Fur Interface with Bristling Effect Induced by Vibration

Masahiro Furukawa
The University of Electro-Communications
1-18-14, Chofugaoka, Chofu, Tokyo, JAPAN
furukawa@hi.mce.uec.ac.jp

Yuji Uema, Maki Sugimoto, Masahiko Inami
Graduate School of Media Design, Keio University
4-1-1 Hiyoshi Kohoku-ku Yokohama-city, Kanagawa, JAPAN
{uema, sugimoto, inami} @kmd.keio.ac.jp

ABSTRACT
Wearable computing technology is one of the methods that can augment the information processing ability of humans. However, in this area, a soft surface is often necessary to maximize the comfort and practicality of such wearable devices. Thus in this paper, we propose a soft surface material, with an organic bristling effect achieved through mechanical vibration, as a new user interface. We have used fur in order to exhibit the visually rich transformation induced by the bristling effect while also achieving the full tactile experience and benefits of soft materials. Our method needs only a layer of fur and simple vibration motors. The hairs of fur instantly bristle with only horizontal mechanical vibration. The vibration is provided by a simple vibration motor embedded below the fur material. This technology has significant potential as garment textiles or to be utilized as a general soft user interface.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Haptic I/O, Input devices and strategies, Interaction styles.*

General Terms
Soft User Interface, Pet Robot, Visual and Haptic Design, Computational Fashion

Keywords
Physical Computer Interfaces, Computational Clothing.

1. Introduction
The important part of wearable technology is its role as an interface between information devices and humans [1]. There have been many improvements in terms of wearable input devices. A lot of research done on them has focused on the context and physical characteristics of the user interface, such as the material and texture. However, improvements to the physical aspects of user interfaces have usually involved only the reduction of thickness and greater flexibility [4][5]. There have also been many improvements with output devices. Head mounted displays are often used to provide textural information [1], while vibration motors have mainly been used to provide non-textural information [6]. The first advantage of a vibration motor is its small size, making it easy to embed in garments [7][21]. This feature makes it possible to keep the unique textures of the garments, fully maintaining their tactile and visual characteristics, while simultaneously making this output device wearable. By combining the physical features of both fur and these vibration motors, we develop an interface that can be used as both an input and output device.

For example, a cat's body is covered in a coat of fur, which he uses not only to maintain his body temperature but also to express his affection through bristling his fur [23] as shown in Figure 1 (a). The hair erection of chimpanzees is also known to have a social role as a means of visual communication [24]. Thus the soft body hair of these animals performs their equally important role as output interfaces. Accordingly, it is important

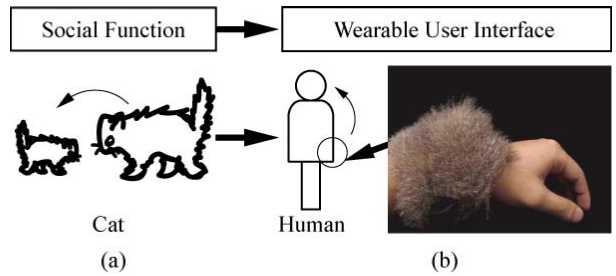

Figure 1. Soft and Flexible User Interface suitable for Wearable Computing Inspired by Hair Erection.

Figure 2. Bristling Effect with Horizontal Vibration Provided from Vibration Motor.

Augmented Human Conference, April 2-3, 2010, Megève, France.

to create a user interface that has a soft and flexible surface, while also exhibiting both visual and tactile messages**.**

1.1 Purpose of Research

In this paper, we propose the novel texture control method, using natural fur as a wearable interface. This method based on the bristling effect allows the texture of natural fur to change suddenly as shown in Figure 2. This technology, which needs only a simple vibration motor and furry material, also has the additional benefit of being a soft and flexible user interface.

1.2 Contributions

The method with bristling effect by horizontal vibration has the following advantages:

- This method only requires commonly available materials and actuators.
- This method can be easily applied to clothing materials, making it compatible as wearable computer technology.
- This method can be used on the surface material of Pet robots, providing a natural and believable platform to express the internal state of these robots
- This method can be used on the soft surface portions of information devices including those found on common household furniture such as couches and cushions that are connected to home electronics.

2. Related Work

Previous related works on soft and flexible wearable interfaces are described as the following.

