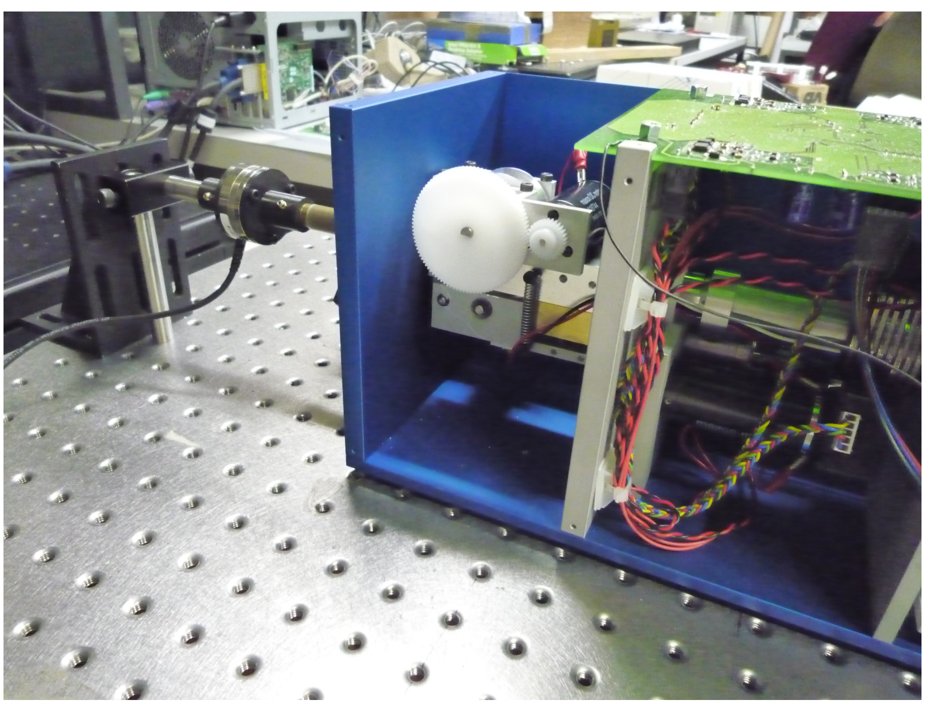
Haptics Symposium
March 4-7, 2012 | Vancouver, Canada

WORKSHOP ON

HAPTIC HARDWARE EVALUATION PRACTICES

SUNDAY, MARCH 4, 2012



HAPTIC HARDWARE EVALUATION PRACTICES

ABSTRACT: With the plethora of haptic devices that are commercially available today, the question often arises: what device is “good enough” for a given application? Since haptics technology is being increasingly used for different applications such as computer games, surgical simulators, mobile phones etc., there is a clear need to understand hardware evaluation practices and their implications on device design, use and application. This workshop aims at meeting this need by establishing standard practices for evaluation of haptic hardware and by identifying significant benchmark metrics.

MOTIVATION: The purpose of evaluation procedures for haptic interfaces is to achieve both qualitative and quantitative statements on haptic rendering realism and performance. While a haptic device may come with specifications for its mechanical and electrical properties, no clear relationship between these properties and application-specific performance is available from the commercial or academic literature. Therefore, bridging this gap by informing haptic device users and developers about common evaluation practices is crucial.

PRIMARY OBJECTIVES: The primary goal of our half-day workshop is to inform participants about the standard hardware evaluation practices and their implications on device design, use and application. This will allow haptic hardware users and developers to create a common language enabling them to communicate hardware needs and improvements. In addition, the workshop will help define a standard for device characterization. The expert speakers in the field will cover one or more topics listed below while presenting how this hardware evaluation informs haptic device users and developers. List of topics: Kinematics, actuation, sensing, impedance measurements, control (stability, transparency) and performance metrics.

TARGET AUDIENCE: Researchers, engineers, students and high-end users who would like to learn more about the standard evaluation procedures together with their implications and challenges.

