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# Design and Development of Lightweight and Sheer Interactive Textile with Illumination

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**Abstract:** The interactive textile adapts light and color to enhance the aesthetics and the performance of traditional textiles, and it can be applied in different fields such as fashion, interiors and medical devices. To create interactive textiles with illumination named “Twist”, the innovative methods of incorporating weaving techniques with electronic integration and laser engraving are explored. Weave design is employed to achieve the lightness and sheerness of the interactive textile, as well as seamless electronic integration. The interactive platform between textiles and users is created through designing and developing interactive textiles. The creative potential of interdisciplinary practice and theoretical research is also explored.

**Key words:** interactive textile; illumination; weaving technique; woven structure

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## 0 Introduction

Nowadays, by integrating with electronic and digital devices<sup>[1-2]</sup>, traditional textiles have been given new functions such as sensing, illumination and interactive abilities. Colors and illumination play important roles in design as people experience their surroundings through perception and cognition, and construct meaning through color. There are different approaches to achieving textiles with illumination which include embedding light emitting diodes (LEDs), photoluminescent materials and electroluminescent materials. In comparison, the polymeric optical fiber (POF) displays yarn-like quality of tactility, flexibility, lightweight and the advantage of relatively low cost. Meanwhile, it requires a lower power supply. Thus, POF is an ideal material to be integrated with smart textiles for wearable applications. Additionally, the dynamic illumination of POF textiles provides a unique visual appearance and artistic value. POF textiles can be fabricated by integrating POFs

directly into the textile structures. POF textiles can be produced by weaving, knitting or embroidering POFs with textile-based yarns. However, macro bending from the knitting or embroidering process can cause severe damage to the POFs, leading to high light losses and affecting the POF textile appearance. The weaving technology with less bending is chosen in this study for lower light losses. In addition, the design and development of woven structures and weaving techniques offer new opportunities for POF textiles. Electronic components, such as LEDs, sensors and power sources, are integrated with the fabric to enable light-emitting and interactive functions.

Current applications of POF textiles include customized home furnishings, apparel designs, safety workwear and multisensory environments<sup>[3-6]</sup>. Prototypes using POF textiles have been developed with a focus on the design process and aesthetics<sup>[7]</sup>. Chen et al.<sup>[8]</sup> developed POF textiles with novel knitted structures with substantial surface lighting areas for apparel. Woven POF textiles with homogenous light emission were developed for the possibility of being used as wearable phototherapy devices<sup>[9]</sup>. The effects of warp yarn density, weave patterns and weft yarn density on the homogeneity and the intensity of light emission for POF textiles were investigated. UK fashion brand Fabrikk designed a handbag in which the interior lining was made of fiber-optic lighting fabrics. The fabric glow helps customers find their belongings inside the handbag easily, especially at night<sup>[10]</sup>. Robertson et al.<sup>[11]</sup> created the light-emitting lace for the context of theater and performance, providing unique visual effects for stage scenery. Their samples showcase a very sheer and delicate quality with intricate patterns. Commercial companies, such as Lumigram and Dreamlux, also developed textiles with illumination which were woven with optical fibers for different applications, including fashion and interiors<sup>[12]</sup>. However, limitations still exist, such as the lack of varieties in fabric qualities and the difficulties in

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electronic integration.

In this study, inspired by the reflected light over the sea, the interactive textile with illumination, lightness and sheerness is designed. The POF textile is woven on a Jacquard loom using POF and textile-based yarns. The integration process between optical fiber bundles and electronics is simplified. After being woven, the POF textile is laser engraved to optimize the illuminating effect. LED light sources are attached on both sides of the textile panel. By integrating with Bluetooth technology, the interactive textile can be remotely controlled via an application within a typical smartphone.

