

## July 21, 2022 Stuttgart ELLIS Unit Kick-off Event European Laboratory for Learning and Intelligent System

Katherine J. Kuchenbecker MPI for Intelligent Systems Stuttgart, Germany







+ Jupiter (Florida, USA), Rome (Italy), Florence (Italy), Luxembourg, Manaus (Brazil), and Nijmegen (The Netherlands)



Büsnauer Wiesental

Naturfreundehaus Vaihingen

**MAX PLANCK INSTITUTE** FOR INTELLIGENT SYSTEMS

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Patch Thrifft Shop

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Deutsches Zentrum für Luft- und Raumfahrt eV

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Parkplatz HdM

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Taverna Elia

Hochschule

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der Medien

Parkplatz Allmandring

Allmandring I

**DHL Packstation 165** 

Unithekle CampusBar

U&D Wiese Temporarily closed

Institut für Zellbiologie und Immunologie (IZI)

Department of Sport and Exercise Science...

Fraunhofer-Institut für Produktionstechnik...

Fraunhofer-Institut für Grenzflächen- und...

Fraunhofer-Institut für Arbeitswirtschaft...

Nobelstraße

Universität Stuttgart - ..

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Max Planck 🦳 💿 Max-Planck-Institut für

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Max Planck Institute Guesthouse

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Heisenbergstraße

**Dedicated space for startups** 





Michael J. Black Perceiving Systems



**Moritz Hardt** Social Foundations of Computing



**Bernhard Schölkopf Empirical Inference** 



Caterina De Bacco Physics for Inference and Optimization



**Georg Martius** Autonomous Learning



Ludovic Righetti Movement Generation and Control



Wieland Brendel **Robust Machine Learning** 



Falk Lieder Rationality Enhancement



Michael Mühlebach Learning and Dynamical Systems









**Christoph Keplinger Robotic Materials** 



**Metin Sitti Physical Intelligence** 



Katherine J. Kuchenbecker Haptic Intelligence



Jörg Stückler **Embodied Vision** 



Alexander Badri-Spröwitz Dynamic Locomotion



Ardian Jusufi Locomotion in Biorobotic and Somatic Systems



Samira Samadi Fairness in Machine Learning



**Justus Thies** Neural Capture and Synthesis



Wenqi Hu **Bioinspired Autonomous** Miniature Robots



# imprs-1s

# **MAX PLANCK INSTITUTE** FOR INTELLIGENT SYSTEMS







### SUMMER COLLOQUIUM



### ) MAX PLANCK INSTITUTE



Opening by Metin Sitti Managing Director Max Planck Institute for Intelligent Systems

13:30

13:35 - 14:35



2022 Max Planck Lecture

Zhenan Bao Skin-Inspired Organic Electronics

Abstract and speaker's short biography >>

14:35 - 15:00	Discussion
15:00 - 15:30	Break
15:30 - 16:10	Intelligent Systems Summer Colloquium Wieland Brendel A more principled way towards machines that see the world like hum Abstract and speaker's short biography >>

## Max Planck Lecture & Summer Colloquium Tomorrow on the MPI-IS campus Lecture Hall 2D5, Heisenbergstr. 1, Stuttgart Starting at 1:30 p.m. with a barbecue The talks will also be live-streamed

https://is.mpg.de/events/intelligent-systems-summer-colloquium-2022







**Rachael B. Burns** Ph.D. Student



Iris Andrussow



**Arnaud Allemang--Trivalle** Co-Advised Ph.D. Student Co-Advised Ph.D. Student



Dominika Lisy Recent Ph.D. Visitor



**Rachael L'Orsa** Recent Ph.D. Visitor



**Guido Caccianiga** Ph.D. Student



Farimah Fazlollahi Ph.D. Student

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**Summer Interns** (several)



Maria-Paola Forte Co-Advised Ph.D. Student



Joey Burns **IT** Administrator



Ifat Gertler Ph.D. Student



## **Could members of my** team please stand up?

attending



Nati Egana Rosa **Technical Assistant** 

Yijie Gong

Ph.D. Student

lightning



Ilona Jacobi Department Assistant







Alexis E. Block **Recent Doctoral Grad** 



MPI-IS



Katherine J. Kuchenbecker Director



Cara Nunez Recent Ph.D. Visitor



Yoojin Oh Visiting Ph.D. Student



Fayo Ojo Recent Ph.D. Visitor



Christian Schöffmann Recent Ph.D. Visitor





**Bernard Javot Research Engineer** 



**Paul Kress** Research Engineer



Lijuan Wang Research Engineer

### We enjoy hosting visiting Ph.D. students and interns!



Mayumi Mohan Ph.D. Student



Saekwang Nam Ph.D. Student



**Julian Nubert** Co-Advised Ph.D. Student



**Benjamin Richardson** Ph.D. Student





Ravali Gourishetti Postdoctoral Researcher



Haliza Mat Husin Postdoctoral Researcher



Gökhan Serhat **Research Scientist** 



Yitian Shao Postdoctoral Researcher







**David Gueorguiev** Scientist (CNRS)



Hyosang Lee Scientist (Uni. Stuttgart)



Hasti Seifi Scientist (U. Copenhagen)



**Yasemin Vardar** Scientist (TU Delft)







# **Underlying Motivation**

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# **Underlying Motivation**

- The sense of touch is fundamental for humans:
  - First sense to evolve
  - Difficult to live without

  - Spread throughout the body with myriad channels



# Deeply coupled to physical action and social interaction







# haptic =

# kinesthetic proprioceptive





# tactile cutaneous

contact location pressure receptor stretch density varies slip spatially vibration temperature hair follicle motion

> muscle length muscle velocity tendon force ligament force joint receptors





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# **Underlying Motivation**

- The sense of touch is fundamental for humans:
  - First sense to evolve
  - Difficult to live without
  - Deeply coupled to physical action and social interaction
  - Spread throughout the body with myriad channels
- But, most engineered systems ignore the sense of touch.



























## physical interaction and touch cues!



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Haptic Interface Technology

Teleoperation Interfaces

Physical Human-Robot Interaction







### **Fingertip Haptics**











Haptic Interface Technology

**Teleoperation Interfaces** 

Physical Human-Robot Interaction



















Physical Human-Robot Interaction













### **Teleoperation Interfaces**







Fingertip Haptics

Physical Human-Robot Interaction

















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Fingertip Haptics

### **Physical Human-Robot Interaction**















Physical Human-Robot Interaction



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**Fingertip Haptics** 

**Teleoperation Interfaces** 





















**Touch Sensing** 











## How did I start working in these research areas?









Joe Romano Penn Ph.D. Student Intern at Willow Garage Now at Berkshire Grey



#### inspiration from human sensorimotor control



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Coding and use of tactile signals from the fingertips in object manipulation tasks. Nature Reviews: Neuroscience, 10:345–359, 2009.

