Huggy Pajama: A Mobile Parent and Child Hugging Communication System

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ABSTRACT
Huggy Pajama is a novel wearable system aimed at promoting physical interaction in remote communication between parent and child. This system enables parents and children to hug one another through a novel hugging interface device and a wearable, hug reproducing pajama connected through the Internet. The hugging device is a small, mobile doll with an embedded pressure sensing circuit that is able to accurately sense varying levels of the range of human force produced from natural touch. This device sends hug signals to a haptic jacket that simulates the feeling of being hugged to the wearer. It features air pockets actuating to reproduce hug, heating elements to produce warmth that accompanies hug, and color changing pattern and accessory to indicate distance of separation and communicate expressions. In this paper, we present the system design of Huggy Pajama.

Categories and Subject Descriptors
H.5.2 [Information Interfaces And Presentation (e.g.,HCI)]: User Interfaces—Haptic I/O, interaction styles

1. INTRODUCTION
In today’s modern urban lifestyle and global 24/7 economy, working parents are constantly kept apart from their children at home by heavy overwork and business trips. It is ironic that while the purpose of work is to enable parents to provide for their loved ones, they have to sacrifice too much time with their loved ones as a result. Children are left at home, while parents are constantly balancing between work and worrying about the well-being of their children. The uncontrolled development of society due to this vicious cycle can result in feelings of isolation, loneliness and a lack of sense of value [13]. Therefore there is a strong need for loved ones to constantly keep in touch, and express affections to one another. In certain scenarios, actions do speak louder than words.

This problem is more pronounced for parents with young children. Children of these young ages need a lot of care, guidance and love [7]. Parents are generally able to reach their children by telephone or video phone, but communication purely by voice or video lacks the physical interaction which has been shown in previous research to be vital in effective communication [1]. Younger children might have difficulties understanding the true meaning of words spoken by their parents. As a consequence, we require a more effective way of remote communication between parents and young children. While it may not always be possible for parents to decline work commitments (such as long office hours and business trips) to spend time with their children, remote haptic interaction may be a feasible alternative when the parent must be away from the home. Although never intended to replace real physical hugging, we believe this system would be of great benefit for times when the parent and child cannot be at the same place. A very related scientific proof showed that infant monkeys grew up healthily when artificial contact comfort was given even in the total absence of their real mothers (although it would be unethical to carry out the same tests to deprive human infants artificially) [5].

In this paper, we present a novel type of physical interaction system for parents and children interaction through the Internet. Huggy Pajama is a mobile and wearable human-computer-human interaction system that allows users to send and receive touch and hug interactions.

Huggy Pajama consists of two physical entities. On one end, we have a novel hugging interface in the form of a small and mobile doll with embedded touch and pressure sensing circuits. It is connected via the Internet to a haptic wearable pajama with embedded air pockets, heating elements and color changing fabric. A general overview of the system is shown in Figure 1. On the left of the figure, we have an input device which acts as a cute interface that allows parents to hug their child and send mood expressions to them. On the right side of the figure, connected through the Internet, we have air actuating module and color cloth changing expressive interfaces to reproduce hug and connect parent and child. This pajama is able to simulate hugs to the wearer.
**1.1 Motivations**

The main motivation for the research in using touch and hug as part of communication is to support social interaction. Processing haptic information is an important function of Parietal Cortex part of the brain and plays a significant role in the cognitive aspect of human's daily activities. This has been shown in various psychological studies exploring how touch is essentially not just important for complex sensory-motor tasks, but offers a deeper neural sensation evoking for recognition and judgment. Such neurological consciousness aroused through available haptic information are important for humans to make decisions pertaining to their surrounding and interaction with others [12]. Furthermore, it has been shown in the proprioception (a process of correlations amongst the multimodals) of the Parietal Cortex, that the human perception can be influenced to create an illusion of something which is unreal. In [4], a touch is reproduced with the right representation (for example a rubber hand in place of a real hand), and human subjects are made to believe that the rubber hand is actually real. This cycle of self-attribution convinces the human subjects that a real hand is touching them. This gives us confidence to believe that with the right haptic feel and with the context of the situation known to the human subject, touch communication could be an effective communication channel.

