# Graffiti Fur: Turning Your Carpet into a Computer Display


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## ABSTRACT

We devised a display technology that utilizes the phenomenon whereby the shading properties of fur change as the fibers are raised or flattened. One can erase drawings by first flattening the fibers by sweeping the surface by hand in the fiber's growth direction, and then draw lines by raising the fibers by moving the finger in the opposite direction. These material properties can be found in various items such as carpets in our living environments. We have developed three different devices to draw patterns on a "fur display" utilizing this phenomenon: a roller device, a pen device and pressure projection device. Our technology can turn ordinary objects in our environment into rewritable displays without requiring or creating any non-reversible modifications to them. In addition, it can be used to present large-scale image without glare, and the images it creates require no running costs to maintain.



### Author Keywords

Fur Display; BRDF; Living Environment;

### ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.


## INTRODUCTION

Computer displays play an important role in connecting the information world and the real world. In the era of ubiquitous computing, it is essential to be able to access information in a fluid way and non-obstructive integration of displays into our living environment is a basic requirement to achieve it. However, common displays such as LCDs are not ideal for continuous use in living environments; they occupy considerable space, emit glaring light that disturbs human vision and consume electric power.



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**Figure 1: The devices convert your carpet into a computer display.**

On the other hand, projection-type displays are suitable for ubiquitous environments because they can project images onto any surface in the living environment [4, 12, 24]. Accordingly, the environment does not require large-scale modifications. In addition, it is possible to switch the projection rapidly and project colorful images. However, projectors have disadvantages. For example, the projected images cause glare and are hard to see in a bright room. In addition, the electricity costs of continuously projecting images are quite high.

There have been many proposals and implementations of non-emissive displays that can easily be integrated into living environments without causing any glare, such as E-ink [1] and wooden displays [18]. They do not require electricity except when rewriting. However, all pixels are integrated in the device as hardware, and they require a large device to be installed in the environment in order to show large images.

Instead of placing a display device, information can be displayed on an object or the environment itself by using passive ink. Traditional inkjet printers are immobile, but

[1] http://www.eink.com/

hand-held printers are now available, making it possible to print on objects or areas in the environment [7, 16]. An ink surface can also be made remotely rewritable by using a projector and thermo chromic ink [19]. For these ink-type displays, as electronic components are not needed on the surface, the system itself can be miniaturized. However, they modify the environment non-reversibly by applying ink materials onto the object surface, which limits their applicability in living environments.

In order to solve the problems mentioned above, we propose a display technology that utilizes the phenomenon whereby the shading properties of fur change as the fibers are raised or flattened. The property is in accordance with Bidirectional Reflectance Distribution Function (BRDF). One can erase drawings by first flattening the fibers by sweeping the surface by hand in the fiber's growth direction and then draw lines by raising the fibers by moving a finger in the opposite direction. These material properties can be found in various items such as carpets and plush toy in our living environment. Our technology can turn these ordinary objects into computer displays without requiring or creating any non-reversible modifications to the objects. In addition, it can be used to make a large-scale display and the drawings it creates have no running costs.

We have developed three different devices to draw patterns on a “fur display” utilizing this phenomenon: a roller device, pen device and pressure projection device. The roller device has an array of rods under it. These rods move up and down independently as the user moves the device on the fur. Lowered rods selectively raise the fibers, leaving a pattern on the surface. The pen device is used for freehand drawing by the user. A small continuously rotating rubber wheel is attached to the pen tip and it raises the fibers when in contact. The pen device is also equipped with a gyro sensor, and it continuously adjusts the orientation of the wheel so that the wheel can raises the fur regardless of the holding posture. The pressure projection device uses focused ultrasound to remotely raise or flatten fur.

Our contributions are summarized as follows:

- We present a new display technology leveraging the natural properties of fur.
- We developed three devices to draw patterns on the display.
- We assessed the capability of using the fur display as a computer display in various experiments.

## RERATED WORK

There have been many proposals for non-emissive displays that can be easily integrated into our living environment without causing any glare effects. In particular, many recent studies have attempted to construct displays from natural materials that can be easily integrated into the living space or easily attract users. Wakita and Shibutani developed a display that consists of threads dyed in liquid crystal ink and conductive fiber, knitted into a square textile [23]. Many researchers proposed hairy displays to give the ambient information by moving hairs which is placed in grid layout [1, 8, 13, 15]. Furukawa et al. proposed Fur Display, a soft material interface for creating an organic bristling effect with a vibration motor embedded in animal fur [2]. However, in all of these studies, electronic devices are required to control each pixel actively on the display's surface, so a large-scale system is needed to create drawings on larger surfaces.