ORGANIZER INFORMATION:

Dr. Evren Samur

Center for Bionic Medicine, Rehabilitation Institute of Chicago

e-samur@northwestern.edu

Dr. Curt Salisbury

Intelligent Systems Robotics and Cybernetics, Sandia National Laboratories

cmsalis@sandia.gov

SCHEDULE:

Haptic Hardware Evaluation Practices		
08:30 – 08:50	Evren Samur / Curt Salisbury	Welcome & Introduction
08:50 – 09:20	John Morrell	Performance Measurements for Robotic and Haptic Actuators
09:20 – 09:50	Antonio Frisoli	A comparative assessment of performance of active exoskeletons for haptic feedback: tendon driven vs harmonic drive based designs
09:50 – 10:20	Mike Zinn	Admittance-based Haptic Interface Performance Evaluation and Associated Challenges
10:20 – 10:40	Coffee Brake	
10:40 – 11:10	Curt Salisbury	Bridging the gap between design requirements and application performance: using human observers
11:10 – 11:40	Evren Samur	Guidelines for Haptic Interface Evaluation: Physical and Psychophysical Methods
11:10 – 12:00	ALL	Summary

PRESENTATIONS AND SPEAKERS

PERFORMANCE MEASUREMENTS FOR ROBOTIC AND HAPTIC ACTUATORS

Dr. John Morrell

Assistant Professor of Mechanical Engineering, Yale University

john.morrell@yale.edu

BIO: Professor Morrell comes to Yale from Segway Inc, creators of a two-wheeled, dynamically stabilized device called the Segway Human Transporter (HT). Dr. Morrell was the Director of Systems Engineering for Segway and for six years where he lead the development of many of core technologies for the Segway HT, including control architectures and algorithms and their implementation into production software. Prior to his work on the Segway HT, Dr. Morrell worked for Dean Kamen at Deka Research and Development as the lead control engineer on the IBOT, a mobility device that allows disabled people to climb stairs and stand at eye-level by using dynamic stablization technology.

ABSTRACT: This talk will discuss basic impedance principles for measuring the performance of actuator systems in both haptics and robotic applications. The nature of actuators and transmissions results in nonlinearities and limits on dynamic range that are difficult to eliminate without excessive cost. Furthermore, the performance of many haptic systems is hard to assess without directly using the device.   I will discuss several measurements that can be used to compare actuators of different designs, focusing on nonlinear effects such as saturation, hysteresis and friction.

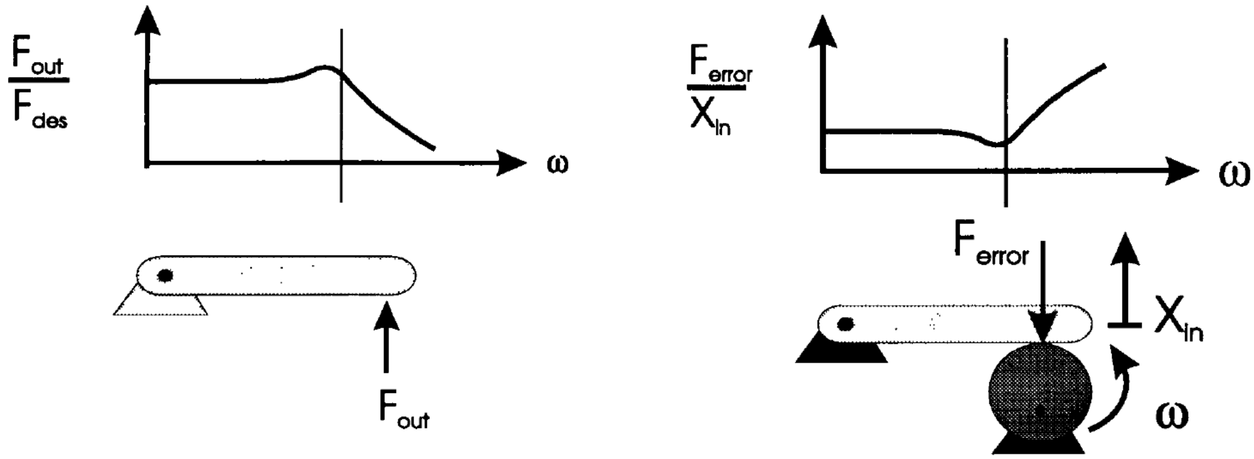


Figure 1 (Left) Force control response (Right) Impedance response [1,2].

