Contact Pressure Distribution as an Evaluation Metric for Human-Robot Hand Interactions

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ABSTRACT

Soft robotic technologies are paving way for physical human-robot hand interactions, creating a need for structured evaluation metrics for robot hands. We propose that the contact pressure distribution of the grasp should be used as a hand benchmark both for naturalness and comfort, and present our initial work in this direction. We describe an experimental setup for measuring the contact pressure distribution, and present a case study comparing the pressure distributions from a robotic hand and a human hand. The grasping force of the human hand is ten times greater than the robot, but the robot hand produces higher peak contact pressures and smaller contact areas.

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1 INTRODUCTION

The creation of robotic companions that entertain or interact with humans, or aid the disabled or elderly, is a long-standing vision among roboticists. It can build on results from the rapidly developing field of soft robotics [21], where advances in compliant hand designs [4, 6, 10] hold the promise of more natural and human-like interaction than with rigid articulation. With regards to metrics for safe physical Human-Robot Interaction (pHRI), much existing work has been concerned with pain (algometry) and injury (the Abbreviated Injury Scale). In contrast, this work is concerned with metrics such as naturalness and comfort which lie below the level of pain or injury, but which are key to a successful human-robot social touch or co-working interaction.

A handshake is of particular interest as an important human social interaction. This work investigates the measurement of the contact pressure distribution during a human-robot handshake, as a benchmark for measuring naturalness and comfort. Human hands are able to exert significant forces on the environment (~500 N). However, the compliance of the palm and fingers, as well as the ability of the grasp to adapt and conform to different object shapes, means that the contact area between a hand and a held object is large, and the contact pressure is fairly equally distributed without peaks. We propose that contact pressure distribution of a handshake can inform robotic hand design in two ways - to mimic the pressure distribution of a human hand, and to ensure the peak contact pressure does not exceed a comfort threshold.

2 RELATED WORK

Physical Human-Robot Interaction (pHRI) [5, 11] is an emerging field that has been enabled by multiple advances in robotics including lightweight robots, variable stiffness actuators, impedance control and soft-material robots. Work concerned with human safety, e.g. in close co-working environments, include collision/impact studies [12, 19] and contact pressure algometry [16]. Standardization efforts include [13] which is an ISO standard for personal care robots, [15] which describes requirements for safe human-robot co-working, and standards under development [14].

Different aspects of human-robot handshaking have been studied. Giannopoulos et al. [9] present a virtual human-robot handshake system with a focus on arm control. Participants shake hands with a metal rod instead of a robot hand, so that only arm control is evaluated. Pedemonte et al. [18] develop a system for human-robot handshaking including a robot arm controller, a custom hand and a hand controller. The complete system is evaluated in a user study. Tsalamlal et al. [22] look at how the perceived affective properties of a human-robot handshake change as the grasping force and arm stiffness are varied, and also with different robot facial expressions.

In the ergonomics literature, contact pressure distribution has been used as an evaluation metric for human hands [3], and commercial systems for measuring the contact pressure distribution in a grasp are available [17]. Contact pressure has also been proposed as an evaluation for soft robotic grippers [8]. This paper proposes that contact pressure distributions should be used as a benchmark for physical human-robot hand interactions.

3 MEASURING CONTACT PRESSURE

A system is required for measuring the contact pressure resulting from hand interactions. As a benchmarking metric, the system should be readily adaptable to different robotic hands which could differ in size, morphology and actuation. It is therefore preferable to sense the contact pressure on the object that is grasped, rather than on the robot hand.

The scenario we wish to study is human-robot hand interactions, and we initially experimented with sensorization of the human

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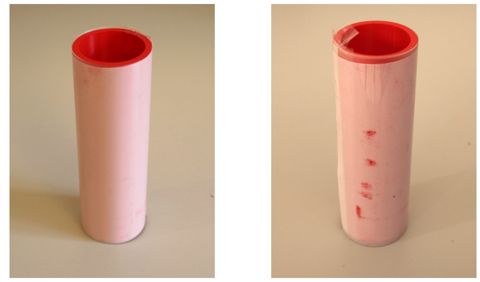
(a) (b)

Figure 1: Pressure sensitive glove with Tekscan Grip System. Although this works well for human-human interaction, the limited sensing area makes it unsuited for robot hands with varying morphologies.



(a) (b)

Figure 2: Cylinder sensorized with Fujifilm Prescale pressure-sensitive film. (a): before applying pressure; (b): after being grasped by Pisa/IIT SoftHand as shown in Fig. 3(b)

hand using a pressure-sensitive glove with tactile sensors (Tekscan Grip System) as has been described in the literature for studying human-human hand interactions [23]. The glove is shown in Fig. 1. It is not feasible to sensorize the entire area of the glove, so sensors must be placed in the areas where contact will occur. For human hands with small variations in size and shape this is acceptable, however we found that for robot hands with varying morphologies and actuation it is difficult to devise a single sensor placement that will work in every case. It is imperative that the contact pressure at every contact point is measured, otherwise we cannot guarantee that the peak contact pressure lies below some safety threshold.

