DRC Task 4 Update

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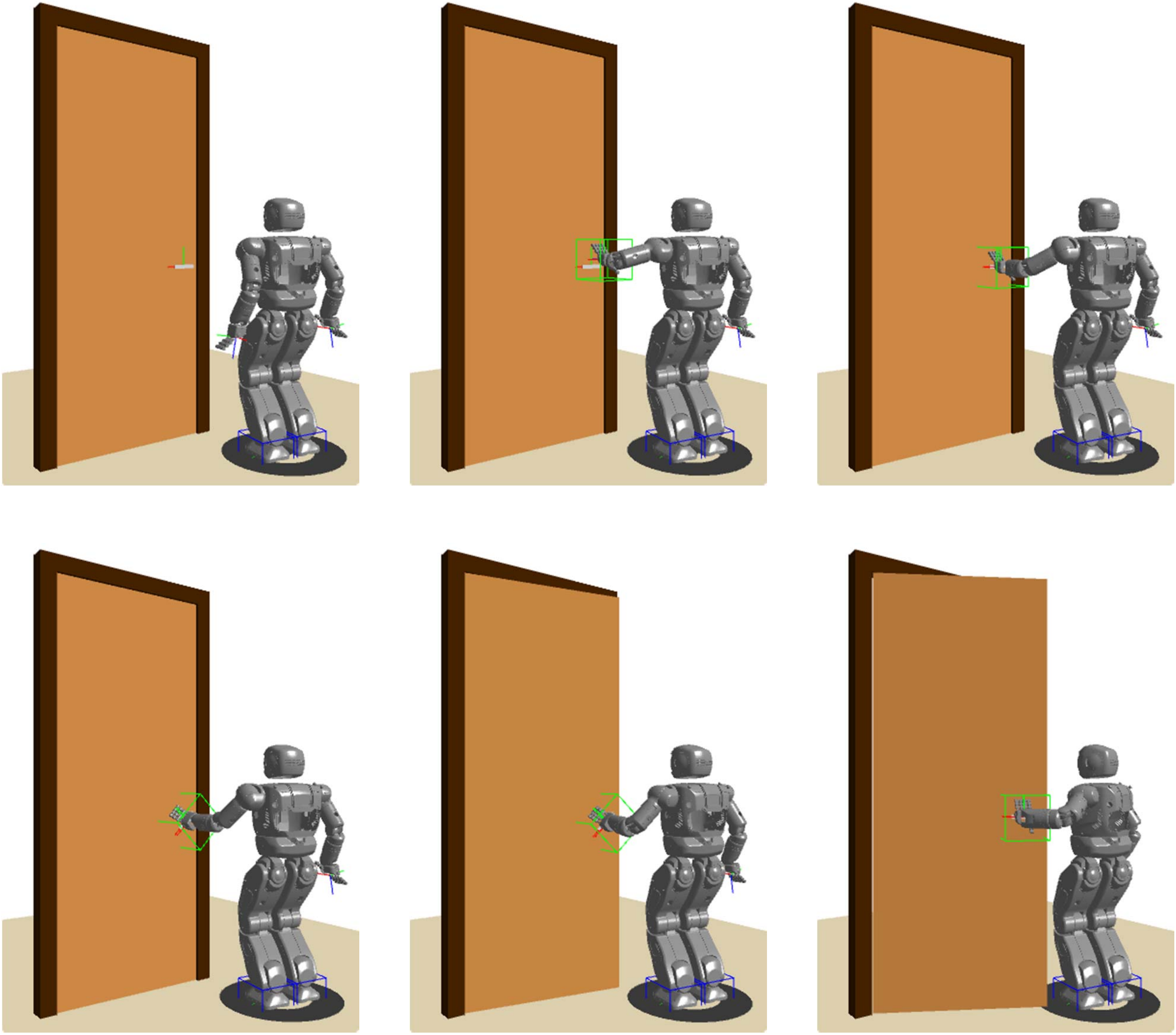
Task 4 description

For Event 4 (open a door and enter a building) the robot must demonstrate the dexterity to operate a door handle and the strength to push the door open. The door and door handle are expected to be standard, commercially available items.

