

## Table of Contents

EXECUTIVE SUMMARY .....	ES-1
1. INTRODUCTION .....	1
1.1 Purpose .....	2
1.2 Scope .....	3
1.3 Limitations .....	3
1.3.1 Organization .....	4
2. VISUAL INTERFACES .....	5
2.1 The Human Visual System .....	6
2.2 Commercial Products .....	10
2.2.1 Datavisor Displays .....	12
2.2.2 FS5 Head-Mounted Display .....	13
2.2.3 CyberEye 100M and 100S .....	13
2.2.4 CyberMaxx CM1800 .....	14
2.2.5 Dvisor Head-Mounted Display .....	14
2.2.6 i-glasses! .....	15
2.2.7 MRG Head-Mounted Displays .....	15
2.2.8 VIM Personal Viewer .....	16
2.2.9 VFX1 Head-Mounted Display System .....	17
2.2.10 VR4 Head-Mounted Display .....	18
2.2.11 VRI HMD 133 .....	18
2.2.12 CrystalEyes Shutter Glasses .....	19
2.2.13 VR-1100 and VR-2000 Stereoscopic Projection Systems .....	20
2.2.14 BOOM 3C .....	21
2.2.15 Cyberface 4 .....	22
2.2.16 Fakespace Simulation System .....	23
2.2.17 PUSH .....	23
2.2.18 Virtual Window .....	24
2.3 Current Research and Development .....	24
2.3.1 ATR Communications System Research Laboratories, Japan .....	25
2.3.2 British Aerospace plc, United Kingdom .....	27
2.3.3 BT Laboratories, United Kingdom .....	29

2.3.4 Canon, Inc., Japan .....	30
2.3.5 Dimension Technologies, Inc. ....	31
2.3.6 Dimensional Media Associates .....	33
2.3.7 IBM Thomas J. Watson Research Center and Georgia Institute of Technology .....	33
2.3.8 Infinity Multimedia .....	34
2.3.9 NASA Ames Research Center .....	35
2.3.10 Purdue University .....	36
2.3.11 Terumo Corporation, Japan .....	37
2.3.12 University of Illinois at Chicago .....	38
2.3.13 University of New Brunswick, Canada .....	39
2.3.14 University of Washington .....	40
2.3.15 Xenotech, Australia .....	41
2.4 Summary and Expectations .....	43
 3. TRACKING INTERFACES .....	47
3.1 Head Tracking .....	48
3.1.1 Commercially Available Trackers .....	53
3.1.1.1 ADL-1 .....	53
3.1.1.2 Vidtronics Wrightrac .....	54
3.1.1.3 Fastrak .....	54
3.1.1.4 Isotrak II .....	54
3.1.1.5 Insidetrak .....	54
3.1.1.6 Ultratrak .....	55
3.1.1.7 Flock of Birds .....	55
3.1.1.8 PC/BIRD .....	56
3.1.1.9 SpacePad .....	56
3.1.1.10 CyberTrack 3.2 .....	57
3.1.1.11 Wayfinder-VR .....	57
3.1.1.12 Mouse-Sense3D .....	57
3.1.1.13 Selcom AB, SELSPOT II .....	57
3.1.1.14 OPTOTRAK 3020 .....	58
3.1.1.15 MacReflex Motion Measurement System .....	58
3.1.1.16 DynaSight .....	59
3.1.1.17 BioVision .....	59
3.1.1.18 Mandala Virtual Reality Systems .....	60
3.1.1.19 REALWare .....	60
3.1.1.20 RK-447 Multiple Target Tracking System .....	61
3.1.1.21 Head/Hand XYZ Tracker .....	61
3.1.1.22 GP12-3D (Freepoint 3D) .....	62
3.1.1.23 Logitech 3D Mouse and Head Tracker .....	62
3.1.1.24 MotionPak .....	62
3.1.1.25 GyroPoint Pro .....	63
3.1.2 Current R&D in Head Tracking .....	63