Modern studies of human infants also reveal that the absence of affectionate touch can cause social problems and even lead to premature death [8]. These studies suggest that children need to constantly be in touch with their parents. We focus on the interaction between parent and young children because young children are at a growing age where they require a lot of attention. One of the more important act of showing affection to young children is hugging. Hugging and touching is a very vital part of human brain communication essential for development of young children [9]. Young children may not fully understand words, but a hug is a natural and intuitive way to tell young children about your care for them. Through hugging, we can spread our spoken language to the language of wider and feeling expression. In different hugs we may speak of security, confidence, trust and sharing in a manner that no word can tell. Hugging is therefore an important interaction between parent and child.

Even though remote textual, visual and audio communication tools exist, remote haptic communication (as a basis for remote contact comfort especially for parents and their young children) are still sorely lacking. As discussed above, with the right representation and right context, neurological proprioception will bring about self-attribution that can make people believe artificial contact to be real. We therefore believe that contact comfort, albeit a reproduced one, can contribute to healthy emotional development between parent and children compared to the situation where there is no contact due to physical separation. Therefore with Huggy Pajama, we hope to further provide haptic communication for contact comfort, even though reproduced and by remote means, in an attempt to give more opportunities for parents and children to show their love.

### Table 1: Modes of Interaction for Huggy Pajama

<table>
<thead>
<tr>
<th>Interactive modes</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Remote touch and hug</td>
<td>Transmits human touch and hug on doll to worn haptic pajama</td>
</tr>
<tr>
<td>Haptic pajama</td>
<td>Reproduces hug sensation and warmth on wearer</td>
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<td>Distance and emotion indication</td>
<td>Color changing clothes and accessories to give indication of separation distance between parent and child and emotion data</td>
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Huggy Pajama focuses on developing a mobile hug communication system for parent and child, and provides a realistic soft touch sensation. We enable users to hug or touch different areas on the hug sensing interface, and map this to actuate different parts of the haptic pajama. Besides that, the hug sensing doll senses varying levels of force acting on it in an accurate and analog manner. The output air actuating pockets applies different levels of pressure to the human body according to the input force. Also, we experimented with color changing cloths to give an indication of distance of separation, and display emotion data of the parent and child.

The interaction between parent and child is possible to be two way. If possible, the parent wears the pajama also (for example on a business trip at night). Each then wears the haptic cloth and interacts with the other through the mobile hugging interface. The interactive modes are summarized in Table 1.
There are also projects that are more specifically related to sending or producing hugs. The Hug [10] senses stroking, squeezing and rubbing actions, and connects to another similar remote device which translates the input gestures into light, heat and tactile vibration. It attempts to address the human need, especially the elders, for physical closeness in remote communications. In contrast to the Huggy Pajama, it maps pressure input into vibrational output and does not present a wearable haptic device.

TapTap [3] is a wearable haptic system that allows nurturing humans to touch to be recorded, broadcast, and played back for emotional therapy. Unlike Huggy Pajama, it does not stress on the importance of real time, remote interaction between parent and child. We believe that it is important for both parent and child to know they are communicating with each other at the same time and not only a delayed or recorded communication. It gives the users assurances about the wellbeing of the other.

The Huggable [14] is a robotic companion capable of active relational and affective touch-based interactions with a person. It is used to aid in therapy for the elderly or lonely people in place of animals. Our system differs in that there is no artificial intelligence involved and that users are communicating with a real, live person instead of a robot.

Cutecircuit’s Hug Shirt [6] has detachable pads containing sensors which senses touch pressure, heart beat and warmth, and actuators which reproduces them. The detachable pads make Hug Shirt washable. However, Hug Shirt embeds touch sensors on the body of the wearer. In addition it has vibration actuators which is not a calm feeling.

