Human Stance: A *Tail* of Balance

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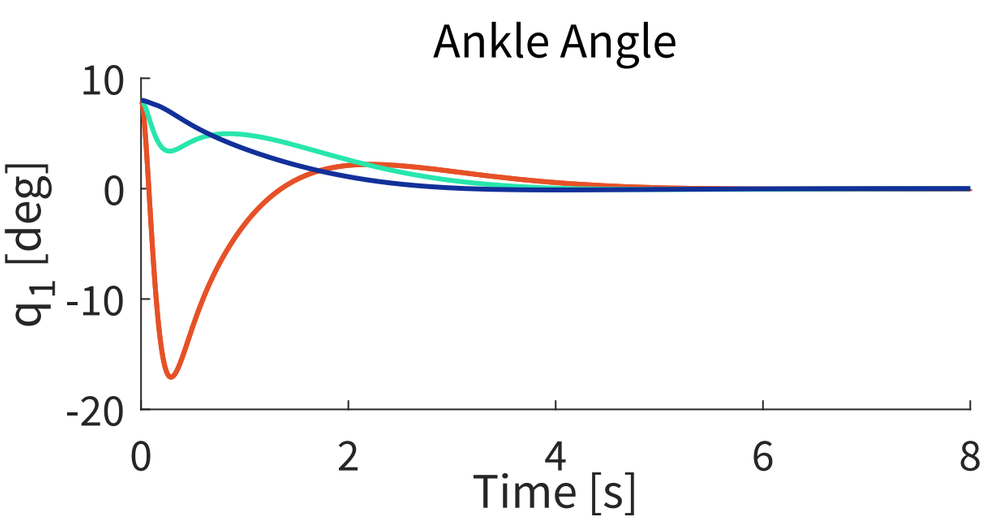
Motivation

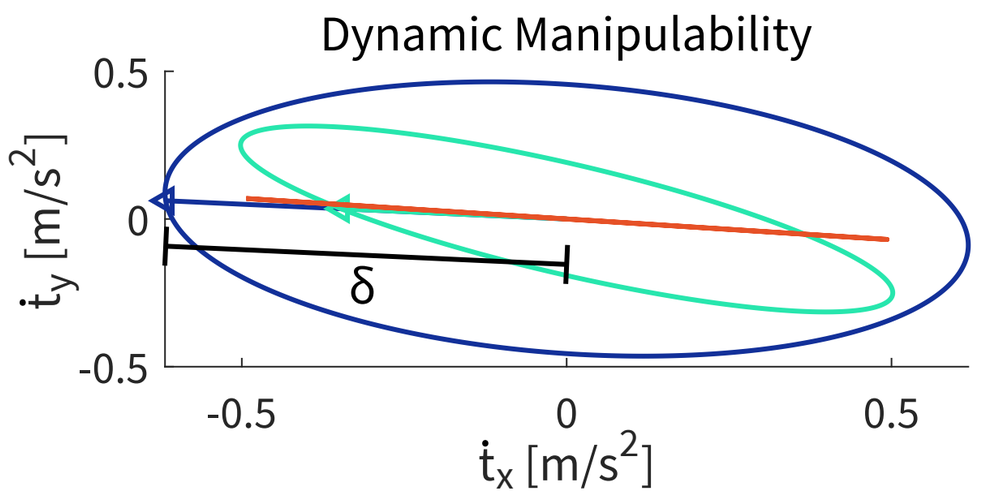
Human stance is inherently unstable
- Insufficient ankle torque
- Delayed neural control
- Small base of support

Animals utilise tail for balance augmentation
- Supernumerary robotic tail for human?

