Stiffness Copilot: An Impedance Policy for Contact-Rich Teleoperation

Yeping Wang, Zhengtong Xu, Pornthep Preechayasomboon, Ben Abbatematteo,
Amirhossein H Memar, Nick Colonnese, Sonny Chan

IROS 2026 PITTSBURGH

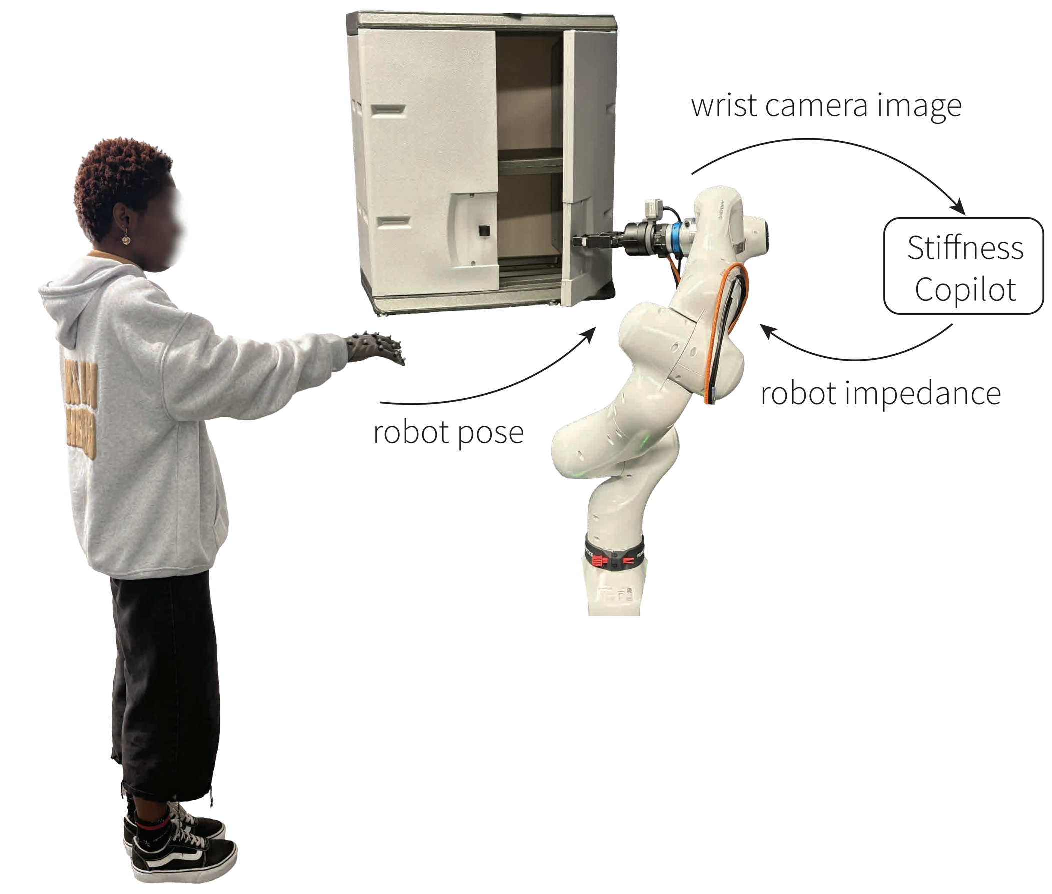
Meta

Synopsis: we present Stiffness Copilot, a policy that adjusts the robot impedance for contact rich tasks.

Motivation

In teleoperation of contact-rich manipulation tasks, selecting robot impedance is critical but difficult. The robot must be compliant to avoid damaging the environment, but stiff to remain responsive and to apply force when needed.

