

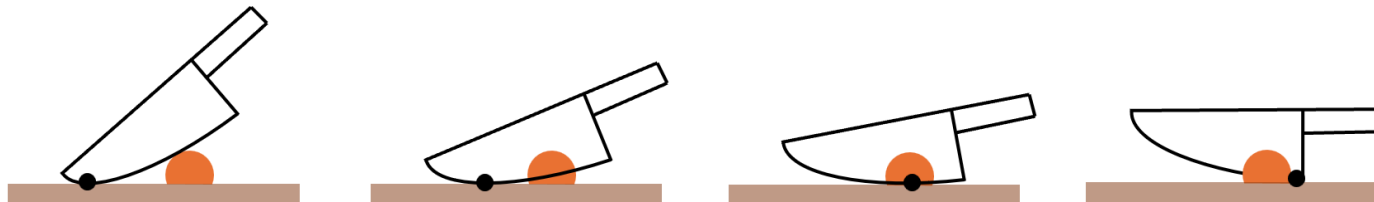


Virtual model control for robot manipulation

Yi Zhang

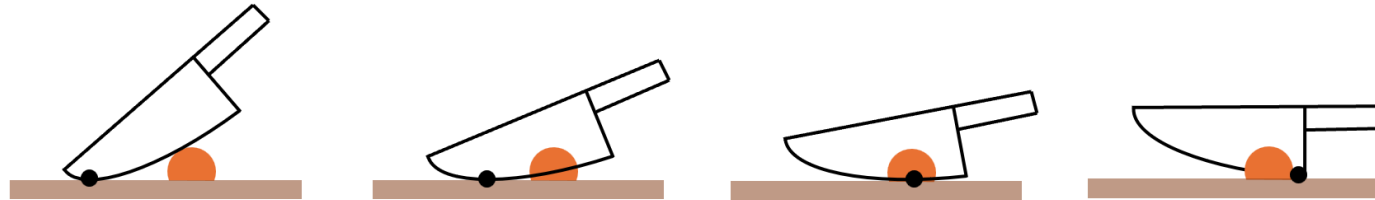
Division F – Information Engineering, Department of Engineering

Supervisor: Prof Fulvio Forni



Rock chop: a type of cutting motion with knife rolling back and forth

Can we achieve effective manipulation in uncertain settings?

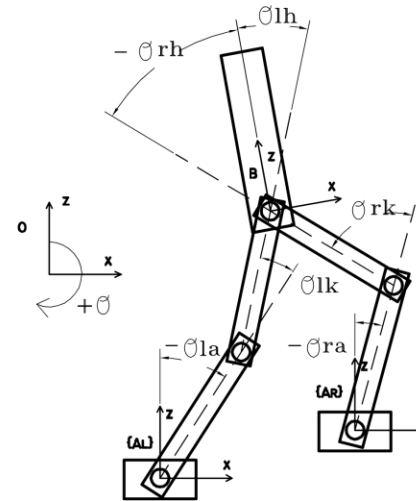
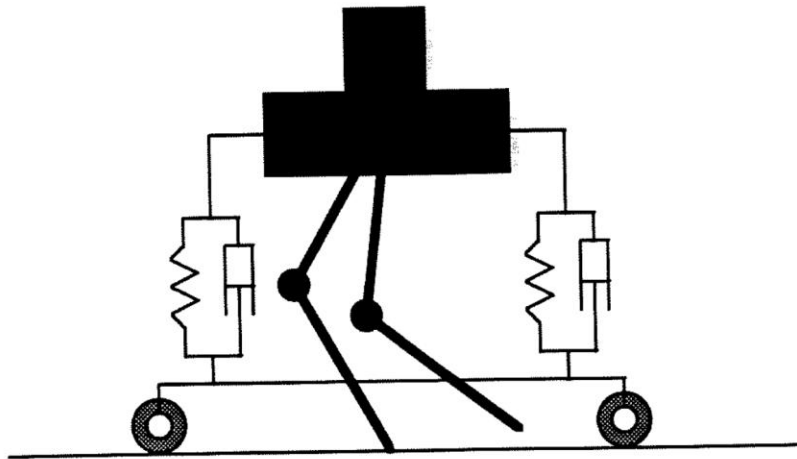


