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Embracing Acceptance: Hugging Robodies Improves Robot Acceptance by the General Population

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***Abstract*— In this short paper, we present the humanoid robotic avatar Robody and the preliminary results of a study examining the influence of physical interaction — specifically hugging — on the avatar's acceptance by the general population. We introduce the details of Robody's tendon-driven actuation system, sensing modalities, as well as operator control interface. The Robody obtains generally high acceptance and a significant increase in acceptance due to the hugging can be observed.**

I. INTRODUCTION

Teleoperated robotic avatars are gradually paving the way for applications of robots in unstructured, dynamic environments, such as domestic settings, extending beyond controlled lab environment or industrial use cases. Successful deployment of these systems in close proximity to humans in private environments, such as homes, hinges on high user acceptance rate [1], which in turn drives the frequency and retention of use, as well as effectiveness of the human-robot collaboration. Securing acceptance for robotic systems from the general population poses a significant challenge, as pre-existing beliefs and concerns about robots persist. Teleoperation of robots has the potential to address these challenges by harnessing human emotional intelligence. Furthermore, the anthropomorphic design and human-like body dynamics of robotic avatars enhance the comprehensibility and predictability of the robot's movements, thereby reducing apprehension during physical interactions [2].

Our motivation for exploring the impact of friendly physical human-robot interaction stems from our own experience of facilitating more than 4000 hugs between humanoid robots and individuals across diverse geographies (Germany, Spain, China), age groups (5 to 80 years old) and locations (elderly care residencies, trade shows, family events, universities, etc.). The positive influence of this physical interaction was qualitatively evident but has not yet been quantified. Furthermore, hugging of robots has been the focus of recent research [6], [7], [8], [9], [10], [11], but no study has been conducted with a larger sample size in a public setting.

In this paper, we conduct a user study with the objective to evaluate and assess the impact of hugging interactions on the acceptance of teleoperated robotic avatars by the general population and present preliminary results.

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II. AVATAR SYSTEM OVERVIEW

A. Avatar

Robody is a tendon-driven, bi-manual humanoid robot that emulates the human body's musculoskeletal system. As a remote robotic body or avatar, Robody allows humans to achieve a physical presence from a distance. Its artificial muscles and tendons enable it to closely replicate human morphology, matching the degrees of freedom of the human neck, shoulders (without the shoulder blade), and elbows. Robody's links are actuated by a set of artificial muscles and tendons, using series elastic actuators. This design permits passive energy storage in the muscles, rendering the robot inherently compliant. The combination of anthropomorphic morphology and these properties proves advantageous for full-body motion mapping during teleoperation, as well as collaborative object manipulation and other close physical interactions with humans.