Ink is a powerful means to put patterns onto the materials. Kawana developed a stamp with electronically controllable pattern [7]. Pixelroller is a performance tool that allows user to draw characters or pictures on the wall by emitting ink from a nozzle [16]. Saakes et al. developed a system in which user can draw rewritable pattern freely on soft material by projecting laser light to object coated by thermochromic ink [19]. However, inking causes non-reversible modification to the environment, which is problematic for the living environment.

The BRDF displays have been proposed in computer graphics and art fields [6, 9, 11, 14, 18]. Hullin et al. proposed a method to change the reflection of an object on a water surface by creating and controlling waves on the surface at high speed [6]. Ochiai et al. proposed a method to project images on the back of a vibrating soap bubble to create a membrane screen [14]. Wooden Mirror is an artwork that is drawn from reflected light by controlling an array of wooden blocks [18]. Our method is advantageous because it is possible to use existing objects in the environment (e.g. standard carpet) as BRDF displays without making any permanent modifications to them.

We are not the first to display information by manipulating the shape of “existing” physical materials or controlling their reflectance. Rice paddy art[2] is an attempt to create large-scale drawings in a farm space over a long period of time, by planting seeds that have buds of various colors. Karesansui[3] is a Japanese traditional culture method of drawing patterns in a garden with stones. A modern version of this art form, Lazy man Zen garden, is able to draw a pattern automatically in sand [10]. Large patterns can also be drawn by walking on the snow[4]. Hanna's Water Calligraphy device is attached to a bicycle and dispenses water from hose array to draw Chinese characters on the streets over [3]. A lawn mower can be used to draw striped and circular patterns on grass fields.

Our work is inspired by recent attempts to expand the functions of existing soft objects in the living environment by using the power of computing. Sugiura et al. proposed a

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[2] http://www.cbc.ca/strombo/news/living-artworks-in-japans-rice-paddys.htm

[3] http://en.wikipedia.org/wiki/Japanese_rock_garden

[4] http://www.viralnova.com/simon-beck-snow-art/

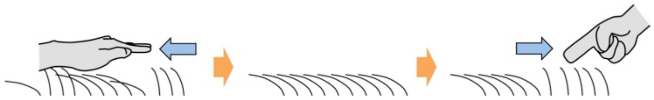

Figure 2: Principle of drawing on fur. Sweeping the fur surface in its growth direction flattens it, and sweeping it in the opposite direction raises it.

ring-type device that can be attached to plush toys to move its limbs [21]. Sugiura et al. also developed FuwaFuwa, a sensor module placed inside a cushion to measure the contact position or change in pressure when a user touches the cushion [20]. Our goal is to enable displays of information on these soft objects without the need to modify them.

Our work is also inspired by hybrid fabrication methods that combine human operation and computer control. Rivers et al. proposed a way to precisely position a cutting tool with a combination of manual and automatic positioning, thereby allowing the system to be used to cut out arbitrary patterns [17]. FreeD is a hand-held, digitally controlled milling device, which matches the user's hand-craft work, to allow user without any sculpture knowledge to create 3D models [25].

## PRINCIPLE

We leverage the phenomenon that raised fur looks different from flattened fur. Fur fibers have a natural growth direction, and one can flatten the fur by sweeping the surface in that direction and raise it by sweeping the surface in the opposite direction. Since raised and flattened regions of fur have different reflectance properties, one can visually distinguish them. In general, flattened fur reflects more light and looks brighter than raised fur. Figure 2 shows how the phenomenon works.

### Shading Property of Fur Display

The appearance of fur dynamically changes according to the incoming light and viewing direction. We ran a simple experiment to measure this appearance change in order to obtain an insight for deciding where to put the light source and from where to view the fur display to maximize contrast. We used three different materials shown in Figure 3. These three materials were selected as representative materials among those available at local stores. For each material, we first prepared flattened surfaces and surfaces in which the fibers were raised by hand. We then illuminated the two surfaces from various light positions and measured the appearance from various viewing positions. Figure 4 shows the experimental set-up. We rotated the light and measurement device positions from −60° to +60° on planes parallel and orthogonal to the fur growth direction (both planes orthogonal to the fur surface). The radiance was


Figure 3: Materials used in the experiment. Numbers indicate fiber length and diameter.

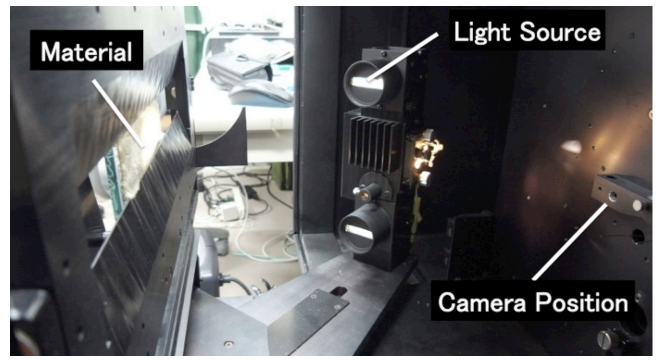


Figure 4: Experiment tool.

