PINOKY: A Ring That Animates Your Plush Toys

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ABSTRACT

PINOKY is a wireless ring-like device that can be externally attached to any plush toy as an accessory that animates the toy by moving its limbs. A user is thus able to instantly convert any plush toy into a soft robot. The user can control the toy remotely or input the movement desired by moving the plush toy and having the data recorded and played back. Unlike other methods for animating plush toys, PINOKY is non-intrusive, so alterations to the toy are not required. In a user study, 1) the roles of plush toys in the participants' daily lives were examined, 2) how participants played with plush toys without PINOKY was observed, 3) how they played with plush toys with PINOKY was observed, and their reactions to the device were surveyed. On the basis of the results, potential applications were conceptualized to illustrate the utility of PINOKY.

Author Keywords

Interactive Plush Toy; Tangible User Interface; Robots; Ubiquitous Computing;

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Design

INTRODUCTION

Plush robots have not only served as toys for children [5] but have also contributed significantly in the areas of medical therapy [28] and communication media [22]. During the March 11 disaster in Japan in 2011, Paro (a seal-like robot) was used as a means of stress reduction for victims in the affected areas [21]. Due to its soft body and friendly appearance, it provides an emotionally richer user experience than typical robots [15]. However, its electrical components (microcontroller, actuators, etc.) must be inserted during fabrication. Also, the behaviors have to be hard-coded and are not configurable by the user. Our goal was to design a system that would enable the user to customize the movement of a plush robot.

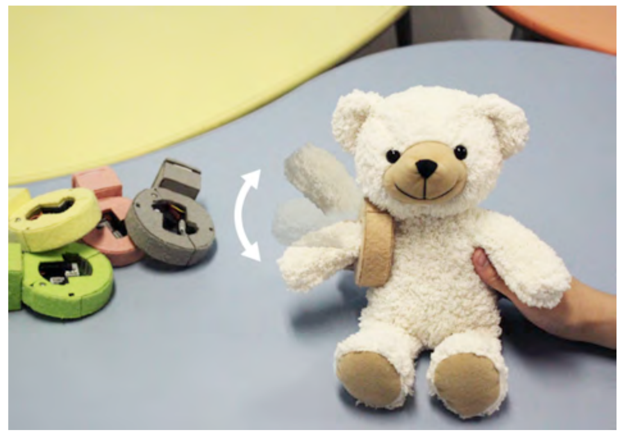

Figure 1. PINOKY attached to the right arm of plush toy, enabling the arm to be moved.

Another goal was to convert an existing plush toy into an interactive robot by augmenting it with a computer system. In the area of ubiquitous computing, there have been several attempts to insert computing systems into everyday objects to convert them into highly compatible user interfaces in the home [2][12]. We chose to focus on plush toys as they are commonly found in the home. Because plush toys typically have an anthropomorphic embodiment, augmenting them with a computer system would enable them to play significant roles as communication agents (for example, between a person and a home appliance or with another person). Depending on the personal memory associated with the plush toy, there could be a variety of service and entertainment possibilities. For example, a grandson and his family could communicate with their grandfather living in a distant location through a plush toy given to the grandson by the grandfather for his birthday many years ago. However, implementing a computer system with actuators in a non-intrusive manner is problematic as it requires the cutting of the body of the user's favorite plush toy. Therefore, we focused on designing a device that converts an existing plush toy into an interactive robot system in the least intrusive way.

The device we developed is called "PINOKY." It is a wireless ring-like device that can be used to animate any plush toy, such as by moving its limbs, ears, or tail (Figure 1). Since PINOKY is battery-powered and equipped with wireless communication, it can easily be attached to a toy externally, the same way a person puts on an accessory. PINOKY consists of a microcontroller, motors, photoreflectors, a wireless module, and a battery. The motors are used to animate the toy, and the photoreflectors are used to sense and record the direction and amount of user-defined movement.

We conducted a user study to 1) examine the role of plush toys in the participants' daily lives, 2) observe how the participants played with plush toys without PINOKY, 3) observe how they played with plush toys with PINOKY, get their reactions to the device, and to get their thoughts on the concept. The results of our qualitative and quantitative analysis showed that users were able to enjoy using the system much more than we had expected.

Our work to convert an existing plush toy into an interactive soft robot has five significant contributions.

- A method has been developed for externally actuating a plush toy in a non-intrusive manner. Current methods require the cutting of the toy's body.
- A palm-sized, battery-operated, ring-like device equipped with wireless communication has been developed. It can be easily attached to various parts of a plush toy as an accessory.
- Our user study revealed how plush toys are used in daily life.
- Our user study clarified the usability of our device and revealed how the participants reacted to it.
- Several example application scenarios for the device were conceptualized.

RELATED WORK

Our work builds upon five distinct areas of prior research that are covered in turn in this section. The first is the body of work on puppets and their significance; the second is the body of work on plush toy interfaces; the third is the body of work on plush animal robots; the fourth is the body of work on giving movement to everyday objects; and the fifth is the body of work on configurable robots.

