FunCushion: Fabricating Functional Cushion Interfaces with Fluorescent-pattern Displays

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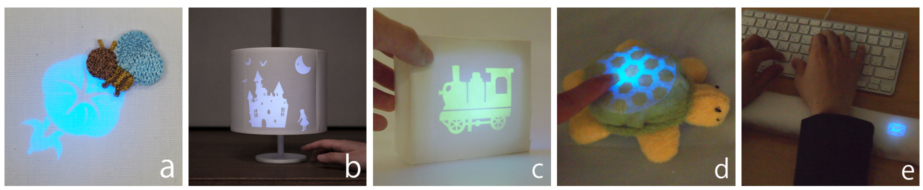

Fig. 1. FunCushion is a digital fabrication method enabling end-users and designers to create fluorescent-patttern displays on cloths of cushion interfaces with push detection: (a) printed fluorescent-pattern (b) lampshade (c) interactive cushion block (d) interactive plush toy (e) wristrest with e-mail notification.

Abstract. We introduce FunCushion, a digital fabrication method for customized fluorescent-pattern displays on cloths of cushion interfaces with push detections. The displayed patterns are printed out onto cloths by an inkjet printer with transparent fluorescent ink, and the patterns can interactively be made to glow with an ultraviolet light source embedded inside the cushion. Furthermore, push detection using infrared light can be easily integrated with the display for interaction. The displays are adaptable to 3D shapes, illuminate with multi-color and gradation, and can be integrated with static visual print and embroidery. This method enables end-users and designers to create soft, everyday products with fluorescent-pattern displays in a lab. Technical evaluations revealed effective materials for the display. Application examples demonstrate FunCushion's applicability.

Keywords: Fluorescence; Ultraviolet Light; Printing Display; Cushion; Cloth; Deformable User Interfaces (DUI); Digital Fabrication

1 Introduction

Cloth is a fundamental material for soft toys, furnitures and everyday commodities such as cushion blocks, sofa and clothing. It beautifully decorates the appearance of these products and provide comfort due to the softness. If visual contents can be dynamically displayed on cloths without compromising the softness, they can enhance the aesthetics of furniture (Fig. 1.b). Furthermore, they can add interactivity and new ways of playing to conventional soft toys (Fig. 1.c) by integrating the displays with input sensing. Whereas sensing methods for cloths and soft objects have been well studied, display methods on cloths have room for improvement. The display methods can be categorized into projection-based methods and visible light-emitting diode (LED) integration. The former projects images onto the surface of cloths from the outside of soft objects, but it often suffers from occlusion and calibration and cannot be applied to portable devices. On the other hand, the latter method uses LEDs or optical fibers on the surface of cloth to emit display light. However, this method has difficulty displaying fine patterns and large images. When a light source is embedded inside soft objects to achieve a smoother touch, then diffusion of lights by the covering materials disturbs the display quality.

This paper introduces FunCushion, a novel method that can display light-emitting fine patterns on cloth while retaining the softness, and a fabrication method to make the display as shown in Fig. 1.a. This is achieved by combining fluorescent ink and ultraviolet (UV) light; specifically, we inkjet-print the patterns on cloths with transparent fluorescent ink and embed a UV light source inside the soft object, in which the soft materials also work as a diffuser to improve the display. The display method can be easily combined with push detection using infrared (IR) lights; thus, we implemented a UV/IR module to simplify the fabrication process. This paper presents four contributions:

1. A novel display method for cloth that displays light-emitting fine patterns while retaining the softness by using UV light and transparent fluorescent inks.
2. Integration of two invisible lights to display fine patterns and detect user motion simultaneously.
3. A digital fabrication process by using fluorescent inkjet printing and a UV/IR module.
4. Technical evaluations to reveal the effective materials (cloth and soft diffuser) to improve the quality of the display.

FunCushion enables end-users and designers to create interactive everyday objects made of cloths. We demonstrate the wide applicability of FunCushion through application examples.

2 Related Work

2.1 Deformable User Interfaces (DUI)

The flexible devices called Deformable User Interfaces (hereinafter, DUI) which can deform into various shapes by physical input have been developed to give users higher degrees of freedom of input in Human Computer Interaction [1,2,3]. They provide physical flexibilities, allow various input movements such as pushing, bending and stretching. They can also be applied to 3D shapes. Furthermore, everyday soft products made of cloths have been augmented to DUI for sensing human behavior by integrating electronics into them [4]. Sugiura et al. provide a pressure sensing method that can be easily embedded into a ready-made pillow cushion and maintain its softness by using

IR light sources and receivers [5]. FunCushion introduces customized cloth displays for DUI that can be embedded into daily soft products and integrated with Sugiura et al.'s pressure sensing method using IR light without compromising the tactile feels and the softness.