Current status

- Constrained CHOMP trajectory optimization
- Kinematic playback
- Passive grasping
- No perception yet



Trajectory optimization

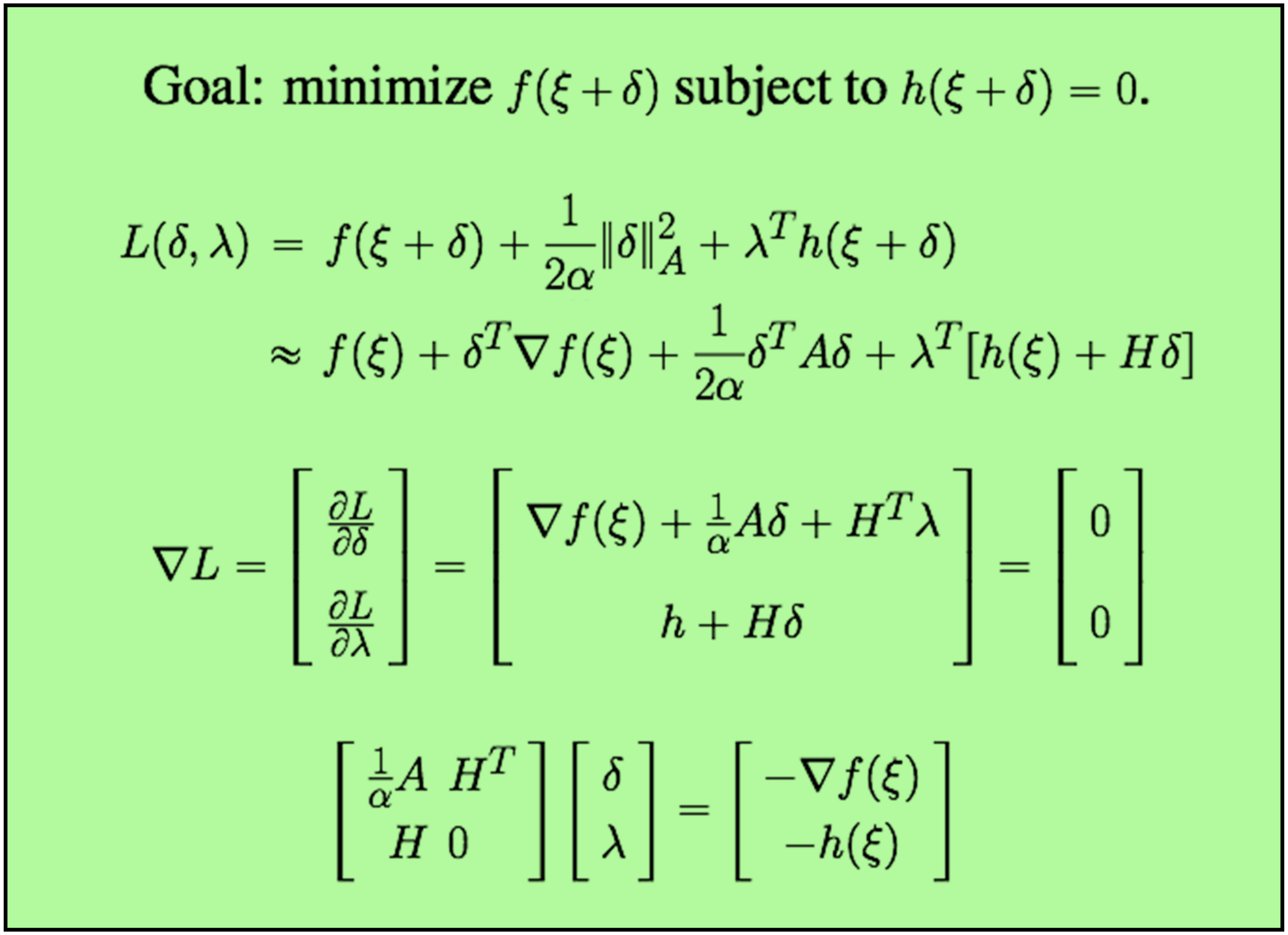
$$\xi = \begin{bmatrix} q^{(1)} \\ \vdots \\ q^{(n)} \end{bmatrix}, \quad q^{(t)} \in \mathbb{R}^m$$

$$K = \begin{bmatrix} 1 & 0 & 0 & \dots & 0 & 0 \\ -1 & 1 & 0 & \dots & 0 & 0 \\ 0 & -1 & 1 & \dots & 0 & 0 \\ & \vdots & & \ddots & & \vdots \\ 0 & 0 & 0 & \dots & -1 & 1 \\ 0 & 0 & 0 & \dots & 0 & -1 \end{bmatrix} \otimes I_{m \times m}$$

$$\begin{aligned} f(\xi) &= \frac{1}{2} \sum_{j=1}^{m} \sum_{t=1}^{n+1} \left(q_j^{(t)} - q_j^{(t-1)} \right)^2 \\ &= \frac{1}{2} \| K\xi + e \| \\ &= \frac{1}{2} \xi^T A \xi + \xi^T b + c \end{aligned}$$

$$\begin{aligned} A &= K^T K \\ b &= K^T e \\ c &= \frac{1}{2} e^T e \end{aligned}$$

