A simple model of dynamic interaction forces during human-robot partnered motion

To this end, we are developing predictive models that translate abstract motor goals into force interactions and body movements based on the capabilities of the human or robot.

We recently demonstrated cooperative partnered forward and backward stepping between expert human leaders & the naive robot Cody. [1] Our objective is to develop a simple model of the force interactions between robot-human and human-human partners to predict how force interactions encode information about motor intentions, motor performance, and motor skill.

We created a simple mechanical model

We hypothesized that humans led by “setting a velocity goal” during periods of forward and backward motion. Due to the admittance control law of the robot, force and velocity profiles covered.

We modeled the leader and follower as two masses coupled by a spring.

Because the leader is modeled with “wheels,” we do not expect to recreate stepping events.

We hypothesized that the leader applies control forces proportional to error between actual and desired velocity $v_l(t)$.

The human leader is also subject to an interaction force from the “spring,” which reflects the stiffness of the coupled human and robot arms.

Based on the control law of the robot, we modeled the robot follower as having direct control of velocity.

We found 3 parameters describing $v_l(t)$ in optimization 1.

Using the leader’s velocity trace as an input, identify $f_c$, $t_f$, and $W^2$, to minimize a weighted sum of squared error and maximum error.

Weighting parameter $r$ has a small effect to decrease undershoot and was set to 50 based on initial results.

We found 3 spring & velocity feedback parameters in optimization 2.

Using recorded force, leader position, and the difference between leader and follower position as inputs, identify $k$, $\dot{k}$, and $\dot{x}$, to minimize a weighted sum of squared error and maximum error calculated between forward simulations of the mechanical system and experimental data.

Mass of human leader was set to an average value for an American adult (80.7 kg). Robot feedback gain was set based on the controlled program law.

Search parameters ($k_s$ and $\beta$) were set based on initial results.

- Our long-term goals are to identify principles of human motor cooperation to drive the development of assistive robots with the ability to enhance, assist, and improve human motor function.
- To this end, we are developing predictive models that translate abstract motor goals into force interactions and body movements based on the capabilities of the human or robot.
- We recently demonstrated cooperative partnered forward and backward stepping between expert human leaders & the naive robot Cody. [1] Our objective is to develop a simple model of the force interactions between robot-human and human-human partners to predict how force interactions encode information about motor intentions, motor performance, and motor skill.

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- The model parameters may be useful in predicting changes in the interaction based on different levels of motor performance and motor skill, and during movement errors.
- Drift in the absolute position of the human leader suggests that the abstract movement goal is velocity, rather than position.
- Drift in the distance between subject suggests that the human leader is modulating arm length to achieve functional interaction forces.
- Step-by-step fluctuations in force and velocity will be predicted by using the abstract model as a goal for a more complex musculoskeletal model of the human and robot.

### Results

1. Human velocity waveforms were characterized with square waves

<table>
<thead>
<tr>
<th>Subject</th>
<th>Trial</th>
<th>High Gain</th>
<th>Low Stiffness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 6</td>
<td>Trial 12</td>
<td>LEVEL 1</td>
<td>LEVEL 2</td>
</tr>
<tr>
<td>Subject 7</td>
<td>Trial 1</td>
<td>LEVEL 1</td>
<td>LEVEL 2</td>
</tr>
</tbody>
</table>

#### Force Interaction Parameters

- **MODEL**: $f_l = 5.72$, $f_r = 0.53$, $k = 5.07$, $\beta = 0.14$, $\gamma = 0.78$

#### Velocity Interaction Parameters

- **MODEL**: $\gamma = 0.78$, $\beta = 0.14$, $\gamma = 0.78$

### References

- Emory University: "Georgia Institute of Technology; 1 Atlanta VA Medical Center Rehabilitation R&D Center of Excellence

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Founding

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1. Emory University: "Georgia Institute of Technology; 1 Atlanta VA Medical Center Rehabilitation R&D Center of Excellence

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