Study of Children's Hugging for Interactive Robot Design

Joohyung Kim, Alexander Alspach, Iolanda Leite, and Katsu Yamane

Abstract— **We have developed a toy sized humanoid robot with soft air-filled modules on its links which sense contact and protect the robot and any interacting humans from damaging collisions. This robot, meant for robust physical interaction, is required to endure contact with children in the form of hugs and other playful interactions. It is therefore necessary to quantify the forces exerted during these interactions so that robots can be designed to both withstand these forces, as well as interact safely and intuitively in these situations. To quantify the range of forces exerted by children when performing both soft and strong hugs, we conduct a study in which 28 children (11 boys, 17 girls) ages 4 to 10 years old hug a pressure sensing doll while the pressure is recorded. The result of this study is a child's maximum expected hugging force (2.623 psi for our setup) during normal play. The data gathered during this study will guide the further development of our physically interactive robot.**

I. INTRODUCTION

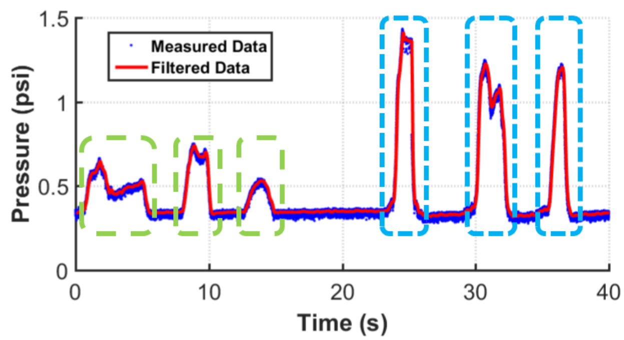
The demand for robots which can work closely and physically interact with with humans has been growing. Such robots can already be found guiding and entertaining patrons in stores and amusement parks [1], [2]. Interactive robots can also be found providing physical, educational and therapeutic assistance in homes, schools and in hospitals [3]–[5].

Robots that are expected to physically interact with humans should be designed with compliant joints and body parts that yield to prevent damage and human injury. This yielding can be passive, realized by fabrication using deformable materials, or active, achieved by using sensor data to react to both expected and unexpected contacts. A soft robot that senses contact combines these approaches to protect itself and humans during physical interaction. Soft, sensing robots like this have been developed and studied in the past. PARO [5] is a furry seal robot that responds to being held and pet, and can be found in nursing homes helping to keep our older generations socially active and engaged. Huggable [6] is another soft therapeutic robot that has a sensorized silicone skin which covers its underlying mechanics. While these robots can react to contact in various ways, their abilities to physically respond are limited. Capable of more motion, humanoids Macket [7] and CB^2 [8] are covered with soft, sensorized skins to prevent injury to humans during physical interaction. We have also previously developed a small toy-sized humanoid robot which is soft and robust during playful physical interaction [9].

It is known that physical interaction between humans and/or animals leads to many positive benefits in a relationship [10]. It is possible to communicate quite a lot through a physical interaction, sometimes more than a verbal conversation, in a short amount of time. Humans can shake hands with, pet, rub and hug each other or animals. Even if robots exist which are able to sense touches accurately, exploration of these physical interactions is needed in the robotics field in order to implement them properly. In the study presented in this paper, we measured the power of children's hugs for the purpose of guiding robot design. We developed a huggable plush doll which is able to measure the pressure of an internal air bladder. As shown in Fig. 1, we designed and performed this study with 28 children.

This paper is organized as follows. We first present our previous work and the motivation of this research. Section III reports the details of our system developed for measuring the hugging power of a child. In Sections IV and V, we present the design of our study with children and the obtained results. Our conclusions and future work are discussed in Section VI.

