Dynamic Guidance with Pseudoadmittance Virtual Fixtures

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Motivation

Expert user

Novice user

1. Motivation
2. Pseudoadmittance
   - Haptic Device Types
   - Pseudoadmittance Framework
3. Our Task
4. Solutions
   - Active Fixture
   - Passive Fixture
5. Tests
   - Vision and Haptics Speed Matching
   - Haptics-only Speed Matching
   - Haptics-only Trajectory Matching
6. Conclusion

Haptic Device Types

Impedance

Sense position, output force

Admittance

Sense force, output position

Pseudoadmittance*

Admittance control on an impedance-type device

PHANToM Omni impedance-type device, ©Sensable Robotics

* J. J. Abbott and A. M. Okamura, "Pseudo-admittance Bilateral Telemanipulation with Guidance Virtual Fixtures." IEEE Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp. 169-175, 2006.

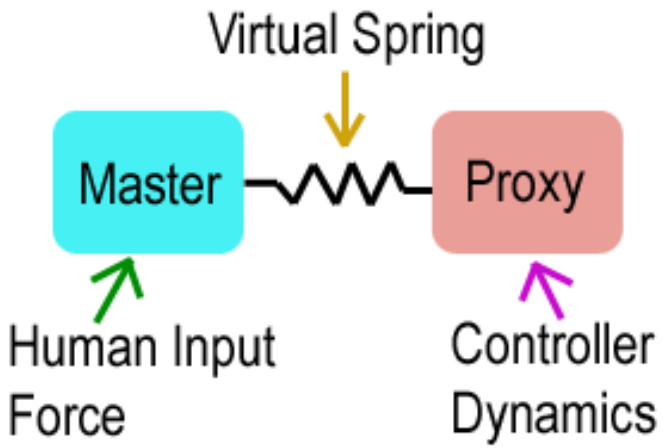
Pseudoadmittance Framework

Virtual Coupling*

Position-Force Transducer

x_p = Proxy position
x_m = Master position
f_{cm} = Controller force on master
f_h = Human input force
k_r = Spring constant
M = Inertia

- $f_{cm} = k_r (x_p - x_m)$
- $M\ddot{x}_m = f_{cm} + f_h$



* J. Edward Colgate, Michael C. Stanley, and J. Michael Brown. "Issues in the Haptic Display of Tool Use." Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), vol. 3, 140-145, 1995.

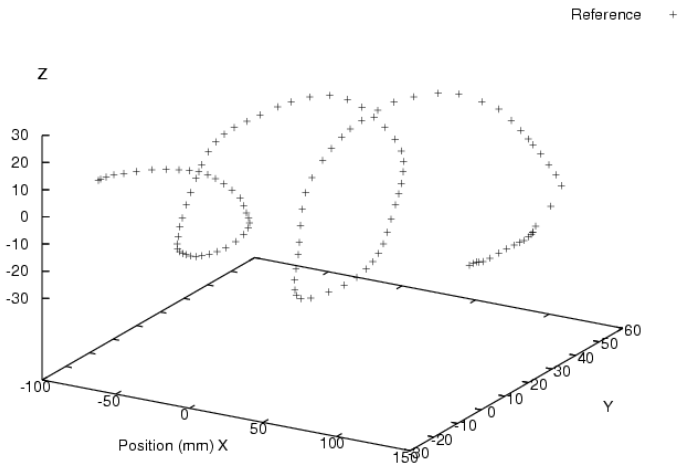
Trajectory Following

Desired Trajectory

$T(s) = [x(s), y(s), z(s)]^T \; s \in [0, 1]$,
$\frac{dT}{ds} \neq 0$
$c(T, \vec{\mathbf{x}})$ – s-value of closest point to $\vec{\mathbf{x}}$ on trajectory T

Preferred direction $\delta_p(s) = \left. \frac{\frac{dT}{ds}}{||\frac{dT}{ds}||} \right|_s$

Desired velocity $\vec{\mathbf{v}}_d(s) = v(s)\delta_p(s)$



Guidance

Correction vector $\delta_c(\vec{\mathbf{x}}_m) = T\left(c(T, \vec{\mathbf{x}}_m)\right) - \vec{\mathbf{x}}_m$

