Comparing the transparency of the haptic paddle using different interaction controllers

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Introduction - Background and Motivation

- Background and Motivation
  - Robotic devices are widely used in neurological rehabilitation
  - Different impairment levels of patients
  - Providing the right amount of support and challenge
  - Impedance control(detailed block diagrams in the backup slides)
    - open-loop impedance control
    - impedance control with model feedforward
    - Impedance control with force feedback

Low impedance
Almost no resistance to motion ($Z \rightarrow 0$)

High impedance
Almost complete resistance to motion ($Z \rightarrow \infty$)

pHRI Lecture 10

Introduction - Problem Statement

- Transparency Mode
  - Transparency mode is when we can freely move the device with less effort
  - Moving the the uncontrolled device requires forces (inherent friction and inertias)
  - May not be suitable for neurologically impaired patients (reduced motor function) or to train fine motor skills.
  - To achieve a *Transparency Mode* behavior (Zapp → 0 or moving hand through air) a force feedback can be implemented

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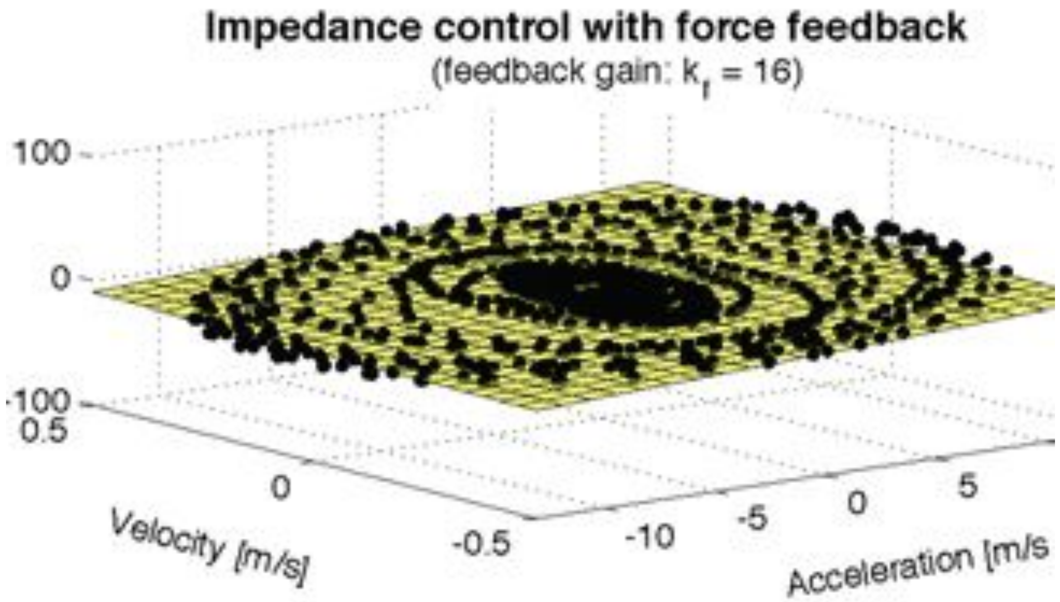
Introduction - Problem Statement

- Transparency Planes
  - Transparency planes are three dimensional plots
  - Allow a comparison of the lower apparent impedance boundaries of a haptic device



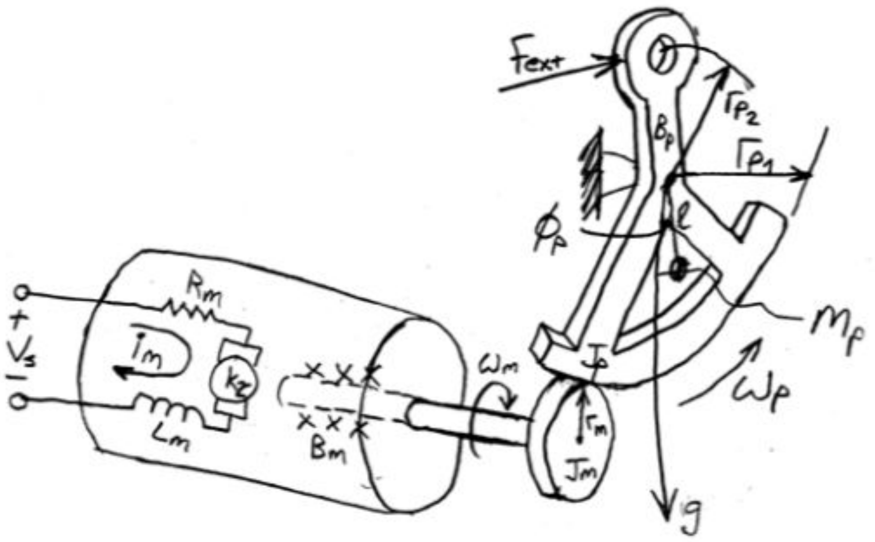
Metzger et al. (2015)

Methods - Implementation

- Tachometer Characterization - Transfer Function

Technical Data			
Output voltage per 1000 rpm	0.52 V	Max. current	10 mA
Terminal resistance tacho	37.7 Ω	Tolerance of the output voltage	± 15 %
Typical peak to peak ripple	≤ 6 %	Rotor inertia (tacho only)	< 3 gcm²
Ripple frequency per turn	14	Resonance frequency with motors on p. 179–181	> 2 kHz
Linear voltage tolerance, 500 to 5000 rpm	± 0.2 %	with motors on p. 184	> 4.5 kHz
Linear voltage tolerance with 10 kΩ load resistance	± 0.7 %	Temperature range	-20 ... +65 °C
Polarity error	± 0.1 %		
Temperature coefficient of EMF (magnet)	-0.02 % /°C	Option: Pigtails in place of solder terminals.	
Temperature coefficient of coil resistance	+0.4 % /°C		