Joseph M. Romano, Kaijen Hsiao, Günter Niemeyer, Sachin Chitta, and Katherine J. Kuchenbecker. Human-inspired robotic grasp control with tactile sensing. IEEE Transactions on Robotics, 27(6):1067–1079, 2011.















Joe Romano Penn Ph.D. Student Intern at Willow Garage Now at Berkshire Grey





Joseph M. Romano and Katherine J. Kuchenbecker. Please do not touch the robot. Hands-on demonstration presented at IEEE/RSJ Conference on Intelligent Robots and Systems (IROS), San Francisco, California, September 2011.

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PR2









Ian McMahon

Penn Masters Student

Now at Toyota RI

Vivian Chu Penn Masters Student Now at Diligent Robotics



Lorenzo Riano **Berkeley Postdoc** Now at Waymo

absorbent	fuzzy	nice	Smooth	sticky
bampy	GRITTY*	porous	soft	textured
compressible	HARD	rough	solid	thick
cool	hairy	scratchy	springy	thin
crínkly	metallíc	slippery	rquirhy	unpleasant



Vivian Chu\*, Ian McMahon\*, Lorenzo Riano\*, Craig G. McDonald, Qin He, Jorge Martinez Perez-Tejada, Michael Arrigo, Trevor Darrell, and Katherine J. Kuchenbecker. Robotic learning of haptic adjectives through physical interaction. Robotics and Autonomous Systems, 63(3):279–292, 2015. Corrigendum published in June 2016.











**Touch Sensing** 









## My ideal touch sensors:

- are soft
- cover my robot
- detect new contact
- have high dynamic range
- respond quickly
- provide useful information
- are robust and reliable
- integrate easily with my robot
- are low cost and accessible











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# HuggieBot











Huanbo Sun MPI-IS Ph.D. Student advised by Georg Martius just graduated!



**Georg Martius** Max Planck Research Group Leader, MPI-IS



Katherine J. Kuchenbecker Director, MPI-IS



**Iris Andrussow** MPI-IS Ph.D. Student co-advised by KJK and Georg Martius

### machine intelligence

#### OPEN A soft thumb-sized vision-based sensor with accurate all-round force perception

Huanbo Sun<sup>1</sup><sup>1</sup>, Katherine J. Kuchenbecker<sup>2</sup> and Georg Martius<sup>1</sup>

Vision-based haptic sensors have emerged as a promising approach to robotic touch due to affordable high-resolution cameras and successful computer vision techniques; however, their physical design and the information they provide do not yet meet the requirements of real applications. We present a robust, soft, low-cost, vision-based, thumb-sized three-dimensional haptic sensor named Insight, which continually provides a directional force-distribution map over its entire conical sensing surface. Constructed around an internal monocular camera, the sensor has only a single layer of elastomer over-moulded on a stiff frame to guarantee sensitivity, robustness and soft contact. Furthermore, Insight uniquely combines photometric stereo and structured light using a collimator to detect the three-dimensional deformation of its easily replaceable flexible outer shell. The force information is inferred by a deep neural network that maps images to the spatial distribution of three-dimensional contact force (normal and shear). Insight has an overall spatial resolution of 0.4 mm, a force magnitude accuracy of around 0.03 N and a force direction accuracy of around five degrees over a range of 0.03-2 N for numerous distinct contacts with varying contact area. The presented hardware and software design concepts can be transferred to a wide variety of robot parts.

obots have the potential to perform useful physical tasks in a wide range of application areas<sup>1-4</sup>. To robustly manipulate Nobjects in complex and changing environments, a robot must be able to perceive when, where and how its body is contacting other things. Although widely studied and highly successful for environment perception at a distance, centrally mounted cameras and computer vision are poorly suited to real-world robot contact perception due to occlusion and the small scale of the deformations involved. Robots instead need touch-sensitive skin, but few haptic sensors exist that are suitable for practical applications.

Recent developments have shown that machine-learning-based approaches are especially promising for creating dexterous robots<sup>2,5,6</sup>. In such self-learning scenarios and real-world applications, the need for extensive data makes it particularly critical that sensors are robust and keep providing good readings over thousands of hours of rough interaction. Importantly, machine learning also opens new possibilities for tackling this haptic sensing challenge by replacing handcrafted numeric calibration procedures with end-to-end mappings learned from data7.

Many researchers have created haptic sensors<sup>8</sup> that can quantify contact across a robot's surfaces: previous successful designs produced measurements using resistive<sup>9-13</sup>, capacitive<sup>14-16</sup>, ferroelectric<sup>17</sup>, triboelectric<sup>18</sup> and optoresistive<sup>19,20</sup> transduction approaches. More recently, vision-based haptic sensors<sup>21–26</sup> have demonstrated a new family of solutions, typically using an internal camera that views the soft contact surface from within; however, these existing sensors tend to be fragile, bulky, insensitive, inaccurate and/or expensive. By considering the goals and constraints from a fresh perspective, we have invented a vision-based sensor that overcomes these challenges and is thus suitable for robotic dexterous manipulation.

This paper presents a new soft thumb-sized sensor with all-round force-sensing capabilities enabled by vision and machine learning; it is durable, compact, sensitive, accurate and affordable (less than Table 1 provides a detailed comparison of representative state-of-\$100). As it consists of a flexible shell around a vision sensor, we the-art sensors. We highlight the most important differences and name it Insight. Although initially designed for dexterous maniprefer the reader to the Methods for a more thorough examinaulation and behavioural learning, our sensor is suitable for many tion. The mechanical designs of all previous sensors employ mulother applications and our technology can be adapted to create a tiple functional layers, which are complex to fabricate and can be variety of three-dimensional haptic sensing systems.

<sup>1</sup>Autonomous Learning Group, Max Planck Institute for Intelligent Systems, Tübingen, Germany. <sup>2</sup>Haptic Intelligence Department, Max Planck Institute for Intelligent Systems, Stuttgart, Germany. Zermail: huanbo.sun@tuebingen.mpg.de; georg.martius@tuebingen.mpg.de

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#### ARTICLES

https://doi.org/10.1038/s42256-021-00439-3

Check for updates

delicate. Insight is the only sensor with a single soft layer. Many tasks benefit from a large three-dimensional sensing surface rather than small two-dimensional sensing patches; however, only a few other sensors offer three-dimensional surfaces<sup>25,27-29</sup>. Some of them require special lenses<sup>25</sup> or use multiple cameras<sup>27</sup>, whereas others are more fragile<sup>28,29</sup>. Insight needs only a single camera and simple manufacturing techniques. Depending on their mechanical design, sensors also have widely varying sensing surface area and sensor volume. We provide area per volume (A/V) in Table 1 as a measure of compactness and find that Insight is among the most compact vision-based sensors with the largest sensing surface.