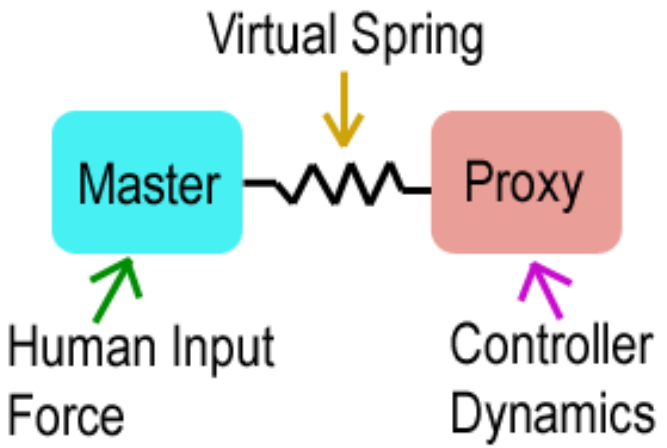
Desired direction $\delta_f(\vec{\mathbf{x}}_m) = \delta_p(c(T, \vec{\mathbf{x}}_m)) + k_e\delta_c(\vec{\mathbf{x}}_m)$

$\delta_d(\vec{\mathbf{x}}_m) = \frac{\delta_f(\vec{\mathbf{x}}_m)}{||\delta_f(\vec{\mathbf{x}}_m)||}$

The Active Fixture

"Active" because it pulls you along
k_{pf} and k_S are scaling constants

- $\dot{\vec{\mathbf{x}}}_p = k_S \left(K_r \left(\vec{\mathbf{x}}_m - \vec{\mathbf{x}}_p \right) + \vec{\mathbf{f}}_{dir} \right)$
- Direction only:
  $\vec{\mathbf{f}}_{dir} = k_{pf} \delta_d$
- With speed guidance:
  $\vec{\mathbf{f}}_{dir} = k_{pf} \left(\vec{\mathbf{v}}_d - \left(\dot{\vec{\mathbf{x}}}_p^T \delta_d \right) \delta_d \right)$

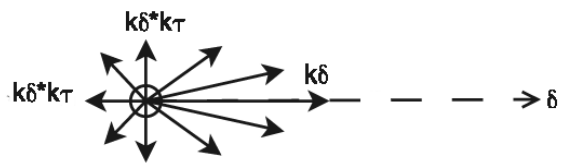


The Passive Fixture

"Passive" because it stays put when you let go

- $D = \delta_d \delta_d^T$
- $\dot{\vec{\mathbf{x}}}_p = k_S k_\delta \left(D + k_\tau \left(I - D\right)\right) \vec{\mathbf{f}}_{\mathsf{cm}}$
- Direction only:
  $k_S = k_{\mathsf{sv}}$
- With speed guidance:
  $k_S = k_{\mathsf{sv}} e^{k_p v_e}$
  $v_e = v(s) - ||v_p||$

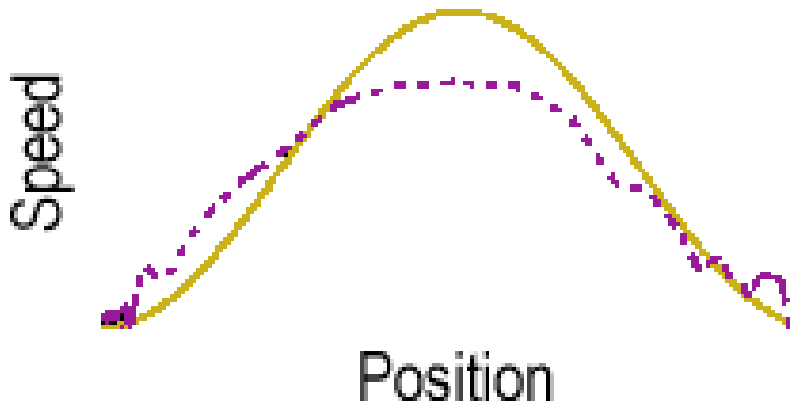
k's are scaling constants.
f_{cm} is the virtual coupling force