2.1 Material for Garment

One of these wearable interfaces makes use of visual changes in the surface itself in order to provide information to the user. For example, Wakita proposed Fabcell, which is a novel type of garment [9]. Fabcell is a non-luminous garment material which is made of conductive yarn inter-woven with fibers dyed with liquid crystal ink. When a voltage is applied to the fabric, there would be a change in temperature, which in turn changes the color of the fabric. In another similar project, the "Huggy Pajama", they also proposed a wearable display with color changing properties [10].

These works are in some ways similar to our system as these interfaces are also non-luminous and change visually to convey information. In addition, they are also soft, flexible and wearable. Nevertheless, the difference is their visual changes are much slower. This is so because the speed of molecular changes caused by temperature changes is much slower than mechanical changes. Examples of interfaces that work based on mechanical changes are described below.

2.2 Artificial Fur

In this work, "Tabby" by Ueki, artificial fur is used as a tactile interface that gives users a soft feeling. Tabby is a lamp that has an animal like soft body covered by this artificial fur and it aims to stimulate communication between people within a public space [16]. Tabby's artificial fur has a form that changes its shape as if it is breathing and this is controlled by a pressure fan within it. There is also an incandescent lamp underneath the fur, whose luminescence captures the people's attention in public. Together with its soft tactile surface, it would encourage people to touch Tabby. Thus, we can suppose that an artificial fur surface plays an important role in communication.

Soft and furry materials are also known to provide psychological comfort [8]. For example, Wada proposed the seal-shaped Mental Commitment Robot that is covered by artificial fur, in order to stabilize the mental state of the mentally ill and to reduce the burden of workers who serve in care facilities [19]. The artificial fur of this robot gives a psychological sense of cuteness and comfort to people. Moreover, Steve Yohaman also proposed the Haptic Creature Project, which involves a rabbit-shaped robot covered by artificial fur, similar to the Mental Commitment Robot [17].

As mentioned above, artificial fur can acts as a soft tactile interface and also provide haptic comfort. Moreover, it is possible to give the user an impression of holding a living mammal using haptics. For example, Hashimoto worked on an Emotional Touch project, which has voice coils to control the air pressure between one's hands and the voice coils in real time, and thus providing a novel haptic impression of holding a living animal [20]. However, this project does not provide changing visual effects, which the artificial fur can.

Other than the merits of haptic and visual feedbacks, the furry material also has another visual effect that makes use of the changing attitude of each hair. Thus furry material has many hair on the base, the appearance changing occurs when the attitude of hair changes. Thus, this feature has the ability to provide information like event reporting, status changing, with remains the surface soft. The technologies that aim to control this attitude of hair are described as the following.

2.3 Static Electricity with Dense Fur

The electrostatic effect is known to affect the "standing" or inclination angle of furs, and thus changing the shape of the furs. The Van de Graaff generator is used to generate static electricity, which makes one's hair stand up when the person touches the electrode of this generator. Thus, it is possible to apply this same principle in order to control the inclination of the furs and produce a bristling effect. However, the Van de Graaff generator is relatively large and so is not very portable for users.

Circuits of high voltage also produce static electricity and are smaller in size than the Van de Graaff generator. Philips Electronics has patented this method known as the Fabric Display [11]. Nevertheless, there is the possibility of an electric shock when the user comes in direct contact with the electrodes, which makes it dangerous to be used.

2.4 Electromagnetic Forces, Shape-Memory Alloy with Sparse Fur

On the other hand, there are works that are based on controlling the inclination angle of individual hair, for example, Raffle's Super Cilia Skin [13]. This method uses electromagnetic forces to control the inclination of stick-like protrusions, which have permanent magnets fixed under them. These protrusions are distributed on an elastic membrane and are controlled by the electric magnet array arranged below the elastic membrane. The distribution density of these protrusions is much lesser than the density of hair on animal fur. Thus the appearance of the surface using this method still differs from that of animal fur.

In another work, Kusiyama proposed the Fur-fly, which involves a servomotor that controls the inclination angle of each batch of artificial feathers [12]. These artificial feathers can provide a soft, haptics interface but as the servomotor used is relatively complex and large in structure, it is not possible to control this interface in a finer and more precise resolution.