1. without accurate models, robust with partial information
2. with parsimonious, computation-aware use of data
3. with guarantees on the safety / stability of the manipulation algorithms

→ Virtual model control

Virtual Model Control_[1]

Place **virtual components** at strategic positions, to automatically generate desired torque or forces at the actuator



[1]

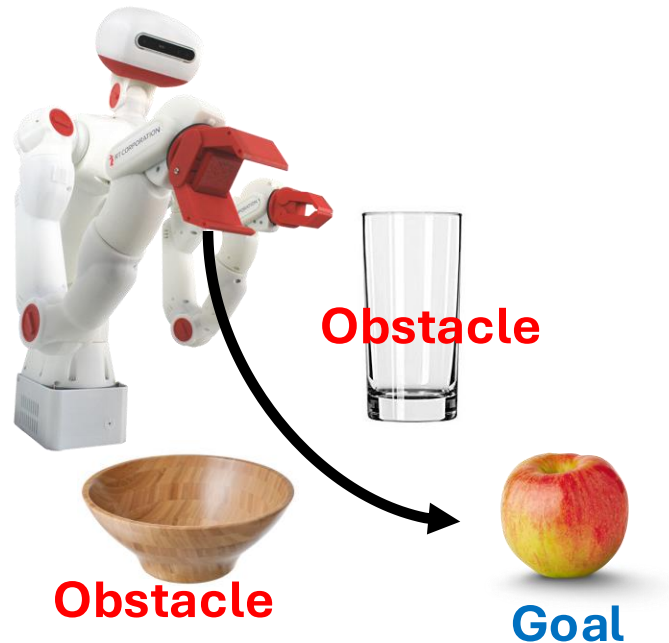
Virtual force: F

Corresponding torque on each joint: $\tau = J(\theta)^T F$

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- Driving question of PhD
- **Compliant reaching under uncertainties**
- Contact-rich task – cutting
- Human-robot collaboration

Stiff control and computation-intensive planning limit robot manipulation



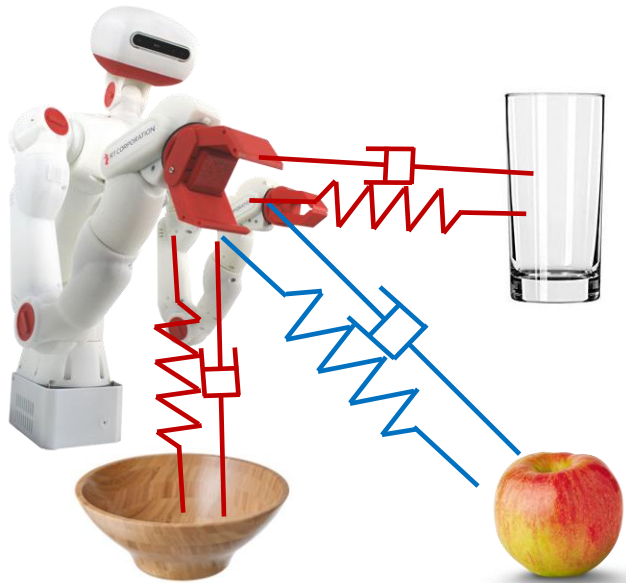
Standard practice and limitations:

- Path planning (sampling-based, learning, optimization)
- Stiff motion for insensitivity
- High computation
- Uncertainties?

Ideal approach:

- Capability to deal with uncertainty
- Lightweight computation
- Guaranteed safety / stability

Virtual Model Control_[1]



Design and place virtual components that generate forces for each planning requirement

Low computation: emergence of behavior

Cope with uncertainties: compliance from virtual mechanics

Intuitive design: all physics!