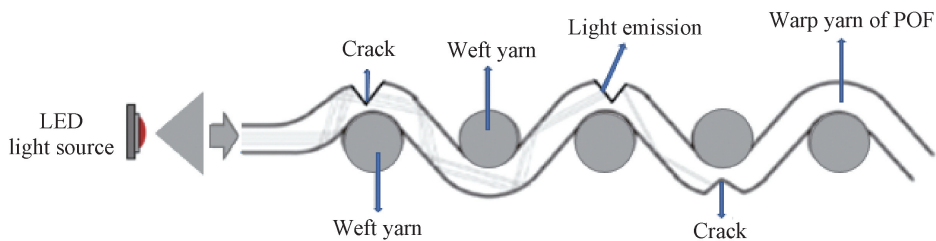


Fig. 1 Principle of side emission effect on POF textiles

The textile structure generates macro bending of POF, allowing for the side emission of light<sup>[14]</sup>. However, in woven structures, the macro bending loss for POFs is low, and further damage to the POF surface can be made to enhance the illumination<sup>[4]</sup>.

## 1.2 CAD design and Jacquard weaving

The interactive POF textile design process started with sketch drawings of motifs inspired by the water texture and reflected light on the ocean surface (Fig. 2). After being rendered in Photoshop software, the image was color-reduced and inserted with weave patterns and structures in ArahWeave software. The blue area represents the illuminative area with longer POF floats. The white area represents the area with less effective illumination using reverse weave.

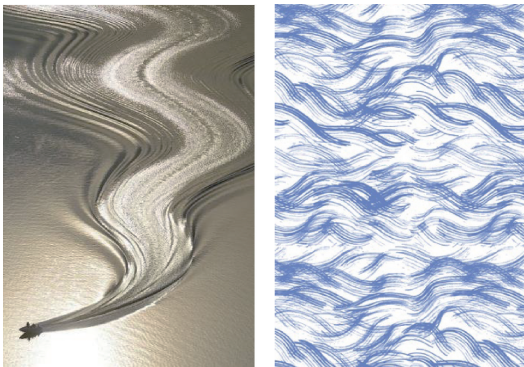


Fig. 2 Visual inspiration and CAD design

# 1 Design Principles and Techniques

## 1.1 Optical fibers and side emission effect

The principle of lighting in POF textiles in this study is from Ref. [11], as presented in Fig. 1. The side emission of light can result from two causes. One cause is the macro bending of POFs, which leads to an increase in the refractive angle of the light. Such macro bending can be created from the yarn interlacement during the textile fabrication process. The other cause is the optical leak from the surface cracks on POF claddings. The cracks can be created by surface treatments, such as laser engraving and chemical treatments.

The POF textile was woven on a Jacquard loom (Fig. 3) to achieve dimensional visual. The Jacquard loom was installed with the JC6 jacquard head (Stäubli Group, Germany) and the PTV 8/J weaving loom (Lindauer DORNIER GmbH, Germany) with 8 192 hooks. Weave patterns were particularly chosen to bring out more vibrant colors and greater details of dry brush motifs. As shown in Fig. 4, the blue color refers to the illuminative area with long POF floats exposed on the fabric surface and the white color represents the reverse weave with more polyester warp exposed. Twelve-harness weft satin was used for the dry brush motifs with long POF floats. In contrast, twelve-harness warp satin was used for the white background with less POF exposed. The reverse satin weaves showcased the color contrast between motifs and background. The warp system was made of 11 tex white polyester. The weft system was made of two types of weft yarns in a ratio of 1:1. The first type of weft yarn was the POF with a diameter of 0.25 mm which yielded positive results in terms of tactility and flexibility. The POF used in this study was high-quality polymethyl methacrylate (PMMA) developed by Mitsubishi Corporation in Japan. The second type of weft yarn was 17 tex light gray polyester. The textile was woven with a weft density of 15 picks/cm. By using lightweight materials and low fabric density, the lightness and sheerness of POF textile were achieved.



Fig. 3 POF textile weaving on Jacquard loom

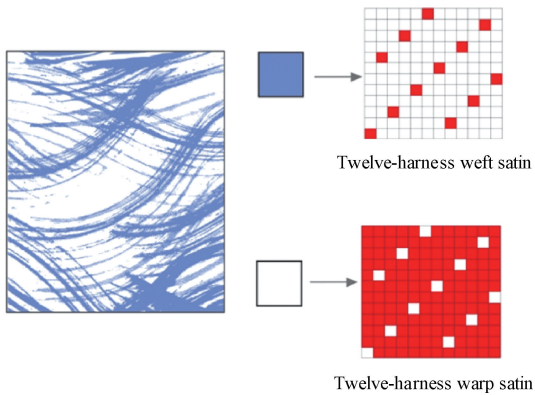


Fig. 4 Weave patterns used for motifs and background

### 1.3 Laser engraving treatment

After the weaving process, laser engraving, as the finishing procedure, was applied to enhance the luminance of POF textiles. By creating mechanical or chemical damage to the surface of POFs, the side emission of the injected light was induced<sup>[15]</sup>. However, the transmission distance of light would be shortened<sup>[13]</sup>. The uniformity and the brightness of luminance are important for the appearance of POF textiles. Therefore, an even distribution of light must be considered when designing laser parameters for POF textiles.