Most existing sensors provide only localization of a single contact<sup>20,25,27,28,30</sup>; some also provide a force magnitude<sup>9,23,31</sup> without force direction. Others are specialized for measuring contact area shape<sup>21,29,32</sup>. Although real contacts will be multiple and complex, a spatially extended map of three-dimensional contact forces over the surface, which we call a force map, is only rarely provided (for example, ref.<sup>22</sup>). Insight is the only sensor that provides a force map across a three-dimensional surface such that a robot can have detailed directional information about simultaneous contacts. Many sensors rely on analytical data processing<sup>22,25,28,33</sup>, which requires careful calibration; it is difficult to obtain correct force amplitudes with such an approach as materials are often inhomogeneous and the assumption of linearity between deformation and force is often violated. Data-driven approaches such as those used with a BioTac<sup>9</sup>, GelSight<sup>21</sup>, OmniTact<sup>27</sup> and Insight can deal with these problems but require copious quality data.

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# **A Haptic Sensor Powered by Vision and Machine Learning**





Huanbo Sun, Katherine J. Kuchenbecker, and Georg Martius. A soft thumb-sized vision-based sensor with accurate all-round force perception. *Nature Machine Intelligence*, 4: 135–145, February 2022.









# **Data Processing Pipeline**



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#### Huanbo Sun, Katherine J. Kuchenbecker, and Georg Martius. A soft thumb-sized vision-based sensor with accurate all-round force perception. *Nature Machine Intelligence*, 4: 135–145, February 2022.









# **Key Design Components**



- 1. Mechanics: soft-rigid hybrid structure
- 3. Data: automatic collection
- 4. Al: deep learning







**2. Imaging**: a single camera & structured light

Huanbo Sun, Katherine J. Kuchenbecker, and Georg Martius. A soft thumb-sized vision-based sensor with accurate all-round force perception. *Nature Machine Intelligence*, 4: 135–145, February 2022.







# Insight Key Design Components: 1. Mechanics















# Insight Key Design Components: 2. Lighting





















# Insight Key Design Components: 3. Data



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# Insight **Key Design Components: 4. Al**



Huanbo Sun, Katherine J. Kuchenbecker, and Georg Martius. A soft thumb-sized vision-based sensor with accurate all-round force perception. *Nature Machine Intelligence*, 4: 135–145, February 2022.















Huanbo Sun, Katherine J. Kuchenbecker, and Georg Martius. A soft thumb-sized vision-based sensor with accurate all-round force perception. *Nature Machine Intelligence*, 4: 135–145, February 2022.















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- **2. Imaging:** a single camera & structured light
- 3. Data: automatic collection
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Overall spatial resolution of about 0.4 mm Force magnitude accuracy of about 0.03 N

Force direction accuracy around 5 degrees over a range of 0.03 N to 2.00 N

Insight can even discern its own orientation relative to gravity









![](_page_36_Picture_3.jpeg)

Huanbo Sun MPI-IS Ph.D. Student advised by Georg Martius just graduated!

![](_page_36_Picture_5.jpeg)

Katherine J. Kuchenbecker Director, MPI-IS

![](_page_36_Picture_8.jpeg)

**Georg Martius** Max Planck Research Group Leader, MPI-IS

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**Iris Andrussow** MPI-IS Ph.D. Student co-advised by KJK and Georg Martius

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Katherine J. Kuchenbecker Director, MPI-IS

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**Georg Martius** Max Planck Research Group Leader, MPI-IS

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![](_page_37_Picture_8.jpeg)

**Iris Andrussow** MPI-IS Ph.D. Student co-advised by KJK and Georg Martius

### Visit Iris' poster to learn about **Minsight!**

### machine intelligence

#### OPEN A soft thumb-sized vision-based sensor with accurate all-round force perception

Huanbo Sun<sup>1</sup><sup>1</sup>, Katherine J. Kuchenbecker<sup>2</sup> and Georg Martius<sup>1</sup>

Vision-based haptic sensors have emerged as a promising approach to robotic touch due to affordable high-resolution cameras and successful computer vision techniques; however, their physical design and the information they provide do not yet meet the requirements of real applications. We present a robust, soft, low-cost, vision-based, thumb-sized three-dimensional haptic sensor named Insight, which continually provides a directional force-distribution map over its entire conical sensing surface. Constructed around an internal monocular camera, the sensor has only a single layer of elastomer over-moulded on a stiff frame to guarantee sensitivity, robustness and soft contact. Furthermore, Insight uniquely combines photometric stereo and structured light using a collimator to detect the three-dimensional deformation of its easily replaceable flexible outer shell. The force information is inferred by a deep neural network that maps images to the spatial distribution of three-dimensional contact force (normal and shear). Insight has an overall spatial resolution of 0.4 mm, a force magnitude accuracy of around 0.03 N and a force direction accuracy of around five degrees over a range of 0.03-2 N for numerous distinct contacts with varying contact area. The presented hardware and software design concepts can be transferred to a wide variety of robot parts.

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<sup>1</sup>Autonomous Learning Group, Max Planck Institute for Intelligent Systems, Tübingen, Germany. <sup>2</sup>Haptic Intelligence Department, Max Planck Institute for Intelligent Systems, Stuttgart, Germany. Ze-mail: huanbo.sun@tuebingen.mpg.de; georg.martius@tuebingen.mpg.de

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#### ARTICLES

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135

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# HuggieBot

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HAPTIC INTELLIGENCE MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

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## HuggieBot

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![](_page_40_Picture_0.jpeg)

2021 Otto Hahn Medal

![](_page_40_Picture_3.jpeg)

**Alexis E. Block Recent MPI-IS/ETH** Doctoral Graduate + Postdoc, UCLA

![](_page_40_Picture_5.jpeg)

Sammy Christen **ETH Doctoral Student** advised by Otmar Hilliges

![](_page_40_Picture_7.jpeg)

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International Journal of Social Robotics https://doi.org/10.1007/s12369-018-0495-2

