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Published in:
2022 IEEE 5th International Conference on Soft Robotics (RoboSoft)

DOI:
10.1109/RoboSoft54090.2022.9762174

Publication date:
2022

Document version:
Accepted manuscript

Citation for published version (APA):

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WISARD: Weight Informing Soft Artificial Robotic Dermis

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Abstract—As robots are rapidly approaching the status of partners rather than tools, nonverbal communication becomes increasingly important to ensure smooth operation. In this paper, we focus on a scenario where a person receives an object of unknown weight from a collaborative robot. As humans, we are used to reading the body language of people around us. When a human lifts an object and hands it to us, we therefore expect to see a suitable reaction in the person’s effort and strain. This nonverbal signal relays information to us about the approximate weight of the object, which we use for applying an appropriate force to smoothly receive the object. Inspired by this nonverbal collaborative task coordination in humans, we propose a concept for a soft robotic addition to a collaborative robot arm. WISARD (Weight Informing Soft Artificial Robotic Dermis) emulates tensed muscles to visually inform a human receiver of the approximate payload weight. Using built-in sensors of the robot arm, inflation of the pouches on the WISARD is automatically correlated with the weight of the lifted object. WISARD was tested in a robot-human handover experiment to determine if it leads to an increase in physical performance. Results indicate that subjects can use the WISARD to predict the weight of objects lifted by the robot arm and react appropriately when receiving objects of unknown weight. The most noticeable improvement was found for the reception of the heavy object. In an online video survey, we also found WISARD to increase the perceived warmth of the robot arm. The study proposes a novel use of pneumatically actuated soft robotics technology as a means to augment traditional robots with nonverbal signalling capabilities to improve human-robot collaboration.

Index Terms—human-robot interaction, soft robotics, nonverbal communication, human-robot collaboration, collaborative robots

I. INTRODUCTION

When a person hands over an object to another person, relevant information about the weight of the object is disclosed in the giver’s body language. This enables the receiver to adjust their expectation about the weight of the object and apply an adequate force from the outset during the reception phase. On the contrary, when a robot arm hands over an object to a person, this important information is not automatically transferred. This can lead to an incorrect estimation of the weight of visually deceptive objects of varying weight (e.g., a packed suitcase) resulting in too little or too much force being applied, which creates an unsafe, inefficient, and unpleasant handover.

To tackle this problem, we propose an aid, WISARD (Weight Informing Soft Artificial Robotic Dermis), that can be attached to a robot arm to visually communicate the approximate payload weight to a human user. The aid consists of two soft robotic sleeves with inflatable silicone pouches (Fig. 1). The two sleeves are attached to a robot arm analogously to a skin layer with the inflatable pouches placed as the muscles of a human arm (more specifically biceps and brachioradialis). When an object is lifted by the robot arm, the soft “muscles” inflate, to a size that corresponds to the weight of the lifted object. WISARD can facilitate efficient and intuitive transmission of weight information to a human user, and increase safety and efficiency in collaborative work processes. Possible applications of the system include cobot use scenarios in dynamic work environments where efficient and intuitive transmission of weight information to a
II. BACKGROUND

Due to the rapid rise of Industry 4.0 (I4.0) and the surge in collaborative robot use in SMEs, robots are increasingly required to work in close proximity to humans. The ability of robots to communicate efficiently with humans is therefore in high demand, as it is a prerequisite to safe and efficient implementation of robots in co-working environments. Prior work has shown that soft robotics technology encourages distinct interaction behaviors from humans and that movements and changes in shape in simple soft robotic systems can be interpreted as socially communicative [1]–[6]. Research also shows nonverbal communication (NC) to be essential to successful human-robot interaction (HRI) in general [7]–[11]. NC contributes to people feeling safe with a robot, it can add anthropomorphic qualities, and can help people form better and more intuitive connections and interactions with robots [2]. Studies also show that a robot’s body language, behavior, and gestures affect whether or not it is deemed appropriate for a given task that is performed in close vicinity of a human. For instance, two equally effective, but qualitatively different, person tracking strategies for mobile robots were rated differently in terms of social acceptance in [7], [8]. Similarly, studies have shown that interaction with a robot in a collaborative task is improved by planning the trajectory in a way that better expresses the robot’s intent over a path calculated solely based on efficiency and obstacle avoidance [9], [10]. Another study [11] found that implementing gestural confirmation feedback from a robot can increase task accuracy in a pick-and-place task. Gaze is an NC modality that has been shown to be salient for a number of human-robot interaction scenarios [13], [14]. The importance of gaze illustrates well the potential of using NC signals that humans perform unconsciously that are tacitly and intuitively picked up by other humans to increase a robot’s performance in a collaborative task. Studies show, for instance, that gaze can be used to balance participation in games [15], [16]. When a robot guides a human participant to find hidden objects, the use of gaze and pointing can also be more effective than verbal cues [17]. Gaze cues can also help a human receiver anticipate when and where a robot-to-human handover will occur [18].