Lastly, shape-memory alloy (SMA) is known to change shape through electrical controls rather than mechanical controls and previous works that use this SMA actuation device include Sprout I/O by Coelho [14] and Shutter [15]. Both works are types of kinetic textures that use wool yam and felt, with SMAs attached onto them. The latter not only has physical shutters that are made by felt with attached SMA, the shutters also form a matrix that can display characters through its cast shadow. Thus the matrix can function like a dot matrix display to provide text visuals. Nonetheless, SMA has the issue of having a relatively lower response speed and it also moves slowly.

3. Prototyping and Implementation

Arrector pili muscle is known to make body hair bristle up [22]. Figure 3 shows the process of the bristling effect and the positional relations of body hair, epitheca, arrector pili muscle and hair root. The arrector pili muscle is a muscle located around the hair root and its relaxed, initial state is shown in Figure 3 (a). As it contracts by parasympathetic activation, traction power is generated that makes the body hair bristles up as shown in Figure 3 (b).

However, industrially available natural fur does not have functioning arrector pili muscles. Thus an alternative method is necessary to make body hair bristle. And we managed to find that vibration is useful as an alternative method for bristling effect. The vibration motor, which is typically embedded in a mobile phone, is inexpensive and also safe electrically. Thus disk-shaped vibration motors were attached to the reverse side of the epitheca of natural fur shown in Figure 4 and were then supplied with current to generate vibration. The size of this natural fur is approximately 2cm in width and 25cm in length. From our test results, bristling effect was observed with several kinds of natural fur. The bristling effect is shown in Figure 2. Figure 2 (a) shows the initial state of the fur while Figure 2 (b) shows the appearance of the fur after the bristling effect had occurred. As Figure 2 shows, this bristling effect causes a visual change, which is apparent. Details of this effect are described as the following.

A prototype of the mechanism that produces the bristling effect is consisted of natural fur and a disk-shaped vibration motor as shown in Figure 5(a). The bristling effect, which is described in this paper, is such that the hair of the natural fur would stand up when the fur is vibrated using the vibration motor as shown in

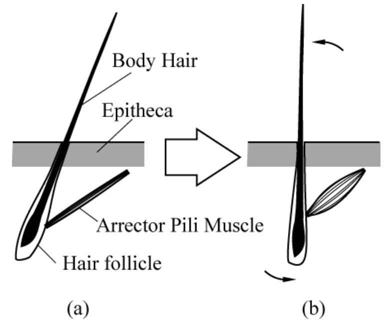

Figure 3. Bristling Effect with Arrector Pili Muscle.

Figure 4. Disk-shaped Vibration Motor To Provide Horizontal Vibration.

Figure 5 (b). Opossum's natural fur and the FM34F[1] disk-shaped vibration motor from T.P.C. are used in this system.

The bristling effect is realized in the following procedure. First, the body hair is stroked with one's hand in order to be compressed as shown in Figure 5 (a). The appearance of this state is as shown in Figure 2 (a). This state remains as such under the condition of no external force being exerted. Secondly, the body hair bristles up when mechanical vibration, generated from the vibration motor, is applied to the fur as shown in Figure 5 (b). The appearance of this state is as shown in Figure 2 (b). Standard voltage 3.0[V] is used to drive the motor. The direction of vibration depends on the direction of the internal weight rotation as shown in Figure 4, and is parallel to the plane surface of the epitheca. Thus this mechanical vibration acts like the action of an arrector pili muscle.

3.1 Selection of Material

This bristling effect is not observed in all types of animal fur. In order to ensure that the conditions of the test are consistent throughout, a fur that would always bristle consistently have to be selected. Thus, a test is conducted in order to select a material which can produce this bristling effect consistently.

Needless to say, artificial fur is a good choice because it can be mass produced, readily available, and has uniform characteristics. Additionally, using artificial fur in place of natural fur is more desirable from the point of view of animal protection. Unfortunately, results from our preliminary study showed that artificial fur was not able to produce consistent bristling effects.