#### Softness, Warmth, and Responsiveness Improve Robot Hugs

Alexis E. Block<sup>1,2,3</sup> · Katherine J. Kuchenbecker<sup>1,2,3</sup>

Accepted: 5 October 2018 © The Author(s) 2018

Hugs are one of the first forms of contact and affection humans experience. Due to their prevalence and health benefits. roboticists are naturally interested in having robots one day hug humans as seamlessly as humans hug other humans. This project's purpose is to evaluate human responses to different robot physical characteristics and hugging behaviors. Specifically, we aim to test the hypothesis that a soft, warm, touch-sensitive PR2 humanoid robot can provide humans with satisfying hugs by matching both their hugging pressure and their hugging duration. Thirty relatively young and rather technical participants experienced and evaluated twelve hugs with the robot, divided into three randomly ordered trials that focused on physical robot characteristics (single factor, three levels) and nine randomly ordered trials with low, medium, and high hug pressure and duration (two factors, three levels each). Analysis of the results showed that people significantly prefer soft, warm hugs over hard, cold hugs. Furthermore, users prefer hugs that physically squeeze them and release immediately when they are ready for the hug to end. Taking part in the experiment also significantly increased positive user opinions of robots and robot

Keywords Physical human-robot interaction · Social robotics · System evaluatio

#### 1 Introduction

Alexis E. Block

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Hugging another person gives each participant social support, relieves stress, lowers blood pressure, and increases oxytocin levels [7]. With the health benefits and prevalence of hugs in daily human interactions, it is natural that roboticists hugging or firmly touching, has been shown to relieve anxihave tried to artificially create this gesture. A major challenge of mechanizing hugs is the safety and comfort of the human during this intimate exchange. Researchers, therefore, have sive and conspicuous. Inflatable or pressurized vests can also taken many different approaches, as summarized in Sect. 2.

Electronic supplementary material The online version of this article material, which is available to authorized users.

- Haptic Intelligence Department, Max Planck Institute for elligent Systems, Stuttgart, German
- Max Planck ETH Center for Learning Systems, Zurich

Haptics Group, GRASP Laboratory, University of Pennsylvania, Philadelphia, USA

Published online: 25 October 2018

Katherine J. Kuchenbecker

### **International Journal of Social Robotics 2018**

![](_page_40_Picture_25.jpeg)

Shari L. Y. Kuchenbecker R. W. Research

![](_page_40_Picture_27.jpeg)

Roger Gassert Professor, ETH Zürich

![](_page_40_Picture_29.jpeg)

**Otmar Hilliges** Professor, ETH Zürich

![](_page_40_Picture_31.jpeg)

Katherine J. Kuchenbecker Director, MPI-IS

![](_page_40_Picture_33.jpeg)

![](_page_40_Picture_36.jpeg)

One related non-robotic approach is the creation of inflatable or weighted vests and jackets to help calm children with sensory processing disorder, children with attention deficit hyperactivity disorder, and individuals with autism spectrum disorder [37]. Deep touch pressure, the kind received from ety for people with these disorders [19]. Because they require a loud pump and air flow, inflatable garments are often obtrube activated remotely by a parent or instructor at any time [12]. In this instance, the child may not understand the cause of the hug. Additionally, weighted vests must constantly be removed to alleviate the pressure and then replaced. A similar invention called the "Squeeze Machine" applies lateral deep touch pressure by squeezing a user between two foam panels [15]. Patients on the autism spectrum, non-autistic college students, and animals all experienced similar calming effects. The Squeeze Machine is operated by the user. who can control the applied pressure and duration of the encounter, gradually building up over time as he or she ecomes more comfortable. While these artificial hug recreations lack the primary component of a second partner, they do address the importance of physical touch

🖄 Springer

#### The Six Hug Commandments: Design and Evaluation of a Human-Sized Hugging Robot with Visual and Haptic Perception

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#### ABSTRACT

Receiving a hug is one of the best ways to feel socially supported, and the lack of social touch can have severe negative effects on an individual's well-being. Based on previous research both within and utside of HRI, we propose six tenets ("commandments") of natural and enjoyable robotic hugging: a hugging robot should be soft, be warm, be human sized, visually perceive its user, adjust its embrace to the user's size and position, and reliably release when the user wants to end the hug. Prior work validated the first two tenets, and the final four are new. We followed all six tenets to create a new robotic platform, HuggieBot 2.0, that has a soft, warm, inflated body HuggieChest) and uses visual and haptic sensing to deliver closed loop hugging. We first verified the outward appeal of this platform in comparison to the previous PR2-based HuggieBot 1.0 via an online video-watching study involving 117 users. We then conducted an in-person experiment in which 32 users each exchanged eight hugs with HuggieBot 2.0, experiencing all combinations of visual ug initiation, haptic sizing, and haptic releasing. The results show that adding haptic reactivity definitively improves user perception a hugging robot, largely verifying our four new tenets and illumi nating several interesting opportunities for further improvement.

#### ACM Reference Format:

Alexis E. Block, Sammy Christen, Roger Gassert, Otmar Hilliges, and Kather-ine J. Kuchenbecker. 2021. The Six Hug Commandments: Design and Evaluaine): Kurtenrecker. 2021. Int 50 Ving Commandents: Design and Data tion of a Human-Sized Hugging Robot with Visual and Haptic Perception. In Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction (HRI '21), March 8–11, 2021, Boulder, CO, USA. ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/s434073.3444656

#### **1 INTRODUCTION**

Hugging has significant social and physical health benefits for humans. Not only does a hug help lower blood pressure, alleviate stress and anxiety, and increase the body's levels of oxytocin, but it also

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![](_page_40_Picture_51.jpeg)

arned fifth place out of 8,850 things, behind only sleep, electricity the Earth's magnetic field, and gravity [27]. The absence of social touch can have detrimental effects on child development [4]. Unfortunately, ever more interactions are happening remotely and online especially during this unprecedented time of physical distancing due to COVID-19. An increasing number of people are suffering from loneliness and depression due to increased workload and pop lation aging [21, 22]. Our long-term research goal is to determine th extent to which we can close the gap between the virtual and physcal worlds via *hugging robots that provide high-quality social touch*. Making a good hugging robot is difficult because it must un-

derstand the user's nonverbal cues, realistically replicate a human ug, and ensure user safety. We believe that such robots need multi modal perception to satisfy all three of these goals, a target no prev ous system has reached. Some approaches focus primarily on safety, providing the user with the sensation of being hugged without being able to actively reciprocate the hugging motion [11, 33, 36]. Conversely, other researchers focus on providing the user with an item to hug, but that item cannot hug the user back [10, 30, 31].