Vision and Haptics Speed Matching

Mean Errors & Std. Dev. on 10 trials

Method	Speed?	Error	Std. Dev
Freehand	no	13.23	3.08
Passive	yes	7.17	2.18
	no	11.06	4.12
Active	yes	6.25	1.51
	no	7.36	2.33



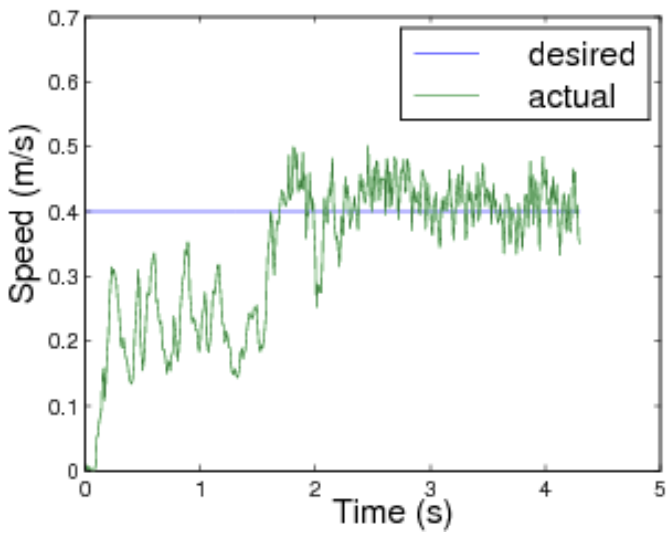
User following a velocity profile with the assistance of the passive fixture.