Datasheet Tachometer DC Tacho DCT 22 0.52 Volt



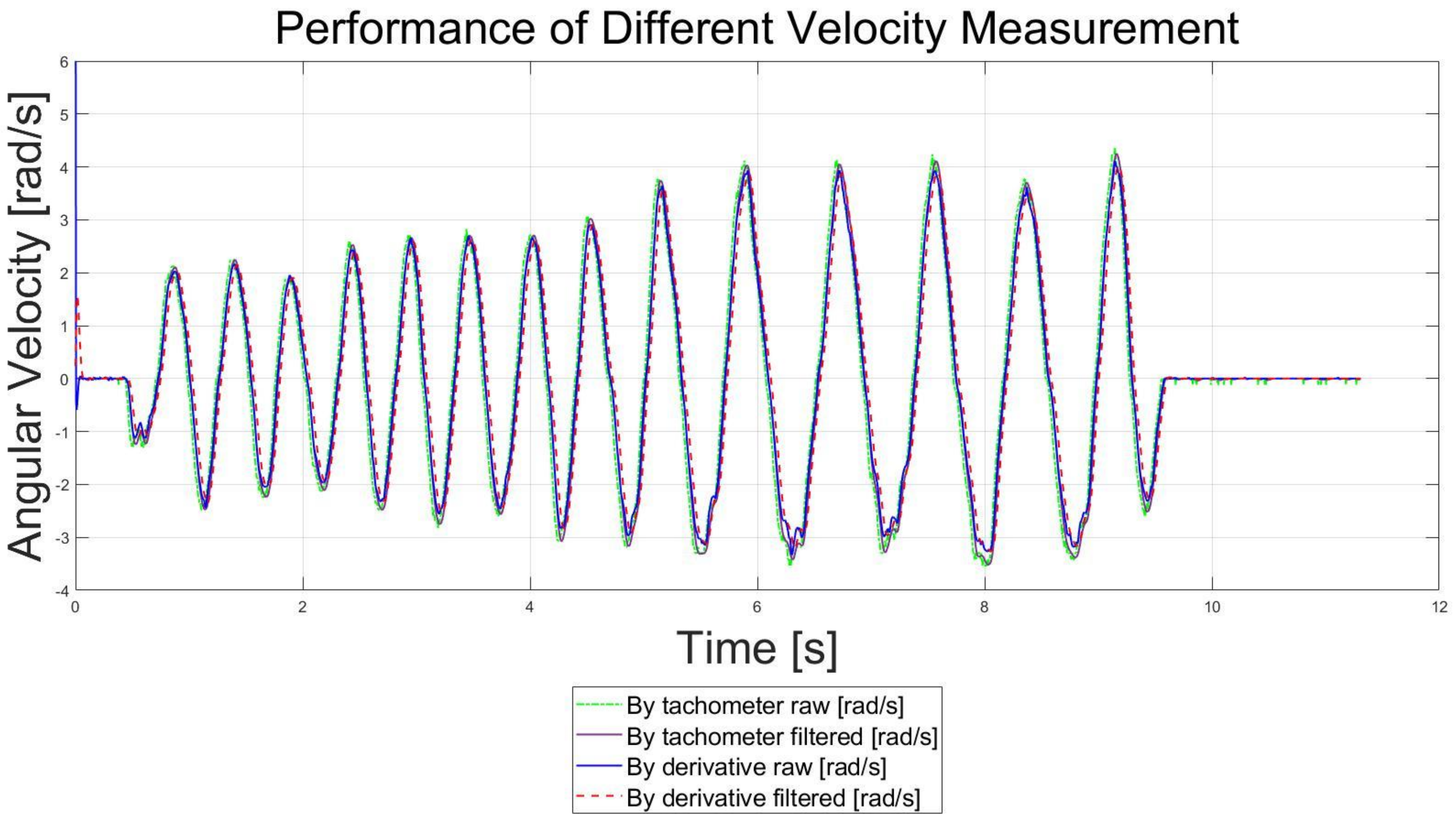
pHRI Lecture 8

$$0.52V = 1000\ rpm_{motor} = 1000 * \frac{r_m}{r_{p1}}\ rpm_{paddle} = 1000 * \frac{0.0043}{0.075}\ rpm_{paddle} \approx 57.333\ rpm_{paddle}$$