(a) Soft hug (b) Strong hug



(c) Measured hugging pressure

Fig. 1. A girl hugging our developed system, a doll with an embedded air bladder, pressure sensor and microcontroller, and the corresponding recorded pressure data. In our study, she was asked for three soft hugs and three strong hugs. Pressure data for these soft and strong hugs can be seen in the green and blue squares, respectively.

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II. Motivation

We have been developing a small toy-sized robot which looks like a given animated character and mimics the character's motion [11]. This robot is designed to be soft and robust during playful physical interaction with children. To achieve this, a 3D printed soft skin module was proposed which has a flexible air-filled cavity to absorb external forces [12]. Further, the module provides contact force feedback by means of a pressure sensor connected to the air-filled cavity. Using this module, gentle interaction with soft objects, such as the grasping of a disposable cup, a rolled sheet of paper and soft tofu, was achieved. We diversified the soft skin modules and integrated them into the upper body of our robot, shown in Fig. 2 [9]. Considering the various design constraints of the target animated character, this upper body was built with 10 actuated degrees of freedom (DOF) and 8 air-filed, soft skin modules on its links. This upper body is capable of physically interactive functions, such as grasping and hugging small objects and a "grab and move" posing interface.

Using this soft upper body robot, it is possible to measure and control gentle interactions with other objects. For physical human-robot interaction, it is also necessary to quantify the range of force or pressure that may be applied to the robot by a person. If a robotic system is fragile and should be handled with care, it will be hard to develop meaningful relationships with humans, especially children. When children hug their dolls, they need not be aware of the strength with which they hug. Even when hugging pets, children sometimes hug so tightly that the pet might avoid future physical interactions. This excessive hugging force is not only because children are not yet accustomed to appropriate hugging, but also because children sometimes prefer these intense hugs. Grandin [13] showed that intense hugs may be calming to animals, as well as beneficial to some children with autistic disorder or attention deficit hyperactivity disorder, and developed a squeeze machine for the treatment of such children. Some researchers have also contributed to the design of a fully huggable robotic device for intimate communication [14]. The goal of our study is finding design guidelines that will allow us to further develop our system into a robot with which a child could develop a strong bond. This same information will also help us to build robots strong enough to withstand the intense hugs of children.

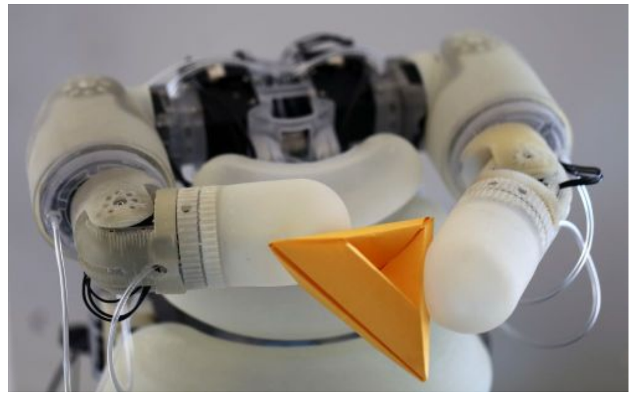


Fig. 2. Our robotic upper body system developed in previous work with 3D printed soft skin modules. This upper body is handling an origami object without crushing it. Our goal is the realization of a robot that can safely and playfully physically interact with children.

III. Hugging System Implementation

The system used to gather and record hugging force/pressure data consists of a soft, huggable plush doll with an embedded air bladder, pressure sensor and a Wi-Fi enabled microcontroller which transmits pressure values to a desktop computer. Data logging software on the desktop computer displays and records data to a text file (Fig. 3).

