Control of maintenance robots for the FCC using digital twins

CERN openlab Summer Student Programme Lightning talks

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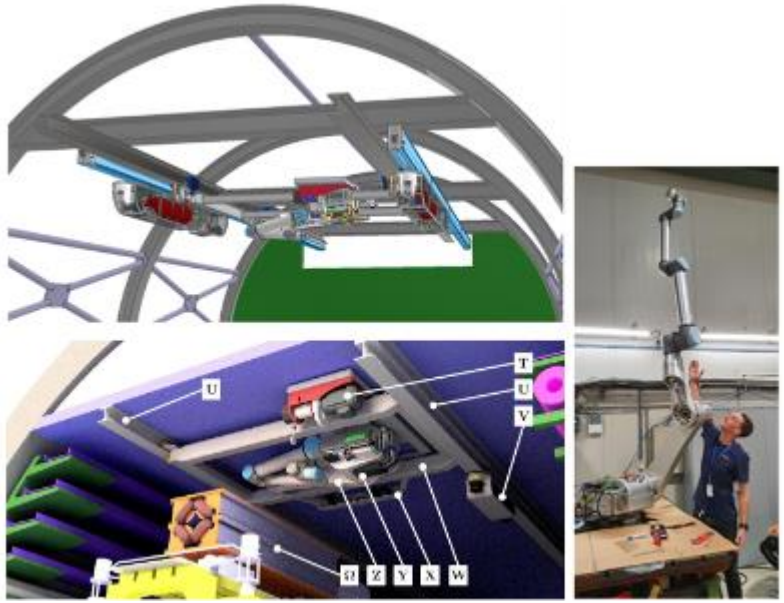
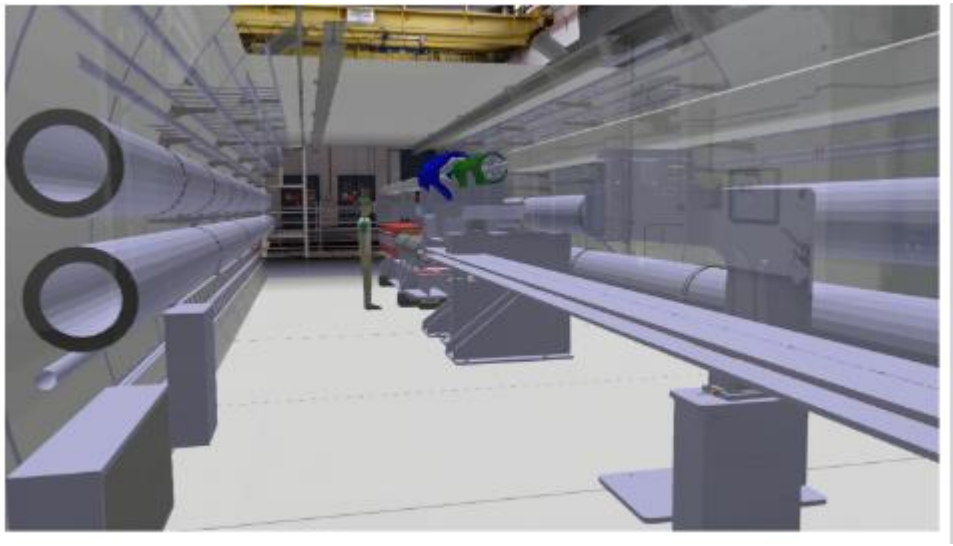
Project specification

Control of digital twins of two maintenance robots working in the FCC. Collision free motion planning, to show the abilities of Isaacsim and prepare a demo of work in the FCC mockup.