In Fig. 5, a POF textile was placed on a platform to receive laser treatment with a proper combination of laser pattern resolution and laser radiation pixel time. In this study, the CO<sub>2</sub> laser engraving technique was employed to provide the mechanical force for POF cladding<sup>[16]</sup>. The laser engraving was enabled by the Jeanologia Flexi-e V2 laser system (Jeanologia, Spain). The wavelength was 10 600 nm, and the output power density of the laser was 1.20 W/cm<sup>2</sup>. The laser parameters used in this experiment were a laser radiation pixel time of 120 μs and a resolution of 20 dpi. POF textiles were laser engraved twice with the same settings to bring out an effective illumination result.

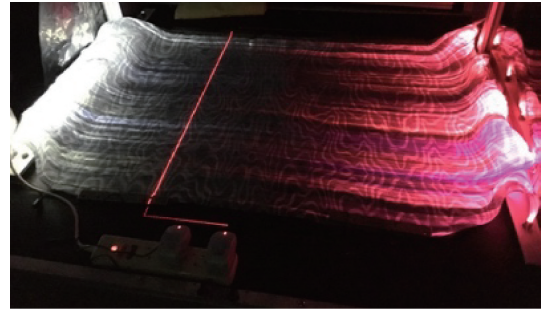


Fig. 5 POF textile treated with laser engraving

The laser pattern was designed to further determine the shape and the density of the laser. The gradient design of the laser pattern contributes to an even illumination for large POF panels<sup>[7]</sup>. Center areas on large POF panels before laser treatment usually lack illumination due to the distance to the light source with failure in light power. Therefore, the laser pattern is designed with a smooth transition of gray, and the center area is dark gray instead of full black, allowing for the gradual changes of laser power to be applied to POF textiles (Fig. 6).



Fig. 6 Gradient laser pattern design

## 2 Weave Design for Seamless Electronic Integration

### 2.1 Weave design

The electronic components for interactive POF textiles include LEDs, power sources, sensors and control systems. LEDs were connected to the photonic fiber ends as a form of light source for the illumination effect. Groups of photonic fibers were bundled together with resin, and then coupled with LEDs with predetermined colors. External power sources were attached. The sensing and interactivity capabilities of POF textiles were enabled by the integrated sensors and the control system on the basis of the microcontroller unit (MCU)<sup>[4]</sup>. The seamless integration of these electronic components is crucial for the usability of interactive POF textiles. Weaving techniques were explored to ease and simplify the process of electronic integration.

As shown in Fig. 7 (a), the POFs were originally woven with textile-based yarns across the entire fabric width during the weaving fabrication process. It required the manual removal of the excess threads woven with POFs to create POF fringes on the left and right sides of the fabric for the subsequent electronic connection. The previous method of making POF bundles for electronic

connection was time-consuming and labor-intensive<sup>[7]</sup>. Moreover, POFs could be accidentally cut off from the separating process with the risk of causing illumination defects from the missing POFs. In addition, the fabric edges of the manually created fringes usually looked raw and unfinished (Fig. 7(b)), which also affected the final appearance and presentation of POF textiles.

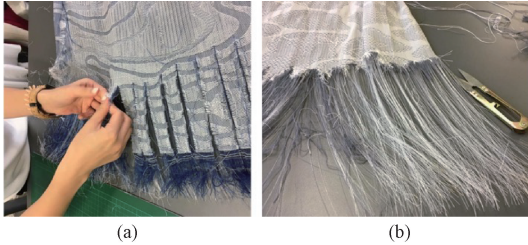


Fig. 7 Manual process of separating POFs for electronics coupling: (a) before manual separation; (b) after manual separation

To produce POF textiles for seamless electronic integration, a novel weaving technique was developed to separate POFs from textile-based yarns directly during the weaving fabrication process. A complex woven structure was designed at the fringe area of POF textiles. As illustrated in Fig. 8, the woven structure consists of two layers with continuous POF floats at the top layer, whereas textile-based weft yarns are interlaced with all warp yarns at the back layer. POF fringes with long floats were designed on both sides of the fabric. To prevent yarns from slipping away at the loose section between the fringe and the design motif area, a 2 mm thin strip woven with plain weave was designed as the lock section to hold the yarns in place.