A. Pressure Sensing Doll

The doll adapted for this experiment is a medium sized "Tsum Tsum" plush doll. Designed to represent a simplified animated character, this doll is capsule-shaped with a length of about 30 cm and a diameter of about 20 cm. The stuffing was removed and a zipper was added to the underside so that the doll can be sealed once the internal pressure sensing components have been installed (Fig. 4(a)). Inside of the doll is an air bladder made of two 0.015" thick sheets of polyurethane film, heat sealed along the perimeter of a 13 cm $\times$ 22 cm ellipse pattern using a Uline impulse heat sealer (Fig. 4(e)). Before the bladder is completely sealed, a stainless steel sealing hex nut, which has an o-ring on one face, is placed inside. After completely heat sealing the bladder and cutting away excess material around the edges, a 5 mm hole is cut into one layer of the two-sheet bladder so that a nylon barbed tee fitting with a threaded inlet can be inserted. The sealing hex nut is tightly fastened onto the threaded tee fitting, and a cyanoacrylate adhesive is applied if necessary at the junction of the fitting and the polyurethane sheet to stop any remaining leaks.

On one branch of the tee fitting is a short length of $1/8$" PVC tubing used as an airway for pressurizing or deflating the air bladder. When the bladder is pressurized, this airway is plugged and tucked into the plush doll. On the other branch of the tee is a second length of $1/8$" tubing which connects the air bladder to a Honeywell ABPDANT015PGAA5 amplified analog pressure sensor. This sensor and a Particle Photon Wi-Fi enabled Cortex M3 microcontroller are contained on a 2 cm $\times$ 5 cm PCB prototype board and are powered by a 3350 mAh lithium-ion battery (Fig. 4(c)). The analog pressure sensor is connected to the microcontroller's 12-bit analog to digital converter (ADC). The raw, unfiltered pressure values, as well as a microsecond integer timestamp, are transmitted at 1 kHz to the data logging computer via Wi-Fi on a local network using TCP/IP.

The deflated air bladder, sensing electronics, battery, a soft foam electronics housing (Fig. 4(d)) and some of the original stuffing to round out the shape (Fig. 4(a)) are arranged within the doll so that the air bladder and stuffing are in the front of the doll, making up the head and thorax, while the electronics and foam housing are at the back. Once arranged, the bladder

Fig. 3. Full hugging data acquisition system including pressure transmitting doll and data logging computer.

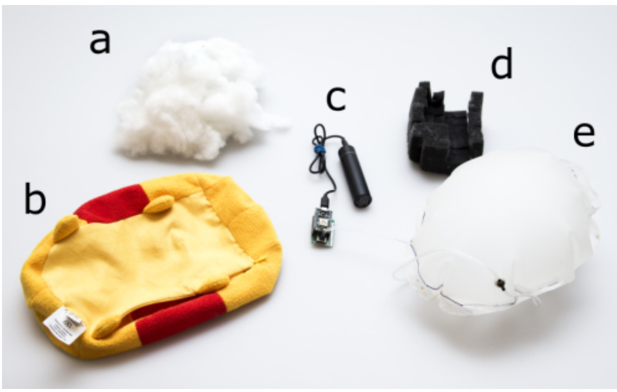


Fig. 4. Pressure data transmitting doll components including (a) stuffing, (b) fabric covering with zipper, (c) 3350 mAh battery, pressure sensor and Wi-Fi enabled microcontroller, (d) foam microcontroller housing and (e) heat-sealed polyurethane air bladder.

is inflated to a pressure of about 0.2 psi using a bike pump with an 1/8" tubing adapter.

B. Data Logging

An interface for visualizing the streamed pressure data in realtime and for saving the data stream to a file was developed using the Processing programming language. Data received over Wi-Fi via TCP/IP was displayed onscreen as a colored bar graph which varied in height with the magnitude of the pressure value. The raw integer pressure value (0-4095) is also displayed onscreen (Fig. 3).

The press of a key begins recording the realtime pressure data and microsecond timestamps streamed from the doll to a tab delimited text file.

