpose is to supplement the current training methods in conjunction with occupational therapists to mitigate travel and scheduling barriers [5]. Virtual environments are complex, immersive, three-dimensional prosthesis simulators. VR training platforms can offer several benefits over current training methods. They allow users to experiment with the prosthesis without fear of causing damage — are engaging, and efficient, making them ideal for use in TeleHealth, i.e. remote community health centers and at-home rehabilitation settings [5,7,8]. VR training has also been shown to be beneficial for managing Phantom Limb Pain [9]. However, it is important to note that while these platforms offer many advantages, most currently have "snap-on" object grasping [5-7] and do not challenge prosthesis grasp control. For this, we have developed the Virtual Prosthesis Emulator (ViPEr) that focuses on grasp control and incorporates sensory feedback. Sensory feedback can enhance the performance of novice users of myoelectric prostheses, as it allows them to make minor adjustments in real-time [10]. However, sensory feedback may become less useful as users gain proficiency in controlling their prostheses since they can create more precise control [10]. Therefore, sensory feedback may be most effective during the training phase, when users are inexperienced. This paper presents an overview of ViPEr and the methods for the implementation of real-time touch and force feedback for virtual object interactions.

METHODS

Virtual Prosthesis Emulator (ViPEr). ViPEr is a virtual reality training platform for prosthesis control with up to 3 degrees of freedom (hand, wrist rotation, elbow). Developed in the Unity Game Engine Version 2019.3.2f1, based on feedback from clinicians, persons with transradial, and persons with transhumeral amputation, ViPEr is an intermediary training platform for use prior to prosthetic fitting (**Figure 1a**). Its current configuration utilizes commercially available computer equipment and myoelectric sensors, including a desktop computer, a Vive VR headset, a Vive Tracker (HTC, Taiwan), a Myo armband (Thalmic Labs, discontinued, Canada), and a mechanotactile feedback system [11]. In ViPEr, the virtual prosthetic hand is the PowerHand [11], a one-degree-of-freedom, sensorized, 3D-printed hand that operates by opening and closing at a velocity proportional to the strength of the input signals (**Figure 1b**). Muscle signals acquired by the Myo Armband are linearly mapped to the opening and closing velocity of the PowerHand via the brachI/Oplexus software [12]. This emulator offers a training environment where participants progress through successively more challenging and gamified training tasks. These tasks are goal-oriented to maximize user engagement [7]. The platform also incorporates mechanotactile sensory feedback to enhance the training experience. As the training scene represent rooms of a house, ViPEr is a versatile prosthesis training tool for activities of daily living.



a) **b)**

Figure 1: a) User's point of view in ViPEr moving a milk carton into the stew recycling bin, **b)** PowerHand 1 DoF prosthesis with fingertip sensors and servo locations.

<u>Force Approximation</u>. We created custom interaction physics for the PowerHand in ViPEr to simulate object interactions and deliver grasp control training. While we used Unity's physics engine in ViPEr, it was not sufficient in an unmodified form for our intended grasp force deployment setting. We recorded hundreds of physical object interactions using fingertip force sensors, embedded in the PowerHand, to identify transfer functions from myoelectric inputs and contact duration to prosthesis force. Four objects were recorded interacting with the PowerHand, which had identical dimensions and were categorized by their deformations under a 1 kg mass into soft, medium, hard, and rigid compliances (**Figure 2a**). To limit mechanical variation and ensure consistent grasping, we fixed the position of the PowerHand and objects. Given the unsteady nature of myoelectric signals, we gave steady input signals across the myoelectric range for repeatability. These recorded inputs are ratios from 0 to 1 in increments of 0.05, corresponding to the percentage of maximum voluntary contraction (%MVC). Once recorded, we removed some of the electromechanical dead zones created by the silicone fingertips, delay in data acquisition, fingertip sensors, and object compliance. Dead zone removal was implemented to create responsive force profiles to relay real-time touch feedback. We then averaged, calibrated for aperture, filtered by batch of input %MVC, and combined the raw data into a training set. We used a polynomial regression to derive smooth transfer functions that best approximated the force profiles of the PowerHand, with the extracted feature being the sum of the %MVC at 64 Hz after object contact (Eq. 1-4). The instant the user attempts to grasp an object in ViPEr, we sum the provided %MVC inputs from their muscle signals (**Figure 2b**).