Pictures from the Status of the Arc Half Cell Mock-up project report

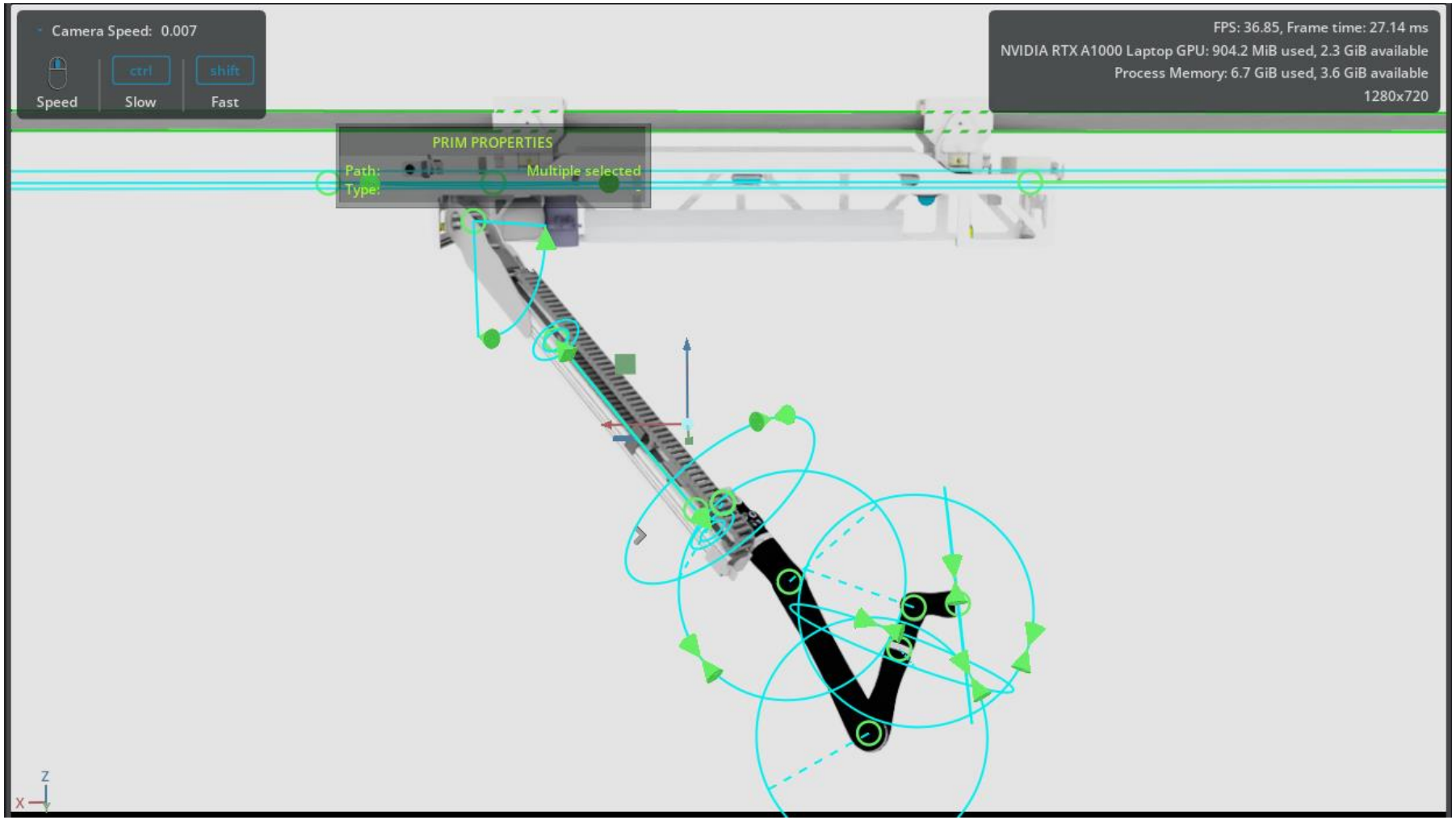
Project outline and motivation

CERN Cranebot - positioning without collision avoidance
CERN Cranebot - positioning with collision avoidance
FCC robot
FCC robot - waypoint following
Environment integration

Why?