2.2 Interactive Fabric Applications and Fabrications

Cloths are essential materials for creating many wearable or carried objects such as clothes, bags, and cushions. Novel fibers, yarns, and weaving technologies have been developed to increase functionality and aesthetic quality. In particular, interactive cloths that include e-textiles are powerful technologies for creating smart wearable and mobile products. They intelligently support daily life by sensing input gestures and displaying visual contents at the positions close to users and enhance the aesthetic qualities of cloths [6,7]. However, these techniques have not yet been established in the fabrication process. The major methods to build interactive cloths are stitching conductive yarns or optical fibers, embroidery, printing conductive inks, and connecting electronic components and microcontrollers [8,9,10,11,12,13,14]. Furthermore, digital fabrication methods of interactive soft products have also been developed to enable end-users and designers to create interactive fabric applications [15,16,17]. Whereas sensing methods for cloths and soft objects have been well studied, display methods on cloths have room for improvement. We thus introduce a novel displaying method called FunCushion and its digital fabrication method.

2.3 Cloth Displays

A cloth display is a cloth that contains embedded display technology and can present information by computer. To take advantage of the properties of cloth, four requirements must be satisfied.

1. *Tactile feel and softness:* The tactile feel and the softness of soft objects are essential for soft user interfaces. Impairment of the original tactile feels and softness of soft objects must be avoided.
2. *Displaying Fine Pattern:* Cloth displays are required to achieve fine patterns to clearly display small icon buttons and aesthetic decorative fine patterns.
3. *Applicability to portable objects:* Cloth displays should be applicable to daily portable and wearable products such as clothes, bags, and plush toys.
4. *Visibility control:* The visibilities of the displays are required to be controlled. The display systems should be invisible and not affect the original look of the fabric when the displays are not working.

No previous method meets all these requirements at the same time. The major display methods can be categorized into two types.

Projection-based method: A projection-based method using a camera and a projector [18,19] can display fine visual contents without compromising the tactile feel of cloths. Although the method provides flexibility of cloths, it often suffers from occlusion and calibration and cannot be applied to portable and wearable objects. Thus, display equipment should be embedded in soft objects for ubiquitous and wearable computing.

Visible LED integration: The other type of method is integrating visible LEDs with objects. In previous work, researchers stitched the visible LEDs to the surface [20] or wove optical fibers into cloths [21,22,23]. However, these methods impair the original tactile feel and softness of cloths, and the quality of displays is limited by their size. In other works, the visible LEDs were embedded into soft objects [24], but when light sources are embedded inside soft objects to achieve a smoother tactile feel, diffusion of lights by the covering materials disturbs the quality of the display.

The previous methods have difficulty providing both the necessary softness and fine pattern at the same time. Therefore, we chose a method for directly printing patterns onto cloths with functional inks.

2.4 Printed Displays with Functional Inks

Printed displays with functional inks are powerful technologies in ubiquitous and wearable computing. They achieve fine patterns and are adaptable to various sizes and shapes. Functional inks change their colors or emit light in response to physical stimulations such as heat [25] and UV light [26,27] by energy projection. However, these methods need a laser system, so they are not suitable for outside use because they present safety issues. On the other hand, there are other energy providing methods that use printed circuits. Researchers developed thin flexible printed displays by printing the display patterns with thermochromic [28] or electroluminescence [29] onto paper. Printscreen [29] introduced thin-film customized displays that can be printed onto thin substrates with the electroluminescence and the conductive ink. However, they cannot be printed onto cloths. Furthermore, functional inks are also used for fabric displays. Many fabric displays use non-emissive color-changing inks such as thermochromic inks [30,31,32,33] and photochromic inks [34]. They have long switching intervals of color-changing. AmbiKraf [30] and TempTouch [33] achieve rapid color-changing by using Peltier elements, but these elements impair the softness.

We choose to use light-emitting inks because they have short switching intervals and their light-emitting patterns are also visible in dark environments. This paper introduces an emissive printed cloth display with fluorescent inkjet-printing.