$$1V = 11.546\ [rad/s]_{paddle}$$

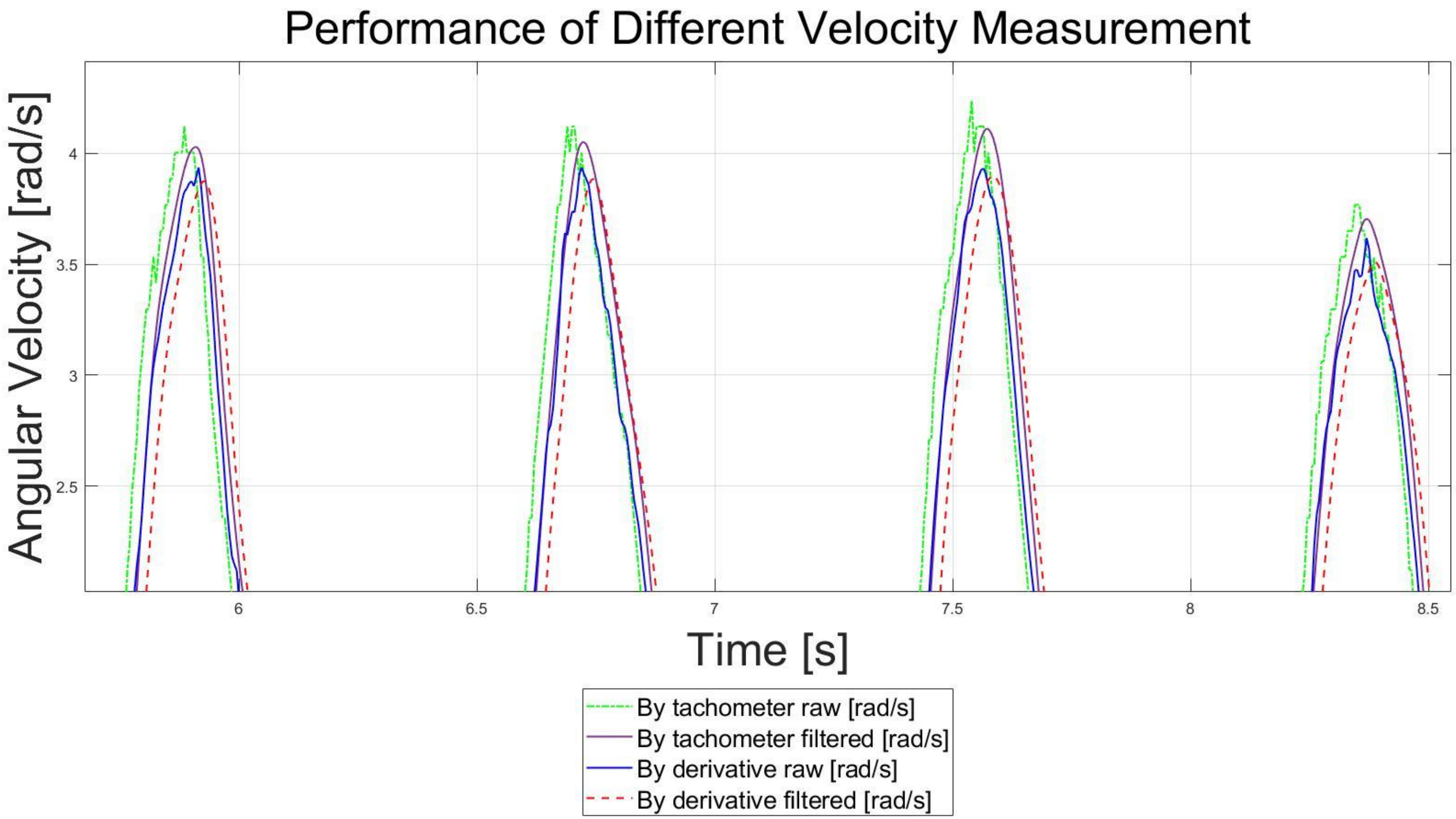
Methods - Implementation

- Tachometer Characterization - Performance Comparison



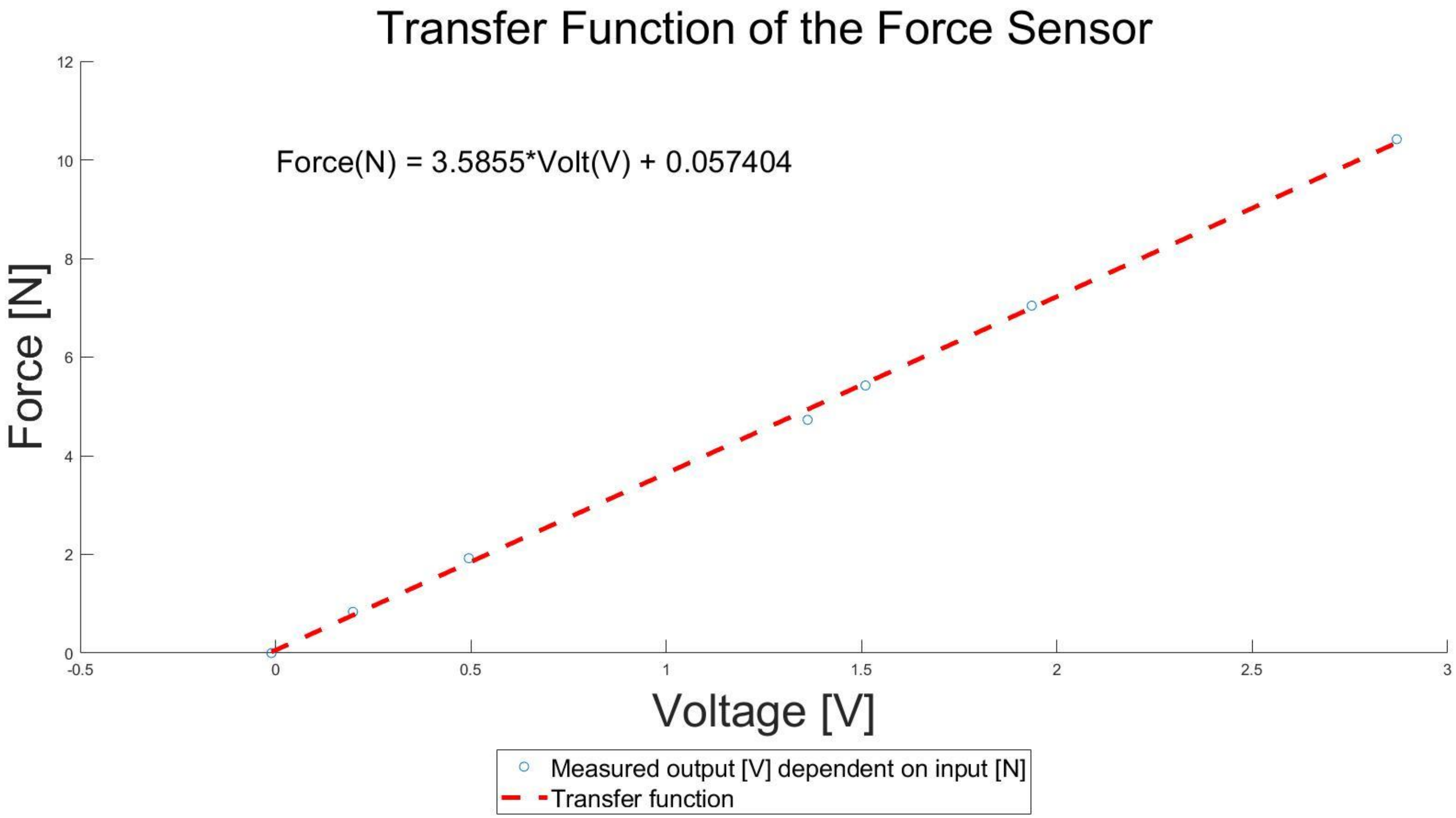
Methods - Implementation

