The current state of the art in natural-feeling human-robot handshaking

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Overview

The Disney use case in SOMA involves a wide range of areas of robotics through passing and placement interactions as well as social interactions. The role of Disney in the consortium is to evaluate the SOMA technology in these use cases. Many aspects of the use case fall outside the main SOMA scope, such as robot arm control or understanding human intent.

The handshake is particularly interesting, as the user forms a dynamic environmental constraint that is essential to the task. The goal of a human-like handshake places requirements on the hand design, its shape and its actuation modalities. There are also individual differences between users that should be adapted to, both in hand size and handshake dynamics.

We will here review the state of the art in work towards human-like human-robot handshaking.

A hierarchy

Natural-feeling human-robot handshaking is an active area of research, where progress is being made. However there are still many unanswered questions and opportunities for exciting research.

Based on our review of the literature, we will define a hierarchy of research areas that make up the field of natural-feeling human-robot handshake interactions, as shown below. Of course, the different areas are highly interconnected. All of these areas are active areas of research.

The hierarchy has 7 levels, with level 1 being low-level skin properties and level 7 being to understand the intent of the human.

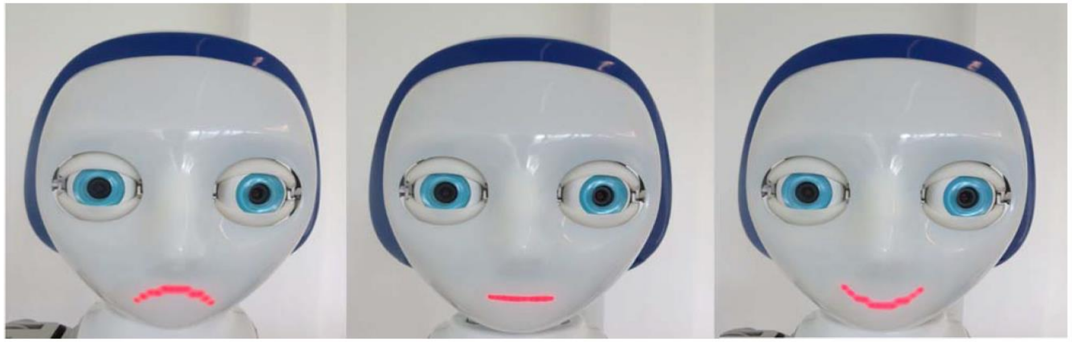
Within SOMA, the focus is within areas 1-4, and it is expected that the main contributions of the consortium will be in areas 2 and 3. Disney will be designing experiments with those areas in mind.

7. **Human intent.** Understanding human intent, path planning
6. **Robot arm control.** Arm control, follow/lead, respond to human
5. **Arm stiffness.** Mimicking human arm stiffness and impedance
4. **Grasp control.** Hand grasp control methods
3. **Hand synergies.** Design of hand synergies, actuation modes
2. **Hand shape.** Design of hand shape/morphology
1. **Skin.** Skin properties, skin compliance, hand appearance.

Areas of research:
Not explicitly investigating robot parameters, other than 4. Grasp control

Group at LIMSI-CNRS

Meka robot, with Meka H2 compliant hand



Facial expressions of the robot

First study looking at **affective evaluation of human-robot handshake**. Ask participants to report three emotional dimensions: Pleasure, Arousal, Dominance, for robot handshakes. Vary **robot facial expressions** (negative, neutral, positive) and **grip strength** (strong, weak) of robot handshake. Demonstrated that both visual and haptic modalities have a significant effect on the affective ratings.

The participant takes the lead of the handshake.

Main reference:

Tsalamlal, Mohamed Yacine, et al. "Affective handshake with a humanoid robot: How do participants perceive and combine its facial and haptic expressions?." *Affective Computing and Intelligent Interaction (ACII), 2015 International Conference on*. IEEE, 2015. http://dx.doi.org/10.1109/ACII.2015.7344592

Preliminary paper, looking at visual and haptic elements in isolation. Less clear results:

Ammi, Mehdi, et al. "Haptic Human-Robot Affective Interaction in a Handshaking Social Protocol." *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 2015. http://dx.doi.org/10.1145/2696454.2696485