### **IEEE/ACM HRI 2021**

#### In the Arms of a Robot: Designing Autonomous Hugging **Robots with Intra-Hug Gestures**

ALEXIS E. BLOCK, Max Planck Institute for Intelligent Systems and ETH Zürich, Germany HASTI SEIFI, University of Copenhagen, Denmark OTMAR HILLIGES, ETH Zürich, Switzerland ROGER GASSERT, ETH Zürich, Switzerland KATHERINE J. KUCHENBECKER, Max Planck Institute for Intelligent Systems, Germany

Hugs are complex affective interactions that often include gestures like squeezes. We present six new guidelines for designing interactive hugging robots, which we validate through two studies with our custom robot. To achieve autonomy, we investigated robot responses to four human intra-hug gestures: holding, rubbing, patting, and squeezing. Thirty-two users each exchanged and rated sixteen hugs with an experimenter-controlled HuggieBot 2.0. The robot's inflated torso's microphone and pressure sensor collected data of the subjects' demonstrations that were used to develop a perceptual algorithm that classifies user actions with 88% accuracy. Users enjoyed robot squeezes, regardless of their performed action, they valued variety in the robot response, and they appreciated robot-initiated intra-hug gestures. From average user ratings, we created a probabilistic behavior algorithm that chooses robot responses in real time. We implemented improvements to the robot platform to create HuggieBot 3.0 and then validated its gesture perception system and behavior algorithm with sixteen users. The robot's responses and proactive gestures were greatly enjoyed. Users found the robot more natural, enjoyable, and intelligent in the last phase of the experiment than in the first. After the study, they felt more understood by the robot and thought robots were nicer to hug.

 $\texttt{CCS Concepts:} \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Local}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Local}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Local}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Human-centered computing} \rightarrow \textbf{Human-centered computer}; \bullet \textbf{Human-centered computer}; \bullet$ pirical studies in interaction design.

Additional Key Words and Phrases: social-physical human-robot interaction, behavioral algorithm, haptic sensing, user study

#### **ACM Reference Format:**

Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. 2021. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. ACM Trans. Hum.-Robot Interact. 1, 1, Article 1 (January 2021), 48 pages. https://doi.org/10.1145/1122445.1122456

#### 1 INTRODUCTION

From the moment we are born, social touch affects our future ability to function well in society. Infants who are held by their mothers for two hours after they are born have better interactions with their mothers and are better at handling stress [72]. In such a close, positive relationship, the hormone oxytocin is released when the two partners see, hear, or even think of each other. In turn,

Authors' addresses: Alexis E. Block, alexis@is.mpg.de, Max Planck Institute for Intelligent Systems and ETH Zürich, Stuttgart Germany; Hasti Seifi, University of Copenhagen, Copenhagen, Denmark, hs@di.ku.dk; Otmar Hilliges, ETH Zürich, Zürich, Switzerland, otmar.hilliges@inf.ethz.ch; Roger Gassert, ETH Zürich, Zürich, Switzerland, roger.gassert@hest.ethz.ch; Katherine J. Kuchenbecker, Max Planck Institute for Intelligent Systems, Stuttgart, Germany, kjk@is.mpg.de.

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https://doi.org/10.1145/1122445.1122456

ACM Trans. Hum.-Robot Interact., Vol. 1, No. 1, Article 1

### **ACM Transactions on Human-Robot Interaction** 2022 (accepted)

![](_page_40_Picture_70.jpeg)

![](_page_40_Picture_83.jpeg)

![](_page_41_Picture_0.jpeg)

![](_page_41_Picture_2.jpeg)

**Alexis E. Block Recent MPI-IS/ETH** Doctoral Graduate + Postdoc, UCLA

![](_page_41_Picture_4.jpeg)

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![](_page_41_Picture_6.jpeg)

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![](_page_41_Picture_8.jpeg)

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![](_page_41_Picture_10.jpeg)

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![](_page_41_Picture_14.jpeg)

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![](_page_41_Picture_16.jpeg)

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ALEXIS E. BLOCK, Max Planck Institute for Intelligent Systems and ETH Zürich, Germany HASTI SEIFI, University of Copenhagen, Denmark OTMAR HILLIGES, ETH Zürich, Switzerland ROGER GASSERT, ETH Zürich, Switzerland KATHERINE J. KUCHENBECKER, Max Planck Institute for Intelligent Systems, Germany

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CCS Concepts: • Computer systems organization  $\rightarrow$  Robotics; • Human-centered computing  $\rightarrow$  Empirical studies in interaction design.

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![](_page_41_Picture_34.jpeg)

![](_page_41_Picture_35.jpeg)

# Hugging confers tremendous benefits

![](_page_42_Picture_1.jpeg)

Alleviate Stress/Anxiety

![](_page_42_Picture_2.jpeg)

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Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. ACM Transactions on Human-Robot Interaction, 1–48, 2022 (accepted).

![](_page_42_Picture_5.jpeg)

![](_page_42_Picture_6.jpeg)

# A lack of social touch causes problems

![](_page_43_Picture_1.jpeg)

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# Previous hugging robots

## Zoomorphic **Hugging Robots**

![](_page_44_Picture_2.jpeg)

### Teddy Bear Robot Shiomi et al., 2017

![](_page_44_Picture_4.jpeg)

### HugBot Hedayati et al., 2019

![](_page_44_Picture_7.jpeg)

The Hug Robot Kaplish and Yamane, 2019 Campbell and Yamane 2020

![](_page_44_Picture_9.jpeg)

HuggieBot 1.0 Block and Kuchenbecker, 2018

![](_page_44_Picture_11.jpeg)

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## Human-Sized Anthropomorphic Hugging Robots

![](_page_44_Picture_15.jpeg)

Disney Patent Yamane et al., 2017

![](_page_44_Picture_17.jpeg)

## **Small Form-Factor** Hugging Robots

![](_page_44_Picture_19.jpeg)

Huggable Stiehl et al., 2005

![](_page_44_Picture_21.jpeg)

### The Hug DiSalvo et al., 2003

![](_page_44_Picture_23.jpeg)

Hugvie Sumioka et al., 2013

Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. ACM Transactions on Human-Robot Interaction, 1–48, 2022 (accepted).

![](_page_44_Picture_27.jpeg)

![](_page_44_Picture_42.jpeg)

![](_page_44_Picture_43.jpeg)

![](_page_45_Picture_1.jpeg)

Be Soft

![](_page_45_Picture_3.jpeg)

Be Warm

![](_page_45_Picture_5.jpeg)

![](_page_45_Picture_6.jpeg)

Respond Quickly

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![](_page_45_Picture_10.jpeg)

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![](_page_45_Picture_12.jpeg)

Be Human-Sized

Not Robotic

![](_page_45_Picture_14.jpeg)

Synchronize to User Approach

![](_page_45_Picture_17.jpeg)

![](_page_45_Picture_20.jpeg)

![](_page_45_Picture_21.jpeg)

# HuggieBot 2.0

![](_page_46_Picture_1.jpeg)

Alexis E. Block, Sammy Christen, Roger Gassert, Otmar Hilliges, and Katherine J. Kuchenbecker. The Six Hug Commandments: Design and Evaluation of a Human-Sized Hugging Robot with Visual and Haptic Perception. Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2021