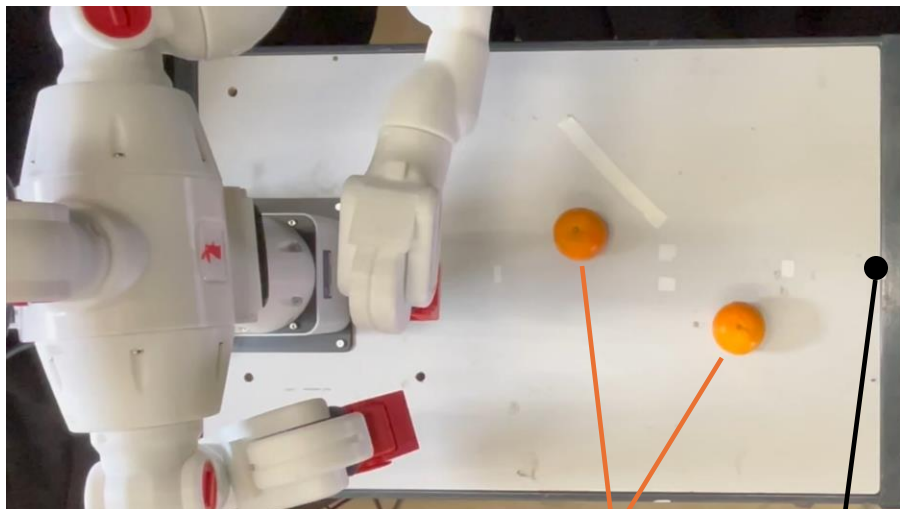
$$\tau = J_1(\theta)^T F_1 + J_2(\theta)^T F_2 + J_3(\theta)^T F_3 + \dots$$

↓
Depends on kinematics

Virtual model control for compliant reaching under uncertainties

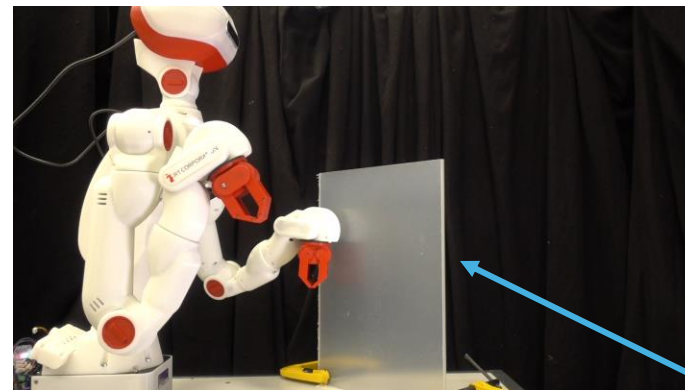


Emergent behaviour

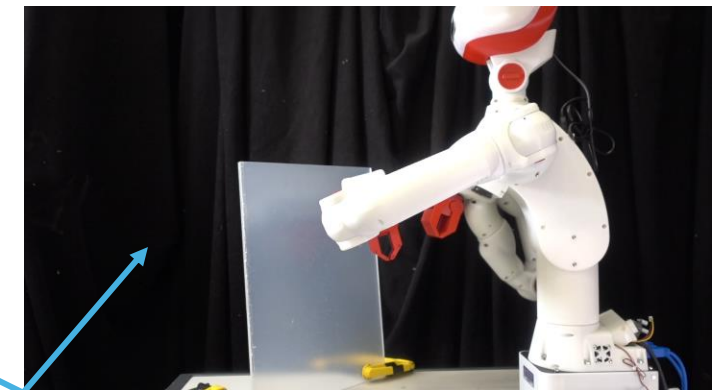


Obstacle Goal

Inverse kinematics approach



Virtual model control



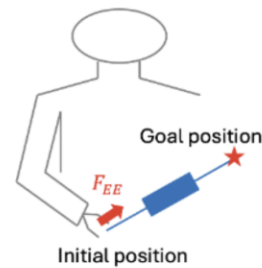
Goal

Virtual model control for compliant reaching under uncertainties

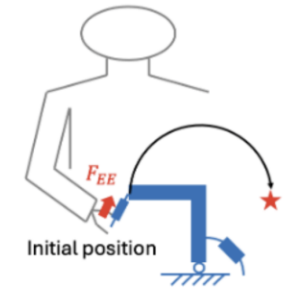
What does it mean to be compliant?



