### Human–Robot Interaction

#### An Introduction

Christoph Bartneck, Tony Belpaeme, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, Selma Šabanović

© copyright by Christoph Bartneck, Tony Belpaeime, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Sabanovic 2019. https://www.human-robot-interaction.org

# Contents

List of illustrations		viii
List of tables		
1	Introduction	1
1.1	About this book	1
1.2	Christoph Bartneck	2
1.3	Tony Belpaeme	3
1.4	Friederike Eyssel	4
1.5	Takayuki Kanda	4
1.6	Merel Keijsers	4
1.7	Selma Šabanović	4
2	What Is Human–Robot Interaction?	6
2.1	The focus of this book	9
2.2	HRI as an interdisciplinary endeavor	9
2.3	The evolution of HRI	11
		10
3	How a Robot Works	18
3.1	The making of a robot	19
3.2	Robot hardware	20
3.3	Sensors	22
	3.3.1 Vision	22
	3.3.2 Audio	25
	3.3.3 Tactile sensors	27
	3.3.4 Other sensors	27
3.4	Actuators	28
	3.4.1 Motors	28
	3.4.2 Pneumatic actuators	30
	3.4.3 Speakers	31
3.5	Software	31
	3.5.1 Software architecture	31
	3.5.2 Software-implementation platform	33
	3.5.3 Machine learning	34
	3.5.4 Computer vision	36
3.6	5 Limitations of robotics for HRI	
3.7	Conclusion	39
		iii

This material has been published by Cambridge University Press as Human Robot Interaction by

Christoph Bartneck, Tony Belpaeime, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Sabanovic.

ISBN: 9781108735407 (http://www.cambridge.org/9781108735407).

iv		Contents
4 De	esign	41
4.1 Des	sign in HRI	43
4.1.	.1 Robot morphology and form	43
4.1.	.2 Affordances	44
4.1.	.3 Design patterns	45
4.1.	.4 Design principles in HRI	46
4.2 An	thropomorphization in HRI Design	47
4.2.	.1 Anthropomorphization and robots	49
4.2.	.2 Theorizing anthropomorphism	51
4.2.	.3 Designing anthropomorphism	53
4.2.	.4 Measuring anthropomorphization	56
4.3 Des	sign methods	56
4.3.	.1 Engineering design process	57
4.3.	.2 User-centered design process	58
4.3.	.3 Participatory design	60
4.4 Pro	ototyping tools	61
4.5 Cu	lture in HRI design	63
4.6 Fro	om machines to people, and the in between	64
4.7 Co	nclusion	66
5 Sp	atial Interaction	69
5.1 Use	e of space in human interaction	70
5.1.	.1 Proxemics	70
5.1.	.2 Group spatial interaction dynamics	72
5.2 Spa	atial interaction for robots	73
5.2.	.1 Localization and navigation	73
5.2.	.2 Socially appropriate positioning	74
5.2.	.3 Spatial dynamics of initiating HRI	76
5.2.	.4 Informing users of the robot's intent	78
5.3 Co	nclusion	78
6 No	onverbal Interaction	81
6.1 Fur	nctions of nonverbal cues in interaction	82
6.2 Ty	pes of nonverbal interaction	84
6.2.	.1 Gaze and eye movement	84
6.2.	.2 Gesture	86
6.2.	.3 Mimicry and Imitation	87
6.2.	.4 Touch	89
6.2.	.5 Posture and movement	90
6.2.	.6 Interaction rhythm and timing	92
6.3 Not	nverbal interaction in robots	93
6.3.	.1 Robot perception of nonverbal cues	93
6.3.	.2 Generating nonverbal cues in robots	94
6.4 Co	nclusion	96
7 Ve	rbal Interaction	98
7.1 Hu	man–human verbal interaction	98
7.1.	.1 Components of speech	99
7.1.	.2 Written text versus spoken language	100

Christoph Bartneck, Tony Belpaeime, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Sabanovic.

ISBN: 9781108735407 (http://www.cambridge.org/9781108735407). This pre-publication version is free to view and download for personal use only. Not for re-distribution, re-sale or use in derivative works.