Stiffness Copilot enables a shared-control teleoperation paradigm in which the human operator commands the robot pose while a vision-based policy adjusts the robot impedance

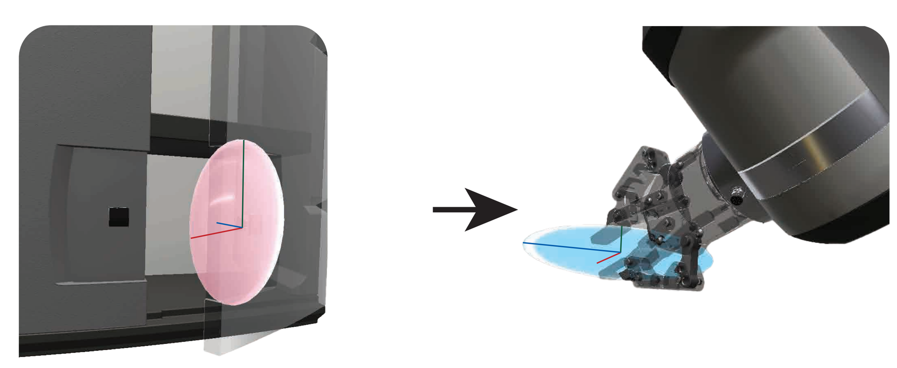


Method

Collect demonstrations in simulation[2]

1. red arrow shows contact force
2. based on Meta PROJECT SuperDex

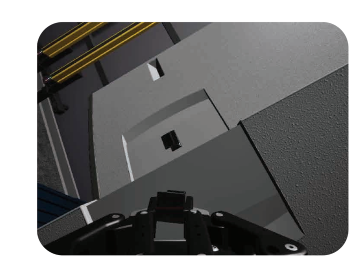
Infer stiffness labels



env stiffness (pink ellipsoid)

robot stiffness (blue ellipsoid)

Train Stiffness Copilot



wrist camera image

$$\begin{bmatrix} \exp(a_1) & & \\ l_1 & \exp(a_2) & \\ l_2 & l_3 & \exp(a_3) \end{bmatrix}$$