Cranebot

10 DoF
Monorail
Kinova arm



Inverse kinematics

Process of finding joint positions that make arm go to a given pose

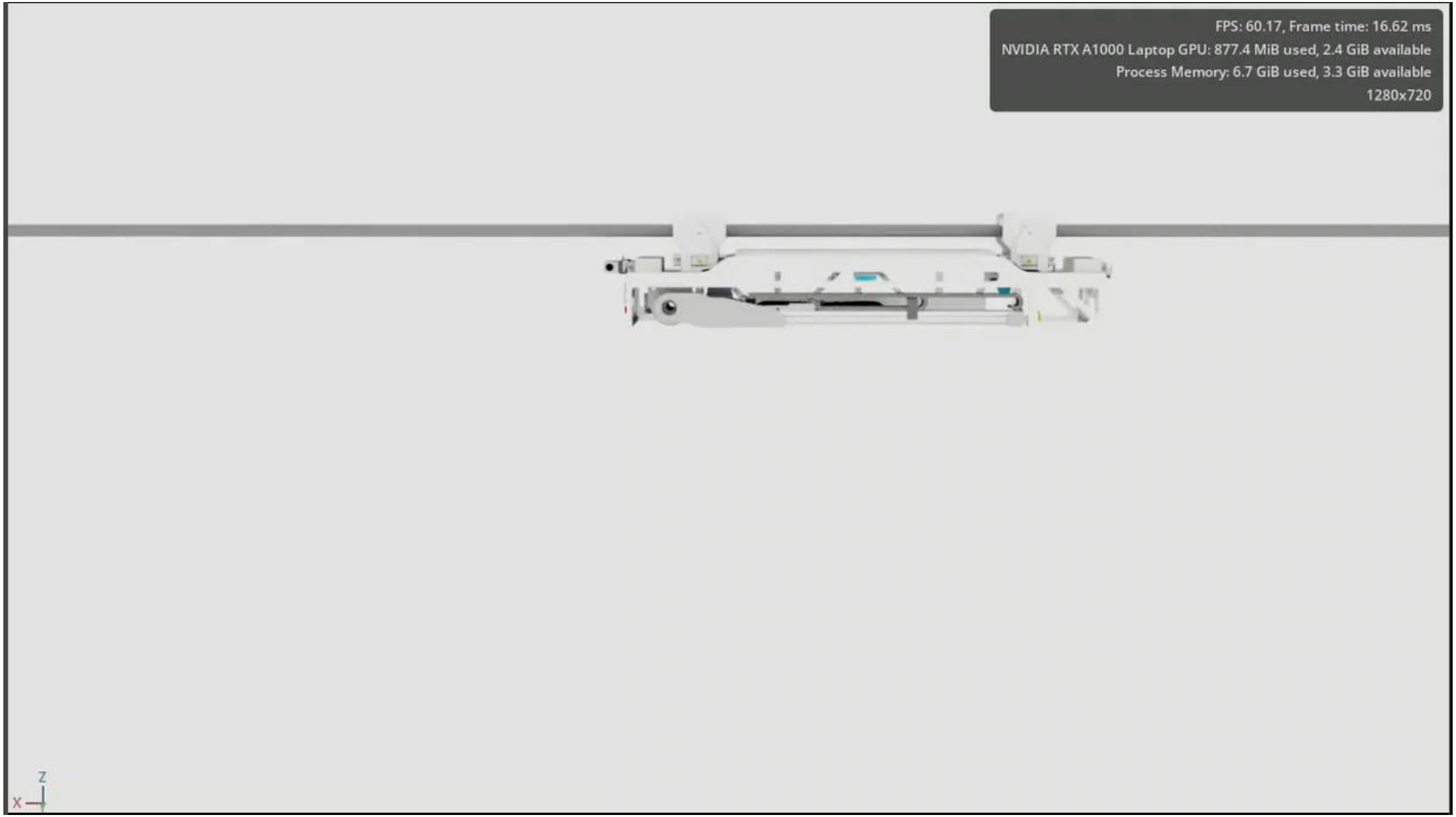
$$p = (x, y, z, r, p, y)$$

Iterative Levenberg-Marquardt least squares optimisation

$$\dot{q}^* = \arg\min_{\dot{q} \in \mathbb{R}^{10}} \|J\dot{q} - e\|^2 + \lambda^2 \|\dot{q}\|^2$$

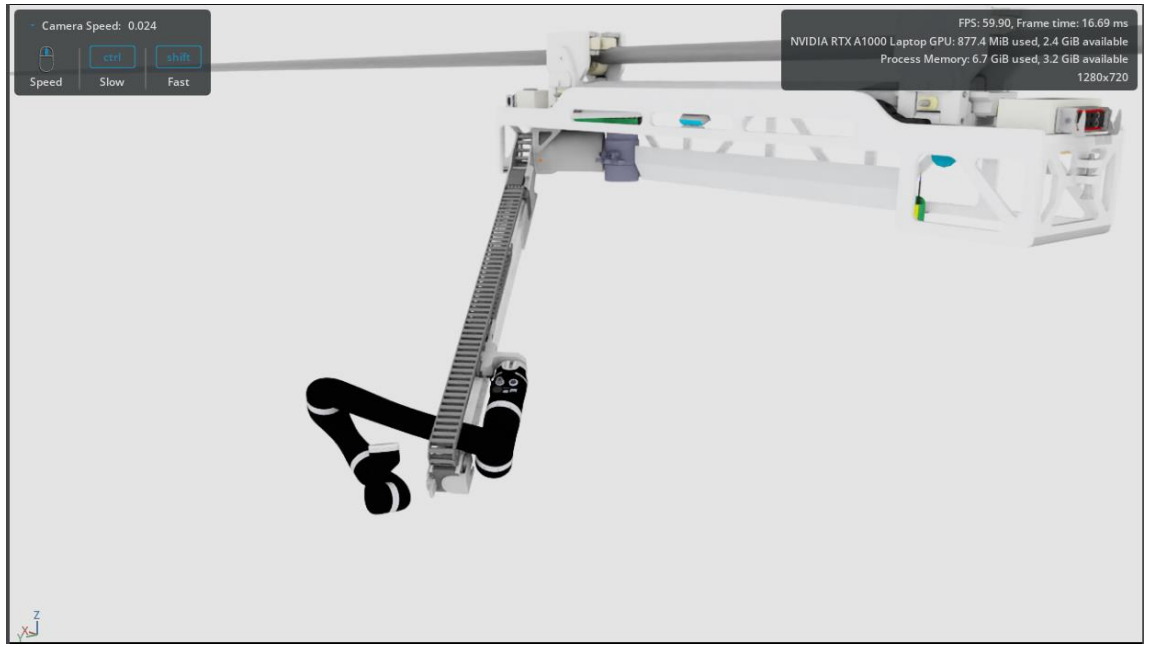
Done in-between physics steps with autocomputed Jacobians

Secondary objective: “untangled” positions


FPS: 60.17, Frame time: 16.62 ms
NVIDIA RTX A1000 Laptop GPU: 877.4 MiB used, 2.4 GiB available
Process Memory: 6.7 GiB used, 3.3 GiB available
1280x720
Z
X

Problem: collisions

Both the final pose and the motion to get there often results in (self) collisions