3 FunCushion

We propose FunCushion, a fluorescent-pattern display on cloth of a cushion interface with push detection. It can display a glow pattern on cloth in response to the user's pushing action. The display system consists of a UV-LED, a soft diffuser, a UV-pass visible-cut filter, transparent fluorescence, and cloth, as shown in Fig. 2. A light-emitting pattern is printed on the surface of cloth by an inkjet printer with transparent fluorescent ink. UV light is emitted to the printed area from the UV-LED. The soft diffuser also works as a diffuser of UV light, without which the LED is so directional that the patterns do not glow homogeneously. A UV-pass visible-cut filter is inserted since otherwise the visible

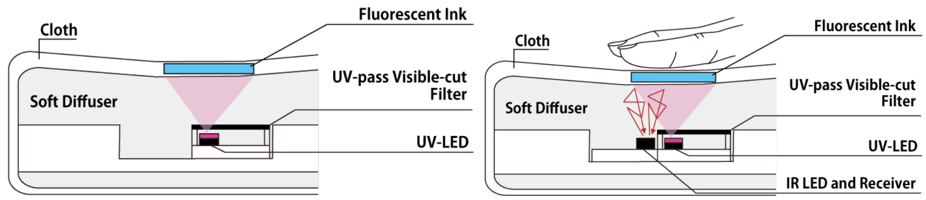

Fig. 2. System Configuration of FunCushion. Display only (left half) and Integration with Push Detection (right half).

light slightly provided by the UV-LED leaks out around the printed pattern, decreasing the contrast of the display.

The sensing system for push detection consists of an IR-LED, an IR-receiver, and a soft diffuser (Fig. 2). We detect a user's push by receiving reflected IR light and measuring the density of the soft diffuser [5]. The amount of the reflected IR light changes as the density of the diffuser changes when pressure is applied to the diffuser. The display and sensing system can be integrated in the same position without interfering with each other since the wavelengths of two invisible light sources are sufficiently different.

The diffuser, cloth, and combination of a UV-LED and filter need to increase the contrast and uniformity of the display. Moreover, the diffuser should be soft and stably change the amount of the reflected IR as the diffuser's density changes. The cloth should be for inkjet printing and not fluorescent itself. We evaluated the luminance and contrast of the display using several materials.

4 Fabrication Process

This paper proposes a digital fabrication approach to create customized cloth displays.The fabrication process consists of two steps: (1) digital designing and printing a light-emitting pattern and (2) embedding a UV/IR module for displaying and sensing inside a soft object. We introduce two printing approaches: direct printing onto cloth and heat transfer.

4.1 Printing

Direct Printing onto Cloth. Light-emitting patterns can be easily designed by using a standard graphics editor such as Adobe Illustrator or Photoshop. The patterns can be printed by using a household inkjet printer (Epson PX-105), three color fluorescent inks (Soken SKI-TRC-R69, G69, B69), and A4-sized cloths for the printer ($240\mu m$ thick, Plus IT-325CO, Fig. 3.a). The direct printing method enables designers to print the patterns onto cloths rapidly without ink bleed. The printed fluorescent patterns are transparent without UV light and visible only when UV light within $350\,nm$ to $400\,nm$ illuminates; thus, the system can control visibility of the patterns (Fig. 3.b).

Fig. 3. Three color fluorescent inks (a) and two printing methods: direct printing onto cloth (b) and heat transfer (c) using thin transfer sheet (d). Printed patterns can interactively glow due to UV light (b, c).

Heat Transfer onto Cloth. The heat transfer method enables patterns to be fixed onto cloths of various sizes, thicknesses, and textures. The user designs a light-emitting pattern reflected in the horizontal direction and prints it onto a semi-transparent transfer sheet (less than $160\mu m$ thick, Elecom EJP-WPN, Fig. 3.d). The sheet is fixed on the cloths by using a heating iron (Fig. 3.c).

4.2 Controller: UV/IR module

We implemented a UV/IR module to embed light sources easily and a light receiver for displaying and sensing in a soft object. To display high contrast images, a UV LED should be powerful and emit only UV light. We selected a $365\,nm$ UV-LED with a powerful center wavelength ($690\,mW$ at $500\,mA$ forward current, irradiation angle is $110°$, Nitride NS365L-6SVG) and a UV-pass visible-cut filter (Sigmakoki UTVAF330U) for energy sources. To detect user action, the photoreflector must include an IR pass filter. We thus selected Genixtek TPR-105F, which is the same photoreflector as in previous research [5]. To make customization easy, we choose Arduino for the controller. End-users can display fine patterns and detect a user's push on the cloth of soft objects easily with the above two steps.

5 Materials

In our proposed method, the cloth and soft diffuser are the essential materials.When end-users and designers fabricate daily soft products, they need to be able to choose various cloths and diffusers with different textures, softness, etc. in accordance with their preferences and the products' uses. FunCushion supports various cloths and diffusers. On the other hand, the quality of the display and the input sensitivity differ depending on the type of cloth and soft diffuser. It is thus important to investigate optically effective materials for output and input of the system. FunCushion needs to satisfy three requirements.

1. *Sufficient luminance of the display:* The display has to emit light with sufficient luminance. In the specifications of standard RGB (sRGB), the screen luminance level is defined as $80\,cd/m^2$, which is the sufficient value of luminance in a dark environment.