![](_page_46_Picture_3.jpeg)

![](_page_46_Picture_4.jpeg)

![](_page_46_Picture_5.jpeg)

![](_page_46_Picture_6.jpeg)

![](_page_46_Picture_7.jpeg)

![](_page_46_Picture_8.jpeg)

Adjust to All Size Users

![](_page_46_Picture_10.jpeg)

**Release User** on Demand

luman

Robot

• Soft, warm, quiet, easy to hug, and safe Robot visually perceives and reacts to approaching user • Arms adapt to user size and location, providing a good embrace • Robot reacts to user's desire to end the hug by sensing: • a reduction in pressure inside the inflated torso • an increase in the torque on any arm joint

![](_page_46_Picture_15.jpeg)

![](_page_46_Picture_17.jpeg)

![](_page_46_Picture_18.jpeg)

![](_page_46_Picture_19.jpeg)

![](_page_46_Picture_20.jpeg)

![](_page_47_Picture_1.jpeg)

Be Soft

![](_page_47_Picture_3.jpeg)

Be Warm

![](_page_47_Picture_5.jpeg)

![](_page_47_Picture_6.jpeg)

Respond Quickly

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![](_page_47_Picture_10.jpeg)

Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. ACM Transactions on Human-Robot Interaction, 1–48, 2022 (accepted).

![](_page_47_Picture_12.jpeg)

Be Human-Sized

Not Robotic

![](_page_47_Picture_14.jpeg)

Synchronize to User Approach

![](_page_47_Picture_17.jpeg)

![](_page_47_Picture_20.jpeg)

![](_page_47_Picture_21.jpeg)

![](_page_48_Picture_1.jpeg)

HAPTIC INTELLIGENCE MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

![](_page_48_Picture_5.jpeg)

Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. ACM Transactions on Human-Robot Interaction, 1–48, 2022 (accepted).

![](_page_48_Picture_8.jpeg)

Synchronize to User Approach

![](_page_48_Picture_13.jpeg)

![](_page_48_Picture_14.jpeg)

![](_page_49_Picture_1.jpeg)

![](_page_49_Picture_2.jpeg)

**Respond Quickly** 

![](_page_49_Picture_4.jpeg)

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![](_page_49_Picture_7.jpeg)

![](_page_49_Picture_9.jpeg)

Be Human-Sized

![](_page_49_Picture_11.jpeg)

Synchronize to User Approach

![](_page_49_Picture_13.jpeg)

Adjust to All Size Users

![](_page_49_Picture_15.jpeg)

Detect and Classify Gestures

![](_page_49_Picture_17.jpeg)

Not Robotic

![](_page_49_Picture_19.jpeg)

**Release User on Demand** 

![](_page_49_Picture_23.jpeg)

![](_page_49_Picture_24.jpeg)

![](_page_50_Picture_0.jpeg)

### Inflated chest with internal microphone and pressure sensor

Test Set - W50 - O37- T0.75

![](_page_50_Figure_3.jpeg)

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![](_page_50_Figure_4.jpeg)

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![](_page_50_Picture_7.jpeg)

![](_page_50_Picture_8.jpeg)

![](_page_51_Picture_0.jpeg)

![](_page_51_Figure_1.jpeg)

![](_page_51_Picture_3.jpeg)

Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. *ACM Transactions on Human-Robot Interaction*, 1–48, 2022 (accepted).

![](_page_51_Picture_6.jpeg)

![](_page_51_Picture_7.jpeg)

![](_page_52_Figure_0.jpeg)

![](_page_52_Picture_1.jpeg)

![](_page_52_Picture_4.jpeg)

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![](_page_52_Picture_6.jpeg)

![](_page_52_Picture_7.jpeg)

![](_page_52_Picture_8.jpeg)

![](_page_53_Picture_0.jpeg)

![](_page_53_Figure_1.jpeg)

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# HuggieBot 3.0

![](_page_53_Picture_6.jpeg)

Detect and Classify Gestures

![](_page_53_Picture_8.jpeg)

**Respond Quickly** 

![](_page_53_Picture_10.jpeg)

Be Affectionate, Pro-active

![](_page_53_Picture_12.jpeg)

Be Semi-Spontaneous, Not Robotic

![](_page_53_Picture_15.jpeg)

![](_page_53_Picture_18.jpeg)

![](_page_53_Picture_19.jpeg)

![](_page_54_Figure_0.jpeg)

![](_page_54_Picture_4.jpeg)

![](_page_54_Picture_5.jpeg)

![](_page_55_Picture_0.jpeg)

![](_page_55_Figure_1.jpeg)

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![](_page_55_Picture_6.jpeg)

![](_page_56_Picture_0.jpeg)

Best Demo Award Winners

#### 1<sup>st</sup> place

Alexis E. Block, Hasti Seifi, Sammy Christen, Bernard Javot, Katherine J. Kuchenbecker

Huggiebot: a human-sized haptic interface

10

HAPTIC INTELLIGENCE MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

![](_page_56_Picture_9.jpeg)

# EUROHAPTICS

![](_page_56_Picture_11.jpeg)

![](_page_56_Picture_13.jpeg)

![](_page_56_Picture_14.jpeg)

![](_page_56_Picture_15.jpeg)

![](_page_57_Picture_0.jpeg)

![](_page_57_Picture_2.jpeg)

Alexis E. Block **Recent MPI-IS/ETH** Doctoral Graduate + Postdoc, UCLA

![](_page_57_Picture_4.jpeg)

Sammy Christen **ETH Doctoral Student** advised by Otmar Hilliges

![](_page_57_Picture_6.jpeg)

Hasti Seifi Recent MPI-IS Postdoc + Asst. Professor, Univ. Copenhagen, Moving to ASU

![](_page_57_Picture_8.jpeg)

Heating pads

![](_page_57_Picture_10.jpeg)

Shari L. Y. Kuchenbecker R. W. Research

![](_page_57_Picture_12.jpeg)

Roger Gassert Professor, ETH Zürich

HAPTIC INTELLIGENCE

MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

![](_page_57_Picture_14.jpeg)

**Otmar Hilliges** Professor, ETH Zürich

![](_page_57_Picture_16.jpeg)

Katherine J. Kuchenbecker Director, MPI-IS

![](_page_57_Picture_18.jpeg)

© Axel Griesch / Max-Planck-Gesellschaft

padded Kinova Jaco arms

and soft clothes

![](_page_57_Figure_23.jpeg)

Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. ACM Transactions on Human-Robot Interaction, 1–48, 2022 (accepted).