---

[1] Specification of Vibration Motor (T.P.C FM34F): Standard Voltage 3.0V / Standard Speed 13,000rpm / Standard Current 100mA or less / Vibration Quantity 1.8G

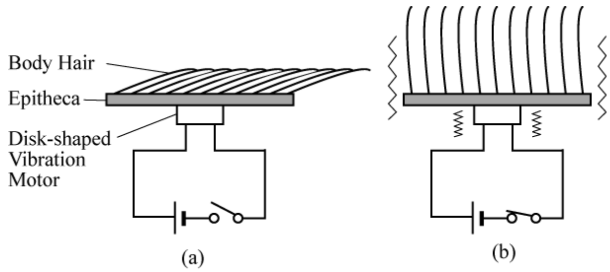

Figure 5. State Transition of Bristling Effect.

Thus we focus on using natural fur. The results of the tests on natural furs and the response time of the natural fur's bristling effect are described below.

The natural furs that are used for estimation are shown in Figure 6. This estimation includes 4 materials which have relatively uniform hair type. The appearances are shown in Figure 6, and the these furs are from (a) an opossum, (b) a rabbit, (c) a mink and (d) a Tibetan lamb.

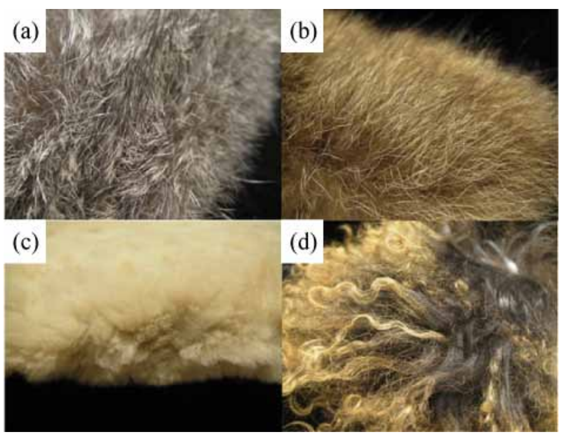

Figure 6. Natural Fur Used for Experiment

Table 1. Mechanical Characteristics and Responses

Material	Thickness	Diameter	Length	R
(a) Opossum	0.33	0.028	48	O
(b) Rabbit	0.53	0.026	36	X
(c) Mink	0.78	–	7	X
(d) Tibetan lamb	0.65	0.047	55	X

Unit: [mm]

A test on the reproducibility of the bristling effect is conducted in the following procedure, which is similar to the previous one. First, one disk shaped vibration motor was attached to the reverse side of the epitheca fur with double-stick tape as shown in Figure 5 (a). Next, the fur was put on velour and the body hair was stroked with one's hand in order to be compressed as shown in Figure 5 (a). Then a standard 3.0[V] voltage was applied to the motor. Lastly, the reproducibility of the bristling effect was estimated by visual judgment.

The result of the reproducibility of bristling effect is as shown in Table 1. Reproducibility is described as 'O' means high-repeatability or 'X' means no repeatability. Opossum's fur is the only natural fur that has a high repeatability of bristling. When the vibration is provided by one motor, approximately 10 cm of the strip of natural fur is bristling.

It can be supposed this bristling effect that we have found is due to the mechanical structure of the natural fur. Thus, the thickness of the epitheca, the diameter and length of the body hair are measured in order to reveal the mechanical characteristics. The diameter is measured in micrometers. The result is as shown in Table 1. The values in the table are taken as the average of 10 readings. There is no value for the diameter of mink's body hair as it is too small to be measured.

The result shows that the epitheca of opossum is less thick than that of the other 3 animals. In addition, although the Tibetan lamb has the greatest hair length, the hair is all bundled together as shown in Figure 5 (d), which makes it more difficult for the bundled hair to "stand" up. On the other hand, the hair of the opossum and the rabbit are not bundled, which makes it easier for their hair to "stand" up. Therefore, we can suppose that the thin epitheca and non-bundled fur of the opossum produces the highest repeatability of the bristling effect.

3.2 Response time of Bristling Effect

One of the characteristics of the bristling effect that we have found is the bristling speed. In terms of mechanical engineering, mechanical findings are necessary for technological application. Thus, as basic findings, the response time of this bristling effect is measured. This response time is the duration of transition from the initial state as shown in Figure 5 (a) to the bristling state as shown in Figure 5 (b). Thus this response time can also be defined as the duration from the start time of supplying voltage to the vibration motor, and to the time of the hair reaching a stable state just after the bristling effect.

