Trajectory Optimization Based Prediction of Sit-to-Stand Motion

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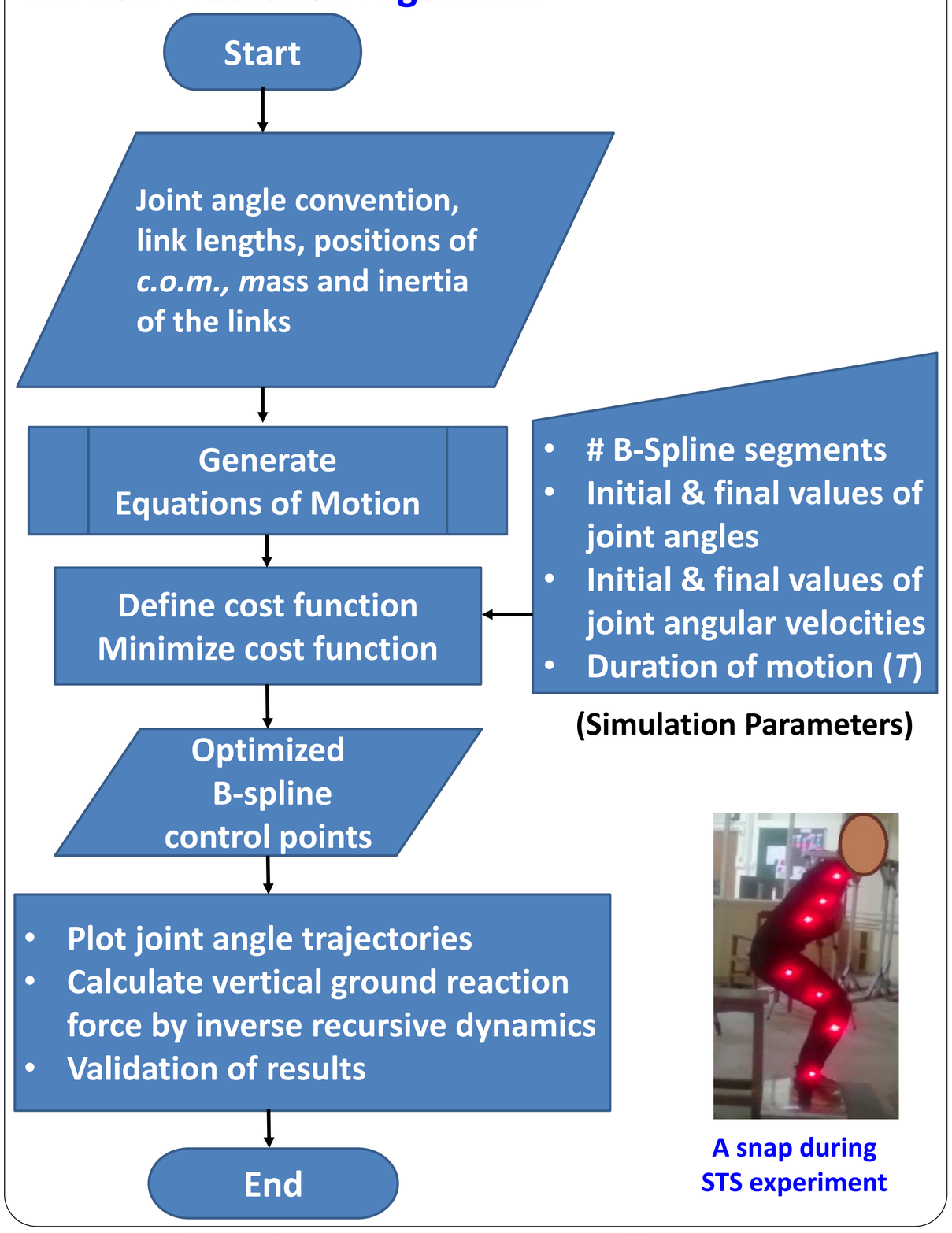
Why Study Sit-to-Stand Motion?

- An example of excellent neuro-muscular coordination
- Ubiquitous activity, prerequisite to a lot of daily tasks, performed ≥ 30 times in a day even by elderly people
- Defines independence of a person in daily life
- Decide motion strategy for the unfit
- Motion planning of humanoid robots

Robotic Model of Human

- Motion observed in sagittal plane only
- Human simplified to three link serial robot (3-R planar)
- Body segment parameters adapted from literature
- Feet are considered to be fixed to the ground, but predicted motion validated by checking for upward ground reaction force

Motion Prediction Algorithm



A snap during STS experiment

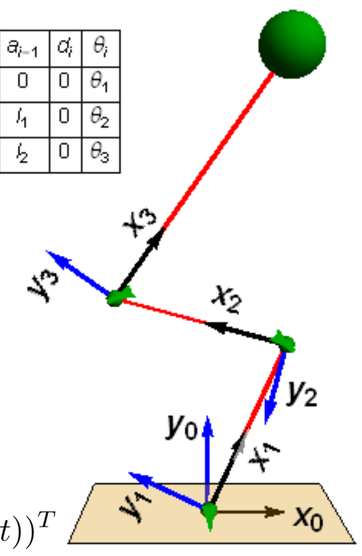
The Optimization Problem

$$\text{Minimize } \mathbf{DE} = \int_0^T (\boldsymbol{\tau}\cdot\boldsymbol{\tau})\mathrm{d}t$$

$$\text{Subject to } \boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} + \boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}})\dot{\boldsymbol{q}} + \boldsymbol{G} = \boldsymbol{\tau}$$

