ISRCS 2012

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

Anthony L. Crawford

August 15, 2012

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 accomodating 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

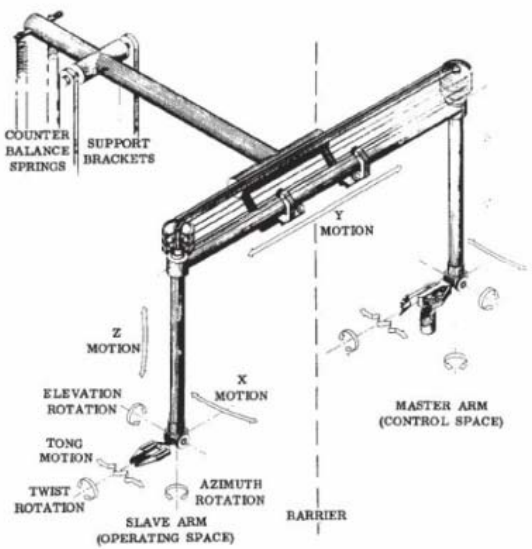
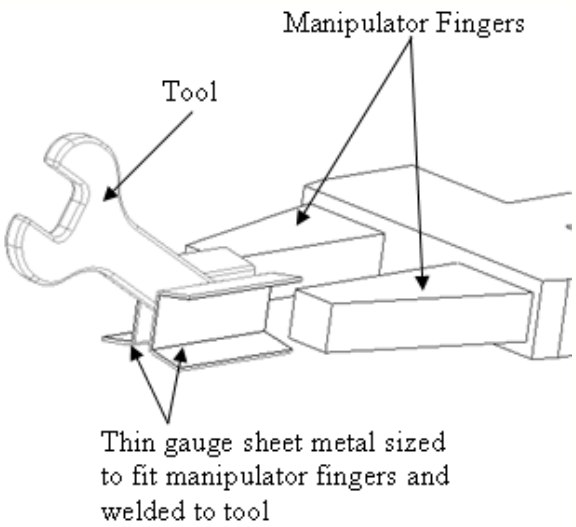
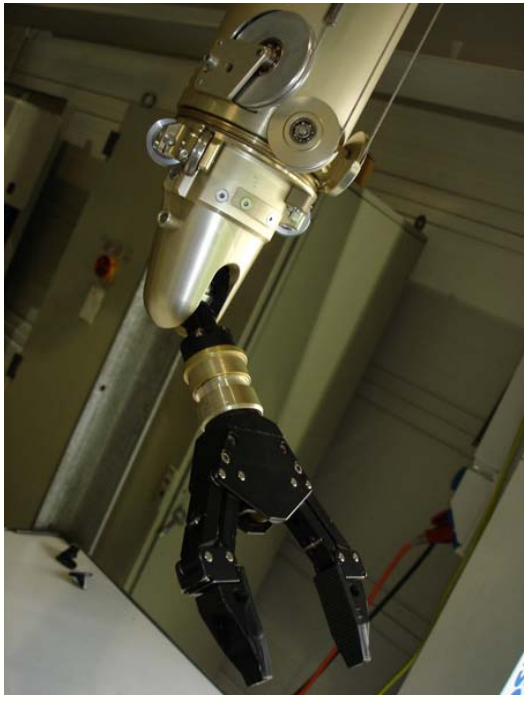