3.2.1 Experimental Setup

The response time was measured by digital high-speed camera Casio EXILIM EX-F1. Experimental setup is as shown in Figure 7 and Figure 8. A matrix and an array of LEDs are set up behind the fur material. The matrix is used to calibrate displacements of the featured points, whereby each pixel is 5mm x 5mm in size. As for the LEDs array, one LED would blink after another in sequence at intervals of 10ms in order to confirm the frame rate of the captured video. The LEDs array was controlled with Arduino Duemilanove (ATmega168) and they would start to blink when a voltage across the vibration motor is detected. An incandescent lamp was also used as the lighting. As indicated above, standard 3.0V voltage was used and one disk shaped vibration motor was attached to the reverse side of the fur material, which was put on the velour (Figure 7).

3.2.2 Measurement Procedure

5 recordings were conducted under the same conditions and for each recording, it would start to record before the vibration motor is activated and end after the fur has reached its stable state. The recording specifications are as such: the frame rate is 600fps and video size is 432 x 192 pixels, in landscape mode. The bristling effect was observed in every recording and analysis is conducted after the recordings. Three featured points of observations were

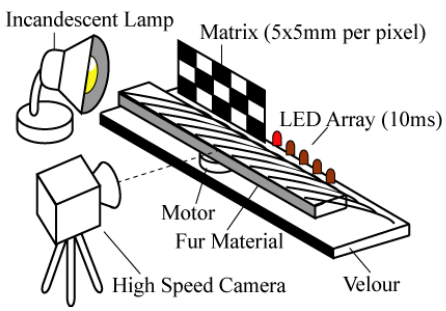

Figure 7. High-Speed Photography Setup

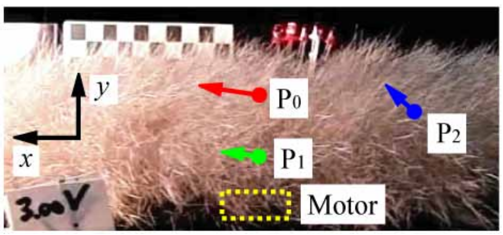

Figure 8. Recording Setup and Displacement of Feature Points Used for High-Speed Tracking.

selected on the fur surface as shown in Figure 8. Pyramidal implementation of the lucas kanade method is also used to track the feature points [25]. During the test, these featured points moved to the left side of Figure 8, with their movement directions and trajectory shown as arrows in Figure 8. The length of the arrow indicates the displacement of the featured point while the positions of the points are described with the x and y axis shown in Figure 8. The actual displacement was obtained after calibration and the transformation coefficients were (x, y) = (0.435, 0.385) millimeter per pixel.

3.2.3 Result and Discussion

The temporal changes of the trajectories of the 3 featured points are as shown in Figure 9. The result of 5 trials shows similar trend of bristling effect. Details of one of these 5 trials are as follow. Time 0 is the time when a voltage across the vibration motor was detected and the trajectories are plotted from this time. The left sided graph of Figure 9 describes the trajectory in x axis, while the right sided graph of Figure 9 describes the trajectory in the y axis. Figure 10 is a larger scaled graph that shows the displacements in between 0 to 500ms. The left side graph of Figure 9 shows that the duration for the bristling effect to happen is approximately less than 500ms. The left side graph of Figure 10 shows that the transition may be finished in approximately 300ms.

As there is no displacement of the featured points in the duration of time before the vibration motor starts, it is supposed that the bristling effect is caused by the mechanical vibration actuated by the disk shaped vibration motor.

The oscillation of the featured point was observed as shown in Figure 10. After comparison to the captured video, we deduced that this is not a tracking error but is instead the oscillation of the fur surface, which continued after 500ms. Frequency analysis was then conducted with the Fast Fourier Transformation. 2,048

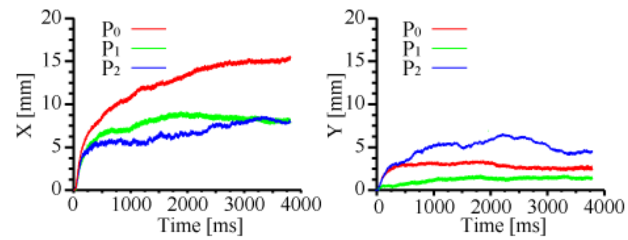

Figure 9. Displacement of Measured Points from Initial Position with High-Speed Camera at 600fps.