3.1.2.1	NASA Ames Research Center .....	63
3.1.2.2	Massachusetts Institute of Technology (MIT), Research Laboratory of Electronics .....	64
3.1.2.3	Computer Graphics Systems Development (CGSD) Corporation ..	64
3.1.2.4	University of North Carolina .....	65
3.1.2.5	Artificial Reality .....	66
3.1.2.6	Massachusetts Institute of Technology, Media Lab .....	67
3.1.2.7	Sony, Computer Science Laboratory .....	67
3.1.2.8	Siemens' Central Research and Development .....	68
3.1.2.9	Boeing Information and Support Services, CMU, Honeywell, Inc., and Virtual Vision, Inc. ....	68
3.1.2.10	University of Washington .....	70
3.2	Eye Tracking .....	70
3.2.1	Commercially Available Eye Trackers .....	70
3.2.1.1	BioMuse .....	70
3.2.1.2	Headhunter Head and Eye Tracking System .....	72
3.2.1.3	Eyegaze System .....	72
3.2.1.4	Dual-Purkinje-Image (DPI) Eyetracker .....	73
3.2.2	Current R&D in Eye Tracking .....	73
3.2.2.1	Hughes Training-Link Corporation .....	74
3.2.2.2	Interactive Systems Laboratories (INTERACT) .....	74
3.2.2.3	State University of New York .....	75
3.2.3	Summary and Expectations .....	76
4.	AUDITORY INTERFACES .....	79
4.1	The Human Auditory System .....	80
4.2	Commercially Available 3-D Audio Products .....	85
4.2.1	Acoustetron II .....	85
4.2.2	Protron .....	88
4.2.3	Q Products .....	88
4.2.4	RSS-10 Sound Space Processor .....	89
4.2.5	SDX-330 Dimensional Expander .....	90
4.2.6	SRV-330 Dimensional Space Reverb and SDE-330 Dimensional Space Delay .....	91
4.2.7	SoundStorm 3D .....	93
4.2.8	Virtual Audio Processing System .....	93
4.3	Current Research and Development .....	94
4.3.1	NASA Ames .....	94
4.3.2	Naval Postgraduate School .....	95
4.4	Summary and Expectations .....	95
5.	PRIMARY USER INPUT INTERFACES .....	97
5.1	Whole-Hand and Body Inputs .....	97

5.1.1	The Human Hand and Arm Position Sense .....	98
5.1.2	Commercially Available Devices .....	99
5.1.2.1	5th Glove .....	99
5.1.2.2	CyberGlove .....	101
5.1.2.3	Dextrous HandMaster .....	102
5.1.2.4	Pinch Glove .....	103
5.1.2.5	Position Exoskeleton ArmMaster .....	103
5.1.2.6	TCAS DATAWEAR .....	104
5.1.3	Current Research and Development .....	105
5.1.3.1	Armstrong Laboratory .....	105
5.1.3.2	Georgia Institute of Technology .....	106
5.2	3-D Pointing Input .....	107
5.2.1	Commercially Available Devices .....	107
5.2.1.1	CyberWand .....	107
5.2.1.2	Immersion PROBE-MD .....	108
5.2.1.3	Magellan 3D Controller and Space Controller .....	109
5.2.1.4	RingMouse .....	109
5.2.1.5	Spaceball 2003 and Space Controller .....	110
5.2.2	Current R&D .....	111
5.2.2.1	Digital Image Design Inc. .....	111
5.2.2.2	University of Toronto .....	112
5.3	Summary and Expectations .....	114
6.	HAPTIC INTERFACES .....	117
6.1	Tactile Interfaces .....	117
6.1.1	The Human Tactile Sense .....	120
6.1.2	Commercially Available Interface Devices .....	123
6.1.2.1	CyberTouch .....	125
6.1.2.2	TouchMaster .....	125
6.1.2.3	Tactool System .....	127
6.1.2.4	Displaced Temperature Sensing System .....	127
6.1.3	Current Research and Development .....	128
6.1.3.1	Armstrong Laboratory .....	129
6.1.3.2	Begej Corporation .....	130
6.1.3.3	Harvard University .....	130
6.1.3.4	Hokkaido University, Japan .....	133
6.1.3.5	Hull University, UK .....	134
6.1.3.6	Massachusetts Institute of Technology .....	134
6.1.3.7	Research Center at Karlsruhe, Germany .....	135
6.1.3.8	Sandia National Laboratories .....	136
6.1.3.9	TiNi Alloy Company .....	137
6.1.3.10	University of Salford, UK .....	138
6.2	Kinesthetic Interfaces .....	139
6.2.1	The Human Kinesthetic Sense .....	140