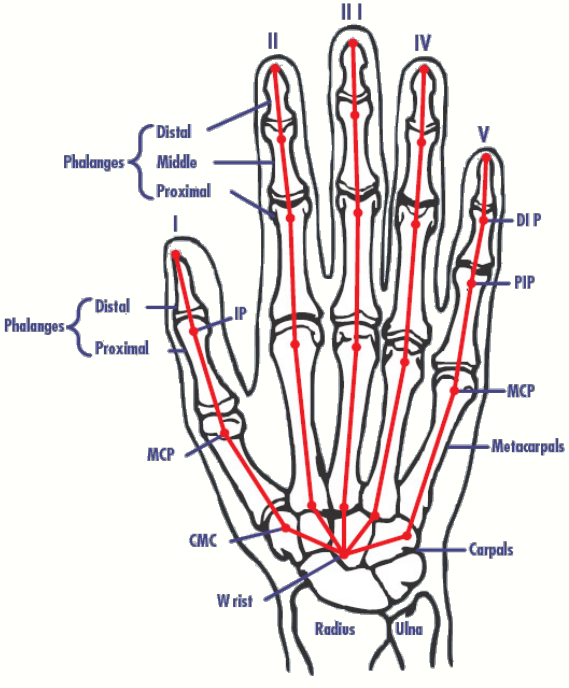
FIGURE 4.—The ANL Model–1 experimental mechanical master-slave manipulator. Motions of the master arm are mechanically communicated to the slave arm. Because the reverse is also true, this is termed a "bilateral" manipulator. (Courtesy of Argonne National Laboratory.)



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



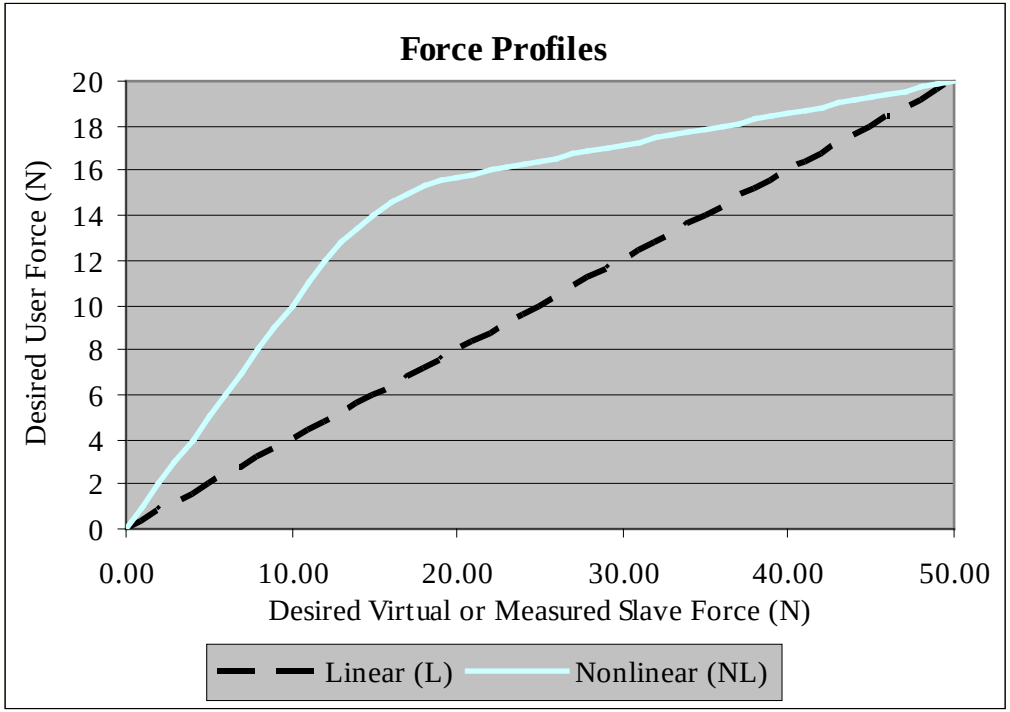


Resiliency Aspects of Human Hand

- Resiliency
  - The hand's dexterity provides adequate resiliency to accomodating 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

