Performance Metrics for Haptic Interfaces

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To the women of my life:
Annem, Ablam, Elif and Ceren

Series Editors' Foreword

This is the fifth volume of the "Springer Series on Touch and Haptic Systems", which is published in collaboration between **Springer** and the **EuroHaptics Society**. *Performance Metrics for Haptic Interfaces* is focused on evaluating the performance of haptic devices by physical and psychophysical metrics. This work represents a significant step forward in haptic interface standardization, which helps the broader dissemination of human interaction devices that include haptic feedback.

The double approach presented in this volume is consistent with the nature of haptic devices: on the one hand, these devices are defined in terms of engineering features such as controllers, actuators, sensors, etc. On the other hand, haptic devices are designed to directly interact with users. Therefore, the human interaction capability will determine the suitable performance measure for such devices.

The basis for this volume is the PhD thesis of Evren Samur who was the winner of the 2011 EuroHaptics Society PhD award. It was selected from a pool of many other excellent works on haptics research. This monograph is an excellent example of the state of the art in the use of engineering and psychophysics for the development of haptics, and as such is an important starting point for future advances in this field.

Manuel Ferre
Marc Ernst
Alan Wing

Preface

The purpose of evaluation procedures for haptic interfaces is to achieve both qualitative and quantitative statements on haptic rendering realism and performance. Since haptic technology is being increasingly used in computer games, surgical simulators, mobile phones etc., there is a need for defining standards for haptic applications. This book aims at meeting this need by establishing standard practices for the evaluation of haptic interfaces and by identifying significant benchmark metrics.

Towards this end, a combined physical and psychophysical experimental methodology is given in this book. First, the existing physical performance measures and device characterization techniques were investigated and described in an illustrative way. The physical characterization methods were demonstrated on a two degrees-of-freedom haptic interface. Second, a wide range of human psychophysical experiments were reviewed and the appropriate ones were applied to haptic interactions. The psychophysical experiments were unified as a systematic and complete evaluation method for haptic interfaces. Seven psychophysical tests were derived and implemented for three commercial force-feedback devices. Experimental user studies were carried out and applicability of the tests to a tactile feedback device was investigated. Finally, synthesis of both evaluation methods is also discussed.

The generic methodology provided in this book enables readers to evaluate the suitability of a haptic interface for a specific purpose, to characterize and compare devices quantitatively and to identify possible improvement strategies in the design of the system.

Chicago, USA — Evren Samur

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Contents

List of Acronyms, Symbols, Greek Letters

Acronyms

Abs.	Absolute
Amp	Amplifier
ANOVA	Analysis of Variance
Co-Me	Computer Aided and Image Guided Medical Interventions
CPT	Counts Per Turn
CSIRO	Australia's Commonwealth Scientific and Industrial Research Organisation
D/A	Digital to Analog
DC	Direct Current
DOF	Degree(s) of Freedom
DL	Difference Limen (Difference or Differential Threshold)
EPFL	Ecole Polytechnique Fédérale de Lausanne
EPs	Exploratory Procedures
Eq.	Equation
Enc	Encoder
Fig.	Figure
fMRI	functional Magnetic Resonance Imaging
FFT	Fast Fourier Transform
GCI	Global Conditioning Index
GIE	Generalized Inertia Ellipsoid
JND	Just-Noticeable-Difference
HD	High Definition
ID	Index of Difficulty
IP	Index of Performance
IR	Infrared
IT	Information Transfer
I/O	Input Output
ISO	International Organization for Standardization
LDV	Laser Doppler Vibrometer
LFFs	Lateral Force Fields

LSRO	Laboratoire de Systèmes Robotiques
MT	Movement Time
n/a	not applicable/not available
NCCR	National Centre of Competence in Research
PC	Personal Computer
RL	Reiz Limen (Absolute Threshold)
RMS	Root Mean Square
SDR	Structural Deformation Ratio
TPaD	Tactile Pattern Display
USB	Universal Serial Bus
var	Variance
VE	Virtual Environment

Symbols

a	Intercept
A	Distance of Movement
b	Reciprocal of IP
B	Damping
c	Constant
d_i	Damping
dW	Workspace Derivative
D	Diameter
$F(\omega)$	Force
F_a^n	Discrete Input Force
F_c	Control Effort
F_d	Desired Force
F_d^n	Discrete Desired Force
F_{ee}	Force at the End Effector
F_h	Voluntary Human Muscle Force
$\boldsymbol{G}$	Generalized Inertia Ellipsoid Matrix
H	Size of Hole
H_f	Transfer Function between Output and Input Force
H_v	Transfer Function between Output and Input Velocity
i	Input Current
I	Reference Stimulus
$\boldsymbol{J}$	Jacobian Matrix
k	Stimulus Categories
k_i	Stiffness
K	Virtual Stiffness/Spring
M	Mass
$\boldsymbol{M}$	Mass Matrix
M_i	Mass/Inertia
n	Discrete Parameter Indicator/Total Number of Trials
$n_{i,j}$	Number of Joint Event
p	Probability
P	Size of Peg

q	Pose
$n_{i,j}$	Encoder Count
$\dot{q}$	Joint Rates
$\dot{q}_d^n$	Discrete Joint Rates
R	Sampled Output Sine
R_j	Number of Responses
s	Laplace Transform Variable
S	Shape Index
S_{cor}	Step Size for Correct Answer
S_i	Number of Stimuli
S_{incor}	Step Size for Incorrect Answer
S_{unsure}	Step Size for Unsure Answer
T_r	Rise Time
$v(\omega)$	Velocity
v_{ee}	Velocity of the End Effector
v_{ee}^n	Discrete Velocity of the End Effector
v_e^n	Discrete Velocity of Virtual Environment
V	Voltage
V_{in}	Voltage to Amplifier
W	Width of Target/Precision
y	True Sine
Y_d	Admittance of Device
Y_f	Modified Admittance of Device
$Z(\omega)$	Mechanical Impedance
Z_c^n	Impedance of Virtual Coupling
Z_d	Impedance of Device
Z_d^n	Discrete Model of a Device Impedance
Z_e^n	Impedance of Virtual Environment
Z_h	Impedance of Human Hand and Arm
Z_i	An Impedance
Z_E^n	Total Impedance of Virtual Environment and Virtual Coupling
Z_t	Total Impedance of Human Hand and Device

Greek Letters

ΔI	Differential Threshold
$\Delta I/I$	Weber Fraction
ΔV	Step Voltage
η	Global Conditioning Index
κ_2	Condition Number
μ	Manipulability Index/Coefficient of Friction
μ_i	Friction
ρ	Encoder Pulse
σ_m	Smallest Singular Value of Jacobian
σ_M	Largest Singular Value of Jacobian
τ_a^n	Discrete Input Joint Torque

τ_i^n	Discrete Input to D/A
τ_m	Joint Torque
ω_b	(Operating) Bandwidth