The effects of anthropomorphizing a robot (i.e., making it look more like a human) on HRI have also been extensively studied. In general, studies indicate that embodied robots with anthropomorphic shapes have a positive effect [19]. Anthropomorphism, for example, has been found to improve customer satisfaction in interactions with a service robot [20].

The prior research summarized above suggests that human- to-human social nonverbal cues can be used to boost the performance in human-robot interaction and collaboration. While various nonverbal cues (such as gaze and gesture) have been used, a bio-inspired soft visual aid has not previously been investigated. Prior work also supports that changing the appearance of a robot arm by equipping it with anthropomorphic “muscles” can have a positive effect on people’s evaluation of the robot’s appearance and behavior, as it makes it appear more human-like.

III. THE WISARD SYSTEM

The WISARD system consists of two soft robotic sleeves with inflatable silicone compartments along with an electro-pneumatic system that controls inflation. The sleeves are attached to a collaborative robot arm to emulate expansion similar to the tensioning and relaxation of the biceps and brachioradialis. The soft sleeves’ levels of inflation are adjusted linearly with the force measured by the sensor in the wrist of the robot arm. When the robot arm picks up an object, it measures the vertical force exerted by the object and the soft sleeves inflate to a corresponding size, allowing the human receiver to anticipate the object weight. This allows the receiver to prepare for a particularly heavy or light object. Fig. 2 shows the experimental setup where three visually identical objects of different weights are positioned next to the robot arm equipped with WISARD.

A. Soft Robotic Sleeves

Two sleeves of different sizes were designed to fit onto the links of a Universal Robots UR5e robot arm. For each sleeve, we used a simple shape and a discrete yet clearly visible color (dark red). The inflated shape was purposefully chosen to resemble an abstraction of a tensed muscle, similar to a cartoon illustration. We chose this design for its simplicity and to avoid the uncanny valley [21]—the notion that a robot elicits an eerie feeling if resembling a human too closely without being indistinguishable. To ensure a reasonable range of visibly different inflations, the WISARD prototype was calibrated based on the weights used in the handover experiment. Fig. 3 shows the three levels of inflation for the used weights.
Each sleeve was cast from silicone (Ecoflex™ 00-30) in two layers which were laminated together. Fabric was embedded in the bottom layer to act as a strain limiting layer, along with the hook and loop straps that were sewn to the fabric for mounting the sleeve on the robot arm. Fig. 4 illustrates the fabrication process, which summarizes as follows:

**Step 1:** The base fabric layer was cut to size and the hook and loop bands sewn on.

**Step 2:** Silicone was mixed manually at a 1:1 ratio by weight and Silc Pig™ pigments added.

**Step 3:** The mixture was degassed in a vacuum chamber.

**Step 4:** The silicone was poured slowly into 3D printed molds in a thin stream (to avoid introducing air bubbles).

**Step 5:** Heat curing was performed in an oven at 80°C for an hour.

**Step 6:** The two cured halves were laminated using liquid silicone as a glue and heat cured again.

**Step 7:** Finally, a small hole was made at the seam with a needle, and silicone tubing pushed through and secured in place with Sil-Poxy™ glue.