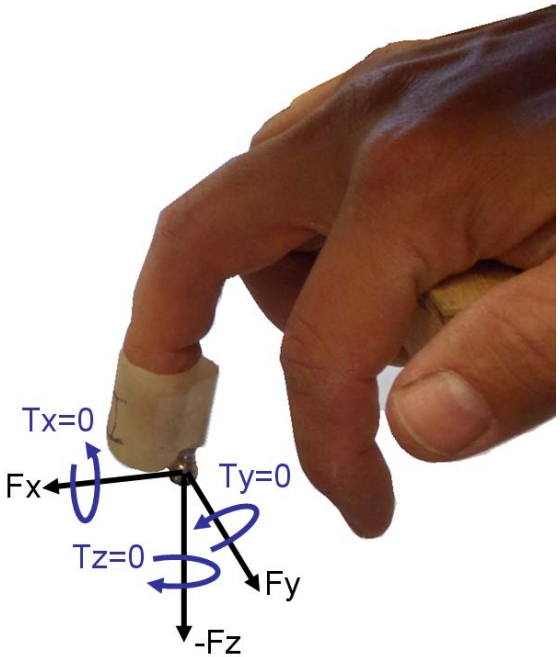
Proposed Nonlinear Profile

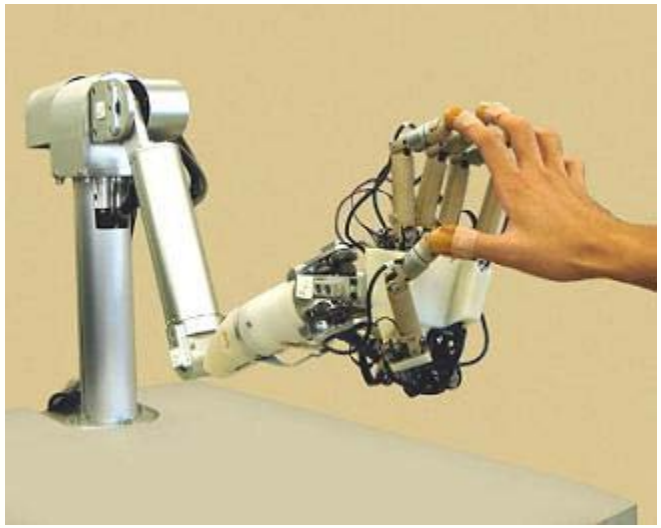
- Developed based on lack of force resiliency during manipulation tasks and significant resiliency during grasping tasks
- Profile form also supported by differences in manipulation to grasping task frequency, muscle dominance, and the associated brain activity



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)