2. *Sufficient contrast of the display:* To display a pattern clearly, sufficient contrast is required. Contrast means the luminance ratio between a fluorescent area and a non-fluorescent area.
3. *Change of IR-reflectivity for push sensing:* To stably detect a user's push, the amount of reflected IR light needs to greatly change when pressure is applied to the cushion.

For luminance and contrast, both an effective cloth and an effective diffuser should be considered. On the other hand, for IR-reflectivity, only an effective diffuser should be considered.

5.1 Cloths

We printed fluorescent patterns onto three types of cloths by using the direct printing and heat transfer methods. The direct printing method supports the cloths dedicated to inkjet printing. We could print fluorescent patterns on 100% white cotton cloth ($240\mu m$ thick, A4 size, Plus IT-325CO) and linen cloth (50% hemp and 50% cotton, $350\mu m$ thick, A4 size, Kawaguchi 11-287) by using the inkjet printer. This method has difficulty printing onto heavy, large, and coarse cloths. The heat transfer method, in contrast, allows for printing onto cloths of various sizes, thicknesses, and textures. We used a semi-transparent transfer sheet (less than $160\mu m$ thick, Elecom EJP-WPN) that supports white and light color cloths. We could adhere the sheets to the white cotton canvas (graded number: No.11).

To achieve sufficient luminance and contrast (Requirements 1 and 2), the texture of cloth must be fine, and a large amount of fluorescent ink must be able to be coated on cloth. We compared luminance and contrast of the three cloths in a technical evaluation.

5.2 Soft Diffusers

We used 100 % polyester cotton, natural cottons, and BREATHAIR® (Toyobo) as soft diffusers. Polyester cotton and organic cotton are commonly used for handicrafts and consumer products. BREATHAIR® (Toyobo) is a cushion material developed by Toyobo [35] that has high resilience, water permeability, air permeability, and pressure durability.

To realize sufficient luminance and contrast (Requirements 1 and 2), a soft diffuser must transmit a lot of UV light. To greatly change IR-reflectivity (Requirement 3), a soft diffuser must reflect IR light and its density must greatly change in accordance with the pressure. In this paper, we compared luminance and contrast of the three soft diffusers in a technical evaluation.

6 Display Primitives

This section provides a systematic overview of display primitives of FunCushion. We developed new display primitives on the basis of a combination of fluorescent inks and UV-LEDs. They are divided into spatial control and luminescent color.

6.1 Spatial Control and Luminescent Color

Spatial Control. There are two types of spatial control of segments: unified control with one UV-LED and separate control of multi-segments with multiple UV-LEDs. For the unified control, light emission of multi-segments can be controlled all together at the same time with one UV-LED (Fig. 4.a). This is suitable for illuminating a large area at one time.

On the other hand, multiple segments can be separately controlled with multiple UV-LEDs. Separate control of segments enables designers to create matrix displays that dynamically change the visual contents (Fig. 4.b-1, b-2). We propose a new system configuration for separate control of multi-segments (the top half in Fig. 5). The optical path from UV-LEDs can be controlled by placing a soft frame with small holes on UV-LEDs. We implemented the matrix display by creating the soft frame (the bottom half in Fig. 5). The small holes can be made by laser-cutting on the NR rubber that does not transmit the UV light. Soft diffusers used in Fig. 2 were put in the holes to diffuse UV light.

The minimum segment size of the matrix display is 13 mm square, and the minimum distance between each segment is 15 mm. The rubber construction affects the softness of the object. The paper provides two directions for end-users, one is the matrix example that can present dynamic contents with more rigid interface, and the other is highly comfortable display but with static contents. The former is suitable for products that users do not push input to the surface of objects.

Luminescent Color. Images of displays can be printed with not only a luminescent single color but also multiple colors and gradation (Fig. 4.c, d, e) by using three fluorescent inks (R, B, G). An image can be printed in 255 levels of gradations for each color.

6.2 Integration with Static Visual Print and Embroidery

Textile graphic design and embroidery are important for handicrafts and fabricating daily soft products. People choose textile graphic design in accordance with their preferences when they make a bag, clothing, or a cushion cover. They also customize them by embroidering and sticking on a patch. FunCushion can be combined with textile graphic design and embroidery

FunCushion extends a conventional textile graphic design to an interactive one by combining a fluorescent print with a static visual print in two ways: overlaying the same image on the static visual print (Fig. 6.a), and printing a different image beside the static visual print (Fig. 6.b). The former simply highlights the pattern by illuminating it (Fig. 6.a). The latter adds interactive visual content related to the static visual print (Fig. 6.b). While static visual images can be printed with an inkjet printer or laser printer, a fluorescent pattern can also be combined with a textile design of a commercially available cloth by using a heat transfer sheet (Fig. 6.c).

