SHANK-FOOT TRAJECTORY CONTROL: A FORWARD DYNAMICS APPROACH USING COMPUTED-TORQUE CONTROL

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AIMS & APPROACH

• Aims:
  - To provide assistance and rehabilitative measures to humans with lower limb disorders.
  - Investigate a rehabilitation protocol method using CPGs.

• Approach:
  - Inverse dynamics approach via adaptive coupled oscillators also known as CPGs.
INTRODUCTION

• Why Rehabilitation?
  - To improve motor unit plasticity of patients.
  - Influencing motor recovery.
  - Minimise functional deficits.

• Rehabilitation Implementation:
  - Manually – Physiotherapist.
  - Robotically – Robotic therapy.
INTRODUCTION

• Robotic therapy:
  □ Traditional robotic platforms.
  □ Robot-assisted platforms.

• CPGs (AFO):
  □ Biological neural networks.
  □ Produce coordinated multidimensional rhythmic signals, via simple input signals.
CONTRIBUTION

• Impact Created:
  - Verify assistive and rehabilitative procedures in humans via simulations.
  - Ascertain the possibility of simultaneously improving motor function of the human lower-limbs having knee and ankle anomalies.
  - Authenticate the use of CPGs as a system used for estimating derivatives and also a coupling mechanism, having treated the knee-ankle model as a decoupled system.
KNEE-ANKLE ORTHOSIS

- Shank-Foot CAD Model:
  - Movements:
    - Flexion/extension (knee).
    - plantar-flexion/dorsal-flexion (ankle).
  - Range:
    - $0 \leq \theta \leq 2.35 \text{ rad}$ (knee)
    - $0 \leq \theta \leq 0.87 \text{ rad}$ (ankle)
CPG DESIGN

- **AFO: (Hopf augmented phase oscillator).**
  \[ \dot{\phi} = \omega + \eta F \cos \phi \quad (1) \]
  \[ \dot{\omega} = \eta F \cos \phi \quad (2) \]

- **Coupled AFO:**
  \[ \dot{\phi}_i = i \omega + \eta F \cos \phi_i \quad (3) \]
  \[ \dot{\omega} = \eta F \cos \phi_1 \quad (4) \]
  \[ \alpha_i = \epsilon F \sin \phi_i \quad (5) \]
  \[ F = \theta - \hat{\theta} \quad (6) \]
  \[ \hat{\theta} = \sum_{i=0}^{N} \alpha_i \sin \phi_i \quad (7) \]
MATHEMATICAL MODEL

- **Building Blocks:** (human knee and ankle + orthosis)
MATHEMATICAL MODEL

- Dynamic Model:
  \[ \ddot{\theta}_j = I_j^{-1} \left( -m_j g l_j \sin \theta_j - b_j \dot{\theta}_j + \tau_j \right) \quad (8) \]

- Coupled AFO (Joint Coupling)
  \[ \dot{\phi}_i = i \omega + \eta F_i \cos \phi_i \quad (9) \]

\[ \dot{\omega} = \left( \eta \sum_{j=1}^{G} F_j \cos \phi_{1,j} \right) / G \]

\[ \alpha_i = \varepsilon F \sin \phi_i \]

- CPG Coupling Structure
MATHEMATICAL MODEL

• Signal estimator:

\[ F_j = \theta_j - \hat{\theta}_j \]  \hspace{1cm} (10)

\[ \hat{\theta}_j = \sum_{i=0}^{K} \alpha_{i,j} \sin \phi_{i,j} \]

\[ \hat{\theta}_j = \sum_{i=0}^{K} \alpha_{i,j} \omega \cos \phi_{i,j} \]

\[ \hat{\theta} = \sum_{i=0}^{K} \alpha_{i,j} \omega^2 \sin \phi_{i,j} \]
MATHEMATICAL MODEL

- Torque estimator:

\[ \hat{\tau}_j = m_j gl_j \sin \hat{\theta}_j - b_j \hat{\theta}_j + I_j \dot{\theta} \]  \hspace{1cm} (11)

- The parameters are defined as above.
MATHEMATICAL MODEL

• Torque estimator:
  \[ \hat{\tau}_j = m_j g l_j \sin \hat{\theta}_j - b_j \hat{\theta}_j + I_j \hat{\theta} \]  
  (11)

• Human Torque:
  \[ \tau_{h,j} = K_{p,j} e_j + K_{i,j} \int e_j dt + K_{d,j} \dot{e}_j \] 
  (12)

\[ \tau_j = \tau_{h,j} + \tau_{e,j} \]
NUMERICAL SIMULATION

• Reference Trajectories:

\[ \theta_{\text{ref}1} = \frac{\pi}{12} \sin(2\pi ft) + 0.5\cos(\pi ft) + 2.25\sin\left(\frac{\pi}{2} ft\right) \]  

\[ \theta_{\text{ref}2} = \frac{\pi}{90} \sin(\pi ft) + 0.8\cos\left(\frac{\pi}{2} ft\right) + 0.6\sin\left(\frac{\pi}{4} ft\right) \]  

\[ f = 0.16Hz \]

• Physiological parameters where chosen for simulation purposes.
RESULTS/DISCUSSION

Figure 1: Knee position trajectory

Figure 2: Knee torque $\kappa = 1$

Figure 3: Ankle position trajectory

Figure 4: Ankle torque $\kappa = 1$
RESULTS/DISCUSSION

Figure 3: Tracking error (knee) $\kappa = 1$

Figure 4: Kne\(\text{a}\) torque $\kappa = 0.5$

Tracking error (ankle) $\kappa = 1$

Kne\(\text{a}\) torque $\kappa = 0.5$
RESULTS/DISCUSSION

Figure 5: Additional information about the figure 5.

Figure 6: Additional information about the figure 6.
RESULTS/DISCUSSION

Figure 7:
CONCLUSION AND FUTURE WORKS

• Conclusion:
  - Based on the above presentation/simulation, a rehabilitation protocol which incorporates the knee and ankle using the robotic-assisted platform by means of the AFO has been proposed.

• Further Works:
  - Verify this assistive effect in a lab (SARChI) based in FSATI @ TUT, Pretoria South-Africa.
  - Carry out parametric identification.
  - Implement this control method on specific human gait systems using its inverse dynamic model.
REFERENCES (RELATED WORKS)


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THANK YOU
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