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A COMPARATIVE ASSESSMENT OF PERFORMANCE OF ACTIVE EXOSKELETONS FOR HAPTIC FEEDBACK: TENDON DRIVEN VS HARMONIC DRIVE BASED DESIGNS

Dr. Antonio Frisoli

Head of Human-Robot Interaction Area , PERCRO Lab, Scuola Superiore Sant'Anna

a.frisoli@sssup.it

BIO: Antonio Frisoli is the head of the Human-Robot Interaction area in PERCRO laboratory of TeCIP of Scuola Superiore Sant'Anna. He holds a PhD (2002) with honors in Industrial and Information Engineering from Scuola Superiore Sant'Anna, Italy and a MSc (1998) in Mechanical Engineering, minor Robotics, from University of Pisa-Italy. He has been assistant professor in applied mechanics (2003-2009) at Scuola Superiore Sant'Anna, where in 2010 he was called as Associate Professor. His research interests are in the field on design and control of haptic devices and robotic systems, rehabilitation robotics and human motor control, virtual reality, advanced human computer interfaces for training. Currently he is studying new designs for exoskeletons systems, portable fingertip haptics and new brain-robot interfaces. He is author of more than 100 papers in peer-reviewed international conferences and scientific journals.

ABSTRACT: The rationale for the design of high performance haptic interface is the satisfaction of the requirements of high force fidelity, transparency and backdrivability. It is well known that two main basic approaches can be adopted in the design of haptic interfaces and more specifically of active exoskeletons: impedance based vs. admittance based designs [1].

In impedance displays these requirements are obtained by adopting actuation schemes that are intrinsically backdrivable by mechanics, employing direct drive actuation, transmissions with high efficiency and low friction, and reduction of moving masses. Cable driven transmissions represent a common solution that can allow both a remote placements of the actuation, with consequent reduction of moving masses, and at the same time high transparent transmission of forces.

On the other side, as a drawback, if we consider high powered design with large workspace, such in the case of active exoskeletons, tendon transmissions might involve complex mechanical design, and introduce some flexibility in the transmission, with consequent limitation in the dynamic bandwidth of the device in case of force closed-loop control. Such a force closed loop control might be required in order to cancel completely the effects of static friction that cannot be compensated by means of feedforward models in the control.

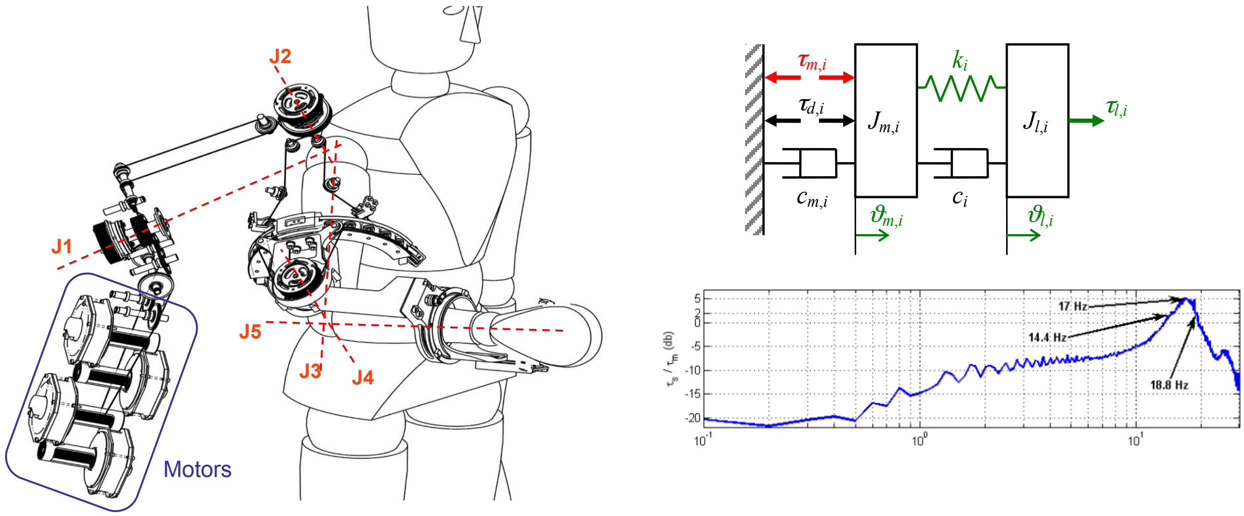

Figure 1 The tendon transmission of the L-Exos system (left) and an example of lumped model scheme for modeling its dynamic response (right) [2, 3]

An alternative approach is the impedance display design. When high forces are required, speed reducers with high transmission ratio are employed. Harmonic drives represent a class of speed reducers commonly adopted in robotics designs, because of their compact size and high reduction, e.g. 1:100 with a single reduction stage. On the other side, speed reducers might introduce mechanical play and other non-linearities, and limit the maximum speed of the device. The backdrivability of the system can then be achieved only by force closed-loop control, thanks also to the high stiffness of the transmission: this requires that the system is equipped with multiple force sensors that can be used to detect the intention of motion of the operator. The maximum performance is now given by the capability of the control of cancel the intrinsic dynamics of the system.