![](_page_57_Picture_26.jpeg)

![](_page_57_Picture_27.jpeg)

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![](_page_58_Picture_2.jpeg)

**Alexis E. Block Recent MPI-IS/ETH** Doctoral Graduate + Postdoc, UCLA

![](_page_58_Picture_4.jpeg)

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![](_page_58_Picture_6.jpeg)

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![](_page_58_Picture_8.jpeg)

Shari L. Y. Kuchenbecker R. W. Research

![](_page_58_Picture_10.jpeg)

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![](_page_58_Picture_12.jpeg)

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![](_page_58_Picture_14.jpeg)

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![](_page_58_Picture_16.jpeg)

#### In the Arms of a Robot: Designing Autonomous Hugging **Robots with Intra-Hug Gestures**

ALEXIS E. BLOCK, Max Planck Institute for Intelligent Systems and ETH Zürich, Germany HASTI SEIFI, University of Copenhagen, Denmark OTMAR HILLIGES, ETH Zürich, Switzerland ROGER GASSERT, ETH Zürich, Switzerland KATHERINE J. KUCHENBECKER, Max Planck Institute for Intelligent Systems, Germany

Hugs are complex affective interactions that often include gestures like squeezes. We present six new guidelines for designing interactive hugging robots, which we validate through two studies with our custom robot. To achieve autonomy, we investigated robot responses to four human intra-hug gestures: holding, rubbing, patting, and squeezing. Thirty-two users each exchanged and rated sixteen hugs with an experimenter-controlled HuggieBot 2.0. The robot's inflated torso's microphone and pressure sensor collected data of the subjects' demonstrations that were used to develop a perceptual algorithm that classifies user actions with 88% accuracy. Users enjoyed robot squeezes, regardless of their performed action, they valued variety in the robot response, and they appreciated robot-initiated intra-hug gestures. From average user ratings, we created a probabilistic behavior algorithm that chooses robot responses in real time. We implemented improvements to the robot platform to create HuggieBot 3.0 and then validated its gesture perception system and behavior algorithm with sixteen users. The robot's responses and proactive gestures were greatly enjoyed. Users found the robot more natural, enjoyable, and intelligent in the last phase of the experiment than in the first. After the study, they felt more understood by the robot and thought robots were nicer to hug.

CCS Concepts: • Computer systems organization  $\rightarrow$  Robotics; • Human-centered computing  $\rightarrow$  Empirical studies in interaction design.

Additional Key Words and Phrases: social-physical human-robot interaction, behavioral algorithm, haptic sensing, user study

#### **ACM Reference Format:**

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#### **1 INTRODUCTION**

From the moment we are born, social touch affects our future ability to function well in society. Infants who are held by their mothers for two hours after they are born have better interactions with their mothers and are better at handling stress [72]. In such a close, positive relationship, the hormone oxytocin is released when the two partners see, hear, or even think of each other. In turn,

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Alexis E. Block, Hasti Seifi, Otmar Hilliges, Roger Gassert, and Katherine J. Kuchenbecker. In the Arms of a Robot: Designing Autonomous Hugging Robots with Intra-Hug Gestures. ACM Transactions on Human-Robot Interaction, 1–48, 2022 (accepted).

![](_page_58_Picture_34.jpeg)

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![](_page_59_Picture_4.jpeg)

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![](_page_59_Picture_6.jpeg)

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![](_page_59_Picture_8.jpeg)

#### Softness, Warmth, and Responsiveness Improve Robot Hugs

Alexis E. Block<sup>1,2,3</sup> · Katherine J. Kuchenbecker<sup>1,2,3</sup>

Accepted: 5 October 2018 © The Author(s) 2018

Hugs are one of the first forms of contact and affection humans experience. Due to their prevalence and health benefits. roboticists are naturally interested in having robots one day hug humans as seamlessly as humans hug other humans. This project's purpose is to evaluate human responses to different robot physical characteristics and hugging behaviors. Specifically, we aim to test the hypothesis that a soft, warm, touch-sensitive PR2 humanoid robot can provide humans with satisfying hugs by matching both their hugging pressure and their hugging duration. Thirty relatively young and rather technical participants experienced and evaluated twelve hugs with the robot, divided into three randomly ordered trials that focused on physical robot characteristics (single factor, three levels) and nine randomly ordered trials with low, medium, and high hug pressure and duration (two factors, three levels each). Analysis of the results showed that people significantly prefer soft, warm hugs over hard, cold hugs. Furthermore, users prefer hugs that physically squeeze them and release immediately when they are ready for the hug to end. Taking part in the experiment also significantly increased positive user opinions of robots and robot

Keywords Physical human-robot interaction · Social robotics · System evaluation

#### 1 Introduction

Hugging another person gives each participant social support, relieves stress, lowers blood pressure, and increases oxytocin levels [7]. With the health benefits and prevalence of hugs in daily human interactions, it is natural that roboticists hugging or firmly touching, has been shown to relieve anxihave tried to artificially create this gesture. A major challenge of mechanizing hugs is the safety and comfort of the human during this intimate exchange. Researchers, therefore, have sive and conspicuous. Inflatable or pressurized vests can also taken many different approaches, as summarized in Sect. 2.

#### Electronic supplementary material The online version of this article material, which is available to authorized users.

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Published online: 25 October 2018

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### **International Journal of Social Robotics 2018**

![](_page_59_Picture_25.jpeg)

Shari L. Y. Kuchenbecker R. W. Research

![](_page_59_Picture_27.jpeg)

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![](_page_59_Picture_29.jpeg)

![](_page_59_Picture_30.jpeg)

Katherine J. Kuchenbecker Director, MPI-IS

![](_page_59_Picture_32.jpeg)

![](_page_59_Picture_33.jpeg)

One related non-robotic approach is the creation of inflatable or weighted vests and jackets to help calm children with sensory processing disorder, children with attention deficit hyperactivity disorder, and individuals with autism spectrum disorder [37]. Deep touch pressure, the kind received from ety for people with these disorders [19]. Because they require a loud pump and air flow, inflatable garments are often obtrube activated remotely by a parent or instructor at any time [12]. In this instance, the child may not understand the cause of the hug. Additionally, weighted vests must constantly be removed to alleviate the pressure and then replaced. A similar invention called the "Squeeze Machine" applies lateral deep touch pressure by squeezing a user between two foam panels [15]. Patients on the autism spectrum, non-autistic college students, and animals all experienced similar calm ing effects. The Squeeze Machine is operated by the user. who can control the applied pressure and duration of the encounter, gradually building up over time as he or she ecomes more comfortable. While these artificial hug recreations lack the primary component of a second partner, they do address the importance of physical touch

🖄 Springer

#### The Six Hug Commandments: Design and Evaluation of a Human-Sized Hugging Robot with Visual and Haptic Perception

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Roger Gassert ETH Zürich Zürich, Switzerland