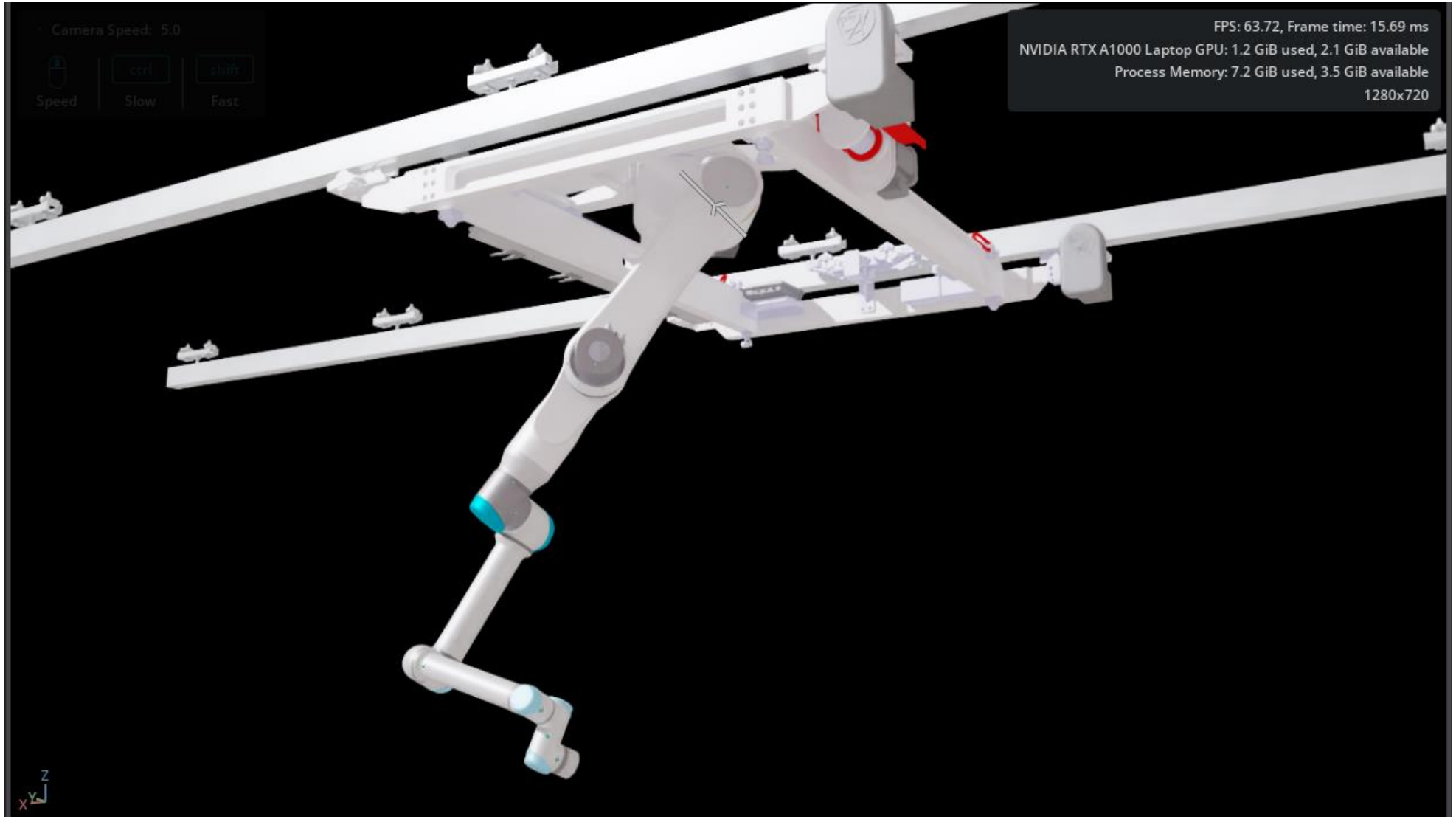


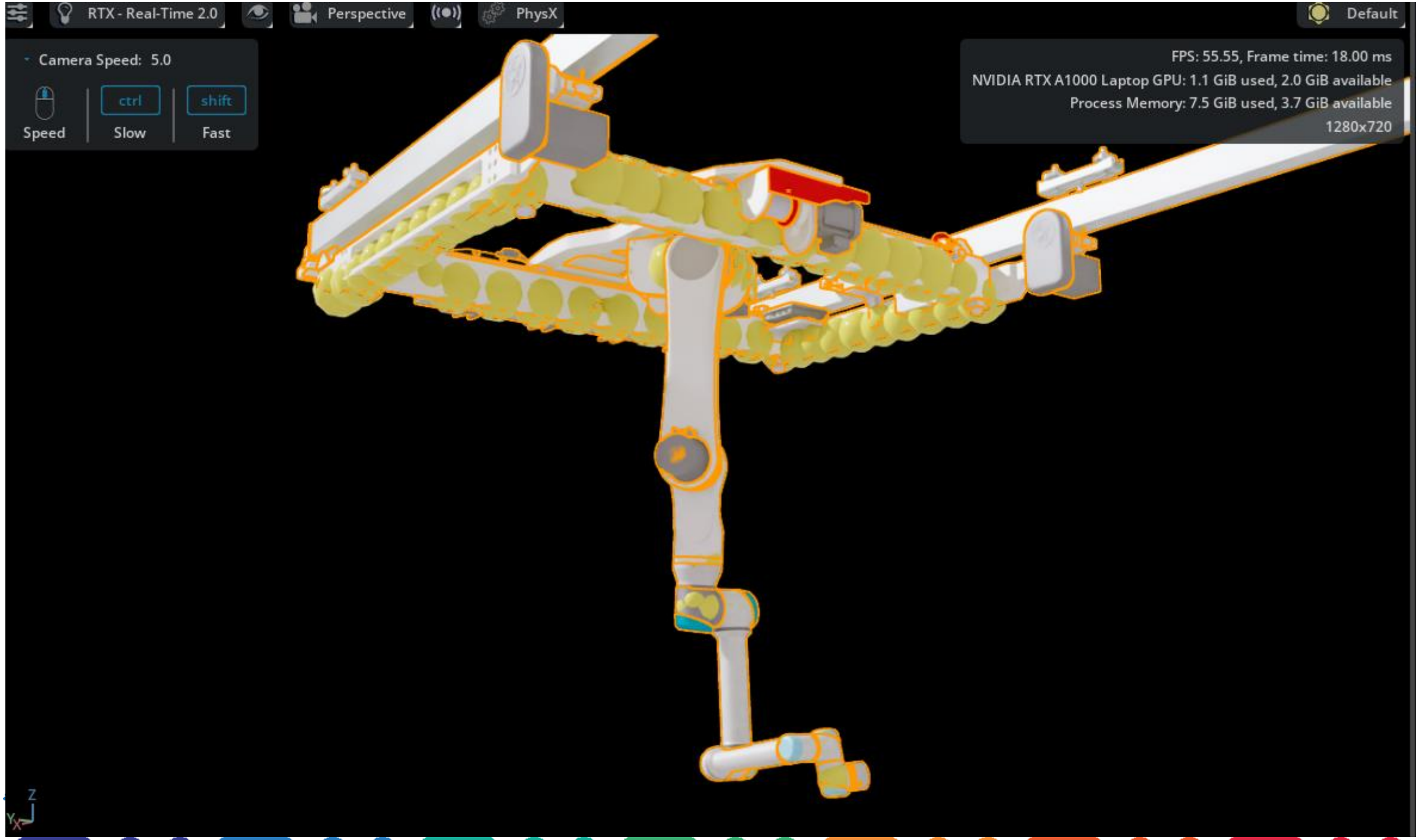
Solution: cuRobo