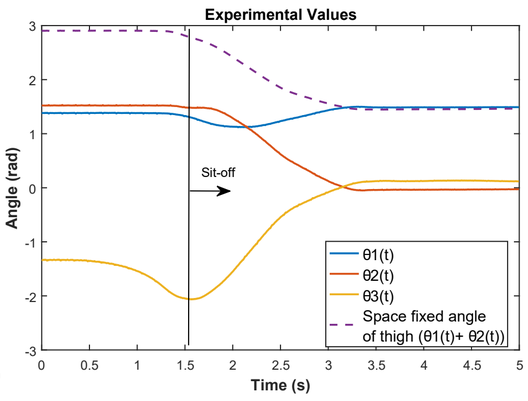
$$\boldsymbol{q}(t=0) = \boldsymbol{q}_{in}$$
$$\boldsymbol{q}(t=T) = \boldsymbol{q}_{end}$$
$$\dot{\boldsymbol{q}}(t=0) = \dot{\boldsymbol{q}}_{ini}$$
$$\dot{\boldsymbol{q}}(t=T) = \underline{0}$$
$$\ddot{\boldsymbol{q}}(t=T) = \underline{0}$$
$$d_{heel} \le x_{zmp} \le d_{toe}$$
$$|\tau_i| \le \tau_{i_{max}} \qquad i = (1,2,3)$$
$$\boldsymbol{q}^{ll} \le \boldsymbol{q} \le \boldsymbol{q}^{ul} \qquad \boldsymbol{q} = \boldsymbol{q}(t) = (\theta_1(t), \theta_2(t), \theta_3(t))^T$$

	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	l_1	0	θ_2
3	0	l_2	0	θ_3



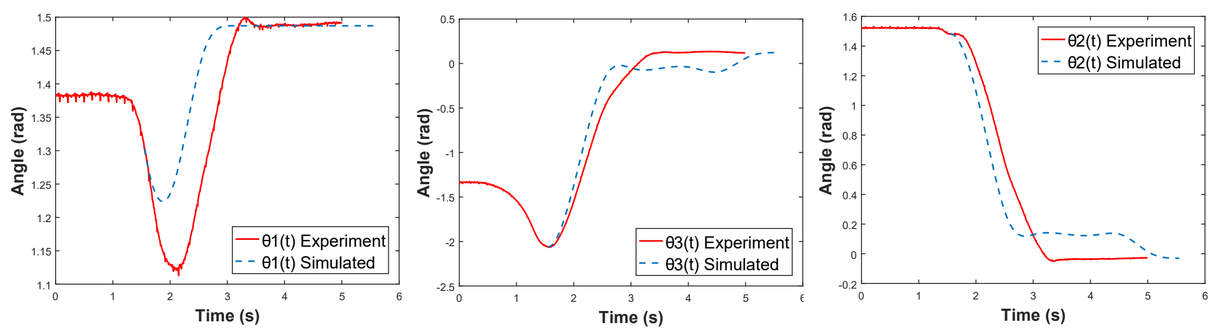
Sit-to-Stand Experiment

- Derive inputs for simulation
- Hands folded close to chest
- Five repetitions performed on a single person
- 3D Motion capture system used to track body segments at 490Hz
- Force plate is placed under the feet, sampling data at 980Hz



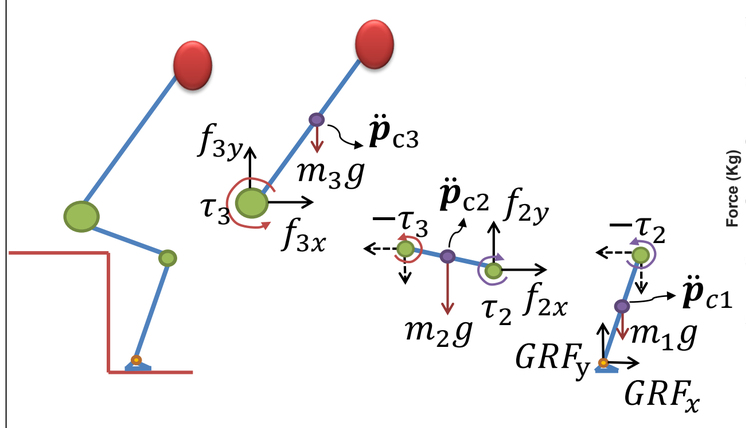
Measured joint angle variation

Validation of Results and Conclusions

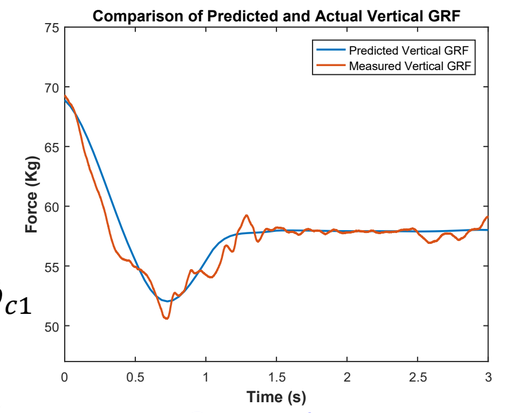


Comparison of simulated trajectories with the experimental ones

- Simulated joint angle variation emulates the natural variation
- Deviation in the joint angles builds up after the body has gained vertical momentum. Optimization criterion may be different once the gross motion is completed
- Vertical GRF calculated using the predicted trajectory tracks the experimental one closely over the complete motion



FBD of Human for calculation of GRF_y



Comparison: predicted & measured GRF_y

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