C. Calibration

The pressure sensing doll was calibrated to establish a relationship between its 12-bit raw output and the real-world pounds per square inch (psi). A pressure gauge was connected to the unoccupied airway attached to the air bladder, which was pre-pressurized to 0.2 psi. The doll was clamped between a table and an aluminum crossbeam so that the air bladder's pressure would increase with clamping pressure. Using the pressure gauge as a reference, the pressure was raised up to 4.0 psi in increments of 0.4 psi or less, and the raw static pressure sensor value was recorded along with the pressure gauge value. This calibration yielded a linear relationship, seen in Fig. 5, between raw pressure sensor output and psi, which can be used to convert raw hugging study data into real-world psi values.

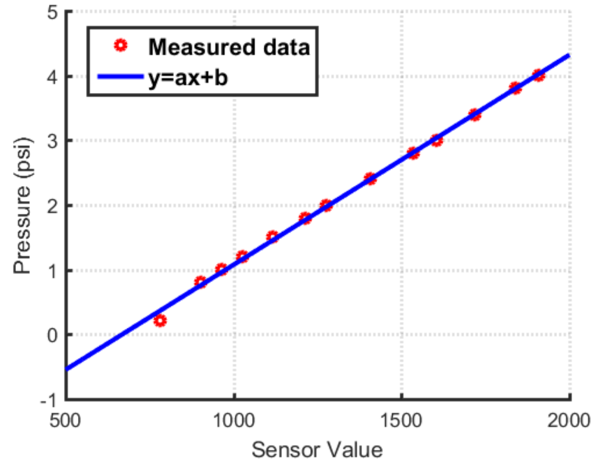


Fig. 5. Pressure sensor calibration plot. The relationship between the pressure sensor data and measured pressure is almost linear. We used the MATLAB polyfit fuction to get the coefficients: a = 0.0032, b = -2.1704.

IV. The Hugging Study

Our study of children's hugging power is described in this section.

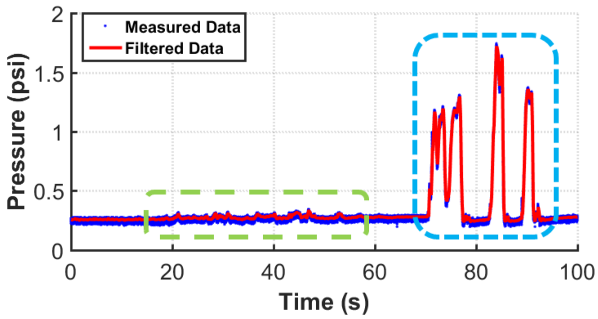
A. Participants

The study was conducted with 28 children ages 4 to 10 years old. We had 11 boys and 17 girls, all of which speak fluent English. This study was approved by our Institutional Review Board, and participants provided informed consent and were reimbursed for their time. The study was performed at Disney Research, Pittsburgh in the presence of participants' parents.

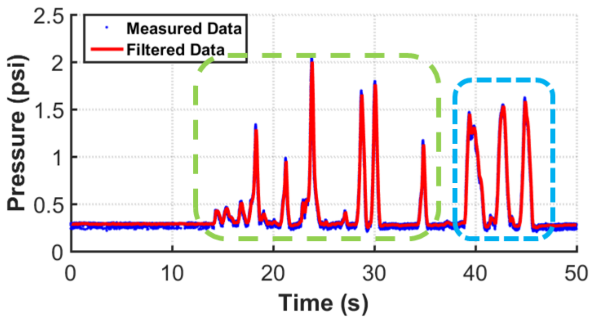
B. Study Design

The setup in Fig. 3 was used for the hugging power study, which was performed by two researchers with one subject at a time. The first researcher operated a computer, which wirelessly connected to the hugging doll to monitor and record pressure information. The first researcher also operated a video camera to record each subject during the given hugging task. The second researcher verbally guided each child through the study's hugging task. Each child was asked to hug the doll six times: three soft hugs and three strong hugs. The following script is an example of instructions given to each child.