Haptics-only Speed Matching

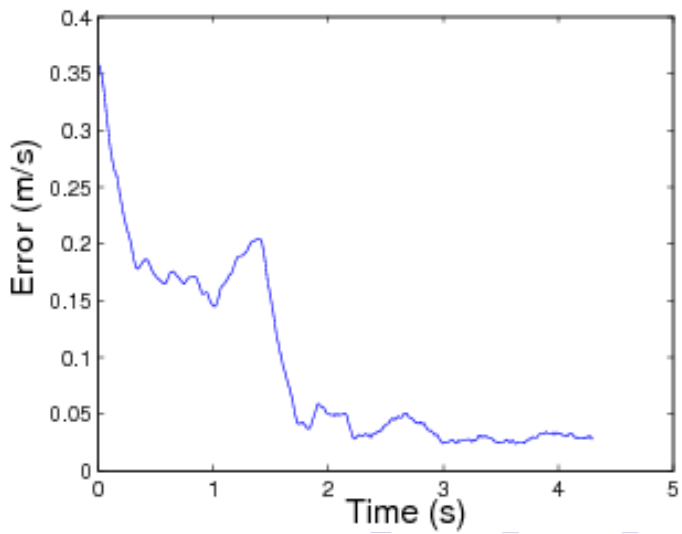
Unknown speed profile

Constant

User's and desired speed



Error

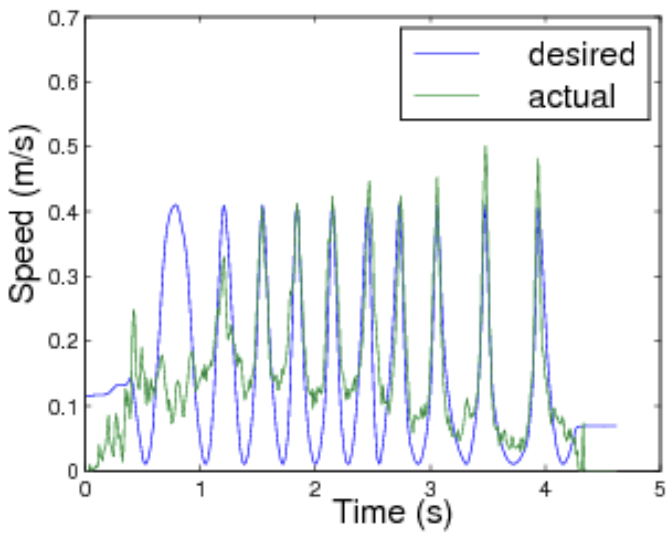


Haptics-only Speed Matching

Unknown speed profile

Sinusoid

User's and desired speed



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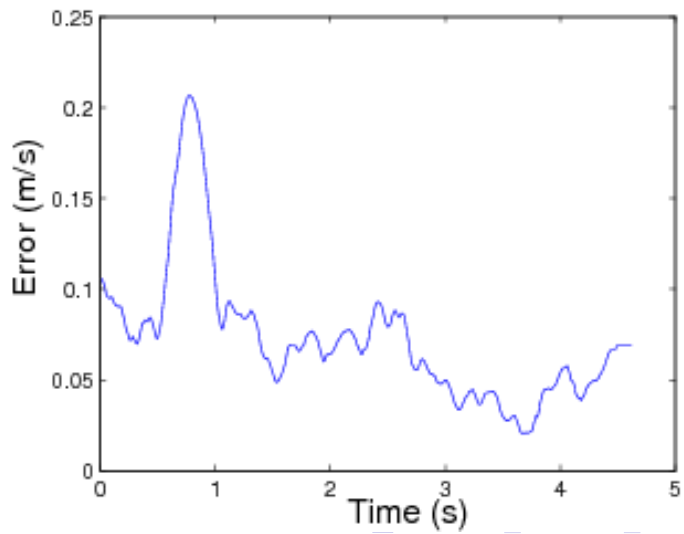


Haptics-only Trajectory Matching

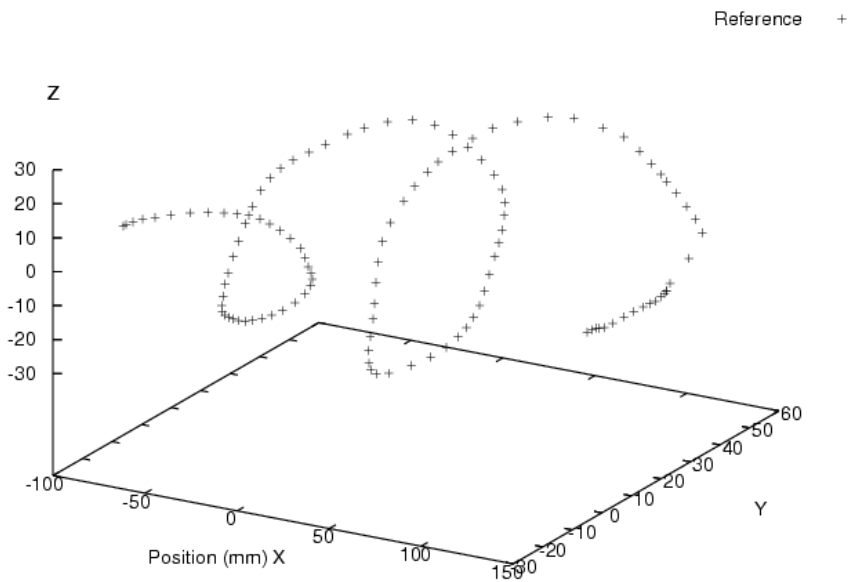
Error Metrics

Position error: $\text{Err}_p = \frac{1}{\lambda} \int_R \left(R\left(c\left(R, \vec{\mathbf{x}}_m\right)\right) - \vec{\mathbf{x}}_m \right) ds$ (m/s)

Speed error: $\text{Err}_s = \int_R \left(v\left(c\left(R, \vec{\mathbf{x}}_m\right)\right) - \dot{\vec{\mathbf{x}}}_m \right) ds$ (m/s)