Mechanical Characterisation[1]

Upright stance modelled as inverted pendulum
- 1-dof about the ankle joint
- Examine 1 and 2-dof robotic tails to augment balance
- Mounted posterior to trunk, at human centre of mass





- Variable coupling inertia critical in creating reaction torque to augment balance
- 2-dof tail has greatest manipulability δ (ability to accelerate to upright pose)

[1] Abeywardena et al., *Mechanical characterisation of supernumerary robotic tails for human balance augmentation*, submitted to ASME Journal of Mechanisms and Robotics
[2] Abeywardena and Farkhatdinov, *Towards enhanced stability of human stance with a supernumerary robotic tail*, submitted to IEEE Robotics and Automation Letters
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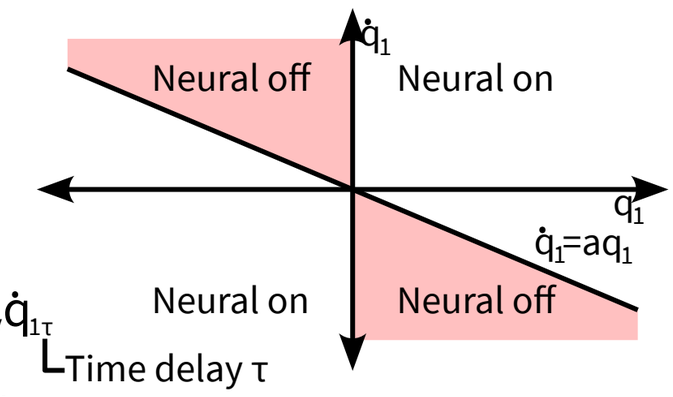
Control[2]

Linearised model of human-tail dynamics

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$

Intermittent switching contol of human stance
- Neural off :

$$\mathbf{u}_p = \underbrace{k_p q_1 + k_v \dot{q}_1}_{\text{Ankle stiffness/damping}}$$



- Neural on :

$$\mathbf{u}_p = k_p q_1 + k_v \dot{q}_1 + \underbrace{\kappa_p q_{1\tau} + \kappa_v \dot{q}_{1\tau}}_{\text{Neural stiffness/damping}}$$

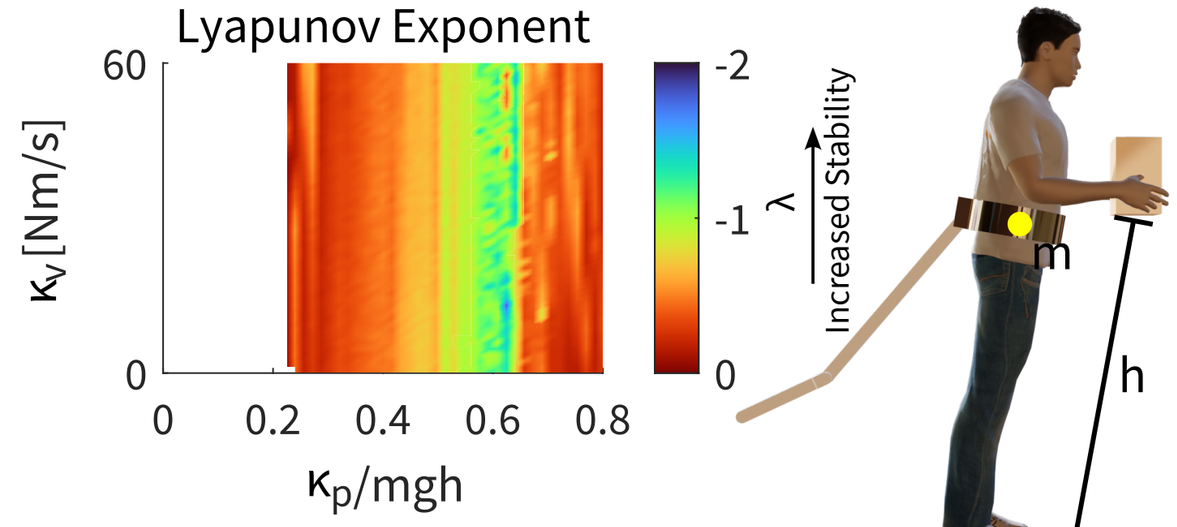
τ: Time delay

Delay dynamics infinite dimensional
- Spectral time approximation → finite dimension
- 66 order system → linear control applicable

