Estimating the sources of motor errors

with Max Berniker

www.koerding.com
Wide range of experiments
“Internal models”

Perturb movement property

Measure movement

see Kording et al, Nature Neuroscience 2007
Ambiguity

Limb impedance: Viscosity, stiffness, inertia, muscle strength
Environmental affordances: Object inertia, force fields

Different disturbances (vector d) may lead to the same error

see Kording et al, Nature Neuroscience 2007
Graphical model

Source Estimation Model
Relevant variables

- Estimate of parameters
- Real parameters

- Estimate all variables using Extended Kalman Filter
Influence of perturbations on movement: linearization

\[ \text{Error} = f(d, \hat{d}, \text{movement}) \]

\[ \text{Error} \approx \sum_{i=1}^{N_d} I_i(\text{movement}) \]

\[ I_i(\text{movement}) := \frac{\partial}{\partial d_i} \text{Error} \]

Numerical differentiation 😞
Simulating trajectories

\[ \frac{\ddot{x}}{m} = EP\text{controller} \]
\[ + \ \Delta F_{\text{jointstiffness}} + \Delta \hat{F}_{\text{jointstiffness}} \]
\[ + \ \Delta F_{\text{musclestrength}} + \Delta \hat{F}_{\text{musclestrength}} \]
\[ + \ \Delta F_{\text{environment}} + \Delta \hat{F}_{\text{environment}} \]
Gaussian changes over time

\[ d_i(t + \Delta t) = d_i(t) + \eta_i(t) \]

Where \( \eta_i(t) \) is drawn from a Normal Distribution of width \( \sigma_i \)

make \( \sigma_i \) proportional to nominal values

Extended Kalman filter for state estimation (converges well)
Force field learning
Shadmehr and Mussa Ivaldi
1994

Learn

Intrinsic disturbance
\( \tau = W\dot{\theta} \)

Generalize

Extrinsic disturbance
\( F = Bx^* \)

Experimental Data

Simulated Results
Criscimagna Hemminger et al.
2003

CCW
Extrinsic
Test

CW
Intrinsic

Learn
Generalize

Experimental Results
Simulated Results

Extrinsic
Intrinsic

Early Training

Late Training

Test
Dizio and Lackner 1995

\[ F = -2m(\omega \times v) \]

Learn

Generalize

Experimental results

Simulated results
Current work: Generalize to contexts

- Variables not always relevant
- Coffee cup only relevant when in my hand

Source Estimation with Multiple Contexts
A normative view on human motor adaptation

Extrinsic world

Error

Extrinsic world