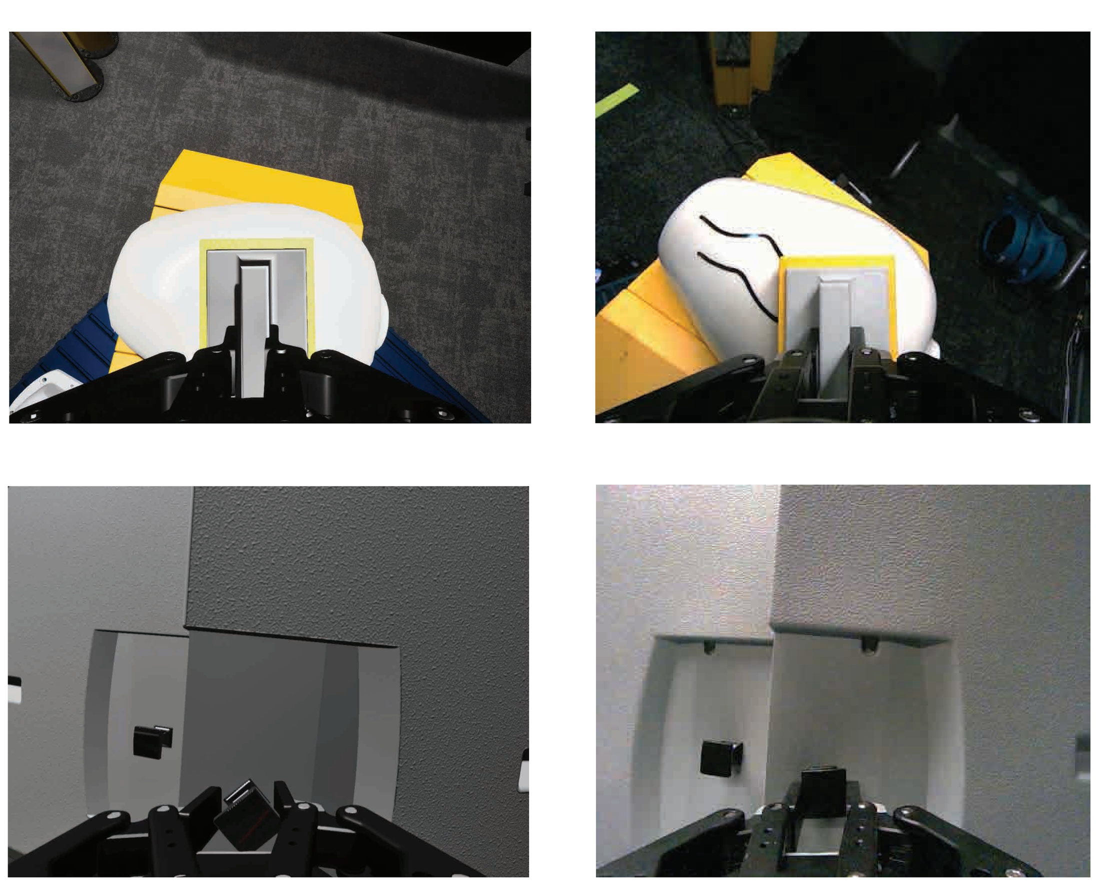
predicted stiffness labels

wrist camera image → DINO v3 → MLP → predicted stiffness labels

Examples

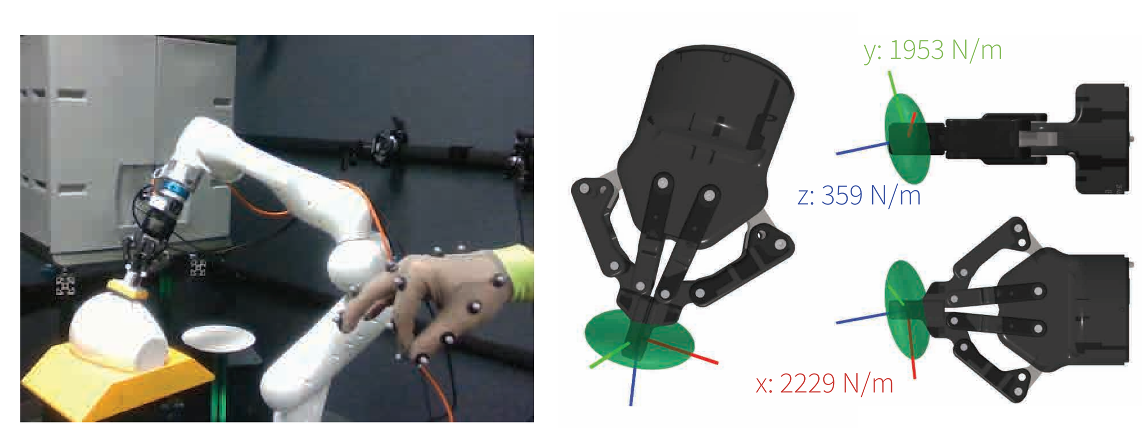
Zero-Shot Sim-to-Real Transfer

Sim wrist image during training | Real wrist image during inference

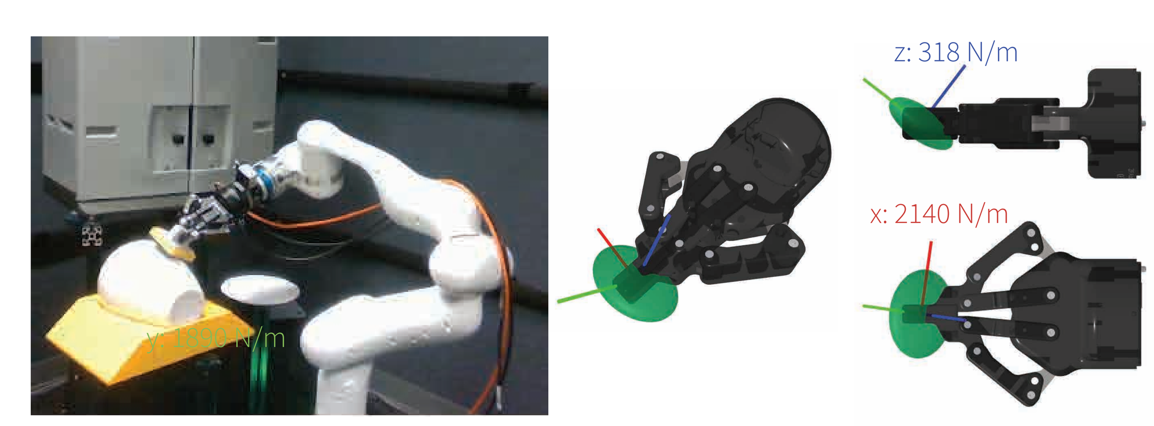


Stiffness Copilot adapts stiffness across different tasks and grasps