FunCushion also extends conventional embroideries and makes them interactive. An embroidery patch can be combined with a fluorescent pattern onto cloths after it is

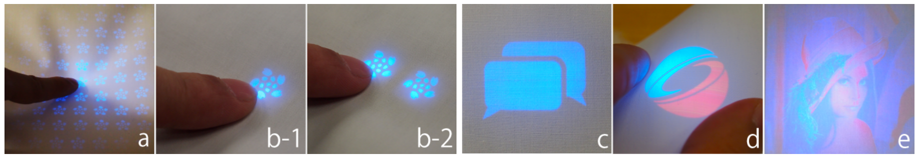

Fig. 4. Display Primitives of FunCushion. Spatial control is classified into two types: (a) unified control and (b) separate control. FunCushion enables images to be displayed with single color (c), multiple colors (d), and gradation (e).

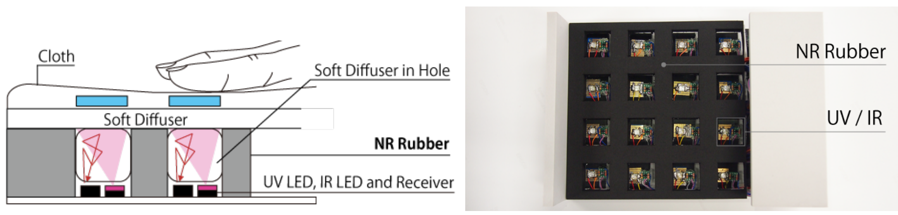

Fig. 5. System configuration and implementation of matrix display. Small holes are made by laser-cutting on NR rubber and filled with soft diffusers.

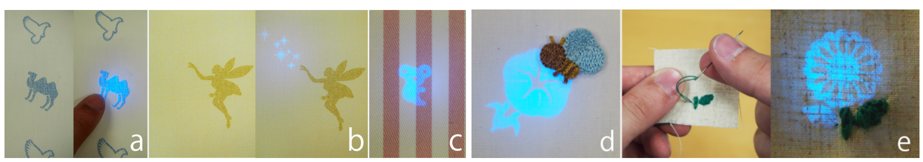

Fig. 6. Integration with static visual print (a, b, c) and embroidery (d, e).

printed (Fig. 6.d). When the linen cloth (Kawaguchi 11-287) is used, the designer can directly embroider on it with a needle.

7 Push Sensing

To design interactions, the relationship of positions between push sensing and the display must be considered. In this section, we provide an overview for determining the position of push sensing in accordance with it use. The relationships of positions are classified into two types: integration at the same position and at different positions.

Same Position. When push sensing is placed at the same position as a display, a light-emitting pattern is expected to work as buttons for a user to push. For instance, patterns work as icon buttons on a cushion for remotely controlling equipment in a room (Fig. 7.a) or as pixels of a touch matrix display (Fig. 4.b-1, 4.b-2).

Different Positions. Push sensing is placed at a different position from a display when two positions are not required to match. We provide example situations.

1. *Input without looking at the area:* When an input sensor is integrated into a position that cannot be seen while a user is inputting, it may be separated from a display. For instance, visual contents are displayed on the backrest of a sofa in accordance with the users' sitting positions in Fig. 7.b.
2. *Different area sizes:* When the input and output areas are different sizes, their positions do not necessarily have to match. For instance, the light-emitting area is larger than the input area in Fig. 4.a and Fig. 7.c.
3. *Remote uses and multiple users:* When multiple users use systems together to communicate remotely, input and output positions may be separated. In response to an input to one device, the other device displays visual contents such as message illustrations at the remote location.

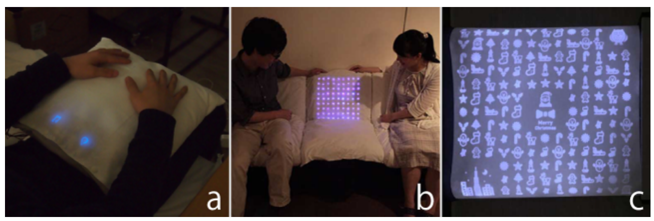

Fig. 7. Application examples of positional relationship between input and output: (a) cushion with remote control buttons, (b) sofa with display on its backrest, and (c) decorative Christmas cushion for children.

8 Shapes and Durability

8.1 3D Shapes

A display must be adaptable to complex 3D shapes and shape deformations to be embedded into soft products made of cloths such as plush toys and cushions. FunCushion supports flat surfaces, simple curved surfaces, and complex 3D shapes composed of doubly curved surfaces. After printing a pattern onto a cloth, a designer can make a 3D shape by cutting, folding, and sewing. We demonstrate the applicability of FunCushion to 3D shapes through four application examples. We also describe the possibilities of the products from the viewpoint of user's experience.

