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Gaze and Motion Synergies in VR Reaching Tasks towards Multi-Joint Prosthetic Arm Control

Abstract: In this poster we present our initial exploration of gaze and motion synergies related to the arm, and the future work we intend to pursue as a direct continuation. Our initial exploration consisted of analyzing gaze and motion data found in a public dataset, which lead to the preliminary results that the gaze point's velocity anticipates the hand's velocity and that the gaze and hand position converge in the lead-up to a grasp.
The dataset we used holds only location, orientation and time data for non-naturalistic reach-and-grab tasks that were performed in VR, and therefore we intend to move forward with our own dataset. This new multi-modal dataset will hold gaze, sEMG and kinematic data recorded during real-world naturalistic activities of daily living (ADLs). Once the dataset has been created, we will use to better understand muscle, postural, and gaze synergies in upper limb movements, and to eventually leverage early motor synergies to predict user intent. The results of the above will then be implemented in a prosthetic arm controller.

Methods: The data analyzed and presented in the poster comes from the public dataset "3D-ARM-Gaze"[1], which holds the arm movements along with visual and gaze information of a number of subjects who were given reach and grasp tasks in VR, while seated. We started by applying a transform from the data's "world" coordinate system (with an unknown origin and orientation) to an egocentric coordinate system centered and oriented on the user's head. Next, numerical differentiation was used to calculate the gaze and hand velocity and acceleration, followed by removing outliers – which were defined as points in the data that were at least 3 standard deviations larger than the preceding or following point on the same axis. Finally, the velocities and accelerations were passed through a 5Hz LPF to reduce noise. The normalized per-axis velocities and accelerations were then plotted to compare the hand's and gaze point's motions, as were the location differences along each axis and absolutes distance between the hand and the gaze point.

Results and Discussion: We see that the person's gaze anticipates the hand's velocity during most of the motion, but starts moving in a decoupled manner once the hand is stationary or nearly so at the end. In terms of positioning, we see that the hand converges on the gaze point's position during the trials.
Based on our analysis of [1] and following the work performed in [2] we intend to perform the following:

a) Develop and integrated platform for recording multi-modal gaze, sEMG and kinematics. Initial efforts can be seen in figure 5 of the poster, in the form of synchronized (triggering and recording of) sEMG and gaze tracking.
b) Conduct an "in-house" study of naturalistic ADLs in a real-world setting, to gather a robust multi-modal dataset using (a).
c) We want to better understand muscle, postural, and gaze synergies during upper limb movements, as we believe they enable simplification of prosthetic arm controllers.
d) Further explore early motor synergies using the data recorded in (b).
e) Implement all of the above in a prosthetic arm controller, which will then be tested – ideally using a real prosthetic arm, but possibly even in a VR environment.

Bibliography:

[1] B. Lento *et al.*, "3D-ARM-Gaze: a public dataset of 3D Arm Reaching Movements with Gaze information in virtual reality," *Sci Data*, vol. 11, no. 1, p. 951, Aug. 2024, doi: 10.1038/s41597-024-03765-4.

[2] N. E. Krausz, D. Lamotte, I. Batzianoulis, L. J. Hargrove, S. Micera, and A. Billard, "Intent Prediction Based on Biomechanical Coordination of EMG and Vision-Filtered Gaze for End-Point Control of an Arm Prosthesis," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 28, no. 6, pp. 1471–1480, Jun. 2020, doi: 10.1109/TNSRE.2020.2992885.