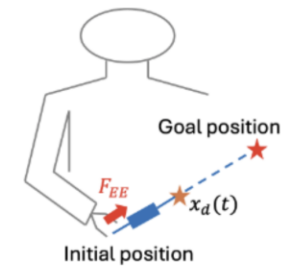
Example virtual component design



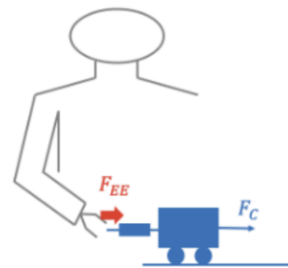
(a) Simple reaching.



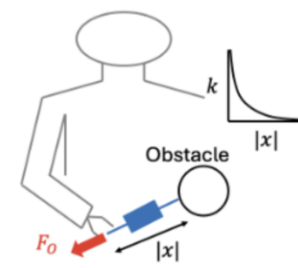
(b) Geometrical reaching.



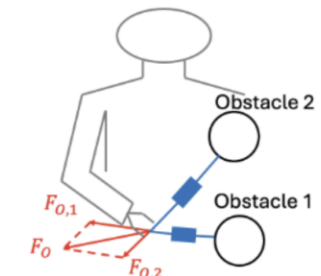
(c) Moving-reference reaching.



(d) Force-driven reaching.



(e) Obstacle avoidance.



(f) Multi-obstacles avoidance.

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Contact rich manipulation -- cutting

Conventional methods require

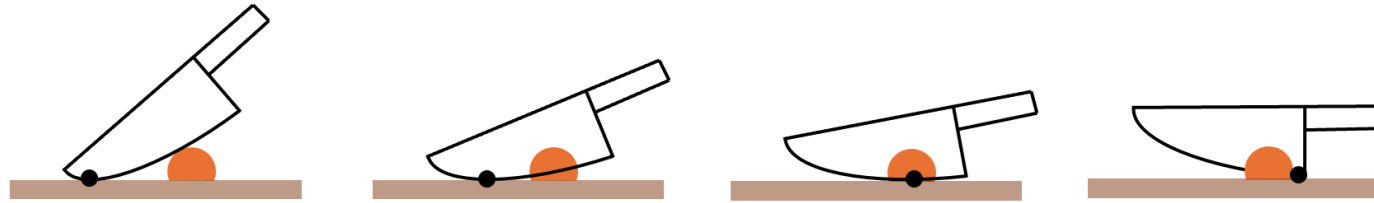
- End-effector trajectory
- Precise environment information