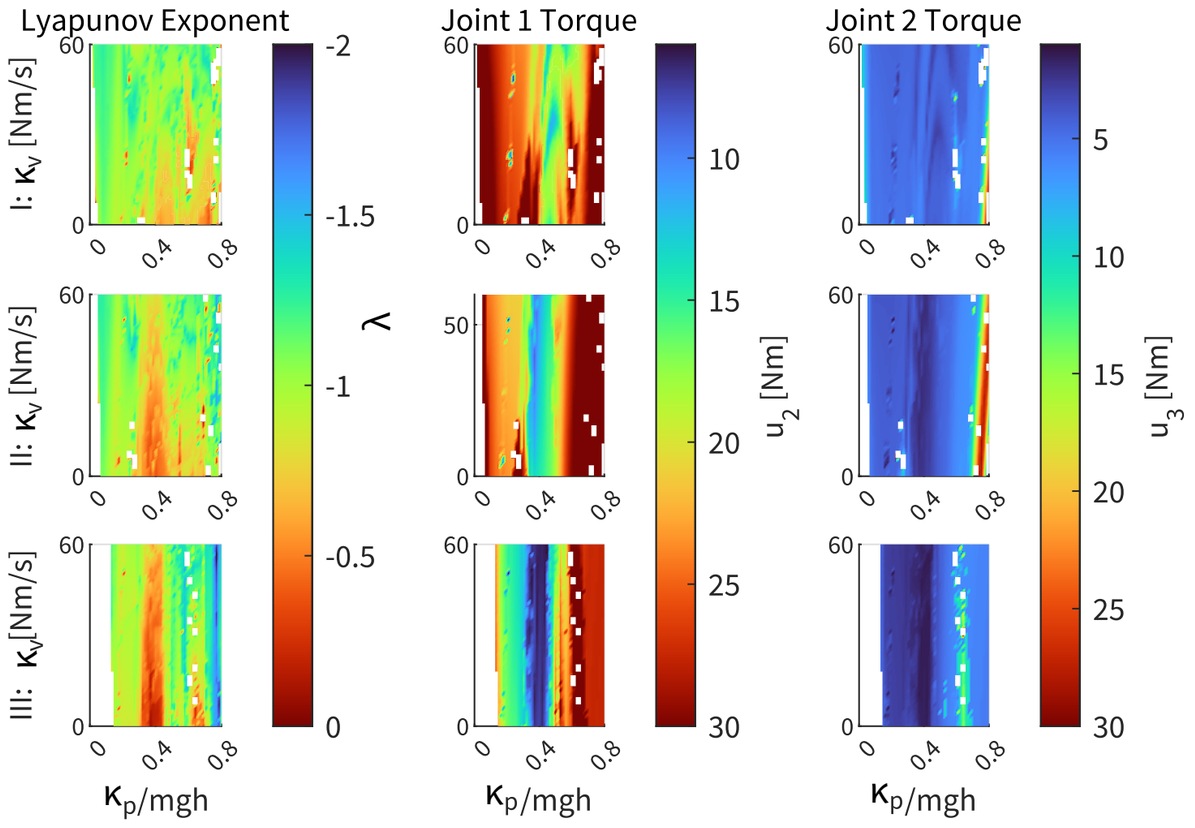
Simulation Results

Joint torque requirments for two-dof tail
- Actuation limited to ±30 Nm
- Potential fields to prevent collisions with body
- Stability assessed with Lyapunov exponent λ

Unassisted standing



Tail assisted standing
- Three cases (total tail mass, total tail length):
  I: (5 kg, 0.9 m) II: (2.5 kg, 0.9 m) III: (2.5 kg, 0.45 m)
- m = 82 kg, h = 1 m, τ = 0.2 s ("challenging")



- Supernumerary robotic tail greatly improves robustness of human stance
- Modelling of delay reduces requirements
- Greater inertia → more robust → larger actuation