3. DESIGN PROCESS

Before the actual implementation of Huggy Pajama is carried out, we brainstormed a set of requirements that determines the functionality and features of the new system. This set of requirements is in line with our objective to create a system for haptic interpersonal communication between parent and child. Other objectives include enabling both parents and child to interact tangibly with each other, enhancing the feeling of physical presence in remote communication and address the need for physical affection in situations where close contact is not possible.

With the above objectives in mind, the set of design requirements are listed below.

- **Input sensing interface**: This interface needs to be able to sense primarily force from the human touch or hug. The shape of the input sensing device should correspond (but not necessarily exactly) with the human body to allow for a meaningful mapping between input and output. It should also be able to detect varying levels of force accurately, and also respond to the normal force level of a human hand’s touch.

- **Output actuating device**: This device lies on the other end of the connection. It should be a form of wearable suit or a shape that fits on part of the human body. It should be able to produce varying levels of output as some kind of force acting on the human body.

Also, the higher the resolution and the wider an area that the output actuators have, the more closely we can simulate the area of touch or hug.

- **Complementary features**: Subtle cues such as facial expressions, warmth radiating from the other person, the tone of speech and body movements all contribute to an eventful interaction between two co-located persons. We need to ask ourselves what additional features that can add to an eventful interaction between two remote persons.

The following are the two scenarios Huggy Pajama we focused on (although these are expected to lead to many other possible scenarios of use):

1. **Parent and child are separated by a distance and the traditional routine of “tucking in” for the night is not possible.** Without the Huggy Pajama system, the users would use telephone to say goodnight. With the Huggy Pajama system, the users would initiate the goodnight routine through telephone and send hugs to each other at the same time.

2. **Parent and child are separated by a distance and the parent wants to make contact with the child by sending a pat/rub on the back and a general message to the child that the parent is thinking of him/her.**

4. **SYSTEM DESCRIPTION**

Based on the design requirements in the previous section, we designed and implemented the Huggy Pajama with a number of features that we believe will make remote interactions more meaningful between parents and young children.

The features are:

- A small, cute doll that is light and mobile for convenience to users. This doll has embedded touch and force sensors, and connects via Bluetooth to a mobile phone or a computer. It allows the user to send touch and hug to a remote person. Users can also convey mood by pressing designated sensors.

- A wearable pajama for the remote person to feel touch and hug from the user with the input doll interface.

- The pajama is able to generate heat to accompany the hug. Warmth from the other person is usually the next thing we notice after the pressure from body contact when two persons are embracing.

- Color change on the pajama. Color attracts both adults and children. Color change can be used to convey information like the relative distance of separation between parent and child. The color change portion should not be inhibitive to the wearer. It can be implemented as part of the design pattern of the pajama, or it can be a detachable fashion accessory. Also color change can be used as an expression of mood. Color changing accessories attached to the pajama makes the
pajama a media interface which users can tell the mood of the other person. The implementation of this is shown in section 4.3 on the color changing display.

### 4.1 System Overview

The overall block diagram of the Huggy Pajama system is shown in Figure 2. It consists primarily of the input force sensing device and the air actuating output module. Both these ends are connected via the Internet.

**Figure 2: Overall block diagram**

This system presents the flexibility for either one-way or two-way communication between parent and child. If parents are at work in a business meeting, it might not be suitable for them to put on the pajama. They can easily hug their child using only the input device. However, in the case of being in office, hotel, or airport, the parent could wear the pajama and have two-way hugging with the child.

### 4.2 Touch and Force Sensing

In order to implement a high fidelity touch input sensing mechanism, the input sensing should be able to measure varying levels of force applied on the doll interface by the user. This range of force should correspond to the normal range of human applied touch on the input interface. We conducted tests to determine the normal range of force exerted by a variety of human subjects. We asked participants to apply pressure directly to the doll interface with one hand, using the appropriate amount of forces that would symbolize most effectively sending a hug to an intended recipient. This served to give a general understanding of the rough order of magnitude of forces that the input sensing would need to be able to handle.