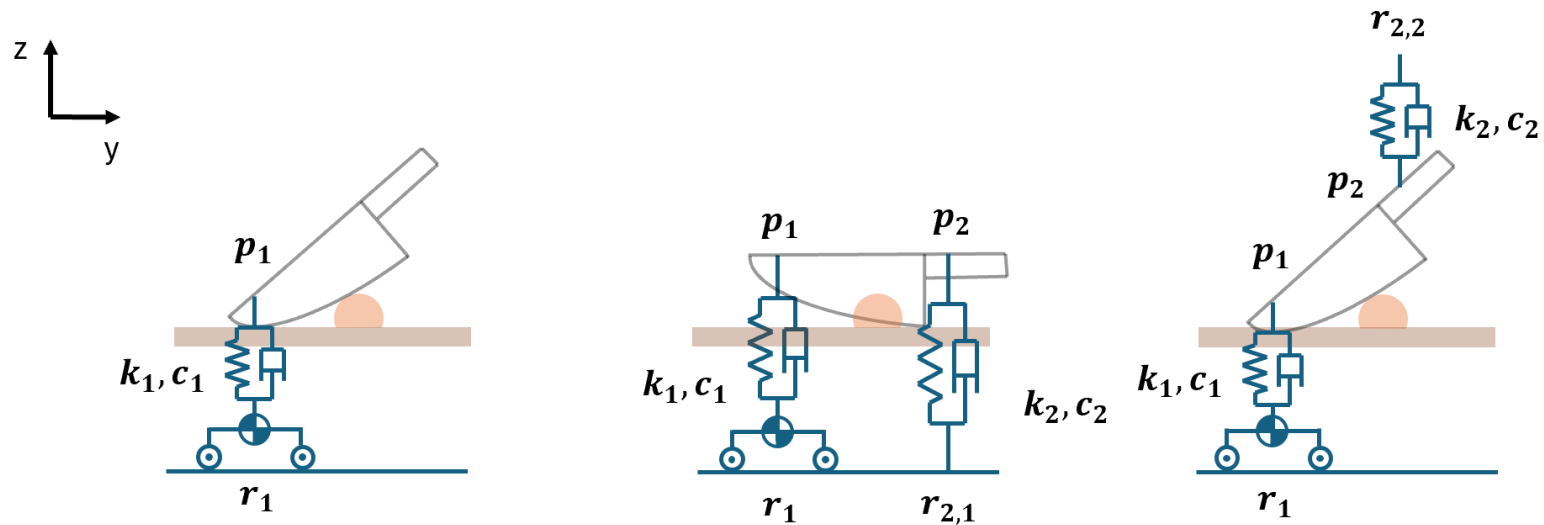
Our method

- Emergence of trajectory from interaction
- Deals with uncertain environments

Designing virtual mechanism --rocking motion

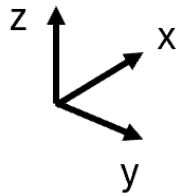


Rocking: a type of cutting motion with knife rolling back and forth

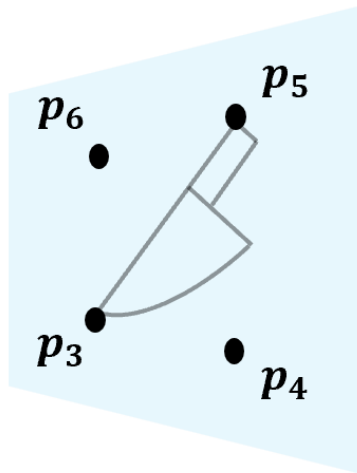


Designing virtual mechanism

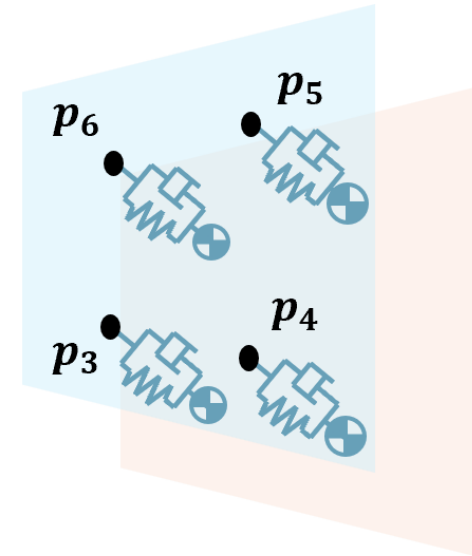
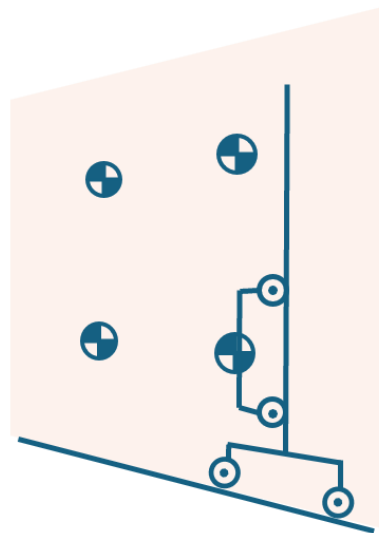
-- cutting in a plane



Knife plane



Slicing plane



From VMC to reality

A package to build virtual mechanisms, simulate and control robots.