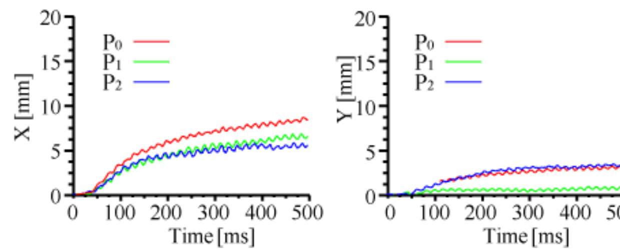

Figure 10. Initial Shifting of Measured Points After Providing Horizontal Vibration to Epitheca

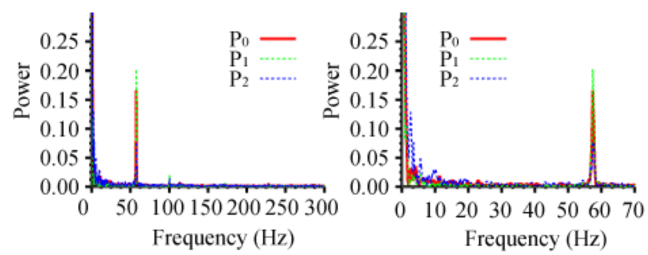

Figure 11. Result of FFT of Vertical Shifting Measured from Feature Point Tracking

sampling points are calibrated from 500ms onwards, and the Hanning window was used for FFT. The result is as shown in Figure 11. The left side graph of Figure 11 describes the regularized power spectrum in the range of Nyquist frequency. The close up of this figure is shown in the right side graph of Figure 11 with the peak frequency at approximately 57 Hz. It is supposed that this peak is the oscillation frequency of the fur surface.

4. Discussion

Our experiments showed that it is impossible to flatten the body hair using vibration. This bristling effect is not reversible with only mechanical vibration. However, manual stroking smoothes out the fur easily. If this interface serves as not only an output device but also an input device, the user strokes the fur naturally. Thus in this interactive system, human reflex instinctively reacts to the fur interface, resolving this reversal issue in the bristle effect. Furthermore, it is relatively easy for capacitive sensors to detect the touch of a hand to the fur.

As mentioned above, the visible physical changes caused by the bristle effect serve as visual information presentation. On the other hand, the mechanical vibration serves as a tactile presentation method [21]. One of the goals of this technology is to increase the desirability and comfort of wearable technology for the user. It is not difficult to present tactile stimulation to human, but through this method, using a single actuator, one can simultaneously provide two modes of sensation—both visual and tactile. This point is another advantage of our method.

5. Conclusion

In this paper, we proposed the texture control method using natural fur and a simple vibration motor as a wearable interface. This method based on bristling effect allows the texture of natural fur to instantly change, and additionally serves as a soft user interface. The result of estimation experiments demonstrated that opossum fur has the best response, with the body hair bristling within less than 500ms and an oscillation frequency of 57Hz. Since our current prototype requires the use of natural fur, the achieved bristling effect is highly dependent on the mechanical properties of the natural fur. Thus, we will further explore the mechanism of the bristling effect in the future using other materials.

6. References

[1] S. Mann, Wearable Computing: A First Step toward Personal Imaging, Computer, vol. 30, no. 2, pp. 25-32, 1997

[2] J. Rekimoto, K. Nagao, The world through the computer: computer augmented interaction with real world environments, Proceedings of the 8th annual ACM symposium on User interface and software technology table of contents, pp. 29 - 36, 1995

[3] H. Ishii, B. Ullmer, Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms. Proceedings of CHI '97, pp. 234-241, 1997

[4] M. Orth, R. Post, E. Cooper, Fabric computing interfaces, CHI 98 conference summary on Human factors in computing systems table of contents, pp. 331 - 332, 1998

[5] D. De Rossi, F. Carpi, F. Lorussi, A. Mazzoldi, R. Paradiso, E.P. Scilingo and A. Tognetti, Electroactive fabrics and wearable biomonitoring devices, AUTEX Research Journal, vol. 3, no. 4, 2003