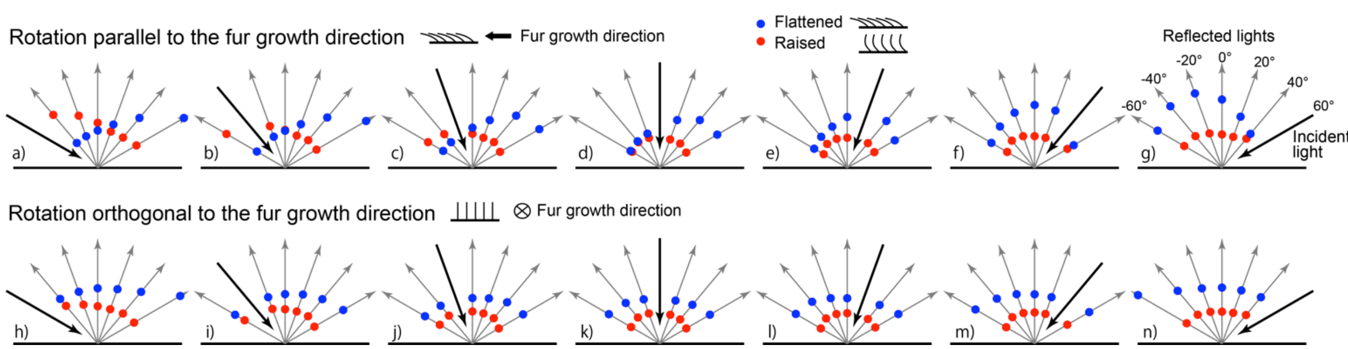


Figure 5: Radial plot of the measured radiances of micro suede. The top row and bottom row respectively show the results of rotating the light and viewing position in planes parallel and orthogonal to the fur growth direction. Each graph (a-n) plots measured radiance values for six reflected light directions and a fixed incident light direction. The incident light direction and reflected light direction cannot be the same because we cannot put the measurement device and light at the same location.

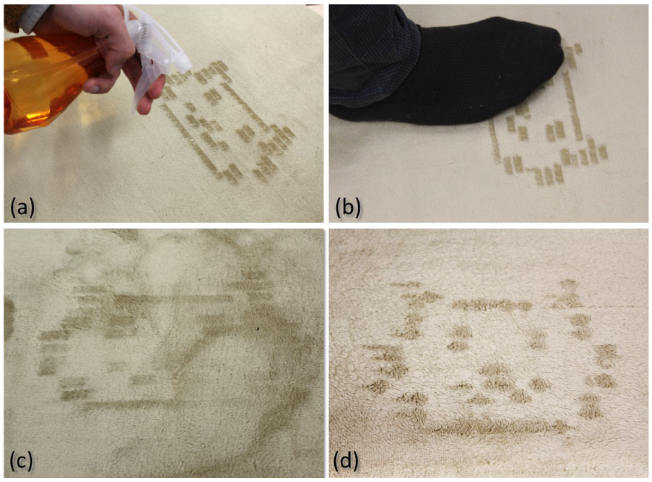


**Figure 6: Fixing a pattern with laundry starch, (a) Fixing a pattern on a carpet by spraying laundry starch, (b) walking on the pattern ten times, (c) result without laundry starch, and (d) result with laundry starch.**

measured using a commercial goniophotometer and goniospectrophotometric color measurement system.

Figure 5 shows the measured radiances of micro suede material. All three materials show similar characteristics. The results show strong anisotropy. Both flattened and raised surfaces show strong specularity when the light and viewing position rotated parallel to the fur growth direction (a-g). The plot implies that the surface normal of the flattened fibers is somewhere around +20° and that of the raised one is around −60°. In contrast, the diffuse component seems to be more dominant when the light and the viewing position rotate orthogonal to the fur growth direction (h-n) with slight specularity on the flattened surface.

We calculated the contrast by dividing the radiance of the flattened surfaces by that of the raised surfaces. The maximum contrast (2.57) was obtained when the surface was illuminated against the fur growth direction (−40°) and viewed from the opposite side (+60°) (b). However, this configuration is not very stable; the contrast vanishes when the viewer is in front of the surface (0°) and even flips when the viewer and light are on the same side (−60°). In order to obtain stable results when the viewer position changes, it is recommended to illuminate along the fur grown direction (g), or rotate the light position orthogonally to the fur growth direction (h-n). The maximum contrast of the other materials were 8.21 (boa cloth short) and 34.72 (boa cloth long).