Animating Puppets

When talking about animating inanimate objects in play, one of the first things that comes to mind is puppetry. Puppets have been in existence for decades, and are present in a wide number of cultures all over the world. Via the usage of strings, sticks or hand movements to manipulate the puppet's limbs, puppeteers breathe "life" into the puppets by giving them motion. This is similar to PINOKY animating previously inanimate plush toys by manipulating the limb it is attached to. Puppets have important roles to play in many situations, for example in regular play, entertainment, education, therapy, and so on. McDonald's Camp Quality Puppets have been used effectively to bring across messages to children on how it is like to live with cancer [3]. Puppets in Education is an educational puppet troupe that utilizes puppets to educate their audience on difficult social issues such as bullying and autism [19]. Hadari has educated others for years on using puppets for education, as a means of social communication, and for therapy purposes [9].

Plush Toy Interfaces

The transition from infancy to childhood to adolescence is characterized by certain behaviors, such as remaining attached to a plush toy [29]. Even adults often display an instinctive desire to touch a plush toy. This has led to the introduction of interactive plush toys to provide an emotionally richer user experience [15]. Yonezawa et al. made an interactive plush toy by equipping it with seven types of sensors (bend, microphone, etc.) [30]. They also created an application to be used with this toy that composes music on the basis of the intensity and frequency of interaction.

Plush toy interfaces are sometimes used to control a character in the virtual environment. Johnson et al. developed the Sympathetic Interface, a plush doll embedded with a wireless module that is used to manipulate a virtual character in an iconic and intentional manner [11]. In a similar manner, Shimizu et al. developed a plush robotic toy interface with haptic feedback [23].

Plush Animal Robots

Plush robots have long been popular as children toys [5]. In recent years, many researchers have developed more intelligent plush robots and tested their use for various applications such as medical therapy [28], collaborative agents [1], communication media [22], and interior lighting [27]. Wada et al. developed Paro, a life-like robot baby harp seal, which is designed to be used for therapy in hospitals [28]. Microsoft's ActiMates Barney Doll is a plush toy embedded with pressure and light sensors, a wireless data connection, voice output, and a simple arm motor [25]. Barney is designed to be a social robot, commenting using computer media at crucial moments to facilitate learning. Leonardo, developed by Breazeal et al., is an agent that supports the user's work by providing accompanying gestures and social cues [1]. Sekiguchi et al. created RobotPHONE [22], a telecommunications device in the form of a plush toy that the caller manipulates to animate another person's plush toy that functions as a telecommunications device. The concept of PINOKY is similar but takes it to the next level by enabling the user to customize and add similar functionality to any plush toy.

There have been several attempts to actuate plush toys. Many existing plush robotic toys use a servomotor at a joint because it is stable, easily handled, and small but with high power [5]. Stiehl et al. used a voice coil actuator instead of a motor because such actuators have a smooth motion without backlash, resulting in life-like motion [24]. These methods impair the softness of the plush toy, and actuators have to be inserted into the toy beforehand. Ishikawa et al. used strings to pull on the surface of the plush toy [10]. However, this makes it difficult for the user to configure and customize the movements.

For the methods above to animate plush animal robots, a microcontroller and actuators must be embedded into the plush toy during manufacture. Additionally, their behaviors have to be hard-coded and are not configurable by the user. The PINOKY device, on the other hand, can be attached to and removed from any plush toy, and is thus able to convert any existing plush toy into an interactive robot.

Giving Movement to Everyday Objects

Physical computing is becoming more commonplace [8]. In the area of ubiquitous computing, there have been several attempts to insert computers into everyday objects [4]. LilyPad is a wearable microcontroller designed to introduce computing into fabrics [2]. Sugiura et al. developed a sensor module that enables the user to convert a soft household object into a touch input interface [12].

Several techniques have been proposed for giving movement to everyday objects. Osawa et al. developed customizable robot parts that personalize existing home appliances and give them movement [16]. Animated Paper enables the user to give movement to paper [13]. A shape memory alloy is attached to the paper and given movement by heating it from a distance using a laser. Probst et al. developed an intelligent paper clip for easily converting conventional Post-it® notes to physical I/O media [18]. Coelho et al. developed shape-changing paper, foam, and cloth [4]. Both the clip and the shape-changing materials use shape memory alloy for giving physical movement. Furukawa et al. found that an animal's fur can be made to stand up by the usage of simple vibration motors [6].

There have been numerous researches on robotic exoskeletons being used to facilitate motion in inanimate beings. One such example is the Berkeley lower extremity exoskeleton that Ghan et al. developed, which works to enhance the strength and endurance of a pilot [7]. Robot Suit HAL by Taal and Sankai is another wearable robot which aids in human motion [26].

These prior works infuse computing into our daily lives, which is what we aimed to do as well. Thus, with PINOKY, we aim to introduce computing into plush toys.

Configurable Robots

Many researchers have explored different types of configurable robots for several purposes, such as smart machines capable of doing tasks that people cannot do [31], as an educational tool kit that children can use to learn about programming [14] or kinetic movement [20], and simply as toys [17]. These configurable robots can be switch between varying forms and behavior autonomously or by user control.

Lego Mindstorm is a programming environment that creates a robot application by graphical programming. Each hardware component is packaged in one module, and can be connected in a simple manner (without requiring soldering) [14]. The Topobo is an educational tool kit for children to learn about kinetic movement and locomotion [20]. Topobo allows the user to record their desired movement by twisting the motorized pieces.