Areas of research:
6. Robot arm control
5. Arm stiffness

LSR Group at TU Munich

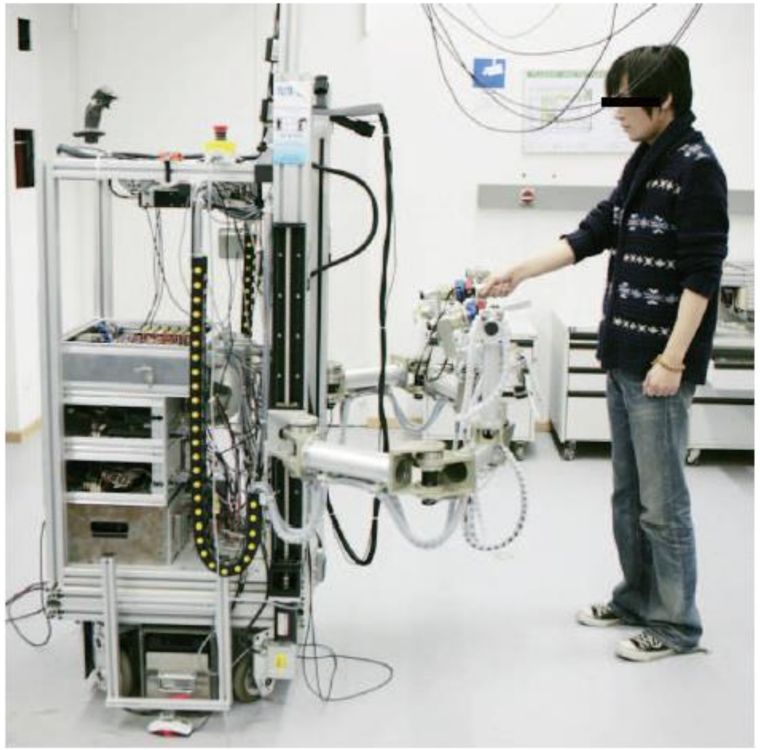
Group led by Martin Buss. Also Angelika Peer, Zheng Wang et al. Funded by EU FP6 project *Immersence.* Roughly 2006-2012.

Haptic rendering of robot **arm** dynamics, for virtual reality applications. **Handshaking** is one main focus. Mostly looking at arm dynamics and control, very little focus on hands. Develop a HMM-based robot controller for realistically following the human motion in a handshake.

They use **custom-built ViSHaRD robot arms**, specifically developed for haptic applications.

Develop **Tekscan glove** for analyzing handshake grip, to map this on to 3-finger robot hand (BarrettHand). The limited sophistication of the robot hand prevent them from carrying out a full implementation and analysis.

Much of the work is summarized in Z Wang's thesis.



ViSHaRD haptic robot arm

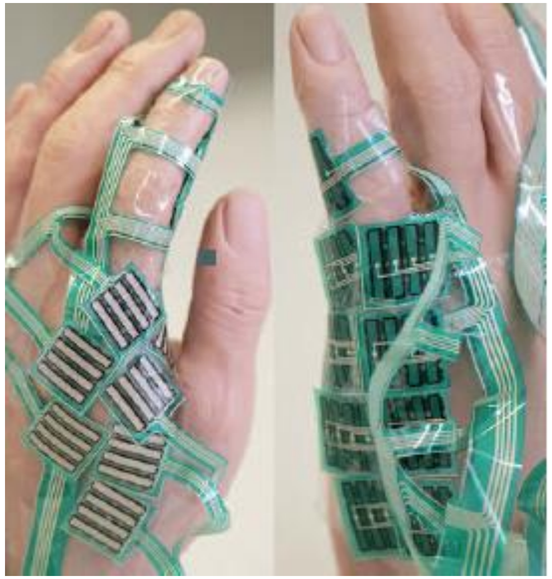
PhD thesis working towards realistic human-robot handshaking:
Wang, Z. (2010). High-Fidelity Haptics in Multimodal Human-Robot Interaction. Technische Universitat Munchen.
https://mediatum.ub.tum.de/doc/977442/977442.pdf

