Regulating Speed and Generating Large Speed Transitions in a Neuromuscular Human Walking Model

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Local Reflex Control Has a Large Potential for Controlling Robotic Legs

Humanoid vs Human Control

Humanoid: HONDA (ASIMO), Boston Dynamics (PETMAN)

CPG + reflex: Taga et al. (1991), Ogihara et al. (2001)

Robotic ankle: iWalk BiOM
Our Reflex Based Neuromuscular Walking Model

Current Limitations

- Confined to the sagittal plane
- Only walks at a single speed

NM Model (Geyer et al., 2010), Ankle prosthesis (Eilenberg et al, 2010)
Walking Speed Adaptation of the Human Model

1. Neuromuscular Model

2. Optimization

3. Speed Adaptation
Control Groups and Underlying Principles

Swing-leg retraction (Seyfarth et al., 2003)

Swing-leg Initiation (Mochon et al., 1980)

PD trunk control (Gunther et al., 2003)

Knee stability (Seyfarth et al., 2001)

Spring mass model & F+ (Geyer et al., 2003 and 2006)

Left leg cycle

Right leg cycle

Right leg control

NM Model (Geyer et al., 2010)
Walking Speed Adaptation of the Human Model

1. Neuromuscular Model

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3. Speed Adaptation
The Cost Function Includes Walking Speed, Energetic Cost, and Pain

\[ J = \left| \dot{x}_{avg} - \dot{x}_{tgt} \right| + C_E + P \]

Target speed  Energy cost  Pain

Cost fn. (Neptune et al., 2001), Energy rate (Umberger, 2003), CMA-ES (Hansen, 2006)
Walking Speed Adaptation of the Human Model

1. Neuromuscular Model

2. Optimization

3. Speed Adaptation
Optimization Results for Steady Walking Matches Human Data

$v$ (Murray et al., 1984), $C_E$ (Minetti et al., 2001), $L$ & $f$ (Hirasaki et al., 1999)
Nine Control Parameters Show Strong Trend

**Trunk Balance**

- $B_{v0}$ (deg)
- $k_5$ (% S deg$^1$)
- $k_6$ (% S deg$^2$)

**Stance**

- $G_{001}$ (deg min$^{-1}$)
- $k_{11}$ (deg)
- $k_{12}$ (% S deg$^2$)

**Swing**

- $\Delta S$ (% S)
- $\Delta R_\text{arrow}$ (cm)
- $\Delta S_\text{arrow}$ (cm)

Graphs show trends in various parameters across different velocities.
Generation of Speed Transition:
Switch Between Steady Speed Walking Controls

Works for small speed transitions.
Fails for large speed transitions!
Generation of Speed Transition:
Explicit Transition Phase Control

\[
J = \left| \ddot{x}_{avg} - \ddot{x}_{tgt} \right| + P_{\Delta st} + C_{E,\Delta st} + n_{\text{step,}\Delta st} + n_{\text{step,}\Delta pc}
\]
Successful Generation of Speed Transition: Explicit Transition Phase Control
Conclusion

We extended a local reflex based walking control to regulate walking speed and generate large speed transitions between 0.8ms\(^{-1}\) and 1.8ms\(^{-1}\)

An explicit transition control was required to generate large speed transitions

To walk faster the model …
  - leans forward
  - makes stronger ankle push-off
  - makes larger swing initiation