The PINOKY is also a configurable robot module that allows the user to transform any plush toy into an interactive robot by augmenting it with a computer system. The device can work as a standalone or in a network, and they communicate with each other over a wireless network system. Thus, the number of devices can be changed freely according to the user's requirement.

DESIGN GOAL

PINOKY was designed to convert existing plush toys into soft interactive robots. Because PINOKY is to be attached to a user's personal plush toys, we needed to be careful when coming up with the design. We thus set the following design goals:

Easy to use – The device must be able to be used by children as well, so its usage should be intuitive.

No damage to plush toy – Using the device should not damage or require the user to modify the plush toy in any way, because it is the user's personal item.

Easily attachable and removable without requiring special tools – Children should be able to attach and remove the device easily and quickly without help from adults.

Scalability – The device should be attachable to any plush toy on almost any location on the toy. More than one device should be attachable.

Aesthetically pleasing – Aesthetics is essential for plush toys, so the device should look aesthetically pleasing on the toy even when not in use.

Safe and robust – As the device is attached externally, it should be safe (for example, it should not catch the user's fingers). Moreover, it should not break if dropped.

Adequate movement actuation – The device should be able to recreate most animations that users use when playing with plush toys.

We will discuss the validity of our design in the Discussion section on the basis of the results obtained from the user study.

THE PINOKY SYSTEM

A major innovation of PINOKY is that it is unobtrusive and easy to attach. It is an external attachment that can animate any part of any plush toy. PINOKY is easy to attach and remove, similar to how one puts on and removes a bracelet, and is crafted to look like an accessory. All electronic parts are packaged in the module, and it is used wirelessly.

Overview

The PINOKY system (Figure 2) consists of a microcontroller (Arduino Pro Mini), a pair of DC servomotors, a pair of photoreflectors (photosensor, IR light), a wireless module (XBee Series 1), and a Li-Po battery. Each servomotor is in contact with the surface of the plush toy through an arm, and causes the area in contact to bend by pushing on the covering. The photoreflectors are used to measure the angle at which the joint is bent. A pair of strong magnets holds PINOKY in position, enabling the user to attach and remove it without using special tools. The user is also able to synchronize the motors of multiple PINOKYs using ZigBee communication. The case is made of laser-cut acrylic and covered with felt to give it a look and feel similar to that of a plush toy (Figure 3).

Actuation

Preliminary design experiments

Before we decided on the current method that we are using to animate plush toys, we developed two prototypes. One was a clip-type device that creates motion by clipping the surface of the plush toy. However, this method does not enable dynamic swinging movement. The other, an implementation more similar to that of the current system, uses a pair of DC motors and gears. However, we abandoned this idea because the gears damage the surface of the plush toy due to friction.

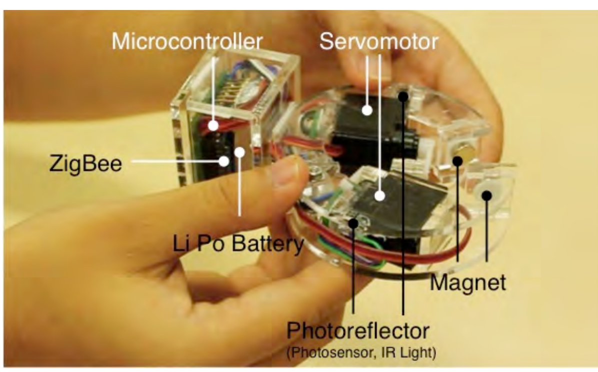

Figure 2. Hardware components.

Figure 3. Design prototypes of PINOKY.

Current implementation

We developed a ring-type actuator that can be attached to and removed from any plush toy. Our prototype actuator creates joint movement using two servomotors (CORONA CS-929MG). Each is fitted with an arm that displaces the surface of the toy. The joint is bent by pushing on the cover (Figure 4). By changing the servomotor speed and rotation angle, we can dynamically control the speed and joint angle of the plush toy. The arms are positioned so that they do not extend beyond the device. We have successfully used PINOKY on plush toys with knit and fleece fabrics. However, it is less effective on cotton stretch fabrics. Filling material like cotton, beans, and sponge can be used without any problems. However, PINOKY is less able to generate identifiable motion on plush toys with high-density filling material (e.g. sand). The diameter of plush toy that can be used depends on device diameter. In our observations, if the PINOKY ring has a diameter d, plush toys within the range of diameter d - 1cm to d + 2cm can be used. The maximal velocity of limb is 0.23sec/60°, and maximal resolution is 0.67° per 1 step. For an 8.5 cm plush toy limb, the joint angle range is $-50° < \theta < 50°$.

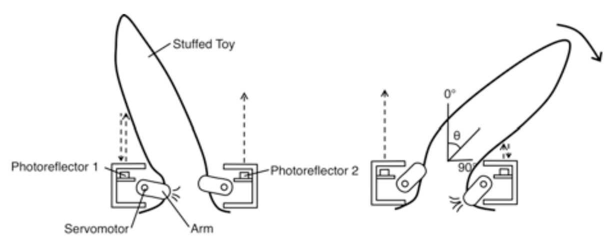

Figure 4. Actuation principle: a pair of DC servomotors push on the toy's cover; two photoreflectors sense joint angle θ by measuring distance between sensor and cover.