– *Lampshade:* FunCushion is applicable to a ruled surface product (Fig. 8 left). We implemented the lampshade as an example of products that do not have IR input. This application shows applicability of products with UV output only. This lamp shade works as a standard room light with the white LED at night. After turning off the light, the UV-LED lights up and works as an ambient illumination with fluorescent patterns in bedroom. Applications without IR input such as the lampshade does not provide interactivity, but they can be used to simply decorate furnitures and clothing in living space.

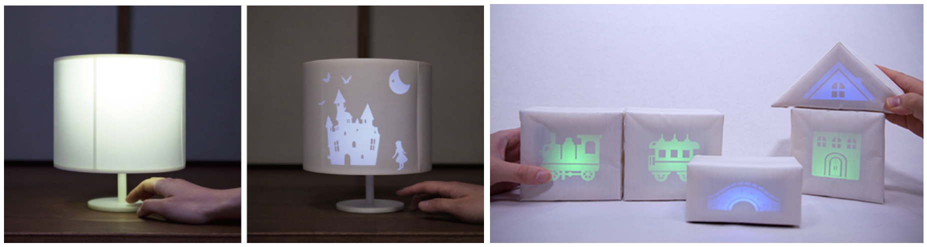

Fig. 8. Applications of FunCushion: lampshade (left half) and cushion blocks (right half).

- *Wristrest:* We introduce the another ruled surface product for office. In this application, a notification display of an e-mail is integrated into a conventional wrist rest (Fig. 1.e). This ambient display gently glows as necessary without impairing the appearance of the conventional wrist rest.
- *Cushion Blocks:* We implemented the kids' cushion blocks(Fig. 8 right) as an example of products that have IR input. Each block dynamically displays pictures on the surface in response to user's push or grip input.
- *Plush Toy:* FunCushion is also adaptable to a 3D soft product with a doubly curved surface such as a plush toy. It extends a conventional plush toy to an interactive and decorative one. The turtle plush toy (Fig. 1.d) changes its body's appearance interactively in response to a user's push. This was implemented with the heat transfer method.
- *Sofa:* FunCushion can be embedded into large soft furniture such as a sofa. We implemented an interactive sofa with a matrix display (Fig. 7.b) that supports communication of users in a living space. The matrix display has the 9×9 pixels in the backrest and five pressure sensors are embedded in each of two sheets. The purpose of it is to make a conversation trigger by displaying some pictures such as heart shape on the backrest in living space when two users sit on the both sides.

8.2 Durability

The surface cloths of FunCushion are durable for shape-deformations with pushing, bending, stretching, crumpling, and sewing (Fig. 9). It can be embedding into various soft products for ubiquitous and wearable computing. The electronics in the objects

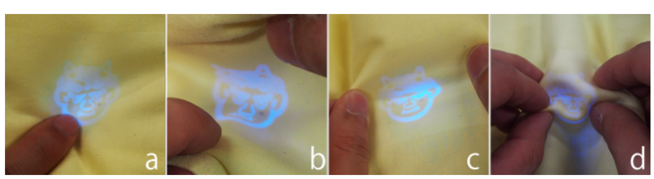

Fig. 9. Durability to shape-deformations: (a) pushing, (b) bending, (c) stretching, and (d) crumpling.

Fig. 10. Experimental setup for measuring luminance. (a) Measured points on cloth. (b) Setup to compare cloths. (c) Setup to compare soft diffusers.

limit the flexibility of the cloths depending on their size. Since the electronics are not elastic, only the surface cloths can be pinched and stretched. To make the entire interfaces bendable, we fix the electronics in urethane foams and cover them by diffusers. This makes the positions of the electronics reasonably durable to bending, while the durability depends on the relative size of the entire interfaces compared to the electronics. The interfaces can be bent if flexible circuits are used, and this can be addressed as future work.

9 Technical Evaluation

We evaluated the quality of the display and investigated effective cloths and diffusers for our system. The quality was evaluated from the viewpoint of luminance and contrast.

9.1 Cloths

We evaluated the luminance and the contrast of the display with several cloths. Three types of 90 *mm* x 90 *mm* cloths were compared: 100 % cotton cloth (Plus IT-325CO), linen cloth (50% hemp and 50% cotton, Kawaguchi 11-287), and cotton canvas (graded number: No.11) with a heat transfer sheet (Elecom EJP-WPN3). The cotton (IT-325CO) and linen (11-287) cloths were printed on by using an inkjet printer. The transfer sheet was adhered to the cotton canvas with a heating iron.