Constrained CHOMP



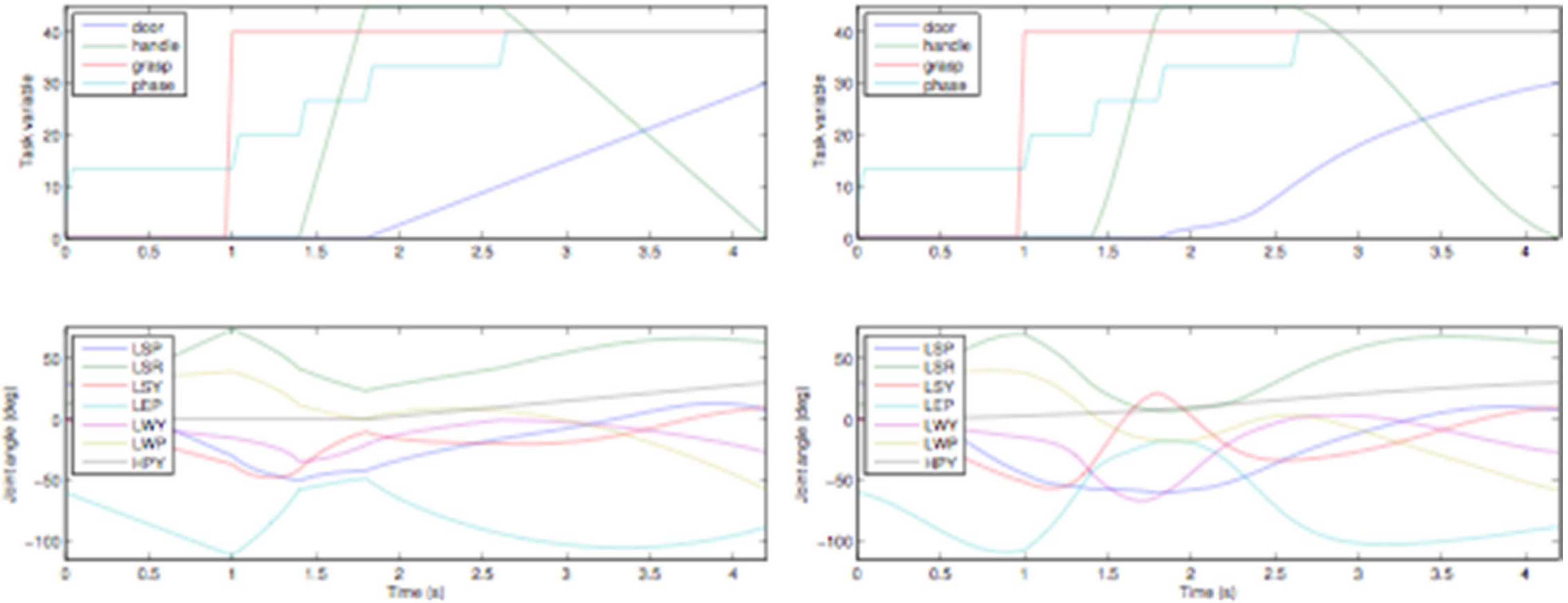
Goal: minimize $f(\xi+\delta)$ subject to $h(\xi+\delta)=0$.

$$\begin{aligned} L(\delta,\lambda) &= f(\xi+\delta)+\frac{1}{2\alpha}\|\delta\|_A^2+\lambda^T h(\xi+\delta) \\ &\approx f(\xi)+\delta^T\nabla f(\xi)+\frac{1}{2\alpha}\delta^T A\delta+\lambda^T[h(\xi)+H\delta] \end{aligned}$$

$$\nabla L = \begin{bmatrix} \frac{\partial L}{\partial \delta} \\ \frac{\partial L}{\partial \lambda} \end{bmatrix} = \begin{bmatrix} \nabla f(\xi)+\frac{1}{\alpha}A\delta+H^T\lambda \\ h+H\delta \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

