Unified Vision-Based Motion Estimation and Control for Multiple and Complex Robots

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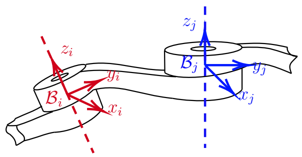
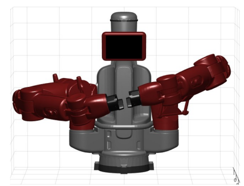
Motivation: Many problems in both computer vision and robot kinematics can be cast through optimization with quadratic costs with linear constraints over bilinear variables.

Example: Revolute joints





Translations

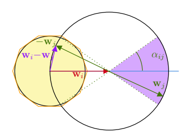
$$T_j - T_i = R_i\,{}^iT_j$$

$$T_{\mathrm{ee}} = T_{\mathrm{base}} + \sum_i R_i\,{}^iT_j$$

Common axis

$$R_i R_e e_z = R_j e_z$$

Joint limits

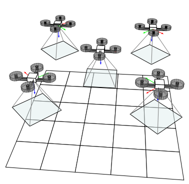


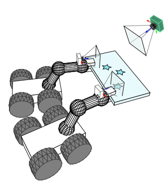
Motivating application: ***Robot Construction Crew.*** Robots are used to assist in the construction of a new building with three main tasks

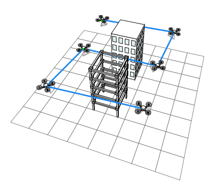
(A) *Localization:* Cameras and robots need to be localized with respect to a common reference frame for the site.

(B) *Collaborative transportation:* Multiple robots localize, pick up, transport and place prefabricated parts

(C) *Vision-aware planning and control:* Periodically, ground or aerial robots need to plan and carry out a 3-D survey







Current work: A novel SDP relaxation

$$\begin{aligned} \|R^{(1)}\| &= 1 \\ \|R^{(2)}\| &= 1 \\ R^{(1)} \cdot R^{(2)} &= 0 \\ R^{(1)} \times R^{(2)} &= R^{(3)} \end{aligned}$$

$$Y = \begin{bmatrix} R^{(1)} \\ R^{(2)} \\ 1 \end{bmatrix} \begin{bmatrix} R^{(1)} \\ R^{(2)} \\ 1 \end{bmatrix}^T$$

$$\begin{aligned} &A\mathrm{vec}(Y) = b \\ &Y \succeq 0 \\ &Y \in \mathrm{rank}(1) \end{aligned}$$

SDP and linear constraints cover all feasible configurations, and the solution is at the boundary of the convex set (rank 1)

Proposed algorithm: First solve SDP, then maximize the largest eigenvalue of Y while keeping convex constraints

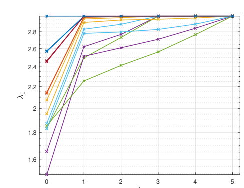
Works because of trace constraints (max eval , other eval)

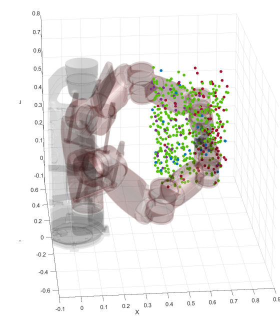
Can be used to check feasibility

Local convergence (maximize a convex function on convex set)

Handles kinematic loops

Method	Success rate	Avg. time
SDP	76.6%	1.2629 s
BFGS	77.6%	0.1966 s





Future work: Extend to

- Prismatic joints
- Grasping
- Vision measurements

Broader impacts

- Collaboration with Autodesk to align relevance for industrial applications
- Problem modeling toolbox

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