RangedIK: An Optimization-based Robot Motion Generation Method for Ranged-Goal Tasks

Yeping Wang, Pragathi Praveena, Daniel Rakita, and Michael Gleicher

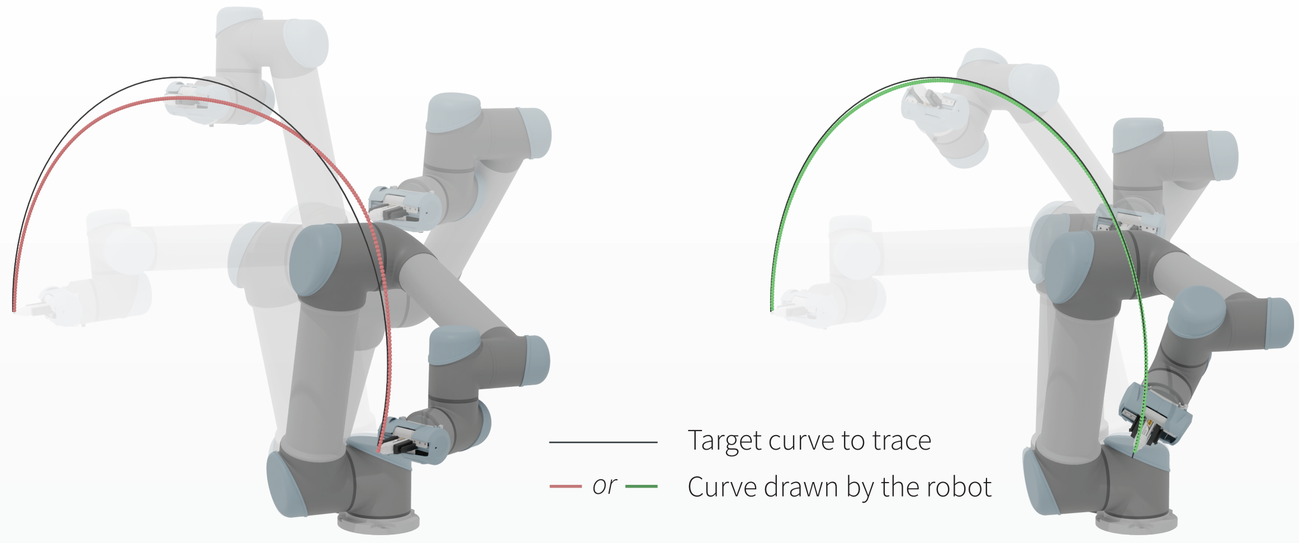
Synopsis: *RangedIK* is a **real-time motion generation** method that accommodates specific-goal or ranged-goal tasks within a single, unified framework and **leverages the flexibility** of ranged-goal tasks to accommodate other tasks.

Motivating Example

Problem: Robots that need to exactly match end effector poses have insufficient degrees of freedom for other requirements such as manipulability or smoothness.

Example: A Drawing Robot exactly matching of a 6dof goal leads to imprecise paths (near right). Allowing the pen to tilt within accetpable limits affords a smooth and (positionally) precise path (far right).

Solution: We provide RangedIK - a motion synthesis method that exploits range flexibility to satisfy multiple requirements.



Imprecise motion when trying to exactly match the pen position and orientation

Precise and smooth motion enabled by rotating the pen

Method

In real-time robotics applications, the robot needs to calculate how to move at each update to satisfy multiple kinematic requirements (i.e., tasks). We classify the tasks into three categories (right) according to the flexibility they afford.

RangedIK incorporates a set of specific-goal or ranged-goal tasks in a weighted-sum **non-linear optimization** structure. Each task serves as an term in the objective function. To combine multiple and potentially competing tasks, we utilize barrier methods with **parametric loss functions** to encode the valid range of a task in optimization. The optimization problem is solved using proximal averaged Newton-type method (PANOC).