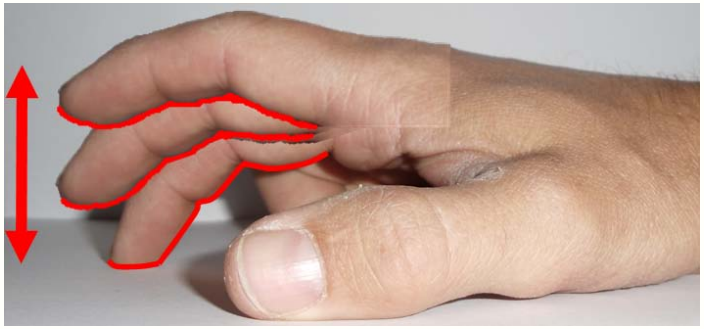


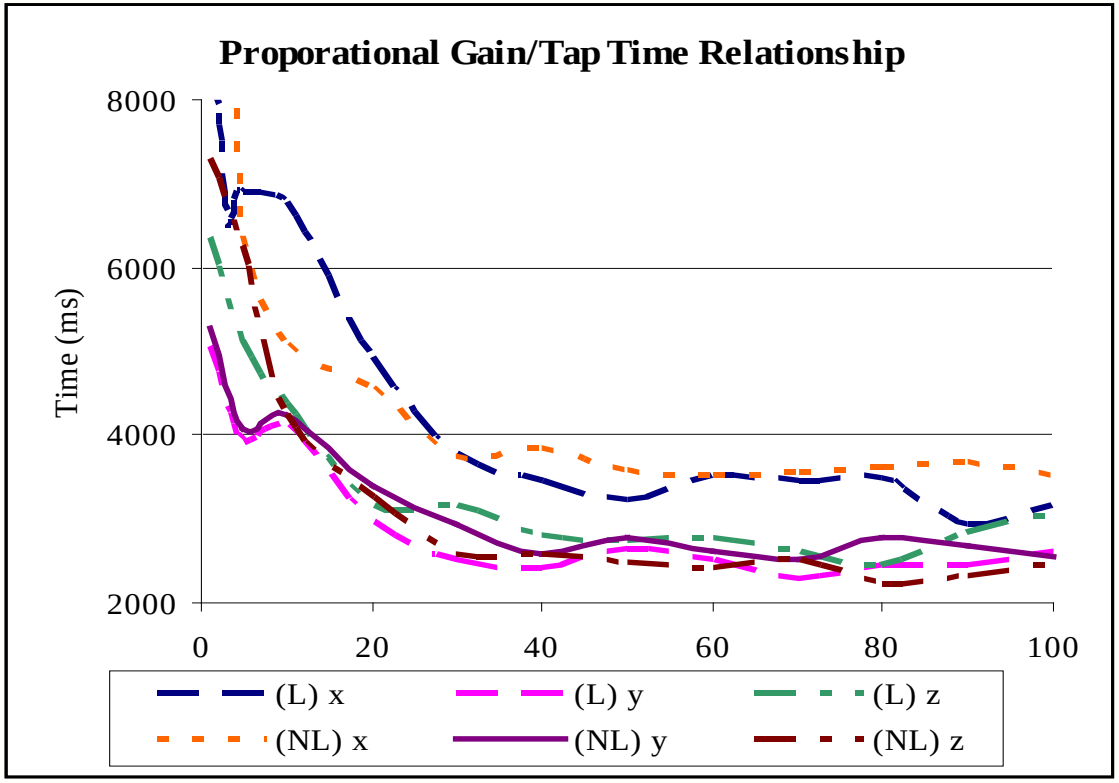


HIRO II

Tapping Experiment

- Employed to determine gains required to achieve free motion
- Executed in x, y, and z directions with both linear and nonlinear profiles

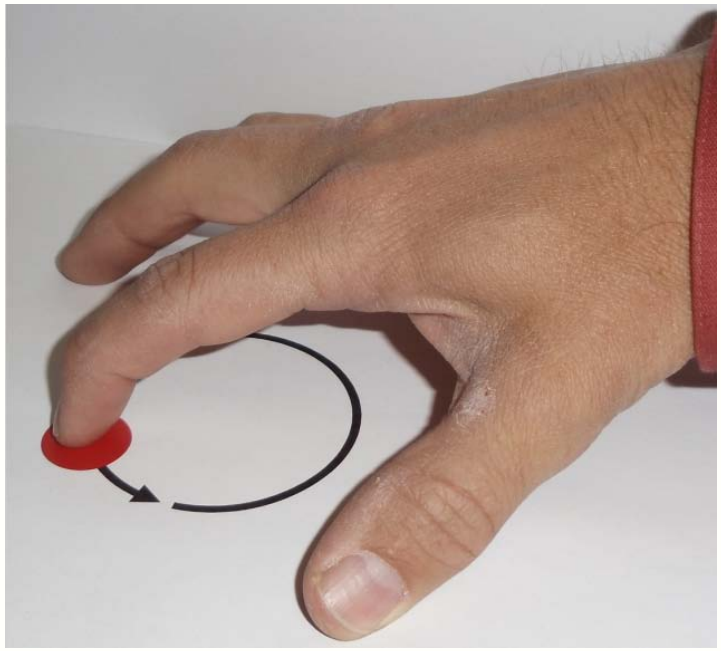




Manipulation Experiment

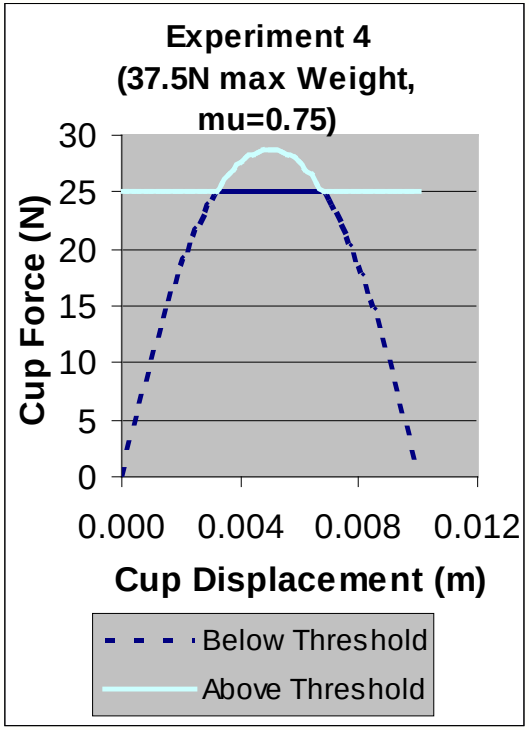
- The user attempted to match a circular pattern on a virtual surface with their fingertip for five complete rotations while also attempting to avoid the application of a virtual downward force in excess of 8N