Sensing

To measure the joint angle, we use a pair of photoreflectors (photosensor and IR LED), which are generally used to measure the distance to objects. As shown in Figure 4, they are embedded in the device at either end of the ring, and they measure the distance to the surface of the toy. When the joint bends, one of the sensors becomes closer to the surface.

We conducted an experiment to investigate the relationship between the change in the joint angle and the photoreflective properties of the sensors (Figure 5). The limb length was 8.5 cm, and the limb was bent from −50 degrees to 50° by hand at intervals of 2°. The results are shown in Figure 5; the red line shows the photovoltaic voltage when a hand covered the sensor. As shown in the figure, the range of joint angles that the system can measure is $\theta < -31.2°$, $34.2° < \theta$.

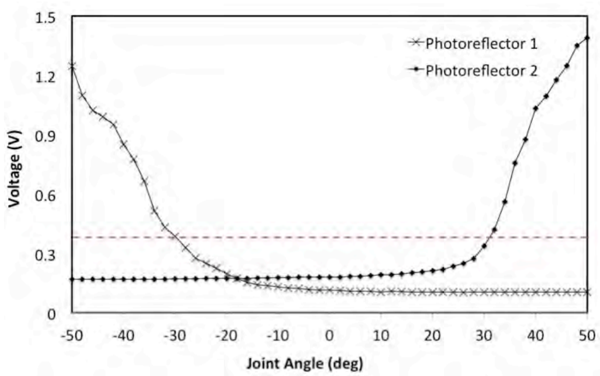

Figure 5. Measurable joint angle range.

Communication

A wireless communication device (ZigBee) is embedded in PINOKY. It is energy efficient and has a self-organization network function. The ZigBee module is able to communicate not only with PCs but also with other ZigBee modules directly without using a server on a PC. In this work, it was used as a standalone module without PC support. However, the device is designed to support other configurations. The use of ZigBee enables the number of devices to be flexibly increased.

Basic Interaction

We created two basic interaction modes for PINOKY on the basis of those of Topobo [20]. The user can switch between them by pushing one of the three colored buttons on the side of the device (see Figure 3).

Record and play mode

In record and play mode, the user can record the behavior desired by directly moving the joint to which the device is attached. The microcontroller memory is sufficient to record behavior for up to 1 minute. The plush toy can then execute the recorded movements.

Synchronize mode

Through the ZigBee network, multiple PINOKYs can be synchronized with each other.

USER STUDY

A user study was conducted to determine the validity of our design direction, evaluate the usability of the PINOKY device, and see how participants react to the concept. Basic interactions between participants and the devices were observed, and feedback was obtained from the participants for the purpose of improving future versions. There was no comparison study performed as there are no existing devices that control plush toys in a similar manner.

Participants

We recruited 51 participants by placing a poster describing PINOKY at the entrance to the study area (in a science museum in Japan) that invited passersby to participate. They were between 2 and 70 years old (average: 23.8 years, standard deviation (SD): 19 years); 24 were male and 27 were female. The number of children from 2 to 9 years old was 18. Participants who were 3 years old and younger were assisted by a parent and the experimenter while using the device. All participants had no prior experience using the device.

Environmental Setup

A closed environment was created by using screen partitions. The participants were seated (individually or in a group) across a table from the experimenter. Each trial was video-recorded.

Experimental Design

Each experimental session consisted of three phases: 1) completion of a questionnaire to survey how plush toys are used in the participant's daily life, 2) observation of how the participants played with plush toys without PINOKY, 3) observation of how they played with plush toys with PINOKY, completion of a questionnaire to survey their reactions to the device, and an interview to solicit their thoughts on the concept.

For the first phase, the participants aged 14 and older (30 participants) completed a pre-experiment questionnaire about the plush toys that they owned. The purpose was to learn about the participants' impressions of plush toys, how many and what types of plush toys they owned, and what kind of memories they associated with them. Occasionally, a casual interview would be carried out as well.

The second phase was a general observation of how the participants interacted with plush toys. They were not told of this observation so that they would not feel self-conscious, thus enabling us to observe their natural interactions with plush toys. During this phase, we did not show the device to the participants. We also carried out a casual interview after the observation.

In the third phase, the PINOKY device was introduced by the experimenter, who explained and demonstrated the two basic functions (record and playback, and synchronization). 5 devices and 12 plush toys (6 humanoid, 3 fish, a teddy bear, an octopus, and a snake) were placed on the table. The participants were then allowed free selection of the number of devices and the type of plush toy to play with, and were allowed a minimum of 10 minutes to freely play with them. Their actions were observed. At the end of this phase, the participants aged 10 and older (32 participants) answered a post-experiment questionnaire about their reactions to PINOKY, and they were interviewed about their thoughts on the concept.

RESULTS

Plush Toy Usage in Daily Life

The 30 participants who answered the pre-experiment questionnaire about the plush toys that they owned ranged in age from 14 to 70 (average: 34.7 years, standard deviation (SD): 13.7 years), 11 male and 19 female. They were encouraged to describe their plush toys: shape and size, location in the house, memories associated with them, and so on. The results showed that about 70% of the participants owned more than one plush toy. The mean number of plush toys owned was 13.6 (SD: 14.5) and was affected by the family configuration.

Participants remembered the circumstances under which they received the plush toys, and had some memory associated with about 76% of the plush toys on the list: about 58% of them were received as a gift on special occasions such as a birthday.