Areas of research:
4. Grasp control
3. Hand synergies

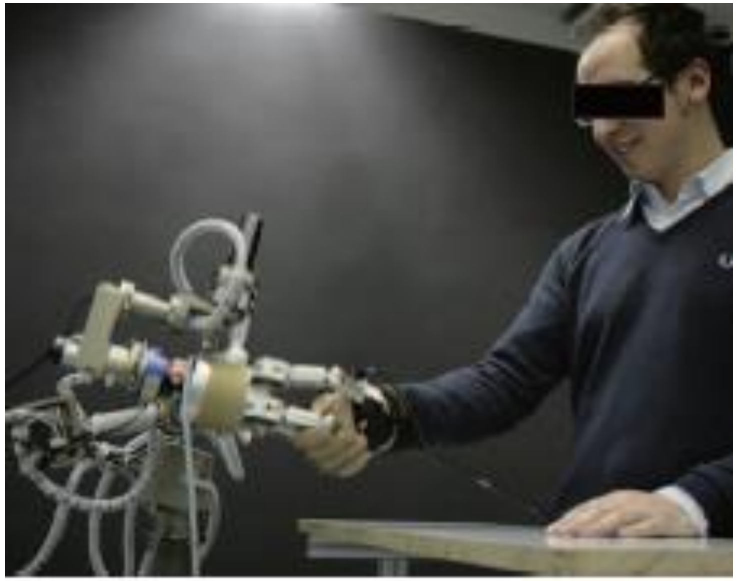
LSR Group at TU Munich: Tekscan

Some work done on haptic rendering of **hand dynamics**. Develop Tekscan system for evaluation of human-human handshakes. Tekscan sensors are attached to the sides of the palm, to evaluate grasp forces and pressure profiles here (see photo). Highlights the **importance of the sides of the palm** for handshakes.

They attempt to map their findings to a robot hand. However, they use a 3-finger BarrettHand (see photo). The robot hand lacks the required sophistication and this work is **left unfinished.**



Tekscan sensors placed on sides of palm, for handshake evaluation

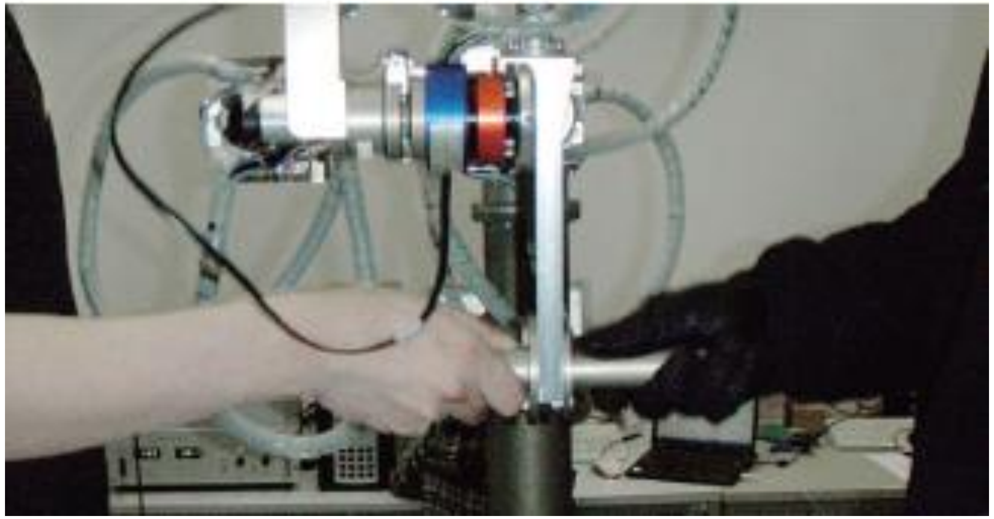


Shaking hands with the 3-finger BarrettHand

Tekscan glove for handshake characterisation (in thesis):
Wang, Z., Hoelldampf, J., & Buss, M. (2007). Design and performance of a haptic data acquisition glove. Proceedings of the 10th Annual International Workshop on Presence., 349–357. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.573.7566&rep=rep1&type=pdf

Areas of research:
6. Robot arm control
5. Arm stiffness

LSR Group at TU Munich: Arm control + VR



For evaluation: double-sided bar on robot. Can compare mediated human handshakes to robot-driven handshakes

Develop HMM-based robot arm controller, designed to respond to human arm movements in a realistic way. To evaluate, install **double-sided end effector** on robot (above). Participant doesn't know if he is shaking hands with experimenter (robot is passive) or robot.

Shaking hands in virtual reality

Also look at **virtual reality** aspects, placing the haptic robot handshake in a virtual environment.