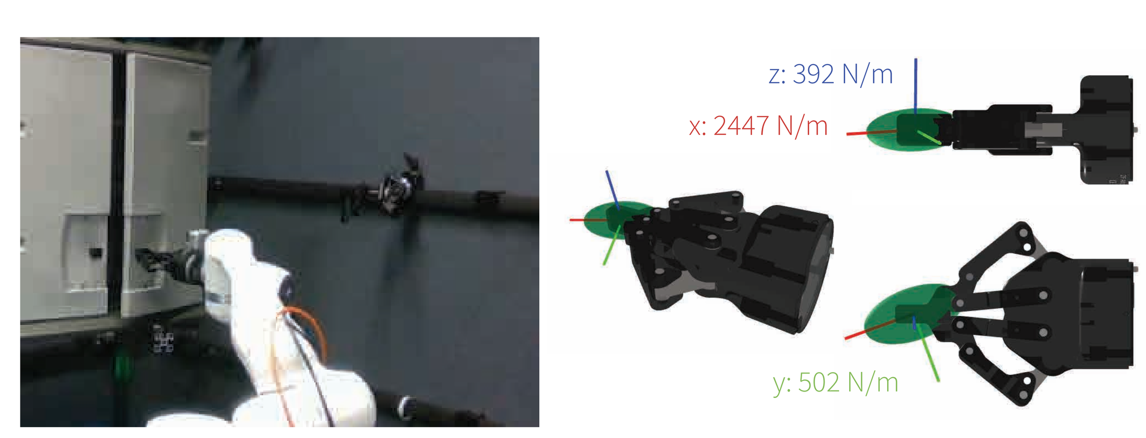
(Green ellipsoids visualize the predicted directional stiffness)



Top-down Grasp



Angled Grasp



Horizontal Grasp

Vertical Grasp

Evaluation

We evaluated Stiffness Copilot against two constant-stiffness baselines in a user study

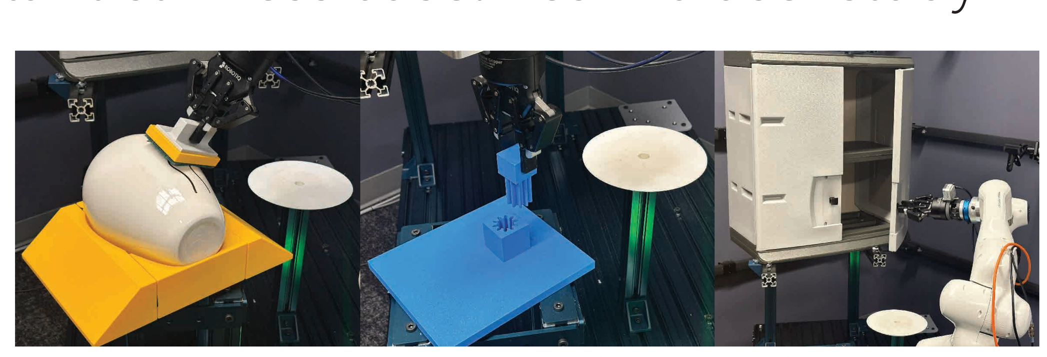
3 conditions

Stiffness Copilot: 300 - 3000 N/m
High Stiffness: 3000 N/m
Low Stiffness: 300 N/m