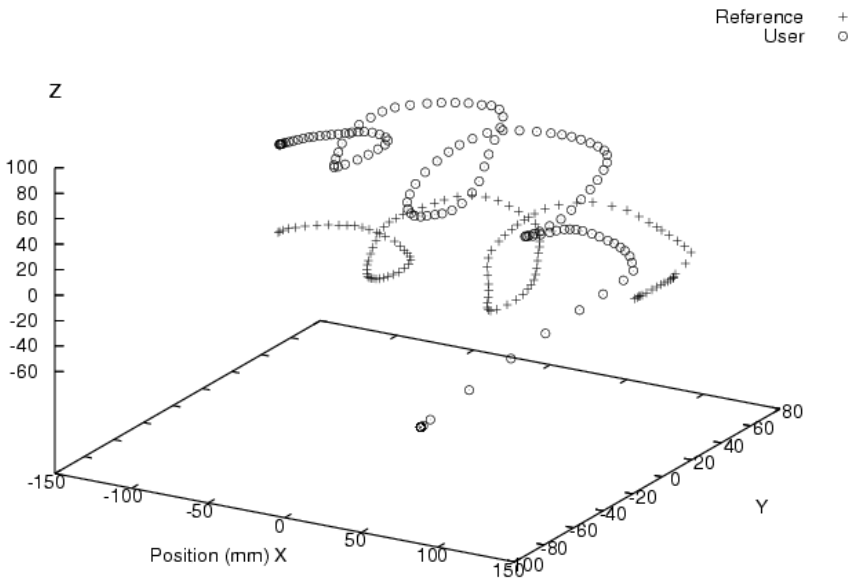
λ – time length of user trajectory

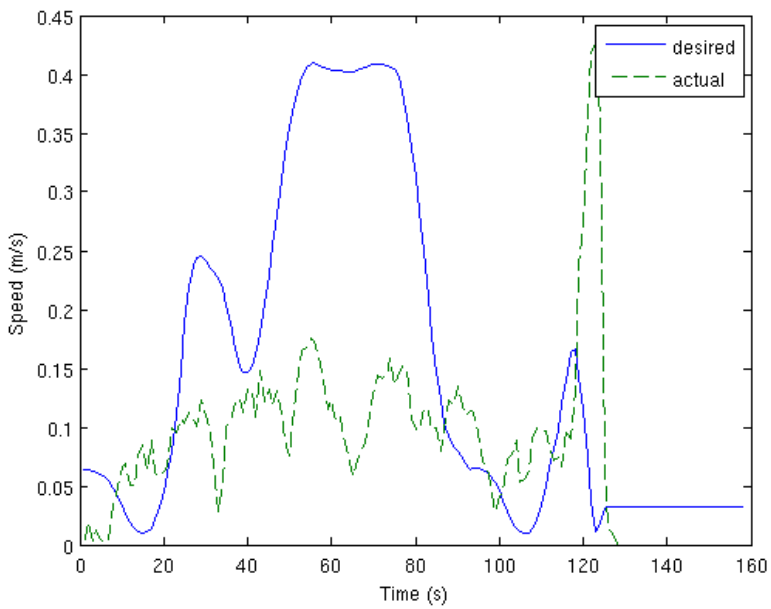
R – reference trajectory



Haptics-only Trajectory Matching: Freehand

Guidance	Err_p w/o Speed	Err_s w/o Speed	Err_p w/ Speed	Err_s w/ Speed
Freehand	73.6	152.9	N/A	N/A
Active	9.8	161.5	29.21	100.6
Passive	10.1	185.3	10.1	83.1





Haptics-only Trajectory Matching: Active Fixture

Guidance	Err_p w/o Speed	Err_s w/o Speed	Err_p w/ Speed	Err_s w/ Speed
Freehand	73.6	152.9	N/A	N/A
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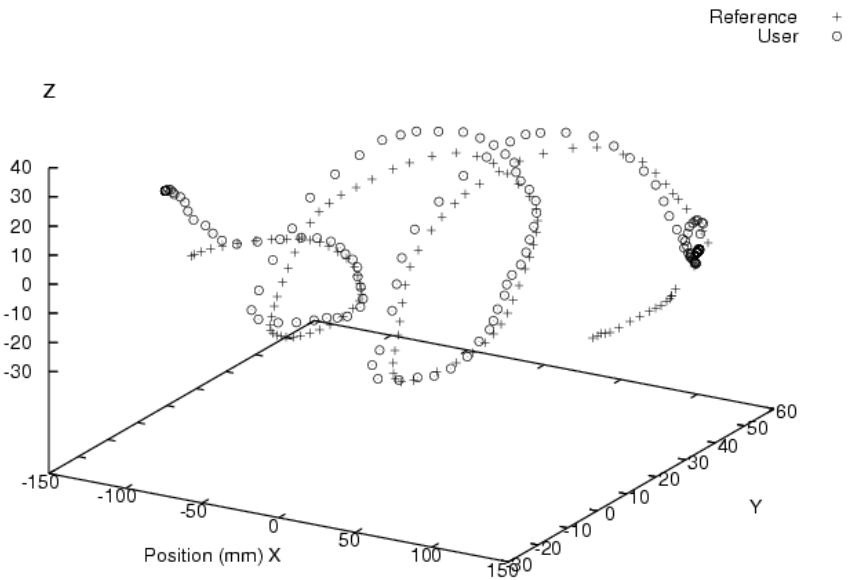

