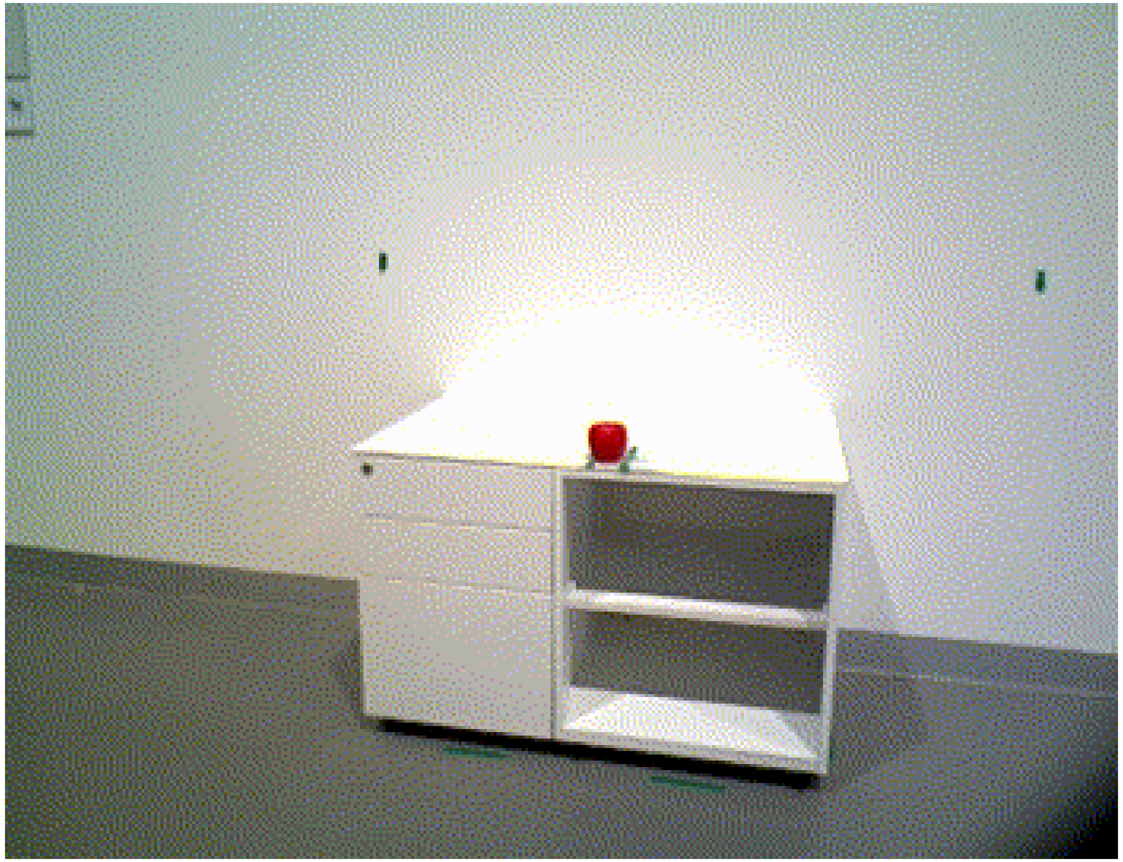
Visibility Maximization Controller for Robotic Manipulation

Kerry He[1] *(Presenter)*, Rhys Newbury[1], Tin Tran[1],
Jesse Haviland[2], Ben Burgess-Limerick[2],
Dana Kulic[1], Peter Corke[2], Akansel Cosgun[1]

[1]Monash University, Australia
[2]Queensland University of Technology, Australia

Introduction: Motivation

- Closed-loop vision-based control is susceptible to **occlusions**
- **Self-occlusions** occur when robot linkages obstruct objects from the camera
- **Redundancy** in robotic manipulators can be used to avoid self-occlusions



Introduction: Related Works

Suzuki et al. [1]

- Stack of tasks controller
- Self-occlusion avoidance objective as secondary objective

Logothetis et al. [2]

- Model predictive controller
- Explicit constraint to avoid self-occlusions

However, both works are limited to:

- Rigidly mounted cameras on mobile manipulator
- Static, single objects

[1] T. Suzuki and K. Sekiyama, “A coordinated control system for dualarm mobile manipulator balancing grasping and viewpoint selection,” in IEEE/SICE International Symposium on System Integration, 2020.

[2] M. Logothetis, G. C. Karras, S. Heshmati-Alamdari, P. Vlantis, and K. J. Kyriakopoulos, “A model predictive control approach for vision-based object grasping via mobile manipulator,” in IROS, 2018.

