Force Control and Nonlinear Master-Slave Force Profile to Manage an Admittance-Type Multi-Fingered Haptic User Interface

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Catalyst

• Increase hazardous material handling efficiency and effectiveness
  – Master-Slaves have changed little since 1945 (patent 2632574) [1]
  – Grippers generally have lack of resiliency with regard to accommodating object shape and adjusting to force perturbations
  – Required time to complete a task via tele-operation is 5-10 times that compared to performing the task with the human hand
Hand User Interface Challenges

• Compared to single degree of freedom end-effectors the human hand is significantly more complex (22 active degrees of freedom)

• If considered by themselves the finger:
  – has a relatively dense strength to size ratio to help the body lift larger loads
  – are relatively quick to achieve nimble tasks and quickly account for object shape anomalies
Resiliency Aspects of Human Hand

• Resiliency
  – The hand’s dexterity provides adequate resiliency to accommodating objects of various shapes during a manipulation task but is less resilient to force perturbations
  – The hand’s enclosed form provides adequate resiliency to respond to force perturbations during a grasping task
Proposed Nonlinear Profile

- Developed based on lack of force resiliency during manipulation tasks and significant resiliency during grasping tasks
- Profile form also supported by differences in manipulation to grasping task frequency, muscle dominance, and the associated brain activity
Developed Haptic User Interface

- Monitors finger’s three positional DOFs and allows free rotation of the three rotational DOFs via a spherical magnetic joint

- Compared to closest competitor (HIRO III)
  - Force (23N vs. 3.6N)
  - Speed (0.45m/s vs. 0.2m/s)
Tapping Experiment

- Employed to determine gains required to achieve free motion
- Executed in x, y, and z directions with both linear and nonlinear profiles
The user attempted to match a circular pattern on a virtual surface with their fingertip for five complete rotations while also attempting to avoid the application of a virtual downward force in excess of 8N.
Grasping Experiment

• Simulation mimicked a collapsible cup being filled with water where user had to apply sufficient normal force to account for increase in weight and stiffness without causing the cup to collapse
  – Polynomial stiffness profile multiplied by an increasing linear factor simulated collapsible cup
Grasping Experiment

• Results

<table>
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<th>Below Limit R1 (%)</th>
<th>Relative Range R1 (%)</th>
<th>Below Limit R12 (%)</th>
<th>Relative Range R12 (%)</th>
<th>Below Limit R2 (%)</th>
<th>Relative Range R2 (%)</th>
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Conclusions

- The nonlinear profile performed much better than that of the conventional linear profile for manipulation due to its increased sensitivity.
- The nonlinear profile performed just as well as that of the linear profile.
Future Work

• Implement a more elegant gain/stability analysis and friction compensation scheme

• Account for user fatigue by reducing the maximum force yet still keeping the same general nonlinear profile form
Acknowledgement

Questions
Developed Haptic User Interface

- HUI C (Controller) (Video)
  - No Control Commands
  - Linear Free Motion
  - Nonlinear Free Motion
  - Linear Virtual Surface ($k=500\text{N/m}$)
  - Linear Virtual Surface ($k=1000\text{N/m}$)
  - Nonlinear Virtual Surface ($k=500\text{N/m}$)
  - Nonlinear Virtual Surface ($k=1000\text{N/m}$)
  - Nonlinear Free Motion
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  - No Control Commands