HMM approach to control of arm for handshake (also in thesis):
Wang, Zheng, Angelika Peer, and Martin Buss. "An HMM approach to realistic haptic human-robot interaction." World Haptics 2009. IEEE, 2009. http://dx.doi.org/10.1109/WHC.2009.4810835

Areas of research:
1. Skin

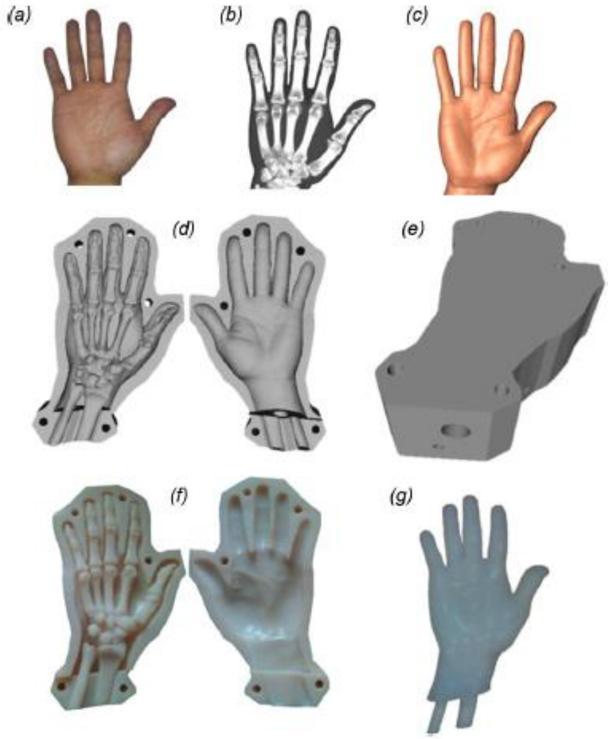
Towards human-like touch

Different focus: working towards creating a **passive** prosthetic hand that feels indistinguishable from a human hand. Preliminary testing asking participants to select most human-like silicone **hardness** and **skin temperature**. Fabricate silicone hand with embedded heaters. With and without **bone** structure (photo).

Experiment: user places arm behind a screen (photo). Has to decide whether a touch is from human or artificial hand. Short simple touch to the arm (no sliding etc).

Results show that participants **struggle to tell the difference** between the real and artificial hands.

Experimental setup



Fabrication process for artificial hands

Cabibihan, J. J., Joshi, D., Srinivasa, Y. M., Chan, M. A., & Muruganantham, A. (2015). Illusory sense of human touch from a warm and soft artificial hand. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 23(3), 517–527. http://doi.org/10.1109/TNSRE.2014.2360533

Earlier paper looking at characterization of handshakes:
Cabibihan, J. J., Pradipta, R., Chew, Y. Z., & Ge, S. S. (2009). Towards humanlike social touch for prosthetics and sociable robotics: Handshake experiments and finger phalange indentations. Springer LNCS 5744, 73–79. http://doi.org/10.1007/978-3-642-03983-6_11

Areas of research:
6. Robot arm control
5. Arm stiffness

Handshake Turing Test

Concept: user should not be able to tell if he is shaking hands with a person or a robot.

Most examples in the literature have the user hold on to a handle, thus focusing on the kinesthetic (arm) elements. The handle is either controlled by a human or by a robot. Thus, all aspects of the hand can be ignored.

These studies allow for focus on arm impedance and arm control algorithms.

We note that the human-like touch (Cabibihan) is also working towards this same goal, but from the opposite direction.

Avraham et al use two Phantom haptic controllers to render real and virtual handshakes

Main reference:
Avraham, G., Nisky, I., Fernandes, H. L., Acuna, D. E., Kording, K. P., Loeb, G. E., & Karniel, A. (2012). Toward Perceiving Robots as Humans : Three Handshake Models Face the Turing-Like Handshake Test. IEEE Transactions on Haptics, 5(3), 196–207. http://dx.doi.org/10.1109/TOH.2012.16

Karniel, A., Avraham, G., Peles, B.-C., Levy-Tzedek, S., & Nisky, I. (2010). One Dimensional Turing-Like Handshake Test for Motor Intelligence. Journal of Visualized Experiments, 46, e2492. http://doi.org/http://dx.doi.org/10.3791/2492