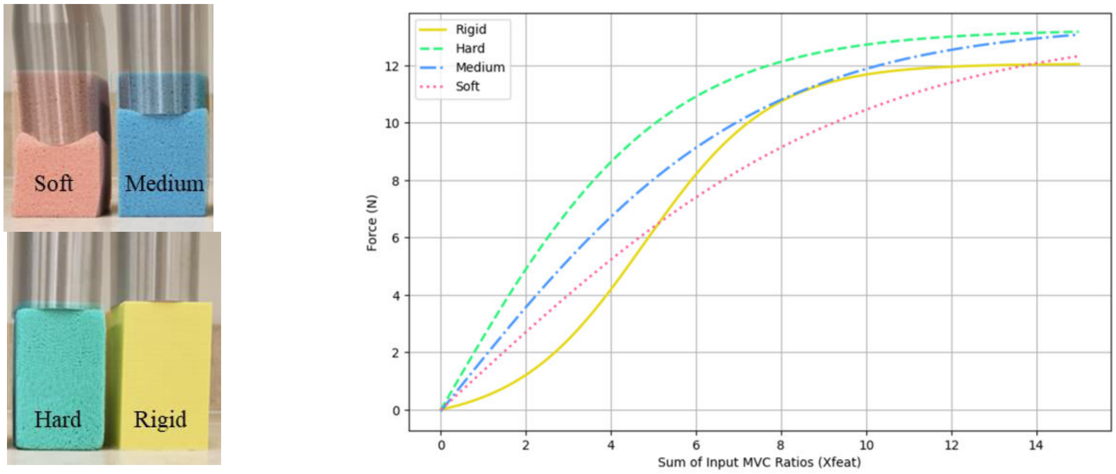
$$\text{Rigid: } f(x) = \frac{12.56}{1+e^{(-0.666\sum|\text{contact}|(\%\text{MVC})+3.181)}} - 0.50 \quad (1) \qquad \text{Med: } f(x) = \frac{26.70}{1+e^{(-0.277\sum|\text{contact}|(\%\text{MVC})+0.031)}} - 13.20 \quad (3)$$

$$\text{Hard: } f(x) = \frac{26.25}{1+e^{(-0.391\sum|\text{contact}|(\%\text{MVC})+0.022)}} - 13.0 \quad (2) \qquad \text{Soft: } f(x) = \frac{25.75}{1+e^{(-0.212\sum|\text{contact}|(\%\text{MVC})+0.090)}} - 12.30 \quad (4)$$

The rigid profile was unexpected and didn't follow the stiffness trend, which we attribute to the dampening effect of the compliant object on the onset of applied force. We intentionally aimed to simulate this behaviour. These TFs are implemented in ViPEr to simulate grasp forces and provide sensory feedback.

<u>Feedback Implementation.</u> The mechanotactile feedback system in ViPEr is designed to enhance the immersive experience by providing feedback on object interactions, typically limited in VR. The emulator utilizes a

mechanotactile tactor connected to Unity via a UDP connection. The tactor relays the virtual force values, based on the TFs, proportionally extending or retracting the tactor head. The design of the mechanotactile tactors is a rack and pinion mechanism detailed in [11].



a)