- Tachometer Characterization - Performance Comparison



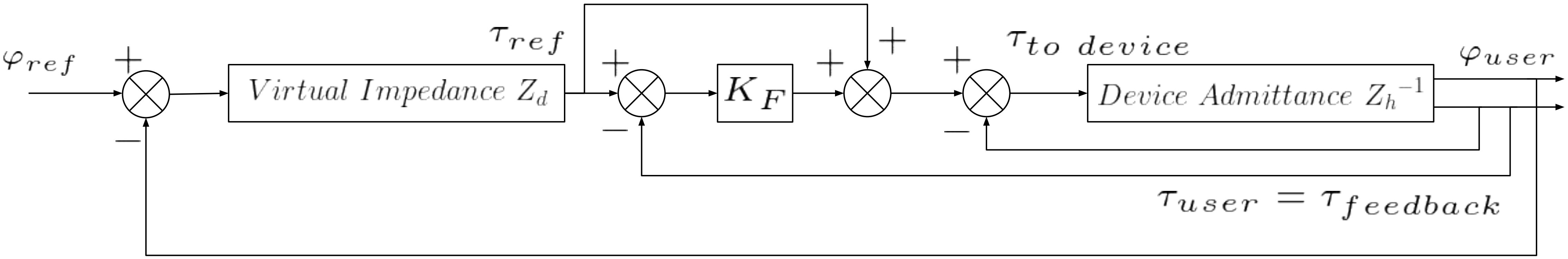
Methods - Implementation

- Force Sensor Characterization



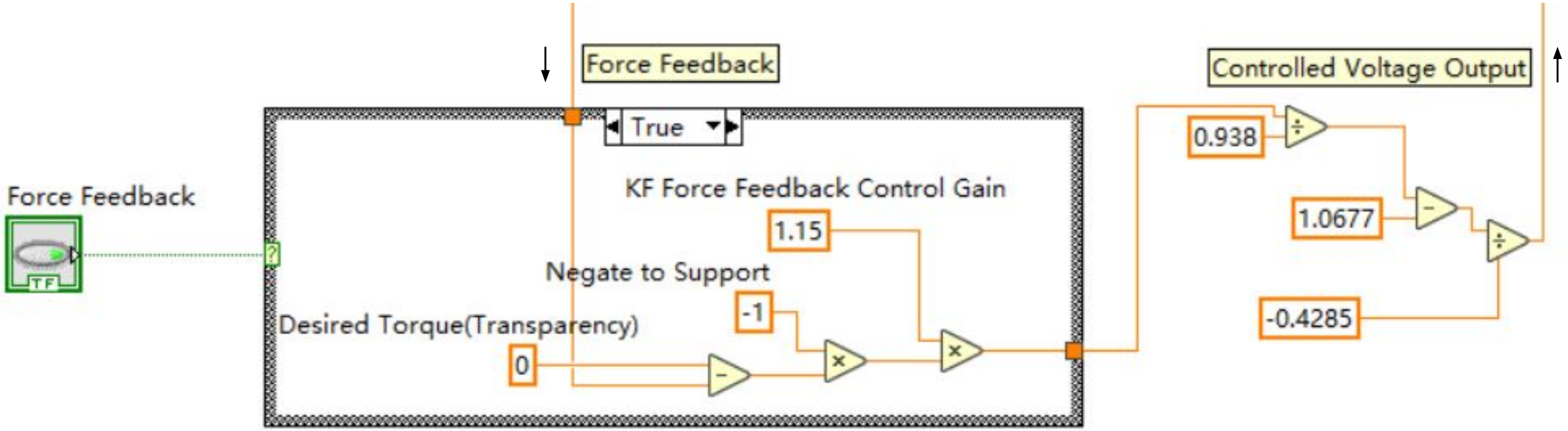
Methods - Implementation

- Force Feedback Implementation in Transparency Mode