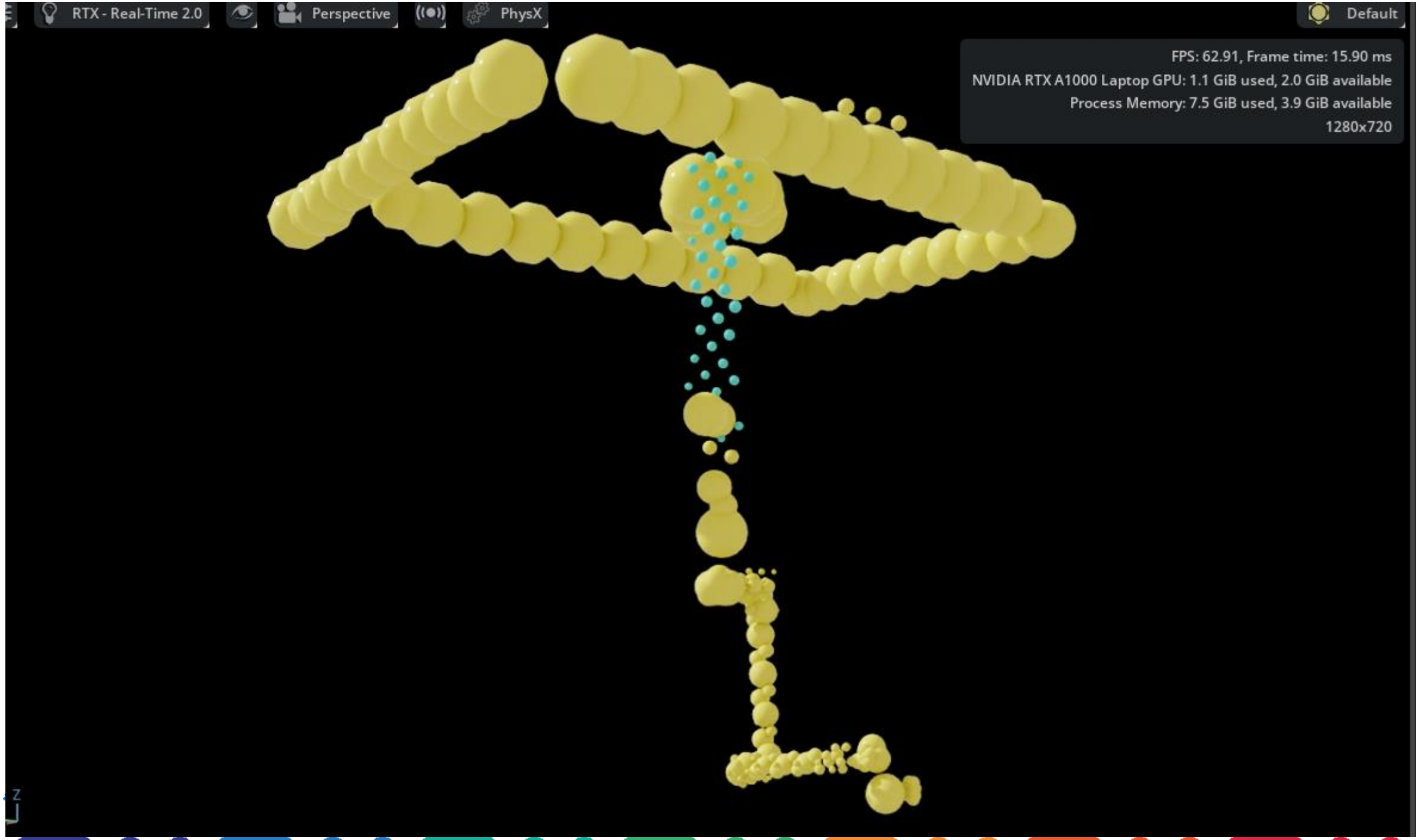
CUDA accelerated inverse kinematics
Motion planning with collision avoidance

