pHRI: specialization groups – HS 2019 - PRELIMINARY

1) VELOCITY ESTIMATION WITH HALL EFFECT SENSOR
2) VELOCITY MEASUREMENT: TACHOMETER VS HALL SENSOR
3) POSITION AND VELOCTIY ESTIMATION BASED ON KALMAN FILTER
4) ANALYSIS OF SAMPLING RATE AND SENSOR RESOLUTION EFFECTS ON VIRTUAL WALL PERCEPTION [myRIO]
5) **IDENTIFICATION OF OUTPUT IMPEDANCE OF HAPTIC PADDLE**
6) **IMPEDANCE CONTROL WITH FORCE FEEDBACK**
7) **ADMITTANCE CONTROL WITH INNER POSITION/VELOCITY LOOP**
8) **ASSESSMENT OF HUMAN MOTOR CONTROL AND ADAPATION**
9) EMG CONTROL
10) **IDENTIFICATION OF HUMAN FINGER IMPEDANCE**
11) PSYCHOPHYSICAL STUDY TO DETERMINE HUMAN PERCEPTION THRESHOLDS
12) **FORCE SCALING IN REHAB**
13) TELEOPERATION
14) **COMPARING THE TRANSPARENCY OF THE HAPTIC PADDLE USING DIFFERENT INTERACTION CONTROLLERS**

BOLD: require a force sensor at the end-effector

1) VELOCITY ESTIMATION (HALL EFFECT SENSOR)

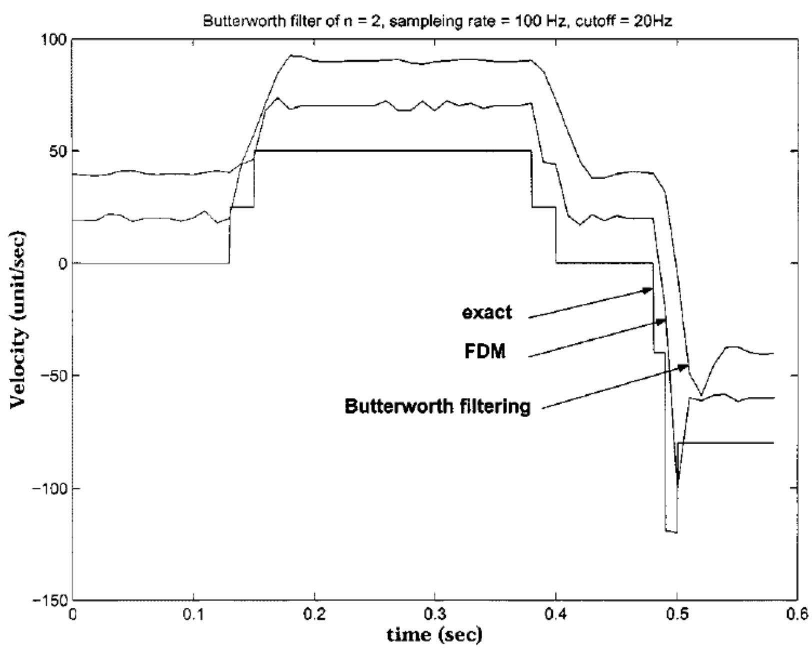
There are several approaches to increasing stability in human-robot interaction. One approach is to digitally filter the velocity estimated from consecutive position measurements. In this specialization project, different velocity filter approaches (such as a simple Butterworth low pass filter or a more advanced discrete-time adaptive window velocity estimator) will be investigated. You will implement 2-3 filters in your (impedance) controller and compare the resulting human-robot interaction stability with K-B plots (K-B-plots indicate the stability of the controller and will be covered in the lecture). During your presentation you will generally discuss the use of a velocity filter in an impedance controller and show the improvements achieved with your implementations.