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#### ABSTRACT

Receiving a hug is one of the best ways to feel socially supported, and the lack of social touch can have severe negative effects on an individual's well-being. Based on previous research both within and utside of HRI, we propose six tenets ("commandments") of natural and enjoyable robotic hugging: a hugging robot should be soft, be warm, be human sized, visually perceive its user, adjust its embrace to the user's size and position, and reliably release when the user wants to end the hug. Prior work validated the first two tenets, and the final four are new. We followed all six tenets to create a new robotic platform, HuggieBot 2.0, that has a soft, warm, inflated body HuggieChest) and uses visual and haptic sensing to deliver closed loop hugging. We first verified the outward appeal of this platform in comparison to the previous PR2-based HuggieBot 1.0 via an online video-watching study involving 117 users. We then conducted an in-person experiment in which 32 users each exchanged eight hugs with HuggieBot 2.0, experiencing all combinations of visual ug initiation, haptic sizing, and haptic releasing. The results show that adding haptic reactivity definitively improves user perception a hugging robot, largely verifying our four new tenets and illumi nating several interesting opportunities for further improvement.

#### ACM Reference Format:

Alexis E. Block, Sammy Christen, Roger Gassert, Otmar Hilliges, and Kather-ine J. Kuchenbecker. 2021. The Six Hug Commandments: Design and Evalua-Ine J. Kucheneveck, 1002. Inte of Ming Commandents, Essginata Database tion of a Human-Sized Hugging Robot with Visual and Haptic Perception. In Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction (HRI '21), March 8–11, 2021, Boulder, CO, USA. ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3434073.3444656

#### **1 INTRODUCTION**

Hugging has significant social and physical health benefits for humans. Not only does a hug help lower blood pressure, alleviate stress and anxiety, and increase the body's levels of oxytocin, but it also

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![](_page_59_Picture_48.jpeg)

arned fifth place out of 8,850 things, behind only sleep, electricity the Earth's magnetic field, and gravity [27]. The absence of social touch can have detrimental effects on child development [4]. Unfortunately, ever more interactions are happening remotely and online especially during this unprecedented time of physical distancing due to COVID-19. An increasing number of people are suffering from loneliness and depression due to increased workload and pop lation aging [21, 22]. Our long-term research goal is to determine th extent to which we can close the gap between the virtual and physcal worlds via *hugging robots that provide high-quality social touch*. Making a good hugging robot is difficult because it must un-

derstand the user's nonverbal cues, realistically replicate a human ug, and ensure user safety. We believe that such robots need multi modal perception to satisfy all three of these goals, a target no prev ous system has reached. Some approaches focus primarily on safety, providing the user with the sensation of being hugged without being able to actively reciprocate the hugging motion [11, 33, 36]. Conversely, other researchers focus on providing the user with an item to hug, but that item cannot hug the user back [10, 30, 31].

### **IEEE/ACM HRI 2021**

#### In the Arms of a Robot: Designing Autonomous Hugging **Robots with Intra-Hug Gestures**

ALEXIS E. BLOCK, Max Planck Institute for Intelligent Systems and ETH Zürich, Germany HASTI SEIFI, University of Copenhagen, Denmark OTMAR HILLIGES, ETH Zürich, Switzerland ROGER GASSERT, ETH Zürich, Switzerland KATHERINE J. KUCHENBECKER, Max Planck Institute for Intelligent Systems, Germany

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 $\texttt{CCS Concepts:} \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Local}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Local}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Local}; \bullet \textbf{Computer systems organization} \rightarrow \textbf{Robotics}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Em-CCS Concepts}; \bullet \textbf{Human-centered computing} \rightarrow \textbf{Human-centered computing} \rightarrow \textbf{Human-centered computer}; \bullet \textbf{Human-centered computer}; \bullet$ pirical studies in interaction design.

Additional Key Words and Phrases: social-physical human-robot interaction, behavioral algorithm, haptic sensing, user study

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### **ACM Transactions on Human-Robot Interaction** 2022 (accepted)

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![](_page_59_Picture_82.jpeg)

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HAPTIC INTELLIGENCE MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

![](_page_60_Picture_3.jpeg)

![](_page_60_Picture_4.jpeg)

## HuggieBot

![](_page_60_Picture_7.jpeg)

![](_page_60_Picture_8.jpeg)

![](_page_61_Picture_0.jpeg)

HAPTIC INTELLIGENCE MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

![](_page_61_Picture_3.jpeg)

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# HuggieBot

![](_page_61_Picture_7.jpeg)

![](_page_61_Picture_8.jpeg)

![](_page_62_Picture_0.jpeg)

![](_page_62_Picture_1.jpeg)

**Touch Sensing** 

![](_page_62_Picture_3.jpeg)

![](_page_62_Picture_4.jpeg)

![](_page_62_Picture_5.jpeg)

![](_page_62_Picture_6.jpeg)

## My ideal touch sensors:

- are soft
- cover my robot
- detect new contact
- have high dynamic range
- respond quickly
- provide useful information
- are robust and reliable
- integrate easily with my robot
- are low cost and accessible

![](_page_62_Picture_18.jpeg)

![](_page_62_Picture_19.jpeg)

![](_page_62_Picture_20.jpeg)

# **Overarching Ideas**

• The sense of **touch** is important!

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- Touch itself is multimodal, mixing many distinct modalities that are not yet standardized like visual and auditory perception.
- Tactile sensors should have should have broad spatial sensitivity and high temporal bandwidth.
- Individual accelerometers, microphones, and pressure sensors can be used to instrument large robot body parts.
- Haptic perceptual algorithms need to work in real time so the robot can quickly react to detected events.

![](_page_63_Picture_9.jpeg)

![](_page_63_Picture_10.jpeg)

![](_page_63_Picture_11.jpeg)

![](_page_64_Picture_1.jpeg)

![](_page_64_Picture_2.jpeg)

MPI-IS Haptic Intelligence Department in October 2021

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![](_page_64_Picture_5.jpeg)

# thank you

- Ingo, Andreas, Dominike, and other organizers Max Planck Society collaborators and central services many generous mentors friends and family
  - anonymous reviewers

![](_page_65_Picture_3.jpeg)

![](_page_65_Picture_6.jpeg)

![](_page_65_Picture_7.jpeg)

# **Questions** and **comments**?

![](_page_66_Picture_1.jpeg)

## Insight

HAPTIC INTELLIGENCE MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

![](_page_66_Picture_4.jpeg)

## HuggieBot

![](_page_66_Picture_6.jpeg)

![](_page_66_Picture_7.jpeg)

![](_page_66_Picture_8.jpeg)

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