6.2.2 Commercially Available Devices .....	144
6.2.2.1 4 DOF Force Feedback Master (Surgical Simulator) .....	144
6.2.2.2 Force Exoskeleton ArmMaster .....	144
6.2.2.3 Impulse Engine Family .....	147
6.2.2.4 Interactor and Interactor Cushion .....	148
6.2.2.5 HapticMaster .....	148
6.2.2.6 Hand Exoskeleton Haptic Display .....	149
6.2.2.7 PER-Force 3DOF .....	150
6.2.2.8 PER-Force Handcontroller and Finger Forcer Option .....	151
6.2.2.9 PHANToM .....	153
6.2.2.10 SAFiRE .....	154
6.2.3 Current R&D .....	154
6.2.3.1 Boeing Computer Services .....	155
6.2.3.2 Computer Graphics Systems Development Corporation .....	156
6.2.3.3 Hokkaido University, Japan .....	157
6.2.3.4 Massachusetts Institute of Technology, Artificial Intelligence Laboratory .....	158
6.2.3.5 Massachusetts Institute of Technology, Department of Mechanical Engineering .....	159
6.2.3.6 McGill University, Canada .....	161
6.2.3.7 Ministry of International Trade and Industry, Agency of Industrial Science and Technology (MITI/AIST), Japan .....	163
6.2.3.8 Northwestern University .....	164
6.2.3.9 Rutgers University .....	166
6.2.3.10 Suzuki Motor Corporation .....	168
6.2.3.11 Tokyo Institute of Technology, Japan .....	170
6.2.3.12 University of North Carolina .....	172
6.2.3.13 University of Tsukuba, Japan .....	174
6.2.3.14 University of Washington .....	175
6.3 Summary and Expectations .....	176
7. FULL BODY MOTION INTERFACES .....	181
7.1 The Human Motion Sense .....	182
7.2 Self-Motion Interfaces .....	186
7.2.1 Commercial Products .....	186
7.2.1.1 Aerotrim .....	188
7.2.1.2 CyberPak .....	188
7.2.1.3 CyberTron .....	189
7.2.1.4 DreamGlider .....	189
7.2.1.5 Orbotron, X-otron VR, and Supertron .....	190
7.2.1.6 PemRAM Motion Bases .....	191
7.2.1.7 SimuPod .....	193
7.2.1.8 SimuSled .....	193
7.2.2 Current Research and Development .....	194

7.2.2.1	Computer Graphics Systems Development Corporation .....	194
7.2.2.2	Cybernet Systems Corporation .....	195
7.2.2.3	Institute for Simulation and Training .....	195
7.2.2.4	Sarcos Research Corporation .....	196
7.2.2.5	Systran Corporation .....	197
7.2.2.6	University College London, UK .....	198
7.2.2.7	University of Tsukuba, Japan .....	199
7.3	Passive Motion Interfaces .....	201
7.3.1	Commercial Products .....	201
7.3.1.1	Cyber Air Base .....	201
7.3.1.2	Cyberchair .....	203
7.3.1.3	CyberMotion Interactive Motion Seat .....	203
7.3.1.4	IntelliSeat .....	204
7.3.1.5	SIM245 .....	205
7.3.2	Current Research and Development .....	205
7.3.2.1	Denne Developments Limited .....	205
7.3.2.2	Flogiston Corporation .....	205
7.4	Summary and Expectations .....	206
8.	OLFACTORY INTERFACES .....	209
8.1	The Human Olfactory Sense .....	212
8.2	Commercial Products .....	213
8.2.1	BOC Group Olfactory Delivery System .....	213
8.2.2	Smell-Enhanced Experience System .....	213
8.3	Current Research and Development in Olfactory Interfaces .....	214
8.3.1	Artificial Reality Corporation .....	214
8.3.2	Marketing Aromatics, Ltd. .....	215
8.4	Summary and Expectations .....	216
9.	CONCLUSIONS .....	217
	REFERENCES .....	233
	LIST OF ACRONYMS AND ABBREVIATIONS .....	235
	APPENDIX A. POINTS OF CONTACT .....	239