Introduction: Contributions

- We propose an optimization-based task space controller to avoid self-occlusions
- Generalizes to:
  - Fixed-base and mobile manipulators
  - Rigid and controllable camera configurations
  - Single or multiple objects to avoid occluding
  - Stationary and moving objects to avoid occluding
- Simulated and real-world experiments performed to validate algorithm for variety of tasks

Methodology: Visibility Maximization Controller

Objective:

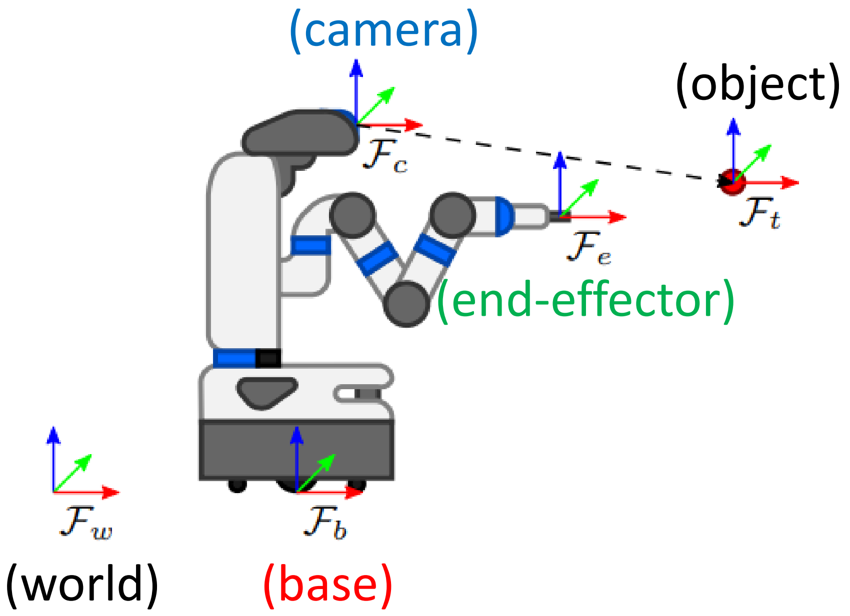
- Effort minimization
- Manipulability minimization

Constraints:

- End-effector velocity control
- **FoV occlusion avoidance**
- **Self-occlusion avoidance**
- Obstacle avoidance
- Joint limits
- Joint velocity limits

Optimization variables:

- Base joints
- End-effector joints
- Camera joints



[3] J. Haviland, N. Sunderhauf, and P. Corke, “A holistic approach to reactive mobile manipulation,” IEEE Robot. Autom. Lett., vol. 7, no. 2, pp. 3122–3129, 2022.

Methodology: Self-Occlusion Avoidance

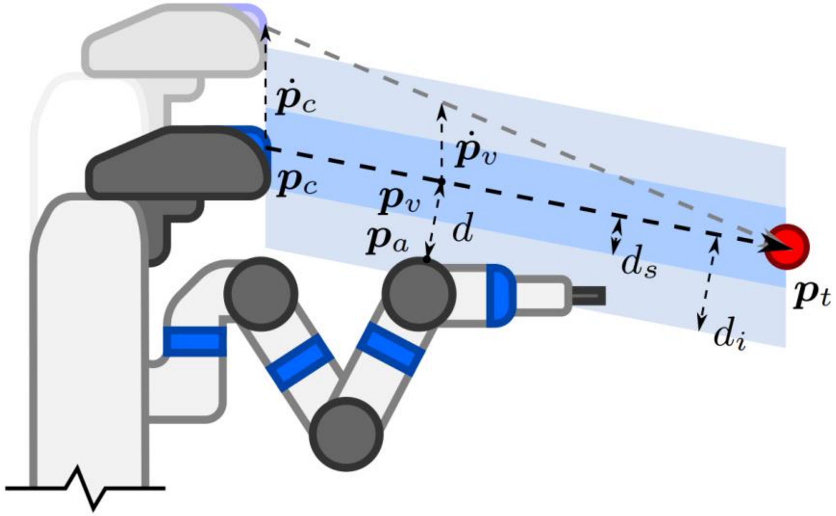
- Treat line-of-sight as collision object
- Velocity damper used to perform object avoidance