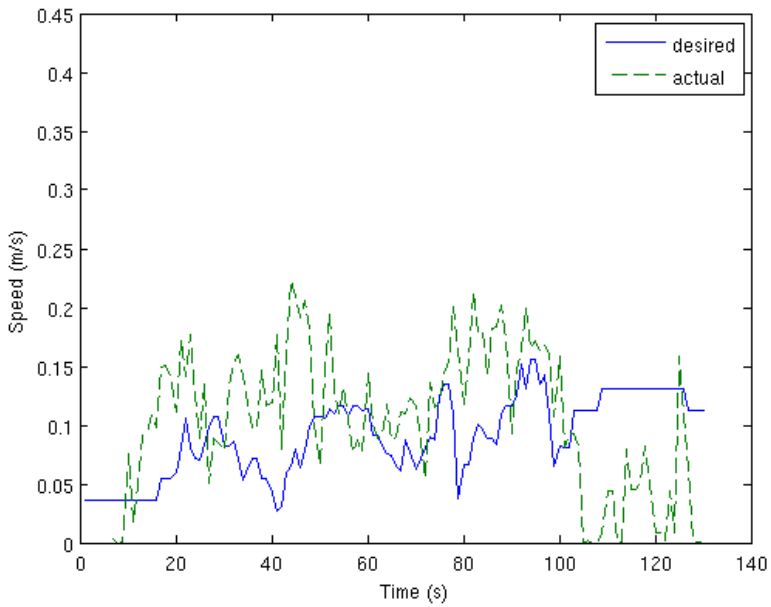

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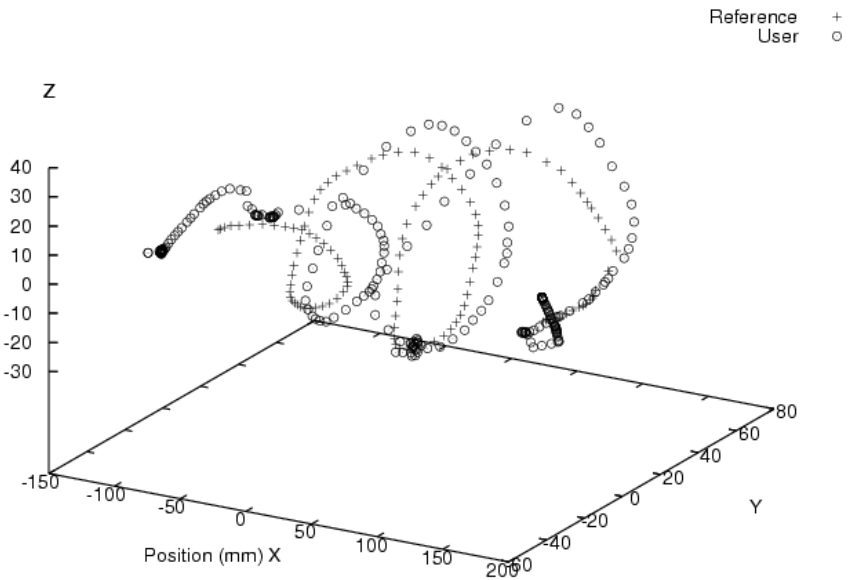