An experiment was conducted on 20 persons of ages between 5 and 35 with an even split of male and female participants. From the experiment, the following results are obtained. We determined that it is sufficient to sense equivalent weight ranging from 0.010 kg to about 2.0 kg for a computer-based human touch sensing system.

Based on these experimental results, we searched for suitable methods for sensing human touch pressure, and compared their characteristics. An important requirement was that the sensors must be lightweight, small, and suitable for small mobile devices.

#### 4.2.1 QTC Sensor Design

The Quantum Tunneling Composite (QTC) technology is used for implementing the touch force sensing interface device. This is a new polymer composite material whose electrical characteristic can change from insulator to near conductor due to applied force [8]. We chose the QTC Sheet form factor as it allows flexibility in terms of size and shape. This greatly helps in designing the sensing interface of the doll.

**Figure 3: Input sensing device and embedded circuitry**

Figure 3 shows the touch and hug sensing device. The aesthetic design is shaped like a small doll with body and side arms to correspond to the human body where we want to reproduce the haptic sensation. The appearance of the input device is considered one very important point which affects the user experience in affective communication. Hence, we opt for a cute, simple, and clean design, with rounded corners. The small size is also such that the device can be used as a mobile phone accessory, similar to a cute phone strap that is widely popular in Asia. The advantage is that this device also adds hugging communication functions to the mobile phone. There are 12 QTC sensing areas, which covers the front and back body, as well as both the side arms. Also shown in Figure 3 is the internal embedded circuitry, which is designed in a modular manner for ease of modification to fit into different device designs.

**Figure 4: Input Sensor Device Block Diagram**

Since QTC sheets respond to applied force by varying its resistance, an excitation circuit is required to obtain the output analog signal. Figure 5 presents the actual measurement...
of the output signal from two sensor samples (labeled sample 1 and sample 2), which exhibits an almost linear characteristic from 0 to 0.60 kilograms (kg) of input. It also shows a very consistent output pattern from the two samples. This indicates a good reproducibility of the design.

Figure 5: Force Input vs. Voltage Output characteristic of our input sensing device, measured for two different sensors. Results are labelled sample 1 and sample 2

4.3 Huggy Pajama and Color changing display

We used conductive yarn sewn onto the Huggy Pajama both to generate heat for warmth and also to control the color change. The microcontroller circuit monitors and regulates the temperature of the area close to the heating element. We used serial digital output temperature sensors for feedback of temperature changes.

For the color changing display, we have considered using electroluminescent (EL) wire. However, emissive lighting on clothes is not very natural, and could be troublesome at night time. The color changing of the pajama to be more organic, calm, and ambient, especially if children is one of the targeted users. Thus we used thermochromic material to implement the color change part of our system.

There were several previous projects related to thermochromism on clothing. The two main ones are Shimmering Flower [2] and Mosaic Textile [15]. Contrary to our method of using leuco dyes, Mosaic Textile uses liquid crystal for color change. Compared to liquid crystals, leuco dyes are more stable when exposed to air and light, and can be directly screen printed onto cotton fabric. It does not need to be applied on a black or dark color substrate, which liquid crystals require. Black fabric is not suitable for our application as it is meant to portray a cozy and homely feel.

On the other hand, the Shimmering Flower project uses color change for the purpose of ambient display, with no particular need for a precise control of color output at different temperatures. In Huggy Pajama, we map different color outputs to distance. Therefore, simplicity, robustness, and consistency of data matching are the main criteria in the design of the color changing portion of Huggy Pajama.