<i>Contents</i> v			
7.2	Speech recognition	101	
	7.2.1 Basic principles of speech recognition	101	
	7.2.2 Limitations	103	
	7.2.3 Practice in HRI	103	
	7.2.4 Voice-activity detection	104	
	7.2.5 Language understanding in HRI	104	
7.3	Dialogue management	106	
	7.3.1 Basic principle	106	
	7.3.2 Practice in HRI	108	
7.4	Speech production	109	
	7.4.1 Practice in HRI	110	
7.5	Conclusion	112	
8	Emotion	114	
8.1	What are emotions, mood, and affect?	114	
	8.1.1 Emotion and interaction	115	
8.2	Understanding human emotions	116	
8.3	When emotions go wrong	117	
8.4	Emotions for robots	118	
0.1	8.4.1 Emotion interaction strategies	118	
	8.4.2 Artificial perception of emotions	119	
	8.4.3 Expressing emotions with robots	120	
	8.4.4 Emotion models	121	
8.5	Challenges in affective HRI	122	
9	Research Methods	126	
91	Defining a research question and approach	128	
0.1	9.1.1 Is your research exploratory or confirmatory?	129	
	9.1.2 Are you establishing correlation or causation?	130	
92	Choosing among qualitative quantitative and mixed methods	131	
0.2	9.2.1 User studies	132	
	9.2.2 System studies	133	
	9.2.3 Observational studies	134	
	9.2.4 Ethnographic studies	136	
	9.2.5 Conversational analysis	138	
	9.2.6 Crowdsourced studies	139	
	9.2.7 Single-Subject Studies	140	
9.3	Selecting research participants and study designs	141	
	9.3.1 Study design	142	
9.4	Defining the context of interaction	144	
	9.4.1 Location of study	144	
	9.4.2 Temporal context of HRI	145	
	9.4.3 Social units of interaction in HRI	146	
9.5	Choosing a robot for your study	148	
9.6	Setting up the mode of interaction	149	
	9.6.1 Wizard of Oz	149	
	9.6.2 Real versus simulated interaction	150	
9.7	Selecting appropriate HRI measures	150	
9.8	Research standards	152	

vi		Contents
	9.8.1 Changing standards of statistical analysis	152
	9.8.2 Power	155
	9.8.3 Generalizability and replication	155
	9.8.4 Ethical considerations in HRI studies	156
9.9	Conclusion	158
10	Applications	161
10.1	Service robots	163
	10.1.1 Tour guide robots	164
	10.1.2 Receptionist robots	165
	10.1.3 Robots for sales promotion	165
10.2	Robots for learning	166
10.3	Robots for entertainment	167
	10.3.1 Pet and toy robots	167
	10.3.2 Robots for exhibitions	168
	10.3.3 Robots in the performing arts	169
	10.3.4 Sex robots	170
10.4	Robots in healthcare and therapy	170
	10.4.1 Robots for senior citizens	170
	10.4.2 Robots for people with autism spectrum disorder	171
	10.4.3 Robots for rehabilitation	173
10.5	Robots as personal assistants	173
10.6	Service robots	174
10.7	Collaborative robots	176
10.8	Self-driving cars	177
10.9	Remotely operated robots	178
10.10	Future applications	179
10.11	Problems for robot application	180
	10.11.1 Addressing user expectations	180
	10.11.2 Addiction	181
	10.11.3 Attention theft	181
	10.11.4 Loss of interest by user	181
	10.11.5 Robot abuse	182
10.12	Conclusion	182
11	Robots in Society	185
11.1	Robots in popular media	186
	11.1.1 Robots want to be humans	187
	11.1.2 Robots as a threat to humanity	188
	11.1.3 Superior robots being good	189
	11.1.4 Similarity between humans and robots	189
	11.1.5 Narratives of robotic science	190
11.2	Ethics in HRI	192
	11.2.1 Robots in research	193
	11.2.2 Robots to fulfill emotional needs	194
	11.2.3 Robots in the workplace	197
11.3	Conclusion	198

Contents		vii
<b>12</b>	<b>The Future</b>	201
12.1	The nature of human–robot relationships	203
12.2	The technology of HRI	205
12.3	Crystal ball problems	206
References		209
Index		247
Notes		252