In this presentation we will report about the mechanical and control design issues of two exoskeletons, developed at PERCRO, with a comparative assessment of pros and contras in the tendon driven vs. harmonic drive based designs.

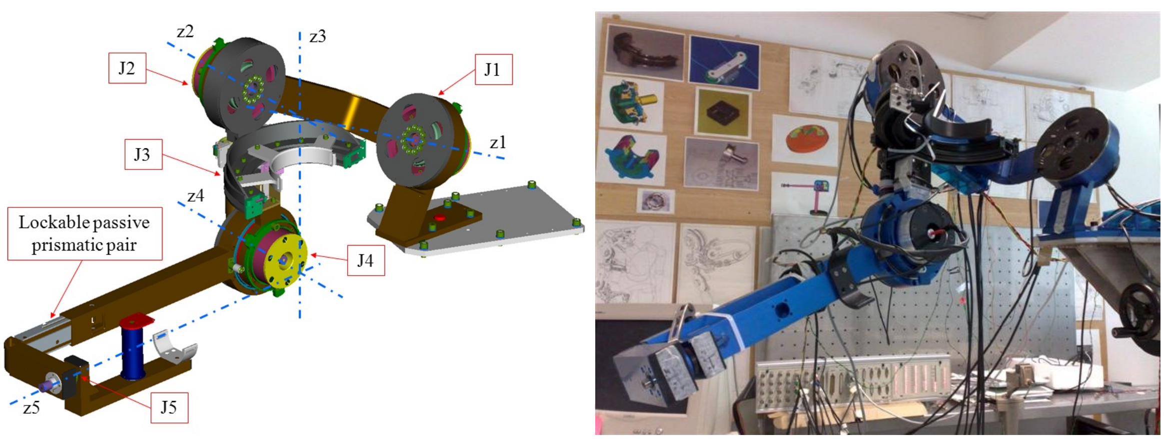

Figure 2 The Rehab-Exos design and prototype with torque sensorized joints and harmonic drives [4].

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ADMITTANCE-BASED HAPTIC INTERFACE PERFORMANCE EVALUATION AND ASSOCIATED CHALLENGES

Dr. Micheal R. Zinn

Assistant Professor, Department of Mechanical Engineering, University of Wisconsin-Madison

mzinn@wisc.edu

BIO: Mike Zinn joined the faculty at the University of Wisconsin - Madison in 2007. His research interests are broadly directed at understanding the design and control challenges of human-centered robotics and developing effective strategies to overcome these challenges. Currently, his research is focused on improving the performance, safety, and efficacy of medical robotic systems including the investigation of advanced control, sensing, and visualization methods for flexible robotic interventional catheters, MRI-compatible interventional systems, and active implantable limb deformity correction approaches, to name a few. In addition, he has worked extensively on the design and control of human-centered robotics, with recent efforts directed toward the development of a large-workspace haptic device. Prior to joining the UW-Madison faculty, he was Director of Systems and Controls Engineering at Hansen Medical where he helped develop the world's first commercially available minimally invasive flexible surgical robotic system. His work at Hansen Medical included the development of the tele-robotic control architecture, user input haptic system design, overall system control architecture, and the development of an in-vivo force sensing system. In addition to his experience at Hansen Medical, he has over 10 years of electro-mechanical system design and control experience. He has a BS and MS from MIT and a Ph.D. in Mechanical Engineering from Stanford University.

ABSTRACT: Haptics devices can be partitioned into two general categories of (1) impedance-based and (2) admittance-based devices. Impedance-based devices generally employ low-friction, light-weight mechanisms and do not require explicit measurement or control of rendered forces. By design, these devices have low uncompensated output impedance – commonly known as transparency. As opposed to impedance-based devices, admittance-based devices generally require measurement and control of rendered forces, and commonly have large uncompensated output impedance, often resulting in a completely non-backdrivable design.