Our mapping of distance to color is as shown in Figure 6. The idea is to have a cool color mapped to a far distance of separation between parent and child, and have the color change gradually to a warmer and brighter color when parents return nearer to the child. The response time for this change in color can be relatively long, as we are mapping to unit distance of kilometers. A gradual change in color is preferred over a step change in color to have a soft and subtle effect to blend with the surrounding. We used two types of leuco dyes with a normal dye, this would give us the effect of three colors displaying when we increase the temperature of the fabric which we applied the leuco dyes.

As the use of thermochromic ink is involved, heating elements are required to change the color of the ink. We used conductive yarn with a resistance of 0.5 Ohm per centimetres as the heating element and these are weaved into the fabric of the pajama without affecting the aesthetics. The heating elements heat up the thermochromic ink area of the pajama, while the digital temperature sensors provide feedback of the current temperature of the locality of their pajama area to the microcontroller. The microcontroller is programmed to maintain temperature around certain bands. For example, a thermochromic ink with a 31 degrees celcius activation temperature is maintained within the 31 to 33 degrees Celcius band. This is to avoid constant switching of the microcontroller. The overall block diagram for the control of this color changing module is shown in Figure 7.

Figure 6: Mapping distance of separation to color change

Figure 7: Block diagram of Color Changing Fabric Display

Our developed system had satisfactory results. Initially when no heat is applied and operating at room temperature, we have a dark brown as a result from mixing the three colors. As the controlled temperature nears 31 degrees celcius, we see a gradual change to orange color. Finally, as temperature hits 38 degrees celcius, we see a yellow color, which is the normal dye color. This shows that the leuco dye materials have all become transparent at this temperature and above. This process of color change is seen in Figure 8.

From the concept of embedding the color change into the design of Huggy Pajama above, we have an interface that allows expression of feelings and moods. We can customize different designs to suit the wearer. For example, young
children can have color changing emotion expressing teddy bears appearing as patterns on their clothes. One example, which we implemented, shows a flower pattern embedded into the printed pattern on the Huggy Pajama in Figure 9 (a). Initially, the flower pattern is not visible. As the parent communicates ones feeling to the child, the flower pattern gradually appears. This is caused by the control of the thermochromic ink using conductive yarn. As the thermochromic ink is heated, it reveals the flower pattern, and the ink becomes transparent upon fully reaching the activation temperature. In another example, a flower fashion accessory is designed for the young child in Figure 9 (b). This flower accessory thus becomes more than just an accessory, it is a connection point between parent and child. It allows the parent to relate his or her feelings to the child, and the child to see their feelings. The flowers reveal intermediate and fully changed color upon changes in the controlled temperature. These color changing design and accessories are cute and emotional interfaces for Huggy Pajama.

4.4 Air Actuating Output
The final objective for Huggy Pajama output is the air actuating haptic module integrated seamlessly into pajama clothing for children.

The air actuating system of the Huggy Pajama consists of 12 individual modules each of which corresponds to each of the 12 sensors on the input doll as shown in Figure 10. We designed a modular style for the air actuators so that construction and operation would have higher robustness and ease of repair. It is also to enable ease of modification based on user feedback.

Each module of the the air actuator system consists of an of an air pouch, a driver circuit, a pressure feedback sensor and two air pumps to produce a hugging feeling on the wearer. The module used on the arm is shown in detail in Figure 11. Similar modules are replicated for the other areas on the body with different air bag size.

The right side (labeled Output Part) of Figure 4 depicts the output side of the system receiving touch sensing data sent via the Internet and transmitted wirelessly. Accordingly, 12 unique touch and force sensors maps to 12 output modules in the form of air-actuated pouches on the pajama. The pressure exerted on the human body is according to the force acting on the sensors. The module also has a visual indicator indicating the current force level as a value between 0-9.

The air actuator module consists of two air pumps. One pumps air into the air pouch and the other pumps air out of the module. Such a configuration of two pumps was used to make the system’s response as fast as possible to the users input (touch sensing). Pumps normally used for medical applications were used, as they are lightweight and of low sound emission.