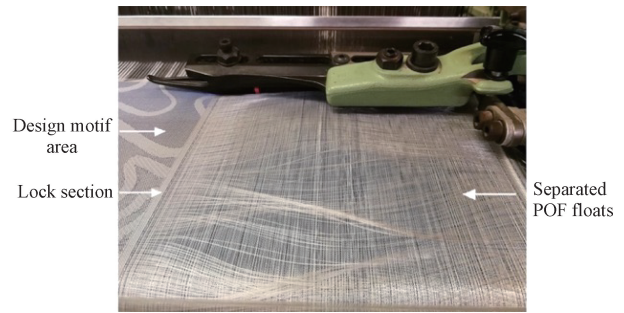


Fig. 8 POF fringe with long floats for direct separation from textile-based yarns

However, as the weaving fabrication proceeded, an unbalanced interlacement was caused across the fabric width because of the evident difference in warp tension between the fringe and the design motif area. Thus, warp yarns were prone to breakage from the unbalanced tension, which slowed down the weaving fabrication. To achieve a balanced weave combination, three compound weaves (named plain-based, twill-based and satin-based compound weave, respectively) were designed. The three compound weaves are illustrated in Fig. 9. The top layer was constructed with continuous POF floats for all three weave combinations. The back layer was woven with plain weave, 1/3 twill and five-harness satin weave for the three structures. In Fig. 9, the white square represents the POF weft yarn raised over the polyester warp yarn, the blue square represents the polyester weft yarn raised over the polyester warp yarn, and the black square represents the polyester warp yarn raised over the polyester weft yarn. By using the plain-based compound weave designed with a plain weave at the back layer, the balanced interlacement across the fabric was achieved with less warp yarn breakage.

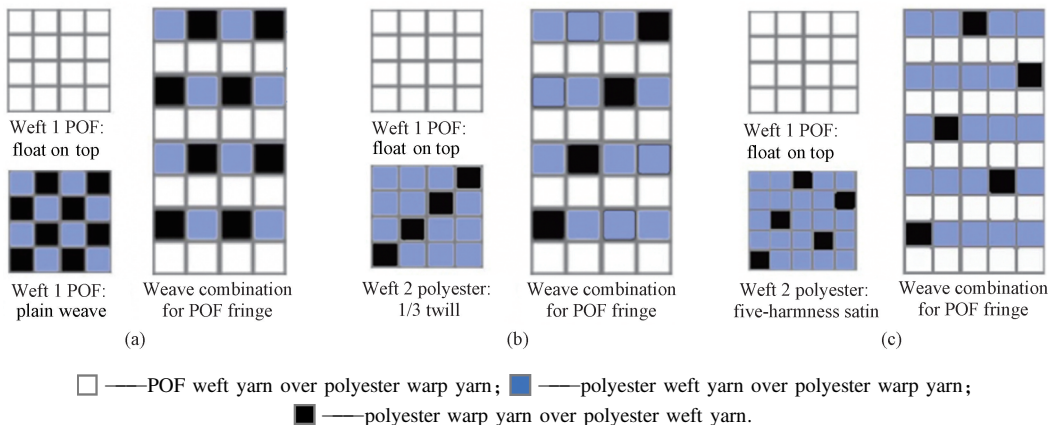


Fig. 9 Compound weaves designed for the POF fringe area: (a) plain-based; (b) twill-based; (c) satin-based

During the fabrication process with the new weaving technique, the POF fringe area was woven in two layers: on the top layer, POFs were floating and had no interlacing points with warp yarns, leading to an additional loose warp yarns at the POF fringe area; at the center motif area, the warp tension was high

because both weft systems were interlacing with all warp yarns in a single layer. Therefore, the interlacement between the two areas was unbalanced, and warp tensions became different. Using a tighter weave pattern on the back layer helped balance the interlacement and warp tension between the POF

fringe area and the center motif area. The plain-base compound weave was tighter than the twill-based compound weave and satin-base compound weave. In this study, the particular weave combination, plain-based compound weave, was used in the POF fringe area for a balanced yarn interlacement to meet the technical fabrication requirement. Figure 10 shows the POF textile designed with the POF fringes and lock sections placed on both sides of the design motif area.