For this reason, we instead take the more general test case of a sensorized cylinder as a starting point. This aligns with work from NIST on developing performance metrics for robotic grasping, where grasping forces are measured using sensorized cylinders [1]. Although we initially consider cylinders, it is also advantageous if our test setup can be readily adapted to other shapes.

A rigid hand grasping a rigid object will result in a discrete set of infinitesimally small contact points. As the compliance of either the hand or the object increases, the contact area will also increase which will lead to a decrease in the contact pressure. Thus, pressure distributions resulting from interactions with a rigid test object represent the worst-case scenario and should be considered in our benchmarking setup.

Electronic tactile sensing systems for sensorized cylinders are available, including the Tekscan I-Scan pressure mapping system and sensorized cylinders for ergonomics research such as the Manugraphy system [17]. However, for systems of suitable dimensions their spatial resolution is relatively low (>2 mm). The flexibility of these systems is also limited: for the Manugraphy sensor the test cylinder is fixed. Although the Tekscan sensor can be wrapped around different cylinders, it is difficult to use it for other geometries. Moreover, the price point of these systems is relatively high ($20k+).

Instead, we use a pressure sensitive film (Fujifilm Prescale, [7]) to create a sensorized cylinder. The film is single use, and changes color with the applied contact pressure. An image processing algorithm is used to compute the pressure from the resulting color. Fig. 2 shows the sensorized cylinder before and after grasping it.

The Prescale film has a high spatial resolution (0.1 mm). The dynamic range of the film is relatively low, and different sensitivity grades are available depending on the required pressure sensing range. We find that the 'LLLW' grade, with a rated sensing range between 0.2 and 0.6 MPa, is well suited for human-robot hand interactions.

The film can be cut to shape using a laser cutter, which offers the potential to sensorize different object shapes provided their shape has zero Gauss curvature. The single-use nature of the film means that repeated experiments are time-consuming compared to an electronic sensing system, but for small numbers of experiments the cost of the film is an order of magnitude smaller than the electronic sensing systems.

4 CASE STUDY: PRESSURE DISTRIBUTION OF THE PISA/IIT SOFTHAND

To illustrate the use of contact pressure distribution as an evaluation metric for robot hands, we measure the contact pressure of a robotic hand when grasping a rigid cylinder. We compare this to the pressure distribution resulting from a human grasping the same cylinder.

The Pisa/IIT SoftHand [4] is a soft anthropomorphic robot hand with a single motor synergistically actuating 19 degrees of freedom. The hand is used in a number of research projects (e.g. [2]), and a version of the hand is commercially available through QB Robotics [20]. The hand has a rated grasping force of 50 N, and a rated holding force of 100 N (due to friction in the actuation system). The hand is 'soft' as it is actuated through soft synergies i.e. the pose of a grasp is a result of interactions with the object and environment. Most parts of the hand are made from rigid plastic, but it is covered by a soft glove.

Pedemonte et al. [18] report a median value for handshake grip strength of 25 N, with 50 N representing a strong handshake. This aligns with the rated grip strength of the SoftHand.

In this experiment, we compare the pressure distribution resulting from a human (male, aged 27) grasping at maximum force (grasping force 500 N, measured using a Jamar Dynamometer) with the pressure distribution from the SoftHand grasping at maximum force (50 N). We measure the contact pressure on a rigid 3D-printed

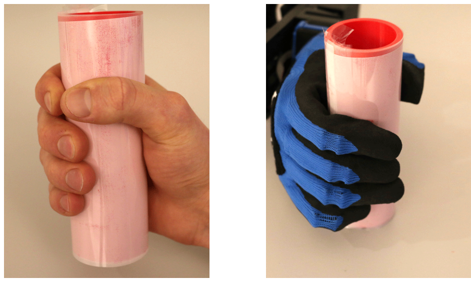

(a) (b)

Figure 3: Photos showing the cylinder-grasping experiment. (a): human, (b): robot.

cylinder with diameter 50 mm and length 150 mm. Fig. 3 shows the grasping experiment.

The resulting pressure distributions are presented in Fig. 4. It is seen that for the human grasp there is a larger contact area and a smooth pressure distribution with no localized pressure peaks. In contrast, the robot hand produces a more localized distribution. Although the human grasping force is an order of magnitude greater than the robot grasping force, the peak contact pressure in the robotic grasp is higher. The peak contact pressure exceeds the dynamic range of the LLLW grade film, so we cannot determine its precise value.