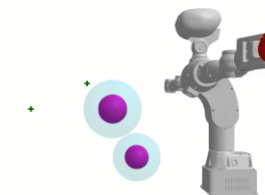
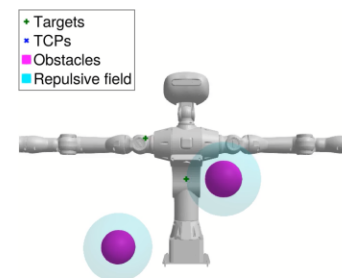
Able to control a robot with ROS.

- Github page:

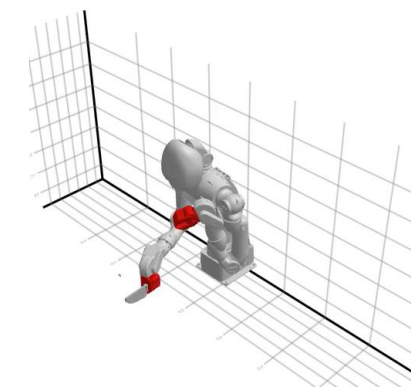
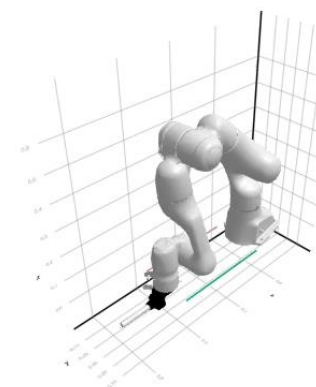
<https://github.com/Cambridge-Control-Lab/VMRobotControl.jl>

- Documentation:

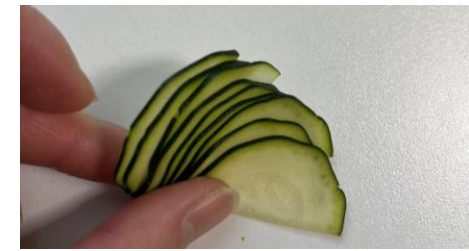
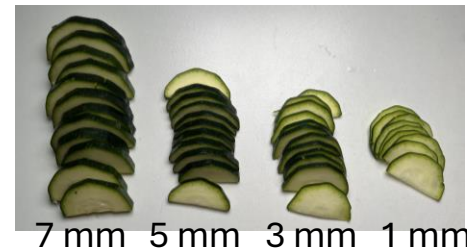
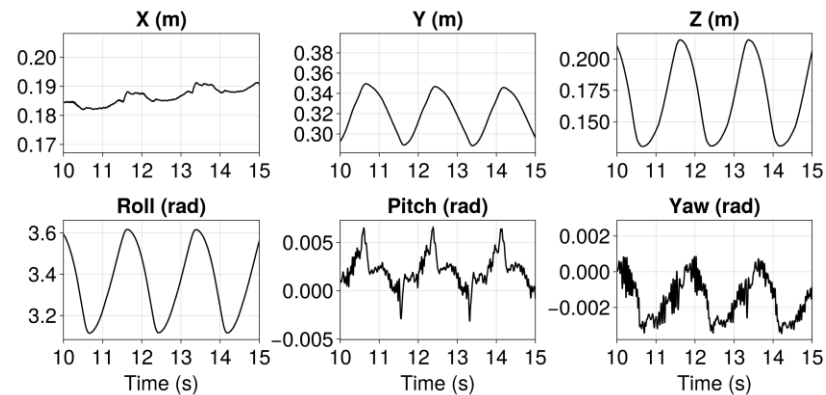
<https://cambridge-control-lab.github.io/VMRobotControl.jl/dev/>