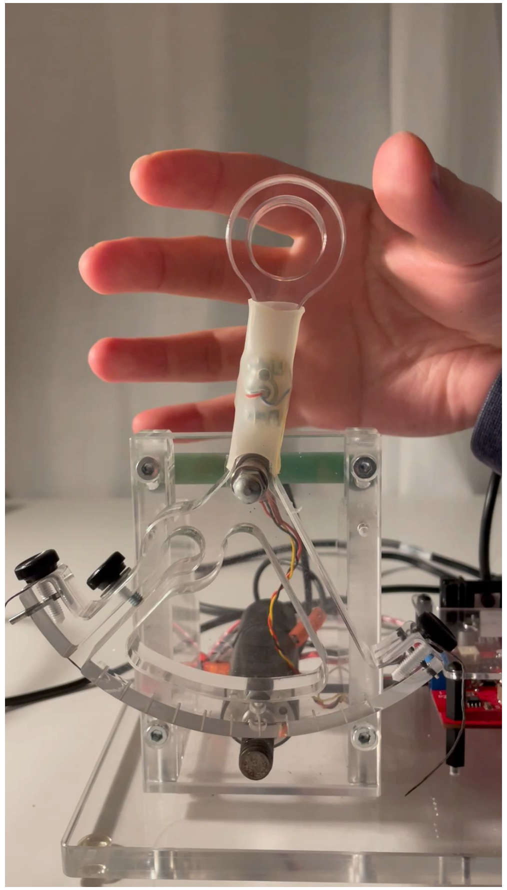


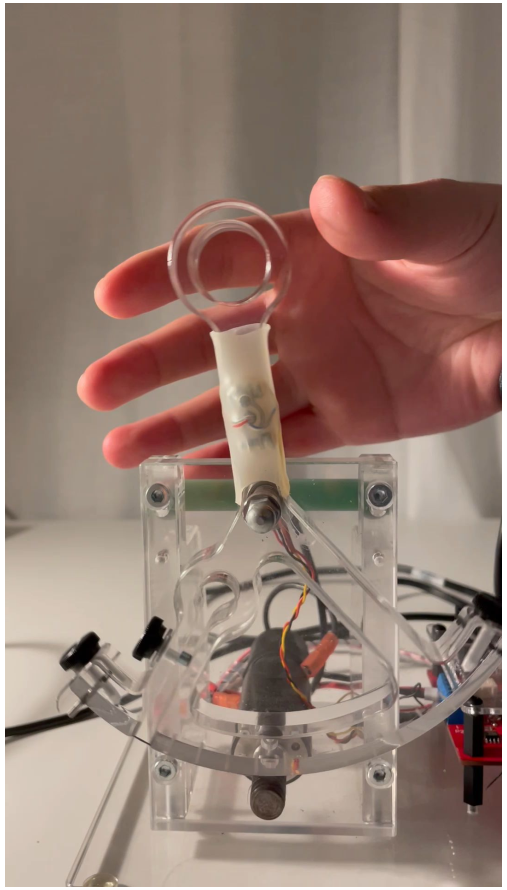
$$\tau_{ref(transparent)} = 0$$

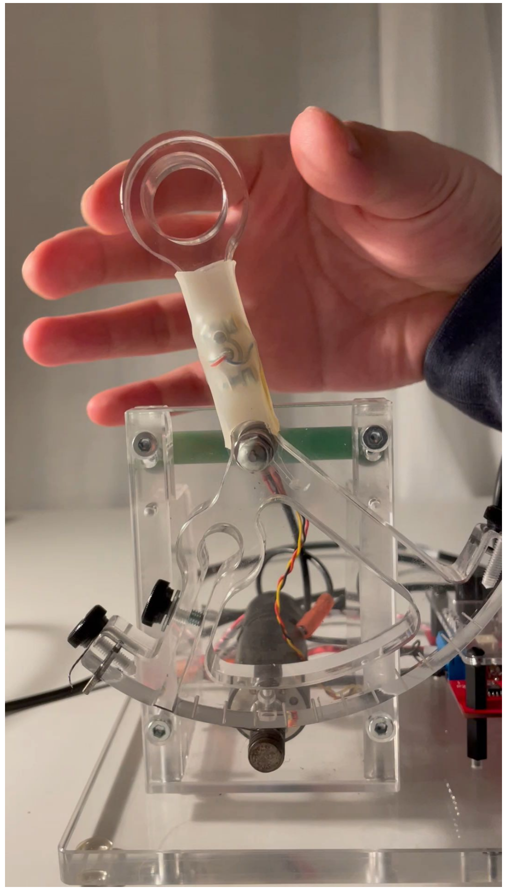
$$Control\ Signal = K_F(\tau_{ref(transparent)} - \tau_{feedback}) + \tau_{ref(transparent)}$$