The presentation will provide a comparison of admittance and impedance-based haptics devices and the challenges associated with the evaluation of each type of design. The

differences between the two device types are due primarily to limitations in device and actuation characteristics, specifically in regards to the limited torque and power density of electromagnetic actuation. These differences have significant impact on device characteristics that limit rendering performance. These factors will be discussed along with various control and sensing strategies to overcome inherent device limitations. In addition, the application of commonly used performance metrics and associated challenges in applying them across the device types will be discussed as well as the significant challenges encountered in evaluating the performance of haptic device hardware and, specifically, the difficulties that the admittance-based approach pose in regards to hardware evaluation.

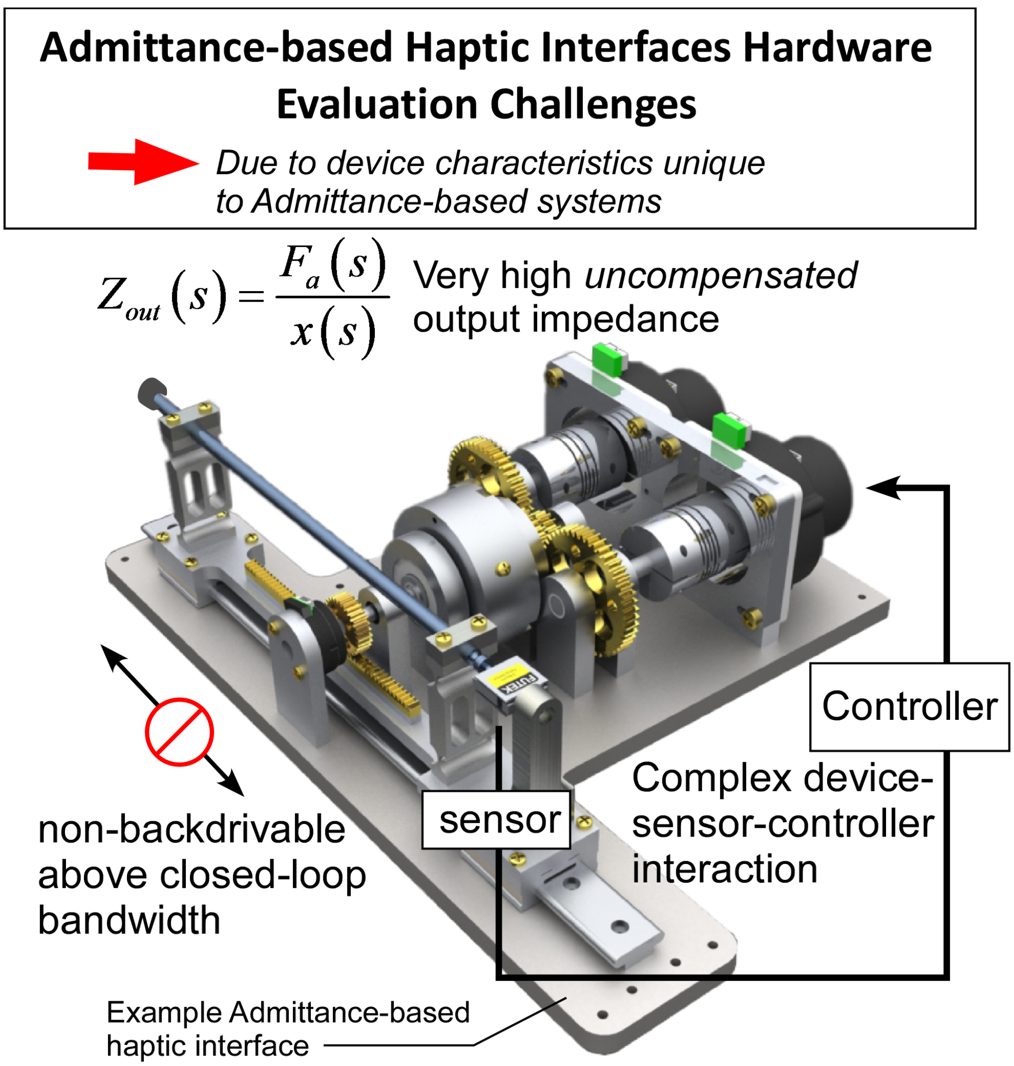

Figure 1 An admittance-based haptic interface.