### B. Electro-Pneumatic System

WISEARD was controlled by the electro-pneumatic system shown in Fig. 5. It consists of an Arduino Uno with an attached motor shield. Three mini electric pneumatic pumps were used to inflate the sleeves along with two solenoid valves for deflation. Two pumps were attached to the large sleeve to balance the inflation speed with the single pump on the small sleeve. Only two solenoid valves were used since the difference in deflation was not as noticeable nor consequential.

### C. Control Strategy

The inflation level used open-loop control based on the input from the built-in force-torque sensor of the robot arm. The sensor was used to measure the approximate weight of the lifted object. Based on the control strategy shown in Fig. 6, the robot arm was programmed to perform a predefined movement for the handover and transmit data from the force-torque sensor to the Arduino after picking up or releasing each object for the sleeve-level inflation.

### IV. HUMAN–ROBOT EXPERIMENTS

To evaluate the communication and perception of WISEARD, we conducted two experiments. Due to COVID-19 lockdowns, the first experiment was designed as an online survey that used an animated video. The second experiment was conducted physically with participants in the SDU Industry 4.0 Lab where the robot system was setup (Fig. 2).

### A. Hypotheses

Based on prior work outlined in Section II, we formed the following hypotheses, which we tested in the two experiments:

- **H1** The addition of the WISARD sleeves will make a collaborative robot arm appear warmer and more competent.
- **H2** During a robot-to-human handover, visual feedback from the WISARD system will result in less deflection of the hand when a person receives an object of unknown weight compared to receiving the object without this feedback.

### B. Methods and Procedures

Both the online survey and the physical experiment used a within-subjects study design. In the online survey an animated robot arm was shown to the participant performing the
Fig. 6. Flowchart illustrating the control strategy of the UR5e robot arm during the handover task implemented for testing WISARD. The control strategy is based on a fixed sequence of movements for the robot controlled by a physical switch. The switch is implemented to ensure participants are safely prepared before the robot hands over each object.

handover task both without, Fig. 7(a) and with, Fig. 7(b) the WISARD present\(^2\). The participant was asked to rate each of these robots on the warmth and competence attributes of the Robotic Social Attributes Scale (RoSAS, \([22]\)) inventory (listed in Table 1).

The order of showing the robot with and without the WISARD as well as the order of the items in the RoSAS inventory were randomized.

In the physical experiment, each participant had to receive the three objects of different weights twice. First the participant received the objects in randomized order with the WISARD mounted but inactive on the robot arm. Afterwards the objects were put back to their starting position in randomized order (while the participant was looking away). The participant then had to receive all three objects in a random order again, this time with the WISARD active\(^3\).

C. Measures

1) Online Survey Measures: In the online survey we collected the following information on each participant relevant to the study.

   Student – With the survey being shared primarily among students, but also publicly on Facebook it was deemed relevant to keep track of how many of the participants were students.

   Familiarity with robots – Each participant was asked to rate their familiarity with robots on a 7-point likert scale.

   Robotic Social Attributes Scale (RoSAS) – The scale is a validated tool that is used to measure people’s impressions of a robot’s sociality. The full scale measures three main constructs (warmth, competence, discomfort) with each six subitems. For the survey we used warmth and competence but omitted discomfort. Ratings of both of these constructs have previously been shown to increase when a robot is made more human-like \([22]\). Participants rated each subitem of warmth and competence on a 7-point Likert scale ranging from "Not at all" to "Very much so". The rating question posed was: "Using the scale provided, how closely are the words below associated with the robot in the video?".

2) Physical Experiment Measures: To measure the physical performance, we video recorded the handovers from the side (as illustrated in Fig. 8) to extract the position of the hand throughout each handover. This position with respect to the initial position of the hand is referred to as the vertical hand deflection. Offline tracking of the hand was performed using the Tracker\(^4\) video analysis software. We make the assumption that less vertical hand deflection means a more successful handover in terms of efficiency and receiver experience. As a score for how successful each handover was, we calculated the cumulative hand deflection, which we define as the integral of the numerical value of the vertical hand deflection over the first second that follows after the gripper has released the object. To achieve comparable and relative score values for each weight, the hand deflection data for each weight was scaled linearly with all data mapped to fall within \([0, 1]\) before the integration was performed. A high cumulative hand deflection expresses that the hand has moved significantly from its initial position during the reception of the object. A high score thus expresses that the human receiver applied too