- Asking for soft hugs: *This task is called 'Hug a Doll'. You are going to hug this doll in different ways. First, a soft little hug, like when you hug a teddy bear. We want you to repeat this three times.*
- Asking for strong hugs: *I want you to think about someone you really missed. And suppose that the person is this doll. You want to give a strong, big hug. We also want to repeat this three times*



(a) Measured hugging pressure of a child who hugged exceptionally softly.



(b) Measured hugging pressure of a child who squeezed the doll more than necessary for the required hugging task.

Fig. 6. Examples of measured hugging pressure data in which comparison with the video recording was necessary to determine where soft and strong hugs occurred.

V. Results and Discussion

In this section, we present the analysis of the data collected during our hugging study. Due to a lapse in communication between the computer and the hugging doll, the hugging pressure data of one child was not recorded. Therefore, the pressure data for 162 hugs was collected; 81 soft hugs and 81 strong hugs from 27 children.

A. Detecting and Classifying Hugs

While soft and strong hugs can be easily recognized and isolated in Fig. 1(c), the recorded pressure data was not always this clear. In some cases it was difficult to tell whether a child was hugging, just holding the doll or doing something else entirely, so it was necessary to analyze the video of each child and the corresponding pressure information simultaneously. Two examples of ambiguous hugging data where video reference was necessary can be seen in Fig. 6. Figure 6(a) represents the data of a child who, when instructed to hug softly, hugged as softly as possible. While the start and end of each soft hug is difficult to determine from the data alone, the synced video can be used to determine when each hug takes place and the corresponding pressure data can be analyzed. Figure 6(b) shows the pressure data of a child who not only hugged the doll as instructed, but also squeezed and poked the doll at various points during the experiment. The synced video was used to determine which of the spikes in the data were strong hugs and which spikes were other extraneous interactions. When analyzing the data and videos, we assume that the doll is being "hugged" when the following conditions are met:

- The doll is being held in both arms by the child in the video.
- The measured pressure is higher than the pressure threshold ($P_{threshold}$).

The normal pressure (P_{normal}) of the hugging doll without external force was set at about 0.2-0.3 psi. The normal pressure was measured at the start of each participant's session because this value varied slightly over time. $P_{threshold}$ was set at 0.015 psi higher than P_{normal}.

B. Hugging Pressure Range

The main goal of this study is to find the range of children's hugging power applied to a hugged object. Figure 7(a) shows the maximum pressure with respect to the average pressure and the error bar of each hug. Blue circles denote the pressure data when we asked for soft hugs, and the red triangles represent the strong hugs. For example, the rightmost red triangle and its error bar in Fig. 7(a) show that: 1) we asked for a strong hug, 2) the maximum pressure during the hug was 2.623 psi, 3) the average pressure of the hug was 1.583 psi with a standard deviation of 0.739. The maximum pressure of all hugs in our study was 2.623 psi.

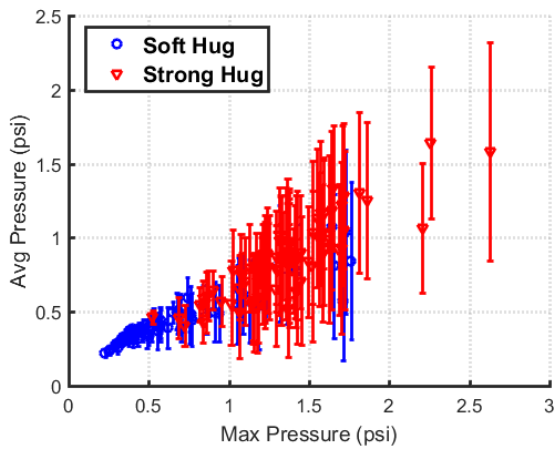
The maximum pressure data of soft hugs and strong hugs were plotted in Fig. 7(b) and 7(c), with respect to the age and gender of each child. The reason we asked the children for both soft and strong hugs was to see how they would receive this request. Most children followed the given instructions well, as shown in Fig. 7(a) by the blue circles, which are distributed in the area of lower pressure, while the red triangles are in a higher pressure area. 83% of the soft hug requests yielded a hugging pressure less than 1 psi (Fig. 7(b)), and 89% of the strong hug requests had a maximum pressure larger than 1 psi (Fig. 7(c)). Figure 7(c) also shows that the maximum pressure of a strong hug increases with age.

