Unifying Scene Registration and Trajectory Optimization for Learning from Demonstrations with Application to Manipulation of Deformable Objects

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Learning from Demonstrations

High-Dimensional, Continuous State and Action Spaces → Trajectory Transfer

Trajectory Transfer with Thin Plate Splines (TPS)

Find smooth mapping from demonstration scene to test scene

$$f = \arg\min_f \sum_{i=1}^{N} ||\mathbf{y}_i - f(\mathbf{x}_i)||_2^2 + \lambda_1 ||f||_{\text{TPS}}^2$$

where the TPS regularizer measures smoothness

$$||f||_{\text{TPS}}^2 = \int d\mathbf{x} ||\mathrm{D}^2 f(\mathbf{x})||_{\text{F}}^2$$

Apply mapping to trajectory $f(\mathbf{p}_{t,k})$

Trajectory Optimization for Trajectory Following

Error between points in trajectory / Trajectory smoothness

$$\min_{\tau} \quad \beta \sum_{t=1}^{T} \sum_{k=1}^{K} ||\mathbf{q}_{t,k} - f(\mathbf{p}_{t,k})||_2^2 + \gamma \sum_{t=1}^{T-1} \sum_{j=1}^{J} (\theta_{t+1,j} - \theta_{t,j})^2$$

subject to τ collision-free and feasible

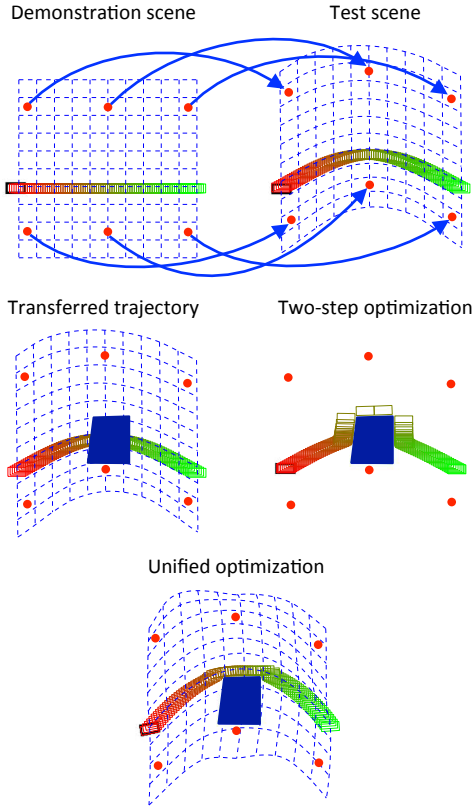
Unified Scene Registration and Trajectory Optimization

$$\min_{\tau, f} \quad \alpha \sum_{i=1}^{N} ||\mathbf{y}_i - f(\mathbf{x}_i)||_2^2 + \lambda_1 ||f||_{\text{TPS}}^2$$ (Scene registration)

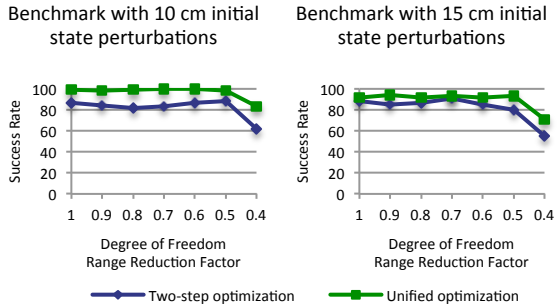
$$+\beta \sum_{t=1}^{T} \sum_{k=1}^{K} ||\mathbf{q}_{t,k} - f(\mathbf{p}_{t,k})||_2^2 + \gamma \sum_{t=1}^{T-1} \sum_{j=1}^{J} (\theta_{t+1,j} - \theta_{t,j})^2$$ (Trajectory following)

subject to τ collision-free and feasible

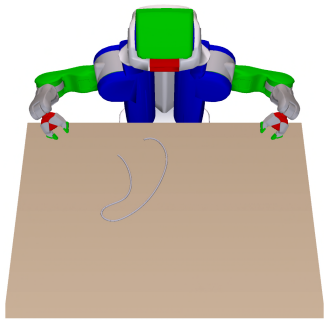
Example of Trajectory Transfer: Box Robot



Experiments and Results: Knot Tying with the PR2



Sample execution of two-step and unified optimization



References

[1] J. Schulman, J. Ho, C. Lee, and P. Abbeel, "Learning from Demonstrations through the Use of Non-Rigid Registration," in Proceedings of the 16th International Symposium on Robotics Research (ISRR), 2013.