First: what is the robots collision mesh?

FCC robot


Camera Speed: 5.0
Speed
ctrl
Slow
shift
Fast
FPS: 63.72, Frame time: 15.69 ms
NVIDIA RTX A1000 Laptop GPU: 1.2 GiB used, 2.1 GiB available
Process Memory: 7.2 GiB used, 3.5 GiB available
1280x720
Z
X Y


RTX - Real-Time 2.0
Perspective
PhysX
Default
Camera Speed: 5.0
ctrl
shift
Speed
Slow
Fast
FPS: 55.55, Frame time: 18.00 ms
NVIDIA RTX A1000 Laptop GPU: 1.1 GiB used, 2.0 GiB available
Process Memory: 7.5 GiB used, 3.7 GiB available
1280x720
Z
Y
X


RTX - Real-Time 2.0
Perspective
PhysX
Default
FPS: 62.91, Frame time: 15.90 ms
NVIDIA RTX A1000 Laptop GPU: 1.1 GiB used, 2.0 GiB available
Process Memory: 7.5 GiB used, 3.9 GiB available
1280x720

Adjusted objective

Cost optimisation using gradient descent:

$$C(q) = w_1 C_{Dist} + w_2 C_{space} + w_3 C_{self_collisions}$$

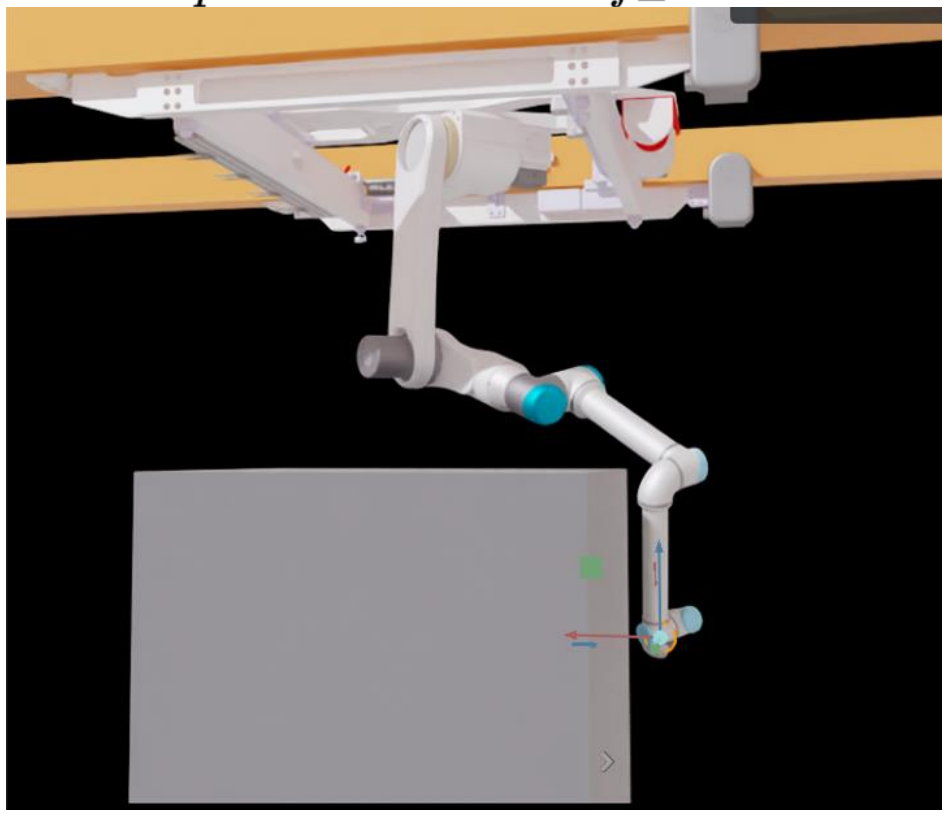
Some link pairs are ignored in the collision calculation.
Difference to before - it is computed before actuation (open-loop control)

Still, during the motion it may collide.

