Controller identification for perturbed standing

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It is hypothesized that a human uses feedback to remain upright in the face of perturbations during surface perturbation. In the past two decades, research has been done trying to mathematically explain human's responses [1-4].

Hypothesis:

- Feedback controllers in human perturbed standing task are nonlinear.
- Controllers can be found that are independent of the perturbation signal.

Objectives:

- Find a general mathematic model to explain human's response during standing with different perturbation.

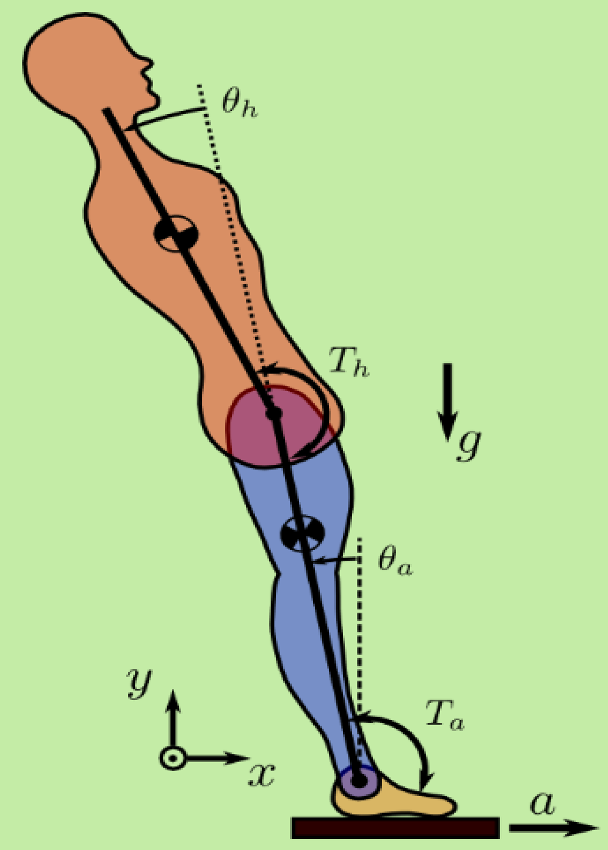

Fig 1. Free body diagram of plant model

Methods

Plant Model and Controller type

Plant model

Torque driven two-link planar inverted pendulum with an accelerating base (Fig 1).

Controller type

Linear PD controller: $\begin{bmatrix} T_a \\ T_h \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} \\ K_{21} & K_{22} & K_{23} & K_{24} \end{bmatrix} \begin{bmatrix} \theta_a \\ \theta_h \\ \dot{\theta}_a \\ \dot{\theta}_h \end{bmatrix}$

Perturbation signals

Two categories of surface perturbation (32 trials) were designed: time domain (ramp perturbation) and frequency domain (stochastic perturbation).

Ramp perturbation

Ramp perturbation are described by peak acceleration, velocity, and displacement (Fig 2).

- Blue points: backward ramp perturbation.
- Red points: forward ramp perturbation.