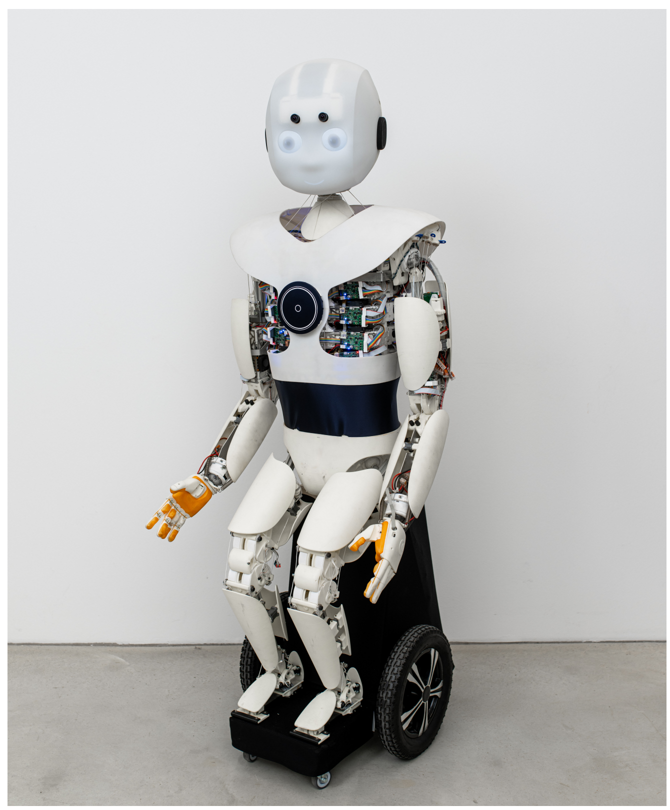

Fig. 1. Tendon-driven humanoid robotic avatar Robody

Robody's artificial muscle units enable antagonistic-protagonistic muscle activation for smooth and compliant movements. They comprise a BLDC motor surrounded by a torsional spring that pulls on a dyneema tendon, generating up to 300 N of tendon force. The custom motor driver board implements PWM, position, velocity motor control modes, as well as provides current muscle's length and force as feedback. The robot's joints are controlled by various combinations of muscle units, with joint position feedback provided by an array of 3D magnetic sensors or magnetic angle sensors[4]. The finger and spine joints, however, do not have feedback mechanisms. Low-level motor control is managed by a Terasic DE10-Nano Kit featuring a Cyclone V SoC FPGA. IceBus, a custom RS485-based bus protocol, facilitates communication between the FPGA and the motor driver boards, while sensor data is collected via the I2C bus. High-level control of Robody utilizes the ROS1-based system (melodic upward), with joint-level control based on CARDSflow, an open-source framework for designing, simulating, and controlling cable-driven robots [3]. CARDSflow calculates the required tendon length for achieving desired joint angles, with RViz and RQT plugins available for visualization and interaction.

Robody's torso is equipped with a speaker and an omnidirectional microphone, as well the stereocamera (Sony IMX477) with 180° fisheye lenses to facilitate bidirectional audio-visual connection to the operator.

Finally, the robot is placed on a wheeled platform with two actuated main wheels and 4 castor wheels and is battery-powered.

B. Operator System

The operator user interface is implemented in Unity3D as an Android application deployable on Meta Quest 1/2/Pro. The operator application implements an inverse kinematics solver, given the pose of operator's endeffectors, and transmits the target joint targets to the robot, a VR controller interface for robot's finger control and locomotion, a stereocamera image fisheye-lens undistortion mechanism and viewer and a bi-directional audio connection.

C. Communication Layer

Communication between the robot and the operator is implemented as ROS publisher-subscriber architecture, based on ROS TCP Endpoint[1] and ROS TCP Connector[2] by Unity Technologies.

III. STUDY DESIGN

A. Objective

The study seeks to explore the influence of hugging on the general public's perception of robotic avatars.

B. Materials and Methods

The experiment was conducted during a 5 day industrial fair, where the Robody was exhibited as part of an industrial partners booth. Visitors were asked to interact with the robotic avatar through hugging. Our study participants were randomly selected from the visitor crowd or approached post hugging. The participants filled in the survey on a tablet that was handed to them. We a priori aspired a sample size of 300 (150 before resp. after) to obtain a robust effect size. Data on gender, age range and educational background were collected as well as questions rated on a 7-part Likert scales aiming to measure perceived likability, eeriness, and intention to purchase derived from [5]. The data was analysed using python 3.10.11 with the pandas and pingouin.ttest packages.

C. Results

In total, 208 surveys have been collected, 105 before and 103 after hugging during the event. Demographics: 132 participants identified as male, 63 as female, 4 as diverse and 9 didn't provide an answer. 31 had previously seen Robody, 177 have not. Participants had predominantly a university degree (108), 12 have completed high school, 7 an apprenticeship, 9 completed primary education and 22 answered "other". 86 had no robotics experience, 33 had high robotics experience. Negatively phrased questions were inverted to calculate aggregate scores.

All reported values are mean$\pm$standard deviation, t-tests are unpaired, use a H1 hypothesis of greater (likability, purchase intent) and lower (eeriness) mean after hugging respectively and the 95% confidence interval is reported together with the p-value (p) and power (P). Overall, likability was very high (5.83 ± 1.55), slightly higher after hugging (5.91 ± 1.57) and lower before (5.75 ± 1.52), but not significantly $([-0.02, \infty], p = 0.067, P = 0.44)$. Eeriness was low (2.53 ± 1.56), and significantly decreased from before (2.66 ± 1.58) to after (2.39 ± 1.54) hugging $([-\infty, 0.34], p = 0.016, P = 0.69)$. Finally, purchase intent was also high (5.06 ± 1.79) and significantly increased $([0.02, \infty], p = 0.037, P = 0.55)$ from before (4.95 ± 1.80) to after hugging (5.16 ± 1.79). Combining all questions together, with eeriness inverted, robodies have a high (5.42 ± 1.69) acceptance and hugging significantly $([0.09, \infty], p = 0.0014, P = 0.91)$ increases it from before (5.32 ± 1.69) to after (5.52 ± 1.69) with a strong effect size.

D. Discussion & Future Work

Lower number of collected surveys (208) as opposed to planned (300) impacted the robustness of data. The preliminary data still shows that hugging significantly influences the perception of the Robody positively and with a strong effect size. The increase in purchase intent and decrease in eeriness were significant, but failed to reach a strong effect size. Therefore, we did not further break down the statistics to look for effects of co-variates collected. All acceptance values were already very positive before the hugging, leaving little room towards the positive side to show a positive effect of hugging. Therefore, we plan to extend this study to further locations & events to collect sufficient data to reach a robust effect size for all categories and also to able to break it further down by co-variates.

[1]https://github.com/Unity-Technologies/ROS-TCP-Endpoint
[2]https://github.com/Unity-Technologies/ROS-TCP-Connector

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