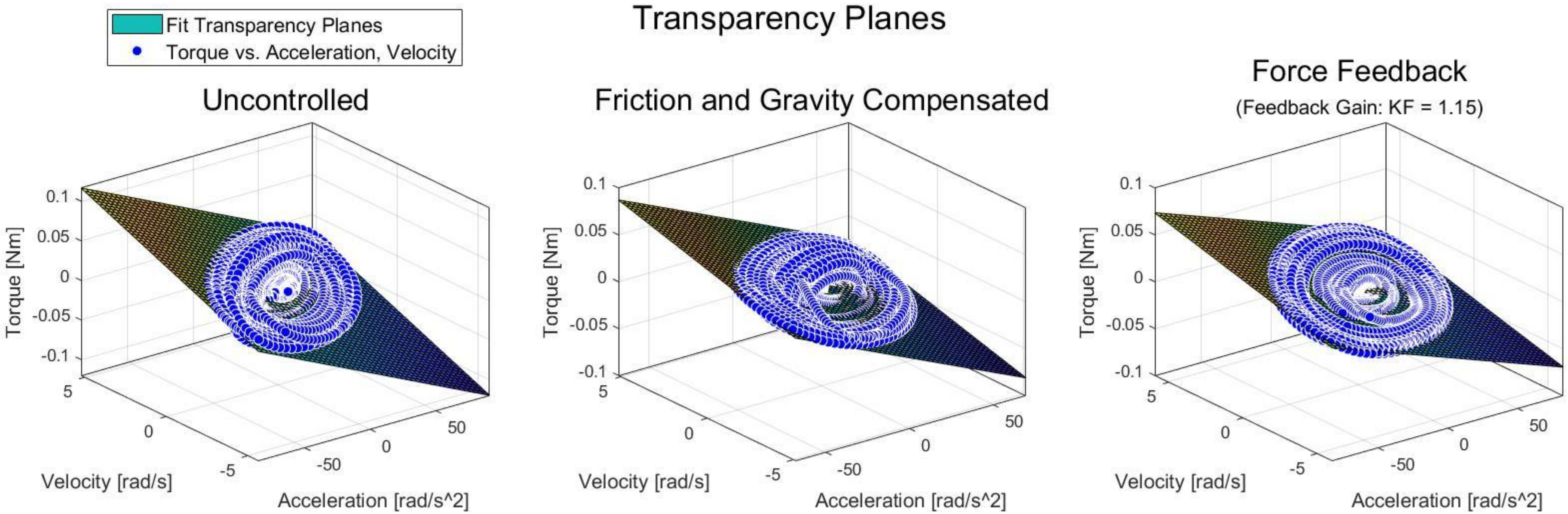
Results - Videos







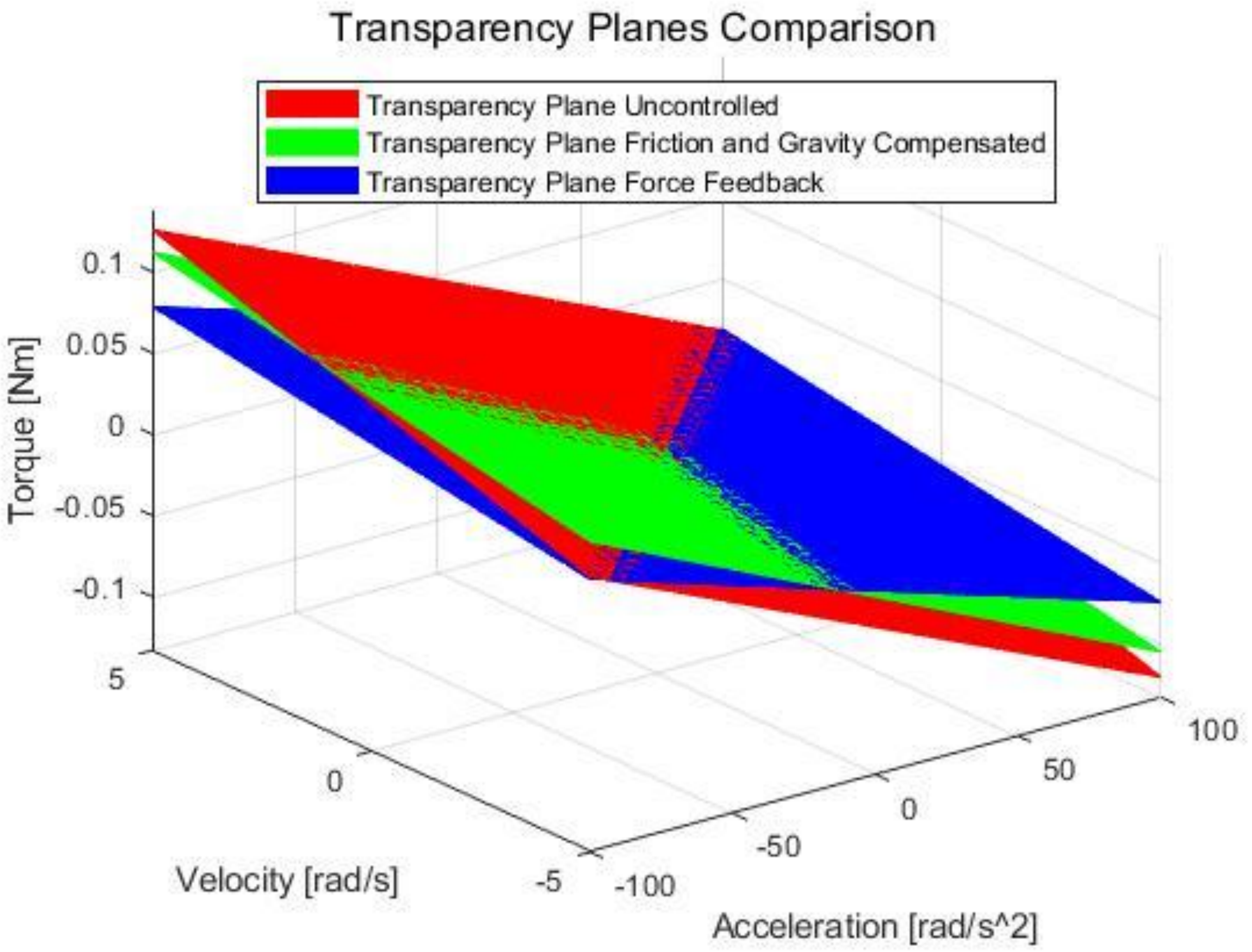
Results - Transparency Planes



Fitting Results / Control Schemes	I_app [kg*m^2]	b_app [Nm/(rad/s)]	R-square	# fitting points	Max. residual [Nm]	Avg. residual [Nm]
Uncontrolled	0.0007852	0.008958	0.8852	5039	0.0218	0.0049
Friction and Gravity Compensated	0.0008166	0.005411	0.8842	4224	0.0335	0.0080
Force Feedback	0.0005468	0.004377	0.9139	4665	0.0262	0.0076

Discussion

- Transparency Planes Comparison



Discussion

Fitting condition	m_{app} [kg]	b_{app} [N/(m/s)]	R^2	# fitted points	Max. residual [N]	Avg. residual [N]
Uncontrolled plant	32	141	0.96	10730	11.6	3.1
Impedance control with force feedback	0.8	2.7	0.99	10082	4.1	0.31
Admittance control	1.3	8.6	0.98	9826	3.3	0.43

Metzger et al. (2015)