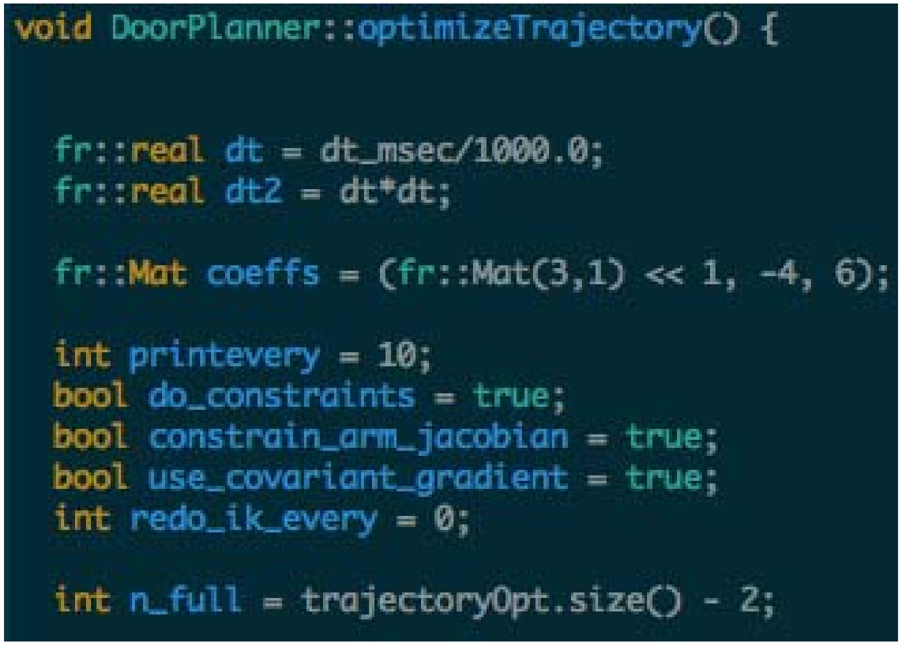
$$\begin{bmatrix} \frac{1}{\alpha}A & H^T \\ H & 0 \end{bmatrix} \begin{bmatrix} \delta \\ \lambda \end{bmatrix} = \begin{bmatrix} -\nabla f(\xi) \\ -h(\xi) \end{bmatrix}$$