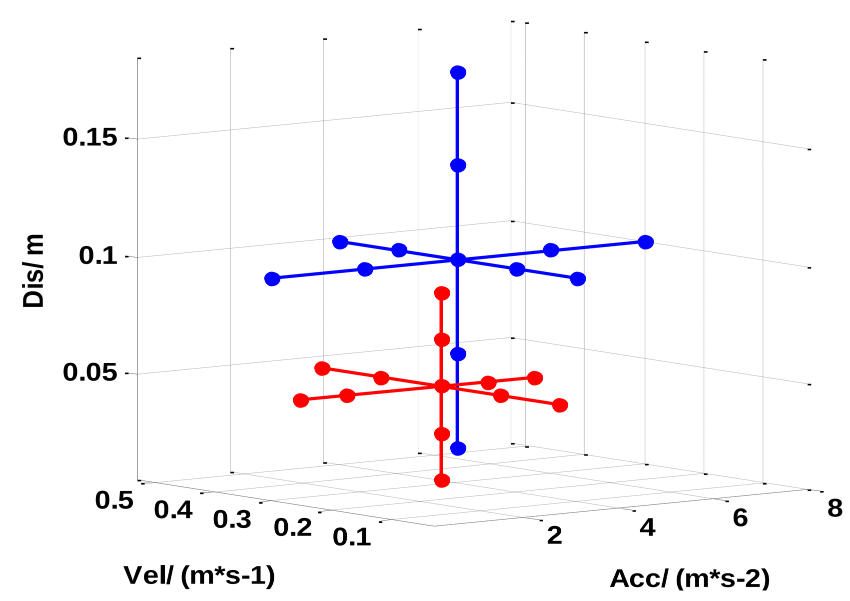

Fig 2. Ramp perturbation parameter

Stochastic perturbation

- Displacement amplitude is limited within $\pm$5cm
- Gaussian signal (Fig 3) and Multi-Sine (Fig 4) signal were chosen.
- Amplitude of acceleration distribution in frequency domain is specified.

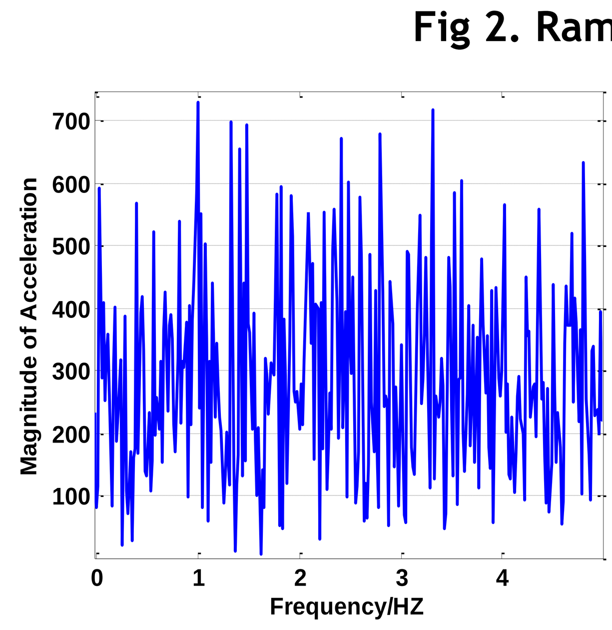

Fig 3. Gaussian Signal

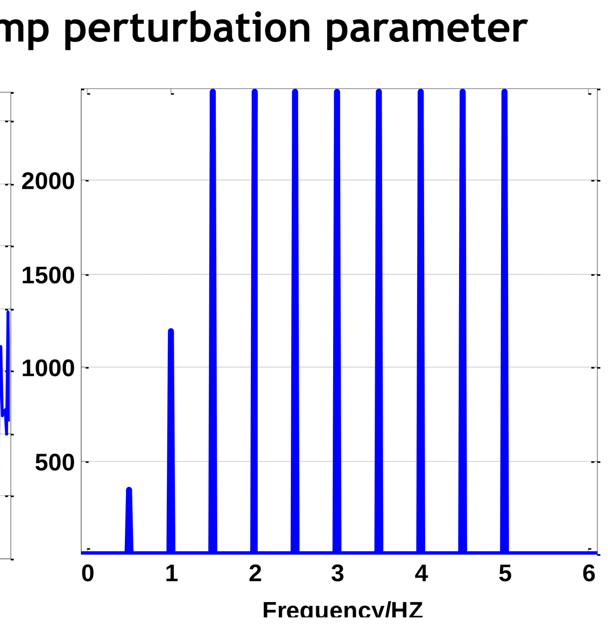

Fig 4. Multi-sine Signal

Experiment setting

- Motion Capture and Treadmill (Fig 5).
- 25 markers attached to subjects.
- 32 trials of perturbations applied to subjects in about 1.5 hours.