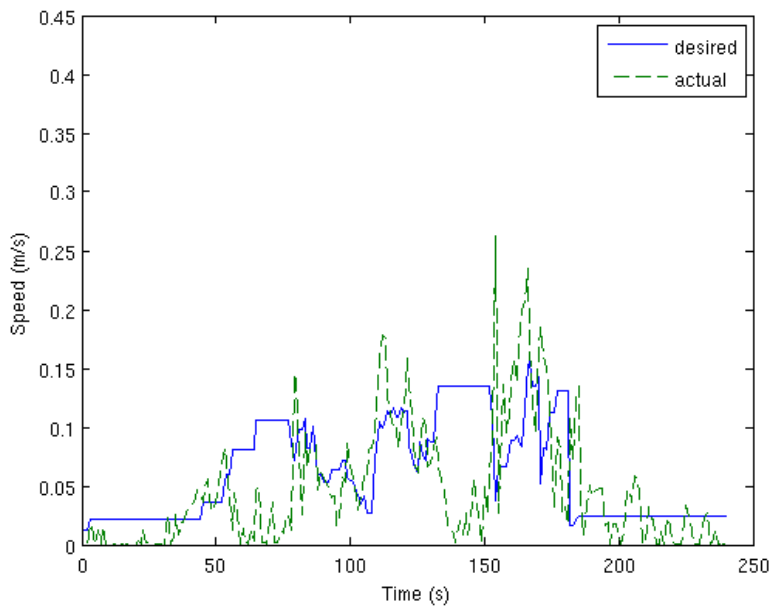

Haptics-only Trajectory Matching: Passive Fixture

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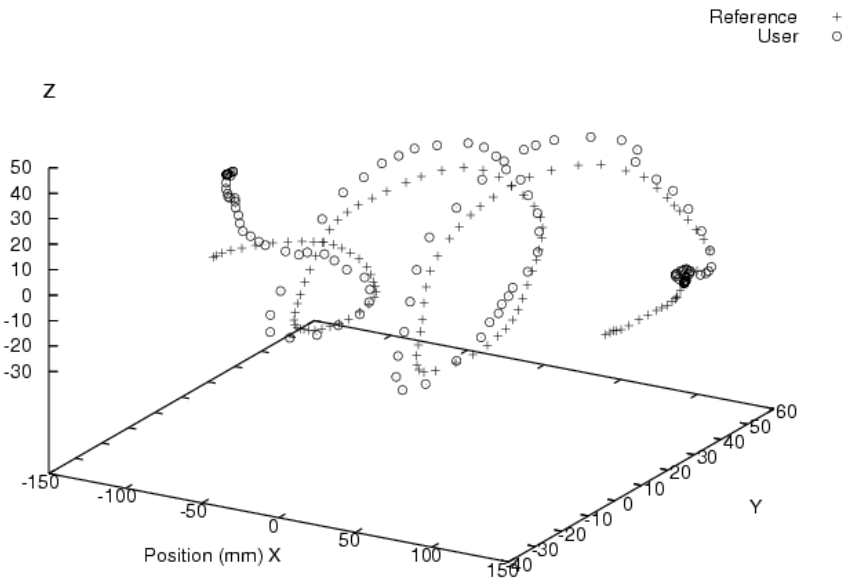