Arm dynamics

Camera dynamics

Object dynamics

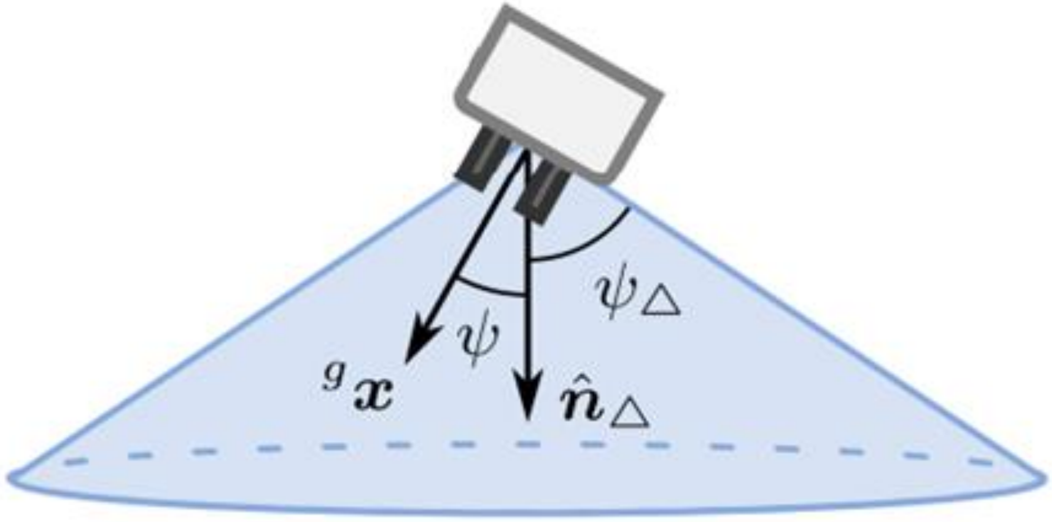
$$\hat{\boldsymbol{n}}_{av}^{\top}\left(J_a^v - \kappa J_c^v\right)\dot{\boldsymbol{q}} - \epsilon_v \leq \zeta \frac{d - d_s}{d_i - d_s} + (1 - \kappa)\hat{\boldsymbol{n}}_{av}^{\top}\dot{\boldsymbol{p}}_t$$



Methodology: End-Effector Orientation

- Relaxing target end-effector orientation constraint frees up degrees of freedom to better form self-occlusion avoidance
- Instead constrain target end-effector orientation within a specified cone

$$\dot{\psi} \leq \frac{\cos(\psi) - \cos(\psi_{\triangle})}{1 - \cos(\psi_{\triangle})}$$



Experiments

- Three different tasks are evaluated
  - Fixed-base manipulation
  - Moving object tracking
  - Mobile Manipulation

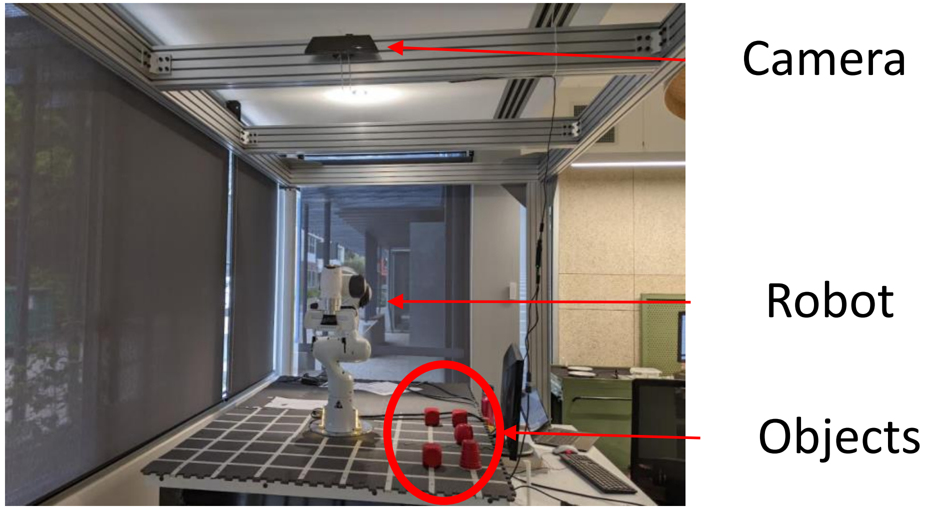
- Controllers used:
  - Visibility Maximization Controller (Ours)
  - NEO [3] (Baseline)

- Metrics:
  - **Occlusion rate**: % frames object is occluded
  - **Task time**: Time elapsed to complete mission
  - **Success rate**: % trials end-effector reached desired pose