### Fixing the Pattern with Laundry Starch

An advantage of our method is that the user can easily erase the pattern by sweeping the fur surface if the result is not satisfactory or the pattern is no longer necessary. However, this feature can be a problem when the user wants to have the pattern stay on the fur surface for a while. In such a case, the user can fix the pattern by spraying a mixture of laundry starch and water onto the fur after drawing a pattern. To check the ability of fixing a pattern with laundry starch, we fixed a pattern drawn by spraying it with 100 g of laundry starch mixed with 200 ml of water. We then walked on the fixed pattern and an untreated pattern ten times respectively (Figure 6 (a-b)). The pattern in the carpet without laundry starch disappeared (Figure 6 (c)). However, the pattern in carpet sprayed with laundry starch remained unchanged after people walked on it (Figure 6 (d)). As laundry starch is water-soluble, the carpet can be restored to its original form by washing it with water.

## IMPLEMENTATION

We developed three different devices to draw figures on fur by exploiting this phenomenon. One is a roller device which raises fur by using an array of rods underneath the device, another is a pen device which raises fur with a rotating robbing wheel attached to the tip, and the other is a pressure projection device which raises/flattens fur without physical contact. The remainder of this section describes these devices.

### Roller Drawing Device

The hardware consists of 16 fur-raising components attached to the bottom of the roller as shown in Figure 7. Each component consists of a rod and a servomotor that lowers and lifts the rod. When the rod is lowered, it raises the fiber as the user moves the roller (Figure 7 top). In addition, a rotary encoder is mounted on the wheel shaft to measure the horizontal movement of the roller. The rotary encoder and servomotors are controlled by an Arduino Mega ADK microcontroller. The system lowers and raises the rods according to the measurements of the rotary encoder to leave patterns on the fur.

Drawing with the device proceeds as follows. The user first measures the size of the canvas and prepares a binary dot matrix of appropriate size using an application program.