\(^2\)Video without WISARD: \url{https://youtu.be/YFwkb2PsNUw}

\(^3\)Video with WISARD: \url{https://youtu.be/Zhd1c6945Kg}

\(^4\)Tracker: Open source video analysis and modeling tool, \url{https://physlets.org/tracker/}

![Fig. 7. (a) Screenshot from the video without the WISARD shown to participants. (b) Screenshot from the video with the WISARD shown to participants.](image)

![Fig. 8. This was to assess their prior experience with robots.](image)

This was to assess their prior experience with robots.
little or too much force, and a good handover with proper force to maintain the object position with only minor deviation will have a low score.

D. Participants

1) Online Survey: In total, 51 subjects participated in the online survey. 26 participants were presented with the video of the robot arm without the WISARD present first, while 25 were presented with the robot arm with the WISARD attached and active first. Participants were recruited through requests shared publicly on Facebook and in a robotics class group of the University of Southern Denmark. 69% of the participants were students with the majority studying robotics. 61% rated their familiarity with robots high as a 6 or 7 out of 7. The participants’ age ranged from 20 to 70 years ($M = 30.73, SD = 12.82$) and their gender distribution was 80% male and 20% female.

2) Physical Experiment: Due to COVID-19 restrictions only 10 participants could be recruited who had permission to access SDU Industry 4.0 Lab at the time of conducting the experiment. The participants were all male students aged from 23 to 40 ($M = 26.9, SD = 4.98$).

V. RESULTS

1) Online Survey: The scores for each of the two RoSAS attributes were calculated as the average of the six subitems (Table I). Internal consistency was checked with Cronbach’s alpha [23]: $\alpha_{\text{Cronbach competence}} = 0.877$, $\alpha_{\text{Cronbach warmth}} = 0.911$, showing acceptable internal consistency above the standard 0.700 threshold. The combined factor score for all participants is given in Fig. 9. Results show no increase in perceived competence while it shows an increase in warmth at $p < 0.001$ using a paired t-test.

2) Physical Experiment: Fig. 10 shows the recorded vertical position from all participants along with the average. From the recorded video, it was determined that all handovers lasted close to one second, marked by the vertical line, and the vertical hand deflection peaked close to half a second after the object was released by the gripper at the end of the robot arm.

The averages (bold lines in Fig. 10) show that for both the medium (1122g) and heavy (1870g) objects the vertical hand deflection decreases, or remains close to constant, at the peak half a second after release, with the heavy object giving the most noticeable decrease. The light object (382g), on the contrary, shows the vertical hand deflection drops lower when the WISARD was activated.

We compared the cumulative hand deflection for each participant when lifting the light, medium, and heavy object with and without the WISARD system active. Performing a two-way repeated measures ANOVA with the scores from the experiment (Fig. 11) as the dependent variable and weight as one factor and the WISARD inactive or active as the other,
we found no statistically significant difference. However, a paired t-test on the light object alone showed a significant difference at \( p = 0.013 \), consistent with our observation that the mean vertical hand deflection dropped lower when the WISARD was active (Fig. 10).

VI. DISCUSSION

A. Interpreting the Results

Results of the online survey showed that adding the WISARD to a robot arm resulted in higher warmth ratings. This finding indicates that soft robotics parts could potentially be used aesthetically as a means to improve people’s impression of a robot, e.g., by making it more bio- or anthropomorphic.

The physical experiment results in Fig. 10 show that the average hand deflection within the first second of the handover is greater for the light object, nearly the same for the medium object, and slightly less for the heavy object when the WISARD is active. This could indicate that the WISARD improves the handover with the heavy object, does not have any noticeable effect on the handover with the medium object, and, in fact, impairs the handover with the light object. However, we may also interpret the graph as reflecting that the light object is over-lifted more without the WISARD active but is restricted because it hits the gripper, which results in only a slightly noticeable deflection, despite the force applied being too large for the light object. If this is the case, it would appear that the WISARD is beneficial for both the light and the heavy object, as the slightly downwards deflection observed for the light object expresses that no overshoot of applied force was present when the WISARD was active.