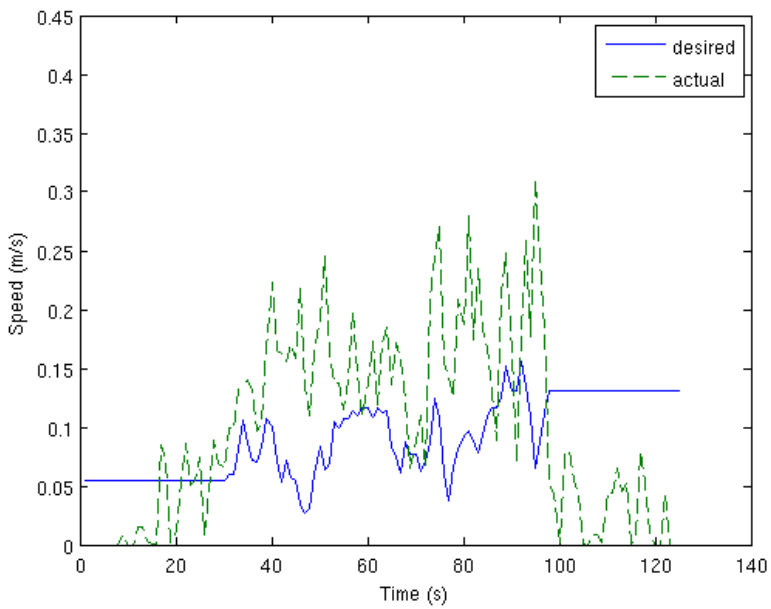

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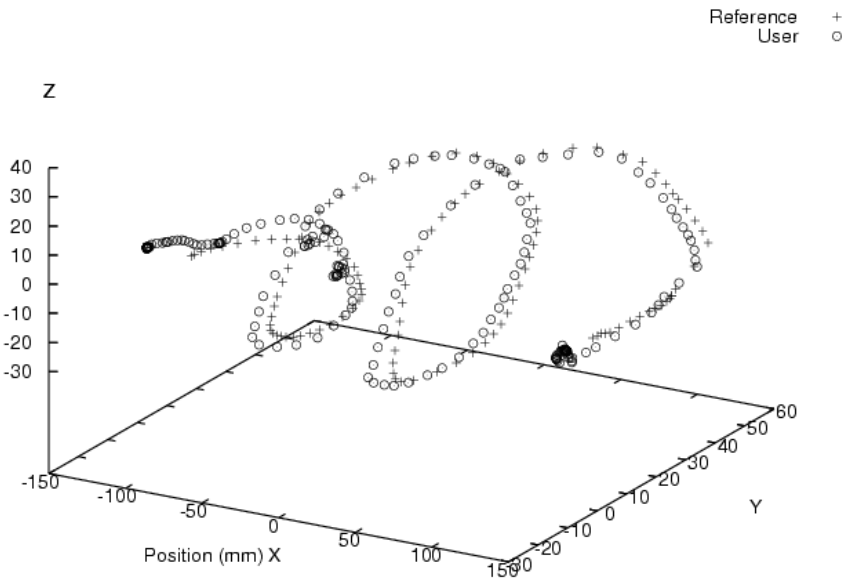

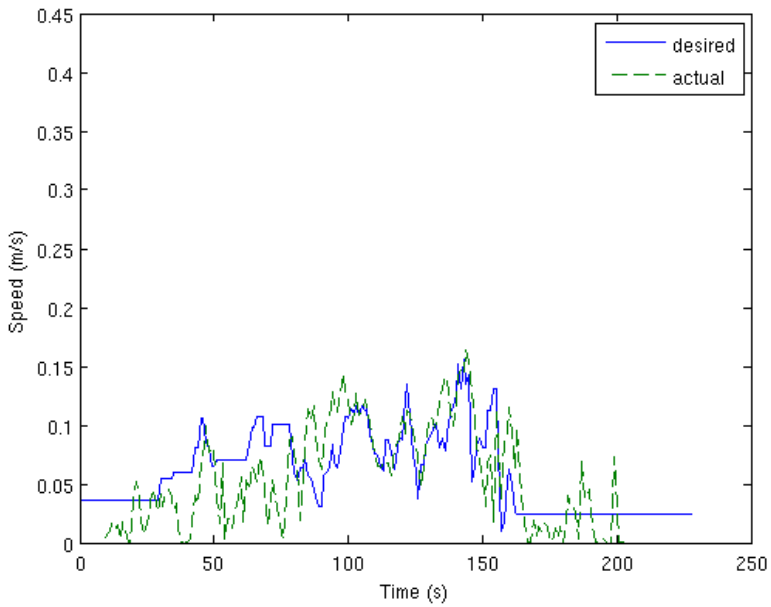

Conclusions

Evaluation

- Both the active and passive fixtures show promise for guidance of both direction and speed.

Future Work

- Experiments with many users
- Integration with context analysis
- Target tasks with dynamics
- Stability analysis

Thanks

- Thanks for listening.
- Thanks to NSF Grant IIS-0205318 for continued support.

- Questions?