Control Schemes \ Fitting Results	I_app [kg*m^2]	b_app [Nm/(rad/s)]	R-square	# fitting points	Max. residual [Nm]	Avg. residual [Nm]
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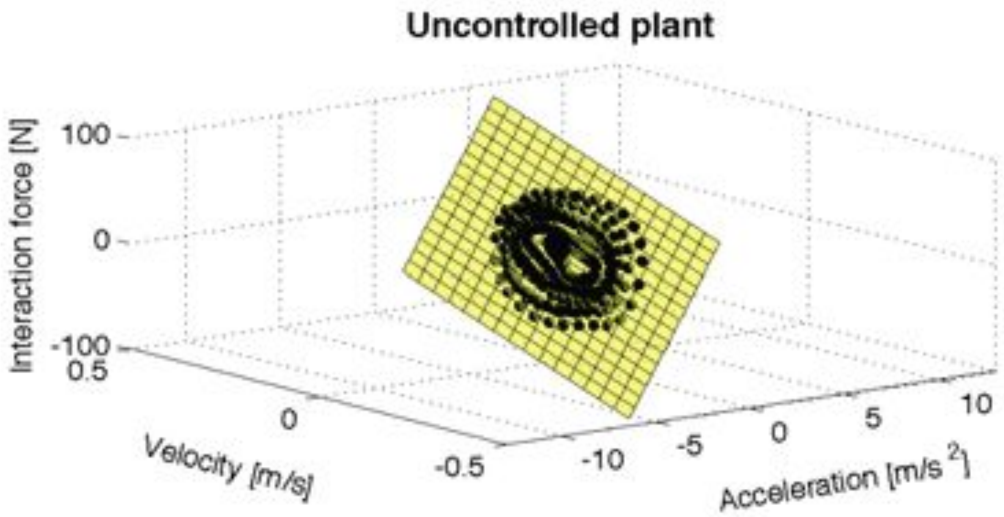
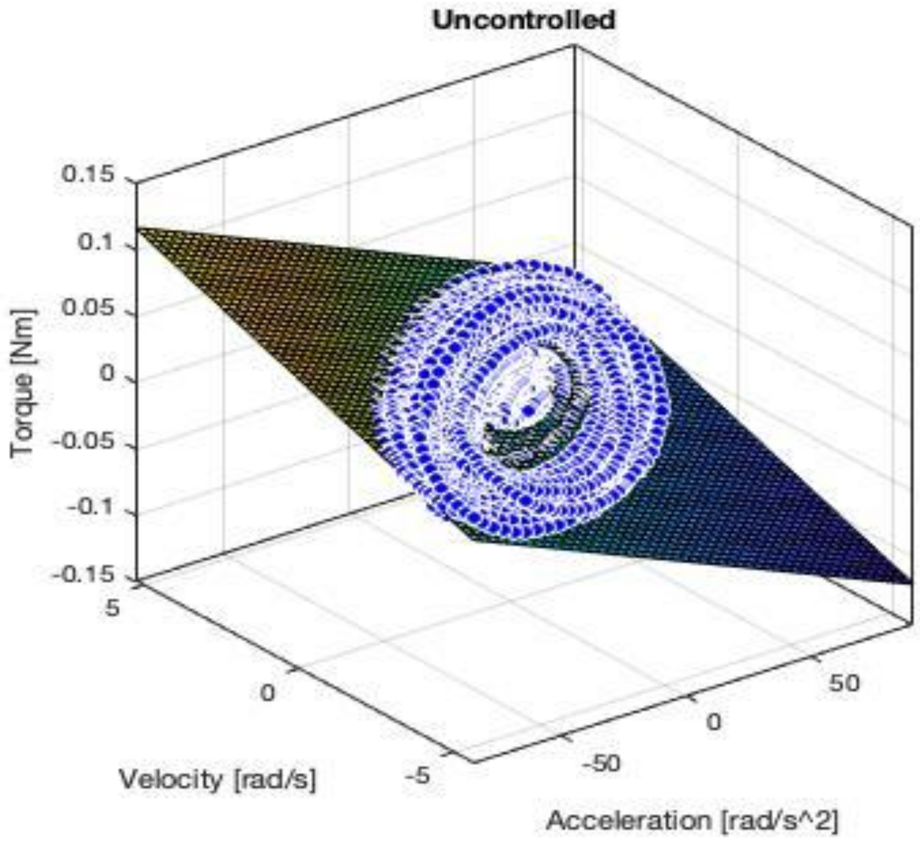
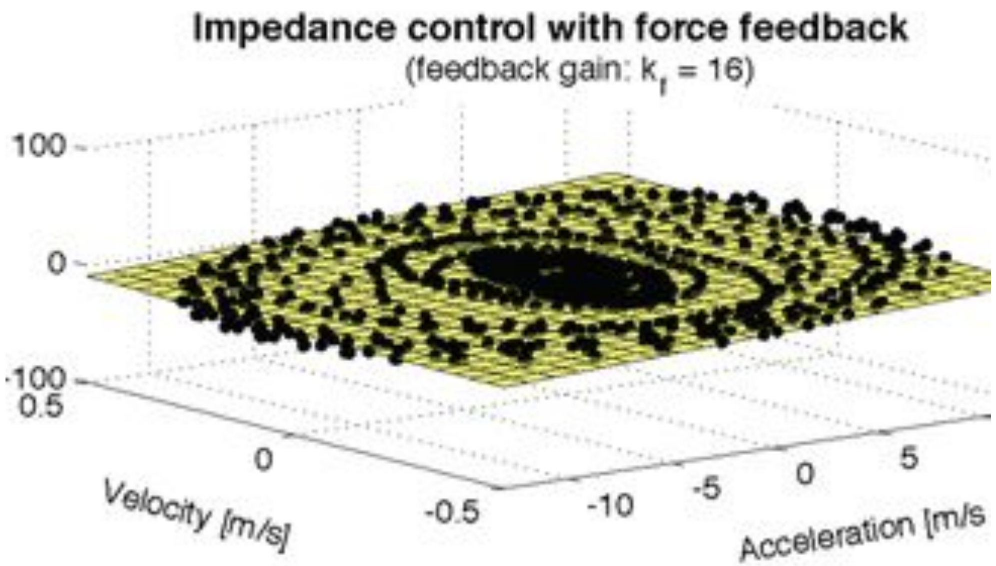


Metzger et al. (2015)



Apparent mass: 32 kg	Apparent inertia: 0.0007852 kg*m^2
Apparent dampening: 141 N/(m/s)	Apparent dampening: 0.008958 Nm/(rad/s)

Discussion



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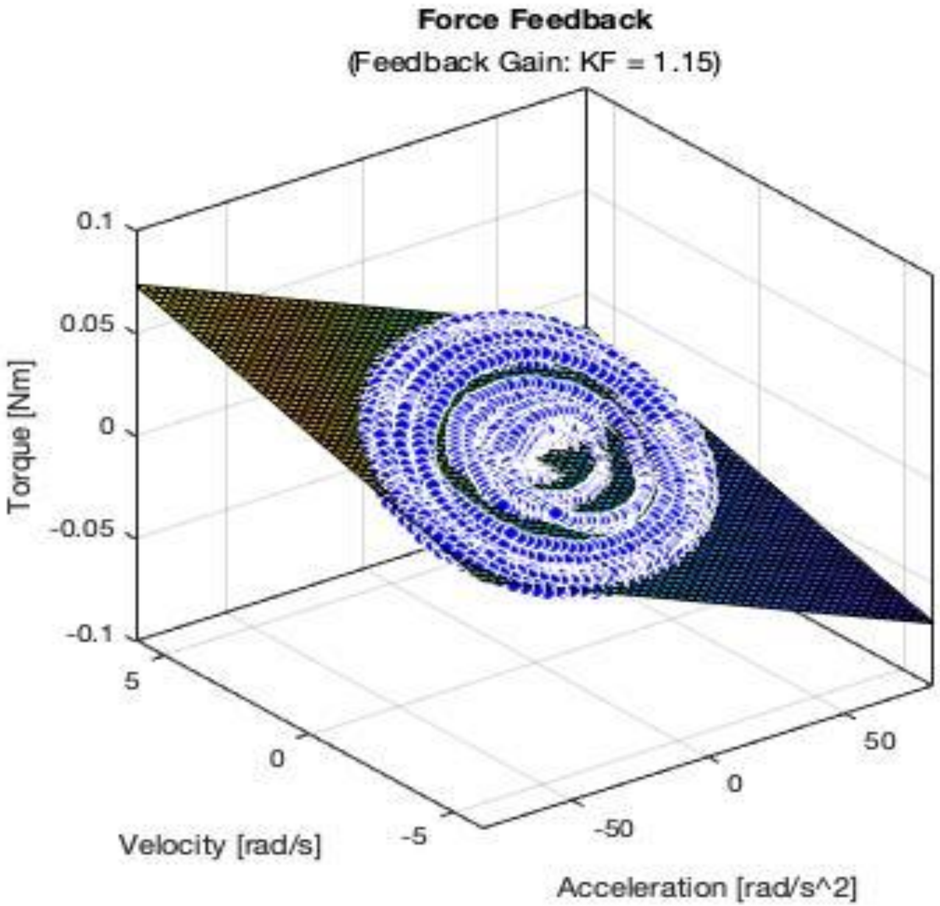

