APPENDIX

ADDITIONAL KINEMATIC POSTURE RETARGETING RESULTS

Three sets of additional quantitative results of kinematic posture retargeting on another trajectory involving finger crossing motions and on the Shadow Hand are shown in Fig. 5. Similar conclusions to the main text can be derived.

ADDITIONAL DETAILS OF OBJECTIVE FORMULATION

Relative position among fingertips: The pinch term is formulated as:

$$\mathcal{L}_{\text{pinch}} = \sum_{i=1}^{N-1} s(d_i) \left\| \boldsymbol{\gamma}_i^r - l(d_i)\hat{\boldsymbol{\gamma}}_i^h \right\|^2, \tag{6}$$

where $\boldsymbol{\gamma}_i$ is the vector from the thumb fingertip to the fingertip of the i^{th} primary finger, $d_i = \left\| \boldsymbol{\gamma}_i^h \right\|$ and $\hat{\boldsymbol{\gamma}}_i^h = \frac{\boldsymbol{\gamma}_i^h}{d_i}$. Instead of using a discrete weight function as DexPilot, we use a continuous weight function

$$s(d_i) = \text{sigmoid}(d_i, \epsilon_1, 10),$$

where $\text{sigmoid}(\cdot)$ is the sigmoid function defined as follows:

$$\text{sigmoid}(\text{x}, \text{c}, \text{w}) = \frac{1}{1 + e^{w(x-c)}}.$$

Our distance rescaling function is defined as follows:

$$l(d_i) = \begin{cases} 0, & d_i < \epsilon_2 \\ \frac{\epsilon_1}{\epsilon_1 - \epsilon_2}(d_i - \epsilon_2), & \epsilon_2 \leq d_i \leq \epsilon_1 \\ d_i, & d_i > \epsilon_1, \end{cases} \tag{7}$$

where fingertip distance within pinching range $[\epsilon_2, \epsilon_1]$ is linearly rescaled into $[0, \epsilon_1]$. This ensures a continuous transition in the pinching range and avoids sudden changes around the threshold ϵ_1. In practice we set $\epsilon_1 = 1 \times 10^{-1}$ m and $\epsilon_2 = 1 \times 10^{-2}$ m.

Overall hand shape: To balance fingertip positions relative to the wrist and the thumb, we also set a switching weight for the fingertip position term $\mathcal{L}_{\text{fingertip\_pos}}$:

$$\mathcal{L}_{\text{fingertip\_pos}} = \sum_{i=1}^{N} \tilde{s}(d_i) \left\| \boldsymbol{v}_i^r - \boldsymbol{v}_i^h \right\|^2, \tag{8}$$

where

$$\tilde{s}(d_i) = \text{sigmoid}(d_i, \epsilon_1, -10),$$

so that the sum of $s(d_i)$ and $\tilde{s}(d_i)$ will be a fixed number. In ablation studies where the pinch term is removed (A1, A6 and A8), we set $\tilde{s}(d_i)$ to be a constant 1.0 as in (2).