VI. Conclusion and Future Work

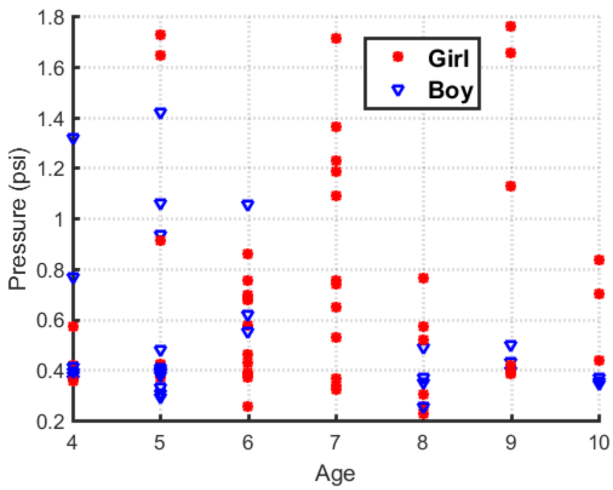
The goal of this study was finding the range of children's hugging power when strongly hugging a doll. To aid in this goal, we developed a pressure measuring system housed within a plush doll. This system consisted of an air bladder, a battery, a pressure sensor and a microcontroller able to transmit acquired data wirelessly. We designed a study with 28 children which used this system to measure and record the pressure data of their hugging. As a result of this study, we found a maximum pressure of children's hugging, as well as the average pressure of an individual hug.

We are planning to update our animation character robot [9] based on the results of this study. Since this robot has multiple unconnected air cavities over its upper body, we must determine how hugging pressure is to be distributed over the various air cavities to achieve natural and interactive hugging with children.

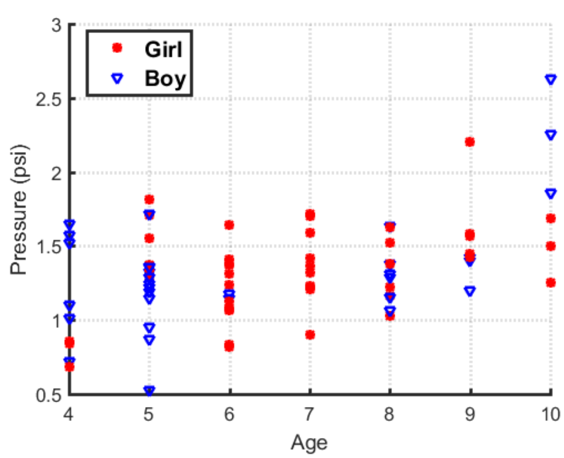
Also, we will try to utilize the collected data to allow robots to recognize behaviors, such as detecting the start or end of a hug. As mentioned in Section V, it is not easy to distinguish whether or not a hug is taking place using the pressure information alone. To recognize the start of a hug, multi-modal sensing will be necessary, such as sensing motion using vision or understanding voice information. However, once a hug is started, the pressure information is important for detecting the end of the hug. Humans also use touch information to sense the end of a hug because we can not see one another's movements while hugging. For this, further analysis of the collected hugging data and the selection of discernible features for behavior recognition will be necessary.



(a) Average pressure versus maximum pressure



(b) Maximum pressure of soft hugs per age group



(c) Maximum pressure of strong hugs per age group

Fig. 7. Measured hugging pressure analysis

ACKNOWLEDGMENTS

We would like to thank Lea Albaugh for her help fabricating the experimental system and Andre Pereira for his help running the study.

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