4.4.1 Functionality of the air actuator system
The module consists of a pressure feedback system for closed loop control (Figure 12). Currently the input force is sensed and mapped to 10 pressure levels and the output pressure is set accordingly. Therefore the system employs PI control
to reach and maintain the required pressure. The pressure sensor reads the air pressure inside the air pouch and outputs a voltage signal between 0-5 V which is fed back to the microcontroller.

Some of the response characteristics of the air actuator system are shown below. Note that all the pressure values have been normalized to values between 0 and 1. Where 0 corresponds to the minimum pressure value which is 103.3kPa close to the atmospheric pressure 101.3kPa and 1 corresponds to the maximum pressure of the system, 106kPa.

The Figure 13 shows the response of the module for one extreme case where the input control level changes from minimum to maximum pressure. The step response curve (Figure 13) for the system shows that the response is obtained faster and is regulated. Fast response of the system is important since most of the time the doll would be at the idle state where the input level is minimum and change to possibly a higher value close to maximum pressure when the user starts to use the input doll. However, the system does not reach its maximum pressure level fast enough when starting from a 0 level, and is regulated between 0.7-0.8 mainly due to the flow rate limitations of the air pumps. Even if the pumps are operated at full speed, it would take approximately 1-2 seconds for the pressure to reach the maximum pressure level. In addition another reason is that in this prototype the air pouch is not perfectly air tight especially in the joints causing the pressure to drop. More powerful motors could be employed to solve this problem. However, the larger sized motors would cause the pajama to be heavier and more bulky, thus causing discomfort to the user.

The Figure 14 indicates another extreme case where the input force level changes from maximum to minimum level. It can be seen that air actuator system is able to respond very fast. This characteristic is important since in most cases when the user removes the force on the input doll, the input force level drops back to 0 from the previous input level. Therefore it is important that the system response is fast for this scenario. This scenario has a faster response than the earlier case of change from minimum to maximum pressure. We could safely assume that reasons such as non-air tight pouch, easier flow of air from high to low pressure, etc, assists the reduction of the pressure inside the pouch faster, thus causing this difference in the response time. The use of two pump configuration is justified here. In contrast, if the air was released under natural atmospheric pressure to lower the pressure in the air pouch, the response would be too slow.

The static response of the system is shown in Figure 15. The graph shows the pressure input to the system (sensed pressure data) and the output created by the air actuator system. The graph implies a linear relationship between the input and the output pressure. Therefore due to such linear relationship the output can be made continuous instead of the current discrete 10 levels if desired.
Figure 16: Testing of force sensing input module and air actuating armband

This is achieved by pumping air into the air pouch until the pressure feedback sensor shows the desired pressure. More LEDs are turned on to give the impression of increasing brightness to the user. All the LEDs are on when the maximum allowed force is reached, thus indicating to the user the force limit of the device.

The above showed one output module being tested in the form of an armband. In Huggy Pajama system, there are 12 unique input sensors which corresponds to 12 unique output modules. These 12 output modules are integrated into a pajama for the children. Currently, as the result is a prototype with the need to fit all modules, we integrate them into a more sturdy soft jacket-like construction. Figure 17 shows the Huggy Pajama actual prototype in action.

Figure 17: Huggy Pajama system overview

5. CONCLUSIONS

Huggy Pajama is a novel wearable system that promotes physical interaction in remote communication between parents and children by enabling each to hug one another through a novel hugging interface device and a wearable, hug reproducing jacket connected through the Internet. Some key contributions that are made by the work include the ability to reproduce a hug between two people. Also, we incorporated cute interfaces for the conveyance of emotions between parent and children. Equally important, the open and configurable architecture that we have created allows for further exploration within the design space without building an entirely new prototype, but allows us to reuse main components, or in some cases, simply make a change to the logic systems. This allows for user testing to take place which will show the user preferences and aesthetic choices from many users with varying sensitivity and style of hug interactions.

6. REFERENCES