Modeling joint action as human movement synchronization in goal-directed tasks

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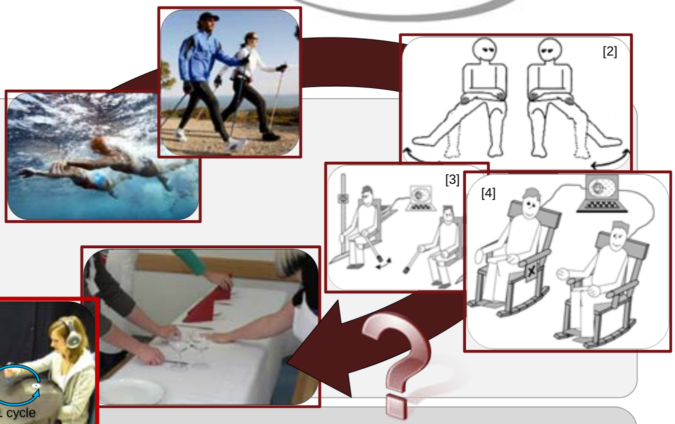
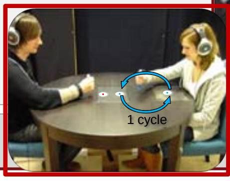


Human movement synchronization…

… is a frequently observed phenomenon in human action that also influences our relationships with others [1]. It seems as if synchrony serves a purpose in human interaction. Research on the topic has been done applying paradigms like leg [2] or pendulum swinging [3] and rocking in chairs [4]. It was found that movement synchronization is a stable phenomenon with attractors at in-phase and anti-phase relation. But these studies focused on the entrainment of synchronization and had thus little in common with joint action tasks that are performed in daily live which require precision and coordination.

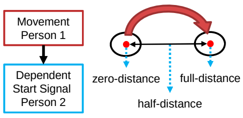
Therefore we ask the question if people do also synchronize their movements during goal-directed tasks [5]. In a subsequent step we develop a model for joint repetitive action [6] in order to transfer joint action principles to human-robot interactive tasks.



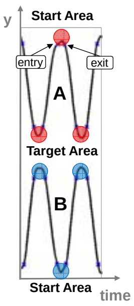
Do people synchronize in goal-directed tasks?

1. Setup and task

- → Two people facing each other (total: 10 dyads)
- → Repetitively hit a target with the pen (10 cycles per trial)
- → 3 start conditions: zero-/half-/full distance
- → Individual acoustic start signal depending on movements of the interaction partner
- → Random start assignment
- → IR-motion tracking
  - Online: 30 Hz
  - Offline: 200Hz



2. Analysis



Lag variability

- → Temporal difference between dyads
- → Calculated at reference points e.g. target entry as temporal difference between participants
- → Median difference over dyads per cycle
- → Mean difference between subsequent cycles

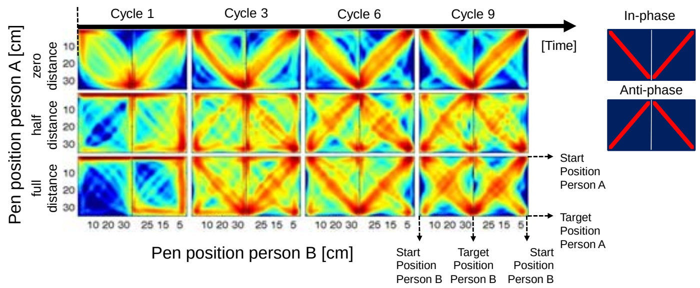
Movement time and dwell time

- → Time spent in start/target area
- → Time spent for moving forwards/ backwards

3. Results

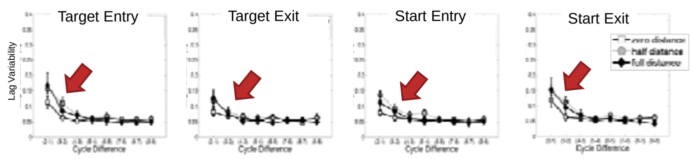
Do people synchronize in goal-directed tasks?