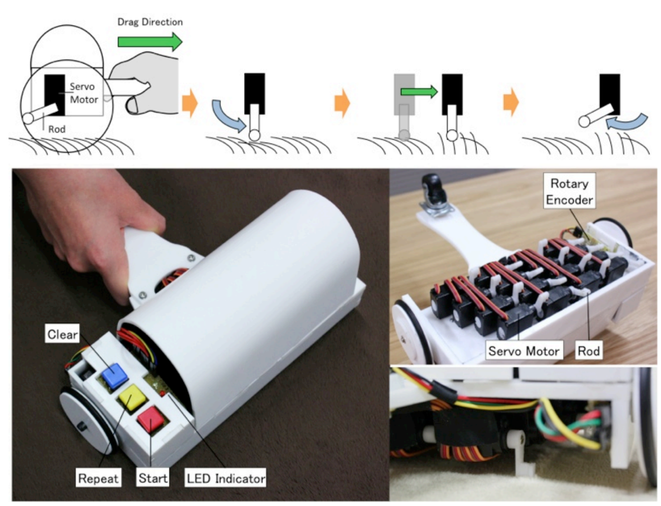


**Figure 7: Roller device. Principle (top) and composition (bottom).**

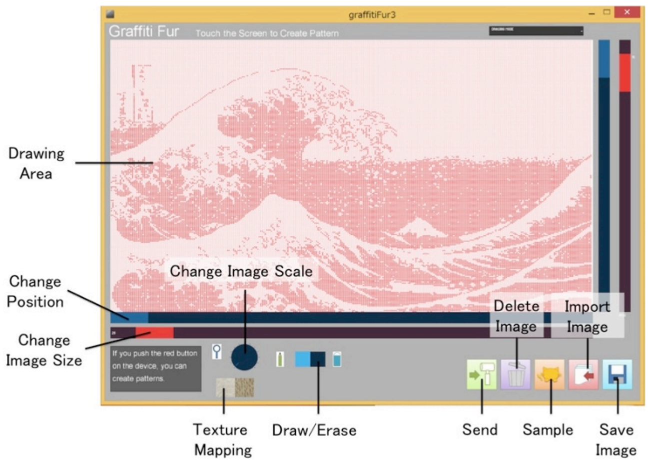


**Figure 8: Application UI.**

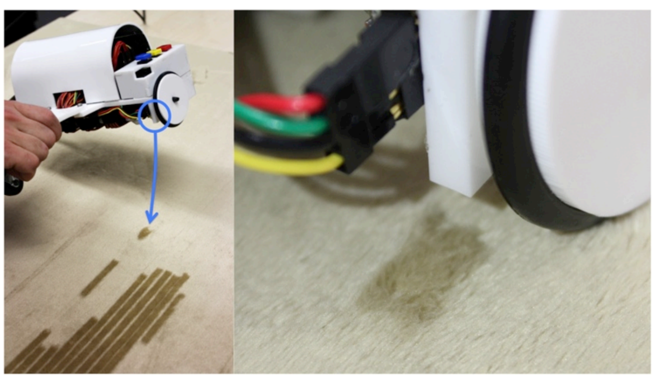

**Figure 9: Marker for making multiple drawings.**

Our current application program provides four methods to prepare the dot matrix (Figure 8): (1) drawing freely using a finger or pen, (2) reading a monochrome picture or illustration, (3) taking a picture with a camera, or (4) typing text. The system provides a preview image of raised and flattened fur.

Second, the user transmits the dot matrix data to the device and starts drawing the pattern on the fur surface by moving the device over its surface in the direction opposite to the fur growth direction. The surface needs to be fully flattened by hand prior to drawing. The user presses the red button on the device to initiate drawing. If the dot matrix consists of a single row, the drawing finishes after a single sweep. If the user continues the sweep, the pattern will be repeated. When the dot matrix consists of multiple rows, the user needs to repeat sweeps multiple times. The system indicates the end of a sweep with an LED mounted on it, and the user starts the next sweep by pressing the red button. To assist the user in aligning the starting point of the sweeps, the system leaves a tick mark at the beginning of each sweep. The user aligns the starting point by pressing the red button and placing the roller so that the mark on the roller aligns with the tick mark (Figure 9). Pressing the yellow button lets the user repeat the same row. The user can move the roller backwards to erase an already-drawn pattern. In this case, all the rods are lowered automatically. The blue button clears the drawing data.

The horizontal and vertical extents of a dot are 12 mm and 8 mm, respectively, assuming that the roller moves horizontally. This means that the display resolution of a pattern drawn by the device is approximately 2.12 dpi. The main limiting factor is the size of the servo motors and capability of the rotary encoder. The drawing speed is constrained by the speed of the servomotors. In our current implementation, the maximum speed of the roller sweep is 15 cm/sec, and the device fails to generate an appropriate pattern if the user sweeps the device faster than this limit. It requires approximately 20 minutes to draw a large picture such as shown in Figure 1 right (size: 2×1.2 m) with all the lines carefully matched together.

**Pen Drawing Device**

The user can draw an arbitrary pattern using his or her bare fingers, raising the fiber selectively after flattening the fur. It is relatively easy to draw a line in the opposite direction of the fur growth because the user can simply move his or her fingers across the fur in that direction once. However, it is very tedious to draw lines in the orthogonal or opposite direction because the user needs to make many short

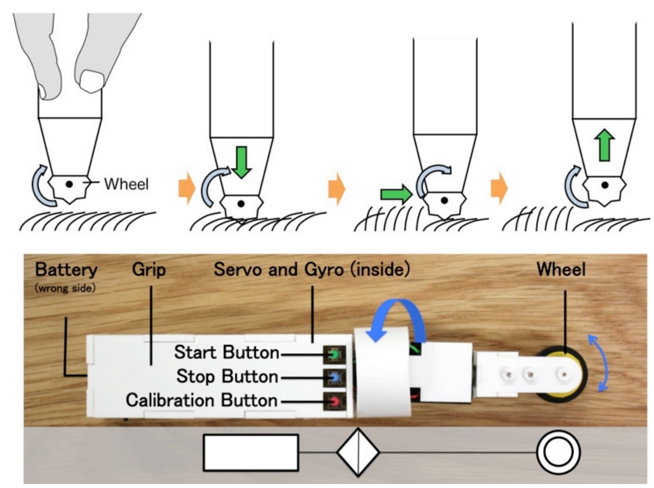


**Figure 10: Pen device. Principle (top) and composition with kinematic diagram (bottom).**

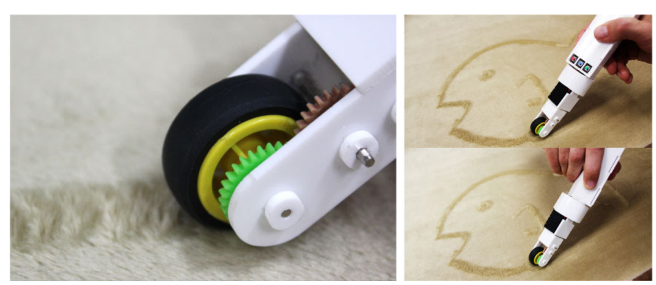

**Figure 11: Tip of the pen device (Left): the system always keeps the wheel orientation parallel to the fur growth direction and adjusts the direction of wheel rotation (Right).**

**Figure 12: Difference between drawing with a finger and pen device: using own finger (left), using pen device (Right).**

scratches. We therefore developed a pen device to save this effort by raising the fibers using a continuously rotating wheel which is always oriented parallel to the growth direction of the fur. (Figure 10 top).