References:

Discrete-Time Adaptive Windowing for Velocity Estimation, Janabi-Sharifi, Hayward, Chen, 2000

Application of Levant's Differentiator for Velocity Estimation and Increased Z-Width in Haptic Interfaces, Chawada, Celik, O'Malley, 2011

On Velocity Estimation Using Position Measurements, Liu, 2002



2) VELOCITY MEASUREMENT (TACHOMETER VS HALL EFFECT SENSOR)

There are several approaches to increasing stability in human-robot interaction. One factor that greatly contributes to this aspect is a good velocity estimate. You will characterize velocity measurements derived from both the Hall effect sensor (through differentiation and filtering) and a tachometer (direct velocity measurement and filtering) in terms of noise, delay and step response, at low and high velocities.

Stability in human-robot interaction will be compared through a K-B plot (K-B-plots indicate the stability of the controller and will be covered in the lecture) for each of the two sensors.

In your presentation, you will present the working principle of a tachometer, discuss advantages and disadvantages of using this type of sensor. You will further present and discuss the characterization of the output signals and the K-B plots.

References:

J. E. Colgate and J. M. Brown, "Factors affecting the Z-width of a haptic display", Proceedings of the IEEE International Conference on Robotics & Automation, pp. 3205-10, 1994.

J. J. Abbott and A.M. Okamura, "Effects of position quantization and sampling rate on virtual-wall passivity", IEEE Transactions on Robotics, 21(5), pp. 952-964, 2005.

Liu, "On velocity estimation using position measurements", American Control Conference, pp. 1115-1120, 2002.

3) POSITION AND VELOCTIY ESTIMATION BASED ON KALMAN FILTER

The Kalman filter was published in 1961 [1] and became famous when it was used in the Apollo program, landing a man on the moon six years later. Ever since, it has been a cornerstone of modern engineering, including applications in aeronautics, automotive industry, robotics, biomechanics and rehabilitation.

In this project you will implement a Kalman filter to estimate the angular position and velocity of the Haptic Paddle. We will use the Hall effect sensor of the paddle, which provides a noisy measurement of the paddle's angular position, and an accelerometer mounted on the paddle lever as input sources for the Kalman filter. This will allows us to produce a cleaner estimation of the paddles position and velocity. The position signal will also have a reduced latency when compared to the direct measurement of the hall sensor.

This improved state estimation is useful for many of the methods covered in this course. For instance, it can improve the performance of the impedance and admittance controller. More importantly, it allows you to gain hands on experience in Kalman filtering with a simple yet realistic state estimation task. Once you have mastered this simple example, you should be able to see applications for the Kalman filter in many if not most of your future real world projects.

References:

Kalman, R.E. (1960). "A new approach to linear filtering and prediction problems". Journal of Basic Engineering 82

http://www.youtube.com/watch?v=n1EacrqyCs8&list=PL1EF620FCB11312A6

https://www.udacity.com/wiki/cs373/kalman_filter_matrices

4) ANALYSIS OF SAMPLING RATE AND SENSOR RESOLUTION EFFECTS ON VIRTUAL WALL PERCEPTION

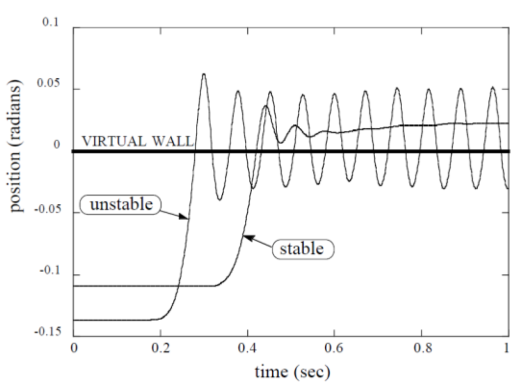
The objective of this project is to investigate how sampling rate and resolution of the position sensor affect the performance of a haptic display. Using the one-degree-of-freedom Haptic Paddle available, your task is to carry out a comparison between two different methods of providing position and velocity information to the controller: (i) using an optical encoder, and (ii) using a hall sensor. Two different DAQ cards (PCI and USB based) will be provided for acquiring and sampling the signal. The following aims should guide you through your work:

- set up the hardware, design and implement the control program in LabVIEW to render a virtual wall;
- discuss the limitations introduced by the sampling rate of the DAQ card and how they influence your wall rendering performance. How does the sensor resolution further affect this? What is the tradeoff here? (evaluate sampling rates from 10 to 500 Hz);
- determine the maximum stable stiffness (i.e. considering passivity criterion → see reference papers) achievable by the Haptic Paddle in each case;
- in your presentation you should also give a short overview of what stability represents when referring to haptic displays and describe several solutions presented in literature to further improve it.

References:

J. E. Colgate and J. M. Brown, "Factors affecting the Z-width of a haptic display", Proceedings of the IEEE International Conference on Robotics & Automation, pp. 3205-10, 1994.

J. J. Abbott and A.M. Okamura, "Effects of position quantization and sampling rate on virtual-wall passivity", IEEE Transactions on Robotics, 21(5), pp. 952-964, 2005.



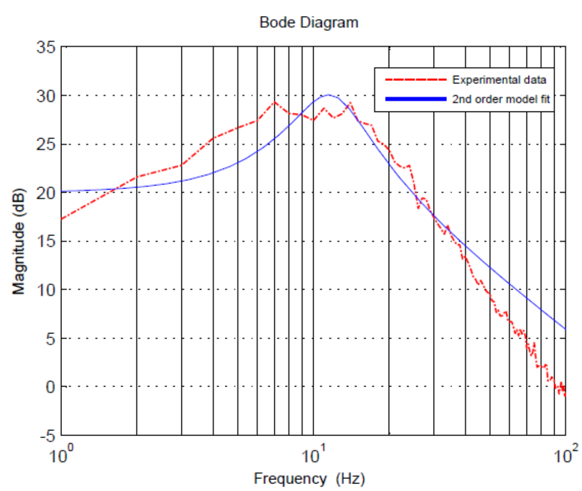
5) IDENTIFICATION OF OUTPUT IMPEDANCE OF HAPTIC PADDLE

The dynamics of the Haptic Paddle will be modeled in one of the exercise sessions. Although we can incorporate a friction model into the dynamics of the device, it will be difficult to describe the real dynamics by this model due to modeling errors and limitations. In this specialization project the real dynamics will be measured experimentally and a second order model will be fitted through the experimentally determined data. Therefore, the Haptic Paddle of this specialization group will be equipped with a force sensor at the end-effector to measure the real dynamics (output impedance). The output impedance of the device will be determined through two consecutive experiments (open end-effector and blocked end-effector). During your presentation you will show the theoretical background of determining the output impedance with the two experiments, show how you carried out the two experiments (pictures of the setup with the blocked end-effector, recorded data) and how you calculated the output impedance based on the measurements of the two experiments. Finally, you will show the 2nd order model fit through your output impedance and compare the result to the modeled dynamics.

References:

Chapter 4 of doctoral thesis "Systematic Evaluation Methodology and Performance Metrics for Haptic Interfaces", Evren Samur, EPFL, 2010

High-Fidelity Rendering of Virtual Objects with the ReHapticKnob – Novel Avenues in Robot-Assisted Rehabilitation of Hand Function, Metzger, Lambercy, Gassert, 2012