Optimization results



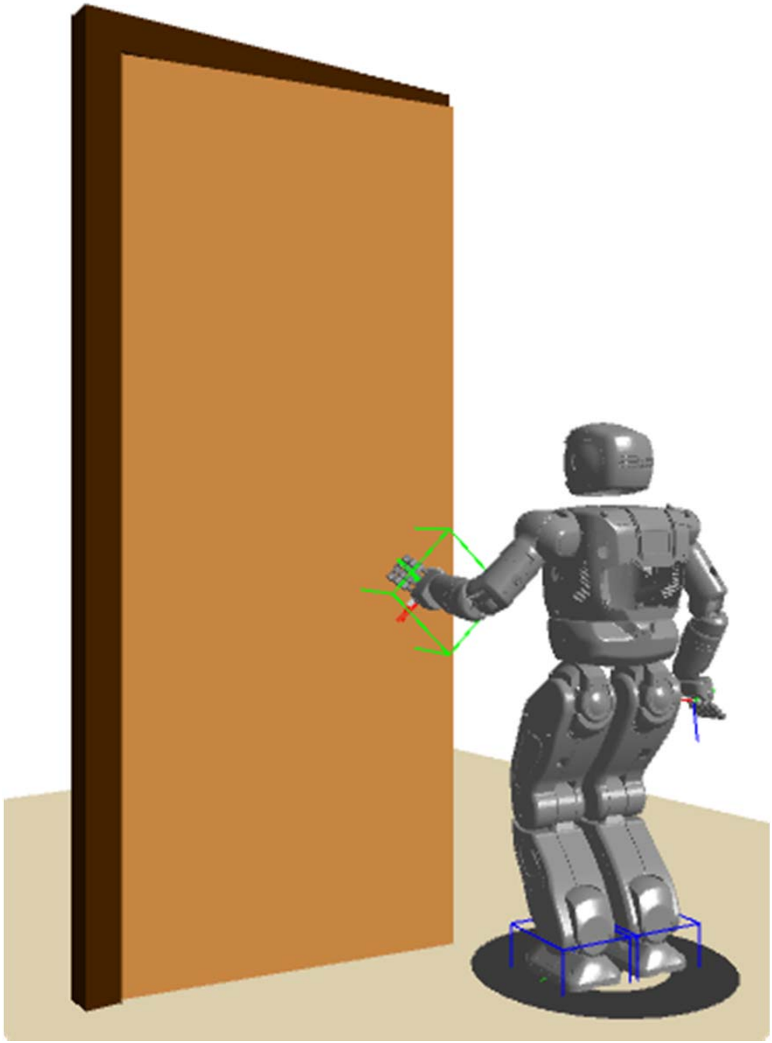
Software details

- C++, ~3K SLOC
- Parse OpenHUBO models
- OpenCV + custom code for matrix manipulation
- Jacobian-based IK



```
void DoorPlanner::optimizeTrajectory() {


  fr::real dt = dt_msec/1000.0;
  fr::real dt2 = dt*dt;

  fr::Mat coeffs = (fr::Mat(3,1) << 1, -4, 6);

  int printevery = 10;
  bool do_constraints = true;
  bool constrain_arm_jacobian = true;
  bool use_covariant_gradient = true;
  int redo_ik_every = 0;

  int n_full = trajectoryOpt.size() - 2;
```

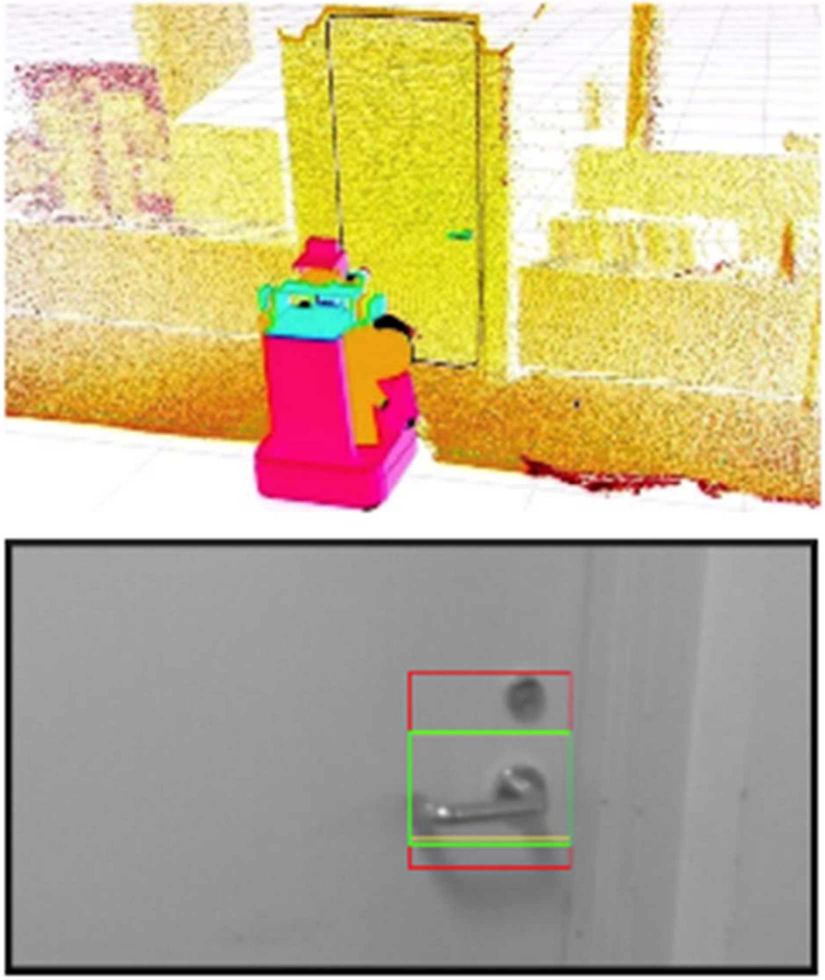
What’s next



- Perception
- Grasping
- Speed up optimization
- Force control/balancing
- Walking, re-grasping

Perception

- Step 1: Mocap
- Step 2: 2D barcodes/fiducials
- Step 3: Point cloud analysis



[Meeussen et al.]

Force control/balance

- Option 0: pure kinematic playback
- Option 1: simple F/T feedback at ankles
- Option 2: extended ZMP controller (Stilman thesis)
- Option 3: floating-base inverse dynamics (Mistry et al)

Wish list

- Position control of fingers via HUBO-ach
- Added wrist DOF
- Closed-form IK
- Upper body calibration
- Sensor calibration
- Better F/T sensing might be useful for force feedback

Questions?