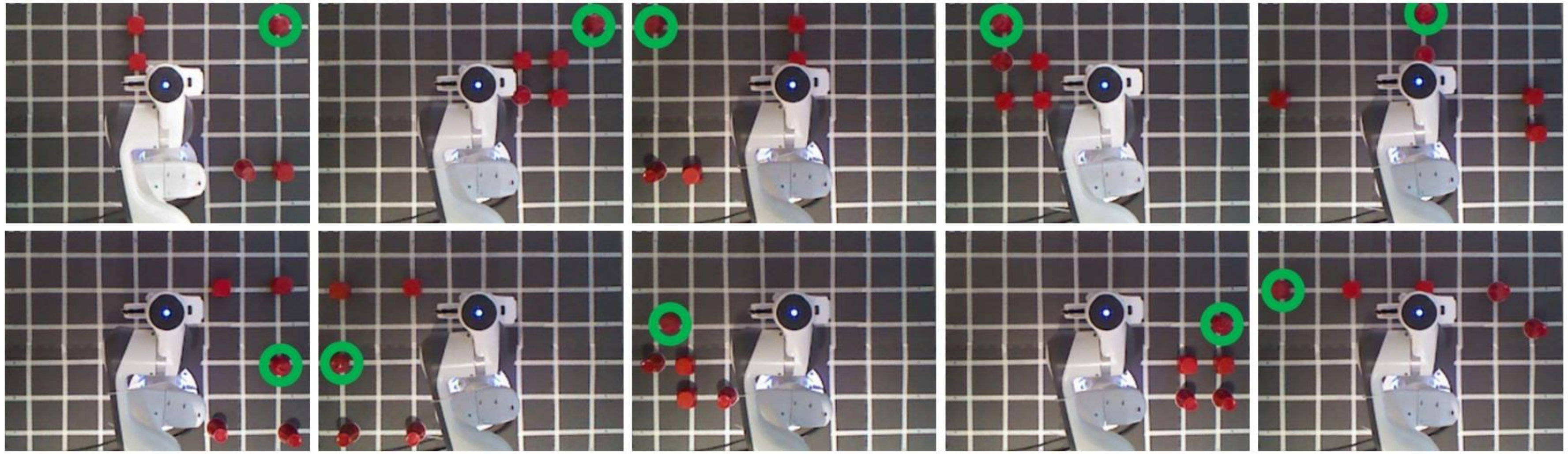
[3] J. Haviland, N. Sunderhauf, and P. Corke, "A holistic approach to reactive mobile manipulation," IEEE Robot. Autom. Lett., vol. 7, no. 2, pp. 3122–3129, 2022.

Experiments: (1) Fixed-Base Manipulation

- Fixed-base Franka Emika Panda serial manipulator
- Task: Reach target object (circled green) while avoiding occluding other red object
- Camera in fixed birds-eye view

