Human-Centered Geodesics for Motion Planning



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Motivation and Introduction

Designing trajectories for human-related applications requires
- Emulation of **human joint coordination**
- Clinical **feasibility**

The **redundancy** in human motion makes planning inherently complex

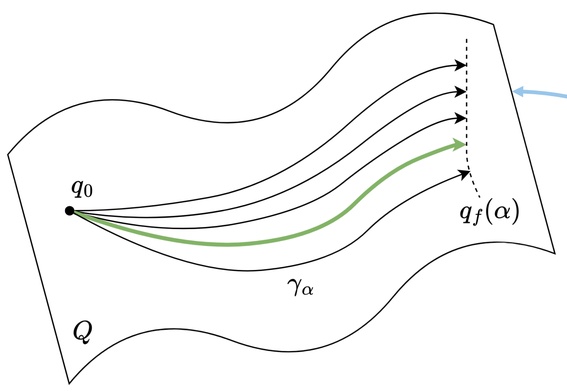
Existing solutions fall into two main categories:
- **Computational Methods**
  - × May fail to represent diverse motions
  - × May not adapt to individual joint constraints
- **Data-Driven Methods**
  - × Require extensive training data
  - × May fail to generalize to unseen movements or users

Human-like Geodesic-Based Trajectory Generation (GEO-HL)
- Extends traditional **energy minimization** models.
- Incorporates **human-likeness metrics** to emulate human coordination
- Uses **barrier-function constraints** to ensure rehabilitation-related constraints.

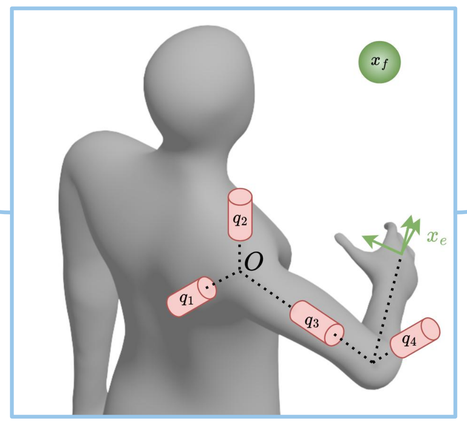


Motion Planning and Geodesic-Based Trajectory Generation

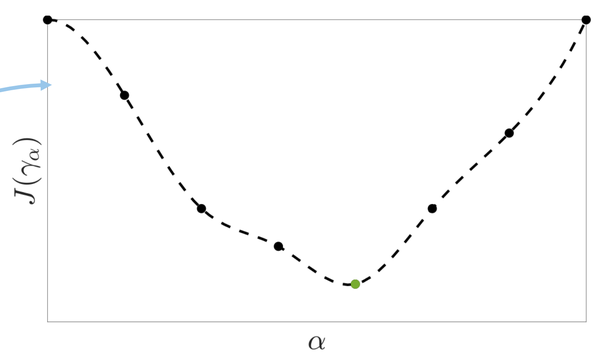
Given an initial configuration $\boldsymbol{q_0} \in Q \subseteq \mathbb{R}^n$ and an end-effector target $\boldsymbol{x_f} \in \mathbb{R}^3$, we optimize over trajectories $\boldsymbol{\gamma}$, connecting $\boldsymbol{q_0}$ and $\boldsymbol{x_f}$.



1



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Generate geodesic **candidate trajectories** $\boldsymbol{\gamma_\alpha}$ joining $\boldsymbol{q_0}$ and $\boldsymbol{q_f(\alpha)}$, where $\boldsymbol{\alpha} \in \mathbb{R}^p$ parameterizes the redundant DoFs.
Geodesics are minimum-length paths in a **Riemannian manifold** with distance defined as

$$d\sigma^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} M_{ij}(q)dq_i dq_j\,.$$

Metric tensor $\boldsymbol{M_{ij}(q)}$ encodes both energy consumption and **joint limit requirements**, in the form of a **barrier function**.

To resolve redundancy, we look for the geodesic minimizing

$$J_{GEO-HL}(\gamma_\alpha) = E(\gamma_\alpha) + w_u U(\gamma_\alpha) + w_a A(\gamma_\alpha)$$

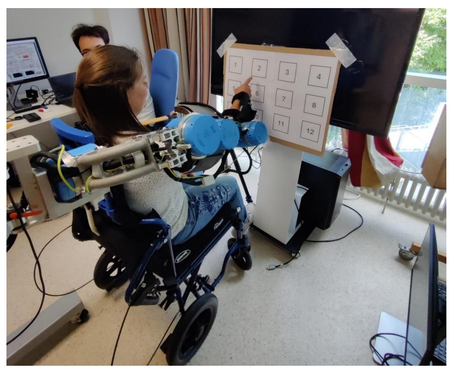
- **Kinetic energy** of the path:
$$E(\gamma_\alpha) = \frac{1}{2}\int_0^1 \mathrm{q}^T(\lambda,\alpha)M(\lambda,\alpha)q(\lambda,\alpha)d\lambda.$$
- **Potential energy** of final configuration: $U(\gamma_\alpha) = U\left(q_f(\alpha)\right)$.
- **Anthropomorphism**: $A(\gamma_\alpha) = \left\|\frac{2(q_f(\alpha)-\bar{q})}{q_M - q_m}\right\|$.