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BRIDGING THE GAP BETWEEN DESIGN REQUIREMENTS AND APPLICATION PERFORMANCE: USING HUMAN OBSERVERS

Dr. Curt Salisbury

Intelligent Systems Robotics and Cybernetics, Sandia National Laboratories

cmsalis@sandia.gov

BIO: Curt Salisbury holds a PhD in mechanical engineering from Stanford University. Dr. Salisbury has experience developing novel subsystem robotic hardware technologies for complex robotic devices and integrating these technologies into functional systems. These include high-performance haptic devices, low-cost and intrinsically safe robot arms and hands, and autonomous mobile platforms. He has also served as Principle Investigator on a number of robotics programs, including DARPA's ARM-H program.

ABSTRACT: As haptic device designers, we observe that there are very few quantitative guidelines available for us to target during the design process. In the absence of these guidelines, we found ourselves sacrificing hardware cost and complexity to minimize inertia and acceleration resolution while maximizing peak acceleration and position resolution. This observation led us to explore how hardware design impacts the utility of a haptic device, with the goal of making a useful haptic device more affordable by better optimizing cost and performance.

In general, we propose to use human observers performing real tasks, or abstracted tasks relevant to real tasks, to understand the relationship between hardware design decisions and the utility of the hardware product. We will present an experiment in which we used human observers to characterize the smallest distinguishable signal generated by different haptic devices. The goal was to characterize the noise floor of the haptic device, and determine if the noise floor could be detected by the human. Our assertion is that haptic hardware is "good enough" in one metric if the noise floor is low enough that a human cannot detect it.

We also showed in this experiment which hardware design parameters were the cause of a detectable noise floor. Furthermore, we present a method for predicting whether or not a design will have a detectable noise floor. These methods provide a hardware designer with quantitative design guidelines and help prevent the overdesign of haptic devices.

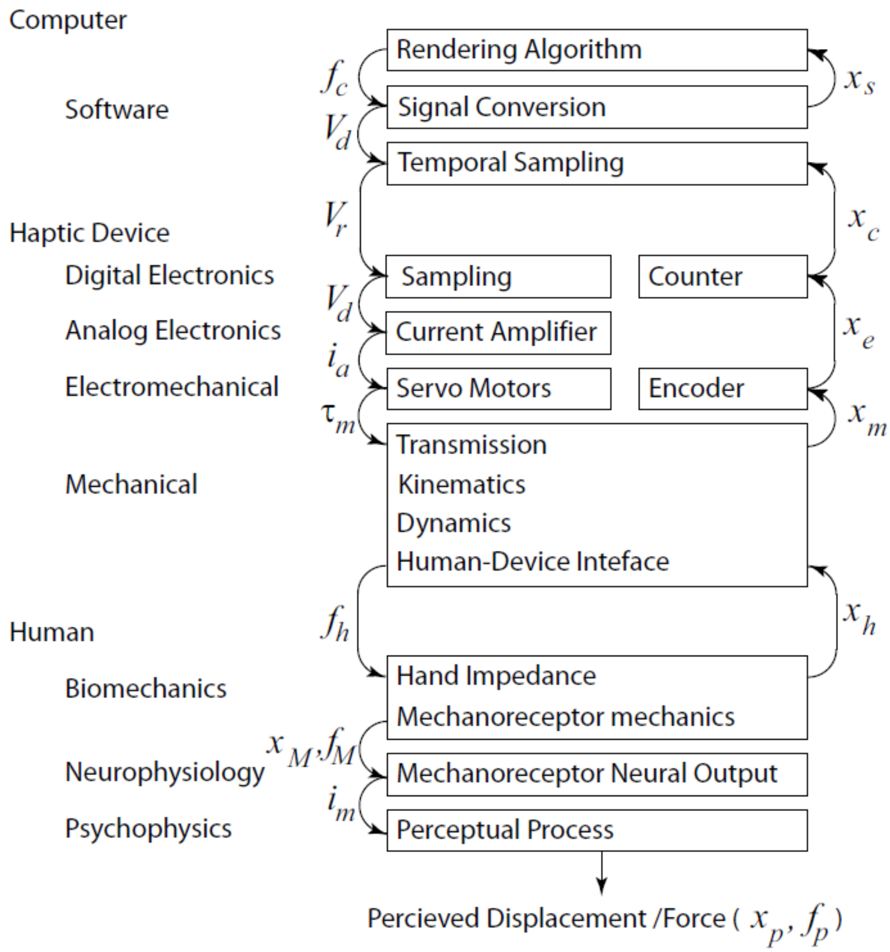

Figure 1 Block diagram of signal flow from computer through haptic device to human and back [2].