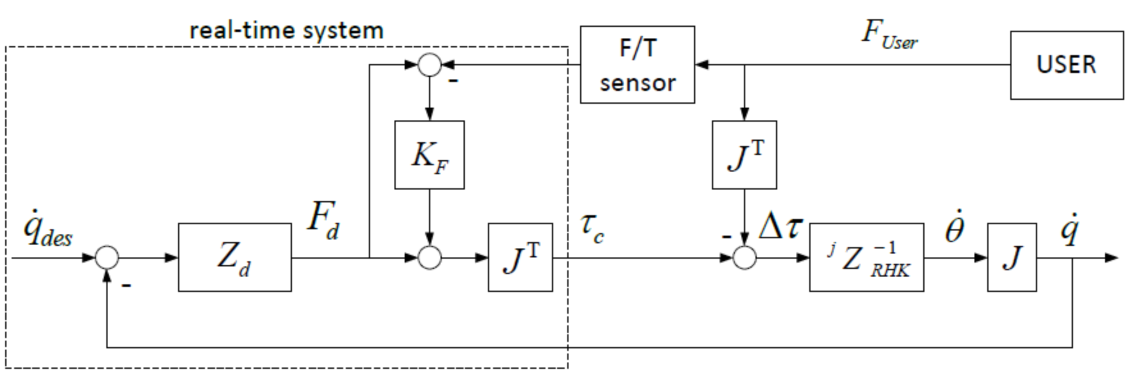
6) IMPEDANCE CONTROL WITH FORCE FEEDBACK

The most appropriate controller for human-robot interaction is the impedance controller. Each group will implement and evaluate a simple impedance controller on the Haptic Paddle. In this specialization project your Haptic Paddle will be equipped with an additional force sensor to acquire the interaction force between human and robot. The measured interaction force will be used in the impedance controller (impedance controller with force feedback) to improve the renderable impedance range. Specifically the low impedance (transparency: friction and inertia of the device are partially compensated) of the Haptic Paddle can be improved through the force feedback. Due to the force feedback and the resulting compensation of the apparent (felt) device dynamics (friction, inertia, etc.) only the desired impedance of your controller will be felt when interacting with the robotic device, which is not the case for the simple impedance controller. This difference will be investigated by measuring the impedance felt at the end-effector (human-robot interaction point) and its comparison to the desired one. During your presentation you will present the concept of adding a force sensor at the interaction point between human and robot (end-effector), show your implementation of the impedance controller with force feedback and discuss the difference to the simple impedance controller. You will also motivate the placement of the sensor as close as possible to the output.

References:

Closed-loop Force Control for haptic Simulation of virtual environments, Carignan and Cleary 2000

High-Fidelity Rendering of Virtual Objects with the ReHapticKnob –Novel Avenues in Robot-Assisted Rehabilitation of Hand Function, Metzger, Lambercy, Gassert 2012