Fig 5. Experimental environment

Direct collocation

Objective: $\min J(\theta)$, $J(\theta) = \sum_{i=1}^{N} h[X_{mi} - X_i]^2$, where $\theta = [X_1, \cdots, X_N, P_u]$

Subject to plant dynamics: $f_c(X_i, X_{i+1}, a_{mi}, a_{mi+1}, P_u) = 0, \quad i = 1 \cdots N$

Initial guess: $\theta_0 = [X_{i1}, \cdots, X_{iN}, random(P_u)]$

- The *Opty* toolbox [5] of direct collocation in Python environment was used, which could quickly solve system identification problem.
- By using direct collocation, the closed-loop system identification was converted to an optimization problem that minimizes error between measured human response data and simulation model output.

Results

By using the direct collocation method, results of closed-loop identification were successfully obtained. In most trials, there is a good fitness between measured data and simulation model output in both ramp perturbation(Fig 6) and stochastic perturbation (Fig 7).

However, the identified results are often locally optimal. In sixty identifications of the same measured data with random initial guess, RMS (Fig 8) shows the results are not in the global optimal.

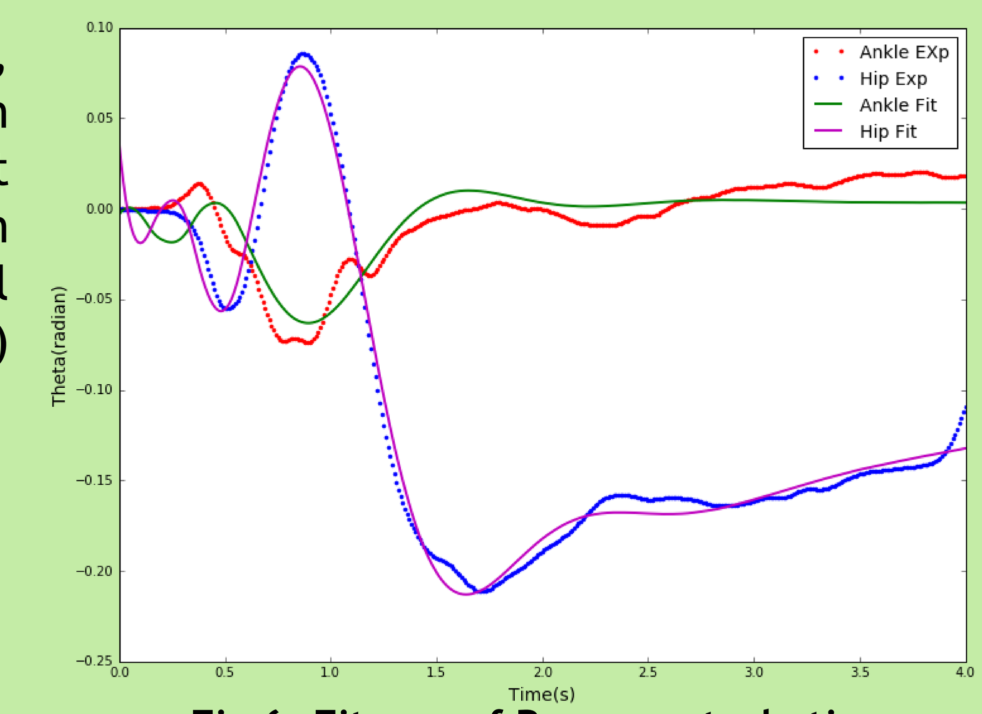

Fig 6. Fitness of Ramp perturbation identification

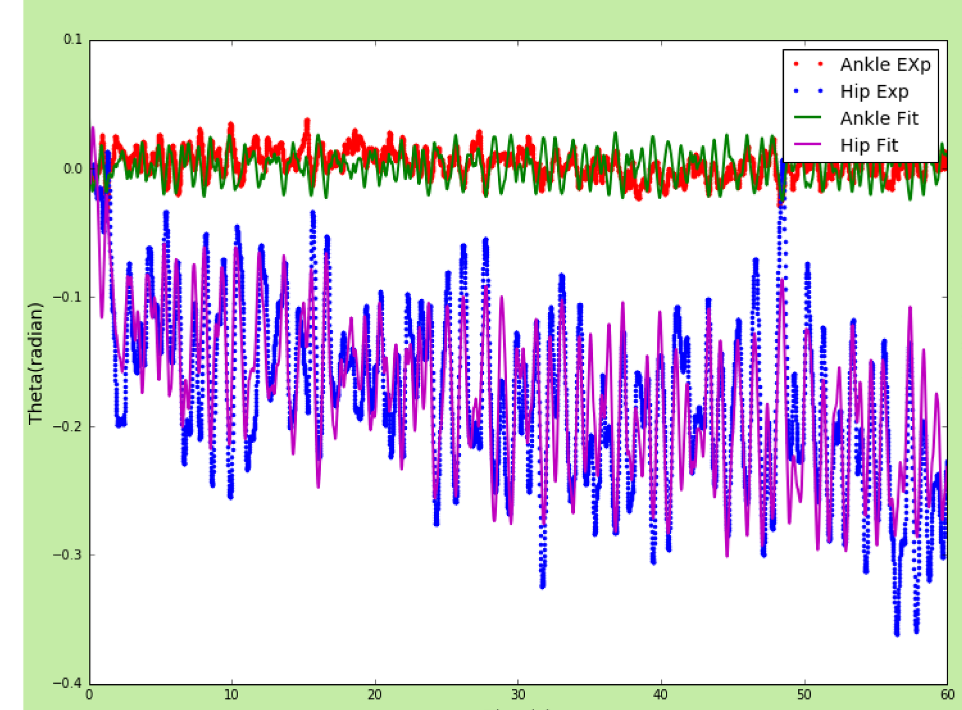

Fig 7. Fitness of Gaussian perturbation identification

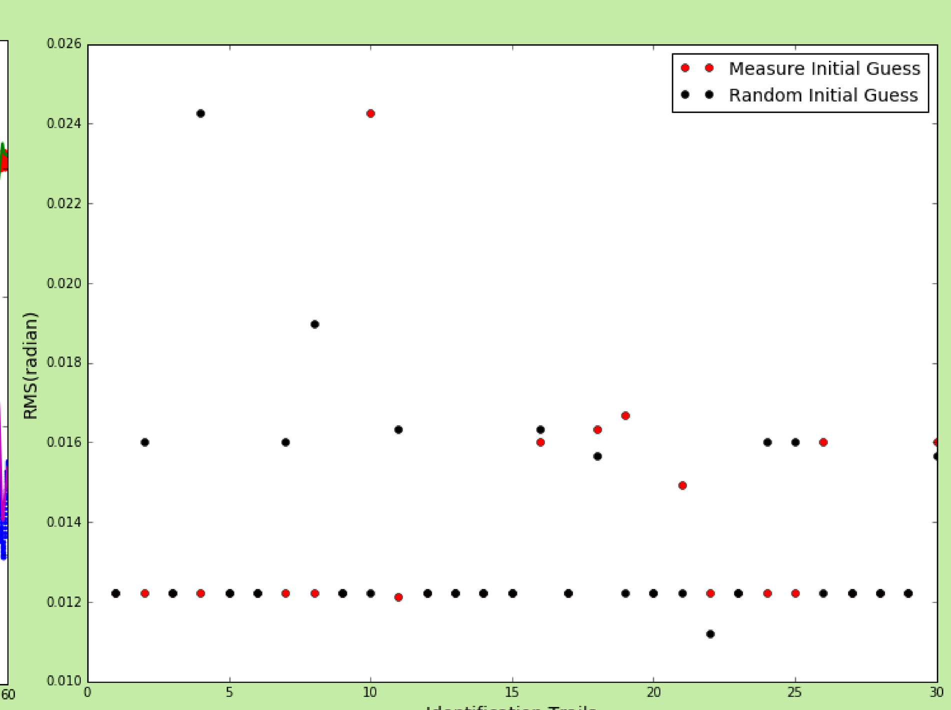

Fig 8. RMS of sixty identifications of Gaussian perturbation

Conclusion

✓ Direct collocation is suitable for feedback controller identification in a perturbed standing task.

✓ Identified results are acceptable but only locally optimal.

Future work

- Avoid local optimization using homotopy method with direct collocation.
- Collect more data by applying more experiments.
- Identify nonlinear and time-delayed controller
- Analysis identified controllers under different perturbation.

References

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