Turing test for simplified haptic interaction (1dof slider)
Feth, D., Groten, R. K., Peer, A., & Buss, M. (2011). Haptic Human–Robot Collaboration: Comparison of Robot Partner Implementations in Terms of Human-Likeness and Task Performance. Presence, 20(2), 173–189. http://doi.org/10.1162/pres_a_00042

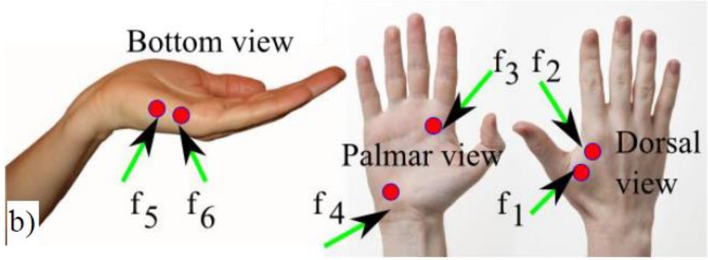
Other interesting papers

Areas of research:
6. Robot arm control
5. Arm stiffness
4. Grasp control
3. Hand synergies
2. Hand shape
1. Skin

Melnyk, A., Borysenko, V. P., & Henaff, P. (2014). Analysis of synchrony of a handshake between humans. IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM, 1753–1758. http://doi.org/10.1109/AIM.2014.6878337

Paper looking at human-human handshaking with instrumented glove, to measure forces on the hand and also hand movements.

Areas of research: 4, 6



Melnyk et al, location of force sensors on glove

Klatzky, R. L., Pawluk, D., & Peer, A. (2013). Haptic perception of material properties and implications for applications. Proceedings of the IEEE, 101(9), 2081–2092. http://doi.org/10.1109/JPROC.2013.2248691

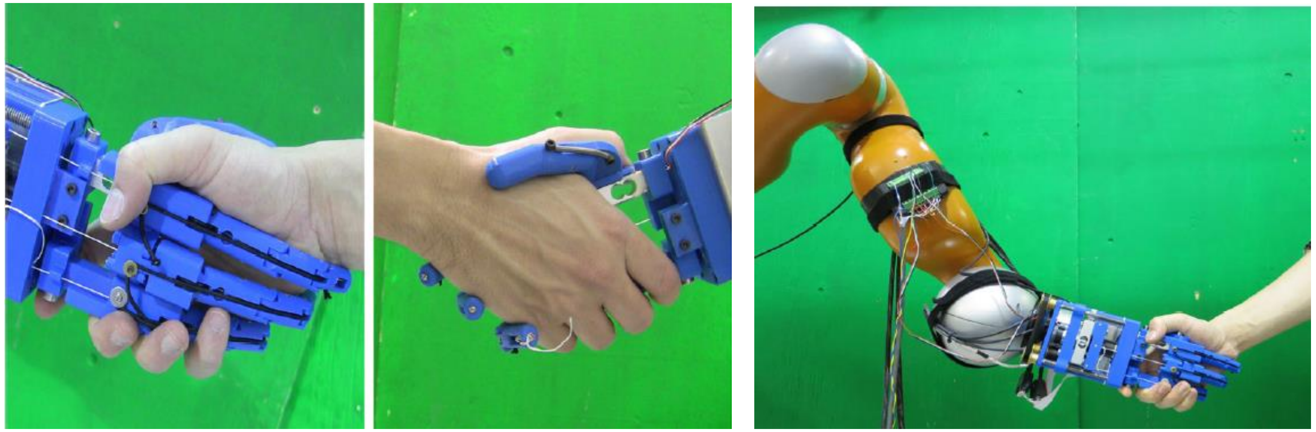
Paper mostly about haptic rendering of material properties, so relatively low-level, but an interesting paper.

Areas of research: 1. Skin

Pedemonte, N., Laliberté, T., & Gosselin, C. (2015). Design, Control, and Experimental Validation of a Handshaking Reactive Robotic Interface. Journal of Mechanisms and Robotics, 8(1), 011020. http://doi.org/10.1115/1.4031167

Develop custom robot hand, mounted on 7DoF KUKA robot. Evaluate it in handshaking experiments. Underactuated tendon-driven hand. Participants asked to shake hands with system and comment on experience, while force and displacement are measured.