Profile	*k (N/m)*	*T (s)*	*re avg (mm)*	*re std (mm)*	*Fz avg (N)*	*Fz std (N)*	*up %*	*down %*	*mid %*
L	-	7.5	-1.7	3.0	-6.3	2.9	2	32	65
NL	-	6.8	-2.4	2.5	-4.1	2.6	6	9	85



Grasping Experiment

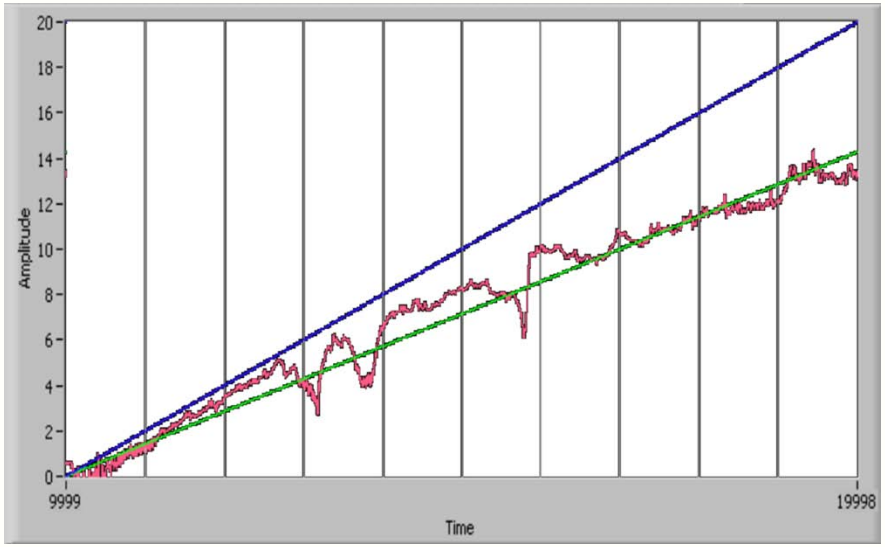
- Simulation mimicked a collapsible cup being filled with water where user had to apply sufficient normal force to account for increase in weight and stiffness without causing the cup to collapse
  - Polynomial stiffness profile multiplied by an increasing linear factor simulated collapsible cup