The experimental setups are shown in Fig. 10. b and c. A 30 *mm* $\times$ 30 *mm* square pattern was printed on a 90 *mm* x 90 *mm* cloth twice by using an inkjet printer with a fluorescent ink (Soken SKI-TRC-B69), (Fig. 10.a). A 365 *nm* UV-LED (Nitride NS365L-6SVG) and a UV-pass visible-cut filter (Sigmakoki UTVAF-50S-33U) were set on the bottom of a 200 *mm* $\times$ 200 *mm* $\times$ 200 *mm* acrylic box, and a cloth with the fluorescent pattern was set 3 *mm* above the filter (Fig. 10.b). A forward current of 0.1 *A* was applied to the UV-LED, and the luminance of two areas where the fluorescent pattern was printed (fluorescent area) and not printed (non-fluorescent area) on the cloth are measured (Fig. 10.a). The forward current was gradually increased in increments of 0.1 *A*, and the luminance was measured. This trial was repeated until the forward current reached 0.5 *A*. The luminance was 0.01 cd/m^2 without UV light. The contrast was calculated as the luminance ratio (R) of two luminance values (l_f, l_n) as shown in equation

(1). l_f and l_n means the luminance of a fluorescent area and a non-fluorescent area, respectively.

$$R = l_f / l_n \tag{1}$$

The results are shown in Fig. 11. The graphs show the relationship between a forward current of a UV-LED and the luminance of fluorescent (Fig. 11.a) and non-fluorescent (Fig. 11.b) areas. The luminance values should be high for the fluorescent areas (Fig. 11.a) and low for the non-fluorescent areas (Fig. 11.b). In Fig. 11.a, the cotton cloth (IT-325 CO) always had the highest luminance values of all three cloths. From the two graphs (Fig. 13.a and b), the cotton cloth also always had the highest contrast.

Fig. 12 shows the differences in the enlarged views of fluorescent contours depending on the compared cloths. The cotton cloth has a fine weave, and the area where the fluorescent ink applied to the cloths is larger than that of linen cloths (Fig. 12.a, b). These enlarged views show that the cotton cloth has the highest sharpness (Fig. 12.a) of the three cloths. From the results, the cotton cloth (IT-325 CO) is the most effective of the compared cloths.

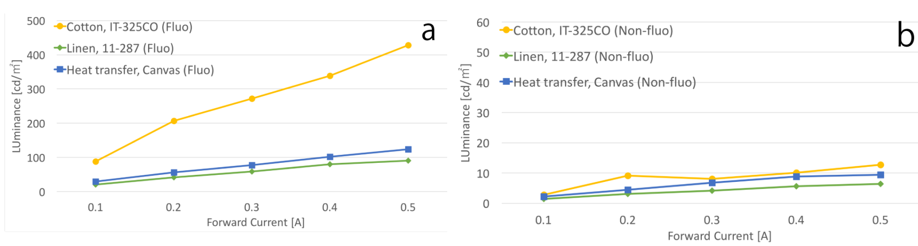

Fig. 11. Luminance of fluorescent area (a) and non-fluorescent area (b) with three types of cloths.

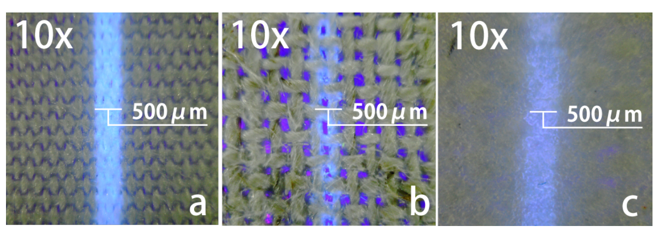

Fig. 12. Enlarged views of fluorescent contours printed on three cloths: (a) cotton cloth (Plus IT-325CO), (b) linen cloth (Kawaguchi 11-287), and (c) cotton canvas (graded number: No.11) with the heat transfer sheet (Elecom EJP-WPN3).

9.2 Diffusers

We evaluated the luminance and the contrast of the display using multiple diffusers. Three types of soft diffusers 40 *mm* thick were compared: 100 % polyester cotton, organic cotton, and BREATHAIR® (Toyobo). The experimental setup is shown in Fig. 10.c. This experiment was also conducted by using a 365 nm UV-LED, UV-pass visible-cut filter, and cotton cloth (IT-325 CO) with the fluorescent pattern The forward current was gradually increased in increments of 0.1 A, and the luminance was measured at two areas on the cloth (Fig. 10.a). This trial was repeated until the forward current reached 0.5 A. The contrast was calculated in the same way as in the previous experiment (1).