The results also showed that about 73% of the participants' plush toys were placed at easily visible locations, such as around the bed (~34%), on a shelf (~16%), and on the sofa (~9%). However, about 23% had been hidden away in a closet, a toy box, or elsewhere.

How Participants Played with Plush Toys without PINOKY

Our observations of how participants played freely with the plush toys were useful when designing the interactions using PINOKY to convert an existing plush toy into an interactive toy. We focused on how the participants interacted with the plush toy.

Some movements we observed the participants making with the plush toy were dancing and jumping. Most participants pretended that the plush toy was alive and used it to talk to someone else. One participant said, "*I often use a plush toy as spokesperson to help me convey what I want to tell my child.*" Several other participants used plush toys to play house. Another participant said that her child found it interesting when she synchronized the movements of two plush toys. For these activities, the plush toys' gestures were created by bending the arms, legs, neck, and tail, and voice was added accordingly (Figure 6).

How Participants Played with Plush Toys with PINOKY

Usability

All participants, across a wide age range (2 to 70 years old), were able to easily attach and remove the device from almost any part of a plush toy. While a quick demonstration was given to all participants before the experiment began, it was observed that some children were able to attach and remove the device even before the demonstration was given. This shows that our device design makes it generally intuitive to use.

The post-experiment questionnaire consisted of eight ease-of-use statements. The results are shown in Table 1, which

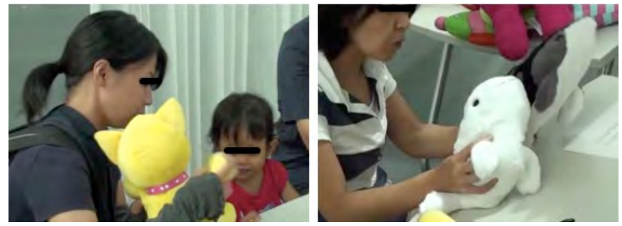

Figure 6. Participants demonstrate how they play with plush toys, bending the limbs (left), synchronizing the movements of similar-shaped plush toys (right).

Table 1. Results of post-experiment questionnaire

No.	Question	Mean	SD	%
1	It was enjoyable to me that the plush toy moved.	5.19	1.07	78.1
2	I was able to use the device easily.	5.16	1.54	71.9
3	I was able to use the device to give movement to the plush toy easily.	5.16	1.44	71.9
4	I was able to use the device with confidence.	4.34	1.57	43.8
5	I think that most people will be able to use the device to animate their plush toys.	4.81	1.42	59.4
6	I think that the device is an adequate one to animate the plush toy.	4.16	1.35	43.8
7	I felt the need to learn many things in order to operate the device.	3.59	1.56	31.3
8	I felt the need to concentrate while using the device.	3.19	1.57	18.8

shows the mean, SD, and percentage of positive responses (>4 on a 7-point Likert scale). 25 users reported that the device was enjoyable to use (Q1: 78.1% positive responses). 23 reported that the device was easy to use (Q2: 71.9%). Many participants (68.7%) reported that they did not feel the need to have to learn how to use it (Q7) and that they could easily use it to give movement to a plush toy (Q3). However, 56.2% of the participants reported that they did not feel confident using the device (Q4).

Number of devices, location of attachment

It was observed that many participants realized that they could attach multiple devices to a plush toy such as an octopus (one to each tentacle) or a snake (multiple devices along the body) and thereby create more complex animations using synchronization mode. It was also observed that different users attached the devices to different parts of a plush toy (Figure 7).

Difference between user expectations and system performance

As this device is still in the early prototype phase, only two sensing points were provided. Initially, some participants were unable to manipulate the plush toy to enable the sensors to detect the user-input movement properly when using the record and playback function. However, once the sensor locations were pointed out to them, they were able to use the function without any problem. Furthermore, there were times when the limb of the plush toy was too short to have its movement detected by the sensors.

Figure 7. Attachment location: ear (left), tail (center), and arms (right).

Likewise, when told about the record and playback function, many users expected full functionality. Thus, while the device is only able to record a forward/backward motion, there were some users who tried to make the plush toy move in a circular manner.

Finally, some of the participants expressed a desire for a smaller device as they felt that it was too chunky. While a smaller device is also something that we hope to create, it is difficult to do so with current technology.

Different styles of play related to demographics

Since all the participants were allowed to freely play with the device, we could observe the relationship between demographics and device use (Figure 8).

Male participants tended to use the devices on more than one plush toy. They also tended to use more devices than the female participants.

Participants who were 2 years old played with the device under the guidance of an adult (parent or experimenter). A 2-year-old girl found the device scary and vehemently refused to allow her mother to attach the device to the plush toy, immediately removing it if attached. A few 2-year-old participants showed no interest in the device. This might be because they were unable to fully understand the concept or because the movements of the plush toys were not big enough. In general, it was observed that the 2-year-old participants were unable to operate the device on their own. The attachment and removing of the device was mostly left up to the adult, with the child occasionally trying to help.

The 3-year-old participants generally needed the guidance of an adult (although one did not need help). One 3-year-old boy was observed using the record and playback function successfully. However, during the synchronization, he focused on moving the plush toy instead of watching the synchronized animation. Another 3-year-old participant was observed attaching the device to random locations on the plush toy. Instead of deriving fun from seeing the plush toy become animated, she seemed to have more fun opening and closing the device. In general, the participants of this age were able to attach and remove the device without help and were able to grasp how to operate the device on their own.