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GUIDELINES FOR HAPTIC INTERFACE EVALUATION: PHYSICAL AND PSYCHOPHYSICAL METHODS

Dr. Evren Samur

Center for Bionic Medicine, Rehabilitation Institute of Chicago

e-samur@northwestern.edu

BIO: Evren Samur is currently a postdoctoral fellow at the Rehabilitation Institute of Chicago (RIC) which is an academic affiliate of Northwestern University Medical School. His primary research focus at RIC is sensory feedback for improved prosthesis control. In 2010, he received his PhD degree in robotics from Swiss Federal Institute of Technology (EPFL) Lausanne where he specialized on haptic interface development and evaluation. The EuroHaptics Society awarded his PhD thesis as the Best PhD thesis in 2010. He was a visiting scholar at the Northwestern University in fall 2008 and worked on a new tactile display under supervision of Prof. Ed Colgate. He holds an MS degree in mechanical engineering from Koc University, Istanbul where he worked with Prof. Cagatay Basdogan on soft tissue modeling and characterization. He received his BS degree in mechanical engineering from Middle East Technical University (METU), Ankara. His research interests include medical robotics, surgical simulation, haptics and human-machine interaction.

ABSTRACT: The discussion about experimental performance evaluation for haptic interfaces goes back to 80s when force-reflecting hand controllers (today's haptic interfaces) were used in teleoperation. The design requirements for teleoperation were described by Brooks [4] and used by many researchers. Hayward and Astley [5] theoretically defined performance measures directed towards isotonic (i.e. impedance type) devices. More or less at the same time, these measures were formalized for coupled micro-macro actuators by Morrell and Salisbury [6]. In addition, practical ways to measure them were experimentally demonstrated on a haptic interface by Ellis et al. [7]. Several projects [8-11] evaluated particular haptic devices based on these technical performance metrics. An experimental identification method was described by Frisoli and Bergamasco [12]. Similarly, the dynamics of PHANToM Premium 1.5A (SensAble Technologies Inc.) were experimentally identified by [13,14]. Ueberle [15] conducted hardware experiments for the comparative performance evaluation of haptic control schemes using the VISHARD interface. Although a set of performance metrics for haptic interfaces has been

defined in literature, there is no consensus on measurement methods which vary considerably between studies.

In addition to physical evaluation, psychophysical evaluation is necessary in order to find sensory thresholds associated with a haptic interface and also to evaluate how well this interface supports haptic interaction modes (see Figure 2). In literature, there are few psychophysical tests that have been used to measure the performance of a haptic interface. Peg-in-hole [16-18], tapping [19-21], targeting [22], object recognition [23-27] and virtual walls [28] tests are the most frequently performed experiments. In all these studies, it has been demonstrated that different haptic interfaces have different performance characteristics in rendering haptics.

In this talk, I will review common evaluation methods for haptic interfaces. Both physical and psychophysical experimental practices will be covered. First, I will describe the physical performance measures (see Table 1) and device characterization in detail. Second, human psychophysical experiments that are applicable to haptic interfaces will be reviewed. Performance metrics will be summarized. This will allow users not only to reutilize the same methods to evaluate haptic interfaces and compare different haptic devices quantitatively, but also to better understand how the limitations of such devices may influence the user experiences with virtual environments.

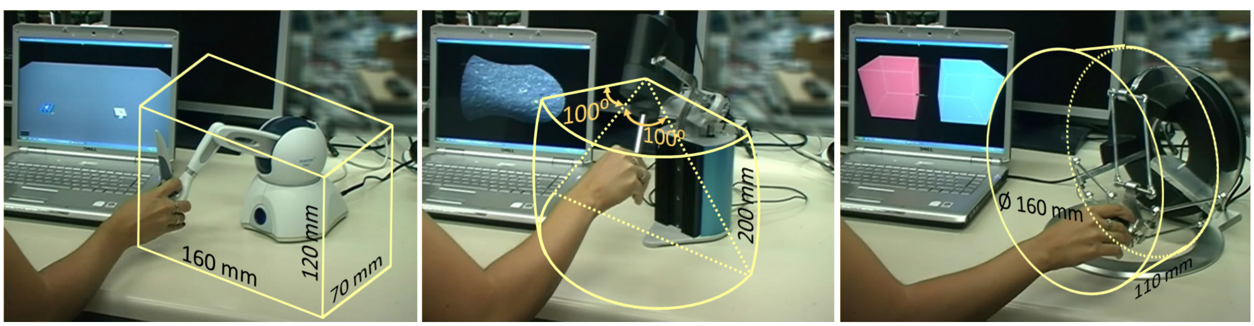

Figure 1 Workspace comparison of different haptic interfaces [1].

