Exploiting Task Tolerances in Mimicry-based Telemanipulation

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Synopsis

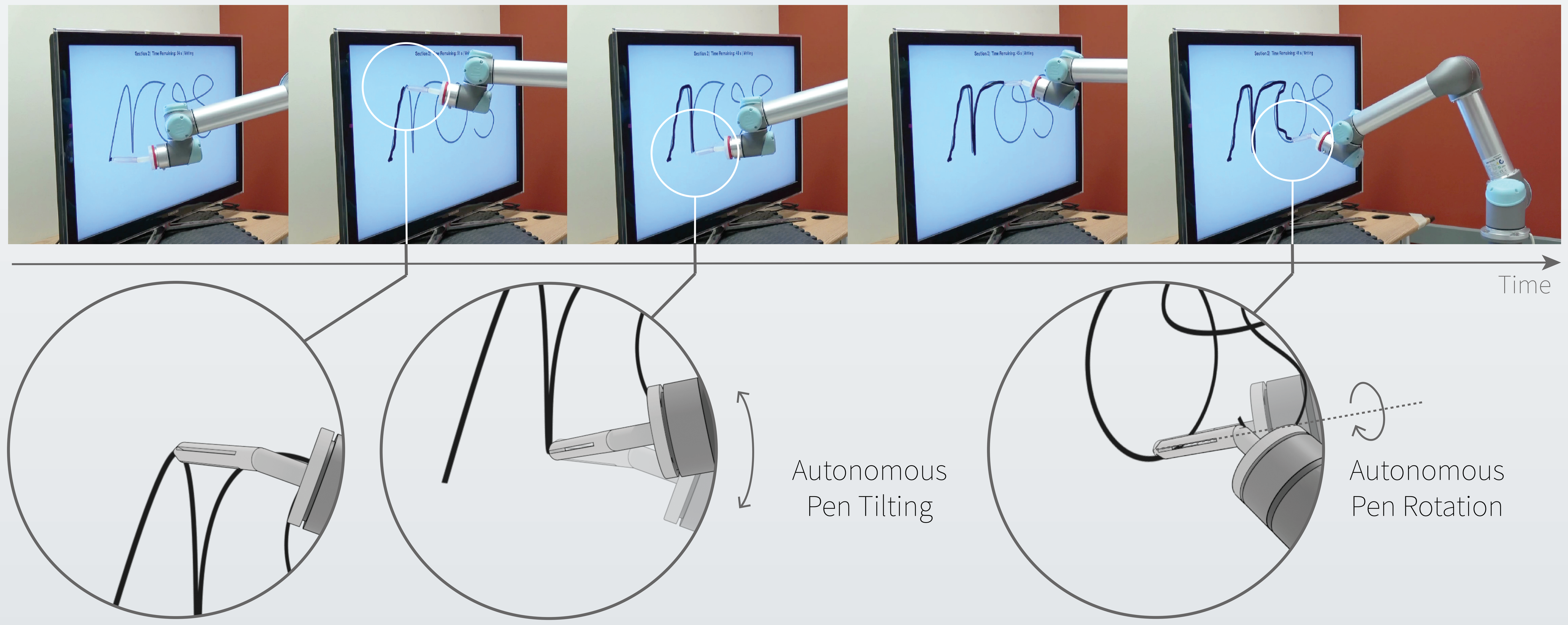
We explore task tolerances, *i.e.*, allowable position or rotation inaccuracy, as an important resource to facilitate smooth and effective telemanipulation.

Motivation

Exact mimicry may cause the robot to lose manipulability or generate jerky motions because of the kinematic and dynamic differences between the robot and the operator.

Functional Mimicry

Our *functional* mimicry paradigm allows a robot to autonomously adjust within tolerances to generate more accurate, smooth, and feasible motions*. Task tolerances are the amount of position or rotation inaccuracy allowed to complete a task.



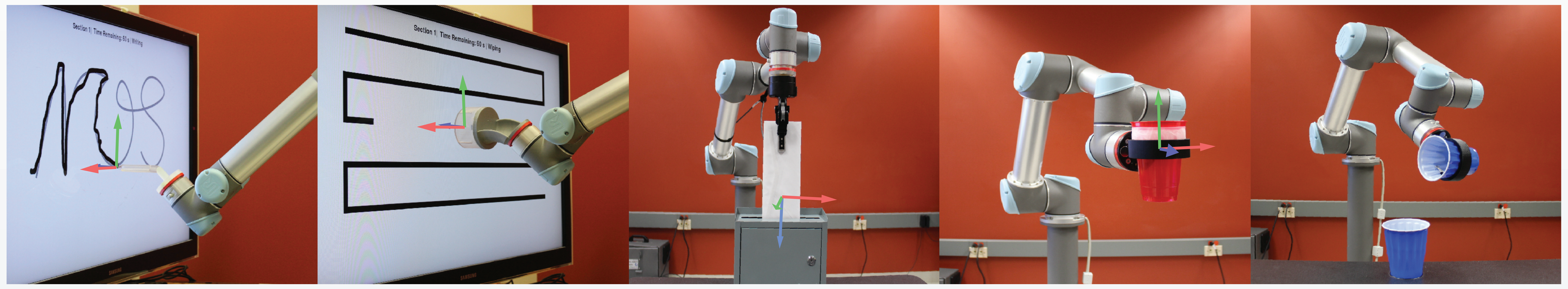
However, the autonomous adjustments mean that the user lacks full control of the robot. *Functional* mimicry may make the user's control less direct.

Hypothesis

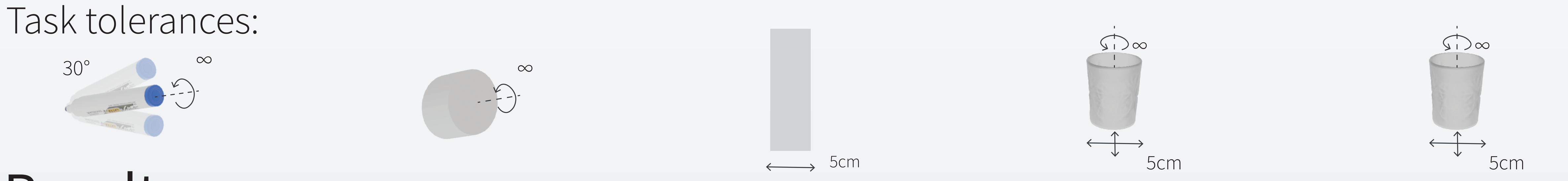
In mimicry-based telemanipulation, allowing a robot to autonomously adjust within task tolerances (*functional* mimicry) will lead to better task performance and user experience than requiring the robot to exactly mimic its human operator (*exact* mimicry), despite users lacking full control of the robot.

Experimental Design

Our user evaluation followed a within-participants design with condition orders being counterbalanced. We recruited 20 participants from a university campus. Our study involves five tasks.



Task tolerances:



Results

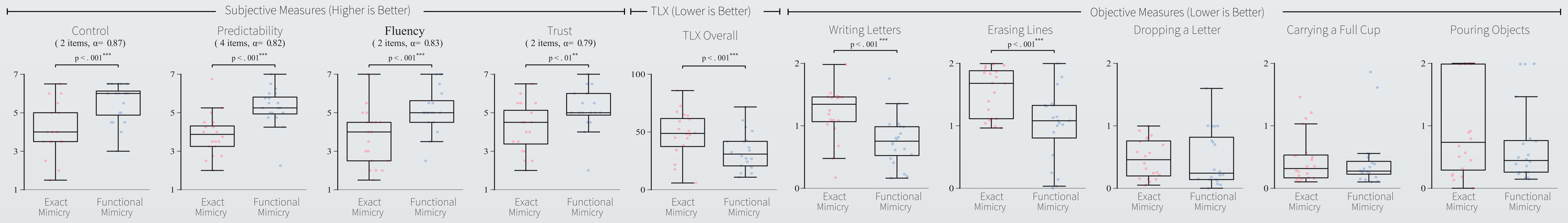
Exploiting flexibility in task tolerances enables

- More accurate, smooth, and feasible motions
- An improvement in perceived control
  - Autonomous adjustments within tolerances feel natural to teleoperators
- An improvement in perceived predictability
- Improvements in perceived fluency, and trust
- Equal or better performance

TABLE III
MOTION QUALITIES†

Task	Method	Mean Pos. Error (m)	Mean Rot. Error (rad)	Mean Joint Vel. (rad/s)	Mean Joint Acc. (rad/s^2)	Mean Joint Jerk (rad/s^3)	Mean Manipulability
Writing Letters	Exact Mimicry	0.091 ± 0.085	N/A‡	0.133 ± 0.05	1.80 ± 0.7	53.9 ± 19.5	0.067 ± 0.02
	Functional Mimicry	**0.006 ± 0.009**	**N/A‡**	**0.076 ± 0.04**	**0.45 ± 0.2**	**10.5 ± 5.1**	**0.085 ± 0.02**
Erasing Lines	Exact Mimicry	0.093 ± 0.074	0.0204 ± 0.007	0.240 ± 0.11	3.11 ± 1.8	91.1 ± 56.3	0.060 ± 0.02
	Functional Mimicry	**0.025 ± 0.020**	**0.0107 ± 0.007**	**0.227 ± 0.08**	**2.23 ± 0.9**	**62.9 ± 26.1**	**0.081 ± 0.02**
Dropping an Envelope	Exact Mimicry	0.090 ± 0.148	0.0073 ± 0.007	0.150 ± 0.05	1.42 ± 0.5	40.0 ± 15.0	0.053 ± 0.03
	Functional Mimicry	**0.028 ± 0.042**	**0.0070 ± 0.004**	**0.149 ± 0.06**	**1.18 ± 0.5**	**32.3 ± 15.7**	**0.069 ± 0.03**
Carrying a Full Cup	Exact Mimicry	0.053 ± 0.093	0.0059 ± 0.009	0.179 ± 0.09	1.63 ± 0.8	45.8 ± 19.6	0.048 ± 0.02
	Functional Mimicry	**0.007 ± 0.004**	**0.0021 ± 0.001**	**0.116 ± 0.05**	**0.90 ± 0.4**	**24.3 ± 9.3**	**0.071 ± 0.02**
Pouring Objects	Exact Mimicry	0.133 ± 0.144	0.0149 ± 0.008	0.218 ± 0.10	2.42 ± 1.9	71.1 ± 71.5	0.035 ± 0.02
	Functional Mimicry	**0.064 ± 0.065**	**0.0102 ± 0.005**	**0.158 ± 0.06**	**1.35 ± 0.7**	**35.9 ± 20.8**	**0.068 ± 0.02**

† The range values are standard deviations. The better value between the two telemanipulation paradigms for each measure is highlighted in bold.
‡ The position and rotation errors were measured in the task-relevant degrees of freedom that do not have tolerances. In the writing task, all three rotational degrees of freedom had tolerances, so no rotation errors were measured.



Conclusion

- Exact mimicry can be overly restrictive for some tasks with tolerances.
- Exploiting task tolerances generates high quality robot motions.
- Exploiting task tolerances leads to user perception and performance improvements.
- We believe that our interaction paradigm is beneficial to teleoperation of welding, sanding, pouring, and many other tasks that allow some positional or rotational inaccuracy.

* The high quality motions in functional mimicry are generated by RangedIK [1], a real-time motion generation method that exploits flexibility afforded by task tolerances.

[1] Y. Wang, P. Praveena, D. Rakita, and M. Gleicher, "Rangedik: An optimization-based robot motion generation method for ranged-goal tasks," in 2023 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2023

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