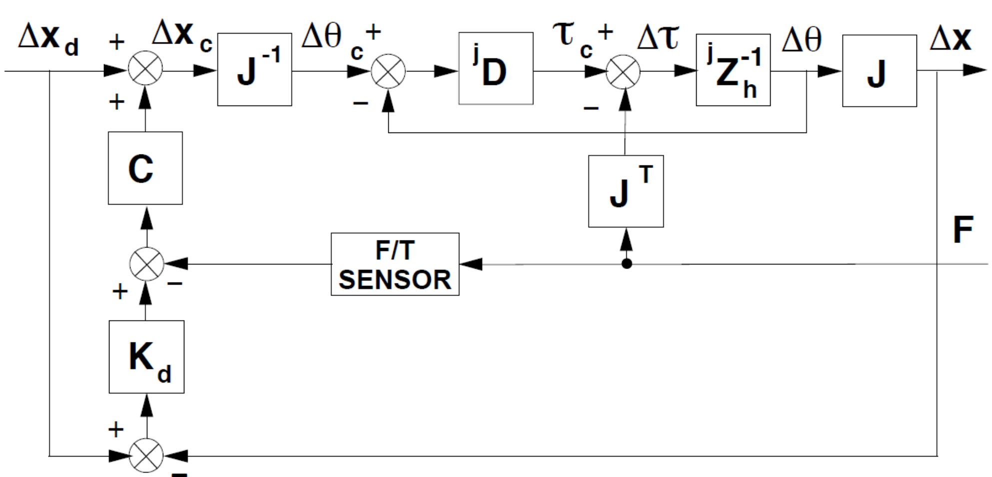


7) ADMITTANCE CONTROL WITH INNER POSITION/VELOCITY LOOP

In this project you will implement an admittance controller which relates input force to output motion. This is the opposite concept of the impedance controller which will be implemented by all groups. The admittance controller is used when the dynamics of the plant are only barely known or too difficult to model. Furthermore, small control gains of the admittance controller allow rendering high impedances which is limited with the impedance controller. In the admittance control scheme the force applied by the user is the input to a virtual model ($m \cdot a + b \cdot v + k \cdot x = F$) which results in a virtual dynamic motion. This resulting virtual motion is used to control the Haptic Paddle in velocity control (PID). Therefore, the virtual dynamics are felt at the end-effector, i.e. the dynamics of the Haptic Paddle are overlaid with those of the virtual model. With the finally implemented controller you will identify the stable human-robot interaction regions and show this in a M-B-K-plot. Your Haptic Paddle will be equipped with a force sensor at the end-effector to measure the human-robot interaction force required for the admittance controller. During your presentation you will present the concept of the admittance controller and show how the controller has been implemented. You will discuss the resulting performance of the controller and the differences to the simple impedance controller.

References:

Closed-loop Force Control for haptic Simulation of virtual environments, Carignan and Cleary 2000



8) ASSESSMENT OF HUMAN MOTOR CONTROL AND ADAPATION

The goal of this project is to use the haptic paddle for the assessment of human motor control and adaptation. Your objective is to create a motor assessment task and to disturb the movement of the user with force fields, thereby providing the possibility to measure motor adaption.

In detail, your tasks include:

- Design of an assessment task for the haptic paddle to study human motor control.
- Proposal and implementation of a set of kinematic metrics (max. 5) that capture quality of different movement aspects based on the provided literature.
- Implementation of a force field to disturb the movements of the user, thereby providing the possibility to study motor adaptation.
- Design and evaluation of a small study (~5 subjects) with a focus on measuring motor adaptation and after-effects in a force field with the implemented kinematic metrics.
- Critical discussion of the methodology and results under consideration of provided literature.
- During your presentation, you should give a brief overview about the assessment of movement quality, motor adaptation in the context of movements in a force field and discuss the methods and results of your study.

References:

Nordin, Nurdiana, Sheng Quan Xie, and Burkhard Wünsche. "Assessment of movement quality in robot-assisted upper limb rehabilitation after stroke: a review." Journal of NeuroEngineering and Rehabilitation 11.1 (2014): 137.

Gandolfo, F., Mussa-Ivaldi, F. A., & Bizzi, E. (1996). Motor learning by field approximation. Neurobiology, 93(4), 3843–3846.

Patton, J. L., & Mussa-Ivaldi, F. A. (2004). Robot-assisted adaptive training: Custom force fields for teaching movement patterns. IEEE Transactions on Biomedical Engineering, 51(4), 636–646.

9) EMG CONTROL

The aim of this specialization project is to design and implement a control strategy allowing a user to control the haptic paddle through the contraction of a muscle, recorded by electromyography. Your task is to familiarize with the physiological principles underlying surface electromyography. You will then set up the hardware (three EMG electrodes and a USB programmable instrumentation amplifier/filter) and implement signal processing and low-level control allowing the muscle activity to be mapped to either position or torque generated by the haptic paddle. In your presentation, you will give a brief introduction to EMG, discuss the selected signal processing steps and the potential of this control method in prosthetics and other fields.