Participants of elementary and junior high school age were allowed to play with the device without adult guidance. Two participants were observed to enjoy playing with the device but eventually removed all the devices and proceeded to have fun hitting each other with the plush toys. In general, all participants were observed to be able to fully utilize the device without any problem. They tried both functions of the device on several different plush toys. These participants tended to enjoy the playtime more in the presence of another person (participants showed off the movements they created to their family).

Participants in the age range of 20 to 39 years, although to varying degrees, showed surprise and a sense of wonderment when the plush toy moved. These reactions were typically more clearly expressed by female participants, with the younger participants showing bigger reactions. Participants also showed an interest (more so for male participants) in the technology behind the device.

There seemed to be a correlation between the age of the participants and how much emotion they displayed. As compared to the previous age category (20 to 39), participants in the age range of 40 to 59 were observed to generally have less reaction and to have more of an air of understanding after they managed to make the device move as demonstrated. There was, however, one exception to this observation. One 59-year-old participant showed much joy when the plush toy moved. She also enjoyed attaching many devices to the plush toy and synchronizing all of them. This might be a cultural difference as this participant was an Australian, while the rest of our participants were Japanese.

Lastly, participants 60 years old and above did not show much reaction. Most of these participants were able to understand the operation of the device. However, there was one participant (70 years old) who took some time to fully comprehend the idea and operate the device properly.

Figure 8. Images of participants using PINOKY.

Difference in impressions between individual experience and group experience

There was a noticeable difference in the amount of satisfaction the participants derived from using PINOKY individually and in a group (two people or more). The results were analyzed with a between-subjects design analysis of variance (ANOVA). The survey responses from the participants who used the device in a group situation were more positive than those from the participants who used the device individually: Q1 ($F(1,30) = 36.8750$, $p<.01$) and Q3 ($F(1,30) = 66.2188$, $p<.05$). This may be because the participants in a group were able to share their play experience with each other and take turns controlling in synchronization mode (one participant commented that it was more enjoyable to him that someone else animated his plush toy rather than animating the plush toy himself). Additionally, participants in a group found the device easier to use than participants who used the device individually. This may be because they had someone (who was not a stranger) to turn to for help if they were unable to make the device operate as they intended.

DISCUSSION

Plush Toys in the Home

From the survey results in phase 1, we can conclude that ownership of plush toys is common, that they are easily visible in the home, and that most owners have memories associated with them. Also, from our observations of how the participants naturally played with plush toys, we can conclude that most of the participants played with a plush toy by giving it some form of animation.

Validity of Design

Here we review the appropriateness of our design goals on the basis of the results of the survey and our observations of the participants' interactions with plain plush toys. We also examine whether our implementation satisfies these goals on the basis of our observations of how the participants used PINOKY.

Easy to use – The child participants started playing with the plush toys immediately upon picking them up. Any enhancement to a plush toy should not interrupt such immediate interaction. All participants were observed to be able to use the device without any practice, showing that the device is easy to use.

No damage to plush toy – From the survey, we learned that many of the participants had strong attachments to their plush toys, so they would likely not be happy to have their plush toys cut open so that movement actuators can be embedded. Our device does not require any alteration to the plush toy, and no damage to the surface of any of the plush toys used in the experiment was detected after their use.

Easily attachable and removable without requiring special tools – One participant commented: "*I wash my plush toy whenever it gets dirty.*" This shows the importance of the design goal: easily attachable and removable. The plush toy should be easily washable. Our device is held in place by a pair of magnets, and it was observed that even some of the 2-year-old participants were able to attach and remove the device without help.

Scalability – We observed that participants move various parts of a plush toy when playing with it. This shows the importance of scalability. Participants were seen to able to attach and use as many devices as they pleased, as the ZigBee module enables multiple simultaneous connections. Some participants encountered the size limitation of PINOKY when they tried to attach it to a part of the toy that was too big to fit within the device.

Aesthetically pleasing – Many participants indicated that they display their plush toys in their rooms, which shows the importance of aesthetics. Covering the device with felt so that it matched the texture and look of plush toys seems to be effective as there were no complaints from the participants about device appearance. However, from earlier observations of the 2-year-old participants, it was seen that some tore off the device. This may be because they still saw it as an alien object, different from their familiar mental image of a plush toy. This shows that there is still room for improvement, such as by shrinking the size to something more acceptable, and redesigning the appearance to look more similar to that of an accessory or a wearable.

Safe and robust – Children often played with the plush toys in a rough manner, so safety and robustness are important. None of the participants were injured during the course of the experiment, demonstrating that the device can be safely used even by very young children. Devices were dropped many times during the experiment, and some participants exerted much force on them. After four days of tests, all the devices were examined and found to be still working properly, showing that our design is stable and durable.

Adequate movement actuation – Our observations of how the participants play with plush toys revealed that plush toys can be animated so as to perform various types of movement: jumping, walking, and so on. The swing motion that PINOKY was designed to create constituted the most often used animation during our observations. We believe that the swing motion is an adequate one for expressing many different types of emotions (for example, many different expressions such as agreement and dislike can be created by manipulating the neck of a plush toy using the swing motion). Therefore, we can say that our design is sufficient to accommodate most motions that users would expect from a plush toy.