## Illustrations

1.1	The authors of the book	3
2.1	Asimo robot	8
2.2	Barriers between the disciplines.	10
2.3	Kismet robot	13
2.4	Nao robot	14
2.5	Keepon robot	14
2.6	Paro robot	15
2.7	Baxter robot	15
2.8	InMoov robot	16
2.9	Kaspar robot	16
3.1	The camera's data translated into a grid of grayscale pixels.	19
3.2	Aibo ERS-1000 robot	21
3.3	Pepper robot	22
3.4	Array of CCDs in RGB camera.	23
3.5	Microsoft Kinect 2	25
3.6	PR2 robot	26
3.7	iCub robot	26
3.8	Robotic Arm	29
3.9	Kuka robot	30
3.10	RoboThespian robot	30
3.11	Sense-plan-act model.	32
3.12	The subsumption behavior-based architecture.	33
3.13	Canny edge detection	34
4.1	TurtleBot	42
4.2	Mythical robots	43
4.3	Robovie-MR2 robot	43
4.4	Muu, Keepon, Naked Invisible Guy	44
4.5	Sociable Trash Box robots	44
4.6	Philip K. Dick Robot	48
4.7	Face on Mars	49
4.8	Geminoid HI 4 robot	50
4.9	Keepon, Wakamaru, Nao, Asimo, and a Kokoro robot	50
4.10	Mori's Uncanny Valley theory.	53
4.11	Boy learning math with a robot.	59
4.12	Snackbot	60
4.13	LEGO Mindstorms robot	62
4.15	Quality	66
4.14	Robert M. Pirsig	66

viii

This material has been published by Cambridge University Press as Human Robot Interaction by Christoph Bartneck, Tony Belpaeime, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Sabanovic. ISBN: 9781108735407 (http://www.cambridge.org/9781108735407).

<i>Illustrations</i> ix			
5.1	Joggobot Drone	69	
5.2	Commuters during rush hour on the Tokyo underground.	70	
5.3	Intimate, personal, social, and public distance	71	
5.4	F-Formations	72	
5.5	A drone builds a probabilistic model of the human's movement.	75	
5.6	Proxemic Study	79	
6.1	Nonverbal interaction between human and robot	84	
6.2	Pupil dilation	85	
6.3	iCub robot looking at object	86	
6.4	Pepper robot	87	
6.5	Chameleon effect	89	
6.6	Telenoid robot	90	
6.7	Nao robot expressing emotions	92	
6.8	Choregraphe	94	
7.1	Pepper in a Store	99	
7.2	Data of a speech sample	102	
7.3	Sarcasm and AI	105	
8.1	eMuu, iCat and Flobi robot	120	
8.2	Cozmo robot	121	
8.3	The OCC model of emotions.	122	
8.4	Russel's circumplex model of affect.	123	
8.5	The PAD emotion model	123	
8.6	Tennis players expressing emotions.	124	
9.1	Cat Roomba	129	
9.2	Spurious correlation	131	
9.3	The Turk	139	
9.4	Robovie in school	146	
9.5	Units of analysis in HRI	146	
9.6	Guess the correlation game	154	
10.1	The Sony Aibo ERS-7 with the Nao	162	
10.2	Qrio and Kuri robot	163	
10.3	The Robovie robot as a museum guide	164	
10.4	Receptionist robot	165	
10.5	Pleo robot	168	
10.6	Animatronic robot.	169	
10.7	EliQ robot	171	
10.8	Papero	172	
10.9	Nao, Elvis, Kaspar and Zeno robot	173	
10.10	Personal assistant robots	174	
10.11	K5 victim	176	
10.12	Walt robot	177	
10.13	Gnost car	178	
10.14	Toyota's T-HR3 robot	179	
10.15	rackbot	100	
10.10	A child kicking a robot in a snopping mail	182	
11.1 11.0	The Termineton	100 100	
11.2 11.9		100 109	
11.0	ISAAU ASIIIIUV	TA9	

© copyright by Christoph Bartneck, Tony Belpaeime, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Sabanovic 2019. https://www.human-robot-interaction.org

х		Illustrations
12.1	Cimon robot	202
12.2	Friendships on Facebook	203
12.3	Stephen William Hawking	204

 $\odot$  copyright by Christoph Bartneck, Tony Belpaeime, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Sabanovic 2019. https://www.human-robot-interaction.org

## Tables

11.1 Topics of HRI in theater

189

xi

© copyright by Christoph Bartneck, Tony Belpaeime, Friederike Eyssel, Takayuki Kanda, Merel Keijsers, and Selma Sabanovic 2019. https://www.human-robot-interaction.org