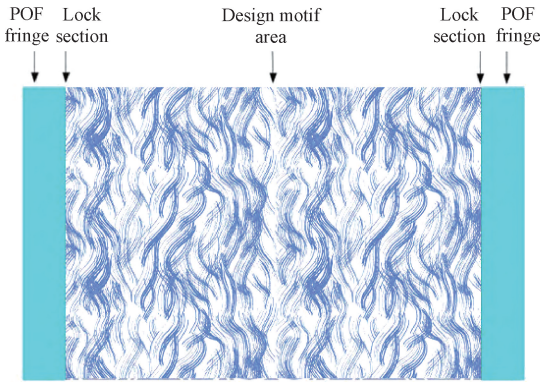


Fig. 10 POF textile developed with new fringes using CAD design

After separating POFs directly from the Jacquard loom, POF floats could be easily and quickly pulled out from the fabric selvage (Fig. 11), significantly reducing the development and fabrication time. The scrap fabric underneath the POF floats was cut off. The separated POFs were later bundled into groups. The POF fringe was designed at the right length of 20 cm to ensure that the fabric stayed flat and neat after the POF ends were bundled into groups. The size of the POF bundles was made into a diameter of 7 mm, which could fit into the customized LED coupler securely.



Fig. 11 POF floats: (a) before separated from selvage; (b) after separated from selvage

**2.2 Integration with electronics**

LEDs were connected to the photonic fiber ends as a form of light source (Fig. 12). Groups of photonic fibers were first bundled together with resin. After curing resin for 24 h, the bottoms of multiple POF ends were sanded to the same level to ensure good contact with LEDs. The POF bundles were then coupled with LEDs with predetermined colors.

Figure 13 (a) shows the interactive textile “Twist”

in non-illuminated state. After connecting the light source, the illuminative effect of the interactive textile “Twist” was formed (Fig. 13 (b)). The illumination including its brightness and colors could be remotely controlled by an application installed on the smartphone (Fig. 14). The interactive mode with illumination was determined by the programmed MCU. The brightness and colors were controlled by the interactive system of POF textile with electronic integration (Fig. 15).

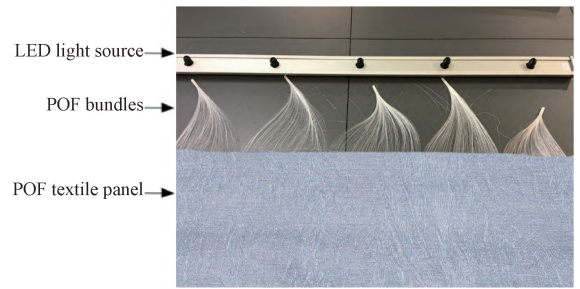


Fig. 12 Connecting POF bundles with LED light source

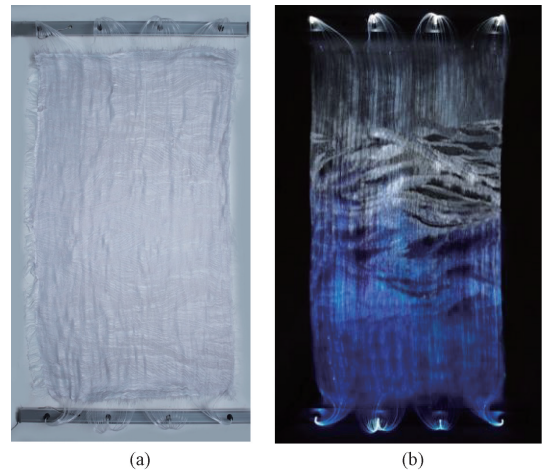


Fig. 13 Interactive textile “Twist”: (a) non-illuminated view (b) illuminated view