From the observations and survey results, we can see that the device design fulfills almost all the requirements we set at the beginning, thus making it a very effective one. In general, the users reacted very positively, and it was observed that they derived enjoyment from seeing the plush toy moves autonomously. They were pleasantly surprised by the movement, and some even commented that it was as if the toy was alive. However, there was a slight problem with regards to scalability, and this will be discussed in the Limitations and Future Work section.

Example Applications

Since users are now able to do things previously impossible, such as controlling multiple plush toys simultaneously, and recording motion data and have it played back. This opens up a variety of new play experiences with plush toys. On the basis of our results, we conceptualized several potential applications of PINOKY.

Telecommunications

Our observation that some participants used a plush toy as an avatar raises the possibility of using PINOKY for a new form of communication, over and above voice and video communication. Plush toys located remotely can be synchronized so that callers communicate not only by voice but also by using the toy's movements to express their thoughts and feelings. A system could be developed for synchronizing PINOKY devices through a TCP/IP network, and other interfaces such as iPhone and Kinect could be used to expand the range of communication.

Story telling

From our user study, we learned that children sometimes create stories using plush toys by giving them voice and movement. Plush toys typically have a humanoid or animal shape, so they are well suited for use as characters in a story. Since PINOKY can be easily programmed, children can easily input the desired movement by simply manipulating the toy. Since the input data is archived, children can program several plush toys and then have them interact.

Watching television programs with PINOKY

Being able to watch television programs with one's favorite plush toy is a unique and enjoyable experience. Although we have created a prototype PINOKY that would cause a plush toy to react during the climax of a horror movie or comedy in order to enhance the emotions of fear or amusement, the behavior currently needs to be hard-coded. In the future, we hope to combine this with an existing video service such as YouTube. By using the annotation function, anyone could control the reaction timing (if they provide the API and if PINOKY can understand the language that the user inputs).

Limitations and Future Work

Our ring device is a "proof-of-concept" implementation, so there are some hardware limitations. We observed that for the plush toys with thinner limbs, the participants had to ensure that the limb was properly inserted between the actuators to be able to obtain the correct movement. We hope to develop a device that is able to adapt its size to the target part of the plush toy. Also, some participants indicated that they would prefer a smaller device. PINOKY is currently implemented using a general-purpose microcontroller (Arduino) and a commercial ZigBee module. In a more customized implementation, we could select components with a smaller footprint and integrate them into a more power-efficient system with a smaller form factor. Moreover, there is a trade-off between servomotor size and torque. While small plush toys can be controlled via other methods such as using smaller actuators with lower torque (such as bio-metal ones), bigger plush toys cannot. The development of smaller actuators with high torque would greatly reduce device size. In the meantime, we are currently working to make the device less noticeable by packaging it into accessories for plush toys, such as the shoulder straps of a backpack.

While it is possible to express many different emotions using the swinging motion that PINOKY can actuate, there are still some emotions that cannot be expressed yet as they require different movements. We are looking at designing a device that can create other types of movement: twisting, expansion and contraction, and so on. We are also working on other attachable devices that can create a jumping and swinging movement for the whole plush toy (for example, a tail-like device that can cause a body-shaking movement). With the new devices, we will conduct another test to see how the new motions affect how participants play with plush toys, and whether it enhances the play experience.

Another limitation of PINOKY is its sensitivity to sunlight. This is because we use photoreflectors, which detect both the infrared light from the emitters and infrared radiation from the sun. This may be solvable using an ultrasonic sensor. Some participants had expressed a wish for alternative input methods, such as using voice instructions. We will thus also look at introducing more input methods, e.g., making a plush toy react by shaking or squeezing it (done by attaching a sensor module consisting of acceleration and pressure sensors to the toy's surface material). Furthermore, by using a motion sensor, we can cause a plush toy react when someone enters the room. Ultimately, we aim to utilize these tangible I/O modules as a programming environment to convert a personal plush toy into an interactive robot.

CONCLUSION

PINOKY is a ring-like device that is able to give movement to a plush toy, such as moving its limbs or tail. As opposed to actuators that have to be embedded into the plush toy, our device operates externally. Thus, the user can convert any plush toy into an interactive robot in a non-intrusive manner without having to make any alterations to the toy. Because the electronic parts (microcontroller, battery, sensor, and actuator) are in one package and do not require external wiring, the user can easily attach the device to any plush toy as an accessory.

We conducted a user study to determine the validity of the design direction of PINOKY, and evaluate the usability of the device. Our surveys of how plush toys are used in daily life showed that ownership of plush toys is common (about 70% of the participants owned more than one plush toy) and that most owners have memories associated with them. Our observations of how the participants used PINOKY showed that all of them were able to fully utilize the device without any serious problems. The results indicate that there are various potential applications of PINOKY.