Areas of research: 2-6 (but not rigorously)



Pedemonte et al, details of robot hand and arm

Areas of research:
7. Human intent
6. Robot arm control

Katsu Yamane, Disney Research Pittsburgh

Build dataset from human-human passing

Use HMM approach to train robot to mimic receiving behaviour

Looking at natural human-robot passing interactions. They build a database of human-human passing motions using optical tracking. This is used as a training set for the robot, using a HMM approach to predict the state of the user and respond accordingly. Perform passing interactions between human and robot.

Yamane, K., Revfi, M., & Asfour, T. (2013). Synthesizing object receiving motions of humanoid robots with human motion database. Proceedings - IEEE International Conference on Robotics and Automation, 1629–1636. http://doi.org/10.1109/ICRA.2013.6630788

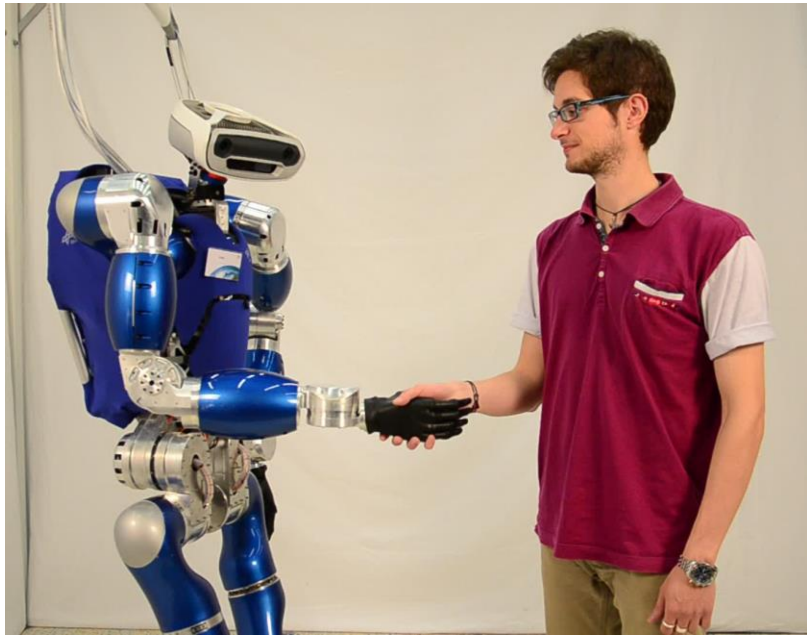
Areas of research:
6. Robot arm control

DLR: Generation of cyclic trajectories with limit cycles

DLR present a novel controller design for generating cyclic arm movements that will adapt to external perturbations, implemented on the sophisticated torque-controlled humanoid robot TORO. Given a desired trajectory, a stable limit cycle is generated that will follow this trajectory. After perturbations, the robot returns to the limit cycle.

As a demonstration, they carry out a human-robot handshake (right), where the intensity of the robot arm oscillations are controlled. As the robot is torque-controlled, the resulting trajectory is affected both by the human and the robot.

This is demonstrated in https://youtu.be/LBeml9AmTT4?t=83



Garofalo, G., Ott, C., & Albu-Schaffer, A. (2013). Orbital stabilization of mechanical systems through semidefinite Lyapunov functions. *2013 American Control Conference (ACC)*, 5715–5721. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6580733

Beyond the state of the art

We have identified two key areas where Disney will contribute to going beyond and improving on the current state of the art.

The Handshake Turing Test

So far, the Handshake Turing Test has been performed with focus on arm control and arm dynamics. A Touch Turing Test for mimicking the 'feel' of human skin has also been considered.

Within the scope of SOMA we wish to take this notion further, looking at aspects of **hand shape**, **hand synergies** and **grasp control** in the context of a Handshake Turing Test.

Our ultimate long-term goal is to have the user directly shake hands with a human and a robot hand, and for the two to be indistinguishable. This is highly ambitious, and has not been done before. In the nearer future, this provides guidelines and direction for our research.

From pHRI to cHRI

Central to the field of physical human-robot interaction (pHRI) are issues of safety and dependability. However, intrinsically safe soft and compliant robots mean that we no longer have to focus on these issues.

Thus, we can shift our efforts more towards a goal of **comfortable human-robot interaction** (**cHRI**). This involves both the physical aspects of the interaction and the higher-level issues of robot planning, control and awareness. Within the field of affective haptics, there is some work in understanding what humans are comfortable interacting with, but in robotics and in particular soft robotics this area appears to be largely unexplored.