Courtesy of Daniel



Emergence of rocking motion through physical interaction



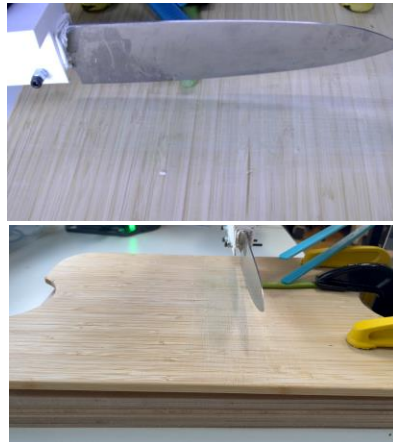
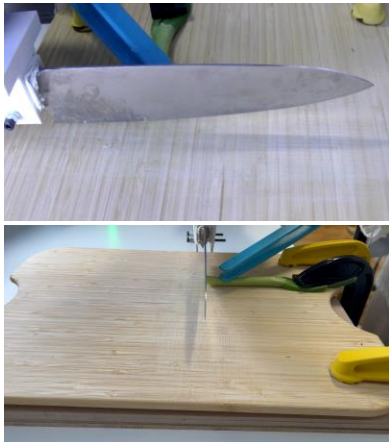
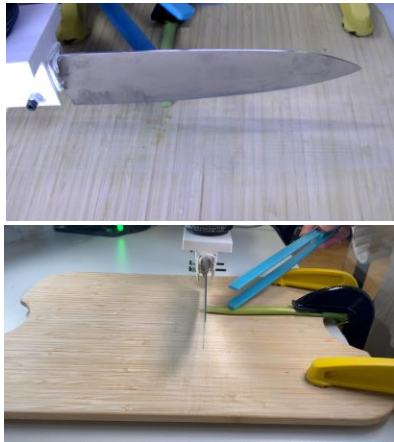
Robustness

Same mechanism and control parameters
With different table height:

0 mm

16 mm

32 mm



With different knives:

1

2

3

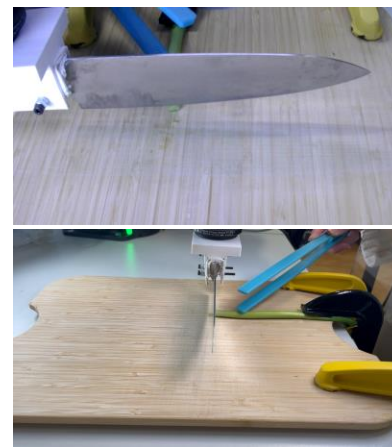


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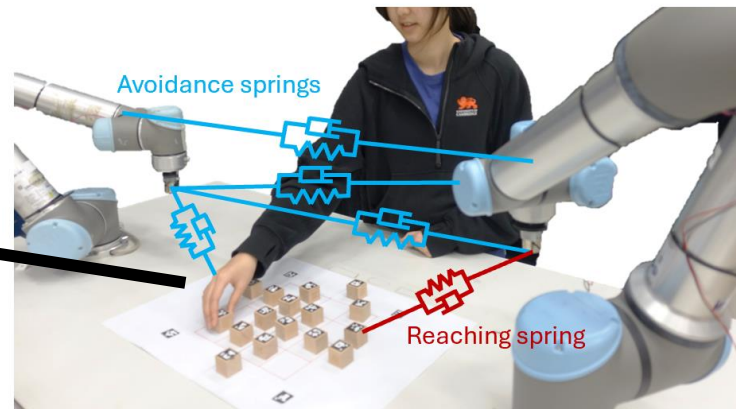
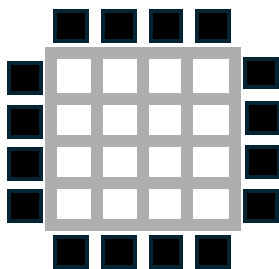
- Driving question of PhD
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- Human-robot collaboration

Human-robot collaboration

- HRC requires **safety** and **scalability** in shared workspaces.
- Existing approaches: rich perception + prediction + optimization/learning —heavy and often human-specific.