ISO15066 Robots and robotic devices — collaborative robots [15] reports the lowest pain threshold for contact pressure on the human hand to be 2 MPa. We would expect the threshold for comfortable interactions to be significantly lower than this, but a thorough study has not been conducted. Through informal experiments with the SoftHand we have observed that at maximum grasping force (50 N) the hand is sufficiently strong to cause discomfort and pain due to the high localized contact pressure peaks.

Note that the pressure distribution from the human grasp is with a grip strength that is an order of magnitude greater than a strong handshake, while the distribution from the robot hand is with a grip strength equivalent to a strong human handshake. As a first-order approximation we can assume that the contact pressure scales linearly with grasping force, with no changes to the contact pressure distribution. We can use this assumption to interpret the results in Fig. 4, implying a large difference between the human and robot pressure distributions.

5 DISCUSSION AND CONCLUSION

This paper proposed that contact pressure distributions should be used as an evaluation metric for physical human-robot hand interactions, and presented preliminary results in this direction. The results show that for safe and comfortable human-robot hand interactions it is not sufficient to control the overall grasping force; the contact pressure must also be considered. This is important for designing safe interactions, and could also be used as a metric for designing interactions that are more realistic and human-like. Our proposed experimental setup uses the Prescale pressure sensitive film which is readily available and performs well, although an automated electronic system would of course be preferable. We are working in collaboration with Pisa/IIT to investigate how contact pressure distribution can inform hand design, through the H2020 project SOMA [2].

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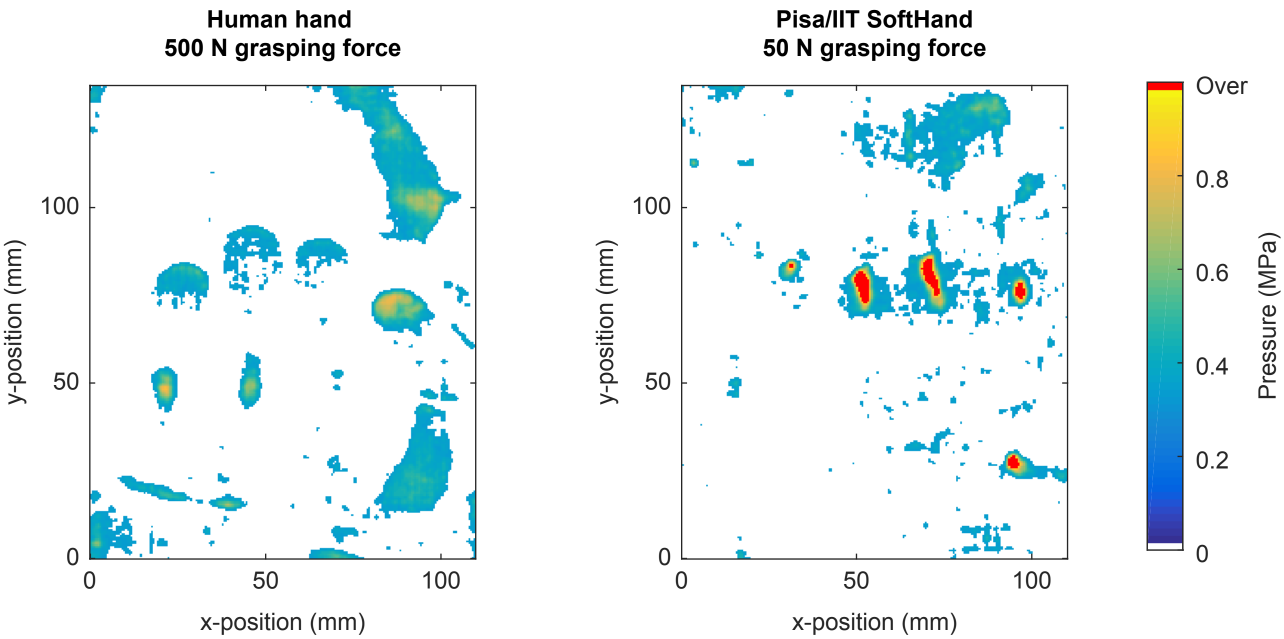

Figure 4: Pressure distributions for human (left) and robot (right) hands grasping cylinder with maximal force. The human has a grasping force an order of magnitude greater than the robot. The x-direction goes along the length of the cylinder, the y-direction wraps around it. The thumb comes up from the bottom of the plot, and the fingers come down from the top. It can be seen that the human hand produces a larger contact area, without localized high-pressure peaks. Note that the red areas correspond to pressures outside the dynamic range of the pressure sensor, so the exact value of the pressure here is not known.

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