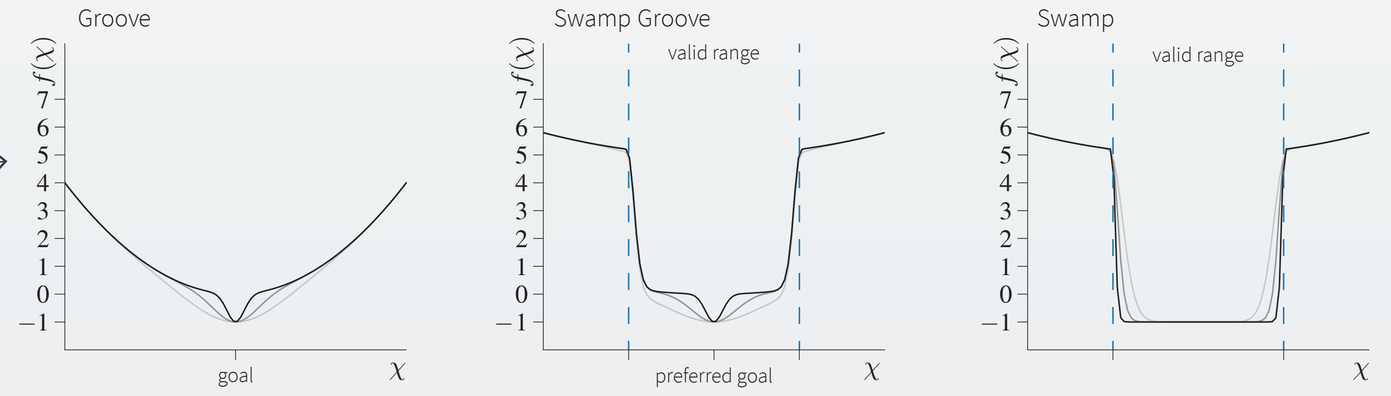
Specific-Goal Tasks	Ranged-Goal Tasks with a Preferred Goal	Ranged-Goal Tasks with Equally Valid Goals
Match pen tip position	Allow tilting pen but prefer it to be pendicular	Allow pen to self-rotate
Maintain manipulability	Keep joint velocities within limits and prefer them to be small	Keep joint positions within limits
Minimize joint jerk	Keep joint acceleration within limits and prefer them to be small	Avoid self-collisions

More flexibility →

Parametric loss function
Task function
Joint states

$$\mathbf{q}^* = \arg\min_{\mathbf{q}} \sum_i w_i \, f_i\left(\chi_i(\mathbf{q})\right)$$
$$s.t.\ \ l_j \le q_j \le u_j, \ \ \forall j$$

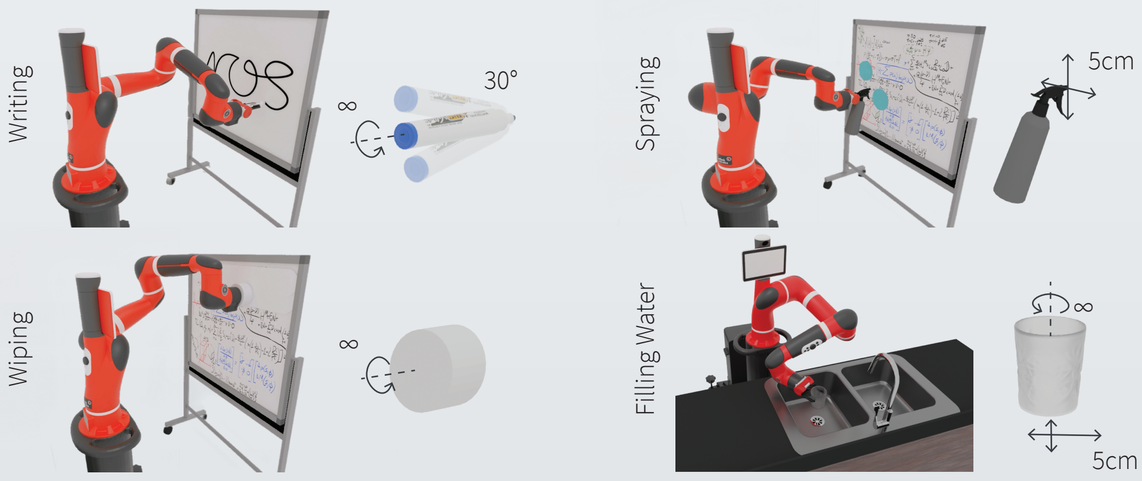
Joint lower and upper position limit



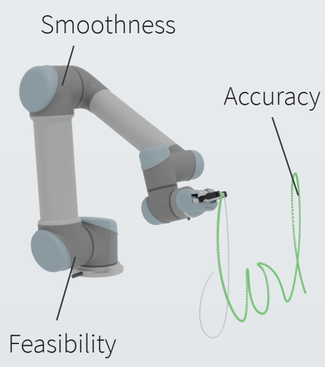
Evaluation

We compare *RangedIK* with two alternative approaches, *RelaxedIK* and *TracIK*, to generate motions for applications that afford some flexibility in end-effector poses.