Environment collisions

Simple meshes for fast compute

$$C(q) = w_1 C_{Dist} + w_2 C_{space} + w_3 C_{self_collisions} + w_4 C_{world_collisions}$$

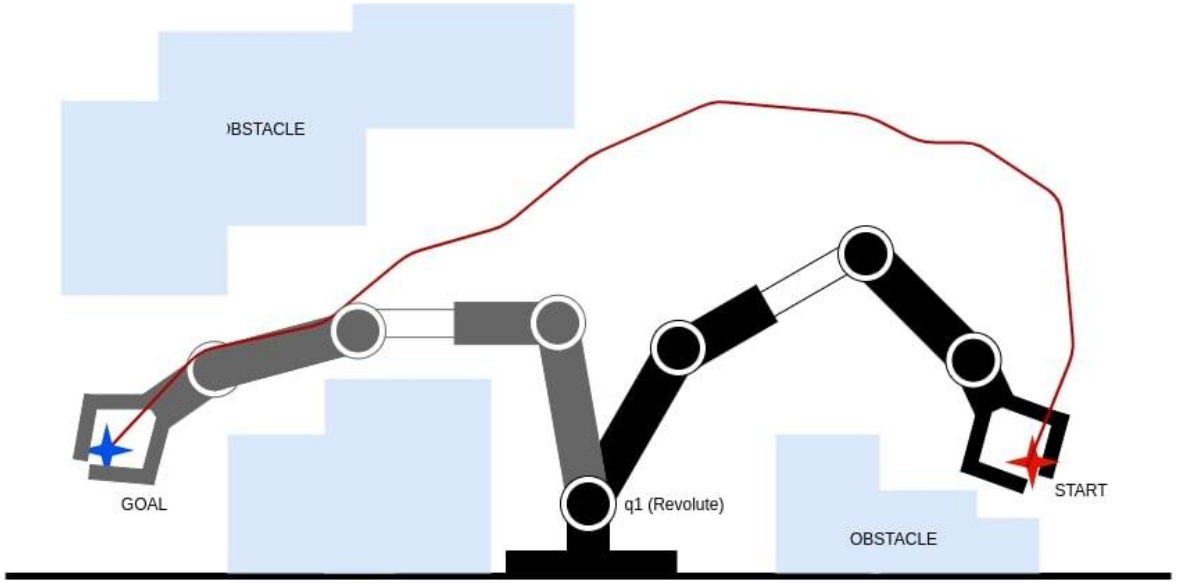


RTX - Real-Time 2.0
Perspective
PhysX
Stage Lights
FPS: 50.48, Frame time: 19.81 ms
NVIDIA RTX A1000 Laptop GPU: 1.2 GiB used, 1.7 GiB available
Process Memory: 8.1 GiB used, 3.7 GiB available
1280x720
Z
X
cm

Motion planning

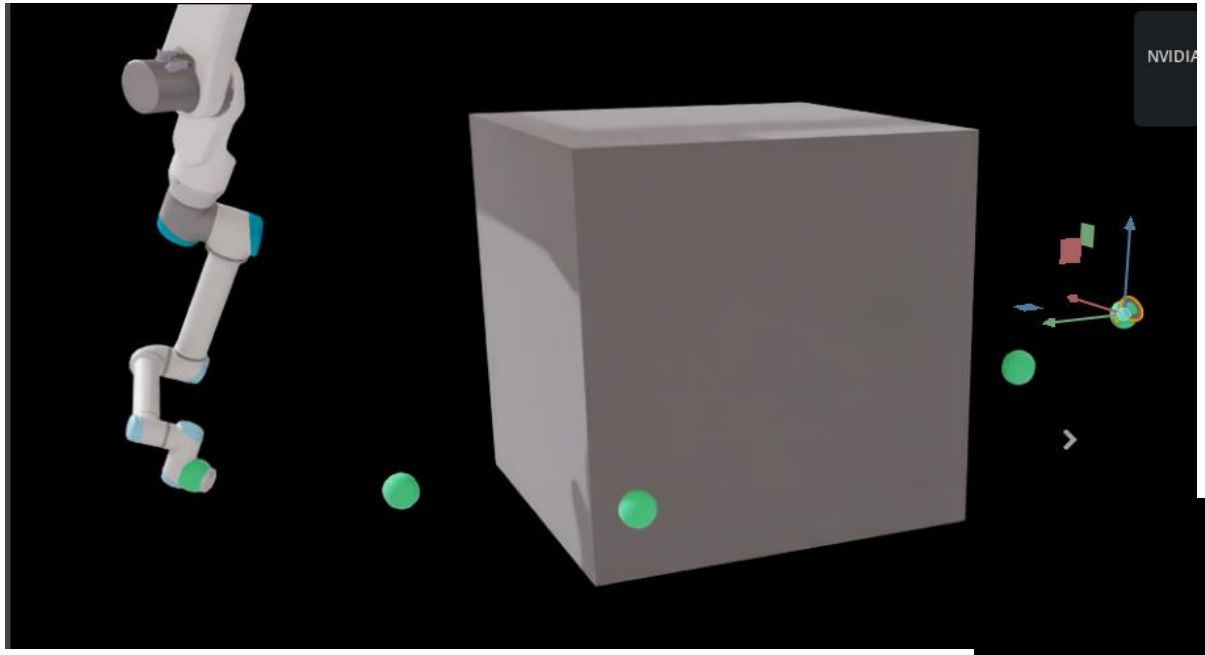
200 collision-free poses optimised at once
Smoothness conditions on neighbouring poses
Avoiding bad positions