[6] T. Amemiya, J. Yamashita, K. Hirota, M. Hirose, Virtual Leading Blocks for the Deaf-Blind:A Real-Time Way-Finder by Verbal-Nonverbal Hybrid Interface and High-Density RFID Tag Space, Virtual Reality Conference, IEEE, pp. 165, IEEE Virtual Reality Conference 2004 (VR 2004), 2004

[7] R.W. Lindeman, Y. Yanagida, H. Noma, K. Hosaka, Wearable vibrotactile systems for virtual contact and information display. Virtual Reality, 9, 203-213, 2006

[8] H.F. Harlow, R.R. Zimmerman. Affectional responses in the infant money. Science, p.130, 1959

[9] A. Wakita, M. Shibutani, Mosaic textile: wearable ambient display with non-emissive color-changing modules. In: Proceedings of the international conference on advances in computer entertainment technology (ACE), pp.48-54, 2006

[10] J. K. Soon Teh, A. D. Cheok, R. L. Peiris, Y. Choi, V. Thuong, S. Lai, Huggy Pajama: a mobile parent and child hugging communication system, Proceedings of the 7th international conference on Interaction design and children table of contents, pp. 250-257, 2008

[11] Philips Electronics N.V. FABRIC DISPLAY. United States Patent, No. US 7,531,230 B2, 2009

[12] K. Kushiyama. Fur-fly. Leonardo, Vol. 42, No. 4, pp. 376-377, 2009

[13] H. Raffle, M.W. Joachim, and J. Tichenor. Super cilia skin: An interactive membrane. In CHI Extended Abstracts on Human Factors in Computing Systems, 2003

[14] M. Coelho, P. Maes. Sprout I/O: A Texturally Rich Interface. Tangible and Embedded Interaction, pp. 221-222, 2008

[15] M. Coelho, P. Maes. Shutters: a permeable surface for environmental control and communication. Tangible and embedded interaction (TEI '09), pp. 13-18, 2009

[16] A. Ueki, M. Kamata, M. Inakage. Tabby: designing of coexisting entertainment content in everyday life by expanding the design of furniture. in Proc. of the Int. Conf. on Advances in computer entertainment technology, Vol. 203, pp. 72-78, 2007

[17] S. Yohaman, K. E. MacLean. The Haptic Creature Project: Social Human-Robot Interaction through Affective Touch. ACM SIGGRAPH 2007 Emerging Technologies, p. 3, 2007

[18] S. Yohanan, K. E. MacLean. The Haptic Creature Project: Social Human-Robot Interaction through Affective Touch. In Proceedings of the AISB 2008 Symposium on the Reign of Catz & Dogs: The Second AISB Symposium on the Role of Virtual Creatures in a Computerized Society, vol. 1, pp 7-11, 2008

[19] K. Wada, T. Shibata, T. Saito, K. Sakamoto and K. Tanie, Psychological and Social Effects of One Year Robot Assisted Activity on Elderly People at a Health Service Facility for the Aged, Proceedings of the 2005 IEEE, International Conference on Robotics and Automation, 2005

[20] Y. Hashimoto, H. Kajimoto, Emotional touch: a novel interface to display "emotional" tactile information to a palm, Intl. Conf. on Computer Graphics and Interactive Techniques archive, ACM SIGGRAPH 2008 new tech demos table of contents, 2008

[21] A. Toney, L. Dunne, B. H. Thomas, S. P. Ashdown, A Shoulder Pad Insert Vibrotactile Display, Proceedings of the Seventh IEEE International Symposium on Wearable Computers, pp 35-44, 2003

[22] C. Porth, K.J. Gaspard, G. Matfin, Essentials of pathophysiology: Concepts of altered health states, Lippincott Williams & Wilkins, Chapter 60, 2006

[23] J.A. Helgren, Rex cats: everything about purchase, care, nutrition, behavior, and housing, Barrons Educational Series Inc, 2001

[24] F. B. M. Waal, Behavioral Ecology and Sociobiology, Reconciliation and consolation among chimpanzees, vol. 5, issue. 1, pp.55-66, 1979

[25] J.Y. Bouguet, et al., Pyramidal implementation of the lucas kanade feature tracker description of the algorithm, Intel Corporation, Microprocessor Research Labs, OpenCV Documents, 1999