Apparent mass: 0.8 kg (32 kg uncontrolled)	Apparent inertia: 0.0005468 kg*m^2 (0.0007852 kg*m^2 uncontrolled)
Apparent dampening: 2.7 N/(m/s) (141 N/(m/s) uncontrolled)	Apparent dampening: 0.004377 Nm/(rad/s) (0.008958 Nm/(rad/s) uncontrolled)

Limitations

- The non-linear friction and gravity we did not perfectly compensate
- The inconsistent behaviour of the force sensor
- The right feedback gain for the force feedback

Conclusion and Outlook

- Conclusion
  - ImpC with force feedback does improve the performance of the haptic paddle
  - But not always…

- Outlook
  - Better modeling of friction and gravity
  - Force sensor
  - Method to find the better gain for the force feedback

References

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Thank you for your attention!

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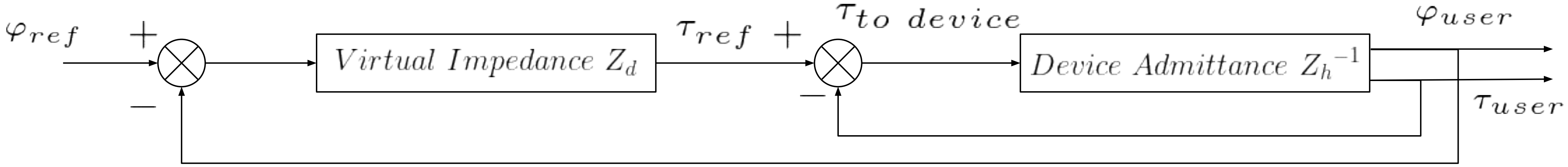
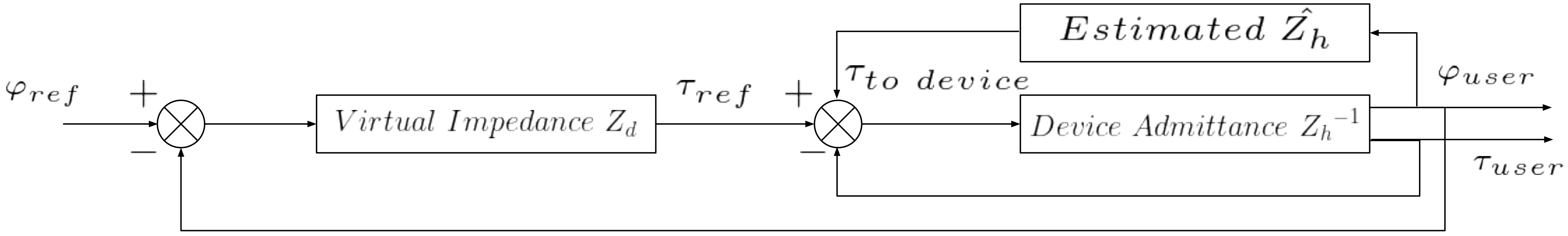
Introduction - Problem Statement - Backup Slides

- Interaction Control Scheme
  - Open-loop Impedance Control



$$-\tau_{user} = Z_h \varphi_{user} + Z_d(\varphi_{user} - \varphi_{ref})$$
$$Z_{real} = Z_d + Z_h$$

  - Impedance Control with Model Feedforward



$$-\tau_{user} = Z_h \varphi_{user} - \hat{Z}_h \varphi_{user} + Z_d(\varphi_{user} - \varphi_{ref})$$
$$Z_{real} = Z_h - \hat{Z}_h + Z_d$$

Introduction - Problem Statements - Backup Slides

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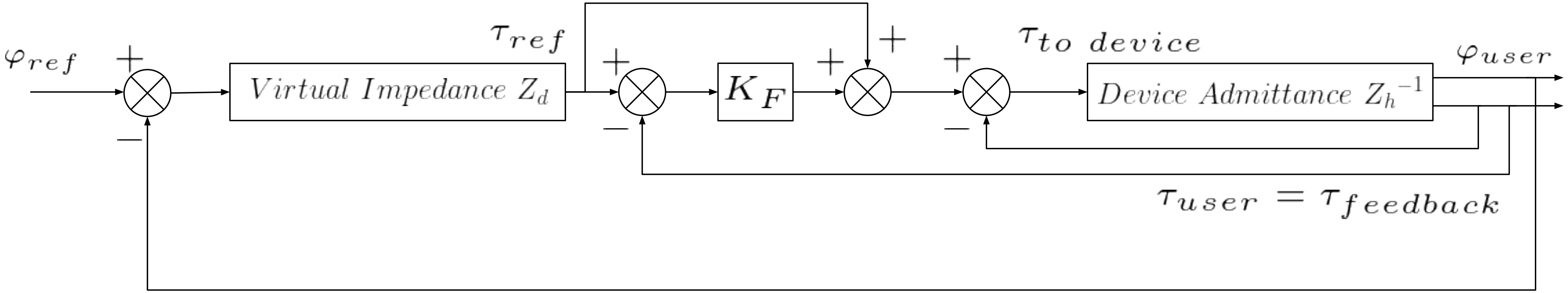
  - Impedance Control with Force Feedback



$$-\tau_{user} = (1 + K_F)^{-1} Z_h \varphi_{user} + Z_d(\varphi_{user} - \varphi_{ref})$$

$$Z_{real} = Z_d + (1 + K_F)^{-1} Z_h$$