Pre-defined Ranges of Parameters for Walking Styles on Bipedal Robot with Pelvis-located Actuation

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The role of pelvis in being a significant contributor to walking is evident from biomechanics [1] and embodied movement analysis [2]. In the light of this importance, a biped model has been proposed in past that considers the simplified effect of human pelvis. In the current work, a range of parameterized trajectories for this simulated pelvis have been investigated such that they result in feasible gaits. With this formal approach of exploring the gaits, it will be easier to classify different walking styles for this biped model.

Modeling of human-pelvis-inspired Biped Model:

The proposed biped model in the past consists of an actuated compass walker with a simulated pelvis on top. The simulated pelvis consists of a prismatic mechanism moving the mass M_t forward and backwards. The modeling is done traditionally using Euler Lagrange modeling in two phases of walking [3]. The resulting equations

Swing Phase:

$$D_s\ddot{q}_s + C_s(q_s,\dot{q}_s) + G_s = \Gamma_s$$

$$\Gamma_s = \begin{bmatrix} 0 \\ \tau \\ F \end{bmatrix} = Bu$$

$$\dot{x}_s := f_{model}(x_s(t), u(t))$$

$$= D_s^{-1}(-C_s\dot{q}_s - G_s + Bu)$$

Strike Phase:

$$x_s^+(t_f) = \Delta(x_s^-(t_f))$$

Δ : pre-impact state $\rightarrow$ post-impact state

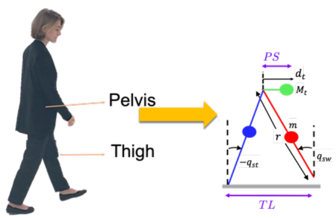


Fig. 1: Biped model inspired from human

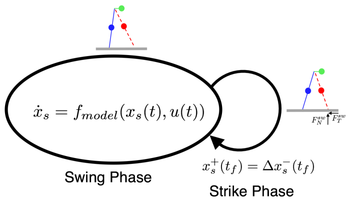
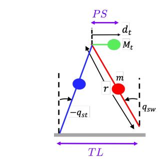


Fig. 2: Hybrid system nature of the biped model [3]

Gait Design Parameters to Gait Generation :

For generating a variety of gaits, varying the gait parameters identified in Fig. 3 can give rise to a range of feasible gaits by using trajectory optimization problem formulation chalked out in Fig. 4.



PS: Waveform profile for simulated pelvis
TL: Step length

Fig. 3: Biped model along with gait parameters

$$\min_{u(t)} \ |u(t)|^2$$

s.t. Dynamics of the robot model

Horizontal distance traveled $= TL$

Desired path by the pelvis mass $= PS$

Periodicity of walking step

Normal ground reaction forces at stance foot greater than zero

Ground reaction forces satisfy friction cone constraint

Fig. 4: Trajectory optimization problem formulation using trajectory optimization tool [4]

Parameter-defined Trajectories for Gaits:

Following a systematic approach, *Pelvic Shift (PS)* can be defined as a Fourier series approximation:

$$PS(t) = a_0 + \sum_{i=0}^{N}(a_i\cos(\pi t) + b_i\sin(\pi t))$$

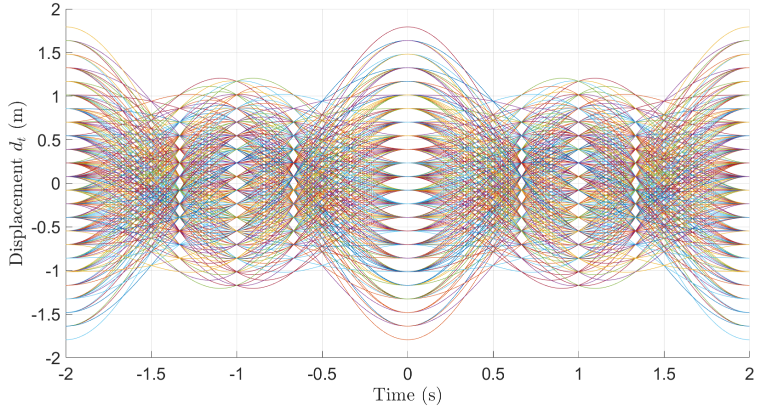


Fig. 5: A set of 26240 trajectories defined by Fourier series approximation in *PS(t)* and ensuring $|d_t(t)| \leq 2\ m$

A set of trajectories has been identified using the Fourier Series approximation where $\boldsymbol{N = 2, a_1, a_2 \in [-0.78, 0.78]}$ and $\boldsymbol{b_1 = b_2 = 0}$ such that pelvis distance $\boldsymbol{d_t}$ is within **2 m**. For each of these trajectories then, feasibility has been investigated using the formulation in Fig. 4 over a range of $\boldsymbol{TL}$ **(step length)** $[\boldsymbol{0.05, 0.55\ m}]$. The resulting number of gaits is presented in Fig. 6.

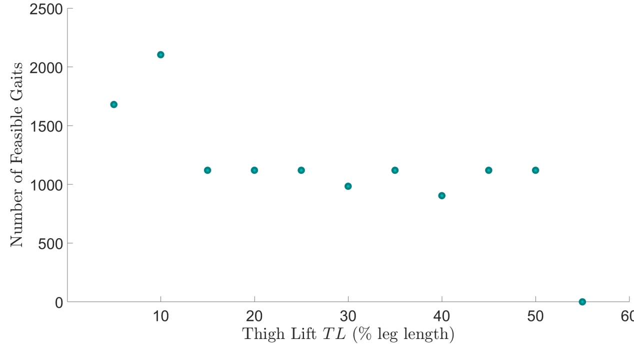


Fig. 6: Number of feasible gaits for each *PS* trajectory applied for corresponding *TL*

By this exhaustive investigation, a gait library is developed. It is observed that for smaller step length (TL), more movement patterns in pelvis are allowed generating more gaits. From human perception perspective, we want to investigate if these gaits are visually distinguishable from each other too.

References:

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[3] U. Huzaifa, C. Fuller, J. Schultz, and A. LaViers, "Toward an expressive bipedal robot with core-located actuation: Comparison of forces required for variable gait in simulation and experimentally measured on a prototype mechanism," in IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2019.

[4] M. A. Patterson and A. V. Rao, "Gpops-ii: A matlab software for solving multiple-phase optimal control problems using hp-adaptive gaussian quadrature collocation methods and sparse nonlinear programming," ACM Transactions on Mathematical Software (TOMS), vol. 41, no. 1, p. 1, 2014.