The device consists of a grip, control buttons, a wheel, servo motor, and gyro (Figure 10 bottom). The gyro measures the global orientation of the pen grip, and the servomotor twists the pen tip according to the measurement from the gyro. The user first calibrates the system by pressing the calibration button while holding the pen in the canonical posture facing toward the fur growth direction. The other button is used for starting and stopping. Afterwards, in whatever orientation the user holds the pen grip, the system always keeps the wheel orientation parallel to the fur growth and adjusts the direction of the wheel rotation so that the wheel continuously raises the fibers (Figure 11).

We did a comparison to observe the differences between drawing with a finger and drawing with a pen-device. When the user drew with his finger, if the drawing direction is aligned with the direction of the fur growth, it was difficult to draw (Figure 12). It is also difficult to draw a line orthogonal to the fur growth direction. On the other hand, using the pen device, the user was able to draw pictures without paying attention to the direction of the fur. However, as the smoothness of the pen-device movement is limited by the power generated by the motor rotation, we found that the user was required to get used to the device before drawing fluently.

### Pressure Projection Drawing Device

It is known that a high-amplitude ultrasound can be used to push objects in the direction of propagation (acoustic radiation pressure). The Airborne Ultrasound Focusing Devices (AUFD) developed in [5] generate high-amplitude ultrasound based on the phased-array focusing technique. This focused ultrasound can be used to raise/flatten the fur fiber without the device making physical contact (Figure 13 (a)). The diameter of the ultrasonic focal point is a few centimeters and its position can be controlled three-dimensionally.

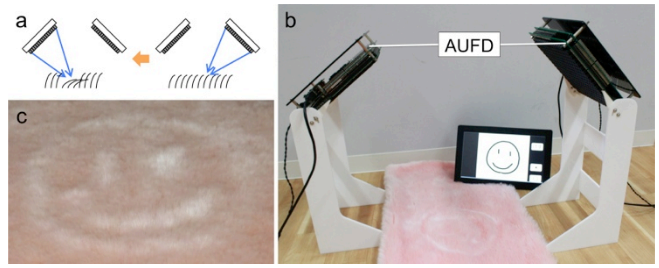


**Figure 13: Pressure projection device; (a) principle, (b) composition and (c) result.**

The specifications of the AUFD are as follows. 285 ultrasound transducers (10 mm diameter, T4010A1, Nippon Ceramic Co. Ltd.) are arranged in a rectangular area whose side length $D$ is 17 cm. The resonant frequency of the transducers is 40 kHz (i.e. $\lambda$ = 8.5 mm). The diameter $w$ of the focal point is determined by $D$, $\lambda$, and the focal length $R$ (the distance between the AUFD and the surface of fur): $w = 2\lambda R/D$. For example, $w$ is 20 mm when $R$ is set at 20 cm. The maximum output force is 16 mN (measured). The spatial resolution of the position of the focal point is 0.5 mm. The position can be updated at the rate of 1 kHz.

Two AUFD are placed face to face in the drawing system (Figure 13 (b)). Before drawing, fur fibers should be in the ordinal raised state. One AUFD is used to raise the fur fibers by projecting pressure. The other AUFD is used to flatten the fur fibers by projecting pressure from the opposite direction. Because the AUFD units have been placed at a tilt, the focal lengths are controlled depending on the projecting point. The display resolution of a pattern is approximately 1.2 dpi in the current implementation. The drawing speed is constrained by the time to raise the fur fibers and pressure level. In our current implementation, the maximum drawing speed of the line is 30 cm/sec on boa cloth (18 mm fur length, 0.02 mm diameter). The material that can be controlled by current pressure level is limited. Fur fiber length should be more than 18 mm in our simple trial. The pattern (size: 20×20 cm) in Figure 13 (c) was drawn by the system in 4 seconds. Erasing the drawing takes around quadruple the time because fur fiber has the tendency to retain shape.

## EXAMPLES

Our display can be used in a number of daily living contexts, in particular, on large spaces such as floors or walls and on objects such as toys, clothes, and curtains. Figure 14 (a) to (e) illustrate the usage of the display in a large space. Users can draw special pictures for their loved ones on their birthday or write messages for visitors (Figure 14 (a)). Children can play storytelling games with others using the drawings they have drawn (Figure 14 (b)). Here, the display is used to make line drawings of train tracks for train toys to move along. Children can easily modify their drawings according to the story or game they are playing. Carpets with various patterns can be used to decorate the


**Figure 14: Application examples: (a) birthday party, (b) having a toy follow a drawn path, (c) drawing art on the floor, (d) visitor navigation guides, (e) greetings on a carpet, (f) changing patterns, (g) Pattern on plush toy, (h) temporary drawing on clothing.**

living space, and users can change the drawings according to their mood (Figure 14 (c)). A hotel can use our devices to display information for guests on their welcome mats. An example would be a mat showing the direction of the entrance (Figure 14 (d)). It is also possible to implicitly tell that a carpet is cleaned by leaving a message (Figure 14 (e)).

