Physics-Based Grasping under Uncertainty

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February 1, 2017
16-662 Robot Autonomy
grasp generation

IK
grasp generation

IK

execution failure
The diagram illustrates a motion planning problem. The configuration space $Q$ is shown, with $Q_{\text{free}}$ indicating the free space and $Q_{\text{obs}}$ indicating the obstacle space. The start configuration $q_s$ and the goal configuration $q_g$ are marked. The diagram also shows a robot (or agent) navigating through the space, avoiding obstacles and approaching the goal.
motion planning problem
What caused these failures?
object pose uncertainty
object pose uncertainty
motion planning problem
proprioceptive uncertainty
proprioceptive uncertainty
RI Seminar: Kris Hauser

“Beyond Geometric Path Planning: Paradigms and algorithms for modern robotics”

Friday, February 2nd at 3:30 pm in NSH 1305

8 PLACEMENT HEADS - SPEED UP TO 20,000 cph

**Source:** https://youtu.be/S8qkaTsr2_o - ESSEMTEC pick and place machine
How can we manipulate under uncertainty?
Closed-loop or open-loop?
Non-deterministic or probabilistic uncertainty?
Closed-form or sample-based representation?
Estimate, react, or plan?
Image-space visual servoing

Markerless real-time articulated tracking

realtime tracking of articulated objects

dark grey: depth measurements colored: tracked model

Visual Feedback

Tactile Feedback

No Feedback
Visual Feedback

Tactile Feedback

No Feedback
Use “guarded moves” to reduce uncertainty
Plan a sequence that maximizes information gain

Estimate the pose of the object using tactile sensing

Estimate the configuration of the robot using tactile sensing

Closed-loop grasping using contact sensing

Learn feedback policies that use sensor feedback

Learn feedback policies that use sensor feedback

Visual Feedback

Tactile Feedback

No Feedback
Visual Feedback

Tactile Feedback

No Feedback
Open-loop robotic part alignment

Rearrangement Planning

Robust Trajectory Selection

Convergent Planning

A brief introduction to POMDPs.
state
\[ s = (q, x) \]

action
\[ a = (\dot{q}, \Delta t) \]
\[ T = p(s' | s, a) \]

observation
\[ o = (o_q, o_c) \]
\[ \Omega = p(o | s, a) \]
Planning in Belief Space

state space

\[ \dim(S) = n \]
Planning in Belief Space

state space
\[ \dim(S) = n \]

belief space
\[ \dim(\Delta) = \infty \]
Offline Planning

Point-Based Methods

Online Planning
Offline Planning

Point-Based Methods

Online Planning
Point-based solvers

\[ V^\pi = \sum_{t=1}^{\infty} \gamma^t R(s_t, a_t) \]
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Point-based solvers

Point-based solvers

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Point-based solvers

Point-based solvers


\[ V^\pi = \sum_{t=1}^{\infty} \gamma^t R(s_t, a_t) \]
\[ \pi^* = \arg \max_{\pi} V^\pi[b(s_0)] \]

Point-based solvers

Offline Planning

Point-Based Methods

Online Planning
Offline Planning

*Point-Based Methods*

Online Planning
$a \sim \pi_{\text{explore}}(b_0)$
$s' \sim T(s, a, s')$
\[ a^* = \arg\max_i Q(b_0, a_i) \]
Offline Planning

Point-Based Methods

Online Planning
The post-contact belief space is small
The post-contact belief space is small
The post-contact belief space is small
The post-contact belief space is small
Decompose into pre- and post-contact policies

pre-contact policy
computed online
move-until-touch
once per problem

post-contact policy
computed offline
closed-loop
once per object

Offline Planning

Point-Based Methods

Online Planning
Offline Planning

Point-Based Methods

Online Planning

Heuristics / Bounds

Combine online and offline planning.
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