Table 1 Physical Performance Metrics [1].

System	Type		Metric
Unpowered	Kinematics	Workspace	Reachable Dexterous
		DOF	Passive Active
		Structure	Serial Parallel Hybrid
		Dexterity	Manipulability Condition number Global conditioning index
	Elastostatics		Structural stiffness
	Dynamics		Structural dynamics Generalized inertia ellipsoid Acceleration radius
Powered	Actuation	Static	Peak force Continuous force Minimum force Hysteresis Sensitivity Output force resolution D/A resolution Dynamic range
		Frequency Response	Force bandwidth Useful frequency range Amplifier bandwidth Output impedance Force fidelity
		Step Response	Rise time Settling time Overshoot Output force accuracy Force precision
		Impulse Response	Peak speed Peak acceleration Structural deformation ratio
	Sensing	Static	Sensitivity Hysteresis Position resolution Dynamic range Position measurement accuracy Precision
		Frequency Response	Sensor bandwidth
Controlled	Impedance Range		Min impedance Max impedance Z-width
	Control Bandwidth		Impedance control bandwidth

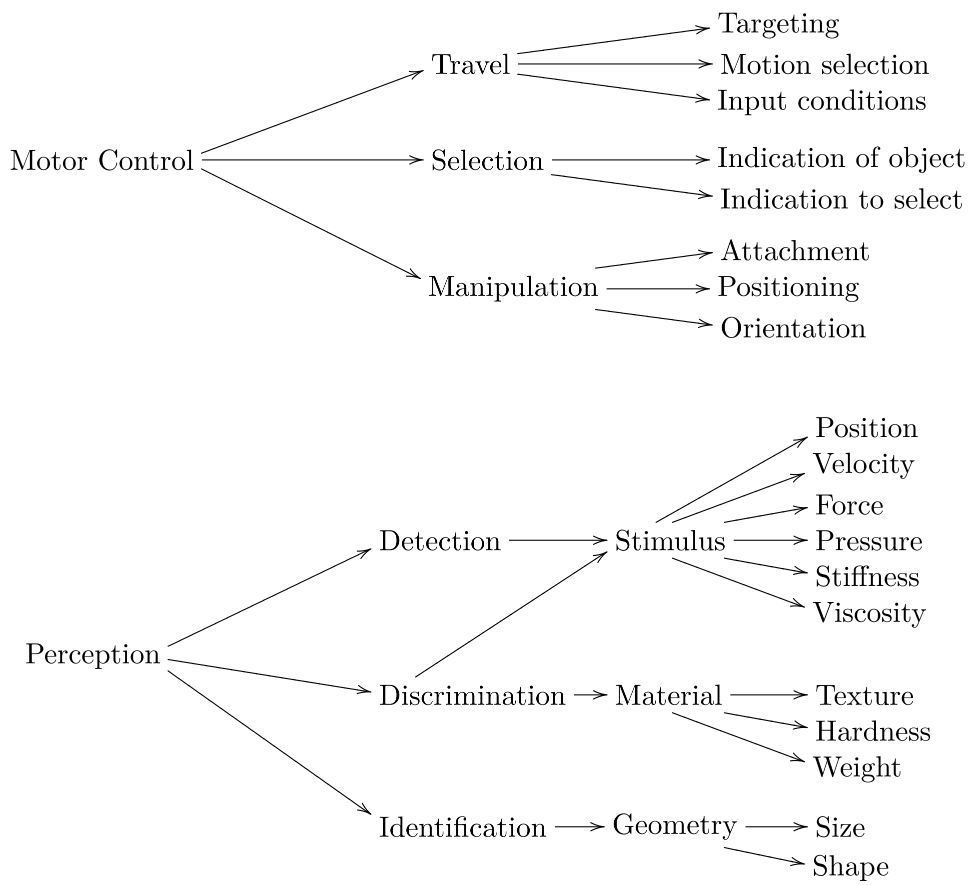

Figure 2 Taxonomy of haptic modes [3].

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