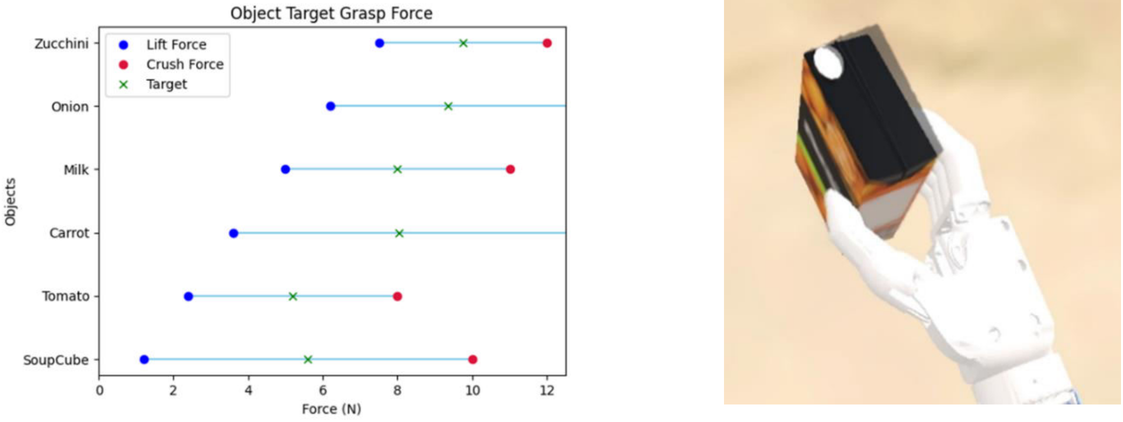
b)

Figure 2: a) (Left to right, top to bottom) Soft, medium, hard, and rigid objects and their deformation under a 1 kg compressive load, **b)** TFs for applied force from the sum %MVC ratios after contact by compliance.

Tasks. Participants with upper limb amputation and clinicians informed task development and constraint identification for ViPEr. ViPEr's levels span a virtual house, including kitchen, living room, and bedroom scenes. To progress through the levels, users must achieve a prespecified success rate on the current level before advancing to the next. The progressive difficulty and success rate only allow users with higher prosthesis grasp control to attempt advanced levels. All tasks in ViPEr are object relocation tasks. In the kitchen, there are two tasks: the recycling task — where the user moves empty common household cartons into a recycling bin - and the stew-making task (**Figure 1a**) — where users move six food objects into a pot. In the living room scene, users move books and small objects around and on a bookshelf. Finally, in the bedroom scene, users put away clothes and other small objects into designated drawers in a dresser. There are four ways to increase the difficulty level. First, we start varying the mass of the objects, affecting how much virtual force the user must put on the object before it can be picked up. Next, we add object fragility by setting the maximum allowable applied virtual force. Interactions with these objects require precise grasp force modulation; too little force causes the object to slip out of the virtual hand, while too much force crushes the object. **Figure 3a)** shows the lift and crush thresholds of the objects in the stew-making task. Third, we add object compliance. The objects in this difficulty level deform along the imaginary line between the fingers and thumb of the virtual prosthesis, as shown in **Figure 3b)**, to the same degree as the soft, medium, and hard objects used to develop the TFs in **Figure 2a)**. Finally, we increase the number of controllable DoFs.

DISCUSSION

A main contribution of the present work and the pilot study with two able-bodied participants is initial evidence that ViPEr should be explored as a training platform by evaluating the skill transfer to wearable prosthesis performance, which is crucial for future clinical translation. Our study design involves recording participants' baseline physical prosthesis performance, followed by three one-hour training sessions in ViPEr, and then repeating the physical prosthesis evaluation to assess skill transfer. We hypothesize participants will improve their myoelectric grasp control after the training. We also examine the effect of training with sensory feedback on the evolution of skill level throughout the training sessions by randomly assigning participants to either a feedback or no-feedback group in ViPEr. We periodically probe the feedback groups' understanding of the grasp force control throughout their training with no-feedback trials. We expect to gain insight into the learning curve of both groups and the role of sensory feedback in training. Finally, we are comparing the post-training performance of the groups with the no-feedback physical prosthesis to evaluate the effect of using sensory feedback as a training tool. We hypothesize that sensory feedback in ViPEr will improve training efficacy and skill transfer. Written informed consent was obtained from participants prior to conducting the pilot study as approved by the University of Alberta's Research Ethics Board (PRO0007893).



a) **b)**

Figure 3: a) Grasp force ranges for the food items used in the stew making task, with blue, green, and red markers representing the required lift, target, and crush forces respectively, **b)** Deformed juice carton when grabbed in the recycling task with a semi-transparent overlay of the undeformed shape, equivalent to the medium object.

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