Concerted Control: A Unified Bioinspired GRF-based Control Framework for Gait Generation at Different Speeds

Shunske Koseki[1], **Omid Mohseni**[2], Dai Owaki[1], Mitsuhiro Hayashibe[1], Andre Seyfarth[2], Maziar A. Sharbafi[2]
[1] Neuro-Robotics Lab, Department of Robotics, Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan
[2] Lauflabor Locomotion Laboratory, Institute of Sport Science, Centre for Cognitive Science, Technische Universität Darmstadt
Email: omid.mohseni@tu-darmstadt.de

Summary

This study proposes a bio-inspired, simple, and easy-to-implement controller, termed *Concerted Control*, which leverages a shared common signal to coordinate movements across multiple joints without requiring predefined trajectories. The backbone of this controller is our previously developed Force Modulated Compliance (FMC) control, which modulates joint stiffness using ground reaction force (GRF). In Concerted Control, FMC is implemented across multiple joints, allowing implicit coordination through the shared GRF signal. We validated Concerted Control on a simulated biped in MuJoCo platform, achieving human-like gaits from 0.7 to 1.8 m/s.

Introduction

Walking is a fundamental mode of human locomotion, and numerous controllers have been proposed for bipedal walking. Among these, Central Pattern Generator (CPG)-based control is a feedforward framework [1] that often requires pre-designed, complex joint trajectories. In contrast, reflex-based control [2] leverages feedback mechanisms to produce human-like gaits but is inherently complex due to redundant muscles and numerous reflex pathways. Despite these advances, there remains a need for a simple yet robust biologically inspired walking controller. In this work, we extend the FMC concept [3] and apply it across multiple DoFs to generate human-like walking patterns. The key innovations of our proposed controller are: (i) A simple joint-level bipedal locomotion control that does not rely on reference trajectories. (ii) Implicit joint coordination through a shared control signal. (iii) The ability to replicate human-like walking across a wide range of speeds.

Methods

In the concerted control framework, the torques for the hip, knee, and ankle joints (τ_j) are generated by the FMC law, along with a combination of spring and damper as follows:

$$\tau_j = \underbrace{c_j F_i(\theta_j^0 - \theta_j)}_{\text{FMC}} + \underbrace{k_j^p(\theta_j^{*p} - \theta_j)}_{\text{spring}} + \underbrace{d_j^p \dot{\theta}_j}_{\text{damper}}$$

where j denotes a lower limb joint, and p denotes the gait phase. k_j^p and d_j^p are the spring and damper coefficients, θ_j and $\dot{\theta}_j$ are the angle and angular velocity, θ_j^{*p} is the spring's equilibrium position, c_j is a constant representing the normalized stiffness, θ_j^0 is the equilibrium position of an adjustable (virtual) compliance implemented by FMC, and F_i is a component of the ground reaction force.

Results and Discussion

Applying Concerted Control to a 2D MuJoCo model (180 cm, 80 kg) produced human-like walking across various speeds, with results at 1.25 m/s shown in Figure 1. Joint kinematics closely match human data, with hip, knee, and ankle angles showing R values above 0.98, 0.83, and 0.89, respectively.

For joint torques, the model accurately replicates hip extension in early stance and flexion in late stance. While knee torque patterns deviate from human data, ankle torque is well-matched, with R values exceeding 0.89 (Figure 1).

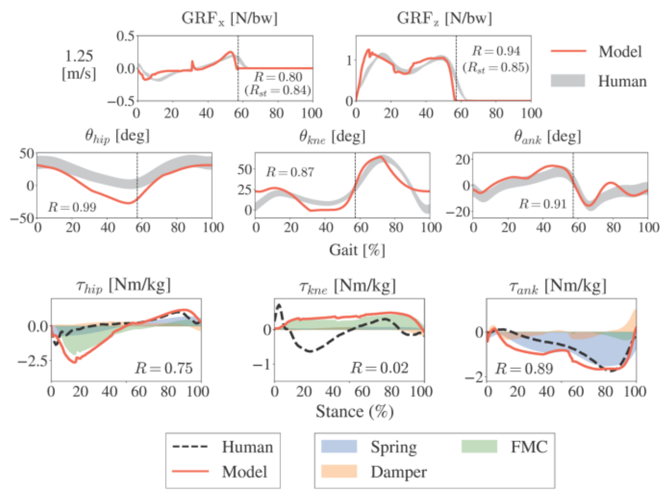

Figure 1: Comparison of kinematics, and kinetics of simulated gait using *Concerted Control* at 1.25 m/s with human data.

Conclusions

The proposed concerted control is joint-level, decentralized, and implicitly coordinates the hip, knee, and ankle joints via the GRF generated through body and environment interactions. Simulation results demonstrate that this approach can reproduce human-like walking at different speeds.

Acknowledgments

Supported by the German Research Foundation (www.dfg.de) within RTG 2761 LokoAssist under grant no. 450821862.

References

[1] Ijspeert, AJ, (2008). *Neural networks* vol. **21**, no. 4, pp. 642-653
[2] Geyer, H. (2010). *Transaction on neural systems and rehabilitation engineering* vol. **18**, no. 3, pp. 263-273
[3] Sharbafi, MA. (2015). *IEEE/RSJ IROS* (pp. 5742-5747)