An EMG primer can be found at:
http://www.delsys.com/KnowledgeCenter/Tutorials_Technical%20Notes.html

References:

Assistive Control System Using Continuous Myoelectric Signal in Robot-Aided ArmTraining for Patients After Stroke, Song et al., IEEE TNSRE, 2008

http://www.alligatortech.com

http://www.alligatortech.com/Downloads/DAA/USBPGF-S1_Data_Sheet.pdf

10) IDENTIFICATION OF HUMAN FINGER IMPEDANCE

The aim of this specialization project is to estimate the stiffness of the human index finger during grasping tasks under different loads. This can be achieved by applying force or position perturbations to the finger, and measuring the resulting position or force variation. Based on the provided literature, you will implement force and position perturbations and adequate safety measures (e.g. position and velocity limits), and carry out measurements on ~6 subjects and analyze the data to estimate joint stiffness. In your presentation, you will describe methods to estimate joint stiffness (also for multiple joints) and discuss their advantages and limitations. You will present and discuss your results.

References:

Finger Impedance Evaluation by Means of Hand Exoskeleton, Fiorilla et al., Annals of Biomedical Engineering, 2011

The Grasp Perturbator: Calibrating human grasp stiffness during a graded force task, Höppner et al., ICRA, 2011

Characterization of Multijoint Finger Stiffness: Dependence on Finger Posture and Force Direction, Milner and Franklin, IEEE Transactions on Biomedical Engineering, 1998

A method for measuring endpoint stiffness during multi-joint arm movements, Burdet et al., Journal of Biomechanics, 2000

11) PSYCHOPHYSICAL STUDY TO DETERMINE HUMAN PERCEPTION THRESHOLDS

The aim of this specialization project is to familiarize with the field of psychophysics and understand how haptic interfaces can be used to investigate human perception thresholds. Your tasks are to:

- propose a list of potential psychophysical studies which can be conducted with the haptic paddle based on the provided literature and motivate the selection of one;
- implement the low and high-level control for this study, and record data from ~6 subjects;
- give a brief introduction to psychophysics to your peers, define the principle of a psychometric curve and how it can be established, and present your results;
- compare your results with those of similar studies reported in literature;
- discuss whether the performance of the haptic paddle was adequate for your study, and how it could have influenced your measurements.

References:

Psychophysics: Method, Theory and Application, Chapters 1&2. Gescheider, 1985

Chapter 7, Using Psychophysics to Study Perception, Psychology 333 Sensory and Perceptual Processes, University of Washington.

12) FORCE SCALING

Haptic interfaces are powerful tools to assess characteristics of human perception and multisensory integration. Knowing the limits and understanding the mechanisms, one can develop strategies to “trick” a subject into showing a desired behavior. Such an approach could have potential in stroke rehabilitation, as discussed in the references.

You will reproduce the force JND measurements described in the references on about 4 subjects, and then design and implement a feedback distortion to be evaluated in a perception study.

In your presentation, you will present the psychophysical methods used to determine force JND, present your results and compare them to the existing literature. You will further present the feedback distortion scenario you came up with, and discuss its potential in sports training or physical rehabilitation.

References:

Allin, S.; Matsuoka, Y.; Klatzky, R.; , "Measuring just noticeable differences for haptic force feedback: implications for rehabilitation," *Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2002. HAPTICS 2002. Proceedings. 10th Symposium on* , vol., no., pp.299-302, 2002

Brewer, B.R.; Fagan, M.; Klatzky, R.L.; Matsuoka, Y.; , "Perceptual limits for a robotic rehabilitation environment using visual feedback distortion," *Neural Systems and Rehabilitation Engineering, IEEE Transactions on* , vol.13, no.1, pp.1-11, March 2005

Fagan, M.; Matsuoka, Y.; Klatzky, R.; , "Feedback distortion for rehabilitation: gauging perceived physical effort," Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2003. HAPTICS 2003. Proceedings. 11th Symposium on , vol., no., pp. 159-165, 22-23 March 2003

