Implementing Kinesthetic Fingertip Guidance and Constraint on Planar Surfaces

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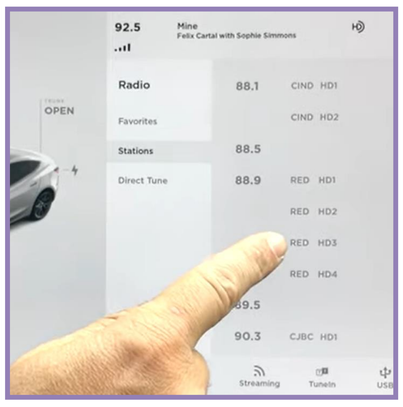
Problem: Inputs to touchscreen interfaces are often not as safe, reliable, or accessible as physical interfaces

Physical Input *vs* **Touchscreen Input**



✓ Eyes-free interaction
✓ Accurate during vibration
✗ Promotes distracted driving
✗ Inaccurate during vibration

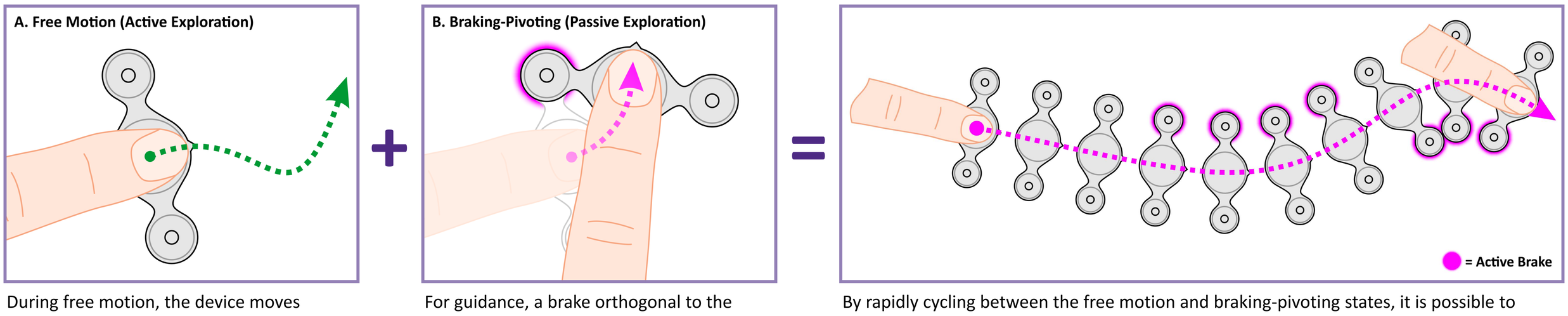
Physical Input *vs* **Touchscreen Input**

✓ Allows grounding of hand
✓ Provides input feedback
✗ Induces hand fatigue
✗ No feedback of input

Physical Input *vs* **Touchscreen Input**

✓ Allows quick input
✓ Works across ability levels
✗ Input requires accuracy
✗ Calls out disability

Approach: Add kinesthetic feedback and guidance to touch surface interactions



During free motion, the device moves passively under the user's fingertip as they explore the touch surface.

For guidance, a brake orthogonal to the direction of motion is activated, creating a pivot and constraining fingertip motion.

By rapidly cycling between the free motion and braking-pivoting states, it is possible to allow the fingertip to travel along the touch surface following a constrained path

Implementation: Use a path's curvature to drive electromagnetic brakes through PWM

Step 1: Obtain the curvature κ of a path at a given point through the radius at that point:

$$\kappa = \frac{1}{R_{curve}}$$

Step 2: Normalize the curvature value with respect to the minimum pivoting radius of the device:

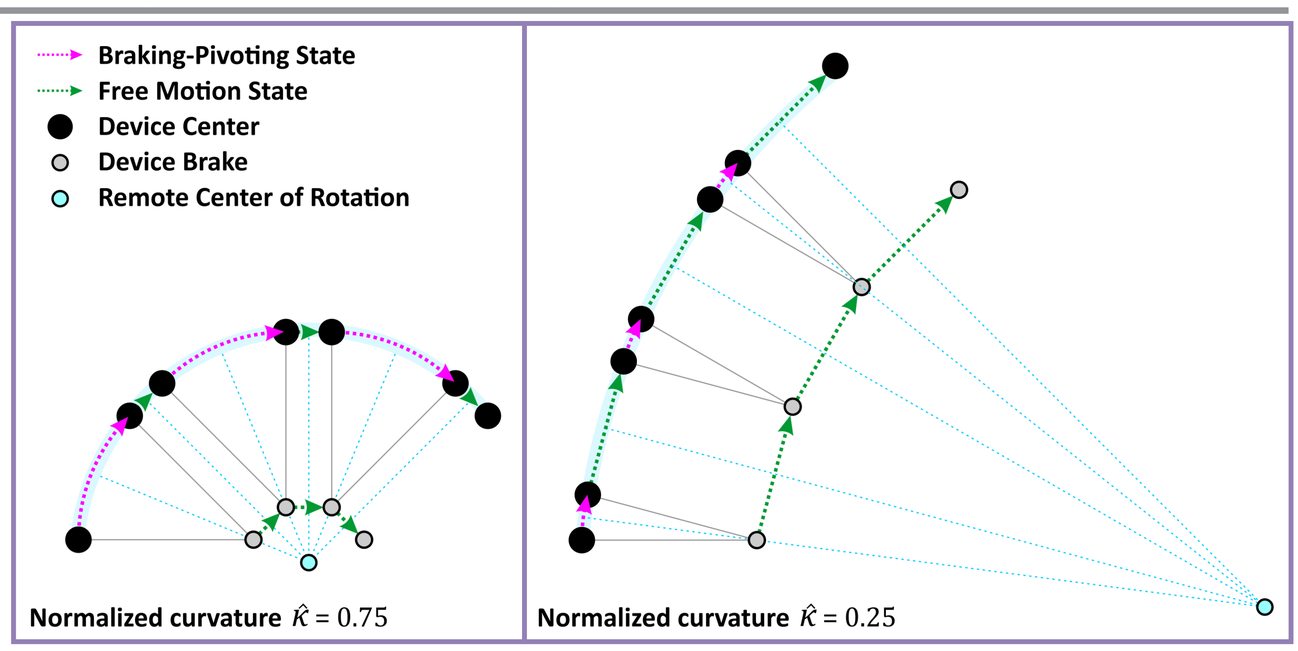
$$\hat{\kappa} = \frac{R_{brake}}{R_{curve}}$$

Step 3: To generate a radius of curvature larger than the minimum pivoting radius, use PWM:

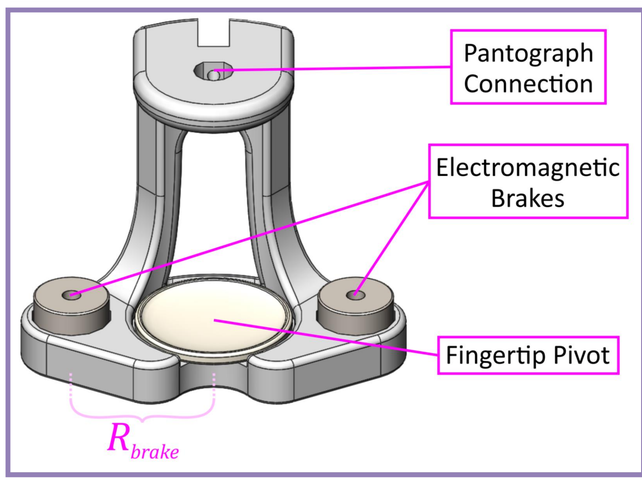
$$t_{braking-pivoting} \cong \hat{\kappa} \times \frac{1}{f_{actuation}} \quad and \quad t_{free-motion} \cong (1-\hat{\kappa}) \times \frac{1}{f_{actuation}}$$

Step 4: To improve path-following performance, a proportional feedback controller is used to account for sources of error, which include $e(X)$, the error of the measured position; $e(\theta)$, the error of the measured device heading; and $e(\varphi)$, the error due to the angle of the user's velocity:

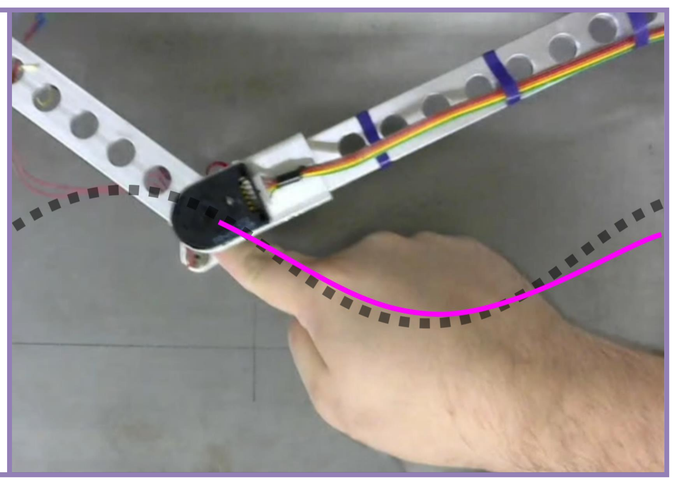
$$u(PWM) = \hat{\kappa}(PWM) + G_X(X_d - X_m) + G_\theta(\theta_d - \theta_m) + G_\varphi(\varphi_u - \theta_m)$$



Prototype and Results: Details and constraint generation

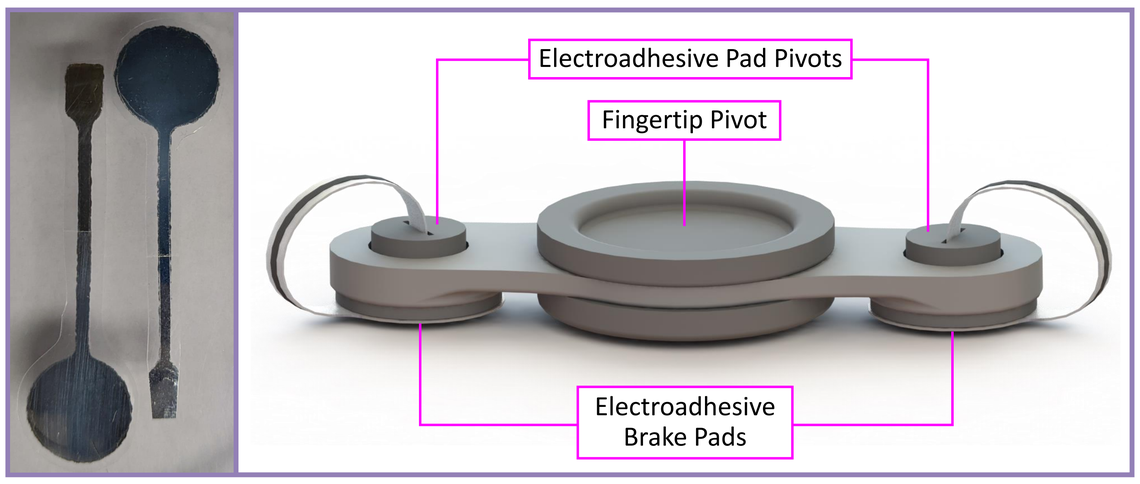


Rendering showing the electromagnetic brakes used to induce the pivoting motion. A point at the top connects to a pantograph, which provides position and orientation data used for control.



Captured video frame demonstrating closed-loop path-based constraint generation (intended path as dashed line, actual constrained path as pink line).

Next Steps: Improvements with electroadhesion



Left: Photo of new electroadhesive brake pads that will replace the electromagnetic brakes in the next iteration, reducing weight (from 7.5g per brake to 0.05g per brake) and vastly improving the PWM switching frequency (from 20 Hz to 20 kHz). **Right:** Rendering of the newer device, showing the implementation of the electroadhesive brake pads.

Acknowledgements: This material is based upon work supported by the National Science Foundation under Grant No. 2106191.