Joint stiffness defines the dynamic relation between the position of the joint and the torque acting about it. Intrinsic and reflex components at the ankle can be modeled by the following parallel-cascade structure:

Joint stiffness is important in control of posture/movement. Thus, finding an accurate model that represents the dynamics well is important.

Objective

Estimate the parameters of the Parallel-Cascade model using only the input position and output torque signals.

Approach

- The nonlinear, block-oriented, continuous-time system will be transformed to a linear, discrete-time, multiple input, single output (MISO) transfer function system.
- A new algorithm for identification of this class of system will be proposed.

Discrete-Time Ankle Stiffness Model

To compute the discrete-time model several approximations are necessary:

\[ s = \frac{2}{T} \frac{z - 1}{z + 1} \]

\[ w(t) = f(dvel(t)) \approx \sum_{i=0}^{m} \kappa_i \Gamma_i(dvel(t)) \]

\( \Gamma_i \) is the \( i \)th Tchebychev polynomial. Applying these approximations lead to the following discrete-time MISO transfer function model of Ankle Stiffness:

\[
\begin{align*}
\text{pos}(k) & \\
\text{vel}(k) & \\
\text{acc}(k) & \\
\sum_{i=0}^{m} \kappa_i \Gamma_i \text{dvel}(k) & \\
\sum_{i=0}^{m} \kappa_i \Gamma_i \text{dvel}(k) & \\
\text{TQ}_0(k) & = K\text{pos}(k) + \text{Bvel}(k) + I\text{acc}(k) + \sum_{i=0}^{m} \kappa_i \Gamma_i \text{dvel}(k) + \eta(k) + \text{Noise}.
\end{align*}
\]

Simulations

Simulated Model:

We used Monte-Carlo simulation with 100 trials, each with different realization of input and noise sequence.

Results:

- Reflex contribution to total torque is very low.
- \( \text{SNR}_{\text{TQ}} = 10 \text{ dB}, \text{SNR}_{\text{R}} = 9 \text{ dB} \) and \( \text{SNR}_{\text{IRF}} = -1 \text{ dB} \).

Simulations: Three algorithms used to identify the model from input output data:
- Parallel-Cascade Algorithm.
- Matlab’s Prediction Error Minimization (PEM) Algorithm
- New Algorithm

Experimental Results

- We presented a discrete-time parametric model for ankle stiffness.
- We introduced a new iterative algorithm based on the minimization of prediction error for ankle stiffness identification.
- Simulations showed that parameters of the ankle stiffness model were accurately identified even with low reflex torque contribution and high levels of noise.

Conclusion

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