Fig. 8 shows the handover of one of the participants, and was selected to display this scenario and illustrate the hypothesis presented above. In the video, it can be seen how the light object is over-lifted, hitting the gripper while the heavier objects both drop lower without the WISARD active. The medium and heavy objects are kept close to stationary and the light object is less violently over-lifted when the WISARD provides visual information.

That no improvement was clearly visible in Fig. 10 for the medium weight object could be due to this object having a weight that is close to what people expect from it based on the visual impression it gives. The WISARD system might thus be most beneficial for objects that deviate from their expected weight.

The results can be used to address our hypotheses (H1, H2, Section IV-A) as follows: H1: From the video survey utilizing the RoSAS we confirmed that the addition of the WISARD system did increase the perceived warmth. However, it did not lead to an increase in perceived competence. Therefore only one of the conditions in H1 are satisfied. H2: Visual inspection of the graph of our results for hand deflection over time in the physical experiment supports that there was an improvement in hand deflection with the WISARD active for the heavy object. As explained, we expect that an improvement might also be found for the light object with an improved experiment setup. We did not see a statistically significant improvement in cumulative hand deflection, but this could be due to lack of statistical power (see VI-B below). Therefore, we observe that, given the limitations of this study, H2 is partly satisfied.
B. Limitations

HRI trials that use video have previously reported similar results as physical experiments under controlled conditions [24]. However, the increase we found in warmth in the online survey with videos of an animation of the robot with the WISARD added, should be replicated in a physical trial to generalize.

The main limitations of the physical experiment are the low number of participants, lack of account of improvement with training, the resolution of weights used, and restriction of overlifting due to hitting the gripper.

Despite an observable improvement in average hand deflection (Fig. 10), we did not find a statistically significant difference in cumulative hand deflection for the heavy object. This could be due to the study being statistically underpowered, as we were only able to recruit 10 participants. Hence, the statistical analysis might be unable to detect a difference that could become significant with a higher number of participants.

It is likely, that the handover performance with the WISARD active could be improved with training. In the present physical study, participants were not able to train with the system. A human receiver might need to gain experience with using the WISARD to benefit optimally from the feedback it provides. To know how many grams a specific amount of inflation translates into might take practice, and the receiver’s performance is likely to increase with use over time. Participant feedback also indicates that information provided by the WISARD was deemed useful but without experience using the system the translation of visual feedback to exact weight might have been difficult. We will investigate this human learning and experience aspect in further work.

An effect that is relevant to take into account that might also have influenced our results in the physical experiment is the size-weight illusion (SWI). The SWI describes how the perceived weight of an object is influenced by its size. That is, people will have an expectation about what weight an object has, e.g., if it is light, medium, or heavy, based on its size as well as their familiarity with it. The objects used for the study were made from tin cans with a height of 11.3cm and a diameter of 8.5cm which previously contained canned pineapple (i.e., supermarket pineapple can). The original weight of the filled pineapple can is close to 600g, which might have influenced the experiment as humans use experience to build models for the expected weight of novel items [25].

To be able to determine to what degree over-lifting is present for the light object, and is lessened by the WISARD, the objects lifted would have to be constructed in a way that allows for lifting them without them being blocked upwards by the gripper, which is not possible with the current setup.

VII. Conclusion

We presented an approach to augment robot-human handovers by implementing a signaling method inspired by implicit nonverbal communication in human body language [26] leveraging the experiential and embodied knowledge of what it means when muscles expand. In an online survey the WISARD was shown to increase the perceived warmth of a robot arm, but it had no effect on the competence factor.

A physical prototype of the WISARD was tested on 10 people. Physical improvement of handovers was not evident for all weight conditions with the WISARD system, but the WISARD appears to have benefitted the handover of the heavy object and possibly also the light object. The physical experiment consolidated the assumption that significant deflection of the hand is present when handed an object of unexpected weight.

ACKNOWLEDGMENTS

This work was supported by the University of Southern Denmark (SDU) under the Digital Autonomous Production (SDU I4.0 DAP) program. The authors thank Saeed Davoud-abadí Farahani and Mads-Christian Krüger of the I4.0 Lab at SDU for providing access to lab facilities and the robot arm and gripper used for the study.

REFERENCES