Figure 14 (f) to (h) illustrate various usages on everyday objects. On a soft, foldable object, one can reveal different images by folding and opening the object. For example, users can draw on a curtain and fold the curtain to show a different illustration (Figure 14 (f)). Many people like to dress up their soft toys as well, to give them their own individuality. Using our system, users can easily draw patterns on their soft toys without needing to modify them (Figure 14 (g)). Finally, our system allows users to draw different patterns on their clothing everyday (Figure 14 (h)).

## USER STUDY

We prepared an environment resembling a living area and conducted an informal observational study to see how people use the roller and pen devices and what kind of drawings they draw. We invited 18 people among visitors to a local science museum to the study, consisting of six parent-child pairs and six children. We placed various fur objects as drawing canvases, including a sofa, mat, cushion, plush toys, carpet, and tapestry in the environment. A couple of roller and pen devices and a Tablet PC were provided for the users to use freely.

Figure 15 shows some snapshots taken in the study. Overall, participants were able to understand how to use the device and the application within five minutes and were able to draw their own drawings in the environment. One child created a story integrating a picture drawn using the device with plush toys. We also observed an unexpected creative use of the technology in which a participant raised all fur fibers first and then draw a pattern by flattening selected fibers using the devices, that is, drawing bright strokes on a dark canvas (this is the reverse of our initial intention). Not only the proposed devices but also users can draw pattern with their fingers. In the user study, we observed

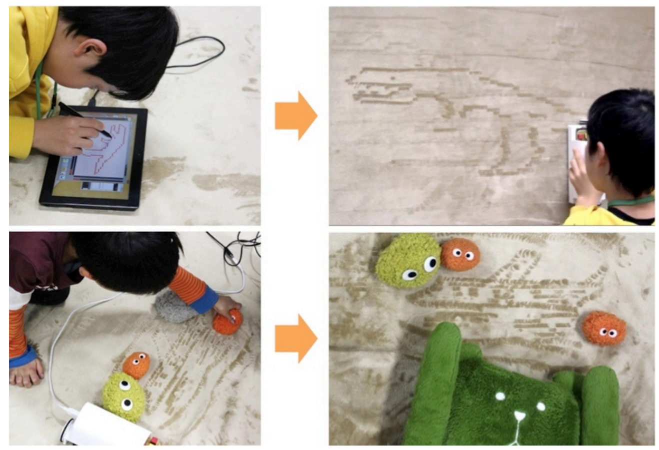

**Figure 15: Drawing a dinosaur using the multiple layer function (top), Making up a story with common household objects (bottom).**

participants could interactively modify the pattern drawn by the devices. The study also revealed some problems with the method. Participants commented that the device was too heavy for young participants to draw on a wall. They also found it difficult to draw patterns on a sofa when users pressed the device strongly because it may sink into it.

## LIMITATION

There are several limitations to our current devices, which we plan to address in the future. The current roller device doesn't have a sensor to detect its own position in the environment, so the users have to fix the device on the floor and carefully drag the device. In the future, by mounting a sensor that can measure the absolute position of the device, we plan to allow user to draw pattern by moving the device more freely. We also plan to combine the roller device with a mobile robot to implement fully autonomous drawing device. As for the pen device, the wheel stops rotating when the user presses the pen tip to the fur surface too hard. Durability of the fur material is another concern. When one draws on the same spot too many times, the fur will be slowly worn off, making it difficult to observe the pattern.

To prevent this, the carpet has to have certain durability. We plan to improve the device to reduce the wear it causes. Finally, our current method cannot draw patterns in multiple colors. One possible solution is to create a special carpet consisting of fur strands with multiple colors and then raise and flatten these colored strands selectively. This is an interesting prospect.

## CONCLUSION

We presented a display technology that utilizes the phenomenon whereby the shading properties of fur change as the fur fibers are raised or flattened. We developed three devices, roller, pen and pressure projection device, to draw patterns on fur display. We assessed the capability of the fur display and discussed various applications in daily living contexts. Our technology can turn ordinary objects into computer displays without requiring or creating any non-reversible modifications to them. It is also free from glare and requires virtually no cost to maintain.