Study design

within-participants design
condition orders being counterbalanced
18 participants

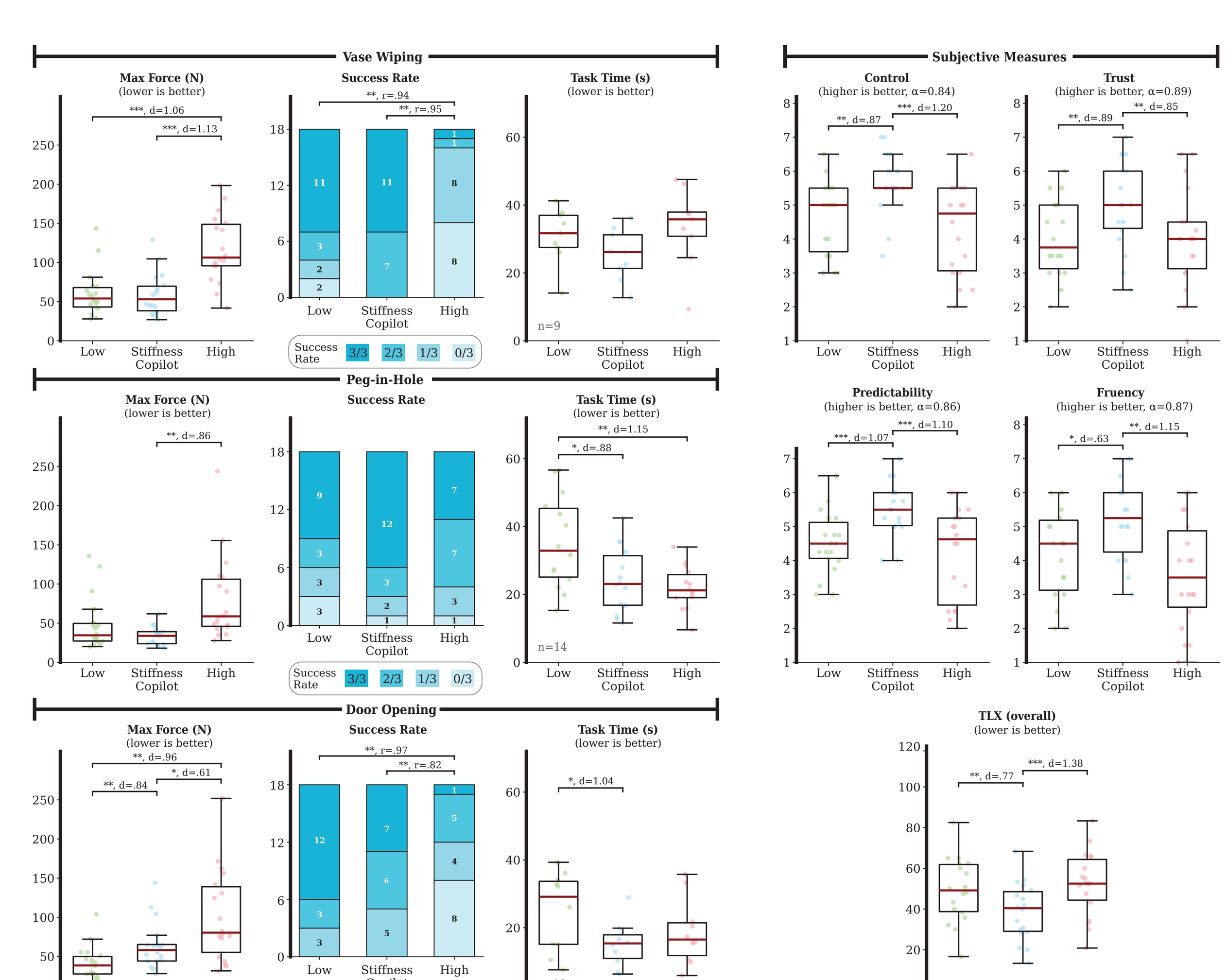
A single policy was trained for three tasks



A. Vase Wiping B. Peg-in-Hole C. Cabinet Door Opening

SUMMARY OF USER STUDY RESULTS ACROSS STIFFNESS CONDITIONS. BEST VALUES ARE SHOWN IN **BOLD**.

		Metric	Low Stiffness Mean (SD)	Stiffness Copilot Mean (SD)	High Stiffness Mean (SD)	Statistical Test
Objective Measures	Vase Wiping	Max Force (N)	60.58 (29.23)	**59.28** (27.04)	117.46 (42.87)	$F(2,34) = 17.15$, $p < .001$***, $\eta_p^2 = 0.502$
		Success Rate	0.76 (0.36)	**0.87** (0.17)	0.24 (0.28)	$\chi^2 = 20.13$, $p < .001$***, $W = 0.559$
		Time (s)	30.96 (8.12)	**25.31** (7.54)	33.62 (11.57)	$F(2,16) = 4.29$, $p < .05$*, $\eta_p^2 = 0.349$
	Peg-in-Hole	Max Force (N)	49.00 (34.25)	**33.41** (11.67)	80.60 (54.44)	$F(2,34) = 6.99$, $p < .01$**, $\eta_p^2 = 0.291$
		Success Rate	0.67 (0.40)	**0.81** (0.31)	0.70 (0.30)	$\chi^2 = 3.21$, $p = 0.201$, $W = 0.089$
		Time (s)	35.35 (13.59)	24.22 (9.58)	**21.95** (6.31)	$F(2,26) = 12.01$, $p < .001$***, $\eta_p^2 = 0.480$
	Door Opening	Max Force (N)	**40.96** (21.97)	63.63 (29.82)	101.42 (58.96)	$F(2,34) = 11.89$, $p < .001$***, $\eta_p^2 = 0.412$
		Success Rate	**0.83** (0.26)	0.70 (0.28)	0.31 (0.33)	$\chi^2 = 19.77$, $p < .001$***, $W = 0.549$
		Time (s)	24.89 (11.68)	**15.09** (6.67)	18.63 (9.67)	$F(2,18) = 4.99$, $p < .05$*, $\eta_p^2 = 0.357$
Subjective Measures		Control	4.64 (1.10)	**5.67** (0.89)	4.29 (1.34)	$F(2,34) = 10.16$, $p < .001$***, $\eta_p^2 = 0.374$
		Trust	4.03 (1.14)	**5.01** (1.27)	4.01 (1.48)	$F(2,34) = 7.22$, $p < .01$**, $\eta_p^2 = 0.298$
		Predictability	4.51 (0.94)	**5.51** (0.79)	4.21 (1.38)	$F(2,34) = 11.31$, $p < .001$***, $\eta_p^2 = 0.400$
		Fluency	4.21 (1.34)	**5.28** (1.23)	3.61 (1.59)	$F(2,34) = 8.44$, $p < .01$**, $\eta_p^2 = 0.332$
		NASA-TLX	49.33 (15.89)	**38.73** (14.15)	52.43 (16.00)	$F(2,34) = 11.36$, $p < .001$***, $\eta_p^2 = 0.401$



All authors are with Meta Reality Labs Research
Yeping Wang is with University of Wisconsin-Madison
Zhengtong Xu is with Purdue University
This work was conducted during internships at Meta Reality Labs

Meta WISCONSIN UNIVERSITY OF WISCONSIN-MADISON PURDUE UNIVERSITY