REFERENCES

1. Breazeal, C., Kidd, C., Thomaz A. L., Hoffman, G. and Berlin, M. Effects of Nonverbal Communication on Efficiency and Robustness in Human-Robot Teamwork. In *Proc. IROS '05*, IEEE (2005), 708–713.
2. Buechley, L., Eisenberg, M., Catchen, J. and Crockett, A. The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In *Proc. CHI '08*, ACM (2008), 423–432.
3. Camp Quality. http://www.campquality.org.au/
4. Coelho, M. and Zigelbaum, J. Shape-changing interfaces. Personal Ubiquitous Comput. 15, 2, 161–173.
5. Furby (1998). Furby, from http://www.furby.com
6. Furukawa, M., Uema, Y., Sugimoto, M. and Inami, M. Fur interface with bristling effect induced by vibration. In *Proc. AH '10*, ACM (2010), Article 17, 6 pages.
7. Ghan, J., Steger, R. and Kazerooni, H. Control and system identification for the Berkeley lower extremity exoskeleton (BLEEX), *Advanced Robotics 20*, 9 (2006), 989–1014.
8. Greenberg, S. and Fitchett, C. Phidgets: Easy development of physical interfaces through physical widgets. In *Proc. UIST '01*, ACM (2001), 209–218.
9. Hadari, F. http://www.speakingpuppetry.com/
10. Ishikawa, T. and Hasegawa, S. The Motion Control of Soft Feeling Stuffed Animal Robot. *Technical Report of Information Processing Society of Japan (2011)*, Vol.2011-EC-19, No.13. (in Japanese)
11. Johnson, M. P., Wilson, A., Blumberg, B., Kline, C. and Bobick, A. Sympathetic interfaces: using a plush toy to direct synthetic characters. In *Proc. CHI '99*, ACM (1999), 152–158.
12. Sugiura, Y., Kakehi, G., Withana, A., Lee, C., Nagaya, N., Sakamoto, D., Sugimoto, M., Inami, M. and Igarashi, T. Detecting shape deformation of soft objects using directional photoreflectivity measurement, In *Proc. UIST '11*, ACM (2011), 509 –516.
13. Koizumi, N., Yasu, K., Liu, A., Sugimoto, M. and Inami, M., Animated paper: A toolkit for building moving toys, *Computers in Entertainment (CIE) 8*, 2 (2011).
14. Lego. Lego Mindstorm. http://mindstorms.lego.com/
15. Marti, S. and Schmandt, C. Physical embodiments for mobile communication agents. In *Proc. UIST '05*, ACM (2005), 231–240.
16. Osawa, H., Ohmura, R. and Imai, M. Using Attachable Humanoid Parts for Realizing Imaginary Intention and Body Image, *International Journal of Social Robotics 1*, 1 (2009), 109–123.
17. Oschuetz, L., Wessolek, D. and Sattler, W. Constructing with movement: kinematics. In *Proc. TEI '10*, ACM (2010), 257-260.
18. Probst, K., Seifried, T., Haller, M., Yasu, K., Sugimoto, M. and Inami, M. Move-it: interactive sticky notes actuated by shape memory alloys. In *Ext. Abst. CHI '11*, ACM (2011), 1393–1398.
19. Puppets in Education. http://www.puppetsineducation.org/
20. Raffle, H., Parkes, A. and Ishii, H. 2004. Topobo: A Constructive Assembly System with Kinetic Memory. In *Proc. CHI '04*, ACM (2004), 869–877.
21. Robot to reduce the stress for victims, Tech-On, Nikkei BP net (June 20, 2011). http://techon.nikkeibp.co.jp/article/NEWS/20110615/192583/. (in Japanese)
22. Sekiguchi, D., Inami, M. and Tachi, S. RobotPHONE: RUI for Interpersonal Communication. In *Ext. Abst. CHI '01*, ACM (2001), 277–278.
23. Shimizu, N., Koizumi, N., Sugimoto, M., Nii, H., Sekiguchi, D., Inami, M. A Teddy-Bear-Based Robotic User Interface, *Computers in Entertainment (CIE) 4*, 3 (2006).
24. Stiehl,W. and Breazeal, C. Design of a Therapeutic Robotic Companion for Relational, Affective Touch. In *Proc. RO-MAN '05*, IEEE (2005), 408–415.
25. Strommen, E. When the interface is a talking dinosaur: learning across media with ActiMates Barney. In *Proc. CHI '98*, ACM (1998). 288–295.
26. Taal, S.R. and Sankai, Y., Exoskeletal Spine and Shoulders for Full Body Exoskeletons in Health Care, *Advances in Applied Science Research 2*, 6 (2011), 270–286.
27. Ueki, A., Kamata, M. and Inakage, M. Tabby: designing of coexisting entertainment content in everyday life by expanding the design of furniture. In *Proc. ACE '07*, ACM (2007), 72–78.
28. Wada, K. and Shibata, T. Social effects of robot therapy in a care house - change of social network of the residents for two months. In *Proc. ICRA '07*, IEEE (2007), 1250–1255.
29. Winnicott, D. Transitional objects and transitional phenomena - A Study of the First Not -Me Possession, *Int. J. Psychoanal. 34*, (1953), 89-97.
30. Yonezawa, T., Clarkson, B., Yasumura, M. and Mase, K. Context-aware sensor-doll as a music expression device. In *Ext. Abst. CHI '01*, ACM (2001), 307–308.
31. Yoshida, E., Murata, S., Kamimura, A., Tomita, K., Kurokawa, H. and Kokaji, S. A Motion Planning Method for a Self-Reconfigurable Modular Robot, In *Proc. IROS '01*, IEEE (2001), 590–597.