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## REFERENCES

1. Coelho, M. and Maes, P. Sprout I/O: a texturally rich interface. In *Proc. TEI '08*. ACM, pp. 221-222.
2. Furukawa, M., Uema, Y., Sugimoto, M., and Inami, M. Fur interface with bristling effect induced by vibration. In *Proc. AH '10*, ACM, Article 17, 6 pages.
3. Hanna, N. Water Calligraphy Device. http://www.nicholashanna.net/.
4. Harrison, C., Benko, H., and Wilson, A.D. OmniTouch: wearable multitouch interaction everywhere. In *Proc. UIST '11*. ACM, pp. 441-450.
5. Hoshi, T. Compact ultrasound device for noncontact interaction. In *Proc. ACE '12*, ACM, pp. 502-505.
6. Hullin, M.B., Lensch, H, Raskar, R., Seidel, H., and Ihrke, I. Dynamic display of BRDFs. In *Computer Graphics Forum (Proc. EG)*, pp. 475-483.
7. Kawana, H. dotanco, http://gekitetz.com/dotanco/.
8. Kushiyama, K., Ikei, R., and Sasada, S. Tactile grass landscape. In *ACM SIGGRAPH 2008 posters*. ACM, Article 39, 1 pages.
9. Malzbender, T., Samadani, R., Scher, S., Crume, A., Dunn, D., and Davis, J. Printing reflectance functions. *ACM Trans. Graph.* 31, 3, Article 20 (June 2012), 11 pages.
10. Master, B. Lazy man Zen garden, http://youtu.be/rNGPErdIqZA.
11. Matusik, W., Ajdin, B., Gu, J., Lawrence, J., Lensch, H. P. A, Pellacini, F., and Rusinkiewicz, S. Printing spatially-varying reflectance. *ACM Trans. Graph. 28*, 5, Article 128 (December 2009), 9 pages.
12. Mistry, P., Maes, P., and Chang, L. WUW - wear Ur world: a wearable gestural interface. In *Ext. Abst. CHI '09*. ACM, pp, 4111-4116.
13. Nojima, T., Ooide Y., and Kawaguchi, H. Hairlytop interface: An interactive surface display comprised of hair-like soft actuators, In *Proc. WHC '13*, IEEE, pp. 431 - 435.
14. Ochiai, Y., Oyama, A., Hoshi, T., and Rekimoto, J. Theory and Application of the Colloidal Display: Programmable Bubble Screen for Computer Entertainment. In *Proc. ACE '13*, Springer, pp. 198-214.
15. Raffle, H. Joachim, M.W., and Tichenor, J. Super cilia skin: an interactive membrane. In *Ext. Abst. CHI '03*. ACM, pp. 808-809.
16. rAndom International. PIXELROLLER. http://random-international.com/work/pixelroller/.
17. Rivers, A., Moyer, I.E., and Durand, F. Position-correcting tools for 2D digital fabrication. *ACM Trans. Graph. 31*, 4, Article 88 (July 2012), 7 pages.
18. Rozin, D. Wooden Mirror. http://www.smoothware.com/danny/woodenmirror.html
19. Saakes, D., Inami, M., Igarashi, T., Koziumi, N., and Raskar, R. Shader printer. In *ACM SIGGRAPH 2012 Emerging Technologies*, ACM, Article 18, 1 pages.
20. Sugiura, Y., Kakehi, G., Withana, A., Lee, C., Sakamoto, D., Sugimoto, M., Inami, M., and Igarashi, T. Detecting shape deformation of soft objects using directional photoreflectivity measurement. *In Proc UIST '11*. ACM, pp. 509-516.
21. Sugiura, Y., Lee, C., Ogata, M., Withana, A., Makino, Y., Sakamoto, D., Inami, M., and Igarashi, T. PINOKY: a ring that animates your plush toys. In *Proc. CHI '12*, ACM, pp. 725-734.
22. Sugiura, Y., Toda, K., Hoshi, T., Inami, M. and Igarashi, T. Graffiti Fur: Turning Your Carpet Into a Computer Display. In *ACM SIGGRAPH 2014 Emerging Technologies*, ACM, 1 pages.
23. Wakita, A., and Shibutani, M. Mosaic Textile: Wearable Ambient Display with Non-emissive Color-changing Modules, In *Proc. ACE ’06*, ACM, Article 48.
24. Xiao, R., Harrison, C., and Hudson, S. E. WorldKit: Rapid and Easy Creation of Ad-hoc Interactive Applications on Everyday Surfaces. In *Proc. CHI '13*. ACM, pp. 879-888.
25. Zoran, A., and Paradiso, J.A. FreeD: a freehand digital sculpting tool. In *Proc. CHI '13*. ACM, pp. 2613-2616.