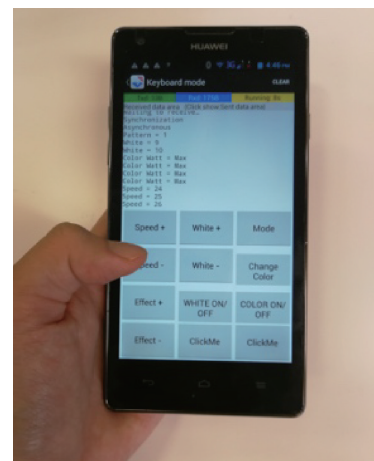


Fig. 14 Smartphone to control the interactive textile via Bluetooth application

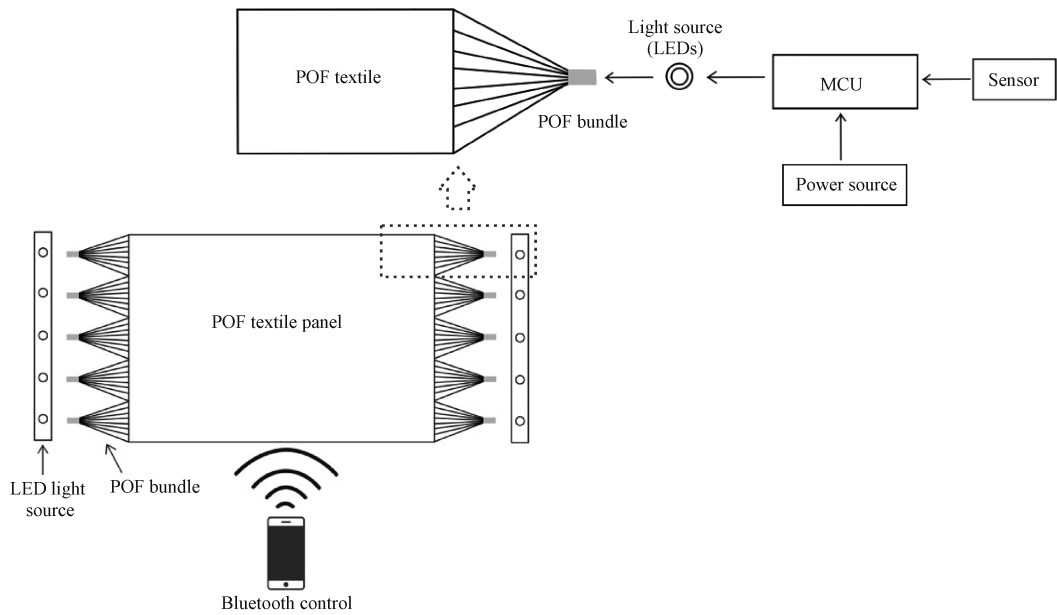


Fig. 15 Interactive textile with electronic integration

### 3 Conclusions

With the ability to illuminate and adapt color, POF textiles have immense application in customizable interior design and fashion design. This study created new weave solutions for lightweight POF textiles and their seamless electronic integration. The designed qualities of lightness and sheerness in textiles were achieved through the exploration of weave design. A particular weave combination was designed to balance the POF bundle area and the motif area. The POF bundles were directly separated through the Jacquard weaving technique. In addition, the interdisciplinary methods of design and technology were utilized in this study. The interactive textile was developed by integrating the POF textile with electronics including LED light source, power source and MCU. The textile illumination could be remotely controlled via a smartphone for users' interactivity. The dynamic POF textiles that emit light with different colors could be efficiently applied to people's daily lives, providing interactive experiences.

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## 一种轻薄化的交互式发光纺织品设计开发

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**摘要:** 交互式纺织品将光和色彩运用于传统纺织品, 以增强其美观性和功能性, 且可应用于时尚、家居和医疗等不同领域。该研究将机织技术与电子集成和激光刻蚀等先进技术相结合, 设计开发交互式发光纺织品“扭转”, 并通过探索纺织品结构和工艺设计, 实现发光纺织品的轻薄化设计和集成化设计。该研究通过交互式发光纺织品的设计开发, 在纺织品和用户之间建立了互动平台, 并在该过程中探索了跨学科设计实践和理论研究的创造性潜力。

**关键词:** 交互式纺织品; 发光; 机织工艺; 机织物结构