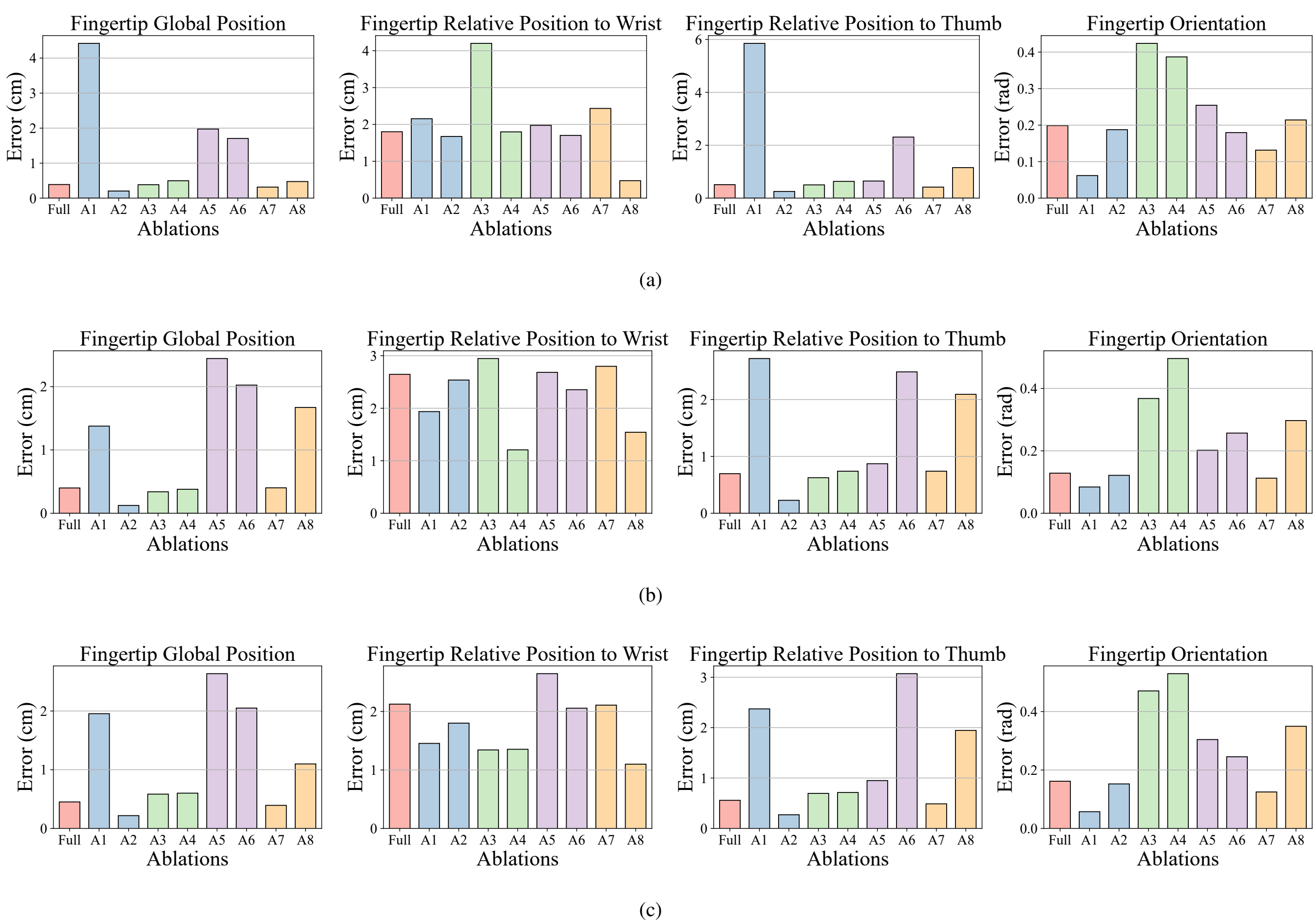

Fig. 5. Additional results on kinematic posture Retargeting. (a) Kinematic posture retargeting results using Leap hand on another trajectory involving finger crossing motion. (b) Kinematic posture retargeting results using Shadow hand on the same pinch motion trajectory as in the main text. (c) Kinematic posture retargeting results using Shadow hand on the trajectory involving finger crossing motion.

Implementation

The hyper-parameters used in the retargeting objective are listed in Table III.

TABLE III
HYPER-PARAMETERS

Hyper Parameter	Value
λ_1	10
λ_2	0.1
λ_3	1
λ_4	10
λ_5	10
w_j^{pos} (Leap hand)	0.5, $j = 7, 11, 15, 18$ 0.1, $j = 20$ 0, else
w_j^{pos} (Shadow Hand)	0.5, $j = 9, 13, 17, 22$ 0.1, $j = 26$ 0, else
w_j^{vel} (Leap hand)	0.1, $j = 0 \sim 6$ 0.01, $j = 7 \sim 22$
w_j^{vel} (Shadow Hand)	0.1, $j = 0 \sim 6$ 0.01, $j = 7 \sim 30$

For the weights of joint position and velocity regularization terms w_j^{joint} and w_j^{vel}, index j from 0 to 6 corresponds to the joints of the Panda arm, while indices $j = 7$ to 22 and $j = 7$ to 30 correspond to the joints of the Leap hand and the Shadow Hand respectively. Note that here we assume all DoFs of the Shadow Hand are actuated. For Leap hand, $j = 7, 11, 15$ correspond to the abduction/adduction joints of index, middle and ring, $j = 18$ corresponds to the DIP joint of the ring, and $j = 20$ corresponds to the rotation of the thumb. For Shadow Hand, $j = 9, 13, 17, 22$ correspond to the finger movements of index, middle, ring and little finger in the palm plane, while $j = 26$ corresponds to the rotation of the thumb. For joints with non-zero position regularization, the pre-defined joint configurations are set to $\bar{q}_j = 0$.

In our implementation, we rescale the size of the human hand by a factor of 1.5 for the Leap hand and 1.0 for the Shadow Hand to address the size difference between human and robot hand. In the real-world experiments, the retargeting control frequency is 20 Hz, and we use an exponential moving average with $\alpha_{\text{ema}} = 0.3$ to further smoothen the joint movements:

$$\boldsymbol{q}_t = \alpha_{\text{ema}} \cdot \boldsymbol{q}_t + (1 - \alpha_{\text{ema}}) \cdot \boldsymbol{q}_{t-1} \tag{9}$$