→ People do synchronize their movements during goal-directed actions mostly to in-phase and anti-phase relation.



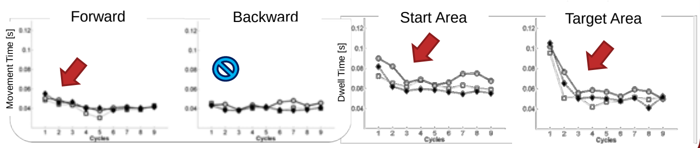
When do people synchronize during interaction ?

→ Adaptation to the interaction partner happens at the beginning of a movement sequence



How do people synchronize?

→ People adapt while moving forwards and through waiting in the target areas

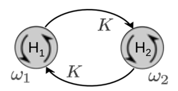


Modeling joint action for human-robot interaction

1. Oscillator model

- → Treat the coordination of a human dyad as a synchronization problem of coupled oscillators
- → Kuramoto model: two harmonic oscillators with a sinusoidal coupling

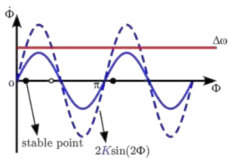
$$\dot{\theta}_1 = \omega_1 + K\sin(\theta_2 - \theta_1)$$
$$\dot{\theta}_2 = \omega_2 + K\sin(\theta_1 - \theta_2)$$



- → Phase difference dynamics of the model are extended to account for the two stable attractors in-phase and anti-phase

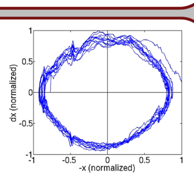
$$\dot{\Phi} = \Delta\omega - 2K\sin(2\Phi)$$
$$\Phi_e = 0, \pi$$

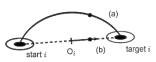
K : gain of bidirectional coupling
$\Delta\omega$: difference of the individually preferred task speed



2. Generalizability to other cyclic movements

- → Model applicable to any kind of cyclic movement, e.g. tapping, walking
- → In phase space, cyclic movements transform into closed trajectories
- → Capturing of the coordination of heterogeneous movements is possible
- → Recorded 3D hand trajectories are projected to 1D-movement signals in the effective task space
- → Instantaneous phase calculation is based on movement signals x_i
- → Calculate a time continuous instantaneous phase to capture time variability in human movement data





3. Phase calculation

1. State-Space approach

$$\theta_i^S(t) = \arctan\left(\frac{\dot{x}_{i,n}}{x_{i,n}}\right)$$

Phase angle of normalized state $(x_i, \dot{x}_i)$

2.Spectral approach

$$\zeta_i(t) = x_i(t) + j\tilde{x}_i(t) = A_i^H(t)e^{j\theta_i^H(t)}$$

Hilbert-Transform:

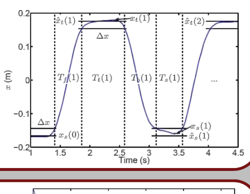
$$\rightarrow \quad \tilde{x}_i(t) = \frac{1}{\pi}\mathrm{P.V.}\int_{-\infty}^{\infty}\frac{x_i(\tau)}{t-\tau}d\tau$$

Phase $\theta_i^H(t)$ is extracted from the analytical signal $\zeta_i(t)$

3. Hybrid approach: include task knowledge

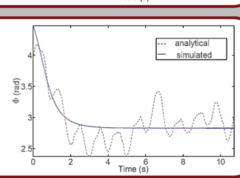
Movement cycle divided into 4 segments:

- → *2 Movement Segments*: inverted minimum-jerk
- → *2 Dwell Segments*: linear phase progress
- → Based on estimates for each segment's duration



4. Parameter estimation

- → Excitation of phase difference dynamics is achieved by the varying initial conditions
- → Identification of parameter sets ($\Delta\omega$,K) by applying non-linear Grey-Box modeling based on the time-series data of Φ



→ The parametrized model is now ready for application in humanoid robots

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