The results are shown in Fig. 13. BREATHAIR® has the highest luminance values at the fluorescent area when a forward current between 0.2 A to 0.5 A was applied (Fig. 13.a). Its luminance could reach the required luminance 80 cd/m^2 [36] at a 0.5 A forward current. The polyester cotton had the second highest luminance values and could reach luminance 60 cd/m^2 at a 0.5 A forward current. The luminance of non-fluorescent areas did not reach 10 cd/m^2 for any diffuser (Fig. 13.b). From the two graphs (Fig. 13.a and b), BREATHAIR® always had the highest contrast.

Fig. 14 shows the difference in the enlarged view of the compared soft diffusers. This enlarged view shows that BREATHAIR® has the largest gap between the fibers and has a structure that allows more UV light to pass through (Fig. 14.c). From the results, BREATHAIR® is the most effective of the compared soft diffusers.

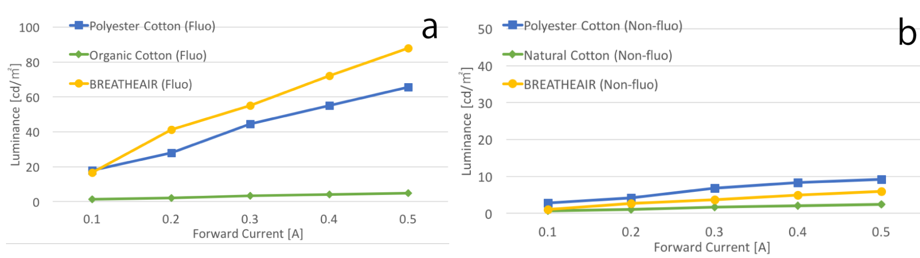

Fig. 13. Luminance of fluorescent area (a) and non-fluorescent area (b) with three types of diffusers.

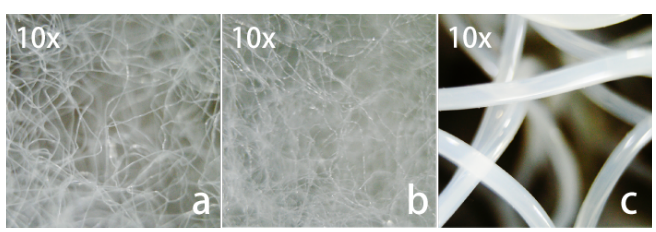

Fig. 14. Enlarged view of three diffusers: (a) 100 % polyester cotton, (b) organic cotton, and (c) BREATHAIR® (Toyobo).

10 Discussion

10.1 System Thickness and Effect on Display and Sensing

The thickness of the entire system ranges from $20\,mm$ (the soft diffuser is $15\,mm$ thick and the visible-cut filter is removed to reduce the size) to $50\,mm$ (the diffuser is $40\,mm$ thick). If it is thin, the UV light does not sufficiently diffuse, and if it is thick, the luminance does not reach $80\,cd/m^2$. The illuminated area with one UV-LED ranges from $15\,mm$ square to $45\,mm$ square. In the point of view of sensing, the system can detect only light push at the minimum, while it can detect deep push at the maximum.

10.2 Discussion of Illuminations and Other Materials

In the paper, we targeted the sufficient luminance at $80\,cd/m^2$ and only BREATHAIR and IT-325CO cloth reached the value at the $40\,mm$ diffuser thickness. However, $80\,cd/m^2$ is a target that has sufficient visibility in a bright room (we will correct the sentence), and other materials tested should also achieve it by reducing the thickness. End-users can select the materials and its thickness in his/her preference. It is hard for some fabrics such as jeans, dark-colored fabrics, wool to apply our method since they do not transmit lights. On the other hand, it is also hard for sparsely woven textiles because fluorescent ink is only sparsely adhered.

10.3 Heat and Power Supply

The effect of heat by a UV-LED needs to be considered. Strong heat dissipation is not needed when about $0.04\,A$ forward current is applied to a UV-LED from an output pin of a microcontroller but is needed when about $0.4\,A$ forward current is applied. If designing a bright display, we recommend using a heat sink.

The limitation of this system is power supply. When a power source is required to supply energy to only a microcontroller, a lithium-ion-polymer battery can be used. However, battery capacity is insufficient for long-time use. In the future, a wireless power supply will solve this problem.

11 Conclusion

This paper introduced FunCushion, a digital fabrication method of customized fluorescent-pattern displays on cloths of cushion interfaces while retaining the softness. The display can be integrated with the previous push detecting method [5] by using two invisible lights. The display is adaptable to 3D shapes and illuminates with multiple colors and gradation. Furthermore, it can be integrated with static visual print and embroidery. This method enables end-users and designers to create soft everyday products with soft displays in lab. The experiments revealed that cotton cloth and BREATHAIR® (Toyobo) are effective materials for the display.

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