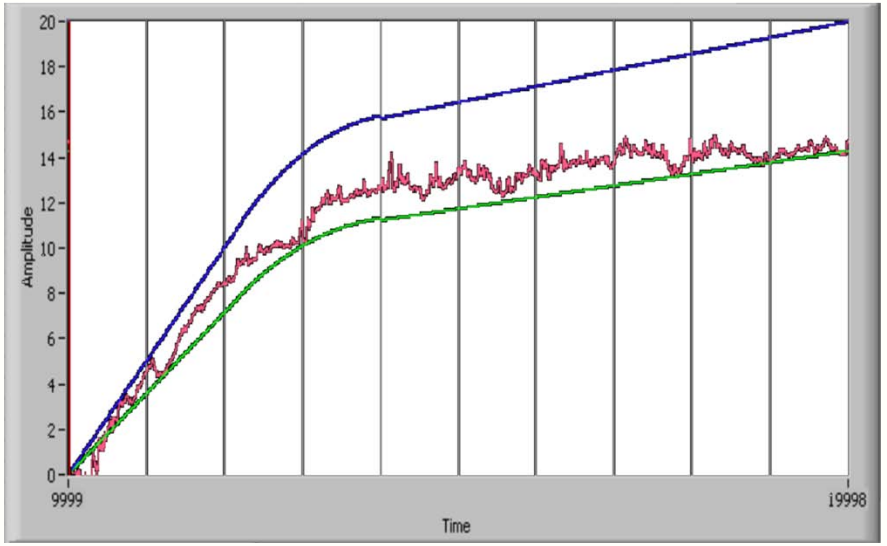


Grasping Experiment

- Results

	Below Limit R1 (%)	*Relative Range R1 (%)*	*Below Limit R12 (%)*	*Relative Range R12 (%)*	*Below Limit R2 (%)*	*Relative Range R2 (%)*
L	38	-200	6	-47	34	-74
NL	33	-164	7	-64	15	-56





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.

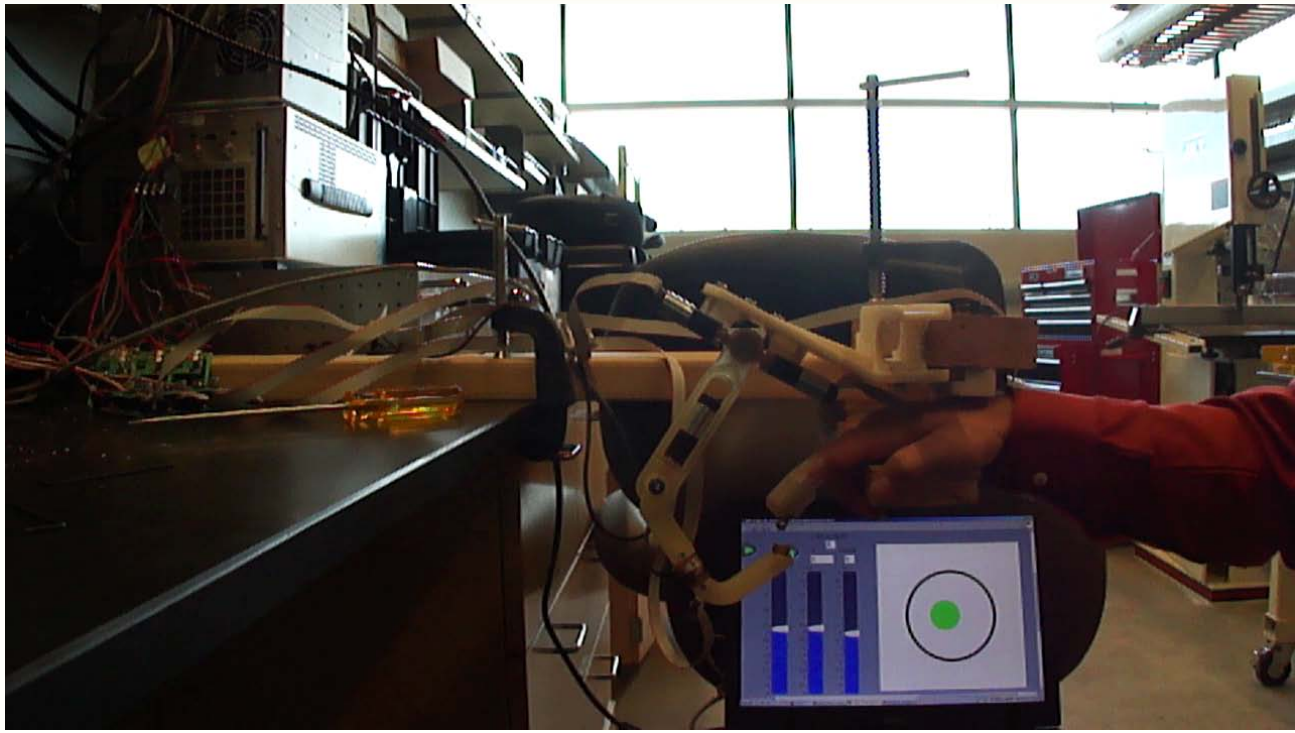
Future Work

- 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

- Prepared for the U.S. Department of Energy Through the INL LDRD Program Under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

Questions

Developed Haptic User Interface

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