13) DESIGN OF FRAMEWORK FOR TELEOPERATION BETWEEN TWO HAPTIC DISPLAYS

Teleoperation represents the control of a machine (often times a robot) from a remote location. In cases where the teleoperator, or input device, is also a robot, the teleoperator is known as the "master" robot and the teleoperated robot is known as the slave robot. The aim of this project is to design and implement a control framework (see diagram below) that allows the user to handle one haptic paddle (the master) and operate on a remote environment or with another human operator via a second Haptic Paddle (the slave). If the master is a force feedback manipulator, such as the Haptic Paddle, then the user can haptically feel the remote environment of the slave via the master. This project will be carried out jointly by two groups. You will receive a PCI data acquisition card allowing you to connect two Haptic Paddles to the same PC. Your tasks will involve:

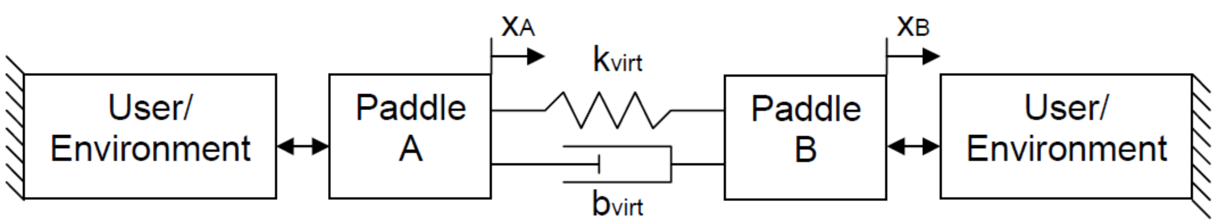
- Design and implement the haptic teleoperation scheme in LabVIEW;
- Establish both a one-way communication (one paddle is the master, and one the slave), as well as a bimodal communication (tele-interaction) in which the two paddles are both master and a slave grounded through their environment or user;
- Derive the mathematical model for both cases above;
- Investigate the effect of a virtual time delay introduced in your controller between master and slave (communication delay)
- In your presentation you will give a brief introduction to teleoperation, present the haptic environments that you explored with the haptic paddle (one-way communication) and the teleoperation modes you experienced (bimodal communication). Are there any discrepancies between the theoretical and experimental results? What are the reasons?
- What are the parameters in your model that affect the stability?

References:

K. J. Kuchenbecker and G. Niemeyer, "Modeling induced master motion in force-reflecting teleoperation", ICRA, 2005.

P. Mitra and G. Niemeyer, "Model-mediated telemanipulation", IJRR, 2008.

N. A. Tanner and G. Niemeyer, „Improving perception in time-delayed telerobotics", IJRR, 2005.



14) COMPARING THE TRANSPARENCY OF THE HAPTIC PADDLE USING DIFFERENT INTERACTION CONTROLLERS

The most appropriate controller for human-robot interaction is the impedance controller. Impedance controllers are well suited for achieving a transparent behavior, especially in combination with force feedback in order to compensate for the device dynamics.
During the exercises, all groups implement and evaluate a simple impedance controller with friction feed-forward on the Haptic Paddle.
In this project, you will improve your feed-forward controller by using force sensor data and additionally implement an impedance controller with force feedback. You will compare the lower apparent impedance boundaries of different interaction controllers (e.g., uncontrolled, impedance control with friction feedforward, and impedance control with force feedback) by rendering transparency planes and by estimating the apparent inertia and damping felt by the user during human-robot interaction.

References:

- Metzger J.-C., Lambercy O., Gassert R., (2015) Performance Comparison of Interaction Control Strategies on a Hand Rehabilitation Robot. Proceedings of the IEEE International Conference on Rehabilitation Robotics (ICORR), Singapore, 846-51
- Tagliamonte NL., Scocia M., Formica D., Campolo D., Guglielmelli E. (2011) Effects of Impedance Reduction of a Robot for Wrist Rehabilitation on Human Motor Strategies in Healthy Subjects during Pointing Tasks, Advances in Robotics, 25:5, 537-562.