The weights $\boldsymbol{w_u}$ and $\boldsymbol{w_a}$ require tuning.

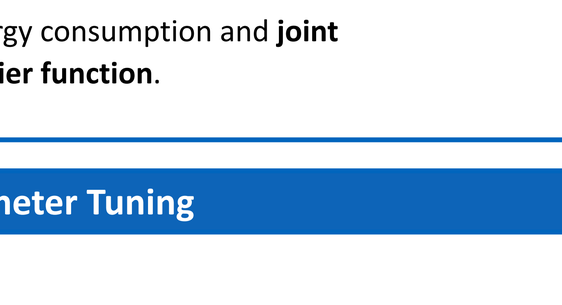
Experimental Setup and Cost Parameter Tuning

Objective of Data Collection
- **Tune** cost parameters $\boldsymbol{w_u}, \boldsymbol{w_a}$ from $J_{GEO-HL}(\gamma_\alpha)$.
- **Compare** existing methods (MJ, IK, GEO) with GEO-HL in terms of **human-likeness**.

Setup
- Data was collected using the **NESM-γ** arm exoskeleton.
- Subjects performed predefined motions targeting 3D workspace objectives.
- 30 motions, each repeated 10 times.
- 7 healthy subjects (25-31 years).

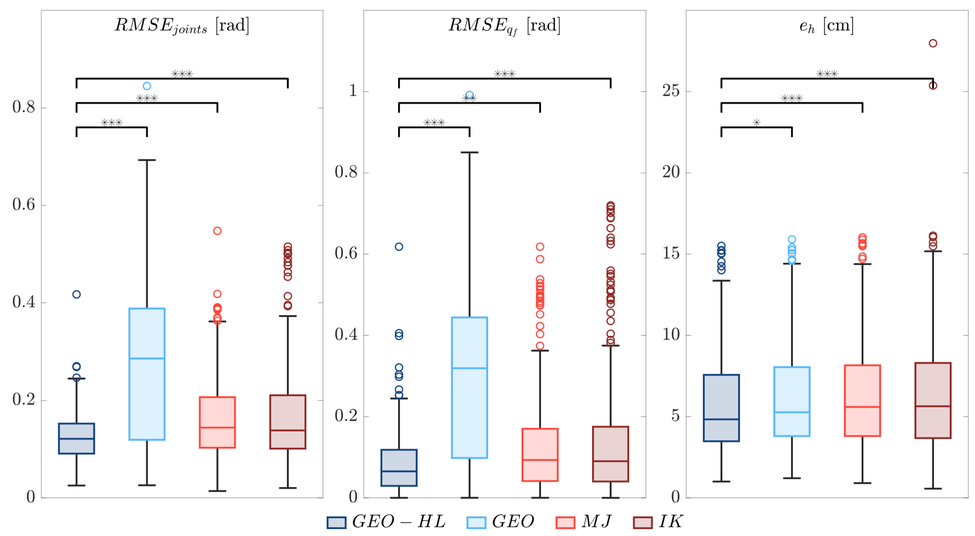


Parameter Tuning
- **Grid search** over $w_u \in [0,0.15]$, $w_a \in [0,1.2]$ to minimize an error measure in joint trajectories.
- **Optimal values**: $w_u \approx 0.08$, $w_a \approx 0.4$.



User Study Results

Methodology:
- Use data not exploited for parameter tuning in order to verify **generalization** properties.
- Evaluate the joint trajectories generated through GEO-HL against **recorded human movements**, in relation to **comparison methods**:
  - **GEO**: minimizes only **kinetic energy** along the trajectory;
  - **MJ**: generates smooth trajectories by **minimizing jerk**;
  - **IK**: directly solves for the **closest final configuration** and interpolates.



Conclusion and Future Directions

We introduced a **geodesic-based motion planning** method tailored for **human-like** joint coordination. Results show significant improvements in **trajectory quality** and constraint adherence. Future work will explore:
- Higher DoF models and real-time implementation.
- Learning-based metrics.

References

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