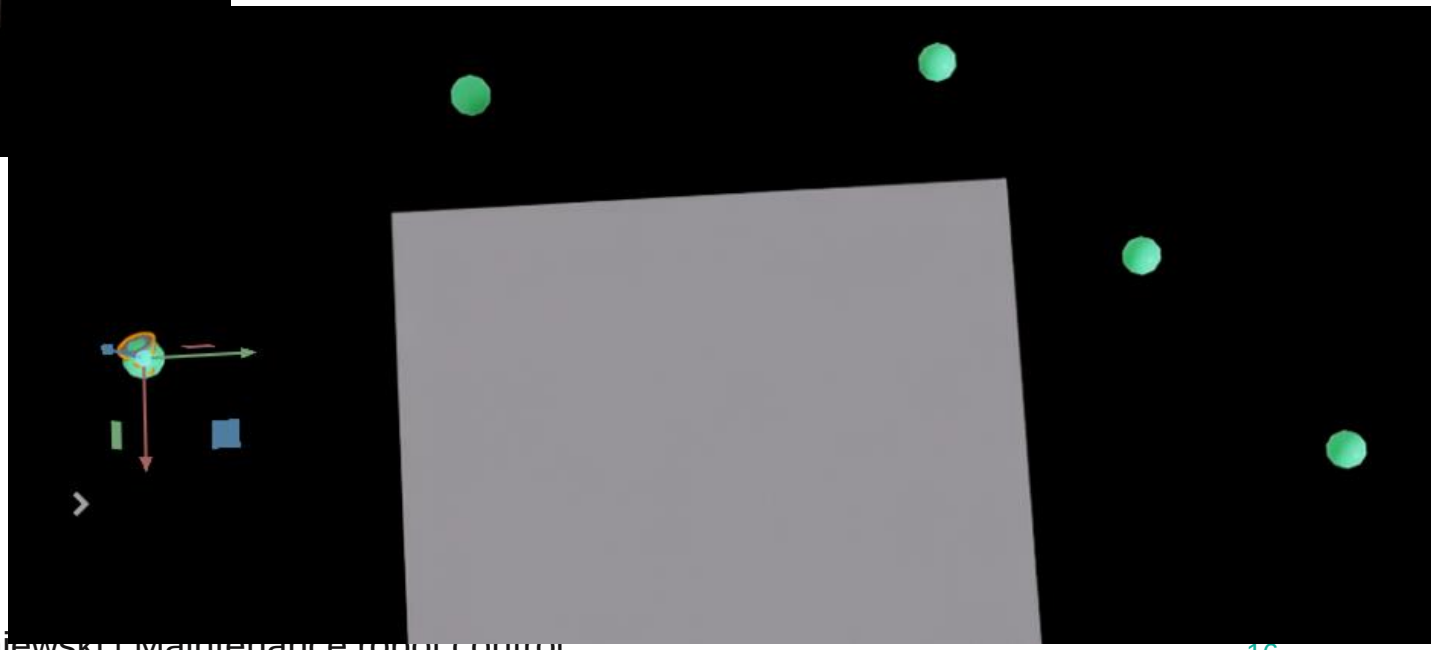
Seeds and graph planning
Path into trajectory



https://control.com/technical-articles/how-does-motion-planning-for-autonomous-robot-manipulation-work/

Waypoints





Limitations and future work

Limitations:
Convergence of the optimiser

Future work:
Waypoint optimisation
Integrating more complex tasks

References

Sundaralingam et al.— *"CuRobo: Parallelized Collision-Free Robot Motion Generation."* NVIDIA (arXiv).

Nakamura, Y., Hanafusa, H. — *"Inverse Kinematic Solutions With Singularity Robustness for Robot Manipulator Control."* ASME Journal of Dynamic Systems, Measurement, and Control, 1986.

Wampler, C.W. — *"Manipulator Inverse Kinematic Solutions Based on Vector Formulations and Damped Least-Squares Methods."* IEEE Transactions on Systems, Man, and Cybernetics, 1986.

Chiaverini et al. — *"Review of the Damped Least-Squares Inverse Kinematics with Experiments on an Industrial Robot Manipulator."* IEEE Transactions on Control Systems Technology, 1994.

Status of the Arc Half Cell Mock-up project – CERN EN/MME F. Carra, et al. Thursday 22nd May 2025 / FCC Week 2025; accessed from https://indico.cern.ch/event/1408515/contributions/6499567/attachments/3072996/5436933/FCC-week_Arc_Half_Cell_Mock-up_status_2025_Final.pdf

Thank you for your attention!