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Abstract Title: Parameter Estimation and Model Evaluation of a Two-Link Swimmer

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Introduction:

Understanding how geometry and mass distribution influence swimming performance is critical in biological model-ing and bio-inspired design. Estimating mechanically meaningful parameters (e.g., segment lengths, masses, damp-ing) from observed kinematics is challenging. To this end, this study uses a simplified model of undulatory swim-ming, which accommodates the effects of the interaction between the solid body and the fluid.

Objective:

We aim to estimate parameters in a low-order mechanical model of a swimmer, derived from response measure-ments of a computational fluid dynamics (CFD) simulation of the fluid structer interaction. We develop and evaluate a model and an inverse modeling framework to estimate dimensional physical parameters from motion data, for-mulated in terms of geometric and mass ratios. This approach reduces parameter correlation and dimensionality, thereby mitigating overfitting by enforcing physically meaningful relationships.

Methods:

We model a planar two-link, nonholonomically constrained fish-like swimmer using Lagrangian dynamics. System properties are defined in terms of length ratio ($\ell r = \ell 2/\ell 1$), mass ratio ($mr = m2/m1$), damping (fd), and stiffness (k1). The inverse problem is formulated as a nonlinear least-squares optimization: minimizing the residual between simulated and observed time series of heading angle and translational velocity. Constrained optimization is per-formed using fmincon in MATLAB. After solving for optimal ratios, dimensional parameters are reconstructed from known total mass and length. Profile likelihoods and scaled sensitivity coefficients are used to assess parameter identifiability. Bootstrapping provides confidence intervals under synthetic noise. Monte Carlo simulations assess the robustness of estimates under randomized perturbations. The harmonic balance identification method is also applied and compared for validation.

Results:

The method accurately recovers dimensional parameters when using noiseless or lightly perturbed data, yielding low root-mean-square residuals. SSC analysis reveals the length ratio as a dominant influence on both heading and velocity. Profile likelihoods exhibit well-behaved cost landscapes for ratios and fd, while k1 remains marginally identifiable. Bootstrapping yields narrow confidence intervals in low-noise settings, but broader distributions when data are degraded or bounds relaxed.

Significance:

This study presents a robust, physically grounded framework for recovering interpretable model parameters from motion data. It offers significant value in biomechanics and robotic design, where mechanistic insight is preferred over black-box fitting.

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