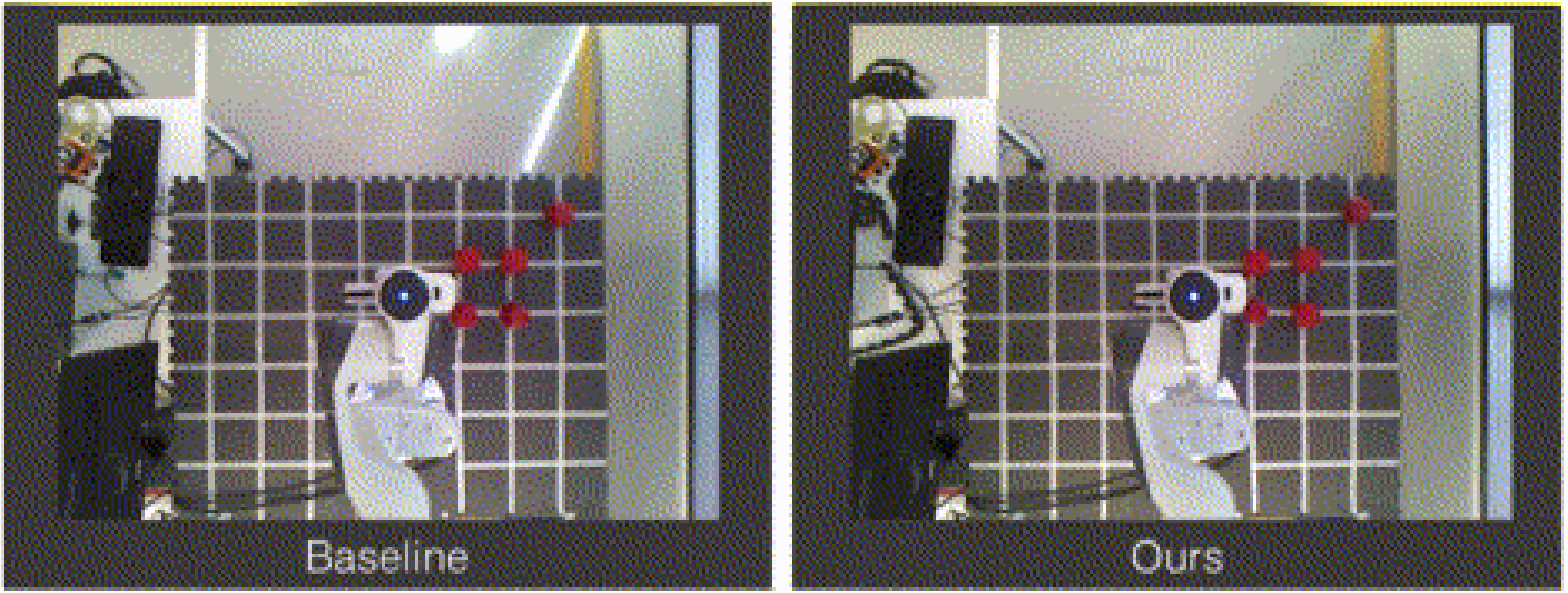


Real world scenarios



Experiments: (1) Fixed-Base Manipulation

- VMC has superior occlusion-avoidance, but worse task time and success rate



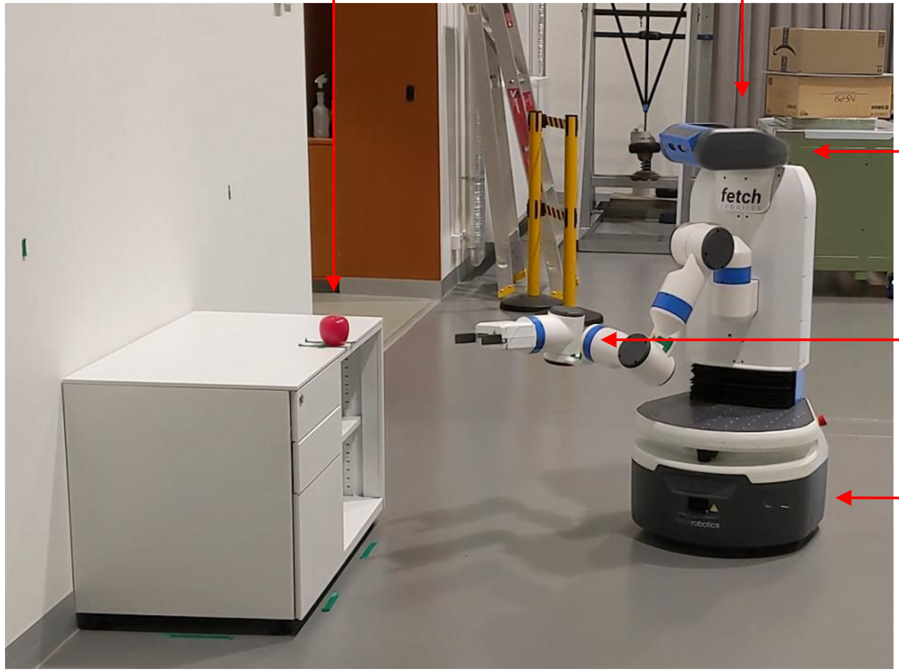
(x2 speed)

(10 trials)

	Occlusion (%)	Task time (s)	Success (%)
VMC (Ours)	**19.4**	17.2	**100**
NEO	45.9	**14.9**	**100**

Experiments: (2) Mobile Manipulation

- Fetch Mobile Manipulator
- Task: Navigate towards and grasp target object
- Baseline NEO augmented with simple camera control method



Experiments: (2) Mobile Manipulation

- VMC has superior occlusion-avoidance and superior closed-loop accuracy

(x2 speed)

(15 trials)

	Occlusion (%)	Task time (s)	Success (%)
VMC (Ours)	**33.7**	**57.0**	**80.0**
NEO	51.8	63.5	33.3

Conclusion

- We present Visibility Maximization Controller to perform **self-occlusion avoidance**
- Able to **generalize** to variety of robotic platforms and scenarios
- Occlusion-avoidance comes at trade-off of less efficient paths, more susceptible to local minima

Future work:

- Improve controller robustness via. multi-step horizon planner, strict hierarchical model etc.
- Validate controller for moving object on mobile manipulator