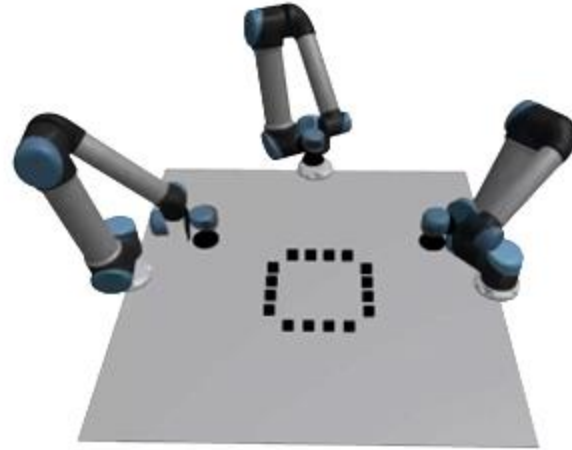
Our approach

- Agent-agnostic control
- Intuitive behavior shaping through virtual component parameters
- Safety via avoidance components and bounded forces

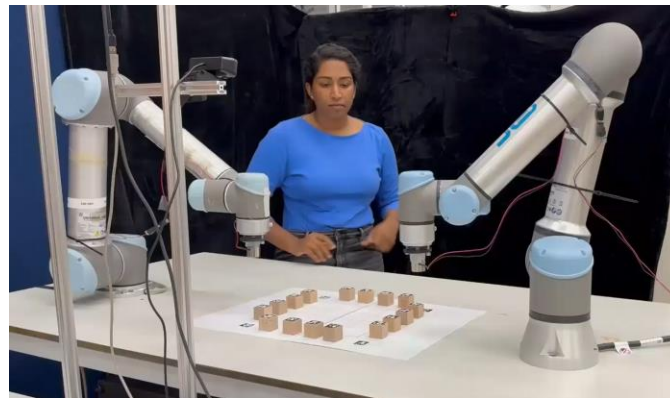


Decentralized approach of VMC allows Scalable Human-Robot Collaboration

Multi-robot collaboration

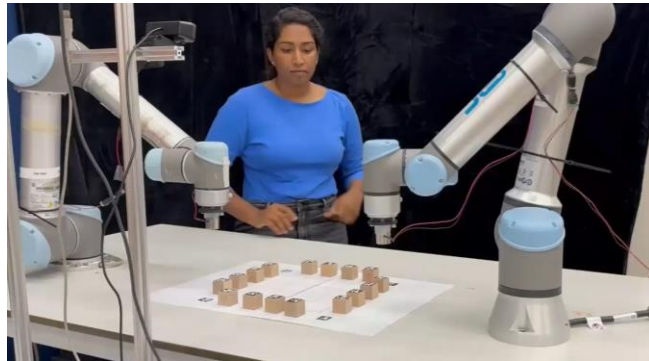


Human-robot collaboration



Virtual Model Control for Robotic Manipulation

Human-Robot Collaboration



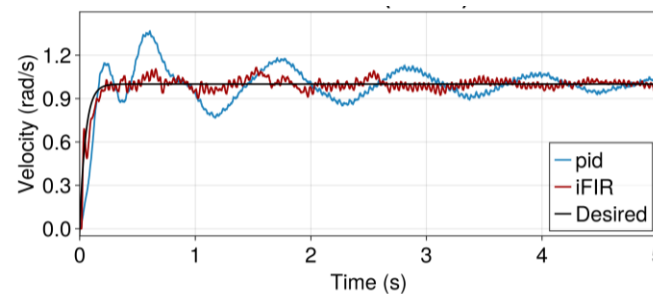
Rock chop



Neuromorphic component



Data-driven component



1. Without accurate models
2. Efficient use of data
3. Safety / stability guarantee

Future Work

- Automatic tuning and adaptation of virtual components
- Automatic virtual components synthesis
- Learning with VMC for computation-aware use of data

...

[1] Y. Zhang, D. Larby, F. Iida, F. Forni. IROS2024. Virtual model control for compliant reaching under uncertainties
[2] Y. Zhang, F. Iida, F. Forni. arXiv preprint. Periodic robust robotic rock chop via virtual model control
[3] Z. Wang, Y. Zhang, F. Forni. European Journal of Control. Dissipative iFIR filters for data-driven design