Applications and the flexibility they afford



Metrics



Results

Accuracy — Smoothness — Feasibility

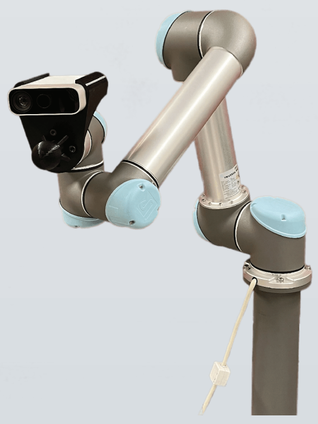
	Method	Mean Pos. Error (m)	Mean Rot. Error (rad)	Mean Joint Vel. (rad/s)	Mean Joint Acc. (rad/s^2)	Mean Joint Jerk (rad/s^3)	Mean Manipulability	# Exceed Tolerances
UR5	*RangedIK*	0.0021 ± 0.002	0.005 ± 0.003	**0.042 ± 0.02**	**0.0269 ± 0.02**	**0.224 ± 0.2**	**0.0544 ± 0.01**	0
	RelaxedIK	0.0023 ± 0.002	0.007 ± 0.005	0.050 ± 0.02	0.0299 ± 0.02	0.336 ± 0.3	0.0533 ± 0.01	0
	Trac-IK	**1.8e-6 ± 1.6e-6**	**1.5e-6 ± 1.6e-6**	0.061 ± 0.04	1.9333 ± 2.48	115.536 ± 149	0.0487 ± 0.01	0
Sawyer	*RangedIK*	0.0014 ± 0.001	0.003 ± 0.002	**0.034 ± 0.02**	**0.0265 ± 0.02**	**0.290 ± 0.3**	**0.1539 ± 0.04**	0
	RelaxedIK	0.0017 ± 0.001	0.006 ± 0.004	0.041 ± 0.02	0.0280 ± 0.03	0.328 ± 0.4	0.1535 ± 0.04	0
	Trac-IK	**1.3e-6 ± 1.1e-6**	**2.0e-6 ± 1.6e-6**	0.047 ± 0.03	1.4882 ± 1.79	88.930 ± 107	0.1440 ± 0.05	0

RangedIK leverages the flexibility afforded by ranged-goal tasks to **generate accurate, smooth, and feasible robot motions in real-time.**

Demonstration

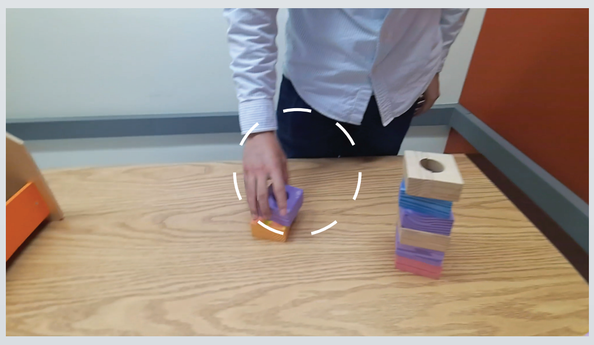
We demonstrate the effectiveness of *RangedIK* on a camera-in-hand robot to track a user's hand.

Tasks for feasible camera motions:

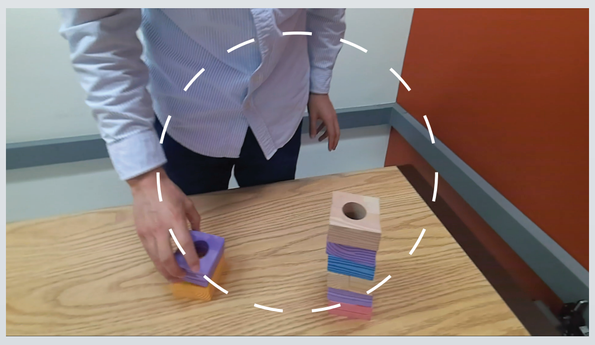


Look at hand
Keep camera upright
Minimize camera movement
Avoid self-collisions
Keep joint vel., acc. within limits and prefer them to be small
Minimize jerk

Baseline:
Point camera towards hand



RangedIK:
Keep hand in view and prefer it centralized



Demo video

RangedIK utilizes the flexibility of the ranged-goal task to **achieve smooth and feasible camera motions.**